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Western Grasshoppers

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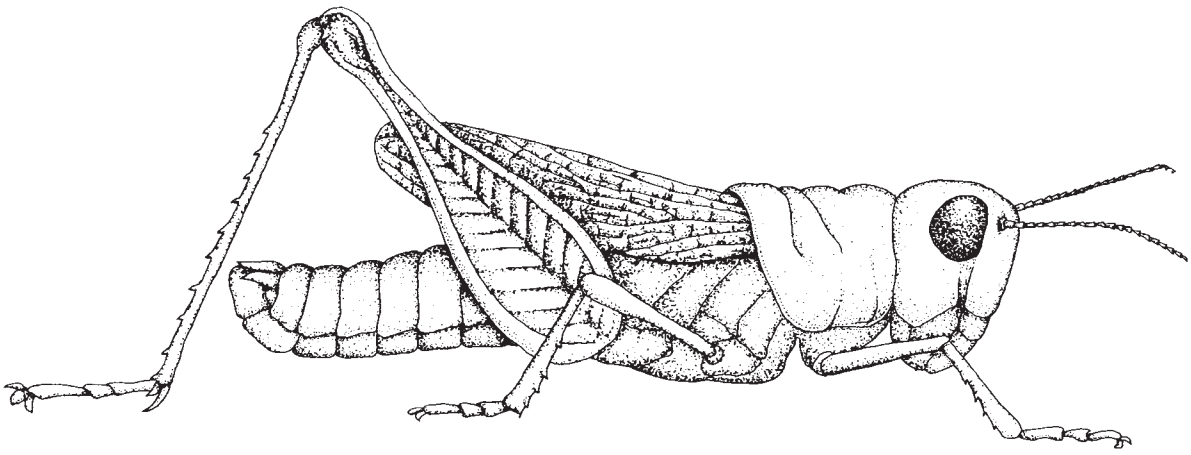
Third Edition

Robert E. Pfadt



Field Guide to COMMON WESTERN GRASSHOPPERS

Third Edition
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Robert E. Pfadt
University of Wyoming

Preface

For some time, grasshopper scouts and supervisors have desired a practical means of identifying common species of grasshoppers in both nymphal and adult stages. The consensus of ideas of APHIS and ARS personnel focused on a field guide that would picture in color not only the adults but also all nymphal instars. In addition the guide should include pictures of diagnostic features of each species. Treatment of 50 species was originally contemplated, but the number increased to 70 as more consideration was given to the species of grasshoppers frequently encountered by scouts working in the 17 western states. Names of 70 species (mainly Acrididae, a few Tettigoniidae) were selected by the technical committee of the Grasshopper Integrated Pest Management Project (USDA 1987-94) and are listed in the project outline of the field guide. From this list the author chose six to twelve species to work on annually. Selection was made on the basis of availability of grasshopper species and of site proximity.

Because new employees often need instruction on grasshopper structure, life history, behavior, and ecology, an introduction covering these subjects was also proposed. The project originally was estimated to be completed in two years but it was soon realized that more time was needed. The first species chosen were common, abundant ones inhabiting sites close to Laramie. As fact sheets on these species were completed, sites farther from Laramie chosen for other common grasshoppers entailed more travel time and left less time for productive work. The paucity of published information on the less researched species and less unpublished data in files of the author required first-hand laboratory and field observations. Another problem encountered was the low densities of certain otherwise common species in recent years, making observation and collection of live specimens more difficult. In spite of these impediments the publication of four new fact sheets in 2002 brings the total number of species treated to 60.

Acknowledgments

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College of Agriculture • The University of Wyoming

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Field Guide to Common Western Grasshoppers

Robert E. Pfadt

Introduction

Nearly 400 species of grasshoppers are known to inhabit the 17 western states. Of these, approximately 70 species are common enough to be encountered regularly by persons scouting for damaging populations. For personnel who lack taxonomic experience, identifying the nymphs and adults of these common grasshoppers is difficult. Yet the need for considering species in control decisions becomes ever more urgent. Control officials need to know both the identities and the densities of species composing infestations to assess accurately the economic threat and select prudent solutions.

There are several reasons why it is necessary to correctly identify species. (1) Species vary in their biotic potential and in their capacity for causing damage. (2) Depending on their food habits, species may be either pests or beneficials. (3) Certain species of pest grasshoppers are highly migratory and often pose a serious threat to distant crops. (4) Species vary in their seasonal cycle (period of hatching, development, and reproduction), which in turn affects the timing of control treatments. (5) Because current chemical and biological methods of controlling grasshoppers are more sophisticated, their effective use requires greater knowledge of the pests' life histories and habits. (6) As environmental impacts of control are more finely evaluated, recognition of pest species of grasshoppers has become essential in the selection of management strategies.

The purpose of this manual is to provide a pictorial guide that will allow plant protection personnel to make grasshopper identifications in the field. Although the surest method for obtaining an accurate identification is submission of the specimen to a specialist, this procedure is not feasible during an expeditious grasshopper survey. To achieve the requisite efficiency in making a useful survey, the scout must be able to identify, and in a short time learn to recognize on sight, the common species inhabiting the infested area.

Grasshoppers are relatively large insects with quite distinct appearances. Diverse traits permit one

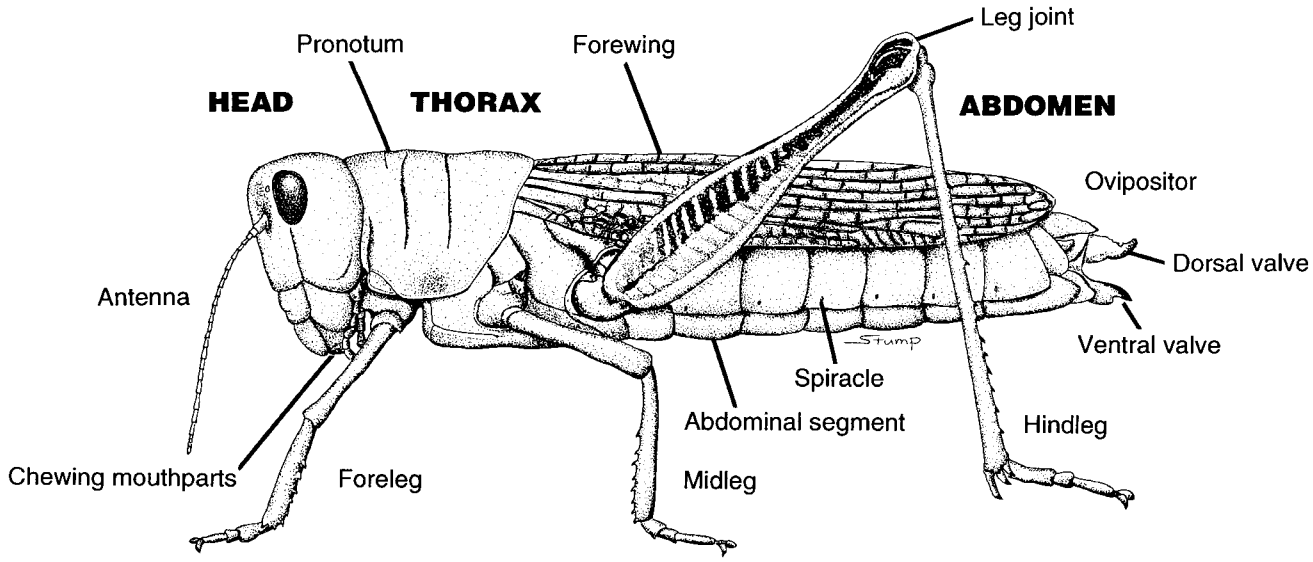

Figure 1. Diagram of a female grasshopper showing characteristic external features. Modeled after *Melanoplus bivittatus* (Say).

to identify a specimen of an unknown species by comparing it with identified museum specimens. One may also identify the specimen by comparing it with good color pictures. When accompanied by illustrations and descriptions of distinguishing characters and their variations, color pictures are probably the best means of accurate identification of an unknown specimen (short of submitting it to a specialist).

This *Field Guide to Common Western Grasshoppers* provides the scout with color pictures of the nymphs, adult male, and female, and illustrations and descriptions of distinguishing characters allowing comparisons with unknown specimens that need identification. The guide also contains distribution maps of species, brief accounts of their seasonal cycles, feeding and reproductive behavior, and habitat preferences. All may serve as additional clues to the identities of specimens as well as provide pertinent information for grasshopper management.

External Anatomy

The basis for classification and identification of grasshoppers consists primarily of the distinctive features of their external anatomy. Gross structures establish the affiliation of grasshoppers with the higher categories of invertebrate animals. For example, grasshoppers belong to the phylum Arthropoda as evidenced by the ringlike segments of their body, their jointed appendages, and their exoskeleton (Fig. 1).

Further segregation places them in the class Insecta, the insects. They have three body regions (the head, thorax, and abdomen) and possess a

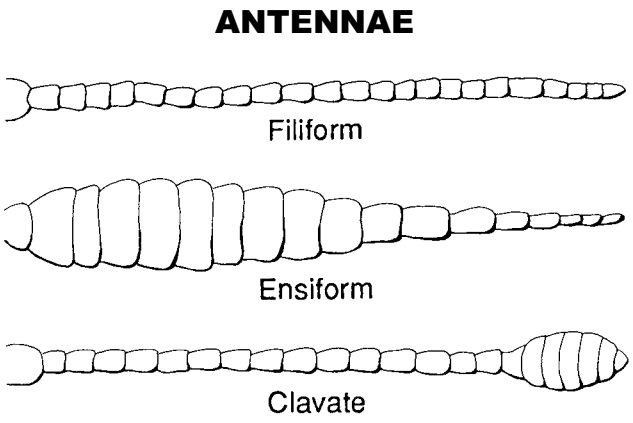

Figure 2. Diagram of three forms of grasshopper antennae: filiform or threadlike, ensiform or sword-shaped, and clavate or club shaped.

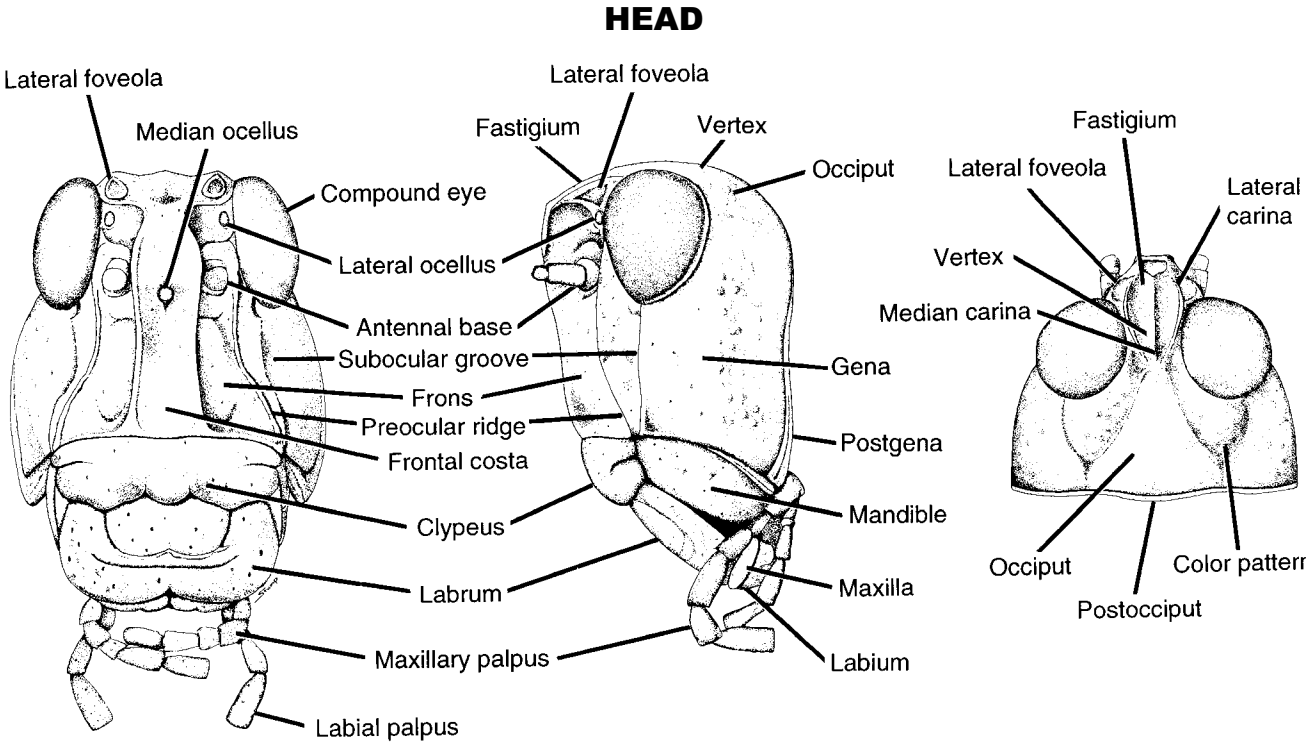

Figure 3. Grasshopper head, front, side, and top views. Modeled after *Trimerotropis pallidipennis* (Burmeister).

tracheal system for breathing, three pairs of legs, and two pairs of wings. Within the Insecta, grasshoppers belong to the order Orthoptera, as they grow and develop by gradual metamorphosis (eggs-nymphs-adults), and they have chewing mouthparts and leathery forewings called tegmina. Grasshoppers may next be placed in the family Acrididae because they possess short antennae and ovipositor (egg-layer), an auditory organ (tympanum visible externally) on each side of the first abdominal segment, and three-segmented tarsi (feet). See Table 1 summarizing the affiliation of the Carolina grasshopper, *Dissosteira carolina* (Linnaeus).

For placing grasshoppers in lower categories of classification, that is, in genus and species, one must resort to finer structures of their external anatomy and also to body size, shape, color, stripes, and patterns. Anatomical structures often have special names that the scout must learn in order to understand the descriptions of species in this guide.

Head

The head of the grasshopper is a hard capsule that contains large muscles, which operate the chewing mouthparts, and the brain and subesophageal ganglion, which serve as the main centers of the nervous system. Prominent on the outside of the capsule are a pair of antennae, two large compound eyes, and the downward directed mouthparts. The antennae of grasshoppers are usually filiform (thread-like) but they may have other shapes, such as ensiform (broad at base, narrowing to tip) or clavate (expanded at tip) (Fig. 2). Compound eyes vary in shape and protuberance. They are usually somewhat round but may be elliptical in grasshoppers with strongly slanted faces.

The head capsule is divided into areas by visible sutures, external ridges (carinae), or by general location (Fig. 3). The top of the head between the compound eyes is known as the **vertex**. Behind the vertex is the **occiput**, and in front of the vertex is the **fastigium**. A pair of variously shaped depressions, the **lateral foveolae**, is often present in front or at the sides of the fastigium. The front of the head between the compound eyes and extending to the clypeus is known as the **frons**. A wide ridge, the **frontal costa**, runs down the middle of the frons from the fastigium toward the margin of the clypeus. The side of the head below the compound eye is named the **gena** or cheek. Grasshoppers have three simple eyes called **ocelli** — one above the base of each antenna and one centrally located in the frontal costa. These and other parts and appendages of the head are illustrated in Figure 3.

Thorax

The thorax, locomotion center of the grasshopper, is a stout, boxlike structure consisting of three fused segments: the **prothorax**, **mesothorax**,

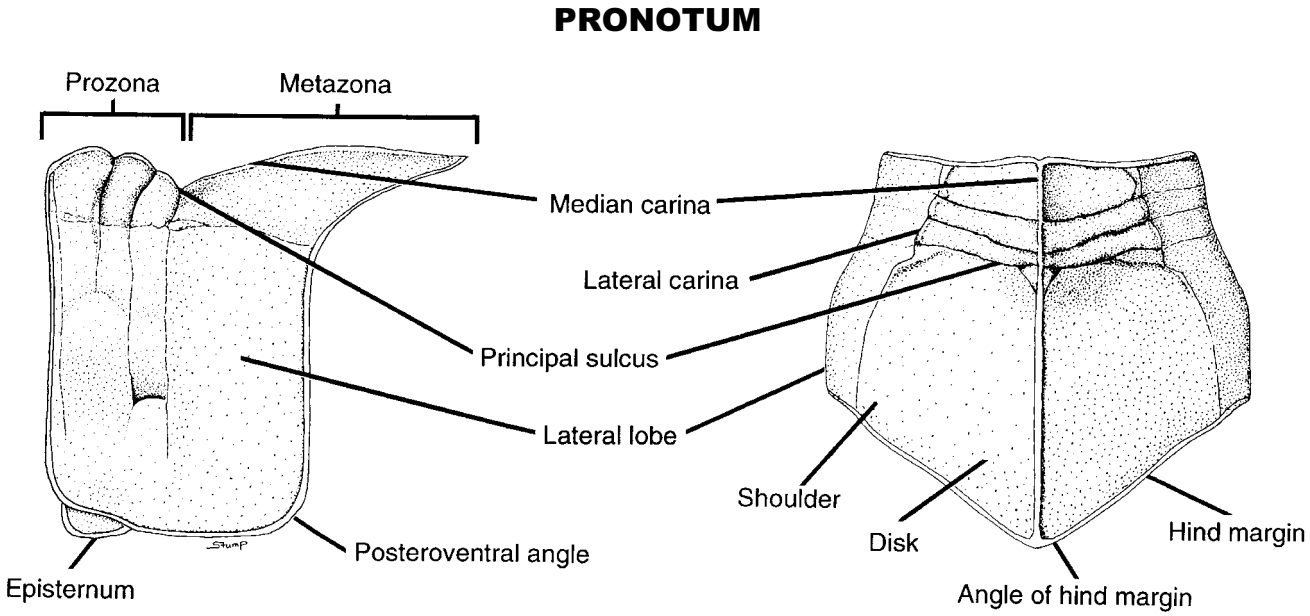

Figure 4. Grasshopper pronotum, side and top views. Modeled after *Trimerotropis pallidipennis* (Burmeister).

and **metathorax**. Each segment bears a pair of legs. The second segment bears a pair of forewings, the **tegmina**, and the third segment a pair of membranous hindwings. The wings of a few species are reduced to small pads or are entirely lacking. The top of the thoracic segments is called the **notum**, the bottom the **sternum**, and the sides the **pleura**.

The **pronotum** situated just behind the head is a prominent, saddle-shaped structure with lateral lobes that hide nearly all of the propleura (Fig. 4). The pronotum has many distinctive features useful in separating both genera and species of grasshoppers. The integument (skin) may be nearly smooth in some species and rough and wrinkled in others. The dorsum or ***disk*** of the pronotum is divided into left and right halves by a longitudinal ridge, the **median carina**. The ridge varies among species from barely visible to a conspicuously high crest. Transverse furrows run across the disk and down the lateral lobes. These furrows, known as **sulci**, cut into the median carina and divide the disk into zones, the **prozona** in front and the **metazona** in the rear. In many species only one sulcus cuts the median carina while in others two or three sulci cut the median carina. The hind sulcus is considered the **principal sulcus**; from its position the length of the prozona and metazona are measured.

STERNUM OF THORAX

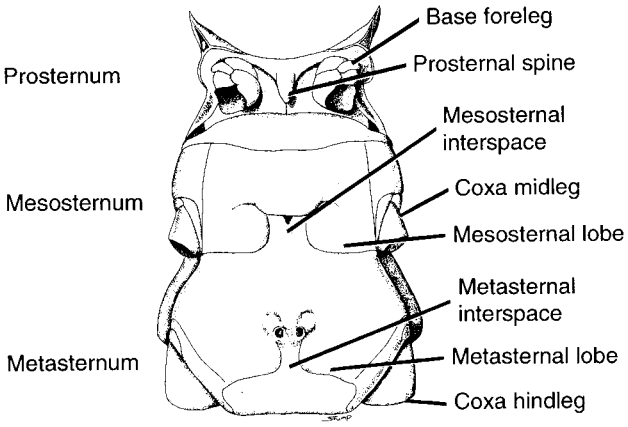

Figure 5. Sternum of thorax, bottom view. Modeled after *Melanoplus bivittatus* (Say) female.

The lateral lobes usually form an angle with the disk and are separated from the disk by lateral carinae that, depending on the species, may be straight and parallel or variously incurved or outcurved. The hind margin of the disk varies from an acute angle to an obtuse angle, or may be convex, truncate, or emarginate.

HINDLEG

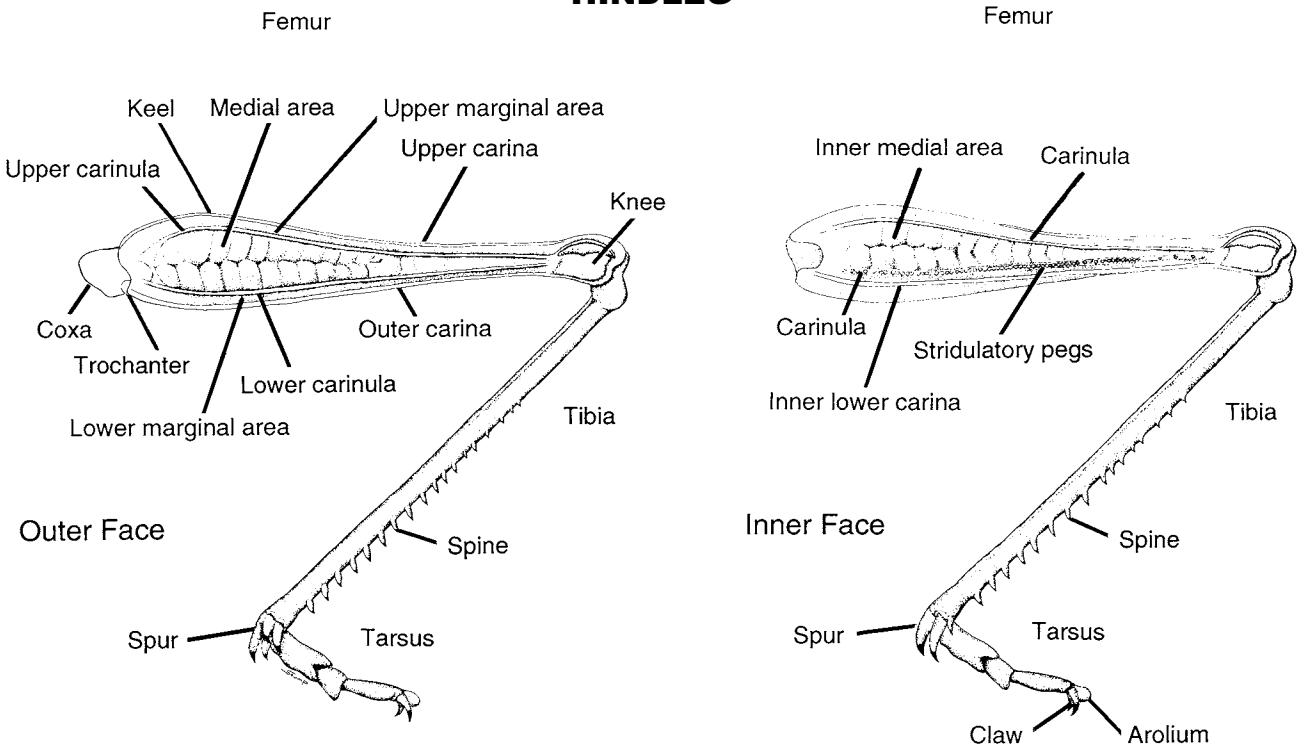

Figure 6. Grasshopper hindleg, views of outer and inner faces. Hindleg of *Mermiria bivittat*a (Serville).

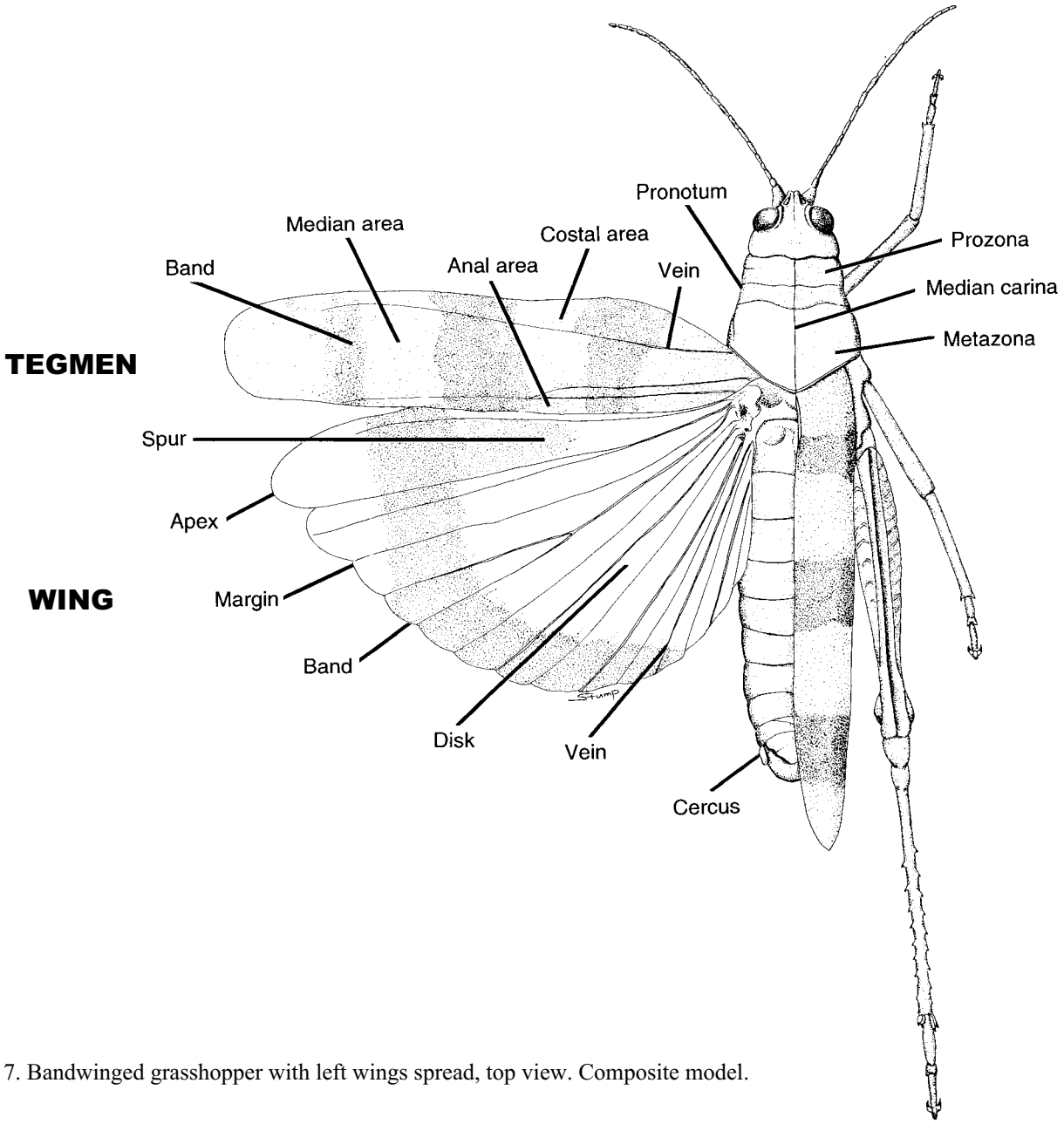

Figure 7. Bandwinged grasshopper with left wings spread, top view. Composite model.

The various shapes, sizes, and protuberance of the sternal sclerites afford reliable taxonomic characters (Fig. 5). A **prosternal spine** located between the bases of the front legs is characteristic of members of the spurthroated subfamily. Shapes and dimensions of the mesosternal and metasternal lobes and interspaces are useful in separating certain species and subfamilies.

Legs

Although the three pairs of legs have the same component parts, the hind pair, adapted for jumping, are much larger than the first and second pair and bear more distinctive features. The color and markings of both the femur and tibia differ among species. The robust **femur** has several surfaces and ridges that have been given names for easy reference (Fig. 6).

The long and slender **tibia** bears along its posterior edges a double row of spines and distally two pairs of articulated **spurs** or calcars. The number of spines and the length of calcars vary among species. The inner medial area of the femur may have a longitudinal ridge bearing a series of **stridulatory pegs**. Up and down movements of the hindlegs cause the pegs to scrape against a raised vein on each tegmen, which produces a song or signal peculiar to that species of grasshopper.

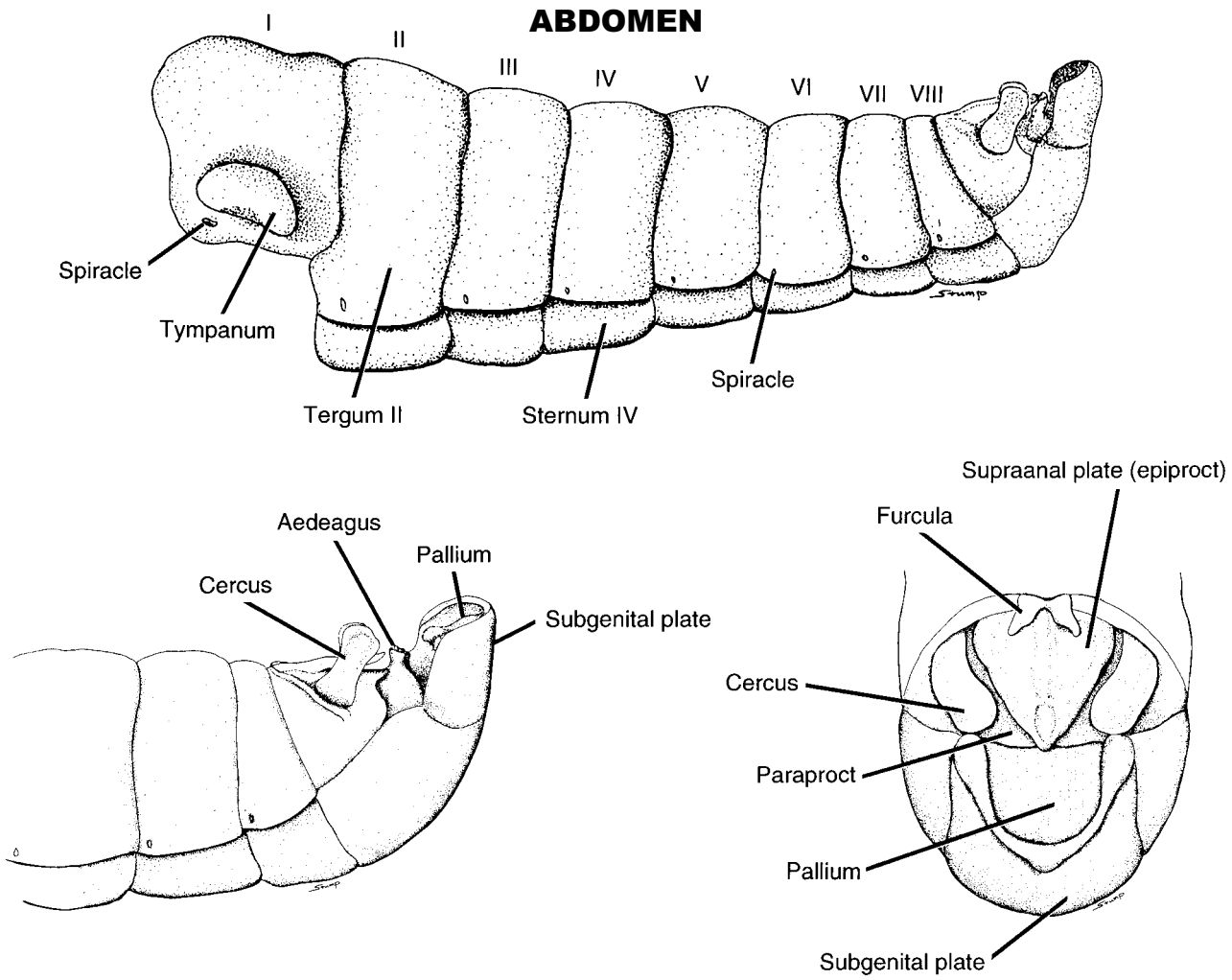

Figure 8. Grasshopper male abdomen, side view and enlarged side and dorsal views of end. Modeled after *Melanoplus packardii* Scudder.

Wings

The two pairs of grasshopper wings differ in shape, structure, and function (Fig. 7). The front pair, or **tegmina**, are leathery and narrow with the sides nearly parallel. The **hind wings** are membranous and fan-shaped. Compared with the tegmina, the hind pair contribute three times as much to flight lift. Both pairs afford diagnostic characters that aid in the identification of species. The **wing veins**, sclerotized tubes providing strength to the wings, vary greatly in thickness. The tegmina vary from immaculate to distinctly spotted or marked. The hindwings of grasshoppers are usually hyaline. Members of one subfamily, the Oedipodinae or bandwinged grasshoppers, have wings with a dark submarginal band and have the disk colored.

Abdomen

The hind region of the grasshopper's body, the abdomen, consists of 11 segments (Fig. 1). Segment I is firmly fused with the metathorax and contains the auditory organ with its eardrum cover, the **tympanum** (Fig. 8).

Segments II to VIII are ringlike in appearance and are separated from one another by pliable membranes. Each segment has a sclerotized **tergum** that covers not only the top but also the sides of the abdomen. A sclerotized **sternum** covers the bottom. Pliable membranes separate the terga from the sterna and with the intersegmental membranes allow the abdomen much flexibility, a requirement for respiratory movements, copulation, and oviposition.

Genitalia

The terminal segments of the abdomen are reduced and modified to bear the external reproductive organs, the genitalia, and the associated structures (Fig. 8). These structures offer the most reliable taxonomic characters for separating spurthroated grasshoppers. Structures of the male are more distinctive than those of the female. The prominent paired **cerci** are usually conical, but in the males of some genera, e.g. *Melanoplus*, they have characteristic sizes and shapes. Likewise, the **furcula**, a pair of projections from the posterior edge of tergum X of males, differs in size and shape. The **epiproct** or **supraanal plate**, although roughly triangular, varies sufficiently in shape and rugosity to be taxonomically useful. The variations in shape and protuberances of the **subgenital plat**e are also useful in identification. These structures are easily seen with a pocket magnifier of 10x magnification. A few distinctive structures, such as the lobes of the **aedeagus**, require the use of a stereomicroscope (magnification of 50x and greater) for clear identification.

The **valves** of the ovipositor are sometimes useful in separating species (Fig 1). The dorsal and ventral pair of valves have various shapes and denticulations. The middle pair of valves are small and hidden.

The sclerotized integument of the abdomen varies in color, patterns, and texture among species and sometimes affords distinguishing taxonomic characters.

Nymphal Characters

Identification of grasshopper nymphs presents greater difficulties because of the absence of several reliable taxonomic characters of the adult stage. In nymphs, the wings are lacking and the genitalia are undeveloped and generalized. Sets of characters, however, are useful in identifying nymphs of the three large subfamilies of western grasshoppers. The chief characters diagnostic of slantfaced nymphs

TABLE 1. Affiliation of the Carolina grasshopper, *Dissosteira carolina* (Linnaeus), with the categories of taxonomic hierarchy and the associated characteristics.

CATEGORY	TAXON	CHARACTERISTICS
Kingdom	Animalia	Sensitivity, voluntary movement, require oxygen and organic food, fixed organs.
Phylum	Arthropoda	Ringlike segments, jointed appendages, exoskeleton.
Class	Insecta	Three body regions, three pairs legs, one pair antennae, tracheal system, usually two pair wings.
Order	Orthoptera	Forewings leathery, hindwgins membranous, chewing mouthparts, hindwings enlarged for jumping, simple metamorphosis.
Family	Acrididae	Short antennae, short ovipositor, tympanum on first abdominal tergum, three segmented tarsi.
Genus	*Dissosteira*	High median pronotal crest deeply cut by one sulcus, body slender, medium to large size.
Species	*carolina*	Hindwings black with yellow margin; tegmina unicolorous or faintly spotted.

(Gomphocerinae) consist of the degree of facial slope, general color pattern, shape of the antennae and foveolae, and the extent of curving of the lateral carinae of the pronotum. Chief characters diagnostic of bandwinged nymphs (Oedipodinae) are: (1) height of the median carina of the pronotum and number of sulci; (2) position and length of the lateral carinae; (3) color patterns of the hindlegs; (4) variations in dark bands on the head and pronotum; and (5) shape of the foveolae. Chief characters diagnostic of spurthroated nymphs (Melanoplinae) are color patterns of the hind femur, color patterns of the gena and pronotum, and markings of the compound eyes. The characters of the compound eyes, namely, color, stripes, and number and size of spots, are evident in fresh specimens, but they disappear in specimens that have been held for any length of time, even frozen ones. In treatment of the individual species later on, the particular diagnostic characters of each are described and explained.

Scientific and Common Names

Grasshoppers have been collected, studied, and named from all but the most frigid regions of the earth. More than 10,000 species have been classified and given scientific names. These are binomials, a method of naming used by the Swedish biologist, Carolus Linnaeus (1707-78) in his book, S*ystema Naturae*. The method proved so successful that other biologists promptly adopted it. The tenth edition of *Systema Naturae* (1758) has been designated as the official beginning for zoological nomenclature. This classic book contains an account of the widely distributed North American grasshopper, *Dissosteira carolina* (Linnaeus).

In addition to the scientific name, species of grasshoppers may have good common names. Some are approved by the Entomological Society of America, such as the Carolina grasshopper for *D. carolina*. Nevertheless, in searching the literature and in communicating information on species of grasshoppers, the scientific name has an unrivaled advantage. All of the known species have scientific names while only a small fraction have generally accepted common names.

The **scientific name** of a species consists of two parts. The first is the name of the genus, a taxonomic category containing a group of closely related species. The second part is the specific epithet or species name. For example, *Dissosteira* is the name of the grasshopper genus that contains four species; *carolina* is the specific epithet of one of the four species. The two words together, *Dissosteira carolina*, comprise the scientific name of the Carolina grasshopper. After the two words the name of the describer, Linnaeus, provides extra information. Linnaeus' name is in parenthesis, which means that originally Linnaeus had placed this species in a different genus (*Gryllus*) and another taxonomist later revised the scientific name by placing the species in a new or different genus. A describer who has assigned a newly described species to an established genus is not named in parentheses, for example *Melanoplus confusus* Scudder.

The scientific name is always italicized. After it has been written in full once, it is usually abbreviated by using the initial of the genus, followed by the full spelling of the epithet, and the dropping of the describer's name, hence *D. carolina*. The first letter of the genus name is always capitalized and the first letter of the specific epithet is always lower case. The genus name may be used alone when referring to the genus only or to all of the species making up the genus such as *Dissosteira* or *Melanoplus*.

How do taxonomists choose a scientific name for a species new to science? Rules of Latin grammar must be followed but otherwise there is much latitude in selecting a name. If the new species can be assigned to a valid genus, a specific epithet not already in use within the genus is chosen. The name may describe a character of the grasshopper or locate the region or state where it was collected. Or it may honor a friend or a renowned scientist. For example, in a taxonomic study published in 1897, Samuel Scudder named a new species *Melanoplus bruneri* in honor of professor Lawrence Bruner, a pioneer grasshopper specialist at the University of Nebraska, Lincoln. To be a valid scientific name, the author must publish the description and name of a new species in a journal article, bulletin, or book.

As a finishing touch in establishing the authenticity of a new species, the describer chooses a particular specimen as the **type** or holotype. In the taxonomy of grasshoppers, the type selected by the author is an adult male from which the original description and illustrations were made. A female specimen is also chosen for description and illustration and is specified as the **allotype**. The author uses other specimens, termed material, for comparison with the types, often describing slight differences in size and color. These may be designated as **paratypes**, both males and females.

The taxonomist must also decide on the deposition of the types in an insect museum. If the author is a member of the staff of a particular museum, the types are usually deposited with that museum. In cases where the author is not employed by a museum, the types are sent to a recognized museum. Many grasshopper types are held in the extensive collections of the Academy of Natural Sciences of Philadelphia, the California Academy of Sciences (San Francisco), the Museum of Zoology, University of Michigan (Ann Arbor), the Lyman Entomological Museum (Ste. Anne de Bellevue, Quebec), and the National Museum of Natural History (Washington, DC). These are favored museums for the deposition of grasshopper types. The author may send the types to one museum and paratypes to the others and, if there is sufficient material, still other specimens to smaller museums.

Although the grasshopper fauna of North America is relatively well known, new species continue to be found in all parts of the continent and to be described in entomological publications. The chance is slim, however, that a scout will pick up a new species where grasshopper infestations occur. In most instances the scout will be able to identify a specimen from the pages of this field guide. On occasion a scout may collect an already described species not treated in the guide, particularly in genera with large numbers of species such as *Melanoplus* and *Trimerotropis*. The scout may then resort to a state grasshopper "key" (see Selected References).

Species

What are species? *Species* in Latin merely means "kind" and so species in an elementary sense are different kinds of organisms. Most, if not all, species of grasshoppers can be distinguished on the basis of obvious anatomical and behavioral characters and are biological realities. In nature, species consist of populations of individuals that usually occur over an extensive geographic range. For this reason one modern view considers a species to be a genetically distinctive group of natural populations that share a common gene pool and are reproductively isolated from all other such groups. The species is the largest unit of population within which effective gene flow occurs or can occur. Higher taxonomic categories, from the genus up, are biologists' inventions that exist only in the human mind. Animals in the same category have anatomical similarities showing clear relationships. Their grouping, however, is a decision based on a mix of objective and subjective evaluations. One taxonomist's family can easily be another's order.

Grasshopper Populations

Grasshopper infestations or assemblages consist of the individuals of several species that live together in the same habitat sharing or competing for available food and space. Members of the dominant species outnumber members of other species and may make up more than 50 percent of the assemblage. Occasionally two or three species may become codominants. No evidence has been found for any essential relationship among species that brings them together. The habitat affords the minimum requirements for all the permanent species and ample measure for the abundant.

Grass-feeding species of grasshoppers are the most numerous in grasslands. In a northern mixedgrass prairie site 18 miles northwest of Fort Collins, Colorado, a total of 24 species were recorded during an outbreak in 1981 (Table 2). Of the total, 14 were grass feeders, six were mixed feeders, and four were forb feeders. The number of individuals of grass-feeding species made up 85% of the total population. The dominant grasshopper, *Ageneotettix deorum* (Scudder), contributed 52% of the population. A second example of an outbreak population in northern mixedgrass prairie was the assemblage inhabiting a site 15 miles north of Hartville, Wyoming, where 16 species were recorded (Table 2). Nine species were grass feeders, one a mixed feeder, and six were forb feeders. The number of individuals of grass feeding species made up 89% of the population. The dominant grasshopper, *Aulocara elliotti* (Thomas), contributed 74% of the population.

Why was *A. deorum* dominant in one mixedgrass prairie site and *A. elliotti* dominant in another? And why was *Cordillacris occipitalis* (Thomas) the second most abundant in one site and entirely missing from the other? Answers to these questions are not available. An hypothesis for the cause of the observed variations in densities was the differences in habitat in conjunction with differences in requirements of the grasshoppers. Although both sites are part of the northern mixedgrass prairie, the soil, slope, and vegetation of each differ significantly. Grasshopper species vary in densities and dominance depending on the soil, vegetation, topography, and use of a habitat. Because of differential effects of weather, parasites, disease, or insecticidal

TABLE 2. Number and density of grasshopper species in mixedgrass prairie and in desert grassland.

	NUMBER/SQ YD		
	Mixedgrass Colorado	**Mixedgrass Wyoming**	**Desert grass Arizona**
Gomphocerinae			
Aeropedellus clavatus	0.2	2.2	
Ageneotettix deorum	26.3	1.4	0.2
Amphitornus coloradus	3.9	0.2	0.3
Aulocara elliotti	2.8	20.7	18.0
Aulocara femoratum	0.3		
Boopedon nubilum			0.2
Cordillacris crenulata		0.2	
Cordillacris occipitalis	4.0		
Eritettix simplex	+		0.2
Opeia obscura	1.6		
Philbostroma quadrimaculatum	0.9		
Psoloessa delicatula	0.1	0.3	0.5
Oedipodinae			
Arphia pseudonietana	0.02		
Camnula pellucida		0.2	
Hadrotettix trifasciatus		0.2	2.5
Mestobregma plattei			0.2
Metator pardalinus	0.3	2.5	1.8
Spharagemon equale	0.2		
Trachyrhachys kiowa	2.5		
Trimerotropis pallidipennis			0.9
Xanthippus corallipes	0.003	0.1	0.2
Melanoplinae			
Hesperotettix viridis	0.2	0.2	
Melanoplus bivittatus	0.1		
Melanoplus confusus	0.2	0.2	
Melanoplus cuneatus			20.9
Melanoplus packardii	0.6	0.2	
Melanoplus fladstoni	0.5		
Melanoplus infantilis	1.2	0.3	
Melanoplus keeleri	0.3		
Melanoplus occidentalis	1.5	1.8	
Melanoplus sanguinipes	2.8	0.6	6.0
Total grasshoppers /sq yd	50.5	31.3	51.9
Number species	24	16	13

+ indicates species present but not recorded in sampling

treatments, the densities of grasshopper species inhabiting a rangeland site may change with time. The abundant species, however, tend to retain their dominant status over the years.

The composition of grasshopper assemblages is characteristic of various grassland types. A scout working in a western state expects particular species to compose economic infestations in certain areas. Table 3 lists species abundant in several grassland types and in disturbed land (crop borders, fence rows, reversions, roadsides). Because the species composition of grasshopper assemblages infesting particular habitats remains almost the same year after year, a scout is aided in identifying nymphs by knowing the species that were present as adults during past years. Widespread species with high biotic potential, such as *Aulocara elliotti* and *Ageneotettix deorum*, inhabit many grassland types and become abundant members in various assemblages of grasshoppers. In outbreaks on desert grasslands of Arizona and New Mexico, for example, *A. elliotti* is often the dominant species (Table 2), as in many infestations of the northern mixedgrass prairie.

Life History

There are probably as many grasshopper life histories as there are grasshopper species. Each species appears to possess a unique set of ecological and physiological adaptations that allow it to grow, survive, and reproduce in its environment. The habitat furnishes individuals with nutritive food plants, adequate living space, satisfactory soil conditions for the eggs, and favorable or tolerable physical and biotic relationships for all the life stages. Because of the distinctive habits and behaviors of grasshoppers, the particular facts of their life histories will be discussed later in treatment of the individual species.

Life Cycle

All grasshoppers begin their lives as eggs. Yet eggs represent the least known stage of the grasshopper life cycle. They are laid in the soil of the habitat and develop hidden from the view of humans. Eggs of a few species, however, have been studied in both field and laboratory (Fig. 9). Incubation of eggs begins immediately after females deposit them in the soil. The embryo, at first a tiny disc of cells laying on the ventral side of the yolk surface and at the posterior end of the eggs (Fig. 10),

Figure 9. One intact and one broken egg pod, exposing the eggs of the migratory grasshopper, *Melanoplus sanguinipes* (Fabricius).

grows rapidly, receiving nourishment from the nutrient stores in the yolk.

In seven days the embryo of the migratory grasshopper, *Melanoplus sanguinipes*, held at an incubation temperature of 30½C, reaches Stage 19. In this stage the embryos of many rangeland species such as *Aulocara elliotti* and *Camnula pellucida* cease growth and begin a **diapause**. The embryo of the migratory grasshopper, however, continues to develop and at Stage 20 actively moves from the ventral to the dorsal surface and revolves 180½ on its long axis (see Figure 10, Stage 20). After 15 days the embryo has grown to Stage 24, having achieved 80 percent of its development. It then ceases growth and enters diapause. The embryo of the twostriped grasshopper, and probably others also, enter diapause at this stage. Exposed to favorable incubation temperatures, the eggs of a few rangeland species, such as *Arphia conspersa* and *Xanthippus*

TABLE 3. Common species of grasshoppers found in several grassland types, in cold desert shrub, and in distrubed land.

Tallgrass prairie

Ageneotettix deorum
Melanoplus bivittatus
Melanoplus differentialis
Melanoplus femurrubrum
Orphulella speciosa
Phoetaliotes nebrascensis
Syrbula admirabilis

Northern mixedgrass prairie

Aeropedellus clavatus
Ageneotettix deorum
Amphitornus coloradus
Aulocara elliotti
Aulocara femoratum
Camnula pellucida
Cordillacris occipitalis
Encoptolophus costalis
Melanoplus infantilis
Melanoplus sanguinipes
Opeia obscura
Phlibostroma quadrimaculatum
Psoloessa delicatula

Southern mixedgrass prairie

Ageneotettix deorum
Amphitornus coloradus
Aulocara elliotti
Boopedon nubilum
Melanoplus sanguinipes
Mermiria bivittata
Opeia obscura
Orphulella speciosa
Phlibostroma quadrimaculatum

Bunchgrass prairie

Aulocara elliotti
Conozoa sulcifrons
Cordillacris occipitalis
Dissosteira spurcata
Melanoplus sanguinipes
Oedaleonotus enigma
Trimerotropis pallidipennis

Shortgrass prairie

Cordillacris crenulata
Hadrotettix trifasciatus
Melanoplus gladstoni
Opeia obscura
Trachyrhachys aspera
Trachyrhachys kiowa

Desert prairie

Ageneotettix deorum
Amphitornus coloradus
Aulocara elliotti
Hadrotettix trifasciatus
Melanoplus cuneatus
Melanoplus sanguinipes
Trimerotropis pallidipennis

Mountain meadows

Aeropedellus clavatus
Anabrus simplex
Amnula pellucida
Chorthippus curtipennis
Melanoplus alpinus
Melanoplus borealis
Melanoplus bruneri
Melanoplus dawsoni
Melanoplus sanguinipes
Stenobothrus brunneaus

Sand prairie

Ageneotettix deorum
Melanoplus angustipennis
Melanoplus flavidus
Melanoplus foedus
Mermiria bivittata
Opeia obscura
Phoetaliotes nebrascensis

Annual grassland

Camnula pellucida
Dissosteira pictipennis
Dissosteira spurcata
Melanoplus devastator
Melanoplus marginatus
Melanoplus sanguinipes
Oedaleonotus enigma

Cold desert shrub

Aulocara elliotti
Cordillacris occipitalis
Dissosteira spurcata
Melanoplus rugglesi
Oedaleonotus enigma
Trimerotropis pallidipennis

Disturbed land (reversions, roadsides, crop borders)

Aeoloplides turnbulli
Dissosteira carolina
Melanoplus angustipennis
Melanoplus bivittatus
Melanoplus differentialis
Melanoplus femurrubrum
Melanoplus lakinus
Melanoplus packardii
Melanoplus sanguinipes

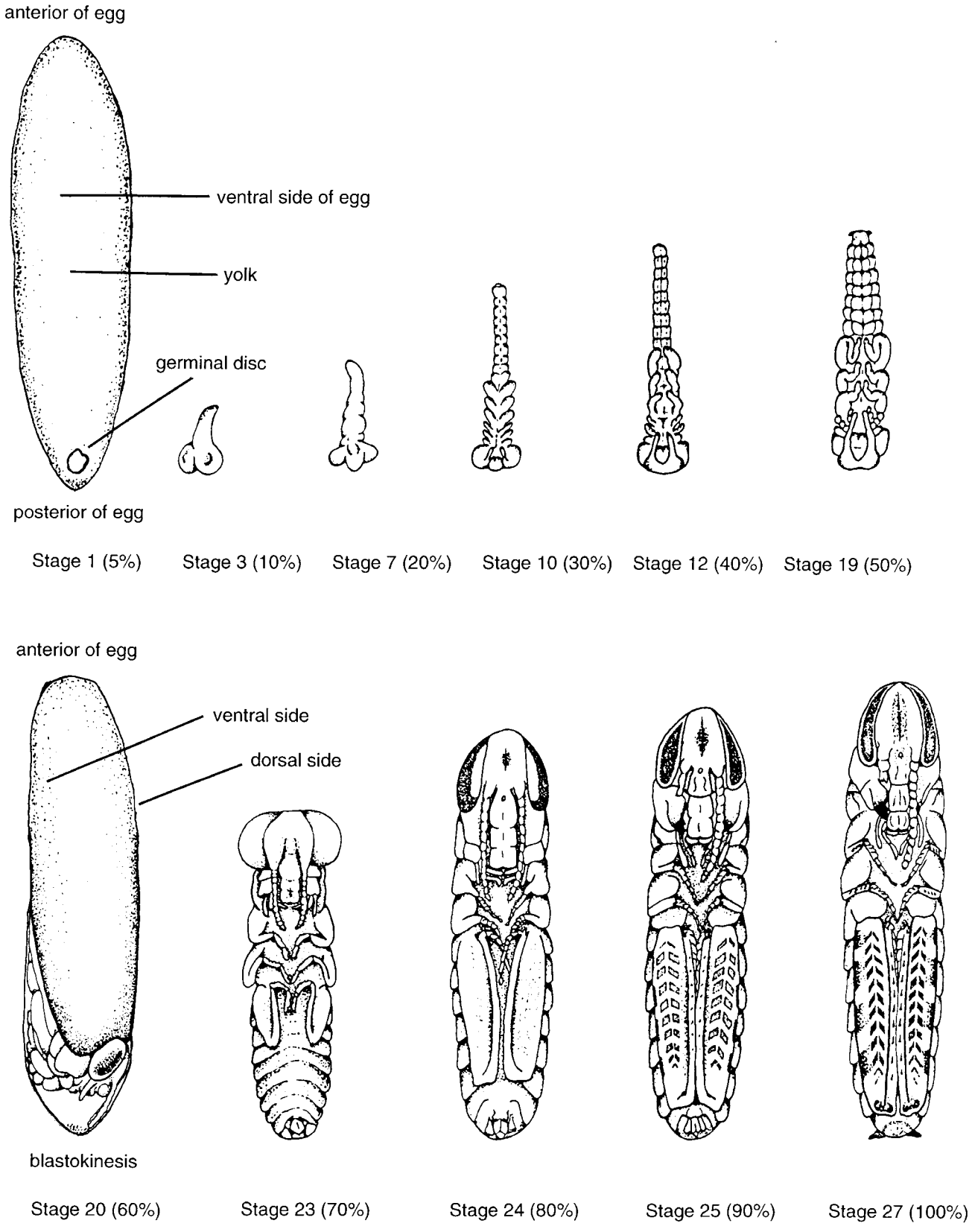

Figure 10. Selected stages in the development of a grasshopper embryo (*Melaoplus sanguinipes*) held at a constant temperature of 30 C. Left two figures show whole egg; other figures show embryos removed from egg. (Illustrations adapted from Riegert, 1961; stages identified and designated for embryos of *Aulocara elliotti* by Saralee Visscher, 1966).

corallipes, develop completely and hatch during the same summer they are laid. The immediate cause of cessation of embryonic growth (diapause) in eggs of the majority of rangeland grasshoppers appears to be the shutdown of growth hormones. The embryos remain physiologically active as transfer of nutrient materials from the yolk into the embryonic fat body and other tissues continues. Cold temperatures of winter, however, slow or end this process and embryos enter a dormant period.

For eggs laid in temperate regions to reach their maximum development before diapause, they must receive sufficient heat, usually measured as day-degrees of heat accumulated in the soil at egg depth. Eggs deposited late in the season or during a cold summer may not receive this amount of heat, especially in northern areas such as the Canadian provinces of Alberta, Manitoba, and Saskatchewan. Eggs that do not reach their potential stage of development have reduced hatchability the following spring and thus do not contribute as much to the maintenance of a population.

During winter, low ground temperatures eventually break egg diapause. As soon as the ground warms above threshold soil temperatures of 50 to 55½F in spring, the embryos are ready to continue their development. Research has shown that for the few species studied, eggs need 400 day-degrees by fall to attain maximum embryonic growth and another 150 day-degrees in spring to initiate hatching. For completion of embryonic growth from start to finish, eggs require totals of 500 to 600 day-degrees.

In spring the emergence of hatching grasshoppers may be readily observed. All embryos of a single pod usually wriggle out one after another within several minutes. Once out, they immediately shed an embryonic membrane called the serosa. An individual hatchling, lying on its side or back and squirming, takes only a few minutes to free itself (Fig. 11). During this time the hatchlings are susceptible to predation by ants. After the shedding of the membrane the young grasshoppers stand upright and are able to jump away and escape attacking predators. In spring, young grasshoppers have available green and nutritious host plants. The majority of individuals in grasslands are grass feeders, but individuals of some species are mixed feeders, eating both grasses and forbs. Others are strictly forb feeders.

As insects grow and develop, they molt at intervals, changing structures and their form. This process is called metamorphosis. A number of insects undergo gradual (simple) **metamorphosis**, such as grasshoppers. With this type of metamorphosis the insect that hatches looks like the adult except for its smaller size, lack of wings, fewer antennal segments, and rudimentary genitalia (Fig. 11). Other insects with gradual metamorphosis include the true bugs, aphids, leafhoppers, crickets, and cockroaches. The majority of insects undergo complete (complex) metamorphosis, as the eggs hatch into wormlike larvae adapted for feeding and have a vastly different appearance from that of the adult insect. Before full-grown larvae can become adult insects they must enter into the pupal stage. In this stage they develop and grow the adult structures. Common examples of insects that undergo complete metamorphosis are beetles, butterflies, bees, wasps, and flies.

For young grasshoppers to continue their growth and development and reach the adult stage, they must periodically molt or shed their outer skin (Fig. 11). Depending on species and sex, they molt four to six times during their nymphal or immature life. The insect between molts is referred to as an instar; a species with five molts thus has five instars. After shedding the serosal skin, the newly hatched nymph is the first instar. After each molt the instar increases by one so that the nymph consecutively becomes a second, third, fourth, and fifth instar. When the fifth instar molts, the grasshopper becomes an adult or an imago.

The new adult has fully functional wings but is not yet ready to reproduce. The female has a preoviposition period of one to two weeks during which she increases in weight and matures the first batch of eggs. Having mated with a male of her species, the female digs a small hole in the soil with her ovipositor and deposits the first group of eggs. Once egg laying begins, the female continues to deposit eggs regularly for the rest of her short life. Depending on the species, production may range from three pods per week to one pod every one to two weeks. The species that lay fewer eggs per pod oviposit more often than those that lay more eggs per pod.

The egg pods of grasshoppers vary not only in the number of eggs they contain but also in their size, shape, and structure. Based on structure, four types have been recognized. In type I a stout pod

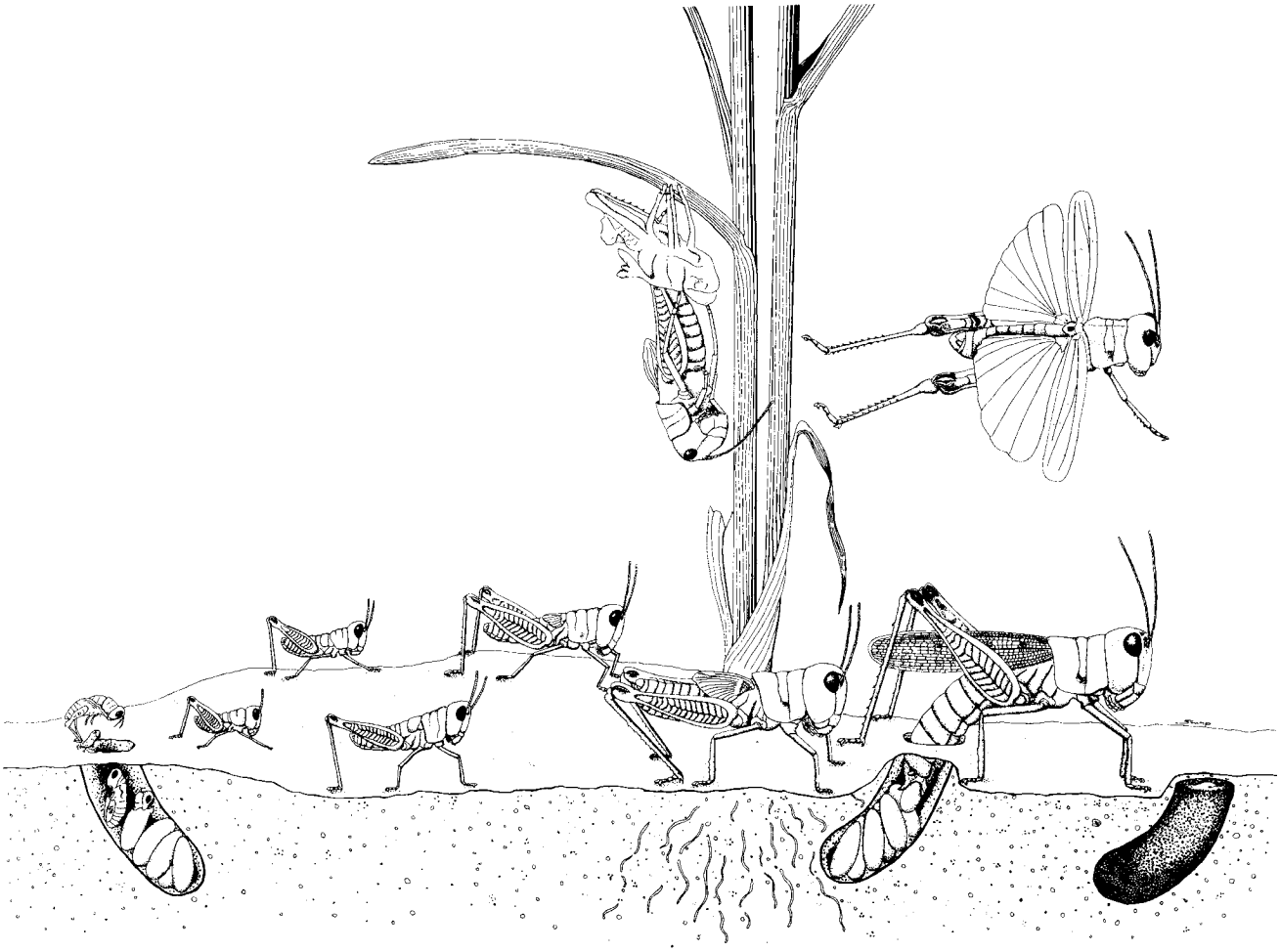

Figure 11. The lifecycle of the bigheaded grasshopper, *Alucara elliotti* (Thomas). During summer in bare spots of grassland the female deposits at intervals batches of eggs. As soon as the eggs are laid, they begin embryonic development and reach an advanced stage in which they enter diapause and pass the winter. In spring the eggs complete embryonic development and hatch. The young grasshopper sheds a serosal skin, the exoskeleton hardens, and the nymph begins to feed and grow. After molting five times and developing through five instars in 30-40 days, it becomes an adult grasshopper with functional wings. The adult female matures groups of six to eight eggs at a time and deposits them in the soil at intervals of three to four days for the duration of her short life.

forms from frothy glue and soil surrounding the eggs; froth is lacking between the eggs. In type II a weaker pod is formed from frothy glue between and surrounding the eggs. In type III frothy glue is present between the eggs but does not completely surround them. In type IV only a small amount of froth is secreted on the last eggs of a clutch, and most of the eggs lie loosely in the soil. Grasshopper eggs themselves vary in size, color, and shell sculpturing. Depending on the species eggs range from 4 to 9 mm long and may be white, yellow, olive, tan, brownish red, or dark brown. Eggs of certain species are two-toned brown and tan.

Events in the life cycle of an individual species of grasshopper — hatching, nymphal development, and adulthood — occur over extended periods. The eggs may hatch over a period of three to four weeks. Nymphs may be present in the habitat eight to ten weeks and adults nine to 11 weeks. Because of the overlapping of stages and instars, raw field data obtained by sampling populations do not answer several important questions. For example, how many

eggs hatched? How many individuals molted successfully to the next instar? What was the average duration of each instar? How many became adults? What was the average length of life and the average fecundity of adult females? To obtain answers to these questions, detailed sampling data must be treated mathematically.

Laboratory data may also be used in studying grasshopper life histories. Table 4 provides information on the life history of the migratory grasshopper, *Melanoplus sanguinipes*, reared at a constant temperature of 86½F and 30-35% relative humidity and fed a nutritious diet of dry feed, green wheat, and dandelion leaves. The entire nymphal period averages 25 days for males and 30 days for females. Each instar takes four to five days to complete development except for the last instar, which takes seven days. Adult longevity of males averages 51 days and females, 52 days. Longevity of adults in the field is no doubt briefer because of the natural predators and parasites cutting short the lives of their prey.

TABLE 4. Life history of the migratory grasshopper, *Melanoplus sanguinipes*, reared in the labratory at a constant temperature of 86²F.

	DAYS	
Stage	**Male**	**Female**
Instar 1	4.5	4.9
2	4.1	4.0
3	4.5	4.3
4	4.9	4.5
5	7.3	4.7
6	____	____
Total nymphal period	25.3	29.5
Average adult longevity	51.0	52.0

Seasonal Cycles

An important component of grasshopper life history is the seasonal cycle - the timing of the periods of egg hatch, nymphal growth and development, emergence of the adults and acquisition of functional wings (fledging), and the deposition of eggs or reproduction. The occurrence of these periods varies among the species and is greatly influenced by weather. An early spring hastens these events and a late one delays them. Latitude also influences the dates of occurrence. In North America springtime comes earlier in the south and later in the north. Consequently, hatching, development and maturation come earlier in the south and later in the north. In the West, altitude is also an important factor. The lower temperatures of higher altitudes, especially those of mountain meadows, are responsible for retarded seasonal cycles of grasshoppers and may often cause a two-year life cycle among species that ordinarily have a one-year life cycle.

Nymphal and adult grasshoppers are present all year long in natural habitats. Several species overwinter in late nymphal stadia and become adult in early spring. The majority, however, pass the winter as eggs protected in the soil. Depending on the species, these eggs hatch at different times from early spring until late summer. The variety of seasonal cycles allows actively feeding and developing grasshoppers to spread out over the entire growing season. Each species has its own time to hatch, develop, and reproduce, but with much overlapping of the cycles. An experienced scout going into the field to survey expects to find certain species at certain times and is thus aided in making identifications. Table 5 arranges the seasonal cycles of grasshoppers into: (1) very early nymphal and adult group, (2) very early hatching group, (3) early hatching group, (4) intermediate hatching group, and (5) late hatching group. The table is especially helpful in the identification of young nymphs.

Behavior

A grasshopper's day (and night) are linked closely with the physical factors of the environment, especially temperature, but also light, rain, wind, and soil. Stereotyped and instinctive behavior patterns serve grasshoppers remarkably well in making adjustments to wide fluctuations of physical factors that otherwise might be fatal. Grasshoppers effectively exploit the resources of their habitat and at the same time are able to tolerate or evade the extremes of physical factors. Their characteristic rapid jumping and flying responses help them escape numerous enemies that parasitize or feed upon them.

In temperate North America, certain behavior patterns are held in common among grasshopper species, especially among those occupying the same

TABLE 5. Species of grasshoppers grouped by seasoned appearances.

SLANTFACED (Gomphocerinae)	**BANDWINGED** (Oedipodinae)	**SPURTHROATED** (Melanoplinae)
Early spring, large nymphs and adults. Overwinted in nymphal stage.		
Eritettix simplex	*Arphia conspersa*	
Psoloessa delicatula	*Chortophaga viridifasciata*	
Psoloessa texana	*Pardalophora apiculata*	
	Pardalophora haldemani	
	Xanthippus corallipes	
	Xanthippus montanus	
Very early hatching group, hatching in early spring.		
Aeropedellus clavatus		*Melanoplus confusus*
Early hatching group, hatching in mid-spring.		
Acrolophitus hirtipes	*Camnula pellucida*	*Aeoloplides turnbulli*
Ageneotettix deorum	*Dissosteira pictipennis*	*Melanoplus angustipennis*
Amphitornus coloradus	*Dissosteira spurcata*	*Melanoplus bivittatus*
Aulocara elliotti	*Trimerotropis pallidipennis*	*Melanoplus cuneatus*
Cordillacris occipitalis		*Melanoplus foedus*
		Melanoplus infantilis
		Melanoplus occidentalis
		Melanoplus packardii
		Melanoplus rugglesi
		Melanoplus sanguinipes
		Oedaleonotus enigma
Intermediate hatching group, hatching in late spring.		
Aulocara femoratum	*Derotmema haydeni*	*Hesperotettix viridis*
Boopedon nubilum	*Dissosteira carolina*	*Hypochlora alba*
Chorthippus curtipennis	*Dissosteira longipennis*	*Melanoplus bowditchi*
Cordillacris crenulata	*Hadrotettix trifasciatus*	*Melanoplus dawsoni*
Mermiria bivittata	*Mestobregma plattei*	*Melanoplus devastator*
Orphulella speciosa	*Metator pardalinus*	*Melanoplus differentialis*
Parapomala wyomingensis	*Spharagemon collare*	*Melanoplus flavidus*
Phlibostroma quadrimaculatum	*Spharagemon equale*	*Melanoplus femurrubrum*
Pseudopomala brachyptera	*Trachyrhachys kiowa*	*Melanoplus marginatus*
	Trimerotropis campestris	*Brachystola magna*
Late hatching group, hatching begins in early summer.		
Eritettix simplex	*Arphia conspersa*	*Dactylotum bicolor*
Opeia obscura	*Arphia pseudonietana*	*Melanoplus alpinus*
Psoloessa delicatula	*Chortophaga viridifasciata*	*Melanoplus borealis*
Psoloessa texana	*Pardalophora apiculata*	*Melanoplus bruneri*
Stenobothrus brunneau	*Pardalophora haldemani*	*Melanoplus keeleri*
Syrbula admirabilis	*Xanthippus corallipes*	*Melanoplus lakinus*
	Xanthippus montanus	*Phoetaliotes nebrascensis*
		Schistocerca emarginata

part of the habitat, while other patterns differ. Individuals of different species have different ways of spending the cool nights. Some retreat under litter or canopies of grasses; others squat on bare ground and take no special shelter. Still others may climb a small shrub or a tall grass plant and rest at various heights within the canopy. Under favorable conditions of temperature and other elements of weather, grasshoppers may be active and even feed during the night. In southwestern states they have been observed on warm nights wandering about on the ground and on vegetation, feeding, and stridulating. Several species have been recorded flying at night and are attracted to city lights. A temperature of 80°F is apparently a prerequisite for night flying with maximum flight activity occurring at temperatures above 90°F.

A grasshopper's day usually starts shortly after dawn. Because body temperatures have fallen during the night, a grasshopper on the ground crawls to an open spot, often on the east side of vegetation, that allows it to warm itself by basking in the radiant rays of the sun. A common orientation is to turn a side perpendicular to the rays and lower the associated hindleg, which exposes the abdomen. Those that have spent the night on a plant make adjustments in their positions to take advantage of the sun's rays or they may climb or jump down to the ground to bask. Although grasshoppers generally remain quiet while they bask, they occasionally stir, preen, turn around to expose the opposite side, and sometimes crawl to a more favorable basking location. Grasshoppers may bask for a second time in the cool of late afternoon. Then as shadows begin to engulf the habitat, they retreat into their customary shelters.

After basking for one to two hours on sunny days, grasshoppers become active. They may walk about, seek mates, or feed. Because grasshoppers are cold-blooded creatures, their usual daily activities are interrupted when the weather turns cold, overcast, or rainy. During such times they generally remain sheltered and inactive.

During warm sunny weather of late spring and summer, grasshoppers take advantage of two foraging periods, one in the morning and one in the afternoon. Different species of grasshoppers have different ways of attacking and feeding on their host plants. Individuals of certain species climb the host plant to feed on leaves, petals, buds, or soft seeds while others cut and fell a grass leaf and feed on it while sitting on the ground. Geophilous (ground-dwelling) species regularly search the ground for food, picking up and feeding on seeds, dead arthropods, and leaves felled by other grasshoppers. In grasslands with considerable bare ground, very little litter is produced by grasshoppers. Severed leaves, dropped by the grasshoppers that feed on the host plant, are soon found and devoured by the ground foragers. In habitats infested by dense populations of grasshoppers, pellets of their excrement, rather than litter, accumulate in small conspicuous piles. Only in habitats of tall grass do grasshoppers produce leafy ground litter that goes uneaten and "wasted." This is because the grasshopper species in these habitats are phytophilous and feed resting on the host plant.

Grasshoppers fastidiously select their food. By lowering their antennae to the leaf surface and drumming (tapping) it with their maxillary and labial palps, grasshoppers taste a potential food plant. Gustatory sensilla located on the tips of these organs are stimulated by attractant and repellent properties of plant chemicals, allowing a grasshopper to choose a favorable host plant and reject an unfavorable one. A grasshopper may take an additional taste by biting into the leaf before it begins to feed freely. Phagostimulants are usually important ones nutritionally -certain sugars, phospholipids, amino acids, and vitamins. Grasshoppers may even make choices among the leaves of a single host plant. They prefer young green leaves and discriminate against old yellowing ones. Nevertheless, individuals of ground-dwelling species often feed in short bouts on old plant litter lying on the ground as well as on dry animal dung. This feeding may be a means of restoring water balance - either losing or gaining moisture.

Later, in the species fact sheets, grasshopper food plants are referred to by their common names. The appendix beginning on page 29 provides a listing of these with their scientific names to clarify any ambiguities.

Amazingly, grasshoppers are able to communicate visually and acoustically among themselves. They produce sounds with structural adaptations on hindlegs and wings and receive these signals with auditory organs (ears) located in the first abdominal segment (Fig. 8). Using their colorful wings and hindlegs they also flash visual messages and receive these with their compound eyes. Intraspecific communication, that which occurs between members of the same species, is used to attract and recognize mates, to ward off an unwanted suitor, and

to defend a territory or a morsel of food. Grasshoppers produce acoustical signals by rubbing the hindlegs against the tegmina (Fig. 12) or the sides of the abdomen. They may also communicate by rapidly flexing or snapping their hindwings in flight, a behavior called **crepitation**. Each species apparently produces its own unique sound and, in human terms, has its own language. The details, where known, of finding a mate are described in the species section of this guide.

Oviposition behavior differs among species of grasshoppers. Most species lay their eggs in the ground. Females of some species choose bare ground, while others choose to lay among the roots of grasses or forbs. A female ready to lay often probes the soil several times before finally depositing a clutch of eggs. Experimental evidence indicates that probing is a means by which a female obtains sensory information on the physical and chemical properties of the soil. The ovipositor is supplied with a variety of sensilla that allow a female to monitor soil conditions. Temperature of the soil must be favorable, water content must be in a suitable range, and acidity and salt content of soil must be tolerable. Females of some species select loose soils such as sand, some rocky soils, while the majority of females prefer compact loamy soils for oviposition. The pods of different species vary in size, shape, and depth in the soil. The latter condition profoundly affects incubation temperature, hatching, and egg survival.

A female actively depositing eggs is often attended by one or more males. Depending at least partly on clutch size, females take from 25 to 90 minutes to lay a full complement of eggs. After withdrawing her ovipositor a female will take a minute or two to cover the aperture of the hole with particles of soil and ground litter. The female uses either her ovipositor or her hind tarsi, depending on species, to do this. The act appears to be instinctive maternal care that provides some protection for the eggs from predation by birds, rodents, and insects. In certain species, as soon as the female retracts her ovipositor, the attendant male mates with her; females and attending males of other species merely walk away from each other.

Grasshoppers have different ways of avoiding excessively high temperatures that may occur in summer for a few hours each day. When ground temperatures rise above 120½F, individuals of certain species climb plants, some to a height of only 2 inches on grass stems, others climb higher (5-12 inches), and some even higher on tall vegetation such as sunflower in the southern mixedgrass prairie or a tall cactus plant in the desert prairie. In these positions individuals usually rest vertically with the head up on the shady side of the plant. Many ground-dwelling species first raise up on their legs or stilt, but as temperatures rise further, they crawl into the shade of vegetation. Individuals of other ground-dwelling species may stilt, then move away from the hot bare ground and climb on top of a short grass such as blue grama. They face the sun directly so that the least body surface is exposed to the radiant rays. In this orientation the grasshoppers are 1 to 2 inches above ground and rays of the sun strike only the front of the head.

Characteristic behavioral responses regularly observed by grasshopper scouts and collectors of insects are the jumping and flying of grasshoppers, apparently to escape capture. The stimuli initiating these responses may be of many kinds but circumstantial observation indicates that movement of the collector's image across the compound eye is usually the primary stimulus. One may noisily push a stick on the ground close to an individual without eliciting a response. Also other insects, such as large darkling beetles or large grasshoppers, may crawl close and elicit no response until they touch a resting grasshopper. Phytophilous species of grasshoppers may not jump or fly to escape intruding scouts and insect collectors, but may shift their position away from the intruder to the opposite side of a stem, retreat deeper into the canopy, or drop to the ground. Collectors and scouts entering the habitat of dense populations of grasshoppers may get the impression of continuous movement by these insects, but investigation of their time budgets indicates that during most daylight hours they are largely quiescent (46 to 80% of the time). Considerably less time is devoted to feeding, locomotion, mating, and oviposition.

The adults of most species of grasshoppers possess long, functional wings that they use effectively to disperse, migrate, and evade predators. Adults regularly fly out from deteriorating habitats caused by drought or depletion of forage, but they may also leave a site for other reasons. Some individuals of a population instinctively fly and disperse while others remain in the habitat. The most notorious migrating grasshoppers are Old World locusts, *Schistocerca gregaria* and *Locusta migratoria*. Several species of North American grasshoppers are likewise notable migrators: *Camnula pellucida*, *Dissosteira longipennis*, *Melanoplus sanguinipes*,

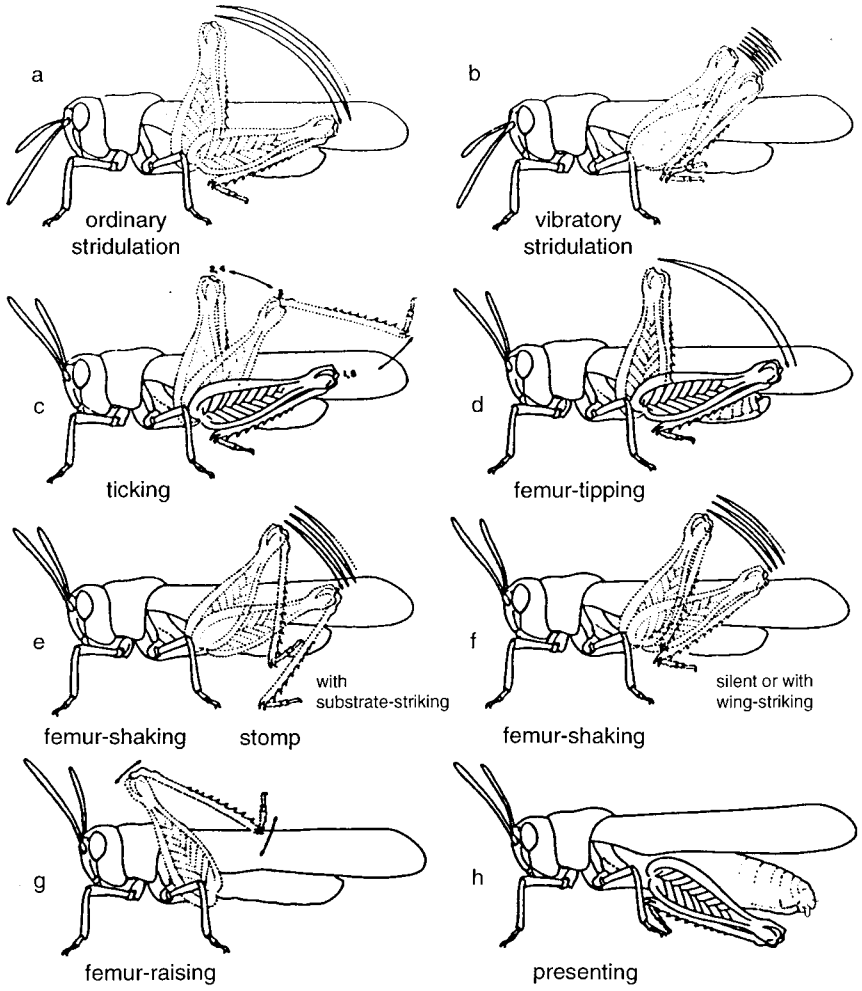

Figure 12. Signals and postures commonly occurring in grasshoppers: (a) **ordinary stridulation** — a slow, stereotyped, repetitive or non-repetitve, high amplitude movement in which the femur rubs against the forewing; (b) **vibratory stridulation** — a fast, stereotyped, repetitive, low amplitude movement in which the femur rubs against the forewing; (c) **ticking** — a stereotyped, repetitive or non-repetitve movement in which the tibiae are kicked out and struck against the ends of the forewings; (d) **femur-tipping** — a silent, stereotyped, non-repetitve raising and lowering of the femora; (e) **Femur-shaking** (with substrate-striking) — a stereotyped, repetitive shaking of the femora in which ends of the tibiae strike the substrate to produce substrate vibration or a drumming sound; (f) **femur-shaking** (silent or with wing-striking) — similar to (e) but the movement is silent, or the femora strike the forewings; (g) **femur-raising** — a slow, graded non-repetitive movement that may or may not be accompanied by mild upward kicking motions of the tibiae; (h) **presenting** — a variable, graded posturing of the female in response to male courtship, in which the end of the abdomen is made more accessible to the male by lowering both the end of the abdomen and the hindlegs. (Courtesy of Otte, 1970, Misc. Publ. Mus. Zool., Univ. Michigan, No. 141.)

M. devastator, *M. rugglesi*, *Oedaleonotus enigma*, and *Trimerotropis pallidipennis*.

Past direct observations of grasshoppers in their natural habitat have revealed various behavioral responses among species. Each appears to have its own way of reacting to a battery of environmental factors. Because a relatively few species have been investigated, much remains to be discovered. The whole subject of grasshopper behavior provides a fertile area for research both in the field and in the laboratory. Acquiring sufficient information on the various aspects of grasshopper behavior will not only serve to improve integrated management of pest species and the protection of beneficial ones, but will also advance the science of animal behavior.

Numerous observations of the behavior of common western grasshoppers have been made during the course of this study. Results of these

observations are reported later in the treatment of individual species.

Grasshopper Collections and Surveys

A well-curated collection of local grasshoppers is useful for identification and display. Insect taxonomists often identify species by comparing unknown specimens with identified museum specimens. They also make comparisons to confirm identifications that they have made from memory or by the use of a "key." These practical uses of an insect collection can also be made by plant protection personnel.

Neatly pinned and completely labeled grasshopper specimens placed in a glass-covered museum drawer make an effective educational display. Visitors —farmers, ranchers, and others — are amazed to learn that there are more than a few kinds of grasshoppers and that many kinds of grasshoppers may actually inhabit their properties. The observation of various species of grasshoppers in a collection reveals the wide diversity within this family of insects.

An interesting and useful grasshopper collection can be made with little effort and at modest expense. Anyone can capture a variety of grasshoppers within the confines of a single county by hunting for them in different habitats and at different times from spring until fall. The equipment needed to capture, preserve, label, and store grasshopper specimens consists of several simple items: (l) insect net, (2) killing jar, (3) insect pins, (4) spreading board, (5) insect boxes or museum drawers, (6) insect trays, (7) pinning block, and (8) label-making materials (paper, crow quill or rapidograph pen, India ink, and scissors).

The standard insect net (15-inch diameter) fitted with a nylon netting bag is suitable for catching grasshoppers (Fig 13). A short handle (2 feet) makes the insect net convenient for sweeping in a semi-circle close to the ground as one walks at a moderate speed over rangeland or in a disturbed area. This procedure is good for capturing nymphs and slower flying adults. Adults of certain species, however, are wary and easily frightened and may fly away. An adult of such a species must be captured by visually following its flight, watching where it lands, approaching it stealthily, and then slapping the net over it. It will usually jump or fly up into the net. Then it may be extracted by hand.

A second method of sweeping for grasshoppers, with the objective of obtaining a sample of all species inhabiting a site, is to take a set of 10 sweeps close to the ground while walking slowly and then a set near the tops of vegetation at a fast walk. Repeat this procedure as necessary to obtain adequate numbers of specimens from the site. A desirable number of specimens from a site ranges from 100 to 150.

For good museum specimens, fill up the net sparsely with grasshoppers, taking a few sweeps at a time (i.e., 10-25 sweeps). For other purposes, however, such as determining relative density by the sweeping method, as many as 100 sweeps may be taken at one time.

Make collections of grasshoppers from one habitat at a time and keep specimens from a single habitat separate from specimens taken in other habi-

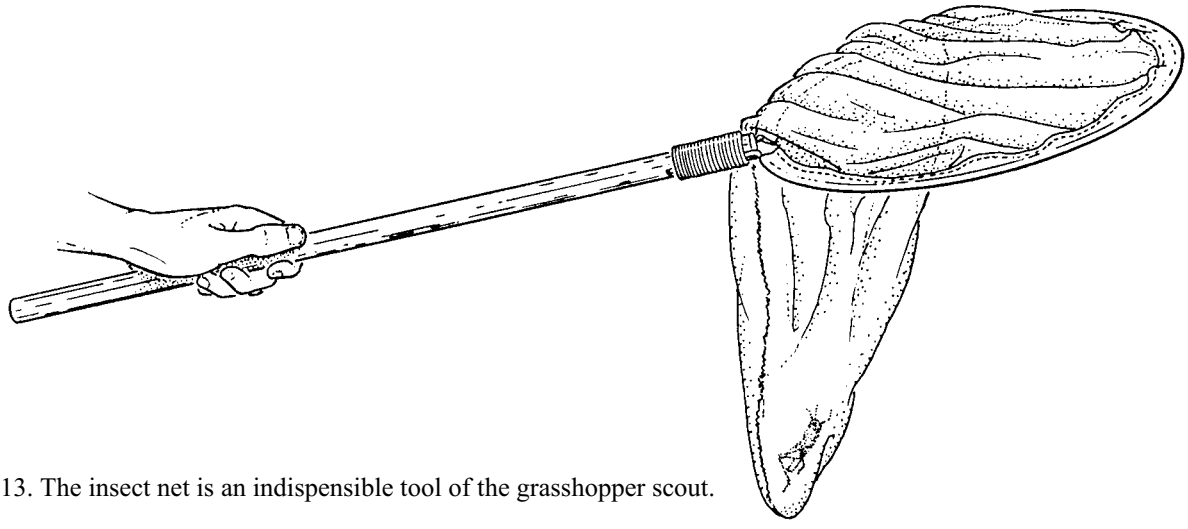

Figure 13. The insect net is an indispensible tool of the grasshopper scout.

tats. This procedure makes possible brief label descriptions indicating the specimen's habitat.

Scouts need to obtain absolute density of grasshoppers (number per square yard) at each surveyed site as well as to collect specimens for determination of species composition. The method consists of counting the number of grasshoppers in a series of 1 square foot areas. Scouts visualize a sample area approximately 15 to 20 feet ahead and on their approach carefully count the number jumping or flying out. When they arrive at the selected square foot area, they run their hands through the vegetation to flush and count any remaining grasshoppers. By walking out at least 50 feet from the road and making the counts in a wide circle, the scouts ensure that samples are taken in typical rangeland habitat. Eighteen 1-square-foot samples are taken and recorded. Scouts add the numbers counted in each square, then divide the total by two to obtain the absolute density in number of grasshoppers per square yard. Detailed instructions for grasshopper survey and recording are provided by the APHIS office in each western state.

There are several ways to kill captured grasshoppers. Killing jars can be made from wide-mouthed pint or quart jars (Fig. 14). To make an ethyl acetate jar, pour about 1 inch of plaster of paris mixed with water into the bottom of the jar and allow the plaster to dry with the lid off. Then add enough of the ethyl acetate to saturate the plaster, pouring off any excess. Whenever the ethyl acetate becomes spent or weak, recharge the jar with more. Another kind of killing jar contains potassium cyanide as the toxic agent. To make this type, pour one-half inch of potassium cyanide crystals into the bottom of the jar. Cover the crystals with one-fourth inch sawdust and then one-fourth inch thick paste of plaster of paris. Add crumpled absorbent paper to prevent condensation of water on the jar's inside surface. When ready to use, put several drops of water on the plaster. In one hour enough hydrocyanic fumes will be generated inside the jar to kill any grasshoppers placed there. To retain color of specimens, do not leave them in a killing jar much longer than it takes to kill them. For prevention of breakage and for safety, wrap the lower half and bottom of killing jars with electrical or packing tape and attach a conspicuous POISON label (Fig. 14C). Biological and entomological supply houses have improved killing jars over the homemade ones described in this bulletin. These can be purchased at reasonable prices and come with directions for charging them with recommended killing agents.

A third effective way to kill grasshoppers is to dunk them into ethyl or isopropyl alcohol for two to three minutes while they are still confined in the net. Drain and transfer them to a clean jar with absorbent paper and place the specimens in the jar in a cooler until you return to headquarters. You may then transfer specimens killed by any of the suggested

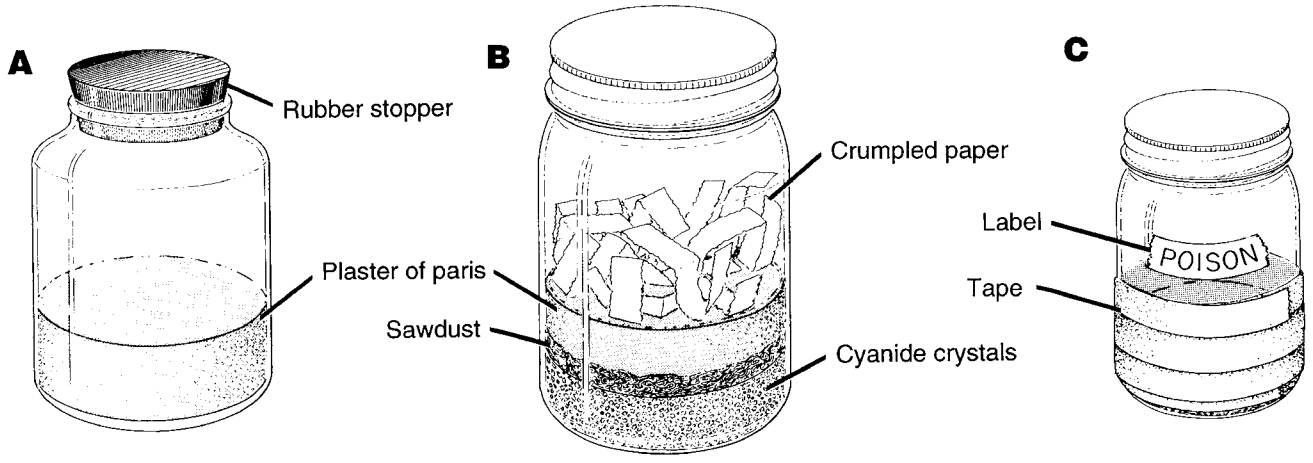

Figure 14. Types of killing jars. A, ethyl acetate saturated in plaster of paris; B, potassium cyanide crystals in bottom of jar; C, complete jar with protecting electrical tape and poison label.

methods to a refrigerator or to a deep freeze to store for periods of more than three days.

After each collection separate all of the grasshoppers from plant material such as grass seeds and pollen, which get into the net as one sweeps the vegetation. Place the grasshoppers in a heavy duty ziploc freezer bag (such as one 5x7 inches, 2.7 mils thick), gently roll the bag of grasshoppers and place it in another bag with a complete label (location, date, collector's name, etc.). Placing the label in the second bag prevents grasshopper exudates from staining it and making it illegible. Put the double-bagged grasshoppers in a cooler charged with ice or a container of frozen blue ice. To prevent soaking of the bagged grasshoppers from melting ice water, set them in a plastic container resting on the ice. At the end of the day, place the collections into a deep freeze until they can be transported to headquarters. To prevent thawing of grasshoppers when they are transported, place them in a plastic container with a tight lid in the center of an ice-filled cooler and add salt. This procedure will usually keep the grasshoppers frozen for a day or longer. These precautions are designed to retain specimens in the best condition possible for accurate identification at a later time.

The correct pinning of a grasshopper is essential in preparing a good museum specimen (Fig. 15). Use a No. 3 or 4 insect pin and for a very large grasshopper, use a No. 7 insect pin. An ordinary straight pin will not do, as it is too short and thick and prone to rust. Holding the grasshopper in one hand and the pin in the other, pierce the top of the pronotum on the right side and near the rear edge. Leave one-half inch of the pin above the specimen for safe handling of the specimen later when it has dried. As you push the pin through, keep the grasshopper oriented so it is level and not tilted on the pin in any direction. If you have erred, the pin can be withdrawn and run through again starting in the hole already made. Because the hindwings of bandwinged grasshoppers possess taxonomic characters, spread the left forewing and hindwing by mounting a few males and females on a spreading board (Fig. 16). Leave the specimens on the spreading board for a few weeks while they dry.

Pin the larger nymphs on No. 1 size insect pins but glue smaller nymphs to paper points (Fig. 17). With a hand punch, make the paper points from unlined index cards. Place a small amount of a Duco-type cement on the pointed end and mount the specimen on top of the cement. To ensure retention of color of pinned grasshoppers, place them in a deep freeze for several months to dry. Nymphs particularly require this freeze-dry method. Adults can be exposed to the air of a room in an open box to dry. During a wet season or in a humid climate, one should place mounted specimens in a Schmitt box (Fig. 18) with desiccating granules (6-12 mesh) of silica gel. Under any condition of humidity the practice will serve to retain life colors of the grasshoppers. This method requires the box with specimens and granules to be closed.

Once specimens are dry they are fully preserved, but need protection from ants and from larvae of dermestid beetles that feed on them. Place balls or flakes of paradichlorobenzene (PDB) or naphthalene in a small cloth bag and pin firmly in the corner of the insect box or drawer. A more effective insecticide is dichlorvos. Cut three-fourths inch squares from No-Pest Strip insecticide. Pin one square per box or drawer of specimens. A square will protect for as long as a year before it must be replaced.

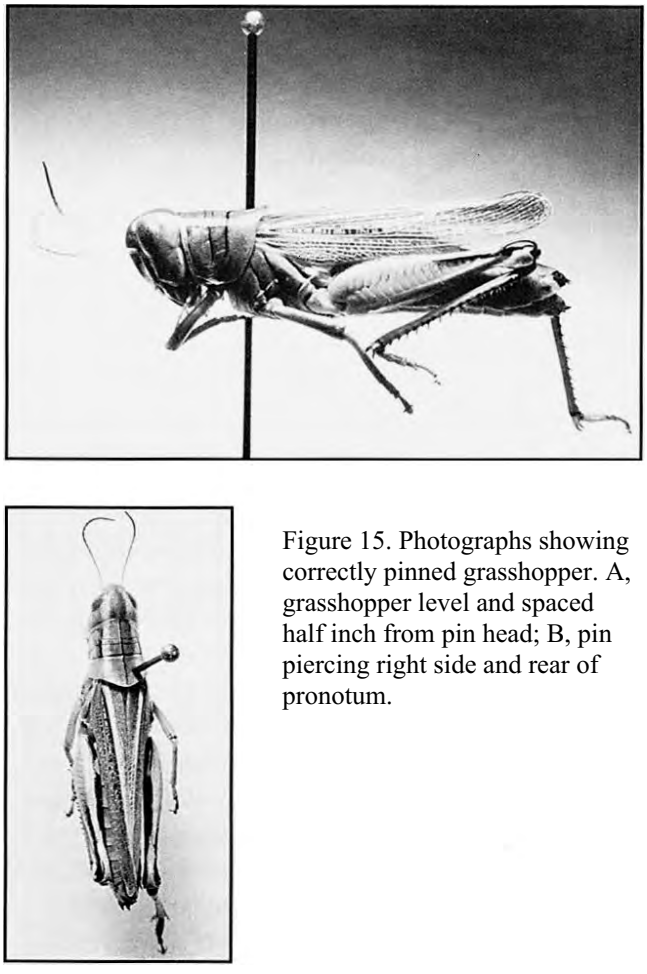

Figure 15. Photographs showing correctly pinned grasshopper. A, grasshopper level and spaced half inch from pin head; B, pin piercing right side and rear of pronotum.

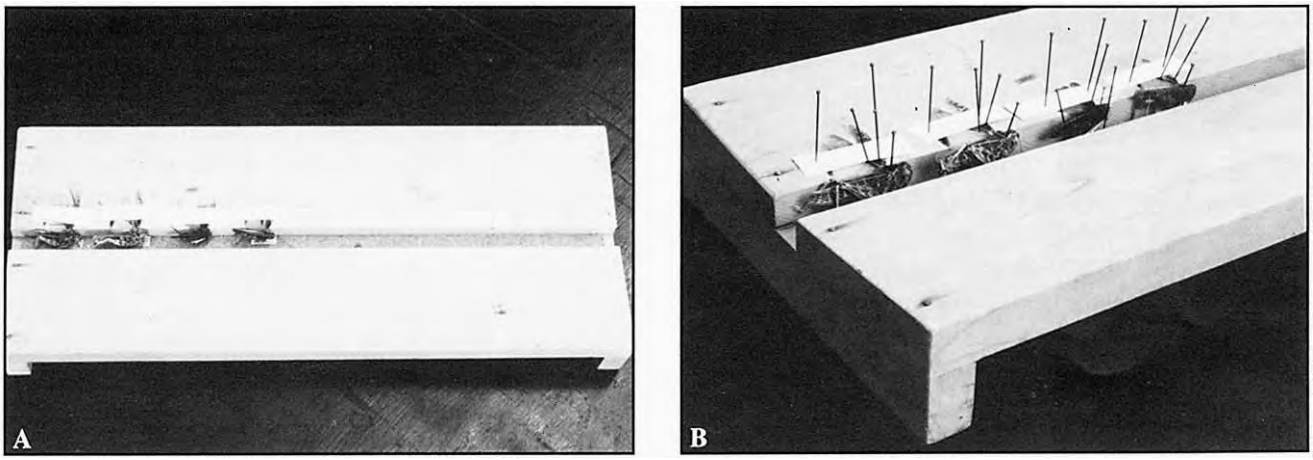

Figure 16. Grasshoppers drying with left wigs spread. left, view of whole spreading board, 19 x 7.5 inches; right, closeup of drying grasshoppers on spreading board.

Many priceless collections made in the 1800s and more recently have been destroyed by dermestids.

Large grasshoppers such as the differential and the lubber do not dry fast enough to make good museum specimens. They decay and discolor. They must be eviscerated before pinning by making a one-half inch cut lengthwise in the bottom of the abdomen (center of first three sterna) with a pair of small scissors. With a fine pair of forceps reach into the inside and extract the entrails. Replace entrails with a small cotton wad and bring cut sides of integument together. The operation will allow a large grasshopper to dry quickly. One may further ensure good preservation by placing specimens in a Schmitt box with a desiccant.

Safe storage of grasshopper specimens requires nearly airtight insect boxes or museum drawers. These are manufactured in standard sizes with hard bottoms or polyethylene foam pinning bottoms. Dimensions of insect boxes measure 9 x 13 x 2 1/2 inches (Fig. 18) and Cornell drawers 19 x 16 1/2 x 3 inches (Fig. 19). It is convenient to use insect pinning trays in museum drawers (a necessity in drawers with hard bottoms) so that specimens can be shifted around. Trays come commonly in three sizes: large 4 3/8 x 7 1/4 x 1 5/8 inches, medium 4 3/8 x 3 5/8 x 1 5/8 inches, and small 4 3/8 x 1 13/16 x 1 5/8 inches. Large and medium sizes are usually used for grasshoppers, but small trays can also be helpful on occasion.

For a museum specimen to have value it must bear fully descriptive labels, either two or three depending on division of information. In the two-label system, the top label gives the state and county in the first line, the latitude and longitude of the collecting site in the second line, the date of collection in the third line, the habitat in the fourth line, and the collector's name in the fifth line. For

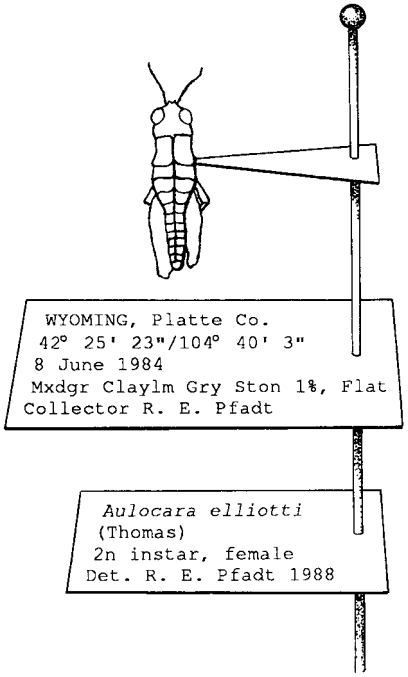

Figure 17. Nymphal grasshopper glued to card point and fully labeled. Dimensions of reduced top label on actual specimen 1 x 3/8 inch, reduced bottom label 7/8 x 2/8 inch. Note content and style of labels.

collectors who do not have available a global positioning apparatus, an equally good way to specify the location of the collection site is to use a county map from which the township, range, and section may be obtained. The second line of the top label in Fig. 17 would then read T28N R65W Sec 4 SE. Do not abbreviate the year, list fully (e.g. 1994). Your specimen may rest safely for centuries in a museum collection. Provide a short description of the habitat such as the examples shown in Table 6. In specifying the habitat, a general classification of the grasslands of the West is helpful (Fig. 21).

Whenever possible one should also indicate soil texture (sandy, loamy, clayey), color, stoniness (gravel) and rockiness (rock outcrop), and slope or relief (hillside, hilltop, flat, swale). For a detailed treatment of soil classification consult the Soil Survey Manual USDA Handbook 18 (1951). The majority of counties in the United States have published soil classifications that may be obtained from the Soil Conservation Service located in each county seat. One may then enter the soil name on the label. The bottom label gives the scientific name of the specimen, the author, the name of the person who made the identification, and the year in which the identification was made. In the three-label system, the collector's name is placed on a separate label and is positioned in the middle between the top and bottom labels. See Figure 17 for the recommended style. Use quality, heavyweight paper for labels (white paper with high rag content). Print labels with a crow quill or rapidograph pen using black India ink. If a typewriter and copy machine are available, one may type the data and reduce the information to small but legible labels. Or if a computer and laser printer are available, one may type the label and have the printer reduce it to the desired size. For a large series of specimens, printed labels may be ordered from a commercial company. Do not make labels too large. A maximum size of 1 x 3/8 inch is recommended. It is preferable, however, to exceed this when pertinent data need to be given. The labels of a specimen may differ in size so that only the size needed for the information is required of each label. Use a pinning block (Fig. 20) to make label levels uniform on all pinned specimens.

A word of caution here. Collectors often become enthusiastic about capturing grasshoppers and leave themselves insufficient time to curate what they have caught. Leave yourself enough time to pin, spread, and eviscerate specimens. Label at least one of the group with all information available. Later, label all specimens. More detailed instructions on techniques for collecting, pinning, preserving, and also shipping to specialists are provided in USDA ARS Miscellaneous Publication Number 1443 (1986).

Figure 18. The schmitt type insect box. It has a polyethylene foam pinning bottom and is nearly airtight with lid closed.

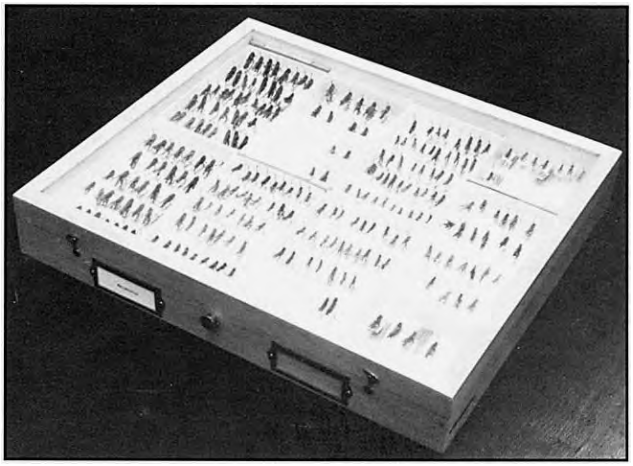

Figure 19. The Cornell type insect drawer. It has a glass cover and contains three sizes of insect pinning trays for ease of handling groups of grasshopper species.

Live grasshoppers are frequently requested by researchers. These can be mailed in a variety of containers. An easy and practical way is to obtain squat paper or plastic pint containers (like the

TABLE 6. Examples of short descriptions of grasshopper habitats. Abbreviate one of A, B, C, and D on label*.

A. VEGETATION
- Annual grassland
- Bunchgrass prairie
- Desert grassland
- Mixedgrass prairie
- Shortgrass prairie
- Tallgrass prairie
- Desert shrubs
- Mountain meadow (below timberline)
- Alpine meadow (above timberline)
- Crop (name crop) dry or irrigated
- Crop border (name crop)
- Improved pasture (name forages)
- Reversion (name plants)
- Roadside (weeds or grass or mixed)

B. SOIL TEXTURE AND COLOR

Clay	Gray
Clay loam	Yellow
Loam	Brown
Silt loam	Red
Sandy loam	Black
Sand	

C. SOIL SURFACE
- Stony %
- Rocky % (outcrops)

D. SLOPE
- Swale
- Flat
- Rolling
- North slope
- South slope, etc.
- Hilltop

** See top label of Fig. 17 for suggested style. For more precise descriptions of vegation types and soil classifications, consult with local botanists and soil scientists.*

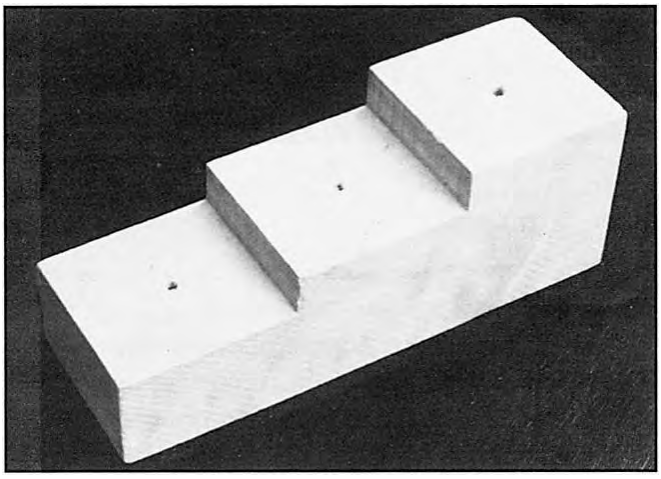

Figure 20. Insect pinning block used to make level of label uniform in the three label system.

containers for cottage cheese). These may be purchased from a market or department store. Depending on size of the grasshoppers, from 10 to 25 individuals may be caged in a pint container along with a small amount of plant food such as lettuce. Do not overload the container with green food and do not place dry cereals in the container. Punch small holes in the lid and secure with tape. Untaped lids may come off in transit, allowing grasshoppers to escape into the packing material with fatal results. Place the containers in a cardboard shipping box surrounded by packing material and ship by US Express Mail, Federal Express, or overnight United Parcel Service.

Grasslands of North America

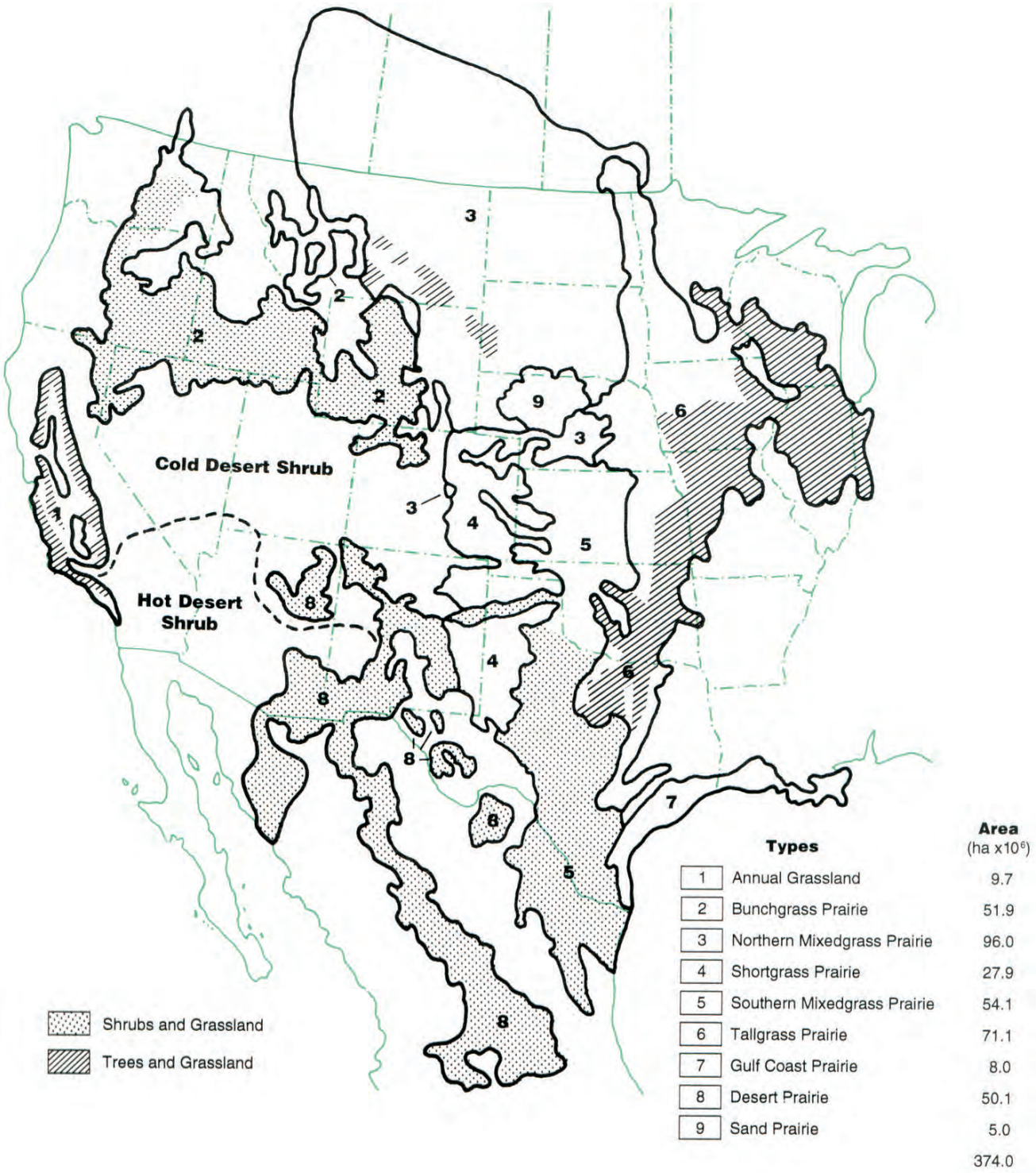

Figure 20. Map shows location of the three kinds of grasslands in North America and the cold and hot deserts dominated by shrubs but also containing sparse grasses (adapted from a map of Grasslands of North America by Dodd, 1982).

Appendix of Common-Scientific Names of Grasshopper Food Plants

Grasses

barley — *Hordeum vulgare*
barnyardgrass — *Echinochloa crusgalli*
basin wildrye — *Elymus cinereus*
big bluestem — *Andropogon gerardii*
bluebunch wheatgrass — *Pseudoroegneria* (*Agropyron*) *spicata*
blue grama — *Bouteloua gracilis*
buffalograss — *Buchloe dactyloides*
burrograss — *Scleropogon brevifolius*
crested wheatgrass — *Agropyron cristatum*
curly mesquite — *Hilaria belangeri*
downy brome — *Bromus tectorum*
fall witchgrass — *Leptoloma cognatum*
foxtail barley — *Hordeum jubatum*
foxtail brome — *Bromus rubens*
giant wildrye — *Elymus condensatus*
green bristlegrass — *Setaria viridis*
green needlegrass — *Stipa viridula*
hairy grama — *Bouteloua hirsuta*
hare barley — *Hordeum leporinum*
Idaho fescue — *Festuca idahoensis*
intermediate wheatgrass — *Elytrigia* (*Agropyron*) *intermedia*
Japanese brome — *Bromus japonicus*
Johnsongrass — *Sorghum halepense*
Kentucky bluegrass — *Poa pratensis*
little barley — *Hordeum pusillum*
little bluestem — *Schizachyrium scoparium*
needleandthread — *Stipa comata*
oats — *Avena sativa*
orchardgrass — *Dactylis glomerata*
Parry oatgrass — *Danthonia parryi*
plains lovegrass — *Eragrostis intermedia*
poverty oatgrass — *Danthonia spicata*
prairie cordgrass — *Spartina pectinata*
prairie dropseed — *Sporobolus heterolepis*
prairie junegrass — *Koeleria cristata*
prairie sandreed — *Calamovilfa longifolia*
quackgrass — *Elytrigia* (*Agropyron*) *repens*
red fescue — *Festuca rubra*
red sprangletop — *Leptochloa filiformis*
red threeawn — *Aristida longiseta*
reed canarygrass — *Phalaris arundinacea*
Sandberg bluegrass — *Poa secunda*
sand bluestem — *Andropogon hallii*
sand dropseed — *Sporobolus cryptandrus*
Scribner panicum — *Panicum scriberianum*
sideoats grama — *Bouteloua curtipendula*
silver beardgrass — *Bothriochloa saccharoides*
sixweeks fescue — *Vulpia octoflora*
slender hairgrass — *Deschampsia elongata*
slender wheatgrass — *Elymus* (*Agropyron*) *trachycaulum*
smooth brome — *Bromus inermis*
soft brome — *Bromus mollis*
spikefescue — *Leucopoa kingii*
squirreltail — *Sitanion hystrix*
stinkgrass — *Eragrostis cilianensis*
subalpine needlegrass — *Stipa nelsonii*
switchgrass — *Panicum virgatum*
tall dropseed — *Sporobolus asper*
thickspike wheatgrass — *Elymus* (*Agropyron*) *casystachyum*
timothy — *Phleum pratense*
western needlegrass — *Stipa occidentalis*
western wheatgrass — *Pascopyrum* (*Agropyron*) *smithii*
wheat — *Triticum aestivum*
wild oat — *Avena fatua*
witchgrass — *Panicum capillare*
wolftail — *Lycurus phleoides*
yellow indiangrass — *Sorghastrum nutans*

Sedges-Rushes

Baltic rush — *Juncus balticus*
elk sedge — *Carex geyeri*
needleleaf sedge — *Carex eleocharis*
Penn sedge — *Carex pennsylvanica*
rock sedge — *Carex rupestris*
sun sedge — *Carex heliophila*
threadleaf sedge — *Carex filifolia*

Forbs and Shrubs

alfalfa — *Medicago sativa*
annual sowthistle — *Sonchus oleraceus*
antelope bitterbrush — *Purshia tridentata*
antelopehorns milkweed — *Asclepias asperula*

Arizona popcornflower — *Plagiobothrys arizonicus*
aromatic aster — *Aster oblongifolius*
arrowleaf balsamroot — *Balsamorhiza sagittata*
arrowleaf butterbur — *Petasites sagittatus*
ball mustard — *Neslia paniculata*
balsamroot — *Balsamorhiza* spp.
big sagebrush — *Artemisia tridentata*
birdsfoot trefoil — *Lotus corniculatus*
bitterroot — *Lewisia rediviva*
black sagebrush — *Artemisia nova*
blood ragweed — *Ambrosia trifida* var. *texana*
bracted spiderwort — *Tradescantia bracteata*
branchy goldfields — *Baeria chrysostoma*
breadroot scurfpea — *Psoralea esculenta*
broadleaf plantain — *Plantago major*
broom snakeweed — *Gutierrezia sarothrae*
budsage — *Artemisia spinescens*
burroweed — *Haplopappus tenuisectus*
bushy wallflower — *Erysimum repandum*
Canada goldenrod — *Solidago canadensis*
Canada thistle — *Cirsium arvense*
chicory — *Cichorium intybus*
clover — *Trifolium* spp.
common groundsel — *Senecio vulgaris*
common lambsquarters — *Chenopodium album*
common purslane — *Portulaca oleracea*
common sunflower — *Helianthus annuus*
common yarrow — *Achillea millefolium*
crested pricklepoppy — *Argemone platyceras*
cudweed sagewort — *Artemisia ludoviciana*
dandelion — *Taraxacum officinale*
dogweed — *Dyssodia* spp.
Douglas rabbitbrush — *Chrysothamnus viscidiflorus*
draba mustard — *Draba* spp.
emory globemallow — *Sphaeralcea emoryi*
European sticktight — *Lappula echinata*
false boneset — *Kuhnia eupatorioides*
false dandelion — *Agoseris glauca*
Fendler sandwort — *Arenaria fendleri*
Fendler springparsley — *Cymopterus fendleri*
field bindweed — *Convolvulus arvensis*
filaree — *Erodium* spp.
fireweed fiddleneck — *Amsinckia intermedia*
flax — *Linum* spp.
flixweed — *Descurainia sophia*
foothill trefoil — *Lotus humistratus*
fringed sagebrush — *Artemisia frigida*
giant ragweed — *Ambrosia trifida*
gilia — *Gilia* spp.
globemallow — *Sphaeralcea* spp.
gray rabbitbrush — *Chrysothamnus nauseosus*
greenflower pepperweed — *Lepidium densiflorum*
gromwell — *Lithospermum ruderale*
groundplum milkvetch — *Astragalus crassicarpus*
groundsel — *Senecio stygius*
hairyleaved aster — *Aster hirtifolius*
hayfield tarweed — *Hemizonia congesta*
heath aster — *Aster ericoides*
hoary puccoon — *Lithospermum canescens*
hoary vervain — *Verbena stricta*
Hooker balsamroot — *Balsamorhiza hookeri*
horseweed — *Conyza canadensis*
kochia — *Kochia scoparia*
larkspur — *Delphinium* spp.
leadplant — *Amorpha canescens*
lemon scurfpea — *Psoralea lanceolata*
lespedeza — *Lespedeza* spp.
littleleaf horsebrush — *Tetradymia glabrata*
little mallow — *Malva parviflora*
lotus milkvetch — *Astragalus lotiflorus*
lupine — *Lupinus* spp.
meadow salsify — *Tragopogon pratensis*
milkvetch — *Astragalus* spp.
Missouri goldenrod — *Solidago missouriensis*
Missouri milkvetch — *Astragalus missouriensis*
narrowleaf bluet — *Hedyotis nigricans*
narrowleaf gromwell — *Lithospermum incisum*
narrowleaved collomia — *Collomia linearis*
narrowleaved microseris — *Microseris linearifolia*
netseed lambsquarters — *Chenopodium berlandieri*
Newmexico groundsel — *Senecio neomexicanus*
peavine — *Lathyrus* spp.
penstemon — *Penstemon* spp.
peppermint — *Mentha piperita*
pepperweed — *Lepidium* spp.
perennial sowthistle — *Sonchus arvensis*
plains bahia — *Picradeniopsis oppositifolia*
prairie onion — *Allium textile*
prairie spiderwort — *Tradescantia occidentalis*
prairie sunflower — *Helianthus petiolaris*
prairie wild rose — *Rosa arkansana*
prickly lettuce — *Lactuca serriola*
prostrate knotweed — *Polygonum aviculare*
rabbitbrush — *Chrysothamnus* spp.
red clover — *Trifolium pratense*
redroot pigweed — *Amaranthus retroflexus*

redstem filaree — *Erodium cicutarium*
rubber rabbitbrush — *Chrysothamnus nauseosus*
Russianthistle — *Salsola iberica*
rusty lupine — *Lupinus pusillus*
saltbush — *Atriplex gardneri*
sand sagebrush — *Artemisia filifolia*
scarlet gaura — *Gaura coccinea*
scarlet globemallow — *Sphaeralcea coccinea*
serrated balsamroot — *Balsamorhiza serrata*
shadscale — *Atriplex confertifolia*
shortstem lupine — *Lupinus brevicaulis*
skeletonweed — *Lygodesmia juncea*
silver sagebrush — *Artemisia cana*
skunkbush sumac — *Rhus trilobata*
slenderleaved microseris — *Microseris gracilis*
slimflower scurfpea — *Psoralea tenuiflora*
slimleaf bursage — *Ambrosia confertiflora*
soybean — *Glycine max*
spiny hopsage — *Grayia spinosa*
splendid fiddleneck — *Amsinckia gloriosa*
spreading fleabane — *Erigeron divergens*
spreading wildbuckwheat — *Eriogonum effusum*
springparsley — *Cymopterus* spp.
starlily — *Leucocrinum montanum*
tall lettuce — *Lactuca canadensis*
tansy aster — *Machaeranthera tanacetifolia*
tar weed — *Hemizonia congesta*
tar weed — *Hemizonia* spp.
tarragon — *Artemesia dracunculus*
thistle — *Cirsium* spp.
threadleaf snakeweed — *Gutierrezia microcephala*
tumble mustard — *Sisymbrium altissimum*
turbinella oak — *Quercus turbinella*
turkey mullein — *Eremocarpus setigerus*
twinpod — *Physaria* spp.
type penstemon — *Penstemon hirsutus*
upright prairie coneflower — *Ratibida columnifera*
vetch — *Vicia* spp.
Virginia pepperweed — *Lepidium virginicum*
wavyleaf thistle — *Cirsium undulatum*
western ragweed — *Ambrosia psilostachya*
western sticktight — *Lappula occidentalis*
whitedaisy tidytips — *Layia glandulosa*
white sweetclover — *Melilotus alba*
wildbuckwheat — *Eriogonum* spp.
wild licorice — *Glycyrrhiza lepidota*
wild mustard — *Brassica kaber*
wild onion — *Allium* spp.
willowleaf lettuce — *Lactuca saligna*
woolly groundsel — *Senecio canus*
woolly loco — *Astragalus mollissimus*
woolly plantain — *Plantago patagonica*
yellow eveningprimrose — *Oenothera flava*
yellow sweetclover — *Melilotus officinalis*

Glossary

Abdomen. The hind region of the insect body consisting of nine apparent ringlike flexible segments in the grasshopper (Fig. 1).

Absolute Density. The number of individual grasshoppers per unit of area, as square yard, square meter, acre, or hectare.

Accidentals. Adult grasshoppers in locations where the species does not complete its life cycle.

Acrididae. A family of insects that comprise the grasshoppers with short antennae, short ovipositor, and tarsi of legs three-segmented.

Aedeagus. The intromittent or insertion organ of the male genitalia (Fig. 8).

Allotype. A paratype specimen of the opposite sex to the holotype used in making the original description of a species.

Alpine tundra. Vegetation in montane habitats above treeline. Vegetation consists of perennial forbs, grasses, sedges, and short woody shrubs.

Anal area of tegmen. Hind or posterior part of tegmen (Fig. 7).

Annulus. A colored or light circular band.

Antenna (pl., antennae). Pair of segmented appendages (feelers) located on head and sensory in function (Fig. 1).

Anterior. Pertaining to the front of the body.

Apex. The terminal or distal part of a body structure.

Appetitive flight. Local movement by flight concerned with finding food, mates, and egg laying sites.

Apterous. Without wings.

Arcuate. Arched or humped.

Arolium. A padlike structure at the end of the insect leg between the claws (Fig. 6).

Arthropoda. A group or phylum of animals that have segmented bodies, exoskeletons, and jointed legs.

Articulate. To connect by a joint.

Bandwinged grasshoppers. A subfamily of grasshoppers, the Oedipodinae, that usually have a submarginal dark band on the hindwings (Fig. 7).

Basal. At or near base of a structure.

Bilobate. Divided into two lobes.

Bioclimatic law. Hopkin's bioclimatic law states that for every rise in elevation of 400 feet, events in the life cycle are delayed four days.

Biotic potential. The inherent properties of an organism to survive, reproduce,and increase in numbers.

Blastokinesis. Active movement of the grasshopper embryo by which it passes from the ventral to the dorsal side of the egg and at the same time revolves 180 degrees on its long axis.

Blowout. An area of renewed wind erosion in a sand dune stabilized by vegetation.

Brachypterous. With short wings.

Brood. All the individuals that hatch at about one time from eggs laid by one series of parents and that normally mature at about the same time; a group of individuals of a species that have hatched into young or have become adult at approximately the same time, and live together in a defined and limited area, and they may be of different generations.

Calcar. A spinelike process of the integument connected by a joint (Fig. 6).

Carina (pl., carinae). An external ridge of the integument (Fig. 4).

Carinula (pl., carinulae). A little carina or ridge (Fig. 6).

Center of distribution. The circumscribed area of habitats in which the species is almost always present and where dense populations regularly occur.

Cercus (pl, cerci). An appendage of the tenth abdominal segment usually triangular and short in grasshoppers (Fig. 8).

Chevrons. A pattern of V-shaped markings in one direction on the medial area of the grasshopper's hind femur.

Chorionic sculpturing. A network pattern on the chorion (shell) of the insect egg.

Cladode. A flat leaflike stem.

Clavate. Clubbed, having a thickened or expanded distal end (Fig. 2).

Clypeus. The front liplike sclerite on which the labrum articulates (Fig. 3).

Complete metamorphosis. Metamorphosis through which the insect develops by four distinct stages: egg, larva, pupa, adult.

Compound eye. An eye made up of many individual eye elements each represented externally by a corneal facet.

Concave. Hollowed out like the interior of a sphere segment.

Convex. Like the outer curved surface of a sphere segment.

Costal. Referring to the anterior portion of any wing (Fig. 7).

Coxa. Basal segment of insect leg articulating leg to body (Fig 6).

Cristate. Having a prominent carina or crest.

Crown. The perennial tissue of grasses, sedges, and forbs located near the soil surface from which all roots, herbaceous stems, and leaves grow.

Curate. To mount, label, store, and protect museum specimens.

Day-degrees. The degrees each day that the average daily temperature is above a thresholdtemperature for development. For each day that a process takes to complete, these degrees are totaled to yield the day degrees required for the process such as egg incubation or nymphal development.

Deme. A local population of a species.

Density. A measure of abundance in terms of average number of individuals per square yard, square meter, acre, or hectare.

Diapause. A state of low metabolic activity mediated hormonally and associated with ceased growth, reduced activity, and increased resistance to environmental extremes.

Dipterous. Of or relating to flies of the order Diptera.

Disk of pronotum. Central upper surface of pronotum (Fig. 4).

Disk of wings. Central area of hindwings within the margins or within the submarginal band when present (Fig. 7).

Dispersal. Outward spreading of grasshoppers from their place of origin.

Dispersion. The spacing of individuals in the habitat.

Distal. That part of an appendage farthest from the body.

Distribution. The location of all habitats in which the species lives and reproduces; the area in which the species has been recorded.

Distribution center. See center of distribution.

Dominant. With reference to grasshoppers, most abundant species in an assemblage of grasshopper species.

Dorsal. Pertaining to the top surface of the body.

Dorsal bask. The behavior of a grasshopper to increase body heat by aligning its dorsum (back) perpendicular to rays of the sun.

Dorsal posture. The position of the body taken in basking by a grasshopper so that the dorsum or back is directly exposed to the sun.

Dot map. A map showing by dots the locations where individuals of a species have been found and recorded.

Eclosion. The hatching of the larva or nymph from its egg.

Egg pod. A case made of grasshopper gluelike secretions and soil particles enclosing a clutch of grasshopper eggs.

Emarginate. Notched.

Ensiform. Broad at base, narrowing to tip (Fig. 2).

Epiproct. A triangular dorsal plate of the eleventh abdominal segment overlying the anus (Fig. 8).

Epizootic. A disease contracted by a large number of animals in a population.

Erratics. Grasshoppers that have dispersed into a habitat in which they are unable to complete their life cycle and reproduce.

Family. A taxonomic category including one genus or a group of genera of common phylogenetic origin.

F_1 generation. The generation of hybrids arising from a first cross.

Fasciate. Banded.

Fastigium. The front part of the top of the head in front of the compound eyes (Fig. 3).

Femoral stripe. The dark stripe running along the dorsal medial area of the hind femur of a grasshopper.

Femur (pl., femora). A segment of the insect leg; the stout segment of the grasshopper's hindleg (Fig. 6).

Ferruginous. Resembling iron rust in color.

Filiform. Threadlike, slender and of equal diameter (Fig. 2).

Flank bask. The behavior of a grasshopper to increase body heat by presenting a side perpendicularly to rays of the sun.

Flanking posture. The position of the body taken in basking by a grasshopper so that a side is directly exposed to the sun. Concomitantly, the associated hindleg is lowered to expose fully the abdomen.

Fledge. Acquisition of the adult wings.

Forb. Broadleafed herbaceous plant (e.g., dandelion).

Foveola (pl., foveolae). A small depression in the integument.

Frons. Front of the head above the clypeus (Fig. 3).

Frontal costa. Broad vertical ridge on the front of the head (Fig. 3).

Furcula. Forked projection from posterior edge of tenth abdominal tergum and overlying supraanal plate (Fig. 8).

Fuscous. Color of dark brown approaching black.

Griseous. Light color mottled with black or brown.

Gena. The sclerite at the side of the head (Fig. 3).

Gene. A unit of heredity on a chromosome in the cell nucleus.

Gene pool. The total genes of all the individuals of a species in a population.

Genitalia. The external reproductive structures (Fig. 8).

Genus. A taxonomic category containing a group of related species.

Geographic range. The area bounded by the location of outlying populations of a species; the location of the smallest area within an imaginary boundary line that encloses all populations of a species.

Geophilous. Living on the ground.

Gomphocerinae. A subfamily of grasshoppers known commonly as slantfaced grasshoppers.

Gradual metamorphosis. Metamorphosis through which the insect develops by three distinct stages, namely egg, nymph, adult.

Hindwings. The fanshaped membranous second pair of wings of grasshoppers (Fig. 7).

Hirsute. Hairy.

Holotype. The single specimen designated as the "type" by the author of the original description at time of publication.

Hyaline. Transparent and glassy.

Imago. A name for the adult insect.

Immaculate. Without spots or marks.

Incrassate. Thickened or swollen usually near tip.

Insecta. The insects; a class in the phylum Arthropoda in which adults have three body regions, head, thorax, and abdomen; three pairs of legs; and a respiratory system of air tubes or trachea.

Instar. The immature insect between two successive molts.

Invertebrate. Animal without spinal column or backbone.

Keel. A sharp, enlarged ridge or carina.

Key. A tabular arrangement of species, genera, families, etc., according to characters that serve to identify them.

Knee. The enlarged end of the hind femur (Fig. 6).

Larva (pl., larvae). The immature insect hatched from the egg and up to the pupal stage in orders with complete metamorphosis, e.g., a caterpillar.

Lateral carinae. The carinae at the lateral edges of the pronotal disk (Fig. 4) or of the vertex of head (Fig. 3).

Lateral foveolae. A pair of small depressions on the head at the side or front of vertex (Fig. 3).

Lateral lobe. The vertical sides of the pronotum (Fig. 4).

Litter. Plant material that falls and accumulates on the soil surface.

Maculate. Spotted.

Macropterous. With well developed long wings.

Medial. Situated in or closest to the middle.

Median area of tegmen. The middle part of tegmen (Fig. 7).

Median carina. Any ridge set medianly on an insect part, such as the pronotum or head of a grasshopper (Fig. 4).

Melanistic. Blackish due to increased amounts of black pigment.

Melanoplinae. A subfamily of grasshoppers commonly known as the spurthroated grasshoppers.

Mesosternal interspace. The area between the mesosternal lobes (Fig. 5).

Mesosternal lobes. The paired separated posterior areas of the mesosternum (Fig. 5).

Mesothorax. The middle segment of the thorax (Fig. 1).

Mesosternum. The ventral plate of the mesothorax between and in front of the middle pair of legs (Fig. 5).

Metamorphosis. The change of body form through which insects pass in developing to the adult.

Metasternal interspace. The area between the metasternal lobes (Fig. 5).

Metasternal lobes. The paired separated posterior areas of the metasternum (Fig. 5).

Metathorax. The hind segment of the thorax (Fig. 1).

Metazona. The posterior part of the pronotal disk, lies behind the principal sulcus (Fig. 4).

Migration. Mass movement of grasshoppers by walking or flying.

Molt. Process of shedding outer layers of the integument.

Nodulate. A surface sculpturing of small knots or swellings.

Notum. The dorsal part or top of a thoracic segment (Fig. 1).

Nymph. An immature insect of species with gradual metamorphosis.

Occiput. Top of head behind the compound eye.

Ocellus (pl., ocelli). The single-faceted simple eye of an insect. A grasshopper has three ocelli, two lateral and one median (Fig. 3).

Outer margin of wing. The margin between apex and anal angle of the grasshopper hindwing (Fig. 7).

Oedipodinae. A subfamily of grasshoppers known commonly as bandwinged grasshoppers.

Orthoptera. An order of insects with gradual metamorphosis, chewing mouthparts, and leathery forewings. Order includes grasshoppers and crickets.

Ovipositor. In grasshoppers the paired digging and egg laying structures at the end of the female abdomen (Fig. 1).

Ovipositor valves. Three pair of digging and egg laying structures at the end of the abdomen in female grasshoppers (Fig. 1).

Pallium. The membrane stretching across the walls of the subgenital plate and covering the male genitalia (Fig 8).

Paratype. A specimen other than the holotype that was before the author at the time of preparation of the original description and was so designated by the author.

Pellucid. Transparent whether clear or colored.

Preapical. Before the apex.

Pleuron (pl., pleura). The side sclerites of the thorax.

Posterior. Pertaining to the rear of the body.

Pottering. Intermittent walking and wandering with frequent changes in direction.

Predominant. Of grasshoppers, the most abundant species in an assemblage of grasshopper species.

Preferendum. The range of temperature at which the grasshopper comes to rest.

Preoviposition period. The period between molting to the adult and the laying of the first group of eggs; in grasshoppers the period normally lasts one to two weeks.

Principal sulcus. The hind sulcus cutting the median carina of the pronotum (Fig. 4).

Pronotum. The saddle-shaped top of the first thoracic segment (Fig. 1).

Prosternal spine. A protuberant process of the prosternum located between bases of front legs (Fig. 5).

Prosternum. The lower or ventral surface of the prothorax.

Prothorax. The front segment of the thorax (Fig. 1).

Proximal. That part of an appendage closest to the body.

Prozona. The anterior part of the pronotal disk, lies in front of the principal sulcus (Fig. 4).

Pupa (pl., pupae). The stage between the larva and the adult in insects with complete metamorphosis; a nonfeeding stage in which adult structures develop and grow.

Quadrate. Resembling a square or rectangular space.

Relative density. With reference to grasshoppers, the number caught per certain number of sweeps with an insect net or caught by hand or seen in a given period of time.

Ruderal. Growing along roadsides or in disturbed or abandoned farmland.

Ruga (pl., rugae). A wrinkle.

Rugose. Wrinkled.

Sclerite. A hardened body wall plate of insects delimited by sutures or membranous areas.

Seasonal cycle. The timing of the periods of egg hatch, nymphal development, adulthood, and reproduction.

Shoulder. The lateral angles of the metazona of the pronotum (Fig. 4).

Sibilant. A hissing sound.

Slantfaced grasshoppers. A subfamily of grasshoppers, the Gomphocerinae.

Spatulate. Round and broadened apically, spoon-shaped.

Species. A kind of organism. A genetically distinctive group of natural populations that share a common gene pool and are reproductively isolated from all other such groups.

Spine. A thornlike outgrowth of the integument not separated from it by a joint (Fig. 6).

Spur. A spinelike process of the integument connected by a joint (Fig. 6).

Spurthroated grasshoppers. A subfamily of grasshoppers, the Melanoplinae, that bear a conspicuous process (spine) on the prosternum (Fig. 5).

Sternite. A subdivision of a sternum.

Sternum. The ventral part or bottom of a thoracic or abdominal segment (Fig. 5).

Stadium (pl., stadia). The time period between two successive molts of larvae or nymphs.

Stridulate. Making a creaking or grating sound by insects through rubbing two rough surfaces against each other.

Stridulatory pegs. A row of small pegs on the inner surface of the hind femur of certain grasshoppers (most slantfaced species) (Fig. 6).

Styliform. Long and slender.

Sub-. Latin prefix meaning under; almost or somewhat.

Subarcuate. A little arched or bowed.

Subdominant. The grasshopper species of lesser abundance than the dominant one in an assemblage of grasshopper species.

Subesophageal ganglion. Three fused ganglia located in head below digestive tract innervating the mouthparts.

Subgenital plate. In the male grasshopper the terminal ventral plate underlying the genitalia (Fig. 8).

Submarginal band. The dark band usually present on the hindwings of species of bandwinged grasshoppers (Fig. 7).

Subspecies. A geographically defined aggregate of local populations which differs from other such subdivisions of a species.

Sulcus (pl., sulci). A groove or furrow in the integument.

Supraanal plate. A triangular dorsal plate of the eleventh abdominal segment overlying the anus (Fig. 8).

Suture. A linelike groove in the integument.

Swale. A depression where soils are deeper and finer textured than on surrounding upland and water availability is greater.

Tarsus. The segmented foot of an insect; three segmented in the grasshopper.

Tectate. Roof-like, sloping from a peak.

Tessellate. Mosaic or checkered.

Tegmen (pl., tegmina). The leathery, narrow, nearly parallel sided forewings of grasshoppers and other Orthoptera (Fig. 7).

Tergum. The dorsal and lateral surface of an abdominal segment (Fig. 8).

Testaceous. Brownish yellow.

Thorax. The middle body region of an insect between the head and the abdomen (Fig. 1).

Threshold. The temperature or level of hormone concentration that must be reached before development or growth can begin.

Tibia (pl., tibiae). The long, slender segment of the insect leg (Fig. 6).

Tracheal system. The respiratory system of insects that consists of internal airfilled tubes.

Trapezoidal. A figure with four sides.

Trochanter. A small segment of the insect leg located between the coxa and the femur (Fig. 6).

Truncate. Cut off squarely at end.

Tympanum. The membrane covering of the auditory organ.

Type. The single specimen that bears the name of the species and from which the species was described.

Vagility. Capacity to disperse.

Valves of ovipositor. Three pair of digging and egg laying structures at the end of the abdomen in female grasshoppers (Fig. 1).

Veins. The riblike tubes that strengthen the wings of insects.

Venation. The entire system of veins of an insect wing.

Ventral. Pertaining to the undersurface of the body.

Vertex. Top of head between the compound eyes.

Wing pads. The developing wings found on nymphs.

Wings. The hindwings of Orthoptera.

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Grasshopper Fact Sheets Arranged Alphabetically

1.	*Aeoloplides turnbulli* (Thomas)	Russianthistle grasshopper
2.	*Aeropedellus clavatus* (Thomas)	clubhorned grasshopper
3.	*Ageneotettix deorum* (Scudder)	whitewhiskered grasshopper
4.	*Amphitornus coloradus* (Thomas)	striped grasshopper
5.	*Anabrus simplex* Haldeman	Mormon cricket
6.	*Arphia conspersa* Scudder	specklewinged grasshopper
7.	*Arphia pseudonietana* (Thomas)	redwinged grasshopper
8.	*Aulocara elliotti* (Thomas)	bigheaded grasshopper
9.	*Aulocara femoratum* Scudder	whitecrossed grasshopper
10.	*Boopedon nubilum* (Say)	ebony grasshopper
11.	*Brachystola magna* (Girard)	plains lubber grasshopper
12.	*Bruneria brunnea* (Thomas)	Bruner slantfaced grasshopper
13.	*Camnula pellucida* (Scudder)	clearwinged grasshopper
14.	*Chorthippus curtipennis* (Harris)	meadow grasshopper
15.	*Chortophaga viridifasciata* (DeGeer)	greenstriped grasshopper
16.	*Cordillacris crenulata* (Bruner)	crenulatewinged grasshopper
17.	*Cordillacris occipitalis* (Thomas)	spottedwinged grasshopper
18.	*Derotmema haydeni* (Thomas)	Hayden grasshopper
19.	*Dissosteira carolina* (Linnaeus)	Carolina grasshopper
20.	*Dissosteira longipennis* (Thomas)	High Plains grasshopper
21.	*Encoptolophus costalis* (Scudder)	dusky grasshopper
22.	*Eritettix simplex* (Scudder)	velvetstriped grasshopper
23.	*Hadrotettix trifasciatus* (Say)	threebanded grasshopper
24.	*Hesperotettix viridis* (Thomas)	snakeweed grasshopper
25.	*Hypochlora alba* (Dodge)	cudweed grasshopper
26.	*Melanoplus alpinus* Scudder	alpine grasshopper
27.	*Melanoplus angustipennis* (Dodge)	narrowwinged sand grasshopper
28.	*Melanoplus bivittatus* (Say)	twostriped grasshopper
29.	*Melanoplus borealis* (Fieber)	northern grasshopper
30.	*Melanoplus bowditchi* Scudder	sagebrush grasshopper
31.	*Melanoplus bruneri* Scudder	Bruner spurthroated grasshopper
32.	*Melanoplus confusus* Scudder	pasture grasshopper
33.	*Melanoplus dawsoni* (Scudder)	Dawson grasshopper
34.	*Melanoplus devastator* Scudder	devastating grasshopper
35.	*Melanoplus differentialis* (Thomas)	differential grasshopper
36.	*Melanoplus femurrubrum* (DeGeer)	redlegged grasshopper
37.	*Melanoplus foedus* Scudder	striped sand grasshopper
38.	*Melanoplus gladstoni* Scudder	Gladston grasshopper
39.	*Melanoplus infantilis* Scudder	little spurthroated grasshopper
40.	*Melanoplus keeleri* (Thomas)	Keeler grasshopper
41.	*Melanoplus kennicotti* Scudder	Kennicott grasshopper

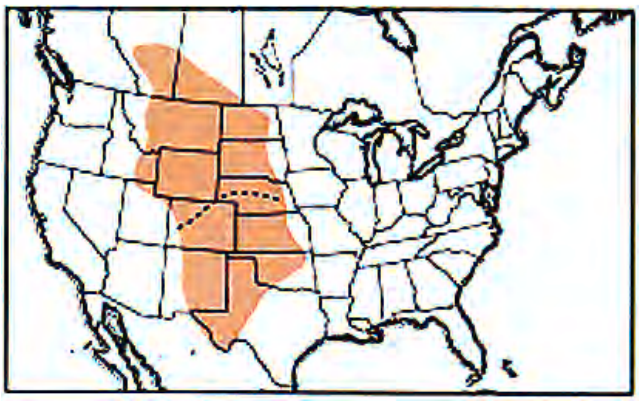
42.	*Melanoplus lakinus* (Scudder)	Lakin grasshopper
43.	*Melanoplus occidentalis* (Thomas)	flabellate grasshopper
44.	*Melanoplus packardii* Scudder	Packard grasshopper
45.	*Melanoplus rugglesi* Gurney	Nevada sage grasshopper
46.	*Melanoplus sanguinipes* (Fabricius)	migratory grasshopper
47.	*Mermiria bivittata* (Serville)	twostriped slantfaced grasshopper
48.	*Metator pardalinus* (Saussure)	bluelegged grasshopper
49.	*Oedaleonotus enigma* (Scudder)	valley grasshopper
50.	*Opeia obscura* (Thomas)	obscure grasshopper
51.	*Orphulella speciosa* (Scudder)	slantfaced pasture grasshopper
52.	*Phlibostroma quadrimaculatum* (Thomas)	fourspotted grasshopper
53.	*Phoetaliotes nebrascensis* (Thomas)	largeheaded grasshopper
54.	*Psoloessa delicatula* (Scudder)	brownspotted grasshopper
55.	*Spharagemon collare* (Scudder)	mottled sand grasshopper
56.	*Spharagemon equale* (Say)	orangelegged grasshopper
57.	*Trachyrhachys aspera* Scudder	finned grasshopper
58.	*Trachyrhachys kiowa* (Thomas)	Kiowa grasshopper
59.	*Trimerotropis pallidipennis* (Burmeister)	pallidwinged grasshopper
60.	*Xanthippus corallipes* (Haldeman)	redshanked grasshopper

Russianthistle Grasshopper

Aeoloplides turnbulli (Thomas)

Distribution and Habitat

The Russianthistle grasshopper enjoys a wide geographic range in western North America from southern Canada to northern Mexico. It inhabits desert shrub sites, local alkali flats vegetated with saltbush and black greasewood, and grasslands, where it does not feed on grasses but relies on the presence of host forbs, species of the goosefoot family (Chenopodiaceae).



Geographic range of *Aeoloplides turnbulli* (Thomas)

Economic Importance

Depending on the vegetation of its habitat or the kind of crop growing nearby, the Russianthistle grasshopper is either a beneficial or a pest species. In western Kansas in 1938, outbreak populations caused severe damage to sugar beets. Two years later during the same outbreak, numerous individuals invaded wheat fields in late June but caused no damage to the crop because of an abundant supply of green Russianthistle, a preferred host plant.

Populations that irrupt in desert shrub communities, such as the Big Horn Basin, Wyoming, damage valuable forage chenopods including Gardner saltbush, fourwing saltbush, and winterfat. Livestock, especially sheep, select these shrubs for feed during winter months when grasses and forbs are scarce or absent.

This grasshopper plays a beneficial role when populations inhabit patches of kochia, Russian thistle, or lambsquarters growing on disturbed land and in field borders and roadsides. The grasshoppers feed on the growing points of these plants, reducing seed production and foliage.

The Russianthistle grasshopper is in the largest third of rangeland grasshoppers. Live weight of males and females collected from a desert shrub community in the Big Horn Basin, Wyoming, with Gardner saltbush the chief host plant, averaged 296 mg and 548 mg, respectively (dry weights: 94 mg and 175 mg, respectively). Live weight of males and females collected from a disturbed site in southeast Wyoming invaded by kochia averaged 242 mg and 462 mg, respectively (dry weights: 76 mg and 146 mg).

Food Habits

The Russianthistle grasshopper feeds on species of the goosefoot family of plants (Chenopodiaceae). Principal host plants are shrubs or stout herbs, which afford the grasshoppers both nutritious food and roosting sites. Shrubs that serve commonly as host plants include fourwing saltbush, Gardner saltbush, white sage, also called winterfat, (*Ceratoides lanata*), and black greasewood, while stout herbs include the weeds kochia, Russian thistle, and lambsquarters. The latter plants frequently occur together in disturbed land providing the grasshoppers with an opportunity for a mixed diet. Likewise, in desert shrub habitats several chenopod species are usually present in addition to the principal host plant. In a desert shrub site of the Big Horn Basin, Wyoming, Gardner saltbush was the principal host plant but other chenopods were available to the grasshoppers. These were chiefly small annuals with five species sustaining grasshopper damage: *Atriplex argenta*, *A. powelli*, *A. suckleyi*, *Sarcobatus vermiculatus*, and *Suaeda nigra*. One species showed no damage, the introduced *Halogeton glomeratus*. This is unfortunate because this weed is very difficult to control and is toxic to sheep due to its high content of oxalates.

Field observations and gut analyses indicate that the Russianthistle grasshopper also feeds sparingly on several forbs belonging to at least six plant families other than Chenopodiaceae.

The Russianthistle grasshopper's method of attacking its host plant is notable for the selection of young tissue. From basking or roosting positions on kochia or Gardner saltbush, the grasshoppers climb to the growing tips to feed. There they consume young leaves and other developing tissues. Timed feeding bouts of two adults took six and seven minutes. In the desert shrub community of the Big Horn Basin, where Gardner saltbush dominates and much bare soil prevails, both nymphs and adults often come down to the ground during the day. They do not, however, appear to feed on ground litter.

Dispersal and Migration

Very little is known about the dispersal and migration of the Russianthistle grasshopper. Two accidentals, a male and a female of the southern subspecies, *Aeoloplides turnbulli bruneri*, were found in the mountains west of Boulder, Colorado. One was an adult male taken at 7,700 feet on 7 August 1933, the other an adult female taken at 12,100 feet on 4 August 1960. Collection of these two provides evidence for dispersal of the long-winged subspecies, *A. t. bruneri*.

Wings of the northern subspecies, *A. t. turnbulli*, vary in length but are usually noticeably short of the end of the abdomen. Compare Figure 7 of a female of the northern subspecies collected in eastern Wyoming (Platte County) with Figure 8 of a female of the southern subspecies collected in southeastern Colorado (Bent County). The wings of adults of the northern subspecies that inhabit the Big Horn Basin, Wyoming (Big Horn County) are even shorter, falling short of the end of the hind femur by 3 to 6 mm. The hind wings of the males averaged 8.8 mm long and of females 9.7 mm. In spite of the relatively short wings and heavy weight, the adults are able to fly. In flushed flight they travel an average distance of 3.6 feet at heights of 4 to 6 inches. The flight is silent and straight with the grasshopper usually landing face away from the intruder.

Instar 1

1. BL 3.8-4.9 mm FL 2.5-2.8 mm AS 12-14.

Instar 2

2. BL 5.6-7.1 mm FL 3.6-4.3 mm AS 15-17.

Instar 3

3. BL 7.7-8.5 mm FL 5.0-5.9 mm AS 18-20.

Instar 4

4. BL 10-13 mm FL 6.5-7.1 mm AS 20-22.

Instar 5

5. BL 14-17.3 mm FL 9-10.3 mm AS 22-24.

Figures 1-5. Appearance of the five nymphal instars of *Aeoloplides turnbulli* - their sizes, structures, and color patterns. Notice progressive development of the wing pads. BL = body length, FL = hind femur length, AS = number of antennal segments.

Identification

The Russianthistle grasshopper is a medium-sized robust species. It has a distinctive color pattern of shades of tan with fuscous markings (Figs. 6 and 7). The wings of the northern subspecies, *A. t. turnbulli,* may be 2 to 4 mm short of the end of the abdomen (and also the end of the hind femur, a less variable measurement). The wings of the southern subspecies, *A. t. bruneri*, are longer, surpassing the end of the abdomen (Fig. 8). Lateral light bands mark the sides of the pronotal disk and are separated by a broad fuscous band. The latter band is divided by the median carina, which may be colored partly or entirely light tan. The hind femur has three characteristic fuscous marks on the medial area. These dark marks usually extend dorsally onto the upper marginal areas. The hind tibia is usually medium blue with a pale tan annulus near the base. The male possesses tiny furcula represented by minute lobes, a subgenital plate with a conspicuous subapical tubercle, and triangular slender cerci (Fig 9).

The nymphs (Fig. 1-5)are identifiable by their structure, color patterns, and shape.

1. Head with face nearly vertical, head tan to pale tan or green with several to many fuscous spots; compound eye with large pale tan spots in brown reticulum; antennae filiform, first two segments (scape and pedicel) pale yellow with several brown spots, rest of segments (flagellum) fuscous, each with pale anterior annulus.
2. Pronotum tan or green with several to many brown spots, median carina pale contrasting with main color of disk, the pale line extends onto abdomen; disk becomes distinctly wider posteriorly (a diagnostic character).
3. Outer medial area of hind femur uniformly tan or green with several to many brown spots or with three fuscous markings, tan, and spotted (Fig. 2). Hind tibia is green, blue or pale gray, usually with brown spots.
4. General body color tan or green.

Characters especially useful in identifying the nymphs are: 1. the shape of the pronotal disk, which widens from front to rear, 2. most individuals heavily spotted brown or fuscous, 3. nymphs are colored pale green, pale tan, or pale gray, 4. in tan or gray nymphs, three characteristically shaped dark markings are usually present on the medial and marginal areas of the hind femur (Fig. 1 and 2), in green forms, these markings are faint or lacking (Fig. 3).

Hatching

The Russianthistle grasshopper is an early-hatching species. In weedy roadside habitats of eastern Wyoming, first instars appear as early as late April or the first of May along with the twostriped grasshopper, *Melanoplus bivittatus*. In the desert shrub of the Big Horn Basin, hatching may occur one to two

Figures 6-10. Appearance of the adult male and female of *Aeoloplides turnbulli turnbulli*, adult female of *Aeoloplides turnbulli bruneri*, end abdomen of male, egg pod and eggs.

weeks earlier. The hatching period is extended, lasting from four to five weeks. No study of egg development has been made.

Nymphal Development

Both the male and female nymphs require five instars to develop to the adult stage. Because of their nature to develop a robust body, their early hatching in spring, and their habitual location high on the host plant where ambient temperatures are lower than on the ground, the Russianthistle grasshopper's nymphal period is relatively prolonged ranging from 50 to 60 days.

Adults and Reproduction

In the desert shrub habitat of the Big Horn Basin, adults may appear as early as mid June, but in the weedy roadsides and disturbed sites of southeastern Wyoming, adults of the Russianthistle grasshopper do not appear until the last week of June. The processes of sexual maturation and courtship have not been determined in this species. The duration of copulation by a pair is unknown, but mating pairs have been observed sitting on host plants and on the ground during July and August from early morning until late evening. Attempts at oviposition by two females were observed in the desert shrub habitat of the Big Horn Basin. The first observation was made on 17 August 1993 from 1 to 1:07 p.m. DST when soil surface temperature was 120°F, air temperature 82°F, and sky clear. The female was discovered walking and hopping on the ground. After traveling a distance of 12 feet, she stopped and began to bore into bare ground for several seconds, then withdrew her ovipositor and walked another 12 feet. When she stopped again at 1:05 p.m., she bore into the soil for approximately one minute. She again withdrew her ovipositor and walked. By this time she was some distance from the observer and was lost to view. In the same desert shrub site another female was observed attempting to oviposit on 19 August 1993 at 1:23 p.m. DST when soil surface temperature was 121°F, air temperature 83°F, and sky clear. After this female was discovered, she crawled 2 feet into the shade of a clump of halogeton. She began to bore into the soil at 1:23 p.m. and continued for four minutes until she was disturbed by the observer and walked away, disappearing into the vegetation. These two attempts at oviposition suggest that the Russianthistle grasshopper oviposits in bare ground. The pods are stubby, 7/16 inch long, 3/16 inch diameter, and slightly curved. They have a sloping cap and the top appears pinched (Fig. 10). A plug of froth is lacking but reddish brown froth completely surrounds the egg mass and the individual eggs. The eggs are light-reddish brown or tan and 4.0 to 4.4 mm long. There are 12 to 18 eggs in a pod. The fecundity of females is high. In Canada, six caged females produced an average of 250 eggs each.

Population Ecology

Populations of the Russianthistle grasshopper develop in sites with an abundant supply of host plants. Such habitats usually occur in disturbed land, crop borders, weedy rangeland, and desert shrub associations dominated by saltbush (*Atriplex* spp.). The high fecundity of this species allows populations to irrupt during environmentally favorable periods. Densities in farmyard patches of weeds, usually less than an acre in size, may reach 100 or more young adults per square yard.

Male

6. BL 18-20.5 mm FL 10-11.2 mm AS 23-26. Northern subspecies *A. turnbulli turnbulli*

Female

7. BL 18.8-25 mm FL 11-13 mm AS 23-25. Northern subspecies *A. turnbulli turnbulli*

Female

8. BL 21-23.5 mm FL 11-12.5 mm AS 22-24. Southern subspecies *A. turnbulli bruneri*

Cercus

9. End of male abdomen showing cercus and subgenital plate with subapical tubercle.

Egg pod

10. Egg pod and exposed eggs in opened pod.

Outbreaks may occur in much larger areas such as the wheat-growing region of western Kansas and eastern Colorado. During the drought period of 1931-41, *A. t. bruneri* came into prominence in 1937. The grasshoppers hatched along the edges of wheat fields where Russian thistles had grown profusely the previous fall. The species became the dominant grasshopper in this area from 1938 to 1941 supplanting the migratory grasshopper, *Melanoplus sanguinipes*, as the most abundant species. In a 10 square mile study area of Finney County, Kansas, the Russianthistle grasshopper averaged one young adult per square yard in 1939. In 1940 the population more than doubled, and in 1941 the population remained high early in the season. During the latter half of May 1941, 150 late instar nymphs per square yard were recorded. But in June an epizootic struck the population and brought the outbreak to an abrupt end. Caused by an undetermined species-specific pathogen, the disease almost completely obliterated the Russianthistle grasshopper from the entire area.

Outbreaks of the northern subspecies, *A. t. turnbulli*, also occur. In 1993 an outbreak of this grasshopper was discovered in a desert shrub habitat of the Big Horn Basin, Wyoming. The vegetation of the infested area, at least 10 square miles in extent, was dominated by Gardner saltbush, a preferred host plant. High densities of this grasshopper ranging from 8 to 13 young adults per square yard occurred everywhere within the area. The adult population sustained a low daily mortality rate of 5 percent. The outbreak has continued for a minimum of two years, as high numbers were present in 1994.

Despite the prevalence of a variety of host plants (chenopods), few rangeland sites of the mixedgrass prairie harbor populations of the Russianthistle grasshopper. Only four sites out of 241 (1.7 percent) surveyed in eastern Wyoming in 1991 and only two sites out of 42 (1 percent) surveyed in the mixedgrass prairie of Montana in 1953 and 1954 contained this species. However, in 1991 in the desert shrub of the Big Horn Basin, this species occupied 23 sites out of 190 (12 percent) surveyed. Densities of grasshoppers in an eastern Wyoming rangeland site with an abundance of host plants of the Russianthistle grasshopper (Russian thistle, winterfat, and slimleaf lambsquarters) were sampled for several years. This survey revealed that for an eight-year period the populations of Russianthistle grasshoppers fluctuated from less than 0.1 per square yard to 0.54 per square yard and that the species held a low rank of abundance in the grasshopper assemblage in all years.

Daily Activity

The Russianthistle grasshopper is a phytophilous species spending much time on its host plant. However, during daylight hours in habitats of sparse vegetation with an abundance of bare soil, the grasshoppers descend regularly to the ground. There they bask, rest, crawl, and disperse short distances.

Extended observations of the species' behavior were made in a native desert shrub habitat of the Big Horn Basin, Wyoming, where Gardner saltbush served as its principal host plant. During the night nymphs and adults usually rest vertically, head-up on the stems of this shrub; a few take positions on ground litter underneath the shrub. One hour after sunrise the grasshoppers resting on the host plant begin to bask by adjusting their positions so that the rays of the sun strike a side or their back. They may also lower a hindleg to expose the abdomen more fully. A few individuals may jump to the ground to bask. Basking lasts for about two hours, after which the grasshoppers become active. Some may crawl to the top of the plant to feed on the growing tips, some may undergo a molt, some may jump from one stem to another, and many continue to roost quietly. Eventually the majority leave the host plant and spend time on the ground during the day until evening when they again seek shelter of the host plant. On the ground they mix among themselves and disperse short distances. Many mating pairs occupy both the host plant and the ground surface. During five-hour periods of observation, 37 single adults and 12 mating pairs were noted on 21 July 1993 and 17 singles and 13 mating pairs on 17 August 1993. Only one attempt at mating was observed; a female resting on saltbush was mounted by a male on 17 August 1993 at 1:54 p.m. The encounter ended unsuccessfully with no consummation of mating. In early afternoon females probed the soil for oviposition but no actual laying of eggs was observed.

When soil surface temperatures are above 120°F during midday, grasshoppers on the ground take evasive actions to prevent overheating. They may directly face away from the sun and stilt, or they may crawl and hop into the shade of vegetation or under the canopy of saltbush. Because the grasshoppers located on the host plant are not subjected to the high ground temperatures, they continue their activities and roosting.

When temperatures cool in the afternoon the grasshoppers on the ground become active again. Continued cooling of the habitat incites the grasshoppers both on the ground and on the host plant to assume basking orientations. Finally, close to sunset, the grasshoppers seek shelter. Those on bare ground crawl to the saltbush host plant; some rest on litter under the bush and many crawl up a stem and rest within the canopy.

In dense stands of kochia and lambsquarters the behavior of the Russianthistle grasshopper differs somewhat from that of the grasshoppers occupying habitats with much bare ground. In dense vegetation the grasshoppers roost all day, most vertically head-up on plant stems, but some horizontally on leaves. Rarely coming down from their perches, they carry out essential activities on the host plants - basking, feeding, molting, and mating. Gravid females, however, are compelled to descend to bare ground to oviposit into soil.

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Clubhorned Grasshopper

Aeropedellus clavatus (Thomas)

Distribution and Habitat

The clubhorned grasshopper, *Aeropedellus clavatus* (Thomas), inhabits grasslands of western Canada and the northern United States and extends its range into mountainous areas as far south as Arizona and New Mexico. In Colorado, one resident population survives above timberline at 13,600 feet in a rocky, grass-sedge habitat. In the prairie provinces of Canada it is the most widely distributed and abundant of the grassland species, occurring on all dry and somewhat sandy areas south of the boreal forest. In four of ten years it was the dominant species of a grasshopper assemblage inhabiting the sand prairie of southeastern North Dakota.

Economic Importance

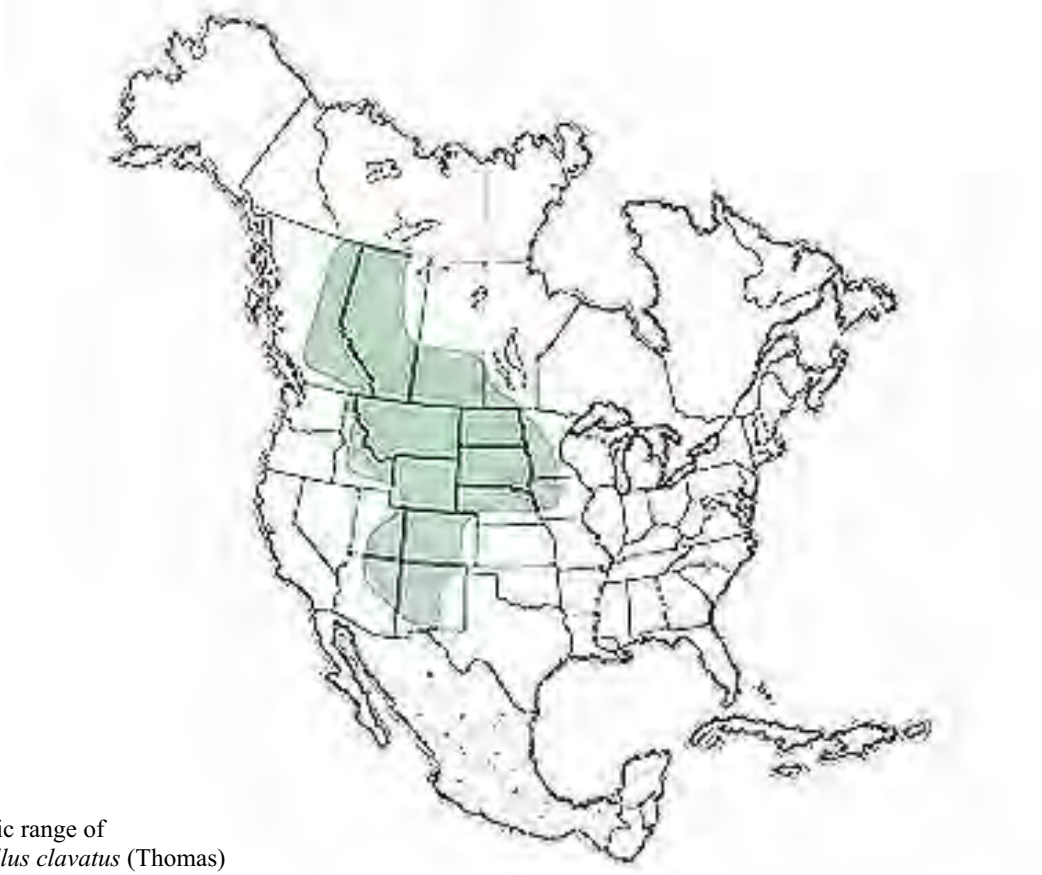
The clubhorned grasshopper is primarily a pest of grasses and sedges in the mixedgrass and bunchgrass prairies and in mountain meadows and parks. Populations may reach 20 per square yard on rangeland in Canada, causing severe damage to forage grasses. It has also attacked seedling cereals; in 1936 an outbreak in Saskatchewan destroyed 300 acres of wheat. In Montana and North Dakota it is frequently abundant in grasshopper assemblages infesting rangeland.

Food Habits

The clubhorned grasshopper feeds on grasses and sedges. Examinations of crop contents show that in mixedgrass prairie this grasshopper feeds on western wheatgrass, prairie junegrass, Sandberg bluegrass, needleandthread, threadleaf sedge, and needleleaf sedge. In mountain meadows and parks different groups of grasses and sedges are used for food. Wherever Kentucky bluegrass has invaded an area, it is a preferred host plant. When grass seeds and glumes become available in the habitat, they are fed upon heavily. The clubhorned grasshopper is known to feed upon 28 species of grasses and six species of sedges. Small amounts of forbs, fungi, pollen, and arthropod parts have been found in crop contents.

Migratory Habits

Little is known about the migratory habits of the clubhorned grasshopper. The females do not fly; their



Geographic range of
Aeropedellus clavatus (Thomas)

Instar 1

1. BL 5.4-7.1 mm FL 2.9-3.4 mm AS 13.

Instar 2

2. BL 6.8-8.1 mm FL 4.3-4.9 mm AS 16-18.

Instar 3

3. BL 11-11.5 mm FL 6.4-6.7 mm AS 20.

Instar 4

4. BL 14-16 mm FL 8.7-9.3 mm AS 22.

Figures 1-4. Appearance of the four nymphal instars of *Aeropedellus clavatus* — their sizes, structures, and color patterns. Notice the progressive development of the wing pads. BL=body length, FL=hind femure length, AS=antennal segments number.

wings are short, not reaching the middle of the abdomen. Males have either short or long wings. In plains habitats the long-winged males fly extensively. A study of predator avoidance conducted above timberline in Colorado showed that the females merely hop away from a predator but the males hop away and then prance (i.e., they take small, repeated hops without appreciable progression).

Identification

Adults of the clubhorned grasshopper are medium-sized and colored gray or green with various markings (Fig. 5 and Fig. 6). They possess clavate antennae that give this grasshopper both its common name and scientific species name. The six terminal segments of an antenna are enlarged and dark. The head has a dark streak running from beneath the compound eye to the base of mandible. Anterior to this streak lies a vertical cream or light tan band. The head has distinct oblong lateral foveolae (Fig. 7). The pronotum has low but definite median carina and lateral carinae, all of which are cut once by a sulcus behind the middle; the lateral carinae converge (curve inward) near the middle of the prozona (Fig. 7); the lateral lobe usually bears a pale diagonal mark (Fig. 6).

The nymphs are identifiable by their shape, external structures, and color patterns (Fig. 1-4):

1. Head with strongly slanted face; antennae flat and nearly same width the entire length in females, clavate in males (instars II to IV); lateral foveolae oblong and distinct.
2. Narrow light line beginning behind middle of compound eye, running along side of head onto lateral carina of pronotum and continuing on abdomen; broad fuscous stripe adjacent and below the light line.
3. Pronotum with lateral carinae converging near middle.
4. Hind femur with entire medial area gray; lower marginal area pale gray.

Hatching

The clubhorned grasshopper is a very early-hatching species. Nymphs begin to emerge ten days before nymphs of the bigheaded grasshopper, or

Figures 5-8. Appearance of the adult male and female of *Aeropedellus clavatus*, diagnostic characters, and the egg pod and loose eggs.

Male

5. BL 17-17.5 mm FL 11.1-11.6 mm AS 24.

Female

6. BL 19.5-21.0 mm FL 11.5-12.3 mm AS 23-24.

Head
Pronotum

7. Dorsal view of head and pronotum of adult male.

Egg pod

8. Egg pod, two eggs in situs, and one separate egg.

about the first week in May in eastern Wyoming. The hatching period lasts for three to four weeks. In mountain areas above timberline in Colorado, hatching begins in mid to late June depending on altitude, location, and seasonal temperatures.

Nymphal Development

The clubhorned grasshopper has four instars that develop rapidly. Accelerated development is a life history adaptation frequently associated with boreal existence. Nymphal development is completed in approximately 30 days on the plains and 42 days in alpine habitats.

Adults and Reproduction

The adults remain in the same area in which the eggs hatch and the nymphs develop. Because of early hatching and rapid development, the adults emerge when there is still an abundance of green grasses and sedges available for food. However, the cost of this early access to food is that this grasshopper may be intensively controlled by predators. Birds, rodents, spiders, and predaceous insects usually reduce the number of clubhorned grasshoppers to fewer than one per square yard by early summer. Later-hatching species, such as the bigheaded and whitewhiskered grasshoppers, may numerically overwhelm predators (trading more intensive competition over poorer food for the potential of swamping the predators' response) and thereby remain abundant through early summer.

Courtship and fecundity have not been studied in this grasshopper. The males stridulate loudly by vibrating the hind femur through a small arc against a raised vein on the tegmen. The "song" is probably part of the courtship ritual. Females select grasses or sedges in which to oviposit, laying the eggs among the roots. The eggs develop rapidly to stage 26 in which the embryo appears as a young grasshopper nearly ready to hatch. Evidently the embryo has entered diapause, as it does not emerge until the following spring. Egg pods (Fig. 8) are 10 to 13 mm long and 3.5 to 4.0 mm in diameter; they are oriented vertically in the soil. The pods contain five to eight eggs surrounded by a tan, hardened froth. Eggs are light tan and 4.6 to 5.5 mm long. They are arranged in two rows and are inclined about 30 degrees from vertical.

The species has one generation annually in plains habitats. The eggs of resident populations of alpine

habitats pass through two, or possibly three, winters before hatching.

Population Ecology

Outbreaks of the clubhorned grasshopper occur in limited areas of the prairie provinces of Canada, where populations may increase to 20 per square yard. In at least one instance, this grasshopper was abundant in a year that followed an unusually wet year. In relatively lush habitats of the mixedgrass prairie in Wyoming, populations may increase to four adults per square yard in early summer. More often, the densities in these habitats range from one to two adults per square yard.

Daily Activity

Cursory observations of adult activity have been made in Montana. Males appear to do much crawling on the ground and they frequently take short flights. The females are slower and remain motionless on the ground for long periods. Further observations of their daily activities are desirable.

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Whitewhiskered Grasshopper

Ageneotettix deorum (Scudder)

Distribution and Habitat

The whitewhiskered grasshopper, *Ageneotettix deorum* (Scudder), is widely distributed in grasslands of North America. Highest densities develop in the mixedgrass and the bunchgrass prairies. In the tallgrass prairie large numbers may occur on high ridges covered by blue grama or in grazed pastures of smooth brome or Kentucky bluegrass. A study of altitudinal distribution of grasshoppers in Colorado shows that this species is common in plains grassland at altitudes up to 5,750 feet but that numbers decline at 6,700 feet. Above 7,500 feet it is a non-resident.

Economic Importance

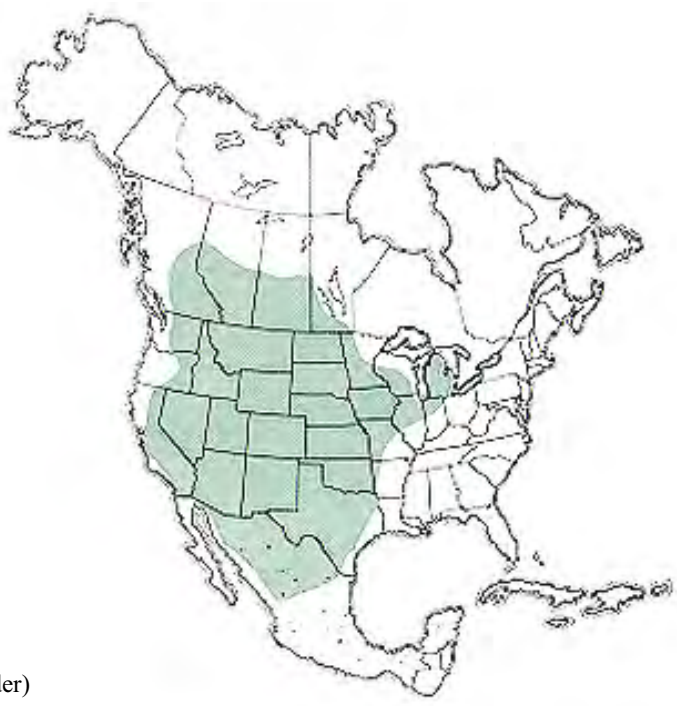
The whitewhiskered grasshopper is a pest of rangeland grasses. It is often the dominant species in outbreaks on the mixedgrass prairie reaching densities of 25 adults per square yard and comprising 50 percent or more of the grasshopper assemblage. Its exact role as a pest has not been experimentally determined. Observations of its behavior in natural habitats show that it not only feeds on green leaves of grasses but also on ground litter (felled leaves, seeds, dung of livestock, and dead insects). In feeding on attached green leaves, this grasshopper often severs them from the plant.

The whitewhiskered grasshopper is one of the smaller rangeland grasshoppers. Males average 110 mg live weight and females 310 mg (dry weight: males 31 mg, females 89 mg). These weights are little more than half that of the bigheaded grasshopper. Because of difference in size and food habits, the smaller grasshopper presumably has less than half the impact of the larger.

Food Habits

The whitewhiskered grasshopper feeds on many kinds of grasses and on several sedges. In its natural habitat it exhibits no clear preference for any particular species of host plant. Laboratory tests, however, show it prefers wheat and Kentucky bluegrass over native grasses. Examinations of crop contents indicate that the amount of each species of grass consumed is directly proportional to its abundance in the habitat. Important host plants include blue grama, western wheatgrass, needleandthread, Kentucky bluegrass, threadleaf sedge, and needleleaf sedge. In a desert prairie of southwest Texas, crop contents of this grasshopper consisted of 76 percent blue grama, 11 percent fall witchgrass, 5 percent buffalograss, and 8 percent of an undetermined forb.

Young nymphs have been observed feeding on green leaves of Sandberg bluegrass. This grass matures and dries up early, becoming less attractive to the older instars and adults. Both direct observations and crop content examinations show that nymphs and adults feed heavily on ground litter as well as on green leaves.

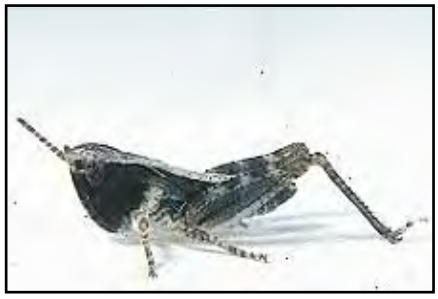


Geographic range of
Ageneotettix deorum (Scudder)

Instar 1

1. BL 4.7-5.1 mm FL 2.1-3.3 mm AS 13.

Instar 2



2. BLl 6.4-6.7 mm FL 4-4.2 mm AS 15-17.

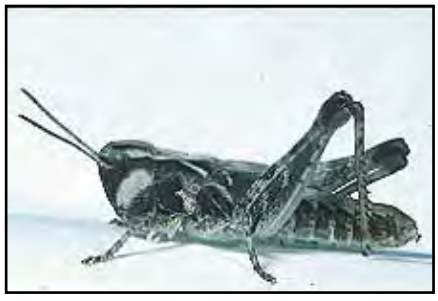
Instar 3

3. BL 8.3-9.2 mm FL 5.1-5.6 mm AS 20.

Instar 4

4. BL 9.9-11 mm FL 7.3-7.7 mm AS 22.

Instar 5



5. BL 14-15 mm FL 9.1-9.8 mm AS 24.

Figures 1-5. Appearance of the five nymphal instars of *Ageneotettix deorum* - their sizes, structures, and color patterns. Notice progressive development of the wing pads. BL = body length, FL = hind femur length, AS - antennal segments number.

The adults have been observed clinging to needleandthread and western wheatgrass and feeding on the leaves in a head-down position. When late summer rains stimulate new growth of western wheatgrass, the adults take advantage of this nutritious food supply. They may eat the young leaves down to the ground. Several species of forbs are consumed in small amounts.

Migratory Habits

The whitewhiskered grasshopper is a vigorous flier near the ground. Evasive flights are straight, silent, low (3 to 6 inches), and short (3 to 6 feet). A competent flier, it is known to make dispersal flights. It has been found at high mountain altitudes as a relatively frequent "accidental" (adults in locations where the species does not complete its life cycle). Adults have also been found in the center of large cities on cement sidewalks and on paved streets and parking lots. No records have yet been made of migrating swarms.

Identification

Adults of the whitewhiskered grasshopper (Fig. 6 and 7) are medium-sized and colored reddish-brown with many fuscous markings. The head has only a slightly slanted face. The antennae have the dorsal side light gray or whitish, a character that has provided the common name for this species. Wings are long, but range from short of the end of abdomen to beyond the abdomen. The tegmina are speckled brown. The hind tibiae are red to orange with the proximal end usually black; the terminal inner spur is elongated, 1.5 times as long as the other inner spur (Fig. 9). The hind femora have the knees black and have three fuscous marks on the upper marginal area; the middle mark is triangular.

The nymphs (Fig. 1-5) are identifiable by their color patterns, structures, and shape:

1. Head with lateral foveolae oblong and visible in dorsal view; antennae filiform but flattened, suffused or ringed light gray or whitish; face moderately slanted.
2. Pronotum with cream-colored bands along each lateral edge of disk; bands continue on head to compound eye (Fig. 8); median carina of disk low but distinct.
3. Tibia with paired terminal spurs unequal in length.

Figures 6-10. Appearance of the adult male and female of *Ageneotettix deorum*, two diagnostic characters, and the egg pod and loose egg.

4. Color distinctively black along front and side of head, side of thorax, side of abdomen, and on medial area of hind femur; dorsum of body light tan with a few brown spots. Instars 2 to 5 with light tan patch below compound eye and on lateral lobe.

Hatching

The whitewhiskered grasshopper is an early-hatching species. Eggs begin embryonic growth in the summer of deposition and continue until they attain 50 percent development at which time (stage 19 embryo) they diapause. During winter, diapause is broken but embryonic development does not resume until temperatures rise in the spring. The nymphs emerge about the same time as the nymphs of the bigheaded grasshopper. The hatching period lasts from four to six weeks. Like the egg pods of the bigheaded grasshopper, those of the whitewhiskered grasshopper lie horizontally just below the ground surface exposed to hot temperatures and extremely dry conditions in summer. The eggs are able to withstand these adverse physical conditions, but many predators - birds, rodents, beetles, bee flies - find them a nutritious food source.

Nymphal Development

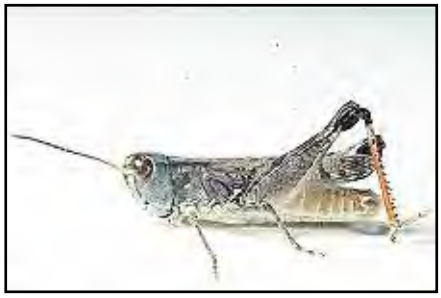
The nymphs of the whitewhiskered grasshopper develop more slowly than those of the bigheaded grasshopper. They complete nymphal development in 40 to 48 days, the females taking longer than the males. Although development of most individuals requires five instars, males may require only four and females may occasionally have six.

Adults and Reproduction

The adults generally remain in the same area in which the eggs hatch and the nymphs develop. There they find the resources necessary for their survival and reproduction and tolerance for large number of enemies - birds, rodents, spiders, and predaceous insects - that use them for food. Populations of adults dwindle over the summer, but daily mortality early in adult life ranges from less than 1 percent to nearly 10 percent.

Males spend much time wandering about on the ground seeking mates. Pair formation is initiated by the males approaching moving females. Courtship consists of visual signals, principally the male raising and lowering his hind femora and antennae. Copulation has been observed to last only five minutes.

Male



6. BL 15.5-16.2 mm FL 9-9.7 mm AS 25.

Female

7. BL 21-24 mm FL 12-12.5 mm AS 25.

Pattern

8. Color pattern of head and pronotum, dorsal view.

Hindleg

9. Inner side hindleg of male showing color pattern and tibial spurs.

Egg Pod

10. Egg pod and loose egg.

The female deposits her first clutch of eggs when she is 14 days old. She then deposits succeeding clutches at a rate of approximately one every three days. The pods contain from three to five eggs and average four.

A female usually selects blue grama or buffalograss sod for her oviposition site but may occasionally choose bare ground. Laying the eggs in soil at a shallow depth, she forms the pod horizontally just below the surface. An ovipositing female attracts several attending males. After completion of oviposition she covers the hole left by the extraction of her ovipositor with litter and soil particles. To do this, she sweeps the ground with her hindlegs using the tarsi as brushes.

The fecundity of the whitewhiskered grasshopper appears to be less than that of the bigheaded grasshopper. Confined as mating pairs in field cages and fed cheatgrass brome and plains bluegrass, 22 females produced an average of 81 eggs each. The greatest reproduction by a female was 107 eggs. Caged females had an average longevity of 88 days and males 85 days. In their natural habitat females live an average of 23 days. The latter figure, along with the preoviposition period of 14 days and rate of oviposition of four eggs every three days, provides an estimate of fecundity in nature that averages 12 eggs per female. There is one generation annually.

The egg pod of the whitewhiskered grasshopper is 10 to 12 mm long and 4 mm in diameter (Fig. 10). It is tough and curved. The cap is slanted and faces upward in the soil. Eggs are 5.0 to 5.3 mm long and pale yellow to whitish.

Population Ecology

The whitewhiskered grasshopper is frequently the dominant species in grasshopper assemblages infesting the mixedgrass prairie. Populations of this species exhibit a variety of responses to their environment. A common response is a gradual increase in numbers of 1.5 to 3-fold annually for a period of about four years and then a sudden increase of 6-fold to precipitate an outbreak. The entire grasshopper population may have risen to 50 adults per square yard and of this density the whitewhiskered grasshopper contributes 50 percent. Crashes of the population may happen suddenly. After three to five years or more of high densities, the population may crash to low levels. The species appears to be highly sensitive to weather and enemies. Daily mortalities of nymphs have been shown to range from 3 - 9 percent and of adults from less than 1 to over 9 percent. The causes of these variations have yet to be investigated.

Daily Activity

The whitewhiskered grasshopper is a diurnal, ground-loving insect. At night, individuals rest on bare ground or on litter often under the protection of a canopy of grass. One to two hours after sunrise individuals move to the east side of grass crowns and begin basking by resting perpendicular to the rays of the sun (side exposed to sun) and by hugging the ground surface. They bask for an hour or more, then the adults begin their normal activities of pottering (intermittent wandering with frequent changes in direction), feeding, mating, and egg laying. Activity slows when temperatures rise in the early afternoon to 90°F (air) or 120°F (soil surface). Individuals then seek the shade of small shrubs sitting on the ground or litter. As temperatures decline later in the afternoon, they again take up normal activities. Two to three hours before sunset they begin basking once more, this time on the west side of grass crowns. As the sun sets individuals remain on the ground to pass the night at rest.

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Striped Grasshopper

Amphitornus coloradus (Thomas)

Distribution and Habitat

The striped grasshopper, *Amphitornus coloradus* (Thomas), is widely distributed in the grasslands of western North America. The greatest numbers occur in the mixedgrass and bunchgrass prairies.

Economic Importance

The striped grasshopper is a pest of grasses and sedges. It climbs the host plant and with head up chews on the green leaves. It cuts leaves and then holds them by the front tarsi. The cut portion is usually consumed but sometimes falls to the ground and is eaten by another grasshopper or less often becomes litter.

The striped grasshopper is a common member of grasshopper assemblages infesting rangeland. It is often the third most abundant species, but rarely the dominant one. Densities of young adults range from less than one to eight per square yard.

Cage plot tests on native grassland of interior British Columbia demonstrated that the feeding of this grasshopper during its nymphal stage reduced the yield of needleandthread grass by 3.5 pounds per acre for each grasshopper per square yard. An infestation of one young adult per square yard reduced yield 1 pound per day over 1 acre. Live weights of males average 144 mg and of females, 275 mg (dry weight: males 41 mg, females 80 mg).

Food Habits

The diet of the striped grasshopper consists almost exclusively of grasses and sedges. Crop analyses indicate that it feeds chiefly on blue grama, needleandthread, threadleaf sedge, and needleleaf sedge. Seventeen other species of grasses have been detected in crop contents including important rangeland forage grasses (viz., western wheatgrass, prairie junegrass, sandberg bluegrass, and sand dropseed).

This grasshopper climbs or rests on the vegetation to feed; it rarely feeds on the ground. Forbs, arthropod parts, and fungi have occasionally been detected in crop contents. Field tests indicate that only 4 percent of a population will feed on bran bait.

Migratory Habits

The striped grasshopper has long wings that extend beyond the end of the abdomen giving it strong powers of flight. Evasive flights are silent, fast, low (2 to 6 inches), short (2 to 7 feet), and straight with a zigzag landing.

Geographic range of
Amphitornus coloradus (Thomas)

Instar 1

1. BL 5.1-7.2 mm FL 2.9-3.3 mm AS 13-14.

Instar 2

2. BL 8.2-9.4 mm FL 4.2-4.6 mm AS 14-17.

Instar 3

3. BL 9.7-10.0 mm FL 5.9-6 mm AS 20.

Instar 4

4. BL 12.3-13.6 mm FL 7.3-7.7 mm AS 22.

Instar 5

5. BL 15.3-16.4 mm FL 8.9-10.0 mm AS 23.

Figures 1-5. Appearance of the five nymphal instars of Amphitornus coloradus — their sizes, structures, and color patterns. Notice progressive development of the wing pads. BL=body length, FL=hind femur length, AS=antennal segments number.

Although no observations of its dispersal and migration have been made, adults have been collected in Colorado at high mountain altitudes as “accidentals” (adults in locations where the species does not complete its life cycle). Sites of resident populations are prevalent in Colorado up to 5,400 feet and are possibly the breeding habitats for accidentals that have been collected above timberline, as high as 11,400 feet. In Montana a female was taken from Grasshopper Glacier in the Crazy Mountains at 9,680 feet.

Identification

Adults of the striped grasshopper are medium-sized, cream-colored, and profusely striped (Fig. 6 and 7). The top of the head is marked by two diagnostic chocolate brown stripes running above the compound eyes (Fig. 8); these stripes continue onto the pronotum. The antennae are filiform and flat. The head is without lateral foveolae. The pronotum has a low median carina cut once near the middle and an accessory carina on each side of the median carina. The hind femur has three dark brown transverse bands and a dark brown knee. Hind tibiae are pale blue.

The nymphs (Fig. 1-5) are identifiable by their color patterns, structures, and shape:

1. Head with chocolate brown stripe above each compound eye (Fig. 9), stripes continue onto thorax and abdomen; face distinctly slanted; antennae slightly ensiform (Fig. 9); head without lateral foveolae.
2. Pronotum with low distinct median carina, entire in first and second instars, cut once near middle in older instars; two accessory carinae present but faint in early instars.
3. Hind femur of first and second instars with medial area pale tan or cream, older instars with upper medial area and knee suffused with brown.

Hatching

The striped grasshopper is an early-hatching species. First instars appear in the habitat about the same time as those of the bigheaded grasshopper. Embryonic development begins in the summer of deposition. Limited observations indicate that the

Figures 6-10. Appearance of the adult male and female of *Amphitornus coloradus,* diagnostic characters, and the egg pod and an opened egg pod exposing two eggs in situs.

Male

6. BL 17.8-20.3 mm FL 10-12 mm AS 25-26.

Female

7. BL 21.5-25 mm FL 12.5-13.5 mm AS 24-25.

Head
Pronotum

8. Dorsal view of head and pronotum of female adult.

Head
Pronotum

9. Dorsal view of head and pronotum of third instar nymph.

Egg pod

10. Egg pod attached to grass stem and an opened pod showing two eggs in situs.

embryos achieve stage 19 and then diapause, as in the eggs of the bigheaded grasshopper. With rising soil temperatures in spring, the embryos complete development and eventually hatch. The period of hatching lasts for four to five weeks.

Nymphal Development

Nymphs in the mixedgrass prairie of Wyoming develop more slowly than those of the bigheaded grasshopper. They become adults in 50 to 56 days, whereas bigheaded grasshopper nymphs become adults in 36 to 42 days. This difference may be due to the different temperatures to which they are exposed. During most of the day, nymphs of the bigheaded grasshopper remain on the soil surface while nymphs of the striped grasshopper roost above ground on grass plants. In Montana the two species appear to develop at the same time and rate. The nymphal stage normally consists of five instars.

Adults and Reproduction

Adults of the striped grasshopper live in the same habitat in which the eggs hatch and the nymphs develop. Their host plants normally stay green through summer and they tolerate the many enemies inflicting mortalities that average 6 percent each day.

Courtship has been observed infrequently. In a study of daily activity, the adults spent 0.3 percent of their time in courtship in the morning and 0.5 percent in the afternoon. The male stridulates briefly before he makes a copulatory leap onto the female.

A gravid female selects a needleandthread or a threadleaf sedge plant in which to oviposit. She climbs into the center of a plant and, vertically oriented, extends her ovipositor down toward the crown. She holds onto leaves with her fore and midlegs but her hind tibiae are flexed tightly against the femora. In about 30 minutes she deposits four eggs and forms a pod on a stem below the soil surface. During this time she may be attended by a male. After laying her clutch, she climbs up a short distance and works her ovipositor around the exit hole, then crawls away from the plant. Because the outer wall of the pod is constructed of dry fragments of grass sheaths as well as soil particles, the pod is easily overlooked in sampling for grasshopper eggs.

There have been no studies of the fecundity of this grasshopper. The species has one generation annually.

The tough, thimble-shaped egg pod of the striped grasshopper is 7 to 8 mm long and 3 to 4 mm in diameter (Fig. 10). The cap is recessed 1 mm. Eggs are 4.5 to 5.4 mm long, pale yellow, and embedded in dried brown froth. The eggs are vertically oriented at the bottom of the pod.

Population Ecology

In natural habitats populations of the striped grasshopper may remain at low densities ranging from 0.1 to 0.8 per square yard for up to nine years. Populations may also grow gradually, as in Parker's model, doubling for three or four years and then tripling or quadrupling in an outbreak year. This population growth generally parallels the growth of other economically damaging species of rangeland grasshoppers (e.g., the bigheaded, whitewhiskered, and spottedwinged grasshoppers). One of the latter is usually dominant but all contribute to a damaging infestation. Apparently the same favorable factors are operating on many species of rangeland grasshoppers. However, crashes of the populations of each species may come in different years indicating variable responses of species to inimical factors (e.g., temperature and precipitation extremes and specific diseases and parasites). Another difference among these species is the fact that the striped grasshopper rarely becomes the dominant species. When it does dominate, densities do not generally exceed eight young adults per square yard. Records of peak densities of the other species are 20 to 40 young adults per square yard.

Daily Activity

The striped grasshopper spends part of its day on vegetation and part on the ground. At night the nymphs roost head-up on grasses in the habitat. One to two hours after sunrise, they move to the ground and bask by orienting either their sides or their backs perpendicular to the rays of the sun. The adults usually rest on the ground at night under a canopy of grasses. An hour after sunrise they begin basking by exposing their side or back to rays of the sun and hugging the ground. After basking one to two hours, they begin their normal activities of pottering, feeding, and mating.

When temperatures in midsummer rise above 90°F, striped grasshoppers, all adult at this time, climb small shrubs and rest head-up 2 to 8 inches off the ground in the shade. When temperatures decline they return to normal activities. During lower temperatures later in the day, they bask on the ground for about one hour and then move short distances to shelter, resting through the night.

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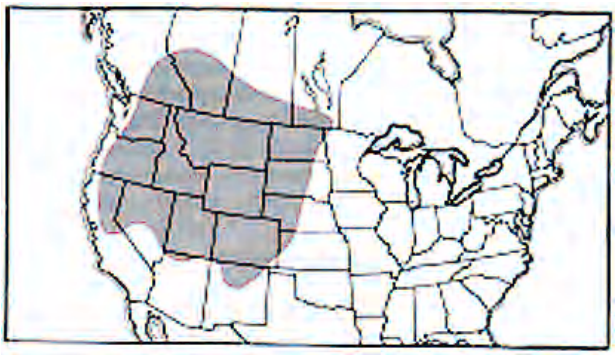
Mormon Cricket

Anabrus simplex Haldeman

Distribution and Habitat

The Mormon cricket, a shieldbacked katydid (family Tettigoniidae, subfamily Decticinae) and not a true cricket, lives in western North America in rangeland dominated by sagebrush and forbs. Large populations develop in the open sagebrush-grass associations of the Great Basin and of mountain ranges. In the Rocky Mountains of Colorado, small resident populations occur from 6,500 feet in forest openings to above 11,000 feet in the alpine tundra.



Geographic range of *Anabrus simplex* Haldeman

Economic Importance

Mormon crickets damage forage plants on rangeland and cultivated crops in the path of their migrations. The adult Mormon cricket is a large insect; males average 3,400 mg live weight and females 4,100 mg (dry weight: males 960 mg, females 1,330 mg). Feeding tests demonstrate that during its nymphal period and 20 days of adult life, an average Mormon cricket consumes 3,518 mg of vegetation (dry weight). Calculations based on this figure indicate that at a density of one per square yard the Mormon cricket consumes an amount of rangeland forage equal to 38 pounds dry weight per acre. Because of their migratory habit, Mormon crickets may be present in a particular site for no more than three or four days. In this short time, their damage to rangeland is perceptible but not measurable by standard quantitative techniques.

The Mormon cricket breeds only infrequently in cultivated fields, but migrating bands of nymphs or adults may completely destroy fields of sugarbeets, small grains, and alfalfa. During the 1937 outbreak, crop damage in Montana amounted to $500,000 and in Wyoming to $383,000.

Food Habits

Although the Mormon cricket has been observed to feed on more than 400 species of plants, this insect discriminates in its choice of foods, preferring certain succulent forbs. Examinations of crop contents and direct observations of feeding show that preferred forbs include milkvetches, penstemon, arrowleaf balsamroot, dandelion, and several mustards such as wild mustard, tumble mustard, and pepperweed. Among the abundant shrubs growing in its habitat, the Mormon cricket has often been observed feeding on saltbush and on species of sagebrush (big sagebrush, budsage, fringed sagebrush). At certain times of the season it may restrict its feeding to two to four staple foods available in its habitat. These may include various forbs, grasses, seeds, fungi, and arthropods. When grasses and forbs begin seed development, Mormon crickets (adult by this time) climb the plants and feed preferentially on the nutritious kernels.

Mormon crickets relish cultivated plants; they feed voraciously on wheat, barley, alfalfa, sweetclover, truck crops, and garden vegetables.

Migratory Habits

Despite its flightless state, the Mormon cricket is a very mobile insect. The first four instars move about extensively in search of food and shelter and in short migration. Their net travel is not far. Older instars and adults, however, migrate in cohesive bands in fixed directions and may cover from one-half to one mile in a day and travel from 25 to 50 miles in a single season. Locomotion is limited to crawling and hopping, as their wings are short and unsuited for flight. Although Mormon crickets have been observed traveling at night, they migrate chiefly during the day when skies are clear and temperatures favorable (65° to 95°F air). When two bands meet, they either coalesce into one larger band or they maintain their separate directions of migration and flow through each other as they intersect.

Hatching

Embryonic growth begins when the eggs are laid in summer. The eggs attain complete development by fall, at which time they diapause before entering winter dormancy. At high mountain altitudes embryonic development may be delayed, prolonging incubation of eggs an additional year. Mormon crickets emerge in spring at much lower temperatures than do grasshoppers. Hatching starts when soil temperatures reach 40°F.

Nymphal Development

Mormon cricket nymphs develop and grow under the cool conditions of spring. They pass through seven nymphal instars and take 60 to 90 days to reach the adult stage. When ready to molt, Mormon crickets climb plants and hang head or back downwards securely fastened to a leaf or branch by the tarsal claws of all three pairs of legs. Molting is accomplished in 10 to 20 minutes, after which the insect turns upright and remains inactive on the plant

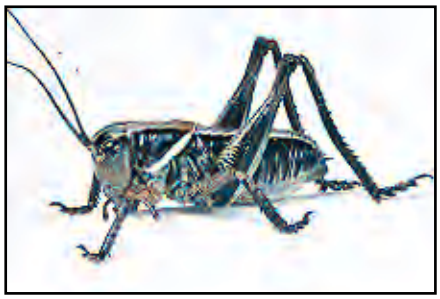
Instar 1

1. BL 6-8.2 mm FL 4.2-4.5 mm DV 0.2-0.3 mm.

Instar 2

2. BL 6.8-8.9 mm FL 5.5-6.1 mm DV 0.5-0.6 mm.

Instar 3

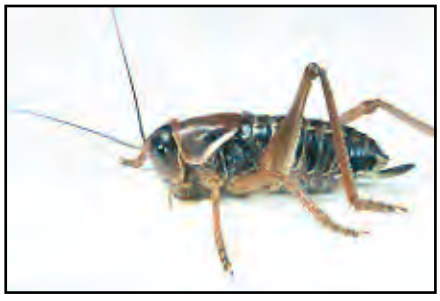


3. BL 10.6-13.3 mm FL 7-7.7 mm DV 1-1.2 mm.

Instar 4

4. BL 12-14 mm FL 8.8-9.6 mm OVP 2.2-2.7 mm.

Instar 5



5. BL 16-19 mm FL 10.2-11.6 mm OVP 4.4-4.6 mm.

Figures 1-5. Appearance of the five nymphal instars I to V of the Mormon cricket – their sizes, structures, and color. BL=body length, FL=hind femur length, DV=dorsal valve of ovipositor length, OVP=ovipositor length.

for several minutes while its cuticle hardens and darkens. Before crawling away, it usually eats its own cast skin.

Identification

Of the more than 100 species of shieldbacked katydids in western North America, only a few are ground-dwelling, rangeland insects. The majority live in shrubs and bushes. To aid in identification of Mormon crickets, compare specimens collected on the ground from grasslands and sagebrush communities with Figures 1-9, noting the long antennae, smooth and shiny integument, color patterns, shapes, and the gentle upward curve of the ovipositor. A diagnostic character of the adult male is the bifurcation and shape of the cercus (Fig. 11). The bifurcation begins to be clearly evident in the fifth instar as a black bump on the inner surface of the cercus. The female cercus remains small and cone-shaped.

Adults and Reproduction

Courting and mating begin 10 to 14 days after Mormon crickets reach the adult stage. From a perch in vegetation a courting male attracts receptive females by rubbing his tegmina together to produce a calling song. When a female approaches, he either drops to the ground to meet her or waits for her to climb to him. The female mounts the male, who assumes a C-shaped position underneath the female, and the pair couple. The male transfers to the female's genetalia a large white spermatophore that consists of two main parts: a small sperm ampulla containing two pockets of sperm and a large proteinaceous bulb, the spermatophylax. The transfer is accomplished in a few minutes, after which the pair separates. While the sperms are draining into the spermatheca of the female, she eats the spermatophylax and then eventually consumes the empty ampulla. The extra protein and other nutrients are used by the female in producing eggs. Because the spermatophore represents up to 27 percent of the male's body weight, he makes a substantial contribution to the growth and survival of his offspring, a relatively rare occurrence among insects.

A gravid female deposits eggs singly in bare ground, often utilizing the mounds of the western harvester ant. As soon as a female lays an egg in the soil, she withdraws her ovipositor and covers the exit hole with soil by several quick, backward movements of this organ. She then moves to another location where she repeats the act of oviposition. Results of cage tests at Billings, Montana indicate that the fecundity of the Mormon cricket is approximately 86 eggs per female. Of 15 pairs caged individually, the greatest reproduction of a single female was 160 eggs and as many as 35 eggs were laid by one

Figures 6-10. Appearance of nymphal instars VI and VII, adult male and female and eggs.

female in a day. Females oviposit in bouts that occur at intervals of approximately seven days. The eggs (Fig. 10) are 7 to 8 mm long, and are dark brown when first laid but soon turn white. After several days of development the eggs become gray.

The Mormon cricket has one generation annually, but in high mountain habitats two years may be required to complete a single generation.

Population Ecology

The Mormon cricket possesses a life history well-suited to its rough habitat in the western states. Long before Europeans explored the area, outbreaks of the Mormon cricket occurred regularly enough that the indigenous peoples developed methods of harvesting these insects. Among the artifacts discovered in a cave inhabited by humans near Ten Sleep, Wyoming, the cooked remains of several hundred Mormon crickets were found in a roasting pit. Charcoal from the fire hearth gave a radiocarbon date of 222 ± 150 years BC.

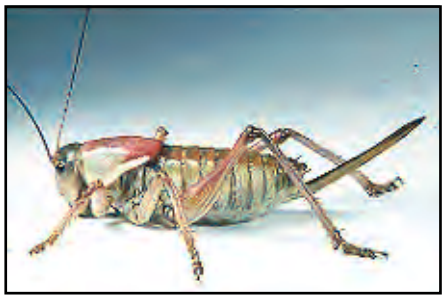
From less than one per square yard in mountain habitats, Mormon cricket densities may grow gradually over a period of several years, reaching densities of adults as great as 100 per square yard. Once populations have reached outbreak proportions, the crickets begin extensive migration to foothills, rangeland, and crops. The high densities may persist for years; numerous outbreaks have lasted from 5 to 21 years. A recent major outbreak began in 1931 and continued for 17 years. At the peak of the infestation in 1938, 19 million acres in 11 states were infested.

In some years, threatening numbers of Mormon crickets do not continue to increase and an outbreak is averted by the action of natural control factors. The exact nature of these factors has not been discovered. Variations in weather have been suspected of contributing to fluctuations of Mormon cricket populations. Yet populations have concomitantly increased and later decreased within climates ranging from 500 feet altitude in the deserts of Nevada and Washington to alpine elevations of 8,000 feet in the mountains of Montana and Wyoming, from average annual rainfall ranging from 6 to 20 inches, and from an average annual frost-free season ranging from less than 30 days to one of 180 days. During the early nymphal period (instars I to IV), substantial reductions in numbers have been observed following prolonged periods of rain, snow, or daily freezing temperatures. Another mortality factor that undoubtedly varies among populations of Mormon crickets is the number of predators, especially California gulls, hawks, crows, rodents, and the digger wasp, *Palmodes laeviventris*. The few parasites of the Mormon cricket do not appear to exert much control. Prevalence of disease varies widely. The microsporidian *Vairimorpha* produces high spore levels in many tissues of Mormon crickets, causing sluggish behavior and high mortality.

Instar 6

6. BL 17.5-22 mm FL 13.4-15 mm OVP 9.7-11.1 mm.

Instar 7

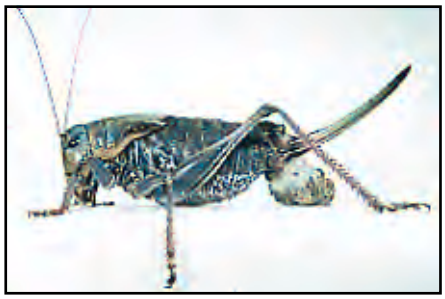


7. BL 27-32 mm FL 16.5-18 mm OVP 19.5-22.5 mm.

Male

8. BL 39-43 mm FL 21.5-23 mm.

Female with spermato-phore



9. BL 41-49 mm FL 22-24 mm OVP 27-30 mm.

Eggs

10. Five eggs dug from soil in habitat.

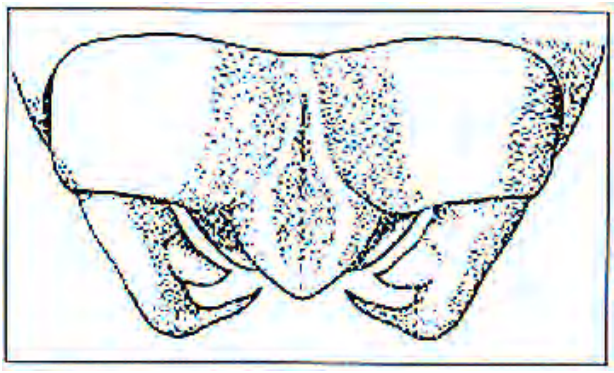


Figure 11. Paired cerci of male Mormon cricket, dorsal view. Drawing by Ashley B. Gurney.

To complicate the ecological problem even more, the Mormon cricket itself may change its morphology, physiology, and behavior as populations increase in density. Similar transformations have been found in locusts of the Old World and to a lesser extent in North American grasshoppers. An explanation of these changes was made by Sir Boris Uvarov in his promulgation of the "phase theory."

Daily Activity

The behavior patterns of Mormon crickets allow the nymphs to cope with cold nights and spells of inclement weather in early spring. They find shelter under canopies of shrubs, crawling into the litter and under large recumbent stems. Big sagebrush is an especially favored refuge, but other sagebrushes and saltbush provide good cover. Mormon crickets also crawl into soil cracks and under soil clods, and under dry sheep and cow dung. A few nymphs, however, may climb to the tops of big sagebrush in the evening and remain on these perches through the night.

On a mild spring day nymphs emerge from their shelters after sunrise and crawl to the east side of the bush to bask in the first rays of the sun. They rest on the ground, individually or in small clusters of four to 12 nymphs, and expose their sides or backs to the sun's warming rays. They may extend both hindlegs behind themselves to expose more body surface. During the basking period Mormon crickets often stir and change positions and are easily agitated by the movement of adjacent individuals.

The nymphs bask for two to three hours, during which time ground temperatures rise from around 40° to 80°F. The warmed crickets then move away from the bush that sheltered them and begin pottering (walking about in various directions) and feeding. Eventually almost all individuals begin walking in one direction as a cohesive band. Individual crickets may stop to feed during the migration, but when satiated they again join the marching band.

Mormon crickets cease migrating two to three hours before sunset and begin basking again, this time on the west side of bushes. They bask on the ground individually or in clusters of 25 to 50 nymphs sitting close together. Near sunset, as shadows cover the ground, individuals may climb big sagebrush or saltbush to bask in the last rays of the sun. During the final three hours of daylight, Mormon crickets also do much feeding. By sunset most crickets have already retreated to their shelters.

When the day is overcast and cold, rainy or snowy, or very windy, Mormon crickets remain in their refuges. A sudden change during the day from mild to inclement weather induces them to retreat to shelters and stay hidden.

Adults behave much like the nymphs. They seek shelter in the evening and pass the night chiefly under the canopy of shrubs. An hour or two after sunrise they emerge from their shelters and bask in the warming rays of the sun. After basking for about two hours they begin to walk about and feed. Adults at low densities may stay in a favorable habitat where they survive and reproduce. At high densities, however, adults migrate extensively. A few individuals begin migrating in early morning when soil surface temperatures reach 76° to 85°F and all join in the migration when temperatures reach 96° to 105°F.

During the middle of the day, migrating adults may encounter soil temperatures too hot (above 110°F) for them to continue. They escape the extreme heat by climbing shrubs and roosting until temperatures moderate. Migration may then begin again.

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Specklewinged Grasshopper

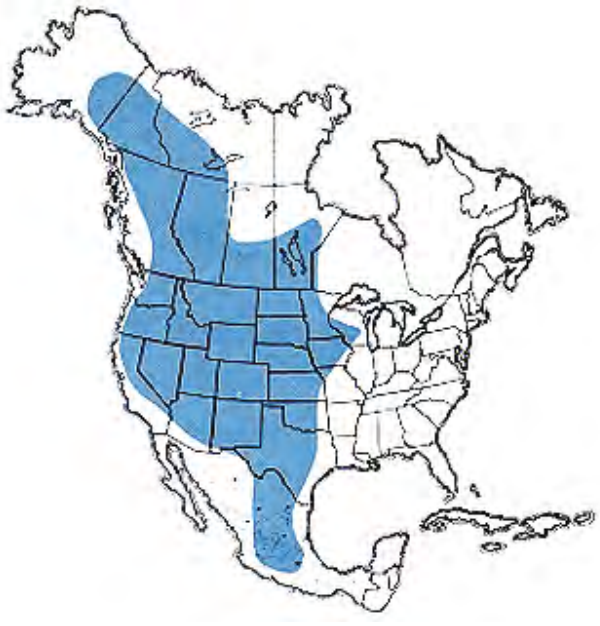
Arphia conspersa Scudder

Distribution and Habitat

The specklewinged grasshopper enjoys a wide distribution in western North America that stretches from Alaska to Mexico. It inhabits all of the grassland prairies and penetrates desert shrub communities wherever grasses make up part of the vegetation. In Colorado and Idaho, resident populations have been found in mountain meadows and other open grasslands up to 11,000 feet.

Economic Importance

Although the specklewinged grasshopper feeds on quality forage, its impact on grazing land is minimal due to low densities throughout its distribution. Populations in desert grassland and in shortgrass and mixedgrass prairie have been determined to range from 0.05 to 0.1 adults per square yard. In mountain habitats, numbers are less, ranging from approximately 40 to 120 adults per acre. In some apparently suitable habitats they appear to be absent. This species is in the largest category of the three size divisions of rangeland grasshoppers. Live weight of males from mixedgrass prairie in Platte County, Wyoming averaged 251 mg, and of females 776 mg (dry weight: males 86 mg, females 178 mg). Individuals from mountain habitats are smaller; live weights of individuals from 10,170 feet in central Colorado averaged 194 mg for males and 494 mg for females.



Geographic range of *Arphia conspersa* Scudder

Food Habits

The specklewinged grasshopper feeds primarily on grasses and sedges. Sixteen species of grasses and three species of sedges have been recorded in crop contents. Specific host plants ingested depend on both the grasshopper's preferences and the availability of plants in diverse grassland habitats. In the sand prairie of southeastern North Dakota, Kentucky bluegrass made up 50 percent of the diet; in the mixedgrass prairie of central Nebraska, prairie junegrass made up 67 percent; in the mixedgrass prairie of eastern Colorado, western wheatgrass and needleandthread in equal quantities made up 58 percent of the diet; and in the shortgrass prairie of northern Colorado, blue grama (27.6 percent), western wheatgrass (18.8 percent), and downy brome (17.6 percent) made up 64 percent of the diet. Other plants found in substantial amounts include threadleaf sedge, needleleaf sedge, sand dropseed, and sixweeks fescue. Small amounts of forbs (12 species), fungi, and arthropods are ingested by this grasshopper. No doubt, the number of grasses and sedges known to be ingested is still far short of the actual number fed upon by this grasshopper.

The specklewinged grasshopper feeds mainly from a horizontal position on the ground, and eats dry grass litter, recumbent attached leaves, or green leaves cut by itself. It attacks a standing leaf by raising up diagonally on its hind legs and cutting the leaf about one-half to one inch above the base. It may hold onto the cut portion with the front tarsi and feed to the tip, or it may drop the cut portion and return to the ground to eat the fallen leaf. Sometimes it will eat the remaining green stub from a horizontal position.

Dispersal and Migration

The specklewinged grasshopper has strong powers of flight, possessing long wings that extend beyond the end of the abdomen in both males and females. Appetitive flights of the males occur regularly and are accompanied by a crackling sound called crepitation. These flights are comparatively rare in females. The sound is produced by the wings, but an explanation of the exact mechanism remains in dispute. Appetitive flights last one to three seconds and describe an arc 6 to 10 feet long and 3 feet high. The flights are a part of courtship and function to bring the sexes together. Because of its behavior to aggregate, the specklewinged grasshopper has low vagility. Evidence for its dispersal is present in montane settings. It often colonizes regrown road cuts and cleared chaparral within five years, wherever nearby populations are present. No records of migration exist for this species.

Evasive flights are made by both males and females beginning about three hours after sunrise when soil temperatures have risen above 60°F. The flights range from 4 to 45 feet in length and from 6 inches to 2 feet high. They

Instar 1

1. BL 4.8-6.1 mm FL 2.8-3.1 mm AS 13.

Instar 2

2. BL 6.4-8 mm FL 3.8-4.2 mm AS 15-16.

Instar 3

3. BL 9-11.5 mm FL 5.3-6.5 mm AS 17-18.

Instar 4

4. BL 12-15.5 mm FL 6.9-8.3 mm AS 20-21.

Instar 5

5. BL 15-18 mm FL 8.7-10.6 mm AS 23-24.

Figures 1-5. Appearance of the five nymphal instars of *Arphia conspersa* - their sizes, structures, and color patterns. Notice progressive development of the wing pads. BL = body length, FL - hind femur length, AS = antennal segments number.

are usually sinuous and accompanied by crepitation. Silent escape flights may occur and extend from 30 feet to over several hundred feet with the wind. The fleeing grasshopper lands horizontally on the ground and often turns to face the intruder.

Identification

The specklewinged grasshopper, prevalent as adults in spring, is a wide-ranging western species. Its genus, Arphia, consists of 16 species. Of these, only the redwinged grasshopper, *Arphia pseudonietana* (Thomas), has an equally wide distribution in the West. Adults of this species, present in late summer and fall, are separated seasonally from adults of the specklewinged.

The adult specklewinged grasshopper (Fig. 6 and 7) is a large rangeland species, the female being much larger than the male. The lateral foveolae of the head are triangular or quadrilateral. The median carina of the pronotum is low but distinct, uniformly elevated, and incised once in front of the middle (Fig. 8). The body is brown except for a yellow abdomen. The tegmina are brown with dark brown speckles and, when folded, often form a pale tan or yellow median stripe. The disk of the hind wing is usually red but may be yellow (Fig. 9). The hind tibia is pale yellowish green with a fuscous annulus at each end.

The nymphs (Fig. 1-5) are identifiable by their shape, external structure, and color patterns.

1. Instar I. Head conspicuously large and rounded; segments of maxillary and labial palps brown with distal ends pale yellow. General body color dark brown. Pronotum with low, entire median carina; lateral lobe black with a triangular light tan patch postero-ventrally (Fig. 1). Hind tibia dark red; hind tarsus black on first segment and distal two-thirds of last segment with middle white.
2. Instars II and III. Head rounded, face nearly vertical, lateral foveolae triangular or quadrilateral. Pronotum with low, median carina (entire or weakly incised) and with disk tectate (rooflike); lateral lobes of pronotum brown with dark brown speckles and marks (without triangular light patch). Hind tibia shiny black; hind tarsus black at both ends and pale in middle.
3. Instars IV and V. Head vertically elongated, not as rounded as in earlier instars; lateral foveolae triangular or quadrilateral; segments of maxillary

Figures 6-10. Appearance of the adult male and female of *Arphia conspersa*, diagnostic characters, and the egg pod and several loose eggs.

and labial palps mainly pale. Pronotum with low, uniformly elevated median carina incised once in front of middle; disk of pronotum tectate. General body color brown with dark brown speckles and marks; venter of abdomen green with brown spots; hind tibia green and black.

Hatching

The specklewinged grasshopper is a late-hatching species. First instars begin to appear in mid-July in the mixedgrass prairie of eastern Wyoming and in the shortgrass prairie of eastern Colorado. Hatching continues for about a month. A laboratory study has revealed that females lay nondiapause eggs that hatch in 40 days at 77°F. This study suggests that the species has a one-year life cycle under favorable temperature regimes. On the other hand, field studies on the plains of central Saskatchewan and in the mountains of Colorado indicate a two-year life cycle. As with several other grasshopper species, this grasshopper appears to have a one-year or a two-year life cycle depending on the climate of its habitat.

Nymphal Development

The nymphs of this species develop relatively fast. In mixedgrass prairie at altitudes of 5,000 feet, they become third instars by late August, and fourth and fifth instars by late September. The majority are in the fifth instar, the stage that overwinters, by October. At the onset of cold winter weather they become dormant. Precisely where they seek shelter is unknown. Nymphs have been shown to survive freezing at temperatures as low as -16°C. Surface ground temperatures seldom get colder than this extreme. In winter, during periods of mild weather, some nymphs become active and may even molt to the adult stage.

The time of general metamorphosis to adulthood comes in early spring and varies as a function of weather, latitude, and altitude. In the mixedgrass prairie of eastern Wyoming, adults are present in April, but in high mountain habitats of Colorado adults may not emerge until July.

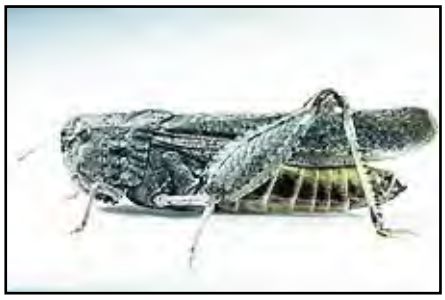
Adults and Reproduction

Adults remain in the same general area in which they developed as nymphs. Densities of the males and females are apparently high enough on the plains to present no difficulty in mate location. In the mountains, however, very low densities present a problem of mate location that is solved by the aggregation flights of males. These flights are also made

Male

6. BL 20-21 mm FL 11-12.2 mm AS 23-25.

Female



7. BL 30-37 mm FL 14-17 mm AS 24-25.

Head and pronotum

8. View of head and pronotum of adult female.

Wings

9. Forewing (tegmen) and hindwing of female.

Egg pod

10. Egg pod and several loose eggs.

in all habitats of the plains. At the peak of daily activity, males make aggregation flights every three to four minutes.

Courtship is conducted on the ground. A male can detect a female from a distance of at least 2 feet away. He moves toward her in a series of spurt-runs; that is, he runs making several complete leg movements, then pauses and stridulates emitting one to three chirps. When he approaches within 1 inch of the female, he orients to her face-to-face. They wave their antennae at one another and the male continues to chirp. Next, the male moves to the female's side, then faces and sometimes butts her thorax. The male continues chirping and places his front tarsus on her middle femur and stomps the ground rapidly with his hind tarsi. He then produces a series of four or five chirps and mounts the female from the rear. If he is accepted, the pair copulates. A receptive female may actively solicit attention from a male by presenting her side, lowering the near hindleg, and raising both the opposite hindleg and the tegmina, which exposes the whole abdomen. One successful copulation of a pair was observed to last 23 minutes.

A gravid female selects bare ground when she is ready to oviposit. She bores more than 2 inches into the soil and deposits a clutch of 20 to 21 eggs. After extracting her abdomen, she covers the hole by pulling debris over the pod and tamps it down with her ovipositor. The eggs are light brown to brown, and range in length from 4.5 to 5.2 mm (Fig. 10). Pods are long and usually break in extracting them from the soil. One entire pod measured one and five-eighths inches long. Neither the potential nor realized fecundity of this grasshopper is known.

Population Ecology

Recorded populations of the specklewinged grasshopper have been small in all habitats. Densities have ranged from 0.05 to 0.1 adults per square yard in desert, northern mixedgrass, and shortgrass prairies. Populations on the high altitude mesa of the Gunnison River in Colorado tend to gather in clusters, occupying 200-400 feet diameter areas within an apparently suitable and much larger habitat. Twenty to 40 adults per acre is the usual density; seldom do densities reach 120 adults per acre even in the clusters. In 1970, populations residing on the mesa above 9,200 feet crashed, but populations at lower altitudes were nearly normal. It is likely that an unusually cold winter killed the nymphs but not the diapausing eggs, which hatched and allowed normal population densities of nymphs in August and September 1970. A small number of nymphs in 1971 indicated there was no recovery of the 1970 brood. Causes of population fluctuations at lower altitudes east of the Rocky Mountains have not been studied.

Of biological interest is the geographic isolation of populations with red or yellow wings. Specific color morphs are associated with particular geographic regions, and between these regions narrow zones of hybrids and mixed colors exist. Predominantly redwinged populations occupy the high plains east of the Rocky Mountains. In central Colorado, yellow morphs occupy isolated grassland habitats of pinyon-juniper and high coniferous forest.

Daily Activity

Because of the generally low densities of the specklewinged grasshopper, few observations have been made of its daily activities. Apparently the adults rest horizontally on the ground at night, their body temperatures declining to the low ambient temperatures of spring. Immobile at dawn, they begin to stir as the sun rises and then bask, orienting their sides to the warming rays. At a soil surface temperature of 57°F they are able to jump but not fly to avoid an intruder. Flight becomes possible at soil surface temperatures a few degrees above 60°F. Feeding begins around 10 a.m. and oviposition around 11 a.m. (MDT). In montane habitats the conspicuous spontaneous flights of males peak between 10 a.m. and noon.

High temperatures suppress activity. Whenever the soil surface temperature reaches 105°F, individuals either assume a stilt posture (legs extended to lift the body off the ground) or move on the ground to the shade of plants. Even without extreme heat, activity in the afternoon subsides. One female was discovered resting horizontally on the ground in a nonbasking orientation at 2:40 p.m. More observations on the behavior of this grasshopper are needed to provide a complete picture of its daily activities.

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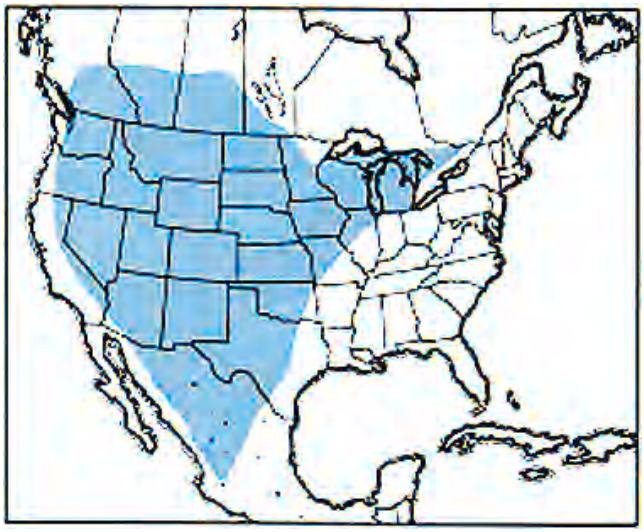
Redwinged Grasshopper

Arphia pseudonietana (Thomas)

Distribution and Habitat

The redwinged grasshopper ranges widely in North America occupying grass and grass-shrub habitats. It reaches highest densities in the mixedgrass prairie. At the periphery of their geographic range, these grasshoppers occupy restricted habitats and are less numerous. In the tall and midgrass prairies of their eastern and northern range, they inhabit the dry, sandy, or gravelly uplands and hilltops, while in their western and southwestern range, they inhabit mesic grassland sites.



Geographic range of *Arphia pseudonietana* (Thomas)

Economic Importance

The redwinged grasshopper is a minor pest in western grasslands. It feeds on a variety of valuable forage grasses and sedges, but because of low numbers it causes no serious losses. Populations, usually less than one young adult per square yard, are not known to reach outbreak densities. It is a large grasshopper, and during a general rangeland outbreak of grasshoppers, it adds to the overall damage. In the fall, adults invade fields of winter wheat located in the vicinity of their normal habitats and contribute to the grasshopper damage of this crop. Live weights of males collected from mixedgrass prairie of southeastern Wyoming average 309 mg and females 684 mg (dry weights: males 97 mg, females 214 mg).

Food Habits

The redwinged grasshopper feeds on grasses and sedges. Data obtained by direct observation and from examination of crop contents show that it feeds on at least 20 species of grasses and four species of sedges. In a particular habitat, two or three species serve as the main host plants. In the shortgrass prairie of north-central Colorado, the redwinged grasshopper feeds chiefly on blue grama, western wheatgrass, and needleleaf sedge; in the mixedgrass prairie of western Nebraska on western wheatgrass and buffalograss; in the sand prairie of northeastern Colorado on needleandthread and western wheatgrass; and in the sand prairie of southeastern North Dakota on Kentucky bluegrass and Penn sedge. Occasionally the redwinged grasshopper ingests small amounts of forbs, such as cudweed sagewort and scarlet globemallow.

Observations in a Montana habitat of the mixedgrass prairie revealed that nymphs spend much time on grass plants and consume green leaves of downy brome, western wheatgrass, blue grama, sideoats grama, needleandthread, and green needlegrass. The adults were observed to spend little time on plants and showed a preference for junegrass.

In laboratory two-choice tests, adults fed sparingly on dandelion and heavily on downy brome and western wheatgrass. In these tests the grasshoppers fed more heavily on young wheat leaves then on either downy brome or western wheatgrass.

The redwinged grasshopper's method of attacking a grass plant has been observed twice in nature and several times in the laboratory. One observation in nature involved the feeding of a female (instar V) on two felled green leaves of needleandthread. Crawling on the ground, the nymph contacted the first leaf (2.5 inches long) at 8:52 a.m., and consumed it entirely from base to tip. As it fed, the nymph handled the leaf with its front tarsi and rested horizontally on the ground. At 9 a.m. it contacted the second leaf, also 2.5 inches long, and ingested it by 9:03 a.m. Ground temperature was 76°F, air 68°F, sky was clear, and a southwest wind prevailed at 0-4 mph.

The second observation was of a male that flew appetitively. Upon landing it walked 2 inches, then in a diagonal orientation with hindlegs on the ground it began to feed on a leaf of grama grass, and then on the grazed end of a leaf of needleleaf sedge. The male finally turned head-down and continued to feed on the sedge. Feeding occurred from 10:33 to 10:38 a.m. DST at soil temperature of 75°F and air 67°F, clear sky, and a south wind of 2-5 mph.

Feeding on felled leaves was observed also in a laboratory terrarium provisioned with transplant of mixedgrass prairie. In addition, the adults fed on attached, recumbent leaves of needleandthread by devouring the leaf from the distal end to the base. Adults also reached with their mouthparts to feed on standing attached leaves. They attacked the leaf from 1/8 to 1 inch above its base, cut through it while feeding, then held onto the detached section, and consumed it completely. If the detached section was dropped, the grasshopper often found it and continued to feed.

Dispersal and Migration

The redwinged grasshopper is a strong flier. Observations made in the George Reserve, Michigan, reveal that flushed males fly 10 to 30 feet. When accompanied by crepitation, the flight is uneven (zigzagging and undulating). However, when the grasshopper is suddenly disturbed, the flight is faster, silent (no crepitation), even, and smooth. Prior to alighting, males turn quickly and sharply, close the wings, and dive into the grass. The change in direction, nearly 180 degrees, brings the grasshopper around to face the direction from which it came. Flushed flight of females is longer than that of males, with females flying distances from 5 to 60 feet. In alighting, females do not turn sharply but drop straight down along the line of flight. Flushed females crepitate more softly than males and for

Instar 1

1. BL 4.8-5.5 mm FL 2.2-2.5 mm AS 11-12.

Instar 2

2. BL 5.8-7.2 mm FL 3.3-3.7 mm AS 13-14.

Instar 3

3. BL 8.3-10.1 mm FL 4.8-5.6 mm AS 16-18.

Instar 4

4. BL 10-15 mm FL 6.4-8.1 mm AS 18-20.

Instar 5

5. BL 14.5-18 mm FL 8.3-10.6 mm AS 19-22.

Figures 1-5. Appearance of the five nymphal instars of *Arphia pseudonietana* - their sizes, structures, and color patterns. Notice progressive development of the wing pads. BL = body length, FL = hind femur length, AS = number of antennal segments.

a shorter period (about 1 second) in the middle of the flight. Both sexes fly farther when greatly frightened.

On warm, sunny days, the redwinged grasshopper makes many voluntary or appetitive flights. In the mixedgrass prairie of southeastern Wyoming the grasshoppers have been observed to fly distances of 1 to 12 feet at heights of 3 to 12 inches. Interesting displays of flight by males have been observed in the grass-forb habitat of the George Reserve. Although most flights are in a straight line, some males fly nearly straight up to a height of approximately 4 feet, and then flutter down slowly with their wings flashing brilliantly red in the sunlight. When they reach the vegetation canopy, they close their wings and drop to the ground. The performance is accompanied by a loud crackling crepitation. This flight behavior as well as appetitive straight flight are exhibited only when the sun is shining brightly. The flights function to bring pairs together for courtship and mating.

Little information is available on dispersal and migration by the redwinged grasshopper. Adults have been found as accidentals at 10,000 feet in the mountains west of Boulder, Colorado, indicating dispersal of 14 miles from the closest resident population.

On 27 September 1993, a collection of seven species of rangeland grasshoppers was made along a sidewalk in downtown Cheyenne, Wyoming. Six male and three female specimens of the redwinged grasshopper were represented in the collection, which also included a total of 17 males and 23 females of Melanoplus gladstoni, the most abundant of the seven species. The collection suggests dispersal of these species from a heavily infested rangeland site of the mixedgrass prairie surrounding Cheyenne. Dispersal of individual adults also occurs, as indicated by the finding of a female on a sidewalk of the campus of the University of Wyoming, Laramie, on 14 September 1992 and a male on a sidewalk of the campus of Colorado State University, Fort Collins, on 9 September 1993.

Identification

The redwinged grasshopper is a large, dark brown to black grasshopper (Fig. 6 and 7). The tegmina are colored like the body and are darkly speckled. The hind wings possess a red disk and a black marginal band (Fig. 8). The apex of the hind wing may be transparent or black. The outer face of the hind femur is dark gray, dark brown, or black and often marked by three tan transverse bands. The hind tibia is dark brown or black with a yellow annulus in the proximal quarter (Fig. 9).

In Michigan, Wisconsin, and Minnesota some demes (local populations) consist entirely of yellow-winged individuals. West of these states all individuals possess bright red wings.

The nymphs (Fig. 1-5) are identifiable by their shape, external structure, and color patterns.

1. Instar I. Head conspicuously large and rounded; segments of maxillary and labial palps fuscous, only tip of terminal segment yellow. General body color

Figures 6-10. Appearance of the adult male and female of *Arphia pseudonietana*, the spread wings, inner face of the hindleg, and the egg pod and exposed eggs.

black. Pronotum with low, entire median carina; lateral lobe black with a few scattered gray or brown spots. Hind tibia dark red; hind tarsus black on first segment and distal two-thirds of last segment with middle yellow or pale green.

2. Instar II and III. Head rounded, face nearly vertical, lateral foveolae triangular or quadrilateral; segments of maxillary and labial palps fuscous, each segment with tan or brown annulus apically. Pronotum with low median carina, weakly incised and with disk tectate (rooflike); lateral lobes of pronotum brown and fuscous. Venter of thorax and abdomen usually shiny black. Hind tibia dark orange, fuscous at both ends; hind tarsus black at both ends and yellow in the middle.
3. Instar IV and V. Head elongated vertically, not as rounded as in earlier instars; lateral foveolae triangular or quadrilateral; segments of maxillary and labial palps fuscous, each segment with yellow annulus apically. Pronotum with low, uniformly elevated median carina incised once in front of middle; disk of pronotum tectate. Color of body dull brown and black; venter of thorax and abdomen solid, shiny black; hind tibia multicolored (fuscous, dark orange, and tan).

Hatching

The redwinged grasshopper is a late-hatching species. In the bunchgrass prairie of southern Idaho, however, eggs may begin to hatch in late May. In the mixedgrass prairie of western South Dakota (elevation 3,000 feet) eggs begin to hatch by June 11, while in the mixedgrass prairie of eastern Wyoming (elevation 5,050 feet) and the shortgrass prairie of north central-Colorado (elevation 5,420) eggs begin to hatch a few days later, June 13 to 19.

Although this species and the specklewinged grasshopper, *Arphia conspersa*, are considered late-hatching grasshoppers, the redwinged grasshopper hatches a month earlier than the specklewinged. Hatching of the redwinged continues for two weeks. A laboratory study has shown that after deposition, eggs develop to stage 19 (50 percent of embryonic development) and then enter diapause. Held at 77°F the eggs reached this stage in 30 days. Available data suggest that eggs of the redwinged grasshopper pass the winter in stage 19 and then complete the remaining 50 percent of their development the following spring.

Nymphal Development

Nymphs emerge in the mixedgrass prairie of eastern Wyoming during the last two weeks of June. Their development proceeds through five instars and coincides with the warm temperatures and green food of early summer. Depending on environmental factors, the nymphal period takes a minimum of 42 to 56 days. Nymphs of different instars occur in the habitat from mid June to mid August.

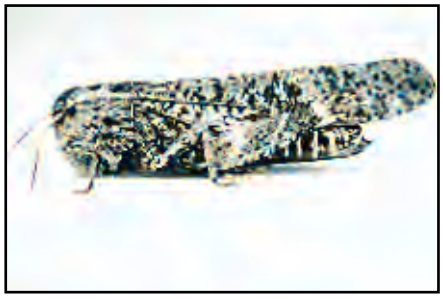
Adults and Reproduction

Adults start to emerge in mid July in the bunchgrass prairie of Idaho and during the last week of July in the mixedgrass

Male

6. BL 20-23 mm FL 11.5-14.3 mm AS 23-24.

Female



7. BL 25.5-31 mm FL 14-16.5 mm AS 21-24.

Wings

8. Forewing and spread hindwing of female.

Hindleg

9. Inner surface left hindleg of male.

Egg pod

10. Egg pod and exposed eggs.

prairie of eastern Wyoming. Most adults appear to remain in the same general area in which they developed. Flight displays often bring the sexes together. Pair formation also occurs when males, by walking or hopping, approach moving females. Reproductive maturation of the females is slow. Caged females held at an average temperature of 76°F and fed green western wheatgrass begin to oviposit when four to five weeks old. Because adults have an extended longevity, they may be present in a habitat of the mixedgrass prairie from early August until late in October, a period of 80 days. This longevity is approximately 30 days greater than that for the bigheaded grasshopper, *Aulocara elliotti*.

The act of oviposition was observed by Norman Criddle (1875-1933), an early student of North American grasshoppers, on 21 September and 1 October 1917 in Manitoba. Females rested on their front and midlegs and held the hind ones in the air, as egg laying took place. Two females were found ovipositing at the edge of an old trail. Because oviposition was underway when discovered, the total time of egg laying was not determined, but the females withdrew their abdomens after 26 and 33 minutes. They then brushed soil and litter over the aperture of the holes using the hindlegs both alternately and in unison. The recovered pods contained 24 and 25 eggs.

Caged females readily oviposit into bare soil. Two pods laid by females from the mixedgrass prairie of southeastern Wyoming contained 31 and 36 eggs. The pods are nearly straight and 1 5/8 inches long. The top 5/8 inch is occupied by froth, the bottom inch by eggs. Eggs are tan to brown and 4.2 to 5.2 mm long (Fig. 10).

Population Ecology

The redwinged grasshopper is not abundant in any of the many grasslands it inhabits. A relatively large population inhabited a mixedgrass prairie site in southeastern Wyoming in 1993. The density of this population was sampled and found to be one young adult per square yard. In different years three other sampled populations inhabiting mixedgrass prairie in Wyoming and Colorado consisted of densities ranging from 0.1 to 0.2 young adults per square yard.

In the shortgrass prairie of north-central Colorado (Central Plains Experimental Range), densities of young adults have ranged from 0.02 to 0.05 per square yard. In spite of low densities, populations persist from year to year. Whenever investigated on this experimental rangeland, the redwinged grasshopper has been a prominent member of the assemblage. Dates of confirmed occurrence include consecutive years from 1968-75 and from 1981-86. Research during the latter period showed that populations fluctuated annually and tracked the density of the entire grasshopper assemblage (Table 1).

In the Davis Range of Texas, Ernest Tinkham reported that the redwinged grasshopper was very abundant in the fall of 1928 and that large swarms flew up from tall grasses. Regrettably, he did not determine the absolute density.

Table 1. Population fluctuation of the redwinged grasshopper and the grasshopper assemblage in a shortgrass prairie site, north central Colorado (Adapted from Capinera and Thompson).

	Number per square yard				
	1981	1982	1983	1984	1985
Arphia pseudonietana	0.05	0.08	0.20	0.23	0.13
Assemblage 5 common species	0.9	2.4	4.0	3.1	1.6

Daily Activities

The redwinged grasshopper is a ground-dwelling insect. Adults spend the night on the surface of small bare areas (3 to 54 square inches) prevalent in the mixedgrass prairie, often surrounded closely by grasses or underneath a canopy of grasses. One to two hours after sunrise they begin to bask by turning a side perpendicular to the rays of the sun and lowering the associated hindleg to expose the abdomen. In August, when temperatures are still warm, they bask for about two hours but as temperatures become cooler they bask longer spending as much as four hours basking in the morning during October. After basking they become active, feeding, walking, and mating. During midday the males fly short distances or rise vertically in display. Aggregations of adults often form, bringing the sexes together. Eight aggregations were observed 20 October 1992 at 2:30 p.m. along a ranch road for a distance of one-half mile. When temperatures in summer become very hot on bare ground (125°F), the grasshoppers crawl on top of blue grama and face the sun directly. This orientation raises the body above the soil surface and exposes only the front of the head to the sun's rays, while the rest of the body is shaded. Late in the afternoon the grasshoppers bask for a second time. Shortly before sunset they retreat to their nighttime shelters.

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Bigheaded Grasshopper

Aulocara elliotti (Thomas)

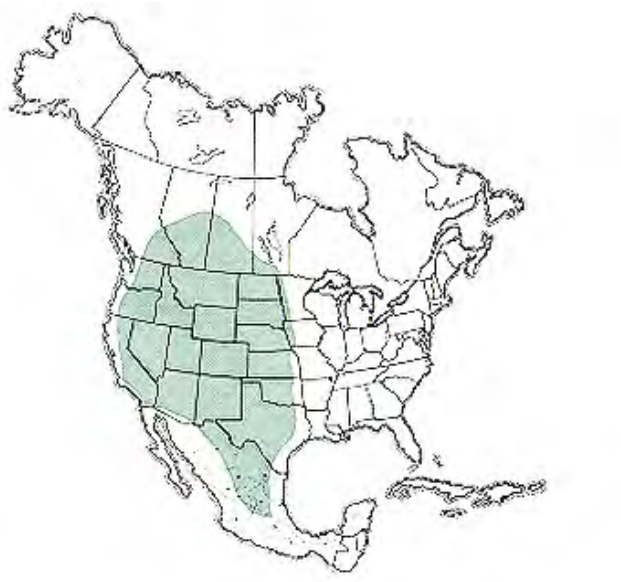
Distribution and Habitat

The bigheaded grasshopper, Aulocara elliotti (Thomas), distributed widely in western North America, inhabits a variety of grasslands from southern Canada to central Mexico. Large populations develop in the desert, mixedgrass, shortgrass, and bunchgrass prairies.

Economic Importance

The bigheaded grasshopper is a serious pest of grasses. It is often the dominant species in outbreaks on rangeland. Survey records reveal that it may reach densities of 20 per square yard in the mixedgrass prairie and 40 per square yard in desert grassland. Such high densities destroy the value of rangeland for grazing of livestock and may even lay the land bare, opening it to wind and water erosion. More often, the bigheaded grasshopper is destructive at lesser densities as a dominant member of an assemblage of species. Although medium sized for a grasshopper, it is one of the largest of the graminivorous species. Live weights of females inhabiting the mixed-grass prairie range from 285 to 663 mg (average 476 mg) and of males 131 to 230 mg (average 189 mg). Dry weights of females average 144 mg and of males 52 mg. In the desert grasslands of Arizona the bigheaded grasshopper grows even larger.

This grasshopper not only reduces grass forage by consuming it but also by cutting it down. The cut grass may become litter but it may also be used for food by grasshoppers including the bigheaded grasshopper and by other insects that feed on the ground. Field cage tests run in Montana and in Wyoming have demonstrated that the feeding activity of one bigheaded grasshopper per square yard reduces grass forage equal to 20 pounds dry weight per acre. In this area of the mixedgrass prairie, annual forage production averages 600 pounds dry weight per acre.



Geographic range of *Aulocara elliotti* (Thomas)

Food Habits

The bigheaded grasshopper feeds mainly on the green leaves of grasses and sedges. It often attacks a plant by climbing a blade, turning around head down, and chewing into the leaf at various distances from the tip. The grasshopper frequently cuts the leaf, which drops to the ground. The insect may then continue to feed on the attached section of the leaf. The bigheaded grasshopper also feeds on ground litter - cut grass leaves (green or dry), seeds, bran, and even dead grasshoppers. It searches these out while crawling about on bare ground.

Microscopic examinations of crop contents of older nymphs and adults show that the majority of crops contain fragments of more than one plant species (average 2.2). Although these determinations indicate that the bigheaded grasshopper is obtaining a mixed diet, one species of plant is most abundant in a crop. Depending on availability, the bigheaded grasshopper grazes heavily on blue grama, western wheatgrass, needleandthread, thread-leaf sedge, and needleleaf sedge. Crested wheatgrass, an introduced forage plant, is a preferred and nutritious host. From direct observations and crop examinations, this grasshopper is known to feed on two species of sedges and 22 species of grasses.

Migration and Dispersal

With fully developed wings, adults of the bigheaded grasshopper are able to fly evasively, to disperse, and to migrate. Flushed by an intruder, the adults fly straight, silently, low (4 to 12 inches), and short distances (2 to 7 feet). Evasive flights may be with the wind, into the wind, or across the wind.

Although no specific investigations of dispersal and migration of the bigheaded grasshopper have been made, evidence of long distance movements has been found incidental to other studies. At two locations, one in Arizona and one in Wyoming, sites that were found with no or few bigheaded grasshoppers at one sampling date had high densities of adults a few days later. Migrants in Arizona have been recorded as traveling

Instar 1

1. BL 5-6.3 mm FL 3.3-3.6 mm AS 14.

Instar 2

2. BL 6.6-9.8 mm FL 4.5-5.3 mm AS 18-19.

Instar 3

3. BL 9.8-12.2 mm FL 6.3-7.2 mm AS 20-21.

Instar 4

4. BL 12.5-16 mm FL 8.3-9 mm AS 22-23.

Instar 5

5. BL 14.5-19.5 mm FL 9.5-11.1 mm AS 22-25.

Figures 1-5. Appearance of the five nymphal instars of *A. elliotti* - their sizes, structures, and color patterns. Note the progressive development of the wing pads. BL = body length, FL = hind femur length, AS = antennal segments number.

distances of one to seven miles. Evidence of mass migration by the bigheaded grasshopper is provided by the recent discovery of large numbers of adults preserved on the ice of Grasshopper Glacier in the Crazy Mountains of Montana. Presumably swarms of the bigheaded grasshopper arose from areas of the mixedgrass prairie lying northeast of the mountains at lower altitudes, where outbreaks occur repeatedly.

Identification

Adults of the bigheaded grasshopper are of medium size and usually colored gray with fuscous markings. They possess relatively large heads with slightly slanted faces and have spotted forewings that extend slightly beyond the abdomen. The disk of the pronotum is distinctively marked by light lines that give the appearance of an “X”; several other patterns, however, exist in every population (Fig. 8). The hind femur has two black bars on the upper part of medial area; bars continue on upper marginal area, and around onto inner medial area; the knee is black. The hind tibia is medium blue. The male (Fig. 6) is smaller than the female (Fig. 7).

The nymphs (Fig. 1-5) are identifiable by their color patterns, structures, and shape:

(1) Head with lateral foveolae triangular and visible in dorsal view; antennae filiform but flattened; face moderately slanted.

(2) Pronotum with disk patterns like the adults, chiefly with light lines in form of an “X.”

(3) Hind femur with two dark bars on upper part of medial area and four to seven dark spots on lower carinula. Hind tibia blue with three dark annuli.

(4) Color drab gray and tan with fuscous markings.

A. elliotti nymphs can be separated from *A. femoratum* nymphs mainly through differences in coloration. Adult females of *A. elliotti* and *A. femoratum* are distinguishable by the shape of the posterior margin of the eighth abdominal sternum. In *A. elliotti* the posterior margin is without deep clefts (Fig. 9); in *A. femoratum* the posterior margin has two deep clefts.

Figures 6-10. Appearance of the adult male and female of *A. elliotti*, diagnostic characters, and the egg pod and several eggs shown in situs in the opened pod.

Hatching

The bigheaded grasshopper is an early-hatching species. Eggs begin embryonic growth in the summer of deposition and continue until they attain 50 percent of development (stage 19 embryo). Because the eggs are laid in early summer and at a shallow depth (average depth three-eighths inch), they are exposed to warm temperatures and most reach the advanced stage before they diapause. Eggs are able to survive desiccation during drought periods of summer and fall, but predators - birds, rodents, beetles, bee flies, and others - take a large toll. Due to predation, density of eggs decreases 54 percent between fall and spring.

Exposed to low soil temperatures, eggs break diapause during winter. In the laboratory eggs held at 37° to 41°F break diapause in 80 days. With warming spring temperatures, the soil temperature rising to 50°F and above, the eggs resume embryonic development. They complete the process after exposure to 450 day-degrees (base 50°F) of heat and are ready to hatch. Emergence of the first instars occurs in mid-spring mainly during morning hours, and especially when the temperature is rising rapidly and the soil is moist. Eggs of a particular pod hatch in succession within seconds of each other. On the surface of the soil the young grasshopper squirms to free itself from the embryonic membrane. It usually takes six to eight minutes to complete this process and crawl away. During this time the young grasshopper is vulnerable to predation by ants.

Nymphal Development

Nymphs emerge in mid-spring over a period of three to four weeks. They feed and develop in the same area as they hatch. Nurtured by warm spring weather and nutritious green grass, they complete nymphal development in 36 to 42 days. The males, usually with only four instars, reach the adult stage sooner than the females with five instars.

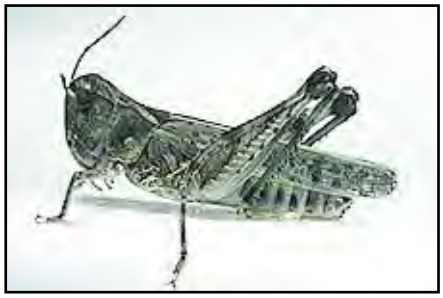
Adults and Reproduction

Adults of the bigheaded grasshopper may disperse to new habitats, but most often they remain in the same area where the nymphs hatched and developed. There they feed, mature, reproduce, and eventually are eaten by a predator or die from other causes.

Male

6. BL 17-20 mm FL 9.5-11.3 mm AS 23-24.

Female



7. BL 20.5-22 mm FL 12.3-14.3 mm AS 24-25.

Patterns

8. Dorsal view, pattern variations of pronotal disk.

Sternum

9. Ventral view, shape of eighth abdominal sternum.

Egg Pods

10. Two egg pods, one opened to show eggs.

Female adults become receptive to mating when they are six to eight days old. Pair formation and courtship consists primarily of visual cues. Normally the male makes a quick approach to the female and silently dis-plays himself by tipping the hind femora and waving the antennae. Once the male mounts and succeeds in making genital contact, copulation lasts 40 to 70 minutes.

Females deposit their first group of eggs when they are 12 to 20 days old (average 15 days). When ready to lay eggs a female will select one of the many bare areas in her habitat and work her ovipositor into the soil. She then deposits in the top one-half inch of soil seven to nine eggs, which become enclosed in a tough pod. Immediately after ovipositing a female spends a minute actively sweeping soil particles over the hole left by the extraction of her ovipositor. She performs this final act of maternal care with her hindlegs using the tarsi as brushes.

Fecundity of the bigheaded grasshopper is less than that of the migratory grasshopper. When pairs were reared individually in field cages and fed leaves of western wheatgrass, females lived an average of 72 days and produced 76 eggs per female. When they were fed wheat leaves, females lived an average of 87 days and produced 116 eggs. The greatest reproduction - 161 eggs - was achieved by a female fed wheat leaves. Unprotected from predators in their natural habitat, individuals have a shorter life and lower fecundity. Under natural conditions, research suggests an average adult longevity of approximately 20 days and a fecundity of 15 eggs per female. There is one generation annually.

The pod is slightly curved, one-half to five-eighths inch long and three-sixteenths inch in diameter (Fig. 10). The pod cap has a short nipple in the center. Eggs are pale yellow and 5.2 to 5.5 mm long.

Population Ecology

Populations of the bigheaded grasshopper irrupt frequently in the mixedgrass and desert prairies. Populations may increase gradually, doubling their numbers each year for a period of three or four years. Then in one year they may increase their densities by three or four fold precipitating an outbreak. Several hypotheses have been proposed to explain these outbreaks - increase in physiological vigor of the grasshopper, changes in nutritive composition of the vegetation, and environmental release (favorable weather and fewer enemies). Scientists doing research on population ecology have yet to gather enough data to make firm conclusions on the causes of these outbreaks.

Once the bigheaded grasshopper has reached an outbreak condition, the population may continue at high densities for five or more years. For generally unknown reasons, populations eventually decline or crash. In a few cases, however, causes are apparent. Naturally occurring diseases such as Nosema may decimate populations, and insecticidal control can reduce densities much below the economic level.

Daily Activity

The bigheaded grasshopper is a ground-loving insect whose activities are influenced greatly by temperature and light. Individuals rest on the ground at night. One to two hours after sunrise they begin basking by resting perpendicular to the rays of the sun (side exposed to sun), lowering the associated flexed hindleg to expose more of the abdomen, and hugging the ground surface. They bask for about an hour, then around 70°F air and 95°F soil surface temperatures, the adults begin their normal activities of pottering (intermittent wandering with frequent changes in direction), feeding, mating, and egg laying. Activity slows when air temperatures rise to 90°F and soil temperatures to 120°F. First, they may stilt by raising up on their legs and holding their bodies off the hot ground. As temperatures rise they leave the bare ground and move into shade of small shrubs. There they rest quietly on the bare soil or litter. When temperatures decline in the afternoon, they again take up normal activities. Two to three hours before sunset they begin basking once more on the ground surface. After sunset they remain on the ground without cover through the night.

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Whitecrossed Grasshopper

Aulocara femoratum Scudder

Distribution and Habitat

The whitecrossed grasshopper is an inhabitant of western grasslands. Although widely spread, its distribution includes only 60 percent of that of its congener, the bigheaded grasshopper, *Aulocara elliotti*. The whitecrossed grasshopper occurs most frequently in vegetation types of the mixedgrass prairie in which the mid grasses, western wheatgrass and needleandthread, are abundant as well as the short grass, blue grama. The species also occurs in the bunchgrass, shortgrass, and desert prairies, but no descriptions of specific habitats in these prairies have been published.

Economic Importance

Because the whitecrossed grasshopper feeds on valuable forage grasses and increases to high densities in certain habitats of the mixedgrass prairie, it is occasionally an important pest species. It is usually a subdominant member of an outbreak assemblage in which *A. elliotti* is often the dominant species, but it may also become the dominant species with densities as high as 13 adults per square yard. The whitecrossed grasshopper is slightly smaller than *A. elliotti*. Live weight of males from the mixedgrass prairie of eastern Wyoming averages 141 mg and females 460 mg (average dry weight of males 42 mg, females 137 mg). It is a less injurious species than *A. elliotti* because of its smaller size, lower densities, less frequent occurrence, and thriftier feeding habits (i.e., little clipping of grass leaves).

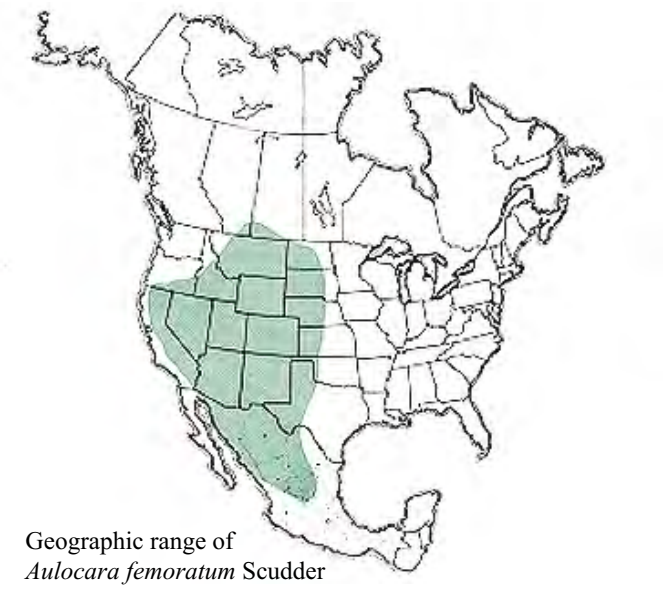
Food Habits

The whitecrossed grasshopper is a general grass feeder. Examination of crop contents of late instars and adults inhabiting a site in the mixedgrass prairie of eastern Wyoming revealed that all eight species of the perennial grasses and sedges growing at the site had been exploited for food (Table 1). Only the senescent annual grasses, such as downy brome, were lacking in the crop contents. The greatest utilization was made of western wheatgrass and needleleaf sedge. This study also revealed a remarkable difference in the diets of adult males and females. The males ingested much larger amounts of short grasses and sedge, while the females ingested more of the mid grasses. These results appear to be due to differences in behavior. The males walk extensively on the ground, presumably to find and court females, and thereby make contact with short grasses more often than the females, which are more sedentary and usually climb mid grasses close by in order to feed.

The majority of crops contained two to three species of grasses and sedge, but a relatively large number contained only one species. Of 22 male crops, nine were found to contain only sedge and one only western wheatgrass. Of 16 female crops, five were found to contain only western wheatgrass and one only sedge.

Examination of crop contents of the whitecrossed grasshopper collected in desert prairie of southwest Texas revealed that buffalograss and blue grama were the main host plants. Other grasses found in the crops were burrograss, fall witchgrass, sideoats grama, hairy grama, and Sporobolus sp.

Direct observations have been made of feeding by the late instars and adults on several species of plants: western wheatgrass, needleandthread, blue grama, prairie junegrass, and needleleaf sedge. The usual method of attack is for grasshoppers to climb a mid grass, turn around head down, and feed on an edge leaving a narrow opposite edge standing as they progress toward the base. On blue grama they may turn around without climbing, because of its shortness, and feed toward the leaf base. They may also feed from a horizontal position on the grazed end of a leaf or stem, ingesting the whole width as they consume it to the base. Infrequently, grasshoppers have been observed to feed on dry fallen grass and on dry cow dung from a horizontal position. The whitecrossed grasshopper feeds on bran bait.



Geographic range of *Aulocara femoratum* Scudder

Dispersal and Migration

In spite of their relatively short wings, whitecrossed grasshoppers have the capacity to fly and disperse. In flushed flight they cover distances of 2 to 6 feet at heights of 4 to 10 inches. The flight is silent and straight with the grasshopper facing away from the intruder upon landing. Evidence for dispersal is the discovery of an “accidental” in a mountain site (altitude 8,500 feet) approximately 10 miles west of the closest resident site (altitude 5,450 feet) near Boulder, Colorado.

Identification

The whitecrossed grasshopper (Fig. 6 and 7) is a medium-sized species with a general appearance similar to *A. elliotti*. The head is noticeably large; most individuals have a dark vertical streak above the front articulation of the

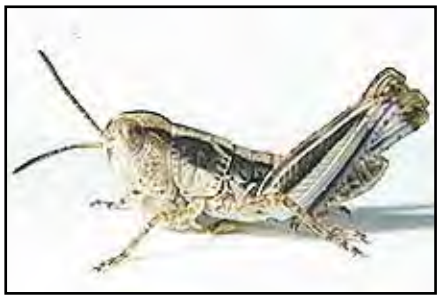
Instar 1

1. BL 6-6.8 mm FL 3.2-3.8 mm AS 13.

Instar 2

2. BL 6.8-8.6 mm FL 4.6-5 mm AS 16-17.

Instar 3

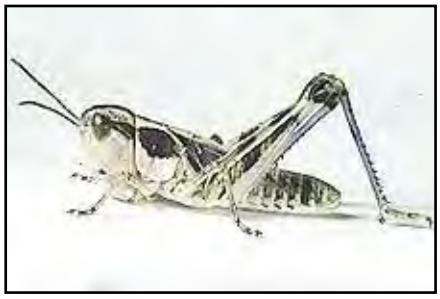


3. BL 9.1-9.9 mm FL 6.1-6.6 mm AS 20-21.

Female Instar 4

4. Males: BL 13-15 mm FL 7.8-8.3 mm AS 22-23.
Females: BL 11.9-15 mm FL 8.4-8.6 mm AS 22-23.

Female Instar 5



5. Females: BL 15-18.6 mm FL 10.5-11.5 mm AS 24.

Figures 1-5. Appearance of the nymphal instars of *Aulocara femoratum* - their sizes, structures, and color patterns. Notice progressive development of the wing pads. BL = body length, FL = hind femur length, AS = antennal segments number

mandible (short distance below the compound eye). The disk of the pronotum is dark and marked by light lines forming an X-like figure.

The wings usually do not reach the end of the abdomen; rare individuals have wings that extend past the abdomen. The posterior margin of the eighth abdominal sternum of the females has two deep clefts (Fig. 9), which is easily distinguishable from the eighth abdominal sternum of *Aulocara elliotti*. The hind femur is cream and conspicuously marked by three dark bands; the hind tibia is blue.

The nymphs (Fig. 1-5) are identifiable by their color patterns, structures, and shape.

1. Head with face moderately slanting; lateral feveolae quadrilateral, visible from above; antennae filiform; dorsum of head light tan, with fuscous middle band divided by narrow light tan stripe.
2. Pronotum with disk chiefly solid light tan in instars I to III, X-figure visible and fuscous triangle on each side of posterior area of disk in instars IV and V; lateral lobes fuscous dorsally and light tan or cream ventrally (Fig. 5).
3. Hind femur with fuscous dorsal stripe entire in instars I to III; broken or interrupted by light patches in instars IV and V; hind tibia of instars I and II two-toned gray, of instars III to V light blue.
4. Top of abdomen with light tan band continuing from disk of pronotum. Posterior margin of eighth abdominal sternum cleft in female instars IV and V, nearly as clear as in the adult female (Fig. 9).
5. General body color light tan or cream with highly contrasting fuscous markings.

Compared with nymphs of *A. elliotti*, the nymphs of the whitecrossed grasshopper are lighter colored with greater contrast between the background color and the fuscous markings. Nymphs of *A. elliotti* are mainly drab gray, which renders fuscous markings less contrasting.

Hatching

The whitecrossed grasshopper is an intermediate-hatching species. Emergence of first instars occurs 10 to 14 days after the appearance of A. elliotti in the habitat. In the mixedgrass prairie of Montana and Wyoming, hatching normally begins during the first week of June. The cause of the later hatch is due, at least partly, to the greater depth of whitecrossed grasshopper eggs in the soil relative to those of A. elliotti.

Nymphal Development

The nymphs emerge over a period of two weeks. They normally have plenty of green grasses available for food, and warm weather predominates during their development. The males have four nymphal instars and take a minimum of 30 days to become adults, while the females have five nymphal

Figures 6-10. Appearance of the adult male and female of *Aulocara femoratum*, color patterns of pronotal disk, eighth abdominal sternum showing deep clefts, egg pod and eggs.

instars and take a minimum of 42 days to become adults. Because the sizes at which males and females start out the nymphal stage are the same, the females require more developmental time and an additional instar to reach the female adult size, which is over threefold that of the male.

Adults and Reproduction

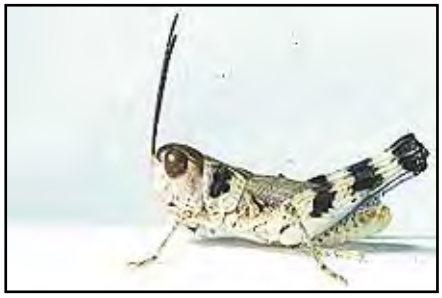
The adults remain in the same habitat in which the eggs hatched and the nymphs developed. In the mixedgrass prairie of Montana and Wyoming, the adult stage is reached during the first and second weeks of July. The males fledge first, and then the females. Upon maturing, the adults begin to mate and reproduce. Weekly observations in a mixedgrass prairie site (Goshen County, Wyoming T20N R60W Sec 3 NE) indicated that mating began three weeks after the fledging of females. During the morning hours the males chase after females, courting those that stop or are sitting quietly. The males court by movements of the hindlegs that resemble stridulation. Although sounds of stridulation have not been heard by human observers, female grasshoppers, which are within 2 inches of the source, may hear courtship signals or may visually detect movement of the hindlegs. No observation of successful engagement of the genitalia has been made. Pairs in copulo, however, have been seen during the morning as early as 10:30 a.m. and as late as 1:30 p.m., and attempts by the males to mate have been observed as late as 5:30 p.m. DST. For oviposition, a female selects a small (1 to 6 square inches), secluded, bare area surrounded by blue grama or other short grass, and faces into one of the plants. One observation of the entire process of oviposition, which took one hour, was made in a laboratory terrarium. The female selected bare ground and worked her abdomen into the soil to a depth of three-quarters inch. After extracting her ovipositor, she spent two minutes brushing soil and litter over the hole with her hind tarsi, and then she walked away. In nature, pods lie in the soil with the long axis oriented vertically and are inserted one-eighth inch below the ground surface and to a depth of three-quarters inch. The pods are nine-sixteenths to ten-sixteenths inch long and one-quarter inch in diameter (Fig. 10). The walls are unusually strong and thick. The cap is without a nipple (present in pods of *A. elliotti*). The egg mass, numbering 9 to 11 eggs, rests in the bottom half of the pod. The eggs are pale yellow and 4.7 to 5.2 mm long.

Overwintering of the species occurs in the egg stage; there is probably one generation annually. The fecundity of the whitecrossed grasshopper has not been studied.

Population Ecology

In the mixedgrass prairie, the whitecrossed grasshopper inhabits the more luxuriant vegetation types where there is a greater abundance of mid grasses such as western wheatgrass and needleandthread in addition to the dominant short grass, blue grama. Often associated with *A. elliotti* or *Metator pardalinus*, it is usually a subdominant member of a diverse assemblage of grasshoppers. As a subdominant it ranges in

Male



6. BL 15.1-17 mm FL 9.8-10.7 mm AS 24.

Female

7. BL 20-25 mm FL 12.2-14.6 mm AS 25.

Patterns

8. Variations of color patterns of pronotal disk.

Sternum

9. Shape of eighth abdominal sternum showing deep clefts.

Egg Pods

10. Two egg pods, one opened to show eggs.

density from 0.1 to 2 adults per square yard. It occasionally becomes the dominant species in Montana and Wyoming, ranging from 8 to 13 adults per square yard in assemblages of 20 to 25 per square yard. In a mixedgrass prairie site near Edgemont, South Dakota the species built up high numbers, reaching estimated densities of 10.5 late nymphs and adults per square yard in an assemblage of 21 grasshoppers per square yard.

It is of less frequent occurrence in mixedgrass prairie sites than *A. elliotti*. Of 278 sites surveyed in the mixedgrass prairie of Wyoming in 1990, five sites were inhabited by *A. femoratum* and 86 sites by *A. elliotti*. In 1991, of 419 sites surveyed, four sites were inhabited by *A. femoratum* and 47 sites by *A. elliotti*. The species appears to be more prevalent in Montana than in Wyoming. Of 38 study sites in the mixedgrass prairie of Montana, it inhabited nine sites and was dominant in two of these.

A three-year study (1949-51) of rangeland grasshopper populations in Montana revealed that the whitecrossed grasshopper can increase from low to high densities in one year, and then fall as suddenly the next year.

Daily Activities

The whitecrossed grasshopper is a geophilous insect spending most of the day and all of the night on the ground. At night both nymphs and adults rest on bare areas of 1 to 10 square inches interspersed among the grassy vegetation. They do not seek shelter under a canopy of vegetation, but are surrounded closely by the dominant short grasses and sedges. Environmental temperatures decline during the night and by early morning, before sunrise, reach lows around 60°F. Under these relatively cold conditions, the grasshoppers are immobile. About two hours after sunrise when the rays of the sun strike the grasshoppers on the ground, they stir and turn a side perpendicular to the rays and usually lower the associated hindleg to expose the abdomen. During this period they are mainly quiescent, but occasionally they walk to another location, turn around to expose the other side, or they may preen their antennae or compound eyes with the front tarsi. During the basking period, soil surface temperatures range from 60° to 90°F and air temperatures at the 1-inch level from 61° to 82°F. After their body temperatures rise to some preferred level, they become active and begin to walk, feed, court, and mate. The morning period of activity lasts for about two hours. Increasing temperatures cause activities to slow down and finally the grasshoppers are compelled to take protective measures. Several behavioral responses keep their body temperatures within tolerable levels. First, they may "stilt," raising up on their legs to hold their bodies off the hot soil surface. They may use all three pairs of legs, or they may use only the first two and raise the flexed hindlegs from contact with the soil. As temperatures rise still further, they may crawl onto a short grass or sedge and rest diagonally facing the sun. In this position they expose the least body surface to the rays of the sun and are 1 inch above the ground and away from hot, bare areas. They also may climb stems of mid grasses, such as western wheatgrass, to heights of 2 to 7 inches. Less often, they crawl into the shade of vegetation.

When temperatures decline in the afternoon, the grasshoppers again become active and when temperatures drop further, they bask. Finally, as the sun begins to set and shadows engulf the habitat, the grasshoppers take their nighttime positions on the ground or litter.

Table 1. Mean percent dry weight of plant fragments in crops of late nymphal and adult *Aulocara femoratum* collected during late morning in the mixedgrass prairie (Wyoming, Goshen County, T20N R60W Sec 3 NE).

	Mean percent dry weight food fragments		
Food Plant	**Instars IV & V**	**Adult males**	**Adult females**
needleleaf sedge	40	37	20
western wheatgrass	32	9	53
needleandthread	17	11	12
blue grama	4	23	1
buffalograss	1	19	9
red theeawn	5	0	0
Sandberg bluegrass	1	0	0
green needlegrass	0	0	5
number crops examined	23	22	16

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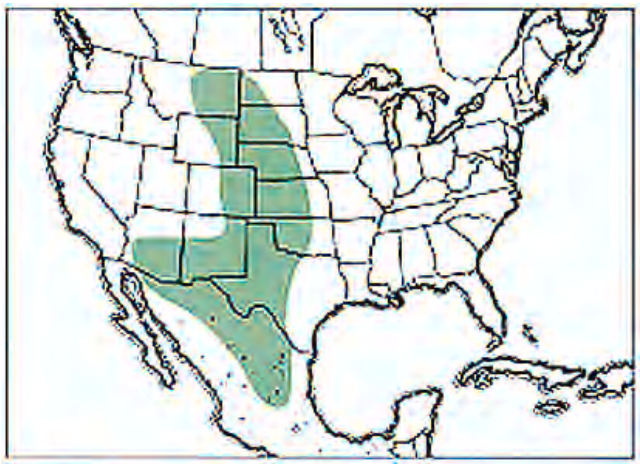
Ebony Grasshopper

Boopedon nubilum (Say)

Distribution and Habitat

The ebony grasshopper ranges widely in the grasslands of the West from Montana to Mexico. The species lives in several types of grasslands including the mixedgrass, shortgrass, sand, and desert prairies, preferring to occupy the more luxuriant stands of these habitats.



Geographic range of *Boopedon nubilum* (Say)

Economic Importance

The ebony grasshopper at high densities can be a pest of rangeland forage. Injurious infestations usually consist of an assemblage of grasshoppers in which the ebony grasshopper is one of several abundant species. Irruptions of the ebony grasshopper occur most often in the southern mixedgrass and desert prairies and may last for several consecutive years. The affected region includes the states of Arizona and New Mexico and western Kansas, Oklahoma, and Texas.

In 1955 a severe outbreak of grasshoppers occurred on rangeland of western Oklahoma in which four species were dominant: *Ageneotettix deorum*, *Aulocara elliotti*, *Boopedon nubilum*, and *Phlibostroma quadrimaculatum*. Rangeland grasshoppers became abundant again in 1973-79 on 1.5 million acres of prairie in western Oklahoma in which the ebony grasshopper was again a prominent member of the assemblage.

In 1956 an irruption occurred on the desert prairie of San Rafael Valley, Arizona. The assemblage of grasshoppers numbered 46 young adults per square yard and consisted of five principal species. Density of young adults per square yard were estimated to be 13.4 *Boopedon flaviventris*, 4.2 *Boopedon nubilum*, 4.6 *Phlibostroma quadrimaculatum*, 2.6 *Trachyrhachys kiowa*, 19 *Melanoplus lakinus*, and 2.6 *Melanoplus* spp. The loss of grass forage due to the whole assemblage of grasshoppers amounted to an estimated 600 lb dry weight per acre. In Arizona the ebony grasshopper has been found also in cultivated areas of corn, sorghum, and wheat.

The ebony grasshopper is a large species. Live weight of young males collected in bunchgrass prairie of northcentral Wyoming averaged 580 mg and of young females 1,452 mg.

Food Habits

The ebony grasshoopper is a fastidious grass feeder. In the desert prairie of southwestern Texas, ebony grasshoppers have been found to consume large amounts of blue grama. Examination of crops of adults revealed that contents consisted of 57 percent blue grama, 17 percent buffalograss, 9 percent common fallwitchgrass, 8 percent bristlegrass, 6 percent common burrograss, and 3 percent hairy grama. From pastures of the Nebraska North Platte Agricultural Experiment Station, a huge number of crops (1,379) were examined to disclose a 72 percent preponderance of western wheatgrass fragments. Other grasses detected in the crops were: needleandthread, 7 percent; blue grama, 5 percent; sand dropseed, 4 percent; prairie sandreed, 4 percent; threadleaf sedge, 3 percent; and witchgrass, 1 percent.

More discriminating than most grass-feeding grasshoppers, ebony grasshoppers in two-choice tests showed decided preferences for certain species of grasses and refused others. Young adults collected from a bunchgrass prairie site 1 mile east of Shell, Wyoming preferred the leaves of blue grama, needleandthread, downy brome, and young wheat. When these plants were available in two-choice tests, the grasshoppers refused to feed on western wheatgrass, crested wheatgrass, Kentucky bluegrass, and foxtail barley. Paired with young wheat (variety Buckskin), the grasshoppers ate less than 5 percent of young cultivated barley (variety Klages). The observation that this grasshopper fed heavily on western wheatgrass in central Nebraska but refused it in food preference tests in Wyoming is perplexing.

Observation of feeding by three instar V females in the Shell, Wyoming site revealed that they climbed an inch or two onto the grass leaf, bit through the leaf, held onto the cut section with the front tarsi, and consumed it entirely. While feeding, the nymph was vertical, head-up on the leaf, but one nymph turned around, head-down, and fed close to the leaf base. The ebony grasshopper was not observed to clip and waste leaves.

Dispersal and Migration

Wings of the male ebony grasshopper are long and functional but the female's are usually short and flightless. In spite of the female's lack of ability to fly,

Instar 1

1. BL 6.4-8.1 mm FL 3.7-4.4 mm AS 13-14.

Instar 2

2. BL 9-11 mm FL 5.3-6.8 mm AS 16-17.

Instar 3

3. BL 11-15 mm FL 9 mm AS 19-21.

Instar 4

4. BL 12-24 mm FL 8.4-11.8 mm AS 21-23.

Instar 5

5. BL 17.8-29 mm FL 10.4-14.5 mm AS 23-25.

Figures 1-5. Appearance of the five nymphal instars of *Boopedon nubilum* - their sizes, structures, and color patterns. Notice progressive development of the wing pads. BL = body length, FL = hind femur length, AS = antennal segments number.

whole populations can disperse or migrate by walking. Displacements of late instars and adults were observed in San Rafael Valley, Arizona in 1956, 1965, and 1966. In the wet season of 1966 the grasshoppers carried out a gradual dispersal, but after denuding their habitat in the dry seasons of 1956 and 1965, they rapidly migrated across low hills to other sources of forage.

A small percentage of females possess long wings that may surpass the tip of the abdomen. Presumably these females are capable of flight. Flying females would account for the widespread occurrence of the species. Males have already been found to disperse long distances. An “accidental” male was captured July 1959, 8 miles west of a pasture north of Boulder, Colorado harboring a resident population. Flushed flight of the males is swift and strong. They fly straight and silently at heights of approximately 12 inches and for distances of 6 to 9 feet.

Identification

The male (Fig.7) is a strikingly black grasshopper with functional wings (Fig. 9). The disk of the hind wing is pale blue and the apical area black. The hind tibia may be entirely black or multi-colored, and either black and red, or cream, black, and red. The female is a large, pale brown grasshopper with short, nonfunctional wings (Fig. 8). A small percentage of females may possess long wings. The sulci of lateral lobes of females are black as are the crescents of the hind knees. A few females of each population are dark brown or black.

The nymphs are identifiable by their shape, structures, and color patterns (Fig. 1-6).

1. Head large with face moderately slanted; face tan, side of the head black, triangular black spot above base of each antenna, top of head tan.
2. Pronotum without lateral carinae but position indicated by light lines; lateral lobe with inverted black trianglular marking, upper side 2/3 or less width of lobe, lateral sides straight, not incurved.
3. Hind femur with dorsal stripe of medial area nearly solid black; tibia with three rings of pale yellow and three rings of black, sometimes tinged with red.
4. Dorsum with a wide tan band; venter is pale yellow.

Figures 6-10. Appearance of the black female fifth instar, adult male, adult female, detached wings of male, and egg pod and loose eggs.

Hatching

The ebony grasshopper is a late-hatching species. In the mixedgrass prairie of eastern Colorado and western Kansas, the eggs begin to hatch the last of May or the first half of June, about two to three weeks after *Melanoplus sanguinipes*. In Larimer County, Colorado, at an altitude of 5,200 feet, hatching began 22 June 1993. In the San Rafael Valley of Arizona (elevation 5,000 feet) hatching did not begin until 22 July 1965, about ten days after 1.24 inches of rain fell, providing the eggs with a good wetting, and in 1966 July 28 ten days after 1.67 inches of rain fell. In Arizona the ebony grasshopper is classified as a summer-developing grasshopper along with several other species that delay hatching until rains soak the eggs thoroughly.

Nymphal Development

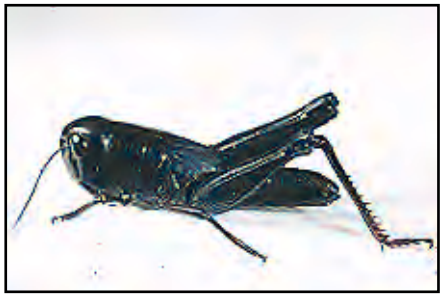
Nymphs of the ebony grasshopper develop through five instars. In 1993 in the mixedgrass prairie of eastern Colorado, the nymphal period took a minimum of 40 days. In the San Rafael Valley, Arizona ebony nymphs completed development in only 27 days in 1965 and 31 days in 1966.

Adults and Reproduction

Adult ebony grasshoppers usually remain in the same habitat in which they develop as nymphs. Apparently preferring thick stands of mixedgrass prairie for habitation and an abundance of green grass for food, they are not prone to wander or disperse unless food shortages occur. In mixedgrass prairie of Larimer County, Colorado, the adults begin to emerge from mid to late July. In this study site five adult males and three adult females, in addition to 57 nymphs, were captured on 15 July 1987, while on 31 July 1993 only one adult female and three nymphs were captured. The appearance of adults is delayed in the San Rafael Valley because of the late hatch. The nymphs, however, develop rapidly and in 1965, adults appeared by 18 August.

Only a few isolated facts are known about the maturation of adults. An examination of the ovaries of 20 females revealed eggs present 21 days after the adults began to appear in the San Rafael Valley. Collected from bunchgrass prairie in northcentral Wyoming, a female fifth instar and two male adults were caged, fed young wheat leaves (Buckskin), and allowed to reproduce. The female laid a pod of 44 eggs by the age of 40 days. During her adult lifetime of 62 days, she produced three pods for a total of

Instar 5



6. Black female nymph, instar V.

Male

7. BL 22-22.5 mm FL 15 mm AS 24-25.

Female

8. BL 36-38 mm FL 19.5-21 mm AS 25-26.

Wings

9. Detached wings of male.

Egg pod

10. Egg pod and several loose eggs.

134 eggs. Females caged in San Rafael Valley produced multiple pods that contained from 38 to 62 eggs each.

Females in San Rafael Valley have been observed to deposit pods in bare soil between clumps of grass and sod during summer and autumn. The eggs overwinter and hatch the following summer. The pods are large, 1 7/8 to 2 inches long and 3/16 to 1/4 inch in diameter. The dark brown eggs are 6.5 to 7.7 mm long. Covered by secretions of the female, the lower section of the pod is dark brown (Fig. 10).

Population Ecology

The ebony grasshopper inhabits western grasslands in company with several other rangeland grasshoppers. Its widespread distribution places many populations in dissimilar environments and under different environmental stresses. In southern Arizona, drought and parasites cause significant mortality. A ten-year study (1956-1965) of the population ecology of the ebony grasshopper disclosed significant annual fluctuations in density (Table 1). Six out of ten years the population was depressed apparently by heavy burdens of the parasite *Neorhynchocephalus sackenii*. This dipterous larval parasite feeds on the internal organs of the grasshopper, preventing the female from developing eggs and eventually killing its host. Application of insecticide caused the drastic reduction of density in 1956.

Table 1. Population density of the ebony grasshopper on rangeland of San Rafael Valley, Arizona (Adapted from Nerney and Hamilton)

Year	No/sq yd	Percent parasitized by *Neorhynchoecephalus sackenii*
1956	4.20	21
1957	.09	17
1958	.08	23
1959	.05	0
1960	.13	0
1961	.28	0
1962	.62	0
1963	2.96	17
1964	2.11	40
1965	.48	33

The ebony grasshopper is normally subdominant numerically in an assemblage of rangeland grasshoppers. Smaller species are usually more numerous, such as *Ageneotettix deorum*, *Opeia obscura*, *Amphitornus coloradus*, and *Aulocara elliotti*. Because of the large size of the ebony grasshopper, it may, however, exceed the total biomass of a smaller species.

One record of the ebony grasshopper being numerically dominant occurred in 1995 in an assemblage inhabiting the bunchgrass prairie of northcentral Wyoming. Four species of the assemblage were estimated to have the following densities of young adults per square yard: *B. nubilum*, 5.2; *Aulocara femoratum*, 1.2; *Ageneotettix deorum*, 0.4; and *Melanoplus occidentalis*, 0.2.

Daily Activities

In its northern range, the ebony grasshopper takes shelter at night in canopies of grasses and low shrubs. Shortly after sunrise, individuals emerge and begin to bask. They turn a side perpendicular to the sun but have not been seen to lower the associated hindleg to expose more of the abdomen as do many other species of grasshoppers. Basking may continue for two hours after which late nymphal females do much stirring, preening of the compound eyes, vibrating of the hindlegs, and intermittent walking with distances ranging from 2 to 12 inches. When soil temperatures rise to 90°F and air to 80°F, at about 9 a.m. DST, the grasshoppers take evasive action. They may remain on the ground and face directly into or away from the sun or they may seek the shade of vegetation by crawling into clumps of grass or into the canopy of small shrubs. Feeding has been observed only three times and only in the evening from 5:30 to 6:30 p.m. Because the female nymphs were close to molting to the adult stage, they probably were not feeding with normal duration and frequency. Shortly before sunset the grasshoppers enter shelters for the night.

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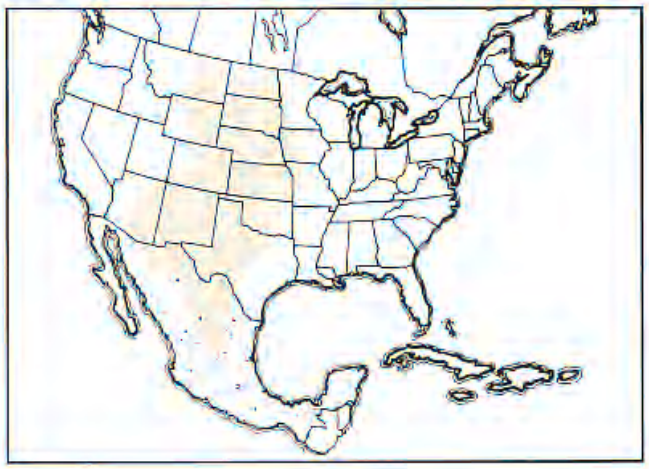
Plains Lubber Grasshopper

Brachystola magna (Girard)

Distribution and Habitat

The plains lubber grasshopper ranges widely on the western plains of the United States and Mexico. It inhabits several types of prairies: shortgrass, mixedgrass, tallgrass, sand, and desert prairies. In these diverse habitats it depends on the presence of certain forbs for its sustenance. It locates patches of host plants along roadsides, field margins, and disturbed rangeland. Patches of common sunflower, *Helianthus annuus*, are especially attractive to this grasshopper.



Geographic range of *Brachystola magna* (Girard)

Economic Importance

In its favored habitat, patches of common sunflower and certain other forbs, the plains lubber grasshopper behaves as a beneficial insect by providing some measure of biological control of weeds. However, large populations inhabiting roadsides and field margins have invaded gardens in Iowa and cotton fields in western Oklahoma and the western plains of Texas. The plains lubber grasshopper can be extremely damaging to young cotton plants; outbreak numbers of adults have completely destroyed stands. They consume all of the foliage and leave only the stems. More often the damage has been limited to 40 or 50 marginal rows. Populations of one adult per 3 feet of row in cotton or two per square yard in vegetation bordering the field are capable of causing economic damage.

Considered an occasional pest of cotton, this grasshopper increased to damaging numbers in 1954, 1959, 1977, and 1979, during a period of 30 years (1951-1980) in Texas.

The plains lubber grasshopper is one of the largest acridids in North America. Collected in Bent County, Colorado from patches of common sunflower, fresh weight of four males averaged 3,935 mg and of five females 4,287 mg (dry weight males 1,188 mg, females 1,292 mg).

Food Habits

The plains lubber grasshopper is a polyphagous insect feeding on a variety of forbs and grasses. Examination of crop contents of 68 individuals collected in a weedy field near North Platte, Nebraska revealed fragments of 16 different species of forbs, four species of grasses, and numerous arthropod parts. The most frequent plants encountered were common sunflower, found in 35 percent of crops, and hoary vervain (*Verbena stricta*), found in 19 percent. Nineteen percent of crops contained arthropod parts. A moderate number of crops contained fragments of western wheatgrass (11 percent), kochia (9 percent), and prickly lettuce (9 percent). Two to 5 percent of crops contained fragments of scarlet globemallow, breadroot scurfpea, Missouri milkvetch, wavyleaf thistle, hoary puccoon, upright prairie coneflower, downy brome, cudweed sagewort, indianpaintbrush (*Castilleja sessiliflora*), horseweed fleabane (*Erigeron canadensis*), western sticktight, foothill bladderpod (*Lesquerella ludoviciana*), and low lupine (*Lupinus pusillus*). These diverse food plants represented nine plant families.

In southeastern Wyoming (Platte County along a gravel road in Whalen Canyon), nymphs and adults were observed to feed mainly on common sunflower. Young nymphs attacked seedling plants, which at the time of observation were 3 to 6 inches tall. To feed, the nymphs climbed the plant, adjusted their bodies, and fed at the edges of leaves, eating into the leaf and creating deep gouges. A third instar was observed to feed on the leaf of a 3-inch plant for three minutes. Later in the season, adults attacked the leaves, buds, and flowers of plants now 17 to 32 inches tall. Two adults (one a female, the other unsexed) were observed feeding into the sides and developing seeds of green heads. Each fed for 16 minutes before completing its meal.

Populations inhabiting two sites near Boulder, Colorado were associated with the sunflower, *Helianthus pumilus.* This leads one to suspect that among the 13 species of *Helianthus* distributed on the Great Plains, other members of the genus may serve as host plants and support isolated populations. A suspected host species is the prairie sunflower, *Helianthus petiolaris*, specimens of which were observed to have been defoliated by a small population of the plains lubber grasshopper inhabiting a roadside in Platte County, Wyoming.

A study of the foraging behavior of the plains lubber grasshopper in a southeastern Arizona site confirmed its highly polyphagus behavior. Adults were observed to feed on 21 species of plants belonging to 15 plant families. Feeding bouts were short with the majority lasting less than two minutes, indicating that few suitable food items were present. Preferred plants included *Boerhaavia coccinea*, *Hymenothrix wislizenii,* and *Gaura coccinea*, but feeding

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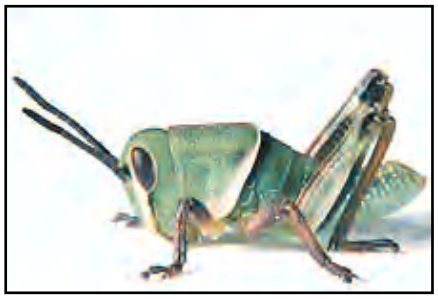


1. BL 9.5-12.5 mm FL4.6-5 mm AS 14-16.

Instar 2

2. BL 12-16.5 mm FL 6.4-7.6 mm AS 17-19.

Instar 3

3. BL 16-22 mm FL 8.2-10 mm AS 20.

Instar 4

4. BL 23-24 mm FL 12-13.5 mm AS 22.

Instar 5

5. BL 34.5-47 mm FL 16-19.5 mm AS 23.

Figures 1-5. Appearance of the five nymphal instars of *Brachystola magna* - their sizes, structures, and color patterns. Notice progressive development of the wing pads. BL = body length, FL = hind femur length, AS = antennal segments number.

bouts were also short on these plants. No common sunflowers were present at this site.

The research in Arizona disclosed a remarkable degree of omnivory and predation by the plains lubber grasshopper. A large part of the diet of 15 closely observed females consisted of animal matter. Foraging on the ground, the females ate incapacitated insects and even captured and ate smaller *melanopline* grasshoppers.

Laboratory food preference tests conducted in Texas revealed that the plains lubber grasshopper preferred common sunflower, western ragweed, and cotton seedlings. Two-choice tests conducted in Wyoming showed that dandelion, prairie sunflower, and annual sowthistle were also preferred food plants.

Dispersal and Migration

The plains lubber grasshopper disperses and migrates by crawling and hopping. Entomologists have frequently observed adults crossing highways and country roads. Just how fast and how far they travel have not been determined. It is known that from roadsides and field margins they invade fields of young cotton plants.

Brief observations of hopping behavior of adult females were made on a dirt road at the Guernsey, Wyoming, airport on the afternoon of 31 July 1998. At this time the sun was hidden by clouds, soil surface temperature was 93° F, air temperature 84° F, and an east wind of 4 to 9 mph was present. Unflushed hops of females measured 3 to 4 inches. Flushed hops of two females measured 14 inches each. No data on males were obtained; however, Ernest Tinkham, while studying the ecology of grasshoppers inhabiting the Trans-Pecos region of Texas, observed that male plains lubber grasshoppers could jump 9 feet in a single leap.

Identification

The plains lubber grasshopper is a large colorful species (Fig. 6 and 7). The robust adults are flightless possessing only short, round wings; the tegmina are pink and marked by conspicuous black dots that occasionally coalesce. The body is strikingly striped and banded green, brown, and pink. The disk of the pronotum is trapezoidal and surfaced with a dense number of small knobs and several short wrinkles (Fig. 8). The hindlegs are large and multicolored; the male's hind femora are noticeably larger than the female's (Fig. 9); outer side of tibia are pale gray or tan, other sides have hues of orange.

The nymphs are identifiable by their color patterns, shape, and external structures (Fig. 1-5).

Figures 6-10. Appearance of the adult male and female of *Brachystola magna*, hindlegs of both sexes, pronotum and egg pod and exposed eggs.

Male

6. BL 43-52 mm FL 24.5-26 mm AS 23.

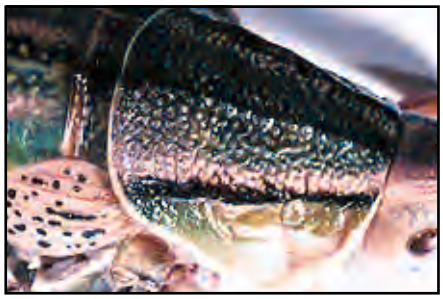
Female

7. BL 44.5-55 mm FL 21-24 mm AS 23-24.

Hindleg

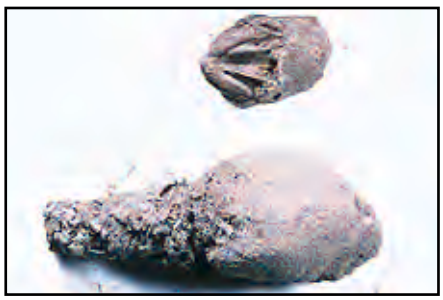
8. Inner face of female hindleg (top) and the larger male hindleg (bottom).

Pronotum



9. Colored stripes and knobs of pronotum.

Egg pod



10. Egg pod and exposed eggs.

1. Head green, tan, or fuscous; antennae filiform and chiefly black, each segment with distal ivory annulus, subocular groove black, instars I and II with vertical ivory bar in front of eye on each side of the frons; compound eyes dark brown.
2. Pronotum: disk and lateral lobes trapezoidal, median carina distinct, black, and entire (uncut), lateral carinae distinct, black and cut once in front of middle, disk banded pink and green with dense number of small knobs (Fig. 8); posterior margin of disk ivory, lateral lobes more or less margined with ivory. Mesonotum smooth and shiny black (see Fig. 1, instar I for exposed mesonotum), in subsequent instars the pronotum overgrows and hides the mesonotum. Metanotum knobbed and colored like rest of body. Hind femur patterned, hind tibia hues of orange in instars I to IV, orange or yellow in instar V.
3. Venter of body usually yellow, ivory, or gray.

Hatching

Phenologically, the plains lubber grasshopper belongs to the intermediate group of grasshopper species. Hatching has been observed to start in eastern Kansas in mid May, in northern Colorado and in Wyoming during the first week of June, and in Montana in mid June. In southeast Arizona hatching appears to be retarded until the summer monsoon rains first wet the soil. A fifth instar nymph collected 7 August 1982 in San Rafael Valley indicated that hatching occurred the first part of July.

Research of the USDA Grasshopper Laboratory has revealed that the eggs of this species require two years of incubation and overwintering before they hatch. In addition to the laboratory evidence, field observations in Montana, Wyoming, and Texas show higher populations in alternate years, which likewise indicate a two-year life cycle.

Nymphal Development

Nymphs of the plains lubber grasshopper develop through five instars. In nature the nymphal period of an individual lasts about 45 days. Reared in the laboratory and subjected daily to 87.8° F for 14 hours of light and 78.8° F for 10 hours of darkness, the nymphal stage lasted 27 days.

Adults and Reproduction

The adult stage of the plains lubber grasshopper is reached commonly in early summer, allowing an extended favorable time for reproduction. In eastern Kansas, adults first

appear during the last week of June, in northern Colorado the second week of July, in Wyoming the third week of July, and in Montana the fourth week of July. The start of egg laying in Montana has been observed to occur in mid August, indicating a maturation period of 23 days. In 1901 at Fort Collins, Colorado, the first adult appeared July 10, mating was observed July 22, and egg laying began August 1. Oviposition then continues for approximately 60 days until the end of September for surviving females. In milder climates some adults survive even longer. In northeast Kansas adults have been observed during the first week of November.

Little information is available on the site of oviposition, but it appears that females select bare, sandy loam areas in which to deposit their eggs. The pod is large, 1 3/4 to 2 inches long and 3/4 inch diameter in the region of the eggs. It is gourd-shaped (Fig. 10) and contains 20 to 35 large (length 10.1 to 10.8 mm) dark reddish brown eggs.

Population Ecology

The range of the plains lubber grasshopper is widespread in the West, but its distribution is patchy. Populations inhabit disturbed sites occupied by forbs, especially common sunflower, a native American plant. This plant often grows in roadsides and field margins providing favorable habitats for the grasshopper. Biennial populations fluctuate and occasionally reach outbreak proportions. A few reports indicate that one young adult per square yard may be rated as a high density equaling in biomass 11 young adults of *Melanoplus sanguinipes*. In Texas, outbreak populations bordering cotton fields may concentrate to 10 young adults per square yard. Attrition of adults occurs during the summer. This grasshopper has been shown to be an edible one for predators such as birds, rodents, and carnivores. A scat, probably of a swift fox, *Vulpes velox* (Say), collected 1 September 1993 from rangeland in Bent County, Colorado contained parts of the plains lubber grasshopper.

As no sustained study of this grasshopper has been made, we know little of its ecology-the factors that cause it to increase in density, the duration of an outbreak, and what factors may cause the decline or crash of an outbreak population.

Daily Activities

The plains lubber grasshopper occupying a patch of sunflowers spends much of each day resting, basking, and feeding on its host plant. Adults and late instars have been observed in the evening and early morning roosting vertically on the stems or sitting horizontally on leaves at heights of 8 to 41 inches. Basking of these grasshoppers occurs shortly after sunrise when rays of the sun strike their host plants. Turning their backs perpendicularly to the rays of the sun, the grasshoppers “dorsal bask.” A few individuals “flank bask” by exposing a side and lowering the associated hindleg. In a site near Guernsey, Wyoming, basking lasted approximately two hours. Some individuals were observed to bask on the ground.

After basking the grasshoppers adjust their orientation to the sun and for a short time rest quietly on the host plant. Later they stir and begin moving about the plant, feeding, and crawling down head-first to the ground. Mating has been observed to occur on the ground as well as oviposition. While on the ground the adults have been observed to disperse by crawling and to feed on injured grasshoppers. They appear to have a strong disposition to disperse through prairie vegetation traveling in one direction at a relatively rapid speed.

In summer, ground and air temperatures during the middle of the day often rise above the tolerance level of this grasshopper. Temperatures of 110° to 140° F of ground surface exposed to the sun and concomitant air temperatures of 93° to 100° F induce the adults on the ground to move to shade of vegetation or to crawl up 20 inches or higher on a host plant. Grasshoppers that have climbed common sunflowers take positions in the shade, or lacking adequate shade on a defoliated plant, they make a postural response in which they face the sun directly. The rays strike the front of the head while the rest of the body is shielded from the intense rays. On the ground this grasshopper has been observed to stilt, a behavior probably occurring early when temperatures first become excessive.

By late in the afternoon the majority of grasshoppers have returned to host plants, where they rest quietly, perched on main and secondary stems and on leaf surfaces. An odd exception was occasionally noticed in which the adult grasshopper hung onto the edge of a sunflower leaf with the fore and midlegs allowing the body and hindlegs to dangle beneath the leaf.

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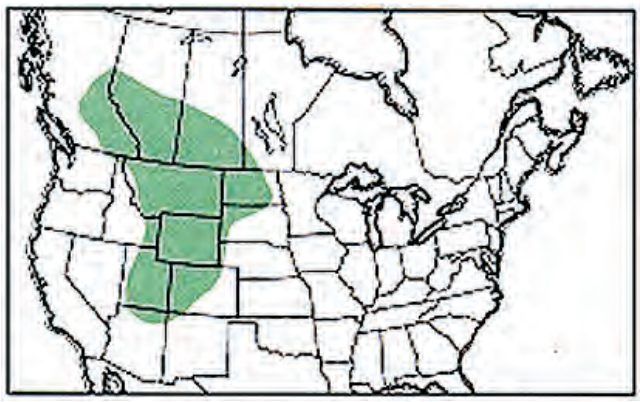
Bruner Slantfaced Grasshopper

Bruneria brunnea (Thomas)

Distribution and Habitat

The Bruner slantfaced grasshopper (also known as *Stenobothrus brunneus*) ranges widely in the hills and mountains of the northwestern United States. It lives in the mixedgrass and bunchgrass prairies, in mountain meadows and parklands, and in alpine tundra. In the northern mixedgrass prairie its distribution extends into eastern North Dakota and southwestern Manitoba, where populations are small and local on suitable hillsides. Altitudes of its known habitats range from 1,600 to 11,100 feet.



Geographic range of *Bruneria brunnea* (Thomas)

Economic Importance

When populations of the Bruner slantfaced grasshopper irrupt, the species becomes a serious pest of mountain and foothill grasslands. In 1920 its depradations were observed on rangelands of southeastern British Columbia. A dense infestation covering 2,000 square miles caused considerable damage to range grasses. The Bruner slantfaced grasshopper made up 50 percent of the assemblage, *Camnula pellucida* 30 percent, and *Melanoplus sanguinipes* and several other species 20 percent. In the mountains and foothills of Wyoming from 1988 to 1994, populations of the Bruner slantfaced grasshopper ranged from less than 0.1 to 15 per square yard. In the latter case, density of the assemblage was estimated to be 25 grasshoppers per square yard. The rest of the infestation was comprised of four other grass feeders and one forb feeder in approximately equal numbers.

As a subdominant species, the Bruner slantfaced grasshopper may add to the damage of a dominant species. In 1989, a grassland site in the Big Horn Mountains of Wyoming was infested by an assemblage of 20 adult grasshoppers per square yard. This assemblage consisted of three grass feeders: *Camnula pellucida*, 40 percent; the Bruner slantfaced grasshopper, 10 percent; *Chorthippus curtipennis*, 10 percent; and three forb feeders: *Melanoplus bruneri*, 23 percent; *M. borealis*, 13 percent; and *M. alpinus*, 4 percent. During the period 1988-94, densities of most populations of the Bruner slantfaced grasshopper recorded in the annual grasshopper survey of Wyoming grasslands were low and economically insignificant; 118 of 148 (80 percent) sites surveyed contained less than one grasshopper per square yard. Although no experimental study of damage to forage has been made, estimates may be made from the weights of adults. Live weights of males collected from a mountain meadow in the Laramie Range averaged 223 mg and females 376 mg (dry weights: males 46 mg, females 96 mg).

Food Habits

The Bruner slantfaced grasshopper feeds on grasses and sedges. The precise diet depends on plants available in its widespread habitats. Observations in Canada indicate that in the northern mixedgrass prairie it feeds on species of *Agropyron*, *Bouteloua*, *Carex*, *Koeleria*, and *Stipa*. In Wyoming, examination of crop contents of Bruner slantfaced grasshoppers collected from two mountain meadows, one in the southern Laramie Range and the other in the northern Big Horn Mountains, revealed that the grasshoppers had fed on mountain grasses and sedges (Table 1). The results suggest that certain grasses and sedges are selected as host plants including Idaho fescue, spikefescue, thickspike wheatgrass (*Elymus lanceolatus*), needleandthread, rock sedge, and threadleaf sedge. Differences in diet of the grasshoppers living in the two meadows appeared to be due to the presence and abundance of individual plant species in the habitat. For example, Idaho fescue was scarce in the Pole Mountain meadow but abundant in the Big Horn Mountain meadow; rock sedge was absent in the Pole Mountain meadow but common in the Big Horn Mountain meadow.

Two-choice cage tests showed that the Bruner slantfaced grasshopper exhibits selectivity in feeding on grasses, confirming that certain grass species in the natural habitat are preferred to others. One field observation of feeding revealed its method of attacking host plants. In a meadow of the Big Horn Mountains, an adult male was discovered walking at 10:55 a.m. DST on 4 August 1994. The temperature of soil surface was 81°F and of air at the 1-inch level 64°F, and the sky was clear. It came to a rock sedge, raised up diagonally on the plant, and cut a leaf 1/2 inch above the base. Resting horizontally on the ground surface, the grasshopper consumed the detached section, about 2 inches long, from the cut end to the tip. Adults caged on transplanted sod from a mountain meadow habitat fed in much the same way on grass. For example, a female raised up diagonally on a grass plant, cut a green leaf 1/2 inch above the base, held onto the cut section with the front tarsi, and consumed the whole 2-inch cut section. It attacked another leaf in the same manner. A male was observed to move onto a grass plant, cut a green leaf of 5 inches length at the 2-inch level, hold onto the cut section with the front tarsi, and feed on the leaf. This male also turned head-down on the plant and cut another green leaf, held onto the cut section with the front tarsi, and consumed

Instar 1

1. BL 5.5-6.9 mm FL 3.2-3.7 mm AS 13.

Instar 2

2. BL 6.5-10 mm FL 4.4-5 mm AS 17-19.

Instar 3

3. BL 8.9-12 mm FL 5.9-7.3 mm AS 20-22.

Instar 4

4. BL 14.5-18 mm FL 8.5-10.5 mm AS 22-24.

Figures 1-4. Appearance of the four nymphal instars of *Bruneria brunnea* - their sizes, structures, and color patterns. Notice progressive development of the wing pads. BL = body length, FL = hind femur length, AS = antennal segments number.

the entire cut section. Caged grasshoppers were also observed to feed in short bouts on ground litter.

Dispersal and Migration

Flushed flight of the Bruner slantfaced grasshopper is straight and silent. The adults travel a distance of 2 to 8 feet at heights of 4 to 6 inches. They usually land on the ground headed away from the intruder.

Evidence for migration is meager. One long-winged female was discovered frozen along with specimens of known migratory species on a glacier in the Crazy Mountains of Montana. The wings of this female extended beyond the ends of the femora indicating exceptional powers of flight for the species. In the 1920 outbreak on rangeland of British Columbia, high numbers moved in August from areas of drought-stricken vegetation to areas of green vegetation.

Identification

Adults of the Bruner slantfaced grasshopper are colorful, medium-sized grasshoppers (Fig. 5 and 6). The head has a slightly slanted face; antennae are filiform; a vertical ivory band runs from base of the antenna to the base of clypeus and mandible; an ivory or pale tan streak runs from rear of eye onto the lateral carina of the pronotum (See Figure 4). A common color pattern of the dorsum of head and the pronotal disk is shown in Figure 7. Pronotum with median carina incised once. Wings are long, extending approximately to end of hind femur and as much as 2 mm longer; tegmen with prominent spots and an ivory streak near front edge. Medial area of hind femur with three light spots in the dark dorsal stripe; tibia orange or red. Color patterns are variable and may differ from the common pattern described. A conspicuous pattern is an immaculate tan dorsum from head to end of abdomen in both nymphs and adults (Fig. 8).

The nymphs are identifiable by their color patterns, structures, and shape (Fig. 1-4):

1. Head with slanted face; ivory or pale tan vertical bar present on face running from base of antenna to base of clypeus and mandible; ivory or pale tan streak running from rear of eye onto lateral carina and disk of pronotum; antennae filiform; lateral foveolae oblong.
2. Pronotum with lateral lobe of instar I colored tan and spotted fuscous, lateral lobe of instars II-IV with large fuscous marking and often with ivory spot near center; median carina entire in instars I and II, incised once near middle in instars III and IV.
3. Hind femur with dorsal stripe of medial area nearly solid fuscous in instar I; three light spots in

Figures 5-9. Appearance of adult male and female, color pattern of top of head and pronotum, nymph with uncommon color pattern, and egg pods.

stripe faint in instar II, distinct in instars III and IV. Hind tibia of instars I and II fuscous, of instars III and IV straw-colored.

4. Venter of abdomen and thorax ivory, yellow, or pale tan.

Hatching

Hatching of the Bruner slantfaced grasshopper occurs in June in both the northern mixedgrass prairie and the meadows of the Big Horn Mountains and the Laramie Range. In mountain habitats time of hatching varies due to yearly variations in snow depth and spring meltdown and their effects on soil temperatures. In 1994, in a meadow of the Laramie Range, hatching began on June 11, but in 1995 a late summer delayed hatching until June 30. The hatching period is short, lasting only two weeks in both Wyoming and Montana. No research of embryonic development has been conducted, but field observations suggest that the species may have a two-year life cycle in mountain meadows and northern grasslands.

Nymphal Development

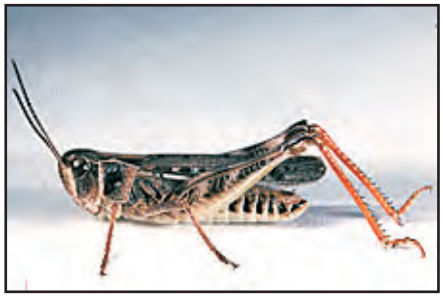
The nymphs emerge over a period of two weeks. In their mountain and foothill habitats, grasses remain green and supply an abundance of nutritious food. Cold temperatures and frequent cold rains and snow retard their development. The nymphal period, nevertheless, is relatively short, ranging from 40 to 46 days. Only four nymphal instars are required by the species to reach the adult stage.

Adults and Reproduction

Adults normally appear in July in the northern mixedgrass prairie and in mountain meadows. Seasonal temperatures greatly influence the precise time of eclosion. In a mountain meadow of the Laramie Range, adults first appeared 14 July 1994, but in 1995, which was a seasonally late year, they did not appear until August 10. The period of eclosion lasted 21 days in 1994 and 16 days in 1995, suggesting that the grasshoppers were exposed to warmer temperatures later in the summer and were partially making up for the retardation of their earlier stages in 1995.

The adults remain in the same habitat in which the nymphs hatched and developed. The habitat provides green grass for food, ground litter for shelter, and interspersed bare ground for basking and oviposition. Meager information is available on mating, maturation, and oviposition. Observations are impeded by the extended duration of basking and evidently the short time they spend in other activities essential for their survival. A Montana study indicated that in the northern mixedgrass prairie, oviposition begins approximately 18 days after the first appearance of adults and continues into late September. In mountain meadows an early, heavy snowfall in August will be lethal,

Male



5. BL 14-16 mm FL 10.2-10.8 mm AS 23-24.

Female

6. BL 18.5-21 mm FL 11.5-12.4 AS 23-24.

Head
Pronotum

7. Dorsal view of head and pronotum of female.

Color
Form

8. Nymphs (instar III) of uncommon color form.

Egg pod

9. Two egg pods, one opened to show eggs.

Table 1. Mean percentage dry weight of food items in the diet of *Bruneria brunnea* in mountain meadow habits.

	Laramie Range meadow		Big Horn Mountain meadow
	7/11/94	8/7/94	8/4/94
Age	Instar V	Adult	Adult
Festuca idahoensis	0.5		37.5
Leucopa kingii	39.9	39.3	27.1
Elymus lanceolatus	35.3	20.8	
Carex filifolia	9.1	15.6	
Carex rupestris			29.3
Stipa comata	13.8		1.3
Muhlenbergia filiculmis	0.4		
Agropyron sp.			2.5
Oryzopsis sp.		10.8	1.3
Grass seed	1.1	7.2	1.0
Arthropod		6.4	
No. crops examined	11	15	13

but in a year with a late fall individuals persist into early October, lengthening the oviposition period.

Caged females oviposit freely into containers of bare soil collected from their habitat. Examination of five pods revealed 2 to 10 eggs per pod with an average of six. The unusual variation in number of eggs per pod may have been caused by the change in temperature from the mountain environment to the laboratory cage. Average temperatures in the cage were 72°F at night and 82°F during the day. Pods are 1/2 to 5/8 inch long and are inserted diagonally into the soil. The top of the pod lies 1/4 to 3/8 inch below the soil surface. The pod wall is thick and strong (Fig. 9). Eggs are yellow and 5.5 to 6.4 mm long. They are surrounded by pale tan froth and topped with 1/16 to 1/8 inch of offwhite froth.

Population Ecology

No specific research of the population ecology of the Bruner slantfaced grasshopper has been conducted. A few facts, however, can be gleaned from general studies of grasshoppers. During irruptions this species may be the dominant member of an assemblage. In the 1920 outbreak on more than 2,000 square miles of rangeland in British Columbia, the Bruner slantfaced grasshopper contributed 50 percent of the assemblage, *Camnula pellucida* 30 percent, and several species the remaining 20 percent. No measurements of density were taken early in the year, but in August during a drought, the grasshoppers moved to areas with green vegetation in which the concentration of the Bruner slantfaced grasshopper measured 720 to 900 individuals per square yard. In meadows of the Big Horn Mountains this species may also rise to dominance. In one meadow in 1991, it was the dominant member in an assemblage of four species. Densities of young adults per square yard were estimated to be: *Bruneria brunnea*, 8.9; *Melanoplus bruneri*, 3.7; *Camnula pellucida*, 3.1; and *Chorthippus curtipennis*, 0.3. Of the 21 meadow sites surveyed for grasshoppers in 1991 in the Big Horn Mountains, the Bruner slantfaced grasshopper was dominant in one, co-dominant in three, and subdominant in 17. In the latter 17 sites, densities of this species ranged from 0.05 to 0.8 and averaged 0.3 young adults per square yard. Apparently in the many disjunct meadows of the Big Horn Mountains, the population ecologies of this grasshopper are separate and may differ substantially.

Daily Activity

The Bruner slantfaced grasshopper is a geophilous species spending its time on the ground surface during the day and hidden in ground litter at night. None can be found in early morning on either the vegetation or on the ground surface. One successful observation of the location of their shelter was made. A male nymph (instar IV) was discovered 1/2 inch deep in ground litter of a meadow in the Big Horn Mountains on 21 July 1994 at 6:12 a.m. DST; the soil surface temperature was 35°F and air temperature 34°F. The nymph was immobile and sitting horizontally on a layer of grass litter and was completely covered by litter. Two hours after sunrise, individuals begin to appear on the ground surface. They rest horizontally on bare ground or on ground litter and bask. During basking they present a side perpendicular to the sun and lower the associated hindleg to expose the abdomen more fully. Basking continues for approximately three hours before they become active. The feeding of a male was noted at 10:55 a.m. on 4 August 1994. Other activities probably commence at this time but were not observed. A second period of basking occurs in the afternoon. Shortly before sunset, when soil temperatures have not yet cooled much (65°F to 70°F), the grasshoppers seek shelter for the night.

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Clearwinged Grasshopper

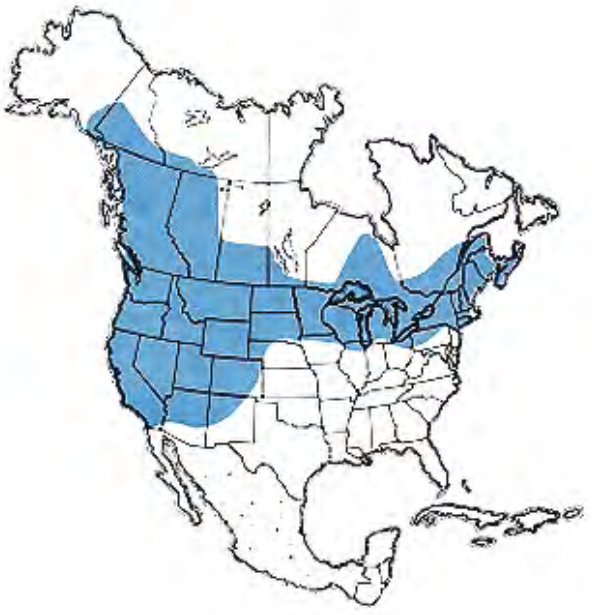
Camnula pellucida (Scudder)

Distribution and Habitat

The clearwinged grasshopper, *Camnula pellucida* (Scudder), is distributed widely in North America. It inhabits a variety of grasslands including the northern mixedgrass prairie, the bunchgrass prairie, and mountain meadows. A resident population lives in a mountain meadow at 10,800 feet in Colorado, just below timberline.

Economic Importance

The clearwinged grasshopper is a severe pest of small grains and grasses. It is most destructive early in the season when it often completely destroys spring wheat. Outbreaks on rangelands may devastate grass forage in areas as large as 2,000 square miles. A population with a density of 20 adults per square yard will consume the entire available yield of forage grasses on rangelands of British Columbia. Cage plot tests on native grassland of interior British Columbia showed that the feeding of this grasshopper during its nymphal life reduced the yield of Kentucky bluegrass by 5.1 pounds (dry weight) per acre for each grasshopper per square yard. An infestation of one young adult per square yard reduced yield 1 pound per day over 1 acre. Swarms may invade vegetable crops and feed preferentially on onions, lettuce, cabbage, and peas. The clearwinged grasshopper is a small species. The live weight of males collected from an open, grassy area of the Big Horn Mountains, Wyoming averaged 201 mg, and of females 605 mg (dry weight: males 55 mg, females 105 mg).



Geographic range of *Camnula pellucida* (Scudder)

Food Habits

The clearwinged grasshopper feeds mainly on grasses. It prefers succulent plants of western wheatgrass, reed canarygrass, barley, and wheat. Field observations at several locations show that it feeds heavily on many species of grasses, including fescues (Idaho fescue and red fescue), bluegrasses (Sandberg bluegrass and Kentucky bluegrass), wheatgrasses (western wheatgrass and crested wheatgrass), bromes (downy brome, smooth brome, and soft brome), and slender hairgrass. These grasses are not equally nutritious. The most favorable diets of single species consist of red fescue, three species of bluegrass, wheat, crested wheatgrass, and intermediate wheatgrass. In its natural habitat, the clearwinged grasshopper consumes small amounts of forbs such as fireweed and several species of legumes.

Migration and Dispersal

Myriads of the clearwinged grasshopper hatch in egg beds that may contain as many as 3,000 to 100,000 eggs per square foot. Pressure of high densities and depletion of food result in movement of the young nymphs away from egg beds to the nearest green vegetation. Immature grasshoppers continue to disperse through all of the nymphal stage. The older instars march in cohesive bands.

Adults may migrate long distances in huge flying swarms at either low or high altitudes, but in recent years only small swarms in flights of short duration have been observed. These flights may occur in the afternoons of hot, sunny days. Masses take off into a gentle wind and fly distances of one hundred to several hundred yards. When egg laying begins, migration ceases but females fly back and forth between feeding grounds and egg beds. They move to the egg beds during the heat of the day for oviposition. After a particular female deposits a clutch of eggs, she flies back to the feeding grounds in the evening or the next morning and stays there until another batch of eggs is mature. The males appear to remain on the egg beds outnumbering and attending the females as they oviposit. Males eventually die on the egg beds.

Migratory behavior is not characteristic of all populations of the clearwinged grasshopper. Individuals infesting sodded pasture near Harney, Minnesota, exhibited little movement. Nymphs developed to maturity close to where they had hatched and the adults showed little tendency to migrate, flying only short distances.

Instar 1

1. BL 4.2-5.5 mm FL 2.4-2.7 mm AS 11-13.

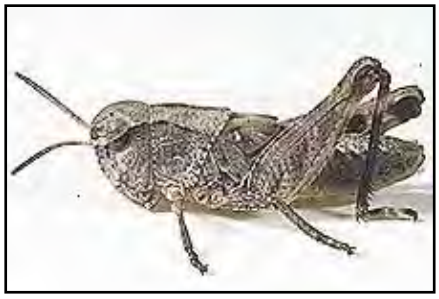
Instar 2

2. BL 5-7.1 mm FL 3.4-3.8 mm AS 14-16.

Instar 3

3. BL 7.3-8.9 mm FL 4.7-5.2 mm AS 18.

Instar 4



4. BL 10-14.15 mm FL 6-7.2 mm AS 20-22.

Instar 5

5. BL 14-20 mm FL 8.4-9.9 mm AS 22-25.

Figures 1-5. Appearance of the five nymphal instars of *C. pellucida* - their sizes, structures, and color patterns. Notice progressive development of the wing pads. BL = body length, FL = hind femur length, AS = antennal segments number.

Mating and egg laying occurred in the same area where eggs had been deposited the previous year.

Identification

Adults of the clearwinged grasshopper are of medium size, yellow to brown, and possess mottled forewings and transparent hindwings (Fig. 8). The forewings have along their angles light stripes that in the resting grasshopper with closed wings converge near the middle. The male (Fig. 6) is noticeably smaller than the female (Fig. 7). First instar nymphs are strikingly colored cream, tan, and black (Fig. 1).

The nymphs (Fig. 1-5) are identifiable by their color patterns and external structures:

(1) Head with lateral foveolae triangular (Fig. 9). Usually a dark bar crosses transversely across front of head under antennal sockets, across lower part of compound eyes, and onto sides of head.

(2) Pronotum with median carina low but uniformly elevated; median carina entire (without notch) in early instars, notched once in front of middle in the older instars (Fig. 9). Pronotum with lateral carinae clearly defined (Fig. 9).

(3) Hind tibia fuscous in first to third instar, fuscous or tan in fourth and fifth instars.

Hatching

The clearwinged grasshopper is an early-hatching species. Eggs begin embryonic growth in the summer of deposition and continue until they attain 50 percent of development (Stage 19). To reach the advanced stage, they require 400 day-degrees of heat at which point diapause stops further summer development. Lack of soil moisture may retard this initial development.

Diapause in eggs is broken during winter. At 41°F eggs require a minimum of 70 days of chilling. The rise of soil temperatures above a threshold of 55°F the following spring starts the final stages of embryonic development. After experiencing 150 day-degrees of heat, the eggs are ready to hatch. Emergence begins when soil temperature reaches 80°F and air temperature 65°F. Hatching of all eggs in an individual pod may be completed on the same day but this process generally lasts two to four days. A warm spring and favorable soil moisture shorten the hatching period of all the eggs in a bed. Because the hatching period may be completed in 12 days, the nymphs seem to appear en masse on bed

Figures 6-10. Appearance of the adult male and female of *C. pellucida*, diagnostic characters, and the egg pod and several loose eggs.

grounds. Cool, dry weather, however, may delay the start of hatching by a month and may extend the hatching period for a month or longer. Hatchlings emerge in the morning when temperatures are rising rapidly, especially after a shower the previous evening. Hatching begins around 9 a.m. and reaches a maximum between 11 a.m. and 12 noon.

Nymphal Development

The nymphs disperse quickly in search of food when large numbers of hatchlings are present on egg beds of native sod. Movement may be in any direction and often continues through the entire nymphal stage. Invasion of fields of young wheat at this time results in extensive crop damage. Nymphs exposed to warm temperatures and nutritious food plants complete development in 26 days. Less favorable conditions may extend this period to 40 days or longer.

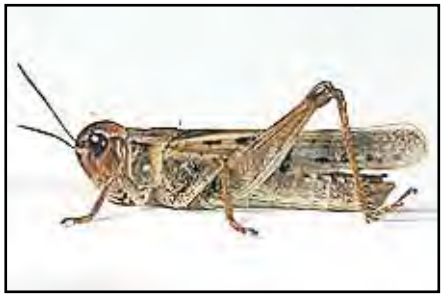
Adults and Reproduction

Because nymphs of the clearwinged grasshopper develop faster than those of the twostriped, adults of the clearwinged may appear first. The young adults are dark brownish gray, but as they mature, they turn lighter. When they become sexually active on the breeding grounds, they turn bright yellow. In laboratory cages under conditions simulating the natural environment, males become reproductively mature in five to seven days after fledging and females in seven to ten days.

Courtship by the male involves holding the antennae upright in a V-shape and moving the hind femora rapidly up and down and against the tegmina (ordinary stridulation). The male climbs onto the back of a receptive female and quickly lowers his abdomen down to make genital contact. Perched precariously and to one side, the male often becomes dislodged and comes to rest on the ground at the side of the female or is pulled along behind her.

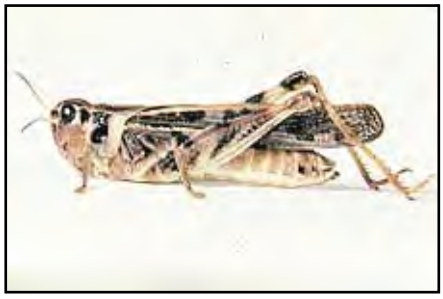
After a copulatory period averaging 55 minutes, the female seeks a suitable oviposition site by probing in sod. She digs her abdomen down among grass roots by opening and closing the ovipositor valves and quickly lays (average time 22 minutes) a clutch of 28 eggs (range 10-38) in the top inch of soil. She then covers the hole with a back and sideways motion of the hindlegs using the tarsi as brushes. The females, in seeking favorable sites for oviposition, often aggregate on egg beds that may range from a few square yards to 20 acres or more depending on size of the grasshopper population.

Male



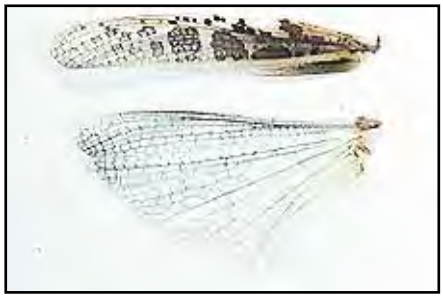
6. BL 19.5-21.5 mm FL 10.5-11.8 mm AS 25-29.

Female



7. BL 22-25 mm FL 12.2-13.6 mm AS 24-26.

Wings



8. Forewing (tegmen) and hindwing.

Head and Pronotum

9. Note lateral foveola on head and carinae on pronotum.

Egg pod

10. Egg pod and four loose eggs.

Pods are short and stout, 5/8 inch long and 3/16 inch in diameter, and are slightly curved (Fig. 10). Eggs are light brown and 4.7 mm long. Confined in field cages on winter wheat and Kentucky bluegrass at Saskatoon, Saskatchewan, females averaged 60 days adult life and produced 8 pods or 180 eggs each. The clearwinged grasshopper has one generation annually.

Population Ecology

Populations of the clearwinged grasshopper exhibit extremes of abundance and distribution. The species can remain virtually unseen for five to ten years, then increase gradually over three to four years and reach peaks the following two to three years. During the period of increase, a population may spread from a few acres of rangeland to more than 2,000 square miles. These outbreaks consist almost entirely of the clearwinged grasshopper. The cause of outbreaks appears to be a combination of favorable weather, nutritious host plants, and reduced rates of predation, parasitism, and disease. Weather that supports population growth consists of above-normal temperatures in spring and summer and sufficient rain to keep host plants green and succulent, particularly fescue, bluegrass, and wheat. Crashes of dense populations are caused by epizootics of the fungus, Entomophaga grylli (Fresenius) pathotype I; by drought resulting in starvation of nymphs or adults; by below- normal spring and summer temperatures that retard development of nymphs and reproduction of adults; or by low soil temperatures in winter that may cause up to 100 percent mortality of eggs.

Daily Activity

The clearwinged grasshopper, a diurnal insect, is active during the day and inactive at night. During the night it rests in sheltered places protected from the cold. As the morning sun warms the habitat, the grasshoppers slowly crawl from their hiding places and seek sunny positions aggregating on bare soil, earth clods, and dried cattle dung. As temperatures rise further, the grasshoppers start moving about and feeding. They are active during the greater part of the day. If the ground becomes too hot, they crawl up stems of plants a distance of 2 inches. Just before sundown, they seek stones and other objects that have retained heat and orient their sides to the sun. As the habitat continues to cool, they crawl to sheltered places and become hidden. Several weather elements, particularly temperature and radiation of the sun, modify behavior (Table 1).

Table 1. Activity of nymphs and adults of the clearwinged grasshopper, *Camnula pellucida* (Scudder), correlated with air and soil temperaturesa (After Parker 1930).

		Average temperature °F			
		Nymphs		Adults	
Name of activity	**Description**	**Air**	**Soil**	**Air**	**Soil**
Beginning of activity	Basking, exposure to sun	60	76	62	78
Beginning of normal activity	Feeding	65	94	67	95
	Starting migration	67	93	75	102
	Molting	70			
	Mating			68	
	Starting oviposition			72	101
Beginning of climbing to escape heat	Climbing vegetation			80	107
Beginning of clustering in evening	Basking, exposure to sun	68	87	70	90
Ending of activity	Moving to shelter	65	77	67	80

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Meadow Grasshopper

Chorthippus curtipennis (Harris)

Distribution and Habitat

The meadow grasshopper, *Chorthippus curtipennis* (Harris), is a widespread species in western and northern states and in provinces of Canada. Of the large number of species in the genus *Chorthippus*, only this one inhabits the Nearctic region. The other 70 to 80 species are Palaearctic.

Habitats of the meadow grasshopper include stands of tall lush grasses growing in hayfields, pastures, swales, roadsides, mountain meadows, and along edges of marshes, lakes, and ponds. In the mountains of Colorado this species is characteristic of moist areas dominated by sedges or rushes up to altitudes of 11,000 feet.

Economic Importance

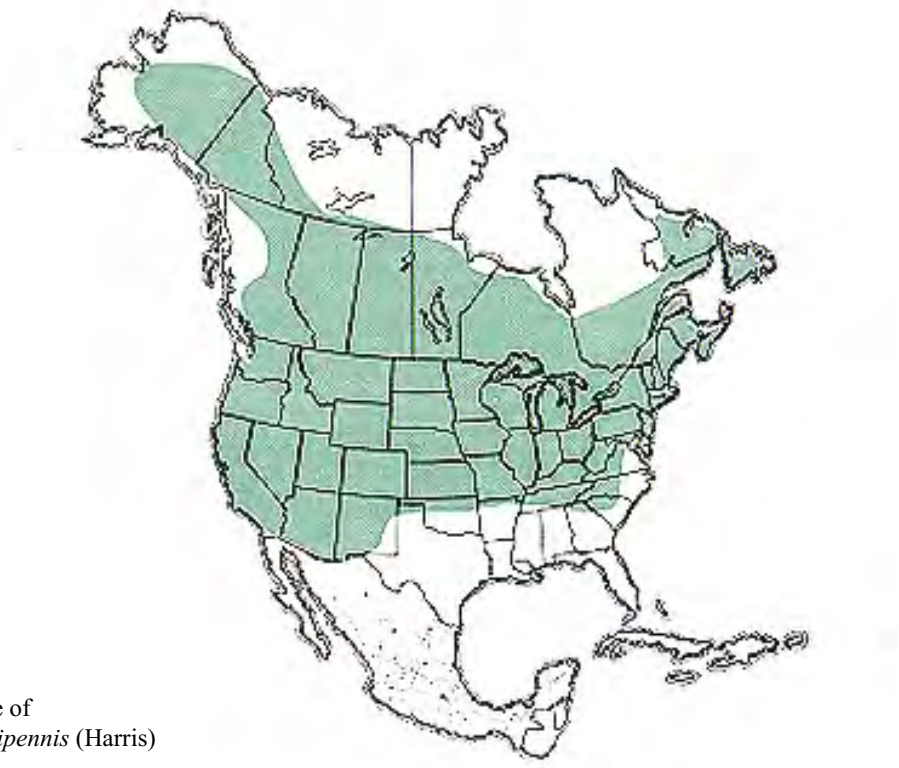
Although the meadow grasshopper feeds on valuable forage grasses, it has not been reported as causing significant damage. Yet, as part of an assemblage of species, this grasshopper undoubtedly contributes to the damage caused by a heavy infestation. In mountain meadows and parks it is often associated with the clearwinged and clubhorned grasshoppers. In the park belt of Alberta it is the most common species of grasshopper, and in the tallgrass prairie of eastern North Dakota it is one of the most frequent and abundant species.

Food Habits

The meadow grasshopper feeds on grasses and sedges. Adults climb plants and while clinging head-down chew on the edges of leaves at various distances from the tip. A grasshopper eats a gouge one-eighth inch long into the edge and continues to take bites of the leaf at this level until nearly the entire width is consumed. Then it progresses in a similar way feeding toward the base of the leaf. If a leaf is severed, the grasshopper holds on to the cut section with the front tarsi and continues to feed on it. Sometimes, however, the segment is dropped and falls to the ground.

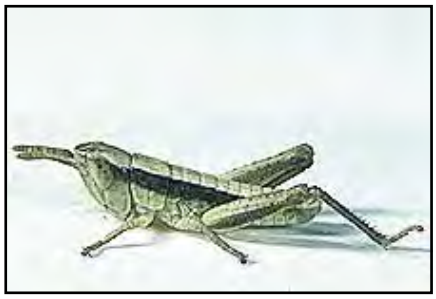
The diet of this grasshopper varies with the kinds of grasses and sedges growing in its habitat. In the tallgrass prairie of the Midwest, patches of little bluestem and big bluestem not only provide favored habitats but also preferred food plants. Kentucky bluegrass is also a preferred host plant in the Midwest and elsewhere. In Idaho the diet of this grasshopper was found to consist of 59 percent Idaho fescue, 19 percent western needlegrass, and 14 percent elk sedge.

A total of 16 species of grasses and 4 species of sedges have been found in crop contents. Undoubtedly this list of food plants is far from complete. Crop



Geographic range of
Chorthippus curtipennis (Harris)

Instar 1



1. BL 5.7-6.6 mm FL 2.9-3.1 mm AS 13-14.

Instar 2

2. BL 6.8-8 mm FL 4.3-4.6 mm AS 17-18.

Instar 3

3. BL 9.5-10.4 mm FL 5.8-6.3 mm AS 20-21.

Instar 4

4. BL 12-16 mm FL 7.9-10.2 mm AS 22-24.

Figures 1-4. Appearance of the four nymphal instars of *Chorthippus curtipennis* - their sizes, structures, and color patterns. Notice progressive development of the wing pads. BL = body length, FL - hind femur length, AS = antennal segments number.

contents may also contain small amounts of forbs, pollen, fungi, and arthropod parts.

Migratory Habits

Wings of the meadow grasshopper vary in length. Normally the females have short wings unsuited for flying, while the males have long wings that reach the end of the abdomen and are used for flight. Evasive flights of the male are straight, silent, low (6 inches), and short (2 to 3 feet). Males may also fly appetitively for somewhat longer distances (10 feet), and greater heights (12 inches). At the end of both kinds of flight, they land on vegetation. The females take evasive action by jumping 6 inches high for distances of 12 to 18 inches; they also land on grass stems. After landing they may drop to the ground and attempt escape by walking along on the ground under the vegetation.

In most years a small percentage of both males and females have long wings reaching beyond the abdomen. In Michigan's George Reserve, 2 percent of adults possess long wings. These adults are equipped to make extensive dispersal flights. Although direct observations of dispersal are lacking, females with long wings have been found in the center of cities several miles from breeding areas. A male and a female were found recently on the ice of Grasshopper Glacier in the Crazy Mountains of Montana.

Identification

Adults of the meadow grasshopper are medium-sized (Fig. 5 and 6). The sides of their body are colored green, tan, or fuscous and the underside is yellow or tan. The head has a strongly slanted face; the antennae are filiform and become slightly thick and black toward the end; the lateral foveolae are oblong and visible when viewed from above. The pronotum has a low and distinct median carina and distinct lateral carinae, all of which are cut once behind middle of the disk (Fig. 7). Wings of the male are long, usually reaching the end of the abdomen; wings of the female are short, covering half to three-quarters of the abdomen. The medial area of the hind femur is tan or brown and unbanded, the knee is black; hind tibia is usually yellow, though sometimes orange or red.

The nymphs are identifiable by their shape, external structures, and color patterns (Fig. 1-4):

Figures 5-8. Appearance of the adult male and female of *Chorthippus curtipennis*, dorsal view of adult head and pronotum, and the egg pod and eggs.

1. Head with strongly slanted face; antennae filiform and flat; lateral foveolae indistinct in instars I and II, oblong and distinct in instars III and IV.
2. Brown stripe runs along side of body from behind compound eye to nearly end of abdomen in instars I and II; face, sides of head, and lobes of pronotum are usually solid green or yellow in instars III and IV.
3. Pronotum with lateral carinae nearly parallel in instars I and II; lateral carinae slightly converging on prozona in instars III and IV.
4. Hind femur with medial area light brown to brown.

Hatching

The meadow grasshopper is a member of the intermediate-hatching group. First instars appear in late spring, about the same time as the redlegged grasshopper with which it is often associated in plains habitats. The eggs diapause during winter and usually hatch the following spring, but the eggs of populations residing in mountain meadows may require as long as three years of development before they hatch.

Nymphal Development

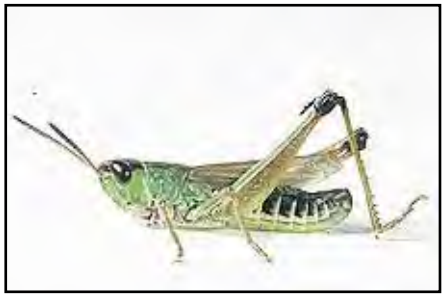
Exposed to the warm temperatures of late spring and early summer, the nymphs grow rapidly and complete development in 30 days. The meadow grasshopper has four nymphal instars. In some regions (Idaho and Quebec), research suggests that they may also have five instars.

Adults and Reproduction

The majority of adults stay in the same area occupied earlier by the eggs and nymphs. The habitat usually remains favorable and food plants stay green and plentiful.

While sitting alone on a blade of grass, the males frequently stridulate to produce a calling song that attracts females. Receptive females respond by stridulating a soft answering song. Males have special songs for courtship of females (stationary, advancing, and mounting) and for aggression against other males. These songs are clearly audible to humans. The calling song has a slower pulse rate produced by first raising both hind femora 70 degrees from horizontal, then pressing them against the forewings and finally lowering the femora to produce each pulse of sound.

Male



5. BL 15.3-16 mm FL 9.6-10 mm AS 23-26.

Female

6. BL 21.5-21.8 mm FL 11.5-12.1 mm AS 23-25.

Head
Pronotum

7. Dorsal view of head and pronotum of adult female.

Egg pod

8. Egg pod and four separate eggs.

The start of a successful mating begins with the male approaching a female 12 inches away and stopping several times to stridulate in courtship. When 1 inch from her, he changes his stridulation to produce an advancing song and then rushes to her side. As he mounts and attaches his genitalia, he again stridulates and produces a mounting song. After 30 minutes of copulation, he dismounts and crawls away. The affair is over.

A gravid female deposits a clutch of four to six eggs in the soil at a depth of three-quarters inch. The eggs are oriented vertically to 20 degrees from vertical at the bottom of the pod. She takes 25 to 30 minutes to complete oviposition. After extracting her ovipositor she brushes over the exit hole with her hind tarsi and walks away. No studies of the fecundity of the meadow grasshopper have been made. There is one generation annually in plains habitats.

Egg pods of the meadow grasshopper are bottle-shaped and 14 to 16 mm long and 4 mm in diameter at their greatest girth (Fig. 8). Eggs are brown and 4.0 to 4.4 mm long. A coffee-brown, hardened froth forms a 7 to 8 mm plug above the eggs and surrounds the egg mass and each egg.

Population Ecology

Populations of the meadow grasshopper and other acridid species were followed over a period of ten years (1959 to 1968) in the sand prairie of eastern North Dakota. Densities of the meadow grasshopper fluctuated between 0.1 and 1.4 individuals per square yard. The low point of the population occurred in 1962, when flooding of the habitat shortly after hatching destroyed many nymphs. The population then recovered at rates of two to three fold for three years, until the density peaked at 1.4 individuals per square yard in 1965. The density remained at this level in 1966, then decreased to 0.8 and 0.7 individuals per square yard the next two years.

Under favorable conditions in mountain meadows and parks of Idaho, the meadow grasshopper reaches densities of ten individuals per square yard.

Daily Activity

The meadow grasshopper is a diurnal insect and is active during the day when temperatures have risen. Both nymphs and adults are very agile; they jump quickly and dodge behind vegetation to evade potential predators. To keep safe their escape, they eventually drop to the ground and crawl away under the vegetation. Normally they rest close to the tops of grasses.

When temperatures fall in the evening, the meadow grasshopper usually takes cover under vegetation and becomes hidden in a manner similar to the clearwinged grasshopper with which they may be associated. The details of their daily activity still require observation and study.

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Greenstriped Grasshopper

Chortophaga viridifasciata (DeGeer)

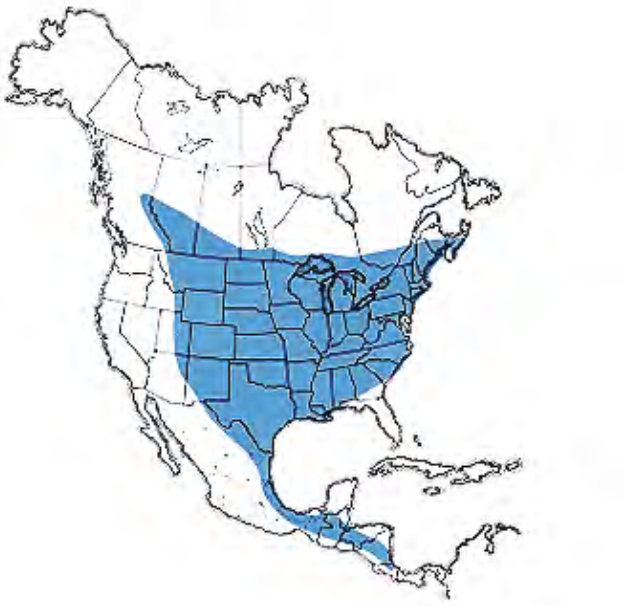
Distribution and Habitat

The greenstriped grasshopper ranges widely in North America and extends southward into Central America. Inhabiting lands dominated by midgrasses, it is more prevalent in grass meadows and slopes of the eastern United States than in the extensive western prairies. Its distribution is patchy in the western region, as the species usually occupies small areas that receive additional moisture by overflow or by subirrigation. Patches of western wheatgrass growing in swales, around ponds, and along streams are preferred habitats of this grasshopper. It also inhabits stands of smooth brome under irrigation or located adjacent to irrigated crops and lawns.

Economic Importance

Because of its usually low numbers and patchy distribution, damage by the greenstriped grasshopper to rangeland forage is minimal and economically insignificant.

In the eastern United States, where it is one of the most abundant and widespread species, it may cause some damage to pastures and hayfields. Records of its presence in fields of red clover and tobacco indicate it may become a minor pest of these crops. However, its food preferences suggest it may actually be feeding on weedy grasses that have invaded these crops. Of medium size, males of the greenstriped grasshopper collected in eastern Wyoming average 177 mg and females 607 mg (live weight).



Geographic range of Chortophaga viridifasciata (DeGeer)

Food Habits

The greenstriped grasshopper feeds mainly on grasses with a preference for succulent plants. Because of its wide distribution, it undoubtedly feeds on many different species of grass, but the only information available on host plants comes from a few localities.

In southeastern North Dakota, where the species inhabits shortgrass areas of the sand prairie, it feeds chiefly on Kentucky bluegrass (44 percent). Additional host plants include foxtail barley, western wheatgrass, quackgrass, little bluestem, junegrass, needleleaf sedge, Penn sedge, and a forb, European sticktight. In the shortgrass prairie of northern Colorado, ten adults collected from a small swale dominated by western wheatgrass had crop contents of 91 percent western wheatgrass, 9 percent needleleaf sedge, and 0.2 percent blue grama. Direct observations of its feeding in Michigan revealed that the species fed upon orchardgrass and poverty oatgrass and a forb, peppermint. In northeastern Texas, food preference tests using several local plants showed that the first choice of greenstriped grasshoppers was new shoots of Johnsongrass. In the absence of Johnsongrass, the grasshoppers preferred a species of brome, *Bromus catharticus*. An unexpected result of the food selection tests was this grasshopper's voracious feeding on a forb, annual sowthistle, even in the presence of lush grasses.

The greenstriped grasshopper's method of attacking a grass is to climb the plant and begin feeding on the edge of a leaf about halfway up. A narrow leaf, like that of Kentucky bluegrass, is cut through, held by the front tarsi, and directed to the mouthparts. In the case of a broader leaf, such as a wheatgrass, the grasshopper may feed to the midrib and then continue to feed up the leaf to the tip. Occasionally, after consuming or dropping a cut section, the grasshopper will turn and feed head down on the attached portion. This grasshopper also feeds on ground litter, in which case a favorite item is a cut green leaf.

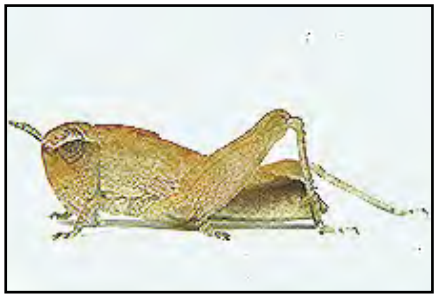
Dispersal and Migration

The greenstriped grasshopper possesses long wings that extend 2 to 8 mm beyond the end of the abdomen. A strong flier, it regularly disperses from its nymphal habitat to other areas. In Michigan the eggs hatch and the nymphs develop in moist swales and in the margins of marshes where Kentucky bluegrass grows

Instar 1

1. BL 5.5-8.2 mm FL 2.4-3.7 mm AS 10-13.

Instar 2

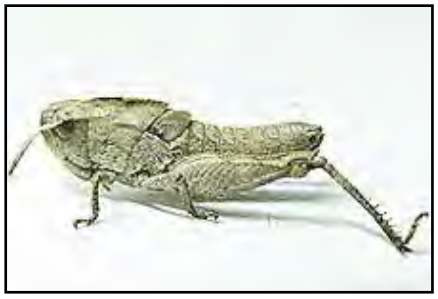


2. BL 7.8-10.1 mm FL 4.6-5.1 mm AS 16-17.

Instar 3

3. BL 9.5-11.8 mm FL 6.1-6.6 mm AS 19-20.

Instar 4



4. BL 13.5-15 mm FL 7.1-8.2 mm AS 20-21.

Instar 5

5. BL 17.3-20 mm FL 9.0-11.1 mm AS 21-22.

Figures 1-5. Appearance of the five nymphal instars of *Chortophaga viridifasciata* - their sizes, structures, and color patterns. Notice progressive development of the wing pads. BL = body length, FL - femur length, AS = antennal segments number.

luxuriantly. Numbers of the young adults fly out from these habitats into the uplands. Another example of dispersive flight is the observation on 8 May 1991 of a male sitting on a sidewalk of the University of Wyoming campus. This grasshopper had likely flown from a favorable habitat on the outskirts of Laramie.

Adults take evasive flights in which the males fly distances of 10 to 30 feet and the females twice that far. The height of these flights ranges from 6 to 24 inches. Usually the grasshoppers crepitate in flight, but when quickly startled they fly without crepitation, which slows their speed. To the human ear the sound produced is a soft buzz. The insects dive and flutter to the ground in alighting. In eastern Wyoming an interesting observation was made of a male that rose up approximately 25 feet and then flew rapidly away from the habitat and beyond the observer's power of vision.

Males also fly and crepitate to attract the females. These flights are of short duration, no longer than two seconds, and most last only one second, and at heights up to 3 feet.

Identification

The greenstriped grasshopper is a green or brown, bandwinged species. The majority of females are green while the majority of males are brown (Fig. 6 and 7). Females are considerably larger than the males. The pronotal disk has posterior angle acute (Fig. 8); median carina is strong, equally elevated over its full length, and weakly cut once in front of middle; top of carina is usually light tan. Hind wings have basal area pale greenish yellow and the dark band is faded and incomplete (Fig. 9). Hind tibiae are bluish gray or red and have a tan annulus near proximal end.

Nymphs (Fig. 1-5) are identifiable by their shape, structures, and color patterns.

1. Head. Face moderately slanting; antennae ensiform, ringed fuscous and white in instar I, fuscous ventrally, tan dorsally in instars II to V; compound eye with light spots and with light line that begins base of antenna and that usually divides eye into a light dorsal half and a dark ventral half.
2. Pronotum with disk tectate; median carina tan, moderately elevated and uncut; a tan band in green nymphs runs down middle of dorsum of

Figures 6-10. Appearance of the adult male and female of *Chortophaga viridifasciata*, head and pronotum of female, wings of female, egg pod and loose eggs.

thorax and abdomen; lateral carinae lacking in instars I to III, weak in instars IV and V.

3. Hind femur with outer medial area green, tan, or brown and with small dark spots.
4. General body color usually green or brown, sometimes tan (Fig. 2).

The early instars (I to III) of Chortophaga viridifasciata and Encoptolophus costalis appear similar; both are usually green and structurally similar. They may be separated by a few characteristics that differ. The antennae of E. costalis are clavate while those of C. viridifasciata are ensiform. The outer faces of the femur and tibia of the fore- and midlegs of E. costalis have four distinct longitudinal ridges, which usually have black lines between them. Those of C. viridifasciata have two distinct ridges, which are the upper and lower carina, and a third weak ridge between them with no black lines between the ridges. Instar I of E. costalis has the medial area of the hind femur pink in the distal half, and that of C. viridifasciata is entirely green. Instars IV and V are identifiable by the shape of the pronotum. The disk of E. costalis moderately, and that of C. viridifasciata is tectate (steep roof-like); the posterior angle of the disk in E. costalis is obtuse, and that of C. viridifasciata is acute.

Hatching

In eastern Wyoming, eggs of the greenstriped grasshopper hatch during the middle of July two weeks ahead of the velvetstriped grasshopper, *Eritettix viridis*, which frequently shares the same moist habitat. In southern states where two or more generations occur annually, hatching takes place earlier and at several times more through the growing season. In Texas, nymphs have been found throughout the year. Eggs deposited in southern states appear to develop without any diapause just as they do in the laboratory, where it is possible to obtain six generations in a year.

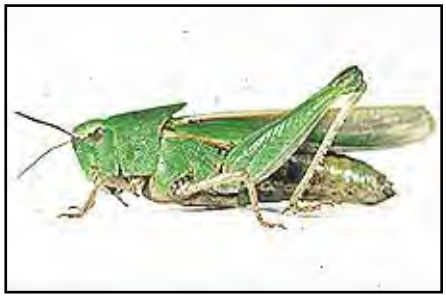
Nymphal Development

In the northern states the nymphs develop slowly, taking about 100 days to become fourth instars. In eastern Wyoming this stage is reached by the middle of October. Many of these nymphs molt to the fifth instar before cold weather compels them to enter dormancy. The nymphs appear to be very cold hardy. A fourth instar nymph

Male

6. BL 18.5-19.8 mm FL 10.7-12 mm AS 22-24.

Female



7. BL 25-29 mm FL 13.5-55 mm AS 21-25.

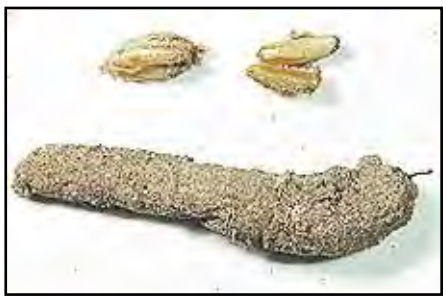
Head and Pronotum

8. Dorsal view of head and pronotum of an adult female.

Wings

9. Spread wings of an adult female.

Egg pod



10. Egg pod and several loose eggs.

collected close to the time of entering dormancy survived for 48 hours at 0°F. Nymphs become active in March and develop to the adult stage in early April. Laboratory research indicates that in winter these late instar nymphs may be in a facultative diapause, which is broken the following spring by an increasing photoperiod rather than the concomitant increasing temperature.

Adults and Reproduction

Some adults may disperse from their nymphal habitats but others remain and reproduce there. Pair formation begins when females are attracted to crepitating males and approach them by flying and crepitating to signal a receptive response. When close, the pair begin to walk and hop toward each other. During courtship both males and females may also perform femur-tipping and other movements. The male stridulates as he approaches and when they touch, he mounts and they copulate. Copulations last 30 to 60 minutes.

No information is available on how soon females begin oviposition or how many eggs they produce during their lifetime. In Indiana a female was observed to oviposit in damp sand at the margin of a pond. In the laboratory females readily oviposit in bare sandy loam soil. Females bore into the ground to a depth of one and one-fourth inches. Pods are one and one-eighth to one and one-fourth inches long and contain 25 eggs in the bottom half inch with the remainder of the pod being hardened froth. Eggs are light tan and 4 to 4.5 mm long (Fig. 10). In the northern part of its geographic range, this species has one generation annually and overwinters in the late nymphal stage.

Population Ecology

In the eastern United States the greenstriped grasshopper is one of the most abundant and widespread species of grasshoppers. Populations, however, do not grow to what pest managers call a grasshopper outbreak (25 adults or more per square yard). This may in part be due to a special auditory communication among the males that spaces individuals. The behavior may not only reduce competition among males for mates but may also limit population density.

In western states populations are neither widespread nor abundant. The species is limited to small moist habitats in which densities of adults are less than one per square yard. As long as these habitats remain favorable, populations persist for years. Although many studies have addressed the behavior and physiological ecology of this species, apparently no special study has been made of its population ecology.

Daily Activity

Because of its wide distribution, the greenstriped grasshopper faces many different environmental hazards and extremes. In the north, e.g., eastern Colorado and Wyoming, late instar nymphs and adults must make adjustments to the cold and inclement weather of March and April. This they do by taking cover under litter, especially during the night. On April 4 in a smooth brome habitat next to an irrigated park lawn, grasshoppers were still hidden at 7 a.m. DST when soil surface temperature was 35°F and air temperature 1 inch high 33°F. By 8 a.m., when temperatures had risen (soil 45°F and air 40°F), the grasshoppers had emerged and were basking either horizontally on the ground or vertically, head up, on old culms of grass. They continued basking at least until 10 a.m. when soil temperature had risen to 67°F and air temperature 52°F During the middle of the day they feed and potter, spending most of this time on the ground.

Further observations are needed to provide a complete picture of their daily activities. Because of low grasshopper numbers, pertinent facts will take considerable time to accumulate.

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Crenulatewinged Grasshopper

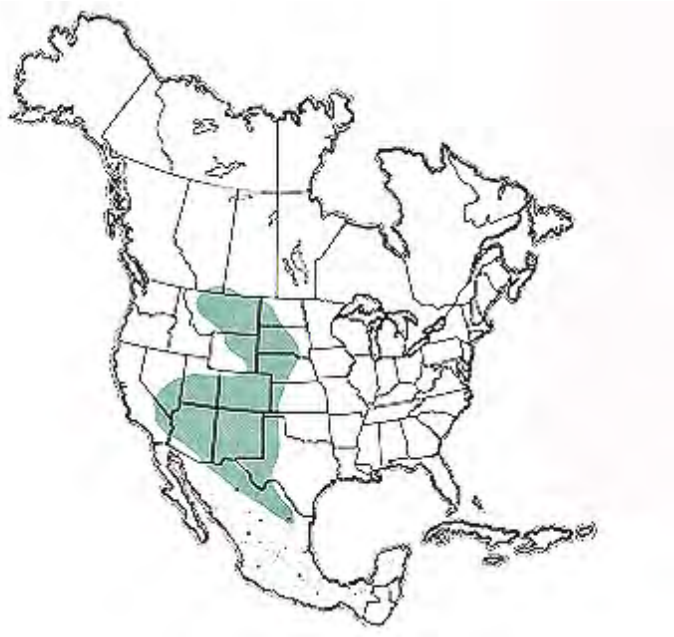
Cordillacris crenulata (Bruner)

Distribution and Habitat

The crenulatewinged grasshopper is a small, grassland species that reaches its greatest abundance in the shortgrass and desert prairies and in heavily grazed upland sites of the mixedgrass prairie. Its geographic range extends westward into the bunchgrass prairie and shrub-grass associations as far as Nevada and California. It prefers short stands of grass in which blue grama is dominant and interspersed with bare ground. The species does not invade the tallgrass prairie nor dense stands of mid grasses in the mixedgrass prairie.

Economic Importance

The crenulatewinged grasshopper attacks and eats the green leaves of blue grama, a preferred forage grass of livestock. The grasshopper's presence in an economically damaging assemblage on rangeland adds slightly to the total damage. In the northern mixedgrass prairie it has been found to comprise 1 to 4 percent of some outbreak populations. Occasionally it becomes the most abundant species in an assemblage, with adult densities reaching eight per square yard. In Montana it has been recorded as causing considerable damage to threadleaf sedge, and in Arizona it has been observed destroying young grasses on newly seeded rangeland. However, because of its small size and generally low densities, it usually is not a serious pest on grasslands. Live weight of males averages 45 mg and of females 110 mg (dry weight males 15 mg, females 24 mg).



Geographic range of *Cordillacris crenulata* (Bruner)

Food Habits

The crenulatewinged grasshopper is a grass feeder, preferring blue grama whenever it is present in the habitat. In the shortgrass prairie of eastern Colorado, it fed almost exclusively on blue grama. This grass comprised over 99 percent of crop contents of instars I to IV and over 96 percent of crop contents of the adults. Small amounts of needleleaf sedge, red threeawn, prairie junegrass, and a trace of one forb, tansy aster, were also found in crop contents.

In Montana the crenulatewinged grasshopper has been observed to feed heavily on threadleaf sedge in addition to blue grama. In a desert prairie of southwest Texas, crop contents of this species consisted of 71 percent blue grama, 7 percent hairy grama, 6 percent buffalograss, 4 percent burrograss, 4 percent of an undetermined grass, 4 percent of flax (a forb), and 2 percent of fall witchgrass. This grasshopper can live in communities where blue grama does not occur, subsisting on other grass species. In the mixedgrass prairie of Wyoming, one observation has been made of its feeding on needleandthread grass.

The method by which older instars and adults of this grasshopper attack the primary host plant, blue grama, has been observed in the mixedgrass prairie of eastern Wyoming. A hungry individual appears agitated and crawls on the ground and over host plants waving its antennae and shaking its hindlegs. It stops at several blue grama plants and tastes leaves until it finds one it apparently likes. The grasshopper crawls up the leaf a short distance, tastes the leaf again, then turns around head down and backs up toward the tip. It begins to feed on the edge about one-quarter inch from the tip and proceeds toward the base. It consumes most of the width, but leaves behind a narrow standing length to which it clings. On a recumbent or detached leaf lying on the ground, an individual feeds from a horizontal position.

Dispersal and Migration

A study of local movement by adult crenulatewinged grasshoppers in a habitat of the desert prairie revealed an average daily displacement of 16 feet and a maximum of 210 feet. Observations of normal activity of adults in the mixedgrass prairie of eastern Wyoming indicate that movement is achieved both by walking and flying. Adults have been observed to walk both in short bouts of a few inches and to walk as much as 6 feet without stopping. Walking crenulatewinged grasshoppers wave their antennae and, when they stop, shake their hindlegs.

Evasive flights are straight and silent with distances ranging from 2 to 8 feet and with peak heights of approximately 6 inches. The grasshopper usually takes off

Instar 1

1. BL 4.8-5.7 mm FL 2.9-3.3 mm AS 13.

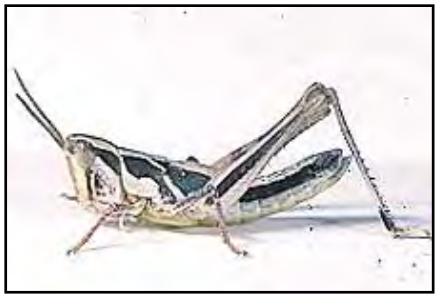
Instar 2

2. BL 6.3-7.5 mm FL 4-4.7 mm AS 15-17.

Instar 3

3. BL 8-11.1 mm FL 5.4-6.2 mm AS 20-21.

Instar 4



4. BL 10.3-13 mm FL 6.7-8.5 mm AS 22.

Figures 1-4. Appearance of the four nymphal instars of *Cordillacris crenulata* - their sizes, structures, and color patterns. Notice progressive development of the wing pads. BL = body length, FL = hind femur length, AS = antennal segments number.

from the ground and lands on the ground facing away from the intruder. No information is available on long-distance dispersal and migration by this grasshopper.

Identification

Adults of the crenulatewinged grasshopper are small and slender (Fig. 5 and 6). The body is cream-colored with brown markings and stripes. A diagnostic character is the wide, brown, crenulate or scalloped stripe on each tegmen (Fig. 7). The subocular groove is edged posteriorly with a narrow brown stripe. On the side of the head behind each compound eye a conspicuous triangular brown stripe is present. The upper part of the lateral lobe is brown; the lower is cream-colored. An anterior cream-colored wedge runs nearly to the top of the lateral lobe separating the brown postocular stripe from the brown stripe of the lateral lobe. The hind tibiae are pale gray to yellowish and have a distal dark annulus.

Nymphs are identifiable by their shape and distinctive color patterns (Fig. 1- 4).

1. Head with strongly slanted face; antennae slightly ensiform in instars I to III, filiform in instar IV. Postocular brown stripe present on side of head. Dorsum of head with brown medial stripe that is usually divided by narrow light line. Subocular groove edged posteriorly with a brown stripe.
2. Pronotum with lateral lobe brown on upper half, cream on lower half. Distinctive cream-colored wedge on upper anterior edge of lateral lobe. Lateral carinae low but conspicuously cream-colored. Disk of pronotum with triangular posterolateral markings.
3. Hind femur with medial area brown dorsally and cream ventrally, as in *Cordillacris occipitalis* but with greater contrast of colors. Hind tibia pale gray with a dark annulus distally.

Hatching

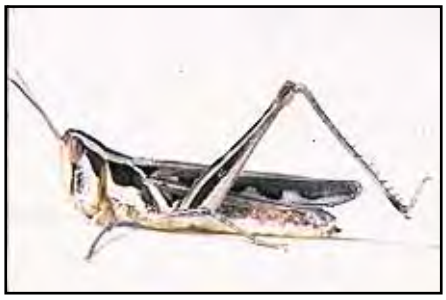
The crenulatewinged grasshopper hatches three to four weeks after the spottedwinged grasshopper, *Cordillacris occipitalis*, and belongs to the intermediate-hatching group of grasshoppers. Eggs probably begin development upon being laid in the ground in summer. They develop to embryonic stage 18 by fall and enter diapause at this time. They overwinter protected in soil cells constructed by the ovipositing

Figures 5-8. Appearance of the adult male and female of *Cordillacris crenulata*, spread wings of female, and clutch of two eggs.

Male

5. BL 12-13 mm FL 8-9 mm AS 23-24.

Female



6. BL 15-16 mm FL 9-10.3 mm AS 23.

Wings

7. Forewing (tegmen) showing crenulate dark pattern and clear hind wing.

Eggs

8. Clutch of two eggs.

females. Eggs lie at a shallow depth in the top one-half inch of soil. When temperatures rise in spring, development resumes. Hatching usually occurs in mid May in the desert prairie of Arizona and during the first half of June in the mixedgrass prairie of eastern Wyoming and the shortgrass prairie of northcentral Colorado.

Nymphal Development

The length of the nymphal period ranges from 30 to 43 days and averages 36 days. The period is approximately five days shorter than that of *C. occipitalis*. This difference is probably due to warmer temperatures experienced by the later-hatching crenulatewinged grasshoppers and the requirement of only four instars to reach the adult stage. A few females require five instars.

Adults and Reproduction

Adults appear in July in the northern mixedgrass and shortgrass prairies, and remain in the same habitat in which the nymphs hatched and developed. Ordinarily, this habitat continues to provide a plentiful supply of green leaves of its primary host plant, blue grama, and a favorable place in which to live and reproduce.

Courtship appears to be similar to that of C. occipitalis. A male moves close to a female, tips his hindlegs, depresses his antennae, and then produces a single burst of stridulation. He then tips his hindlegs forward and advances towards the female. The act of mounting and initial copulation has not been observed. A field observation was made of a pair in copulation at 11:20 a.m. DST 27 July 1973 in the usual manner of grasshoppers with the male atop the female.

One observation of oviposition from start to finish was made in the mixedgrass prairie of eastern Wyoming on 22 August 1991. A gravid female selected an old crown of blue grama grass in which to oviposit. She braced herself with the forelegs and midlegs on an adjacent blue grama plant and held the hindlegs off the ground. Oriented diagonally at a 45° angle she started boring into the soil at 10:53 a.m. DST (soil surface was 105°F, air temperature 1 inch above ground was 82°F, clear, wind 0-5 mph). An attending male stridulated briefly at the beginning of oviposition, but otherwise stood quietly one-quarter inch from her pronotum. She completed oviposition and withdrew her abdomen after 26 minutes (soil surface was 112°F, air temperature 1 inch above ground was 89°F, clear, wind 0-5 mph). For one minute she brushed soil and litter over the hole with her

hind tarsi, but the opening remained visible. Afterwards, she climbed on top of a blue grama plant and rested, while the attending male walked away. Three eggs, lightly cemented together and vertically oriented, were recovered from the soil cell. Another observation of oviposition was made 26 July 1978 between 8:30 and 9:00 a.m. (air temperature at 8:30 was 72°F); this female also bored into an old blue grama crown.

Crenulatewinged females produce two to three eggs at one time, but do not produce a pod for their protection. The eggs are pale yellow and 5 to 5.5 mm long (Fig. 8).

Population Ecology

The crenulatewinged grasshopper is a resident of western grasslands, and lives most often as a subdominant member of an assemblage of 12 to 18 acridid species. Densities usually remain low, ranging from 0.05 to 1 young adult per square yard. In many areas of the mixedgrass, shortgrass, and desert prairies it does not appear to be present as measured by square foot visual sampling or by sweep net collection. On sites where it is present, populations persist from year to year in fluctuating low numbers (Table 1).

The environmental factors that allow increases in typically dominant species also allow increases in the crenulatewinged grasshopper. How increases arise in the latter species to dominance of eight per square yard is unknown.

Daily Activity

The crenulatewinged grasshopper spends the night resting in the crown of blue grama grass or on ground litter under a canopy of blue grama. At sunrise the grasshoppers are immobile and quiet. At this time, ground surface and air temperatures are low, ranging from 50° to 60°F. About 90 minutes later, the grasshoppers begin to stir and take basking positions in which they assume two main orientations. Sitting on top of blue grama or on ground litter they may present a side perpendicular to the sun's rays and lower the exposed hindleg. In this orientation, some grasshoppers tilt their bodies slightly to expose their backs as well as their sides. In the second orientation, grasshoppers rest diagonally on blue grama with their hindlegs on the ground so as to expose their backs to the sun's rays. Grasshoppers bask for about one to two hours before they begin normal activities of pottering, feeding, mating, and ovipositing. These activities continue until temperatures become too hot (surface of soil 120°F and air temperature 1 inch above ground 85°F). The grasshoppers then either climb grass leaves and rest head up one-fourth to one inch above ground level or they climb on top of blue grama and face the sun to expose a minimum of their body surface. In the latter orientation, they may spread apart their flexed hindlegs. When temperatures moderate they again become active. Only one observation has been made of this grasshopper as it settled down for the night. Shortly before sunset, a female was discovered sitting quietly on the ground under a canopy of blue grama plants.

Table 1. Density of young adult crenulatewinged grasshoppers in an upland northern mixedgrass prairie site (5 miles west of Guernsey, WY) in a shortgrass prairie site (5 miles northeast Nunn, CO).

	Number young adults per sq. yd.						
Site	**1968**	**1969**	**1970**	**1971**	**1972**	**1973**	**1974**
Guernsey, WY	0.05	0.05	0.05	0.1	0.1	0.5	0.9
Nunn, CO				0.5	0.4	0.6	0.9

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Spottedwinged Grasshopper

Cordillacris occipitalis (Thomas)

Distribution and Habitat

The spottedwinged grasshopper, *Cordillacris occipitalis* (Thomas), has a wide distribution in western North America. It inhabits grasslands including the mixedgrass, shortgrass, desert, and bunchgrass prairies.

Economic Importance

The spottedwinged grasshopper is a pest of rangeland grasses, especially in areas of the mixedgrass prairie where the texture of soils is sandy loam. There it is often the dominant species. Young adults reach densities as high as 40 per square yard. In areas with heavier soils, densities are less or the species is virtually absent, as it is in much of the bunchgrass prairie. Light densities of one to five per square yard are common in the mixedgrass and shortgrass prairies, and these numbers of the spottedwinged grasshopper then add to the damage of the dominant species.

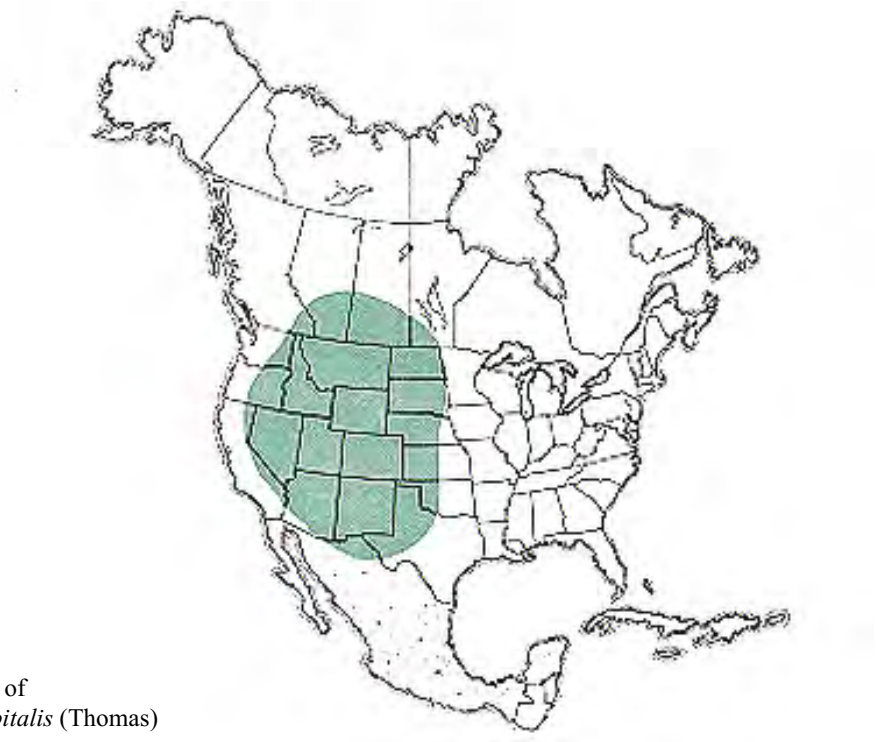
The spottedwinged grasshopper weighs approximately half that of the bigheaded grasshopper. Live weights of spottedwinged males average 101 mg and females average 224 mg (dry weight: males 30 mg, females 67 mg). As both species have similar feeding habits, the assumption is that a spottedwinged grasshopper has half the impact of a bigheaded grasshopper on rangeland forage.

Food Habits

The spottedwinged grasshopper feeds on the green leaves of grasses. It climbs a plant and in a head-down position chews on a leaf. It holds onto the leaf with its front tarsi and usually consumes all of the cut portion. Sometimes it loses a leaf, especially a short tip, which then falls to the ground. This usually is eaten by other grasshoppers or becomes litter.

A study in eastern Colorado has shown a high and significant correlation between the frequency of plant species in the diet of this grasshopper and the frequency of grass species in its habitat. The study indicates that this grasshopper is not highly selective, as it feeds on a variety of grasses. Common host plants of the spottedwinged grasshopper include blue grama, needleandthread, western wheatgrass, sand dropseed, downy brome, threadleaf sedge, and needleleaf sedge. Observations of its feeding and analyses of crop contents reveal that it grazes on a minimum of 15 species of grasses and four species of sedges.

Only rarely does this grasshopper consume forbs or ground litter. Arthropod parts have occasionally been found in crop contents. No information is available on whether this grasshopper feeds on bran bait. It is



Geographic range of
Cordillacris occipitalis (Thomas)

Instar 1

1. BL 5.2-6.0 mm FL 3.2-3.4 mm AS 13.

Instar 2

2. BL 8.2-8.8 mm FL 4.5-4.8 mm AS 17.

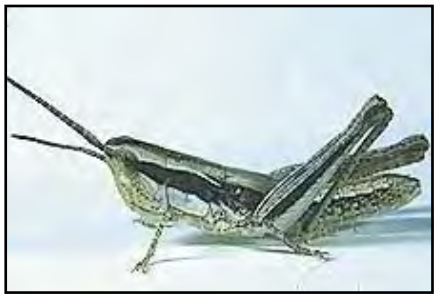
Instar 3

3. BL 9.3-10 mm FL 4.9-5.9 mm AS 19-20.

Instar 4

4. BL 9.7-13.1 mm FL 5.7-8.0 mm AS 21-22.

Instar 5



5. BL 12.7-16 mm FL 7.9-9.8 mm AS 22-24.

Figures 1-5. Appearance of the five nymphal instars of *Cordillacris occipitalis* - their sizes, structures, and color patterns. Notice progressive development of the wing pads. BL = body length, FL = hind femur length, AS = antennal segments number.

attracted, however, to discarded fresh apple cores, which it eats from a horizontal position on the ground.

Migratory Habits

There are no records of the spottedwinged grass-hopper making dispersal or migratory flights. The possession of long wings, however, that extend to the end of the abdomen or beyond, provide it with the necessary appendages for lengthy flight. One indication that it may make dispersal flights is found in the observation of a large population of young adults on a site in the mixed-grass prairie of eastern Wyoming. These grasshoppers disappeared between weekly samplings. Neither live grasshoppers nor their carcasses were observed in this area where an economic infestation existed a week earlier.

Evasive flights of the spottedwinged grasshopper are straight, silent, low (2 to 4 inches), and short (2 to 4 feet). These flights are usually with the wind but may be across the wind.

Identification

The adult of this species is a tan and gray, slim, medium-sized grasshopper (Fig. 6 and 7). Antennae are tan or pale and slightly ensiform. A conspicuous brown stripe is present on the side of the head extending from behind the middle of the compound eye and continuing onto the lateral lobe of the pronotum. The pronotum has a low but distinct median carina, which is cut once behind the middle, and low lateral carinae highlighted in ivory. Wings are long, extending to the end of the abdomen or slightly beyond; tegmina are spotted brown (the character that gives this grasshopper its common name) with an ivory streak above base of hindleg (Fig. 6 and 8). Hind tibiae are pale orange.

The nymphs of the spottedwinged grasshopper are identifiable by their shape, color patterns, and external structures (Fig. 1-5).

1. Head with strongly slanted face; antennae ensiform and colored brown with anterior edge of segments light tan.
2. Conspicuous brown stripe on side of body starts from behind middle of compound eye, runs on side of head, and continues onto side of thorax and abdomen. Wide tan stripe with brown spots on dorsum of body.

Figures 6-10. Appearance of the adult male and female of *Cordillacris occipitalis*, wings, and the egg pod and an opened pod exposing three eggs in situs.

3. Pronotum with low, distinct median carina; lateral carinae colored light yellow or ivory.
4. Hind femur with upper medial area brown, lower medial area light gray.

Hatching

The spottedwinged grasshopper is an early-hatching species. Eggs begin incubation upon being laid in the ground and develop to embryonic stage 19 by fall. At this time they are in diapause. Development resumes when temperatures rise in spring. The nymphs emerge five to seven days ahead of the nymphs of the bigheaded grasshopper. The hatching period lasts four weeks. The eggs lie at a shallow depth (top one-half inch of soil) and are exposed to hot temperatures and dry conditions in summer. Eggs are able to withstand the heat and desiccation; they remain viable and absorb lost water whenever moisture conditions become favorable. Predators - birds, rodents, beetles, bee flies - hunt for them in the ground and feed on them.

Nymphal Development

Although nymphs are present in the habitat for eight weeks, individual nymphs do not take this much time to reach the adult stage. From twice weekly sampling and mathematical calculation, the length of the nymphal period has been estimated to be 22.5 days. Further divisions of this period are estimated as 5.5 days for the first instar, 6 days for the second, and 11 days for the last two or three nymphal instars. From our knowledge of grasshopper development in several other species, the figure of 11 days for the last instars appears to be underestimated. For an individual female nymph to develop to adulthood, a more reasonable distribution of instar development times would be 5.5, 6, 7, 8, and 9 days, or 36 days for the entire period. This figure is closer to the estimate of 41 days for nymphal development based on the usual method of estimating the length of the nymphal period in nature (i.e. the number of days between the first appearance of nymphs and the first appearance of adults.)

Adults and Reproduction

Adults remain in the same habitat in which the nymphs hatch and develop. This habitat continues to furnish nutritious food and a favorable place in which to

Male

6. BL 16.5-18.5 mm FL 10-10.4 mm AS 24-25.

Female

7. BL 21-23.5 mm FL 12-12.8 mm AS 24-25.

Wings

8. Forewing (tegmen) showing spots and clear hindwing.

Egg pod

9. A whole egg pod and one opened to show eggs.

live, in spite of an abundance of deadly enemies, such as birds, rodents, spiders, and insect predators and parasites.

Mating pairs are seen in the habitat after a week or two of adult maturation. The male attracts females with his calling song, made by stridulating (rubbing a line of pegs on the hind femur against a raised intercalary vein of the tegmen). He approaches an attracted female and sends visual signals by raising and lowering his antennae and tipping his hindlegs. Before he mounts her, the male assumes a position at right angles to the female. Both mating and oviposition usually occur in the morning.

When ready to lay eggs, the female may brace herself on a clump of grass and then work her abdomen down into bare ground, or she may simply oviposit in a bare area. The pod is formed in a vertical position and usually contains two or three eggs oriented vertically in the bottom half.

No cage studies have been made to determine the fecundity of the spottedwinged grasshopper. Field sampling of eggs indicate that fecundity is about half that of the bigheaded grasshopper. Peak adult densities of both species were nearly the same in a mixedgrass prairie site in eastern Wyoming, 5.7 per square yard of the spottedwinged grasshopper and 5.8 per square yard of the bigheaded grasshopper. Sampling of eggs in fall showed the presence of 22 eggs per square yard of the spottedwinged grasshopper and 45 eggs per square yard of the bigheaded grasshopper.

The pod of the spottedwinged grasshopper has the shape of a tiny test tube. It is three-eighths inch long and one-eighth inch in diameter (Fig. 9). A froth plug is recessed about one-eighth inch from the top. Eggs are pale yellow and 4.4 to 5.6 mm long.

Population Ecology

For periods of five years and longer, low densities of 0.2 to 0.5 individuals per square yard of the spottedwinged grasshopper occur in assemblages of grasshoppers inhabiting the mixedgrass prairie. In sites of sandy loam soils, however, the spottedwinged grasshopper may follow Parker's model of population growth in which the population increases by two fold each year for three successive years then by three to four fold in the fourth year, reaching outbreak numbers. Such an irruption occurred in an eastern Wyoming site in 1974. In the assemblage of grasshopper species of the outbreak, the spottedwinged grasshopper was dominant at a density of 20 per square yard. This density was followed by the whitewhiskered grasshopper at nine per square yard, the bigheaded at seven per square yard, and the striped grasshopper at seven per square yard. Nine other species of grasshoppers made up the remainder of the assemblage and totaled six per square yard. The causes of the phenomenal increases of the spottedwinged grasshopper are unknown but may be related to variations in predation of the adults. Detailed sampling of natural populations indicates that when adults survive into late summer the females are released from reproductive control and lay more eggs.

Daily Activity

The spottedwinged grasshopper spends part of its day on the ground and part in vegetation. During the night the nymphs usually rest head-up on grass leaves two to seven inches above the ground. Adults rest either on vegetation or on the ground. About one-half to one hour after sunrise the majority of individuals have moved to the ground and are basking - sides perpendicular to rays of the sun and hugging the ground. They bask for an hour or longer. When air temperature rises to 70°F, they begin normal activities of pottering, feeding, and mating. The females oviposit later in the morning, when air temperature registers 82°F.

When air temperatures for brief periods rise above 90°F and soil temperatures above 120°F in midsummer, the grasshoppers, adults by this time, climb small shrubs (e.g., fringed sagebrush and spreading wildbuckwheat) for protection from the heat. They rest head-up in the shade two to eight inches above the ground.

Later in the afternoon when air temperatures have declined to 90°F or lower, the grasshoppers once again become active and begin a second period of feeding. Later they may bask, and eventually they take up their night resting positions in the vegetation or on the ground.

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Hayden Grasshopper

Derotmema haydeni (Thomas)

Distribution and Habitat

The Hayden grasshopper has a wide geographic range in western North America. It inhabits the mixed-grass, shortgrass, desert, and bunchgrass prairies. In these divisions of vegetation it usually occupies disturbed land with a high percentage of barren area. It is frequently found in prairie dog towns, at the sides of county and ranch roads, in abandoned fields, and in vacant city lots.

Economic Importance

The Hayden grasshopper causes little damage to rangeland forage. Densities of this grasshopper are usually low, and it feeds mainly on forbs.

Food Habits

This grasshopper appears to prefer certain forbs. In laboratory preference tests, adults clearly preferred leaves of dandelion to leaves of blue grama, western wheatgrass, prostrate knotweed, and Russian thistle, but fed nearly as well on downy brome as dandelion. In Montana it has been observed to feed on common purslane. Crop contents of one nymphal and five adult specimens collected in the shortgrass prairie of the Pawnee Grassland (Colorado) consisted of 69 percent plains bahia, 10 percent scarlet globemallow, 7 percent needleleaf sedge, and 6 percent fringed sagebrush; three other forbs and three grasses made up the remaining items (8 percent).

Several direct observations of its feeding indicate that it feeds on dry plant litter and on recumbent green leaves from a horizontal position on the ground. In the laboratory it was observed feeding on the edge of a green dandelion leaf. Further observations are needed to find out how it attacks upright plants such as plains bahia and scarlet globemallow.

Dispersal and Migration

No observations of dispersal or migration by this grasshopper have been made. However, its possession of long wings that extend beyond the abdomen in both males and females suggests that it has the capacity to fly long distances.

Evasive flights of the species have been observed. Their distances range from 2 to 6 feet and their heights

Geographic range of
Derotmema haydeni (Thomas)

Instar 1

1. BL 3.8-4.7 mm FL 2.2-2.4 mm AS 13-14.

Instar 2

2. BL 5.0-6.7 mm FL 3.3-3.6 mm AS 16-17.

Instar 3

3. BL 6.3-8.2 mm FL 4.1-4.3 mm AS 18-20.

Instar 4

4. BL 8.1-12.7 mm FL 5.5-6.2 mm AS 21-22.

Instar 5

5. BL 12-18.5 mm FL 7.5-8.7 mm AS 23-26.

Figures 1-5. Appearance of the five nymphal instars of *Derotmema haydeni* - their sizes, structures, and color patterns. Notice progressive development of the wing pads. BL = body length, FL = hind femur length, AS = antennal segments number.

from 4 to 10 inches. The flights may be straight or the grasshopper may make a right angle turn midway in the flight. Flights begin from the ground and end on the ground. They may have a smooth trajectory or they may end abruptly by a quick turn of the flying insect. In the latter trajectory the grasshoppers appear to drop out of the air to the ground facing in various directions on landing.

Identification

The Hayden grasshopper is a medium-sized, bulbous-eyed, bandwinged species (Fig. 6 and 7). General body color is tan and brown. The tegmina are marked with many fuscous spots; the hindwings have a broad dark band that extends from front to hind margin and a red or yellow basal area (Fig. 9). The disk of the pronotum has prominent ridges and nodules; the median carina is distinct and cut twice, once near the middle and once in front of the middle; the posterior margin of the disk is angulate.

The nymphs are identifiable by their shape, structures, and color patterns. First instar nymphs are distinctively marked by four shiny black nodules on the front of the head and two on the pronotum (Fig. 1). A flat black patch is located on the head behind each compound eye. Below these marks, a broad yellow or light tan band runs around the head and onto the lateral lobes of the pronotum. The band becomes less clear, and the nodules flatten and become less dark and shiny in instars II and III and disappear in instars IV and V.

Other distinguishing characteristics of the nymphs (Fig. 1-5) include the following:

1. Head with protruding, bulbous compound eyes; fastigium steeply slanted; antennae filiform.
2. Thorax raised in instars I to III, giving a humpbacked appearance to the early instars. Pronotum with distinct median carina, cut twice; disk rugose and nodulate, more so in older instars; posteroventral angle of lateral lobe rounded.
3. Bottom of abdomen cream or tan with a pair of rust-colored spots on each segment (Fig. 8), spots fainter and fewer in instar I, spots more numerous in instar V.
4. General body color brown and tan.

Figures 6-10. Appearance of the adult male and female of *Derotmema haydeni*, rust spots on abdominal sterna of nymph, wings of an adult female, and egg pod and exposed eggs.

Hatching

The Hayden grasshopper is considered a late-hatching species. The eggs hatch four to five weeks after those of the bigheaded grasshopper, Aulocara elliotti. In eastern Colorado and eastern Wyoming hatching occurs during June. No investigation of embryonic development of this species has been made.

Nymphal Development

The five nymphal instars require about 40 days to develop to the adult stage. Because of the extended hatching time, as many as three different instars may be found in the habitat during much of the nymphal period. In eastern Colorado and Wyoming adults begin to appear during the last few days of July.

Adults and Reproduction

The adults remain in the same habitat in which they developed as nymphs. They live active lives during August and September. Little is known about their reproductive biology. Observations have been made on courtship, which appears to vary slightly among populations studied in Colorado, Utah, and California. However, at all three locations courtship was rather short and simple and usually consisted of the male tipping his hind femora, stridulating one to three times, and then mounting the female.

No information is available on when females begin to oviposit, how many eggs they produce during their life, or where they oviposit. In the laboratory, females readily oviposit into a container of bare soil. They take approximately one hour to complete an oviposition. The pods are curved, about an inch long, and contain 16 to 17 pale yellow eggs 4.3 mm long (Fig. 10). There is one generation annually.

Population Ecology

No special study of the ecology of this grasshopper has been undertaken. From other studies we do know a few facts about their population ecology: the species has a wide geographic range in the West, densities are usually low, and dispersion of individuals is concentrated in the bare areas of mixedgrass and shortgrass prairies. In shrub-grass habitats with a preponderance of bare areas, individuals are scattered throughout the habitat. Densities

Male

6. BL 15.5-17 mm FL 9-10.2 mm AS 24-26.

Female

7. BL 20-25 mm FL 10.7-12.6 mm AS 24-26.

Abdominal Sterna

8. Paired rust spots on abdominal sterna and metasternum of nymphal instar IV.

Wings

9. Spread wings of female.

Egg pod

10. Egg pod and exposed eggs of another pod.

of clumped adults are usually no more than one per square yard, but on occasion they may become higher. In the Marfa prairie of the Big Bend Region of Texas, Ernest R. Tinkham (1904-87), a well-known entomologist and naturalist, found this species “quite abundant” on bare adobe patches.

Daily Activity

The Hayden grasshopper is a ground-dwelling insect. At night nymphs and adults rest horizontally on the ground surface either under a canopy of plants, or exposed without any cover. Approximately one hour after sunrise both nymphs and adults begin to bask in the warming rays of the sun. They turn a side perpendicular to the rays and lower the hindleg of the exposed side to the ground. After basking for about two hours, adults begin normal activities of walking about on open ground, occasionally producing femur-tipping movements, feeding, and mating. These activities continue until ground temperatures in the afternoon become too hot (120°F and above). Then they seek the shade of vegetation and rest horizontally on the ground surface. After soil temperatures moderate they again become active. They may come out into the sun too soon and take a stilt posture in which they hold their bodies off the hot (101°F) ground surface. In the evening they bask again and finally take their night time positions sitting horizontally on the ground surface.

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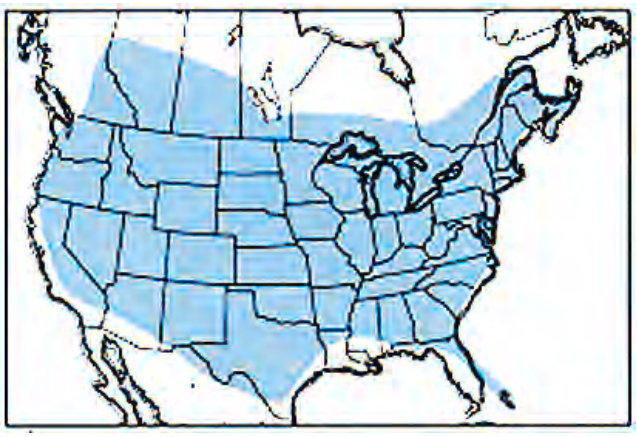
Carolina Grasshopper

Dissosteira carolina (Linnaeus)

Distribution and Habitat

The Carolina grasshopper, a large bandwinged species, ranges widely in North America inhabiting weedy grasslands. Blowouts, field margins, roadside strips, weedy fence rows, railway cuttings, and disturbed rangeland support moderate populations of this species. During the day when temperatures warm, the adults move from vegetated to bare areas such as dirt roads where they fly about and become highly conspicuous.



Geographic range of *Dissosteira carolina* (Linnaeus)

Economic Importance

The Carolina grasshopper is a minor pest of rangeland grasses. Populations occur chiefly in disturbed areas where it feeds mainly on several species of weeds. The populations that irrupt in favorable habitats, however, may disperse and damage crops. Disturbed areas reseeded with smooth brome foster large numbers of this species, which not only feed on the brome but often fly to fields of fall wheat where they cause stand damage. An outbreak of the Carolina grasshopper that irrupted in southern Saskatchewan in 1933 and 1934 caused considerable damage to the crops of this region. In some years the species has damaged tobacco in southern Ontario. It has also been recorded as causing minor damage to alfalfa. In 1935 it was especially destructive to field beans in the vicinity of Flagstaff, Arizona. In Oklahoma it has been reported to damage corn, sorghum, cotton, and potato. No detailed study of its economic importance, however, has been made.

Because of its large size the Carolina grasshopper has been regarded as a voracious feeder capable of causing much damage at moderate densities. The live weight of males averages 570 mg and of females 1,467 mg (dry weight: males 171 mg, females 387 mg).

Food Habits

The Carolina grasshopper selects food plants from both grasses and forbs. An individual's diet depends largely upon the kinds of host plants present in its habitat. An investigation of plants ingested by adults living in two different habitats reveals the wide variation that may occur naturally in their diets. In a disturbed site that had been reseeded to smooth brome and crested wheatgrass, crop contents of adults consisted of 98 percent smooth brome, while in a disturbed site where no reseeding was done but weed invasion had taken place, crop contents consisted of 64 percent weeds and 33 percent native grasses (Table 1). Although the Carolina grasshopper may be considered a polyphagous species, it prefers some plants over others. Ingested weeds in Site 2 (Table 1) consisted principally of kochia and Russian thistle; weeds rejected included netseed lambsquarters, redroot pigweed, and curlycup gumweed.

Two-choice laboratory tests revealed that the Carolina grasshopper fed readily on downy brome, smooth brome, western wheatgrass, wheat, barley, dandelion, and kochia. Because of its wide distribution, the Carolina grasshopper undoubtedly has many more host plants than presently known.

Table 1. Mean percent dry weight of plant fragments in crops of adult *Dissosteira carolina*.

	Food	Site 1	Site 2
Grasses	Agropyron	0.6	10.9
	Andropogon		3.8
	Bromus	98.3	8.5
	Carex		7.9
	Sporobolus cryptandrus		11.0
	Sporobolus seed		0.2
Forbs	Atriplex		0.2
	Kochia scoparia	1.1	32.3
	Kochia seed		2.0
	Salsola iberica		21.4
	Seed sp.		0.6
	Sphaeralcea coccinea	0.1	
	Feather		2.0
	No. grasshopper crops	15	19

Site 1 Wyoming, Laramie Co. Pine Bluffs Rest Area, 4 September 1992, disturbed mixedgrass prairie, reseeded to smooth brome and crested wheatgrass.

Site 2 Wyoming, Laramie Co. 11 miles west Pine Bluffs (R62W T14N Sec36 NW) 16 September 1992, distrubed mixedgrass prairie, invaded by weeds.

Several observations of the Carolina grasshopper's feeding in nature have been made. On 5 August 1992 at 6:51 p.m. DST with soil temperature 81°F and air at 1-inch level 74°F, an instar III female climbed a 3-inch tall kochia plant and in a vertical head-up position fed on a kochia leaf (2 x 7 mm) beginning at the tip and devouring it to its base leaving a 2 mm stub.

On 27 July 1990 at 9:10 a.m. an adult male was discovered sitting on ground litter facing the sun in a city lot. At 9:13 a.m. the male began to stir and walked a short distance to a short grass, *Buchloe dactyloides*. At 9:14 a.m. the male reached up with its mouthparts to the tip of a leaf and consumed the whole leaf to the base. He then attacked another leaf of the same plant, cutting it near the middle. Holding onto the cut section with the front tarsi, he consumed all of it from

Instar 1

1. BL 6.5-7 mm FL 3.5-3.8 mm AS 12-14.

Instar 2

2. BL 7.8-9.1 mm FL 3.7-4.2 mm AS 15-16.

Instar 3

3. BL 8.8-13.5 mm FL 4.6-7.3 mm AS 18-20.

Instar 4

4. Males: BL 13-15 mm FL 7-7.5 mm AS 21-23.
Females: BL 16-20.5 mm FL 9.3-10.3 mm AS 20-21.

Instar 5

5. Females:
BL 20.5-22.5 mm FL 12-17.7 mm AS 21-24.

Figures 1-5. Appearance of the five nymphal instars of *Dissosteira carolina* - their sizes, structures, and color patterns. Notice progressive development of the wing pads. BL = body length, FL = hind femur length, AS = antennal segments number.

the cut end to the tip. He then cut another leaf of the same plant near the base, held onto it with the front tarsi, and ate all of it. A fourth and final leaf was eaten from the tip to the base. Feeding ended at 9:24 a.m. During all of the feeding the male sat horizontally on the ground, resting on the mid- and hindlegs and using the forelegs to handle the food. The weather was clear, warm, and calm (soil surface 94°F, air 72°F, at 1-inch level, wind 0-2 mph).

On 2 October 1992 from 4:28 to 4:37 p.m. DST (soil surface 92°F and air 1-inch level 80°F), three females wandering around on bare ground were observed to feed on ground litter (dry grass and unidentifiable vegetation). The females were horizontal on the surface. One female was observed to spread out her front legs rather than use the front tarsi to handle the food.

These few observations suggest that the Carolina grasshopper is a thrifty feeder because it appears to eat all of whatever it attacks.

Migration and Dispersal

The Carolina grasshopper is a strong, adept flier. During warm, sunny days the adults frequently fly over bare ground interacting with one another. Males are noted for their hovering flight. They rise almost vertically from the ground to heights of 3 to 6 feet, occasionally higher, and hover for 8 to 15 seconds. At the end they flutter down to the ground close to where they started. They may repeat this maneuver as many as five times. During the hovering flight they produce a soft, sibilant sound. The hovering behavior may be a part of courtship in that it attracts females. The display also attracts males so that a small aggregation of several males and a female may gather on the bare ground beneath the hovering male.

In voluntary or appetitive flights, adults fly a distance of 2 to 36 feet at heights of usually 1 to 2 feet. They undulate and may crepitate as they fly. Adults are wary and flush readily at the approach of a person. In flushed flight they may travel a distance of 4 to 70 feet or much farther in a strong wind. They fly at heights of 1 to 5 feet and often make a right angle turn at variable distances into the flight before landing on the ground.

No special study of dispersal or migratory flight has been made, but it is known that adults have moved from resident localities near Boulder, Colorado to nonresident mountain sites above 10,000 feet, approximately 14 miles west. In the vicinity of Washington, D.C., considerable numbers frequently fly around the electric lights during warm summer nights. The species has also been collected at lights in Presidio, Texas and in North Branch and Minneapolis, Minnesota.

Identification

The Carolina grasshopper, one of North America's largest grasshoppers, is a conspicuous species because of its size, colorful wings, and habit of flying over dirt roads and other bare ground (Fig. 6 and 7). The wingspread of the males

Figures 6-10. Appearance of the adult male and female, wings, inner surface of hindleg, and egg pod and exposed eggs.

measures 3 inches and that of the females 3 1/2 to 4 inches. The hind wings are black with a pale yellow margin (Fig. 8). The tegmina are colored tan, brown, or gray matching the general body color and are faintly speckled.

The nymphs are identifiable by their color patterns, shape, and external structures (Fig. 1-5).

1. Head with face nearly vertical; antennae filiform, terminal segments dark, basal segments colored like body; lateral foveolae small and triangular.
2. Pronotum with median carina strongly elevated and cut once.
3. Hind femur with medial area evenly colored like body, may be spotted in instars IV and V; inner knee tan or fuscous, basal half of inner medial and lower marginal areas fuscous, distal half with two pale yellow transverse bands (Fig. 9); hind tibia of instar I and II black with basal annulus pale yellow, hind tibia of instars III to V with variable patterns of tan, gray, and black; hind tarsus white or pale yellow except distal end fuscous.
4. General body color tan, brown, or gray. Reddish in individuals developing on red soils.

Hatching

The Carolina grasshopper is an intermediate-hatching species. In eastern Wyoming hatching may start in early June or may be delayed until late June. Although egg development has not been studied in this species, the fact that oviposition takes place late in summer suggests that much development probably occurs during the following spring. This speculation appears more plausible in view of the results of subjecting overwintered field-collected eggs to five different constant temperatures. At 77°F, eggs of the Carolina grasshopper completed incubation in 22 days, whereas the twostriped grasshopper *Melanoplus bivittatus* completed incubation in 7 days and the differential grasshopper, *M. differentialis* in 21 days. Egg development of the Carolina grasshopper appears more like that of the differential grasshopper, which achieves less growth before diapausing than the twostriped.

Nymphal Development

The nymphs emerge over a period of at least two weeks and develop in a habitat of grass and weeds with much interspersed bare ground. Hatching, however, may at certain times and places be extended over several weeks so that as many as four different instars (I to IV) coexist together in a habitat. Limited data obtained in eastern Wyoming indicate a nymphal period of 40 days at an altitude of 4,700 feet and 55 days at an altitude of 6,100 feet. Reared in the laboratory, nymphs complete development in 52 days at a constant temperature of 77°F and 26 days at a constant temperature of 86°F. The Carolina grasshopper has been described as a heat-loving species that prefers the hot, bare areas of its habitat.

Male

6. BL 29-32 mm FL 14.5-16 mm AS 25-26.

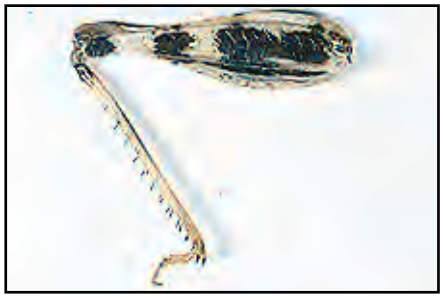
Female

7. BL 36-39.5 mm FL 17.5-19 mm AS 25-27.

Wings

8. Left forewing (tegmen) and hindwing of female.

Hindleg



9. Inner surface of left hindleg of adult female.

Eggs

10. Egg pod and several exposed eggs.

Adults and Reproduction

The adults appear during May in New Mexico and eastern Nebraska, during early July in eastern Wyoming, and during late July in western Idaho. Once Carolina grasshoppers acquire functional wings, they fly and disperse extensively. Adults may move distances of several miles or more, as they have been found in the center of large cities. The full extent of individual dispersal, however, is unknown.

The habitat in which the eggs hatched and the nymphs developed remains occupied by adults, most likely by an assemblage composed of some of the original inhabitants and some immigrants. The males court females by producing a calling signal using their hindlegs and wings to stridulate. One hindleg at a time is rubbed against the tegmen in a behavior called alternate stridulation. A male sits horizontally on bare ground in sunlight and may continue to call for 5 minutes or longer until he attracts a female. She walks toward him and when she is close he approaches her and mounts. If he is successful, the pair mate. They may remain in copulo for as long as 16 hours.

Sexual maturation of females appears to be prolonged. In Minnesota, where the adult stage is reached in early June, the females do not begin to oviposit until early August, suggesting that nine weeks are required for maturation. In Manitoba, oviposition has been observed in September and in Wyoming in September and October.

The female selects compact bare ground exposed to the sun in which to oviposit. The selected site is often the edge of a gravel or dirt road. She works her ovipositor to a depth of 1 1/2 inches and deposits a large clutch of eggs that she encloses in a sharply curved pod (Fig. 10). After approximately 1 1/3 hours, she extracts her ovipositor and for one to three minutes brushes surface particles with her hind tarsi over the aperture of the hole. The pod, nearly 2 inches long, usually contains more than 40 eggs. Two egg pods obtained after observing the females oviposit at the edge of a gravel road in southeastern Wyoming contained 50 and 57 eggs, respectively. Reared in a greenhouse, caged females have laid from 30 to as many as 70 eggs in a pod. The eggs are reddish brown and 4.8 to 5.8 mm long.

Population Ecology

The population ecology of the Carolina grasshopper has received no special study. Several population characteristics, however, can be inferred from general studies of grasshopper assemblages in which the Carolina was a member. Populations appear to persist year after year as long as the habitat remains intact. Because of the Carolina grasshopper's association with human activities, habitats may be destroyed by development projects, by rerouting of ranch roads, or by changes in farming and ranching practices. Collections of nymphs and adults from a city lot in Wheatland, Wyoming were made for a period of four years, 1989-92, during which the densities of the successive populations remained approximately the same.

Although adults are conspicuous because of their size and flashy wings, giving the impression of large numbers, the density of populations is usually low, around 0.1 to 0.2 young adults per square yard. Populations irrupt infrequently, as in southern Saskatchewan in 1933 and 1934, causing serious loss of crops. No estimates of absolute densities were determined during this outbreak.

Daily Activities

The Carolina grasshopper, a ground-dwelling species, is active chiefly during daylight hours. Emerging from overnight shelters, both nymphs and adults bask in the morning sun for two to three hours beginning approximately two hours after sunrise. They turn a side perpendicular to the rays and lower the associated hindleg to expose the abdomen, and they often appress the flexed hindleg close against the ground.

After basking, the adults begin to walk and fly about the habitat. The males are more active than the females, perhaps searching for receptive females with which to mate. Females walk and fly far less than males, but do more feeding, grooming, and resting. Seven observations of feeding by adults indicate that this activity occurs in the afternoon from approximately noon to 5 p.m. DST. An observation of courting occurred at 12:25 p.m. Mating pairs have been observed in the afternoon: two pairs at 2:15 p.m., one pair at 3:15 p.m., and one pair at 3:47 p.m. In the George Reserve, Michigan, a pair observed in copulo at 5:20 p.m. on August 4, remained together until 7:50 a.m. the next morning. Three extended observations of oviposition in eastern Wyoming indicate that females perform this function during midday with oviposition beginning as early as 10:30 a.m. and as late as 2:30 p.m.

Hot ground temperatures of 110°F. and air temperature of 90°F., 1-inch level, induce the adults to stilt. As temperatures rise, the grasshoppers climb on vegetation and place themselves 1-3 inches above ground. They face the sun directly so that only the front of the head is exposed to the rays and the rest of the body is shaded.

In the afternoon the adults bask on bare ground for a second time beginning about 3 p.m. and ending about 5 p.m. Then they walk or fly to vegetated areas where they seek shelter usually under canopies of grasses. Sampling of their density on a bare, gravel road in Laramie County, Wyoming on 4 October 1992 showed that adults (0.06 per square yard) were 20 times more prevalent at 4 p.m. DST than at 5:17 p.m., and none were found at 5:29 p.m.

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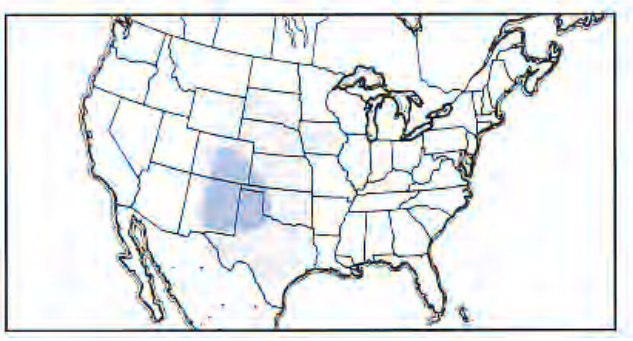
High Plains Grasshopper

Dissosteira longipennis (Thomas)

Distribution and Habitat

The High Plains grasshopper inhabits the shortgrass prairie, a floral province dominated by shortgrasses, principally blue grama and buffalograss. In addition, this province supports a moderate amount of three or four species of midgrasses in any one locality. Common among these midgrasses are western wheatgrass, needleandthread, sand dropseed, red threeawn, and *galleta hilaria*. Also present in the shortgrass prairie are several sedges, forbs, and small shrubs along with much interspersed bare ground. The biogeographic map of the High Plains grasshopper shows an inner area (colored dark blue) where scouts found both nymphs and adults during the 1934-40 outbreak of the species and an outer area (colored pale blue) where they collected only adults. During the outbreak, swarms of the High Plains grasshopper dispersed widely from habitats of their origin. The species has been recorded infrequently in assemblages of rangeland grasshoppers during nonoutbreak years, yet it continues to survive and reproduce in especially favorable habitats. Such a habitat occurs in Otero County, Colorado, 5 miles southwest of Hawley. The area is characterized by sandy loam soil (Olney) with a 0 to 3 percent slope. Readily absorbing rainfall, the soil fosters an abundance of three midgrasses (sand dropseed, galleta hilaria, and red threeawn) in addition to the short grasses, (blue grama and ring muhly).



Geographic range of *Dissosteira longipennis* (Thomas)

Economic Importance

The High Plains grasshopper can be a pest of rangeland grasses. During outbreaks enormous numbers completely devour the grasses in their habitat. Hatching from concentrated egg beds, the young grasshoppers spread out in all directions from these loci and eventually consume the grasses of the invaded areas. When the nymphs become older they march in bands seeking food. In their progression they completely consume the grasses of the rangeland and any fields of wheat, barley, corn, or millet they encounter. The adults have a propensity to migrate in huge, flying swarms and cause forage and crop destruction wherever they land. During the 1934-40 outbreak, ranchers whose pastures were infested found it necessary to move their cattle to distant pastures only to have these destroyed by alighting swarms. These dire outcomes forced many ranchers to sell their entire herds.

Described in 1872 by Cyrus Thomas, the High Plains grasshopper was considered a rare species until migrating swarms were observed in Colorado in 1890 and the first known outbreak was recorded a year later (Table 1). The most recent outbreak from 1934 to 1940 was calamitous. Entomologists now recognize that this grasshopper may also occur as a damaging member of destructive rangeland assemblages. The High Plains grasshopper is one of the largest species among those destructive to rangeland forage. Collected in the Hawley site on 16 July 1997, live weight of males averaged 647 mg and of females 1,371 mg (dry weight: males 245 mg, females 450 mg).

Food Habits

The High Plains grasshopper is a general grass feeder. Field entomologists have often reported this grasshopper's damage to short grasses (blue grama and buffalograss), but it feeds also on midgrasses. In two-choice preference tests, the High Plains grasshopper fed as well on midgrasses (sand dropseed, needleandthread, and *galleta hilaria*) as on blue grama. Although it fed on western wheatgrass, this host was not consumed as much as the other midgrasses.

The feeding of five late instar nymphs and 13 adults was observed in their natural habitat (Hawley, Colorado) during the summer of 1997. Four nymphs and nine adults fed on sand dropseed, one adult fed on blue grama, and one on needleandthread. One nymph and an adult were observed feeding on ground litter. Although the grasshoppers were observed to taste leaves of nearby plants before feeding, no evidence was obtained of their moving to find particular species of grass.

Spring 1997 was very dry in Otero County, Colorado. When the majority of observations of feeding were made, sand dropseed had been grazed heavily by cattle and grasshoppers. Plants were short with stems grazed down to 1 to 3 inches, and most leaves were dry. The grasshoppers fed chiefly on the short stems that were still green. Evidently these conditions of sand dropseed made the plants convenient for High Plains grasshoppers to attack from their usual positions on the ground.

The common method of attack by a High Plains grasshopper was to walk up to a grass plant, taste it, and while remaining horizontal on the ground surface begin to feed at the tip of a low-lying leaf or on the stub of a grazed stem. When leaves were higher, the grasshopper raised up diagonally on the plant at approximately a 45° angle and began to feed on a leaf at or near the tip. The hindlegs remained on the soil surface, the midlegs on the plant, and the tarsi of the front legs handled the leaf conveying it to the mouthparts. Only once was a grasshopper observed feeding off the ground in the middle of a grass plant facing head down and feeding on a leaf or stem. The High Plains grasshopper appeared to be a very thrifty feeder as no clipping and dropping of leaves were observed. Laboratory observations revealed that whenever these grasshoppers severed a leaf, they held on to it and consumed all of the green but dropped the yellow, dry tissue.

Dispersal and Migration

The High Plains grasshopper is a very mobile insect. During outbreak years huge numbers of hatching nymphs, up

Instar 1

1. BL 7.8 mm FL 3.8 mm AS 13-14.

Instar 2

2. BL 6.1-8.5 mm FL 3.9-4.5 mm AS 14-16.

Instar 3

3. BL 9.8-13.4 mm FL 4.7-6.5 mm AS 18-19.

Instar 4

4. BL 13-15.5 mm FL 7-7.6 mm AS 20.

Instar 5

5. Females BL 18.5-24 mm FL 10.7-11 mm AS 23.
Males BL 23 mm FL 12 mm AS 23-24.

Figures 1-6. Appearance of the six nymphal instars of *Dissosteira longipennis* - their sizes, structures, and color patterns. Notice progressive development of the wing pads. BL = body length, FL = hind femur length, AS = antennal segments number.

to 2,000 per square yard, soon crawl away from the egg beds that range in size from one-half to 200 acres and average about 15 acres. Dispersal usually begins near the end of the first week after emergence and increases rapidly as nymphs age. The rate of travel of first instars was clocked at 3 feet per minute, the third instar at 6 to 12 feet, and late instars at more than 10 feet per minute. In 1937 one band of nymphs was found to travel 2 1/2 miles in one day. In 1993 and 1997 in Colorado's Bent and Otero counties, nymphs at low densities of less than 1 per square yard appeared to remain close to their hatching sites.

Soon after transforming to the adult stage, the grasshoppers of dense populations begin to disperse. On their first flights, they cover from 25 to several hundred yards at a time and at heights of less than 50 feet. Later, the adults rise in swarms taking high, long flights that disperse the grasshoppers widely over great distances. Swarms appear to fly during both day and night; the lights of cities attract huge numbers and induce them to land. In 1937, 2,940 adults were marked with nontoxic paints to determine direction and distance of migratory flights. Sixteen grasshoppers were recovered 1 to 13 days later and at distances of 17 to 175 miles mainly in a northwest direction from the point of release. The results indicated that rate of movement ranged from 10 to 37 miles per day and that the grasshoppers flew with the prevailing winds. After the grasshoppers land in distant pastures, they concentrate into populations numbering about 20 per square yard. Fourteen days later the females begin to deposit eggs. At this time the adults no longer migrate, but they make regular low flights of one-half to 3 miles between egg beds and feeding grounds. Observations of small populations, less than one per square yard, in Otero County, Colorado in 1997 revealed that the adults form mating aggregations of approximately one adult per square yard on one-quarter to one-half acre of land. Three aggregations approximately 1 mile apart were discovered in an infested area of 6 square miles. As the whole area was not inspected, it is probable that several other aggregations were undetected.

Flushed flight is usually silent without crepitation, but a soft rustling of the wings is sometimes audible. Distances traveled ranged from 1 foot in early morning to more than 90 feet at midday at heights of 4 inches to 3 feet. The short flights are straight but the long flights are either straight or zig-zag and circuitous. Toward the end of a long flight, the grasshoppers may make a right angle turn before landing.

Identification

A conspicuous insect in the shortgrass prairie, the High Plains grasshopper is distinguished by its large size, attractive black hindwings, and quick, elusive flight (Fig. 7 and 8). The hindwings have a transparent outer margin bordering the large black disk that widens greatly at the apex and is marked by several large fuscous spots (Fig. 9). The tegmina or forewings are pale tan with many large brown spots. The median pronotal crest is notably high and deeply incised once. The

Figures 7-10. Appearance of adult male and female of *Dissosteira longipennis*, wings of female and broken egg pod showing eggs in situ.

inner side of the hind femur is yellow with two large dark markings near the middle. The hind tibia is distinctively golden. Wingspans of males range from 2 1/2 to 3 3/8 inches, and females 3 1/4 to 4 inches.

The nymphs are identifiable by their color, shape, and external structures (Fig. 1-6).

1. Head with face nearly vertical; antennae filiform, majority of segments pale tan, terminal segments dark; lateral foveolae small and triangular; compound eyes tan or brown with light spots; usually narrow light band on side of head behind the compound eye.
2. Pronotum with median carina strongly elevated and incised once.
3. Hind femur with medial area tan and often with three transverse diagonal dark bars, inner medial area tan with two or three black transverse bars; hind tibia of instars I and II black with pale yellow annulus located proximally, instar III black and tan or entirely golden, instar IV, V, and VI golden.
4. General body color tan with brown round spots; venter generally immaculate cream to yellow.

The high pronotal crest and tan, heavily spotted body are diagnostic features of the younger nymphs. The golden hind tibia and high pronotal crest are diagnostic features of the older nymphs.

Hatching

The High Plains grasshopper is an intermediate-hatching species; the first instars appear two to three weeks after *Aulocara elliotti* nymphs. In 1939 the first hatch occurred May 2 in Colorado. Because of an unusually warm spell in the spring of 1939 in eastern New Mexico and the Texas Panhandle, hatching began two to three weeks earlier than normal on April 21. In 1997 in Colorado's Bent and Otero counties, hatching was calculated to have begun on May 14. The hatching period usually lasts from 11 to 18 days but may be extended to 30 days by spells of cold weather. In egg beds with southern exposures, the hatch is sooner and faster than in those with northern exposures.

Nymphal Development

Nymphs develop in late spring when temperatures are warm and grasses young and green. In 1939, based on the dates of first appearance of nymphs and first adults, the developmental period lasted 44 to 45 days in Colorado, New Mexico, and the Texas Panhandle. In New Mexico and Texas the majority of nymphs had five instars, while in Colorado they had six.

Adults and Reproduction

The first adults of the High Plains grasshopper appear in June. In 1939 they were discovered June 5 in New Mexico and Texas and June 15 in Colorado. In 1997 the first adults appeared in Bent and Otero Counties, Colorado on June 25. Maturation of the females is lengthy, as they require six to seven weeks before laying their first clutch of eggs. In 1939 this occurred July 17 in

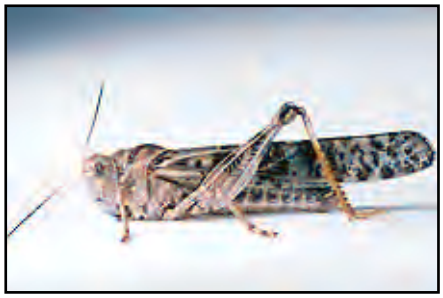
Instar 6

6. Females BL 28-31 mm, FL 14-15 mm, AS 25-26. Males BL 25-25.5 mm, FL 13-13.6 mm, AS 25.

Female

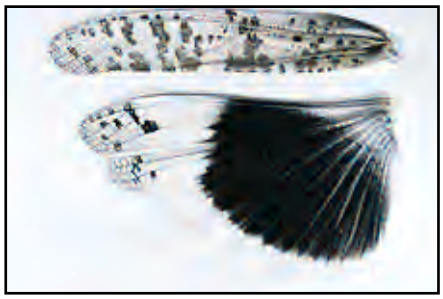
7. BL 36-44 mm FL 19.2-22 mm AS 24-26.

Male



8. BL 31-35 mm FL 15.8-17 mm AS 25-28.

Wings



9. Left forewing (tegmen) and hindwing of female.

Egg pod

10. Dissosteira longipennis egg pod and broken pod exposing eggs in situ.

New Mexico and August 1 in Colorado. Male courtship of females appears to be brief. Only two observations of this behavior were made in nature. On 1 August 1997 at 8:35 a.m. DST, a male was discovered walking on bare ground. He approached within a few inches of a basking female and began to signal with his hindlegs. The female raised her hindlegs to reject him, but he persisted in the approach, still signaling. Within an inch of her, he jumped suddenly and mounted. The female knocked him off and walked 3 feet away. Caged males have been seen to signal the females by femur-tipping and vibratory stridulation followed by sudden leaps onto the females that sometimes end in a successful mating.

Observations made in 1939 revealed that most egg deposition occurred between 9 and 12 a.m. when air temperatures ranged from 80° to 90° F. At the beginning of this period they made shallow holes without depositing eggs. Later on, they selected bare ground around the edges of grass plants and dug holes into the soil depositing large clutches of eggs nearly 2 inches deep. Several males usually attended the ovipositing female. In a laboratory cage a female took 1 hour and 5 minutes from the start of drilling to withdrawal of the ovipositor. Afterward she used her hind tarsi for 1 minute to cover the aperture with soil particles and debris. In nature, a male mounts the female immediately after oviposition and mates successfully.

Egg beds occurred in various soil types, but during the 1934-40 outbreak the greatest number were found in sandy loam soil. The majority of pods were deposited in egg beds, although a few were interspersed in the extensive areas between them. In the spring survey of 1939, 187 pods were examined and found to contain an average of 65 eggs with a range of 32 to 84. The egg pod is large and slightly curved ranging from 1 to 2 inches long (Fig. 10). The eggs, 4.4 to 5.6 mm long, are pale yellow when laid but eventually turn tan.

Population Ecology

Populations of the High Plains grasshopper irrupt during periods of drought and above-normal temperatures. Rainfall and temperature have their greatest influence during the hatching period when the nymphs are delicate. Numerous observations made during the 1934-40 outbreak revealed that cold, wet weather decimated populations of young nymphs and warm, clear weather fostered their welfare. When the nymphs were older, rains had little effect on survival. Biotic factors reducing populations during the outbreak were predatory birds, rodents, and insects. These took their toll, yet many adults survived through August and September and a few into October. A thorough summary of the life history, ecology, and control of the High Plains grasshopper was published in 1958 by Claude Wakeland as USDA Technical Bulletin 1167.

Daily Activities

In spite of its notorious reputation as a strong migratory flier, the High Plains grasshopper spends most hours on bare ground in its habitat. In the shortgrass prairie southwest of Hawley, Colorado, late instars and adults did not seek shelter at night but rested horizontally on bare ground within an inch of clumps of grass. After sunset they often crawled short distances, but in the morning before sunrise they were immobile. In the summer of 1997, ground temperatures at the Hawley site were approximately 77° F at sunset and 65° F shortly before sunrise. One-half to one hour after sunrise, the grasshoppers adjusted their bodies to bask. They rested horizontally on bare ground, turned a side perpendicular to rays of the sun, and lowered the associated hindleg to expose more of the abdomen. In July and August, basking lasted two to three hours, approximately from 6 a.m. to 9 a.m. DST. During this time individuals may turn around 180° and continue basking, or they may walk distances of 4 to 6 inches and then resume basking, apparently in a better location. During the basking period almost all High Plains grasshoppers rest quietly, absorbing the heating rays of the sun. Toward the end of this period, a few individuals may walk short distances to find a host plant and feed. A few males may also start to court nearby females. Of 18 observations of feeding, seven occurred between 8 and 9 a.m., six between 9 and 10 a.m., four between 10 and 11 a.m., and one at 2:51 p.m. DST. Temperatures of the unshaded soil surface during the period of morning feeding ranged from 85° to 112° F; shaded air at 1 inch high ranged from 67° to 90° F. The temperature at the time of the one afternoon observation of feeding registered 130° F at the soil surface and 105° F air. Courting was observed twice between 8:35 and 8:49 a.m. 1 August 1997, but no pairs in cap were seen anytime.

In the Hawley site on clear days the ground temperatures rose rapidly in July and August, reaching 120° F by 10 a.m. DST. Heat induced the grasshoppers to stilt and to face directly into the sun or to face directly away from the sun. As temperatures rose further, the grasshoppers crawled onto the top of short grasses raising the body about an inch above the soil surface and away from the surrounding hot bare ground. They assumed a diagonal orientation on top the short grass facing the sun directly and shading the body.

Observed in low-density populations of less than one individual per square yard and away from egg beds, the High Plains grasshopper appears mainly quiescent-little jumping, walking, or flying unless flushed. After the basking period on 21 August 1997 from 9:20 to 11:08 a.m. DST, four appetitive flights of 15 to more than 50 feet were observed when ground temperatures ranged from 100° to 123° F and air temperatures from 77° to 85° F. Appetitive walking (pottering) was also observed on five different days. Eight observations revealed movements of 1 1/2 to 15 feet over bare ground; the grasshoppers usually broke the walk into two or three segments separated by brief pauses.

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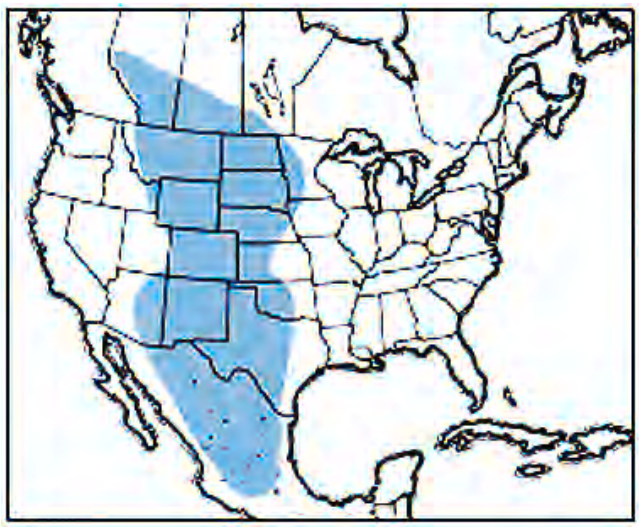
Dusky Grasshopper

Encoptolophus costalis (Scudder)

Distribution and Habitat

The dusky grasshopper ranges widely in western North America from Canada to Mexico. The species inhabits several kinds of grasslands including the mixedgrass, shortgrass, bunchgrass, and desert prairies. It is most abundant in the northern mixedgrass prairie, and is the dominant species on certain rangelands of Saskatchewan. There it favors moist areas of rich grass and sedge growth interspersed with bare ground. In its southern distribution, mesic swales and roadsides dominated by western wheatgrass and prairies with Houston black clay soil dominated by Texas needlegrass afford favorable habitats.



Geographic range of *Encoptolophus costalis* (Scudder)

Economic Importance

The dusky grasshopper is a rangeland species that feeds on native grasses and sedges. In the assemblage of grasshoppers inhabiting a grassland site, it is usually a subdominant member that does little damage by itself but adds to the damage of more serious pests. Occasionally, in habitats favorable to the species, it becomes the dominant grasshopper. In the Matador site of the International Biological Program (northern mixedgrass prairie in southwest Saskatchewan), the dusky grasshopper was the dominant species, making up as much as 74 percent of the grasshopper population. The density, however, was low, with approximately 2.5 young adults per square yard. Estimates made from meticulous laboratory studies of food consumption suggested that in the field the population of grasshoppers ingested 2.4 percent of annual production of grass in 1968 and 1.5 percent in 1969. There was a lack of apparent damage to the vegetation such that the rather small population of grasshoppers had no great impact on the standing crop of grasses.

The dusky grasshopper has been reported as a minor pest in alfalfa in Arizona and North Dakota and as a pest in fall wheat in Nebraska. In the latter case, adults migrated from depleted rangeland into the adjacent wheat crop.

The dusky grasshopper is a medium-sized species with marked sexual dimorphism in body size. Live weight of males averages 168 mg and of females 468 mg (dry weights: males 50 mg, females 135 mg).

Food Habits

The dusky grasshopper in its prairie habitat feeds on grasses and sedges. Western wheatgrass and needleleaf sedge are its principal host plants. Other plants eaten in substantial quantities include northern wheatgrass, needleandthread, green needlegrass, and blue grama. Analyses of crop contents of grasshoppers collected in Colorado, Kansas, North Dakota, and Saskatchewan reveal that eight additional grasses and one sedge are consumed in variable amounts: quackgrass, prairie junegrass, sand dropseed, little bluestem, sideoats grama, Kentucky bluegrass, foxtail barley, timothy, and Penn sedge.

In an unusual habitat, such as an alfalfa field or a roadside, the dusky grasshopper may feed on a mixture of forbs and grasses. Of 52 specimens collected from an alfalfa field in North Dakota, 30 had ingested alfalfa. In laboratory tests, starved individuals limited to single food plants fed well on certain forbs and refused others. Well-eaten plants included scarlet globemallow, prairie coneflower, dandelion, and a vetch, *Vicia sparsifolia*.

The dusky grasshopper attacks host plants in several ways. Sitting head-up on a leaf of needleandthread grass, an adult may begin feeding halfway up the leaf, cut through it, hold onto the cut section with the front tarsi, and consume it to the dry tip. Occasionally an adult will turn head-down on a grass or sedge and feed on green basal tissue. On short host plants such as needleleaf sedge, an adult from a horizontal position on the ground may reach up with its mouthparts and begin to feed on a green leaf 3/4 inch above its base, cut through it, hold onto the cut section, and consume it as far as the dry tip. From a horizontal position on the ground, adults may feed on recumbent green leaves or stubs of host plants. A noteworthy observation was made of the feeding of a nymph (instar IV) perched head-up on a 4-inch leaf of needleandthread. The nymph did not feed on the leaf on which it rested but reached out with its mouthparts and fed on the tip ends of three younger, 2-inch leaves. Dusky grasshoppers appear to be thrifty feeders as they consume most of whatever they attack eating all of the green and dropping chiefly the dry brown parts of leaves. They have been observed, however, to feed on dry plant litter and on dry cow dung.

Dispersal and Migration

The long wings and strong thoracic muscles of the dusky grasshopper enable it to disperse and migrate by flight. A significant observation indicative of migrant behavior was made of a mixed swarm consisting of seven species that

Instar 1

1. BL 4.5-4.7 mm FL 2-2.2 mm AS 11-12.

Instar 2

2. BL 5.2-6.9 mm FL 2.9-3.5 mm AS 13-16.

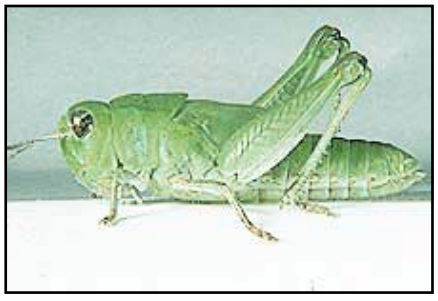
Instar 3

3. BL 6.7-8.2 mm FL 4-5.3 mm AS 16-18.

Instar 4

4. BL 10.1-13.7 mm FL 5.5-7.2 mm AS 20-23.

Instar 5



5. BL 10.7-16 mm FL 7.3-9.3 mm AS 23-25.

Figures 1-5. Appearance of the five nymphal instars of *Encoptolophus costalis* - their sizes, structures, and color patterns. Notice progressive development of the wing pads. BL = body length, FL = hind femur length, AS = antennal segments number.

landed in downtown Cheyenne, Wyoming, on 27 September 1993. From a total of 63 collected specimens, three males and three females of the dusky grasshopper were obtained. The collection of grasshoppers suggested dispersal from a heavily infested site of the mixedgrass prairie that surrounds Cheyenne.

Another example of fall dispersal by the dusky grasshopper is that of a population in western Nebraska that moved from depleted rangeland into adjacent winter wheat on 27 September 1967. Adults were also found in winter wheat in southeast Wyoming during October 1992, indicating earlier dispersal from surrounding mixedgrass prairie.

In flushed flight, the dusky grasshopper softly crepitates and travels 3 to 9 feet at heights of 3 to 12 inches. The flight is usually straight, with an occasional turn near the end.

Identification

The dusky grasshopper is a medium-sized, dark brown, sometimes greenish species with long wings that extend 1 to 4 mm beyond the end of the abdomen (Fig. 6-8). The tegmina are banded and the hind wings have weak apical dark bands. Occasionally these bands are dark and distinct (Fig. 9). The fastigium is distinctly longer than wide in males and ranges in females from slightly to distinctly longer than wide. The outer surface of the hind femur has three dark bands and the knee is dark. The hind femur of green specimens may have only weak bands or none at all. The hind tibia is blue.

The nymphs are identifiable by their structures, color patterns, and shape (Fig. 1-5).

1. Head. Face moderately slanting; antennae short and weakly clavate (club-shaped) in instars I to III, filiform in instars IV and V, compound eyes brown with pale tan spots, light line runs from base of antennae diagonally across middle of eye.
2. Pronotum with distinct median carina and plainly evident lateral carinae, disk sloping but not tectate; in green individuals usually a reddish brown to purple band runs down middle of pronotum and continues onto mesonotum, metanotum, and abdomen.
3. Hind femur with outer medial area green, tan, or grayish brown; instar I with medial area often pink in distal half. Tibia and femur of fore- and midlegs carinate (ridged) longitudinally; four ridges visible on outer face, often with black lines between the ridges.
4. Body color green, tan, or grayish brown.

The early instars (I to III) of the dusky grasshopper and *of Chortophaga viridifasciata* appear similar; both are usually green and structurally similar. They may be separated by a few characteristics that differ. The antennae of the dusky grasshopper are clavate while those of *C. viridifasciata* are

Figures 6-10. Appearance of the adult male and two females of *Encoptolophus costalis*, spread wings, egg pod, and exposed eggs.

ensiform. The outer faces of the femur and tibia of the fore- and midlegs of the dusky grasshopper have four distinct longitudinal ridges, which usually have black lines between them. Those of *C. viridifasciata* have two distinct ridges, which are the upper and lower carina, and a third weak ridge between them with no black lines between the ridges. Instar I of the dusky grasshopper has the medial area of the hind femur pink in the distal half, and that of *C. viridifasciata* is entirely green. Instars IV and V are identifiable by the shape of the pronotum. The disk of the dusky grasshopper slopes moderately, and that of *C. viridifasciata* is tectate (steep roof-like); the posterior angle of the disk in the dusky grasshopper is obtuse, and that of *C. viridifasciata* is acute.

Hatching

The dusky grasshopper is an intermediate-developing species. In the northern mixedgrass prairie hatching of eggs begins in early to mid June, about three weeks after the initial hatch of *Ageneotettix deorum*. The hatching period is prolonged, continuing for six to eight weeks. The unusually long period may be due to early and late oviposition in the fall and to heterogeneous soil temperatures in well-vegetated habitats.

Nymphal Development

The nymphs develop during early summer when temperatures are warm and host plants are green. The nymphal period, however, is relatively long. Based on first appearances of the first instar and the adult in the northern mixedgrass prairie, this period ranges from 56 to 66 days. Both males and females require five instars to complete nymphal development. In the species' southern distribution, such as northeastern Texas, juvenile stages are present throughout the year and at least two generations occur annually.

Adults and Reproduction

Although dusky grasshoppers may disperse by flight, the majority of adults remain in the habitat in which the eggs hatched and nymphs developed. Adults begin to appear August 8 to 10 in the mixedgrass prairie of southeast Wyoming (altitude 5,200 feet) and August 11 to 14 in the mixedgrass prairie of southwest Saskatchewan (altitude 2,100 feet). In northeastern Texas, adults appear by mid April and the adults of a second generation by August. Fledgling adults are sexually immature. They require two to three weeks of growth and maturation before mating and producing eggs. Oviposition may ensue by the 16th day of adulthood. An unknown number of days prior to oviposition, pair formation, courtship, and mating occur. Males make frequent crepitation flights to arouse the females. When an individual grasshopper moves nearby, a male on the ground in pursuit of a mate produces a single burst of vibratory stridulation. Then the male moves toward the individual while making a single pulse of ordinary stridulation. If the individual is a receptive conspecific female, she will lower her hind femur closest to the courting male, spread it away from her abdomen, and turn her genitalia toward

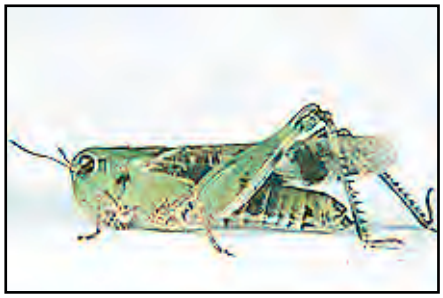
Male

6. BL 15-18.5 mm FL 9.5-11 mm AS 24-25.

Female

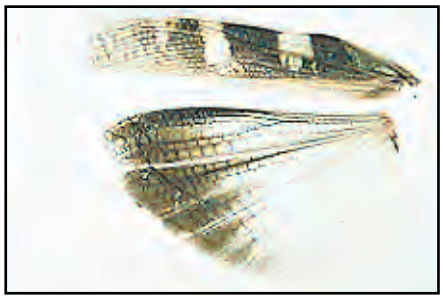
7. BL 21.5-25.5 mm FL 11.5-14 mm AS 23-26.

Female



8. Green form of adult

Wings



9. Spread wings of female.

Egg pod

10. Egg pod and exposed eggs (bottom of pods at right).

the courting male as he mounts. During copulation the male transfers a spermatophore (a proteinaceous capsule enclosing sperm) to the female.

For oviposition, females select bare ground that is interspersed among the native grasses of their habitat. Females test the soil by boring into the ground several times before finally depositing a clutch of eggs. When given a choice of five Texas soil types, ranging in coarseness from clay to gravel, ovipositing females preferred Houston black clay; they laid 111 of 204 egg pods in this soil. Males often attend an ovipositing female and may contact her, but they are kicked away by the female. After completing oviposition and withdrawing her ovipositor from the soil, the female brushes particles of soil and litter over the aperture of the hole with her hind tarsi. The pods are 3/4 inch long, slightly curved, and contain from 14 to 20 eggs (Fig. 10). Eggs are tan and 4.0 to 4.4 mm long.

Population Ecology

The ecology of the dusky grasshopper has been investigated by several scientists working at the Matador site of the International Biological Program (east of Kyle, Saskatchewan). This site supports a minor type of the northern mixedgrass prairie, characterized by heavy clay soil and vegetation dominated by northern wheatgrass, western wheatgrass, and needleleaf sedge.

An assemblage of 19 species of grasshoppers occupied the site during the period of study from 1967 to 1971. In 1968 the dusky grasshopper made up approximately 74 percent of the population, reaching a peak density of 12 early instar nymphs per square yard. Mortality of young nymphs was high in both 1968 and 1969. Daily mortality decreased after the grasshoppers reached instar IV. The average daily mortality from instar IV through the adult stage was 3 percent in 1968 and 5 percent in 1969. The population gradually declined from 1968 to 1971. The unusually luxuriant growth of vegetation in 1970 and 1971 suggested that the cause of grasshopper decline was decreased soil temperature due to shading of the soil surface. These physical factors delayed the development and maturation of the dusky grasshopper, resulting in a decrease of egg production. Additionally, because the dusky grasshopper oviposits in bare ground, a reduction of such sites probably incited adults to emigrate. Circumstantial evidence for such movement was observed after lightning caused a fire in part of the study area in August 1969. All grasshoppers perished in the burned area, but the next year dusky grasshoppers migrated from the unburned area, which supported a heavy growth of vegetation, to the burned area, which supported light growth and contained an abundance of bare ground.

Observations in Montana, Texas, and Saskatchewan indicate that the dusky grasshopper finds a favorable habitat in sites of heavy clay soil covered by a good growth of wheatgrasses or needlegrass and prevalent bare ground for basking and oviposition. Nevertheless, the species also inhabits areas of fine sandy loam soil in the mixedgrass prairie. As a case in point, in southeast Wyoming (Laramie County), sites dominated by blue grama, needleandthread, and needleleaf sedge support assemblages in which the dusky grasshopper is a subdominant with densities of 0.1 to 1 young adult per square yard. In a few roadside sites, with sparse western wheatgrass and abundant bare ground, the dusky grasshopper becomes dominant and reaches peak densities of approximately ten young adults per square yard.

Daily Activities

The dusky grasshopper is a geophilus species, spending almost all of its time on the ground. At night it rests sitting horizontally on bare soil and litter, often resting under a thin canopy of leaves and surrounded closely by the grasses of its habitat. One to two hours after sunrise, individuals begin to bask on bare ground by turning a side perpendicular to the rays of the sun and lowering the associated hindleg to expose the abdomen. They bask for two to three hours and then become active - walking, flying occasionally, and feeding. The males search for mates and may chase after females on the ground. Nonreceptive females may escape by flight. Feedings have been observed to occur during midday hours from 9:12 a.m. to 1:27 p.m. DST at ground temperatures ranging from 76°F to 126°F and air temperatures 66°F to 79°F. At extreme high temperatures, 125°F and higher, the grasshoppers take evasive actions to avoid overheating. They rest in partial shade or sit on grass one-half inch above the ground surface. They may crawl into the full shade of grasses or climb onto litter, thus raising themselves about an inch above the soil surface. In the latter position they face the sun exposing the least body surface. When temperatures ameliorate, the grasshoppers once more become active. On 29 September 1992, 3:40 p.m. DST, in the mixedgrass prairie of southeast Wyoming, an aggregation of two males and six females was observed underneath a dry cow dropping that had been hollowed out by their feeding.

Later in the day the grasshoppers bask for a second time until sunset, after which they enter nighttime shelters.

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Velvetstriped Grasshopper

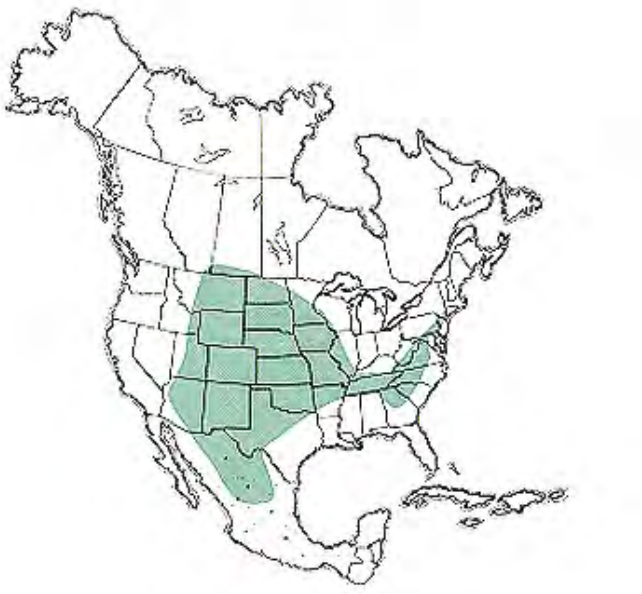
Eritettix simplex (Scudder)

Distribution and Habitat

The velvetstriped grasshopper has an extensive range in North America. There are two main centers of distribution, the larger lies in the Great Plains of western North America and the smaller in the Appalachian Mountains and their eastern slopes. In the West this species develops its highest densities in the tallgrass prairie. Populations find preferred habitats in stands of mid and tall grasses and forbs where the understory is blue grama, a short grass and a preferred food plant. This grasshopper extends its range into desert, mixedgrass, shortgrass, and bunchgrass prairies by occupying mesic swales and drainages.

Economic Importance

Because it feeds almost exclusively on grasses and sedges, the velvetstriped grasshopper is a potentially damaging pest of rangeland. However, densities of less than one per square yard in most areas of its distribution and its development in spring, when range plants usually have adequate moisture, render populations innocuous. High numbers of this grasshopper have been found in at least one area, the Sheyenne National Grasslands of eastern North Dakota, a sand prairie region. For three of ten years (1959 to 1968) the velvetstriped grasshopper was the dominant species. In 1960 the population peaked at an estimated density of approximately seven grasshoppers per square yard. The species is in the smallest of three weight divisions of rangeland grasshoppers; average live weight is 108 mg for males and 269 mg for females (dry weight: males 33 mg, females 110 mg).



Geographic range of *Eritettix simplex* (Scudder)

Food Habits

Host plants of the velvetstriped grasshopper consist almost exclusively of grasses and sedges. When the nymphs emerge from their winter quarters in early spring, they feed on the growing, cool-season plants: bluegrasses, downy brome, junegrass, threadleaf sedge, and needleleaf sedge. As the season progresses, the diet of this grasshopper shifts to warm-season plants, particularly blue grama. This grass appears to be highly preferred and is often the only plant found in the crops of adults. Other grasses found in crops in substantial amounts include hairy grama, sideoats grama, sand dropseed, and needleandthread. In summer and fall the new generation of nymphs feed almost exclusively on blue grama.

A total of 25 species of grasses and three species of sedges have been recorded as eaten in various amounts by this grasshopper. Trace quantities of five forbs, fungi, pollen, and arthropod parts have been found in crop contents.

To feed, the velvetstriped grasshopper normally rests in a head up position on the plant. It may either lean on the plant raising itself by its hindlegs and then attack the plant about 1 inch above ground level, or it may jump or climb onto the plant and attack a leaf near the middle. It will cut a narrow leaf and hold onto the detached section with its front tarsi, feeding toward the tip. The detached leaf may be eaten entirely or may be partly eaten and dropped. Although the feeding posture is usually vertical or diagonal with head up, an individual may turn around head down and feed on the leaf base. Individuals may feed across the entire width of relatively wide grass leaves, or feed only to the midrib and leave the other half attached and standing.

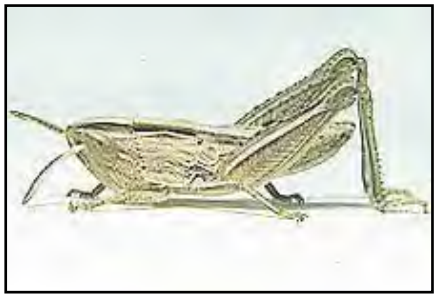
Dispersal and Migration

The velvetstriped grasshopper possesses long wings. Those of the female do not quite reach the end of the abdomen; those of the male extend slightly beyond. Measured evasive flights have ranged from 2 to 6 feet at a height ranging from 4 to 12 inches. Flight is silent and usually straight; the landing is horizontal on the ground, with the head pointing in the direction of flight and away from the intruder. Occasionally a fleeing

Instar 1

1. BL 6.6-7.5 mm FL 3.3-3.9 mm AS 13-14.

Instar 2



2. BL 8.1-8.8 mm FL 4.5-5.5 mm AS 16-18.

Instar 3

3. BL 8.5-10.2 mm FL 4.9-6.1 mm AS 18-21.

Instar 4

4. BL 11.2-13.2 mm FL 6.3-7.6 mm AS 20-22.

Instar 5

5. BL 12-18.5 mm FL 7.5-10.4 mm AS 23-24.

Figures 1-5. Appearance of the five nymphal instars of *Eritettix simplex* - their sizes, structures, and color patterns. Notice progressive development of the wing pads. BL = body length, FL = hind femur length, AS = antennal segments number.

grasshopper will turn near the end of a flight and face the intruder.

A study of dispersal of grasshoppers into the mountains of Colorado showed that the velvetstriped grasshopper did not fly from resident habitats into nonresident habitats at higher altitudes, as did several other rangeland grasshoppers. These findings, however, do not prove that the species is lacking dispersive behavior. Its long wings and wide geographic range suggest that dispersal occurs. A positive piece of evidence for dispersal is its distribution in experimental plots on the Pawnee National Grassland in Colorado. In 1 hectare plots of two irrigated treatments of the shortgrass prairie, the number of adults doubled over the number of late instars. The increase in adults evidently came from outside the experimental plots, as the species was not present in the adjacent unirrigated control plots and existed in very low numbers in the adjacent unirrigated fertilized plots.

Identification

Adults of the velvetstriped grasshopper are medium-sized and tan-colored with brown markings or brown and green markings (Fig. 6 and 7). Top of head bears three diagnostic longitudinal carinae or ridges: a median carina and one accessory carina on each side. The pronotal disk likewise has three carinae: a median and one accessory carina on each side; pronotal disk with distinct lateral carinae colored white or cream and moderately constricted near middle; all carinae cut once near or behind middle; disk usually with dark brown, velvet-like band along each lateral carina and between the velvet bands a wide central tan or gray band (Fig. 9). A few specimens have the disk tan, sparingly spotted brown and pronotal lobes with broad brown band. Medial area of hind femur with a dorsal brown stripe and a ventral pale tan stripe.

The nymphs are identifiable by their external structure, shape, and to a lesser degree color patterns (Fig. 1-5):

1. Head with face strongly slanted and with fastigium pointed; top of head with three longitudinal carinae and lateral brown bands that continue on thorax and abdomen; head with a wide middle pale tan band that continues on thorax and abdomen (Fig. 8).

Figures 6-10. Appearance of the adult male and female of *Eritettix simplex*, diagnostic characters, and the egg pod and several loose eggs.

Antennae broad and flat, slightly ensiform.

2. Disk of pronotum with median carina and two accessory carinae; lateral carinae white or cream, slightly constricted near middle, dark brown velvet band along each lateral carina.
3. Medial area of hind femur in instars I to III unicolored pale tan or with brown central or dorsal stripe; in instars IV and V brown dorsal stripe and pale tan ventral stripe.
4. General color of nymphs cream or pale tan.

To compare early instar *Eritettix simplex* nymphs with two similar species, click here. Both nymphal and adult specimens may have color patterns different from those described above. In one pattern, the top of the head and disk are pale tan or cream with brown spots, and a wide brown band begins behind the compound eye on the side of the head and continues on the thorax and abdomen. In another pattern, the body is olive brown with dark brown spots, and the lateral carinae of the pronotum are also olive brown or pale tan.

Hatching

The velvetstriped grasshopper is a late-hatching species. In the mixedgrass prairie of eastern Wyoming at altitudes of 4,000 to 5,000 feet, hatching begins the latter part of July and continues for about one month. It is unknown whether the species has a one-year or two-year life cycle, as no thorough study of the life cycle or even egg development has been made.

Nymphal Development

The nymphs develop and grow during summer and fall for about 100 days. At the onset of winter, nymphs are in the third and fourth instars and take refuge under ground litter. They may, however, become active during spells of warm weather. Nymphs are cold-tolerant, surviving freezing and experimental temperatures as low as -15°C, which is about the lower limit of surface ground temperatures in the mixedgrass prairie. Nymphs complete development the following spring in April and May, as temperatures increase and daily photoperiods become longer. Because of the slow growth in fall and the winter dormancy, the nymphal period lasts a relatively long time - approximately nine months.

Male

6. BL 15-16.5 mm FL 9.1-10.2 mm AS 23-25.

Female

7. BL 22-23.5 mm FL 12-12.7 mm AS 23-25.

Dorsal view

8. Dorsal view of first instar.

Head and pronotum

9. View of head and pronotum of adult female.

Egg pod

10. Egg pod and loose eggs.

Adults and Reproduction

Although adults may disperse, most appear to remain in the same habitat in which they have developed as nymphs. The habitat, including vegetation structure, food plants, and oviposition sites, normally remains favorable. Populations of adults peak in May, slowly declining to sparse densities by July.

Mating occurs in grass foliage. The male follows a female, and when he is within an inch begins to rock from side to side. He then stridulates with one hindleg at a time by rubbing the inside of the femur against a raised vein on the tegmen. After a burst of stridulation, he rushes forward and mounts the female. If she allows, he copulates with her.

Gravid females oviposit into bare ground, taking an hour during the late morning to lay a cluster of about 18 eggs. The eggs are pale yellow and 4.4 mm long. The fragile pod is an inch long and one-eighth inch in diameter (Fig. 10). No study of the potential or realized fecundity of this species has been made.

Population Ecology

In the West, populations of the velvetstriped grasshopper are mainly present in the mesic swales and drainages where densities in early spring range from 0.1 to 0.6 grasshopper per square yard. Only in preferred habitats of the sand prairie of southeastern North Dakota have populations increased to high densities, reaching a maximum of 6.7 grasshoppers per square yard. A study of grasshopper populations in this area over a ten-year period revealed that populations of the velvetstriped grasshopper fluctuated annually, ranging from 0.1 to 6.7 grasshoppers per square yard. The velvetstriped grasshopper became the dominant species in three of the ten years. Mortality was greatest among the late instars during winter and early spring.

Daily Activities

Because nymphs of the velvetstriped grasshopper appear early in spring, they must choose favorable microhabitats that allow them to keep their body temperature at tolerable levels. They take shelter under ground litter during the night, a time when temperatures may fall to near freezing (32°F). Three hours after sunrise, when soil temperatures reach about 60°F, nymphs emerge and bask in the warming rays of the sun. They posture by exposing one side perpendicular to the rays and by lowering the flexed hindleg nearest the sun to the ground and raising the opposite flexed hindleg above the abdomen. Another posture consists of exposing their backs perpendicular to the rays of the sun by resting diagonally on ground litter. Experiments have shown that the nymphs suffer evaporative water loss in dry air at moderate temperatures. This physiological response is probably the reason for their restriction in the West to moist or humid locations.

The adults also take cover in ground litter at night, and in the morning bask on the ground in similar postures as the nymphs. They begin to feed when soil temperatures reach 80°F and air temperatures 55 to 60°F. Only one observation of oviposition in the natural habitat has been made. Oviposition occurred in bare ground in the shade of threadleaf sedge from 10:17 to 11:15 a.m. (DST), when air temperatures 1 inch above the surface ranged from 76 to 79°F.

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Threebanded Grasshopper

Hadrotettix trifasciatus (Say)

Distribution and Habitat

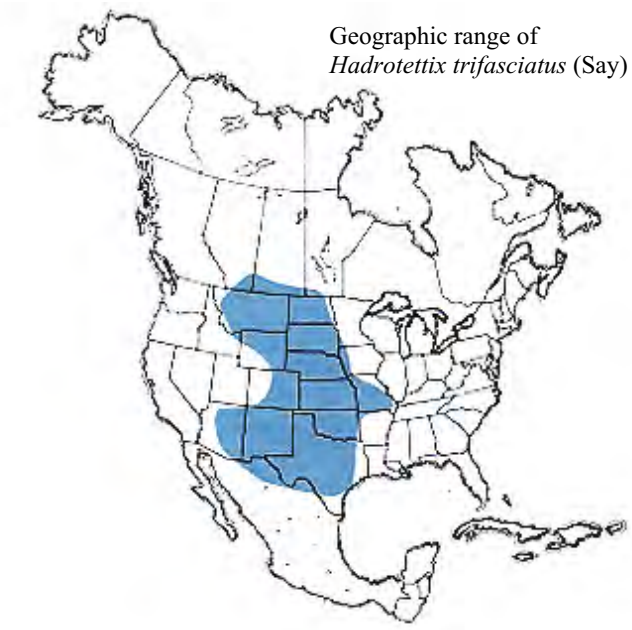
The threebanded grasshopper ranges widely in the grasslands of the West. It is a common species of the shortgrass, desert, and mixedgrass prairies. It is less abundant in other prairies and is rare in grass-shrub communities of the intermountain basins. In the tallgrass prairie it occupies areas of sparse vegetation on gravelly hilltops and slopes.

Economic Importance

Because of its low densities in most western grasslands, the threebanded grasshopper does not appear to be of great economic importance either as a damaging pest or as a beneficial insect. Its feeding on good forage grasses would tend to give it pest status, but research has shown that it feeds more heavily on poor forage plants and plants poisonous to livestock (death camus, milkweeds, some milkvetches, and others). The threebanded grasshopper is one of the largest rangeland species. Live weight of males and females collected from the mixedgrass prairie of eastern Wyoming averaged 540 and 1,654 mg, respectively (dry weights 152 mg and 469 mg, respectively).

Food Habits

The threebanded grasshopper is a polyphagus species feeding on grasses, forbs, sedges, dead and weakened insects, plant litter, and dry cattle dung. It feeds chiefly on forbs, with as many as 40 species recorded from analyses of crop contents and direct observations in nature. Examination of 152 specimens collected from several habitats near North Platte, Nebraska revealed that 75 percent of crop contents consisted of forbs, 21 percent grasses and sedge, and 4 percent arthropod parts. Of the 18 forbs identified in the crops, scarlet globemallow was most abundant (8 percent). The next most abundant were a group of four species, each contributing 4 percent to crop contents: Missouri milkvetch, Virginia pepperweed, scarlet gaura, and breadroot scurfpea. Two grasses (western wheatgrass and blue grama) and one sedge (threadleaf sedge) each comprised 4 percent of the crop contents.



Geographic range of *Hadrotettix trifasciatus* (Say)

In multiple-choice tests, F. B. Isely, an early investigator of grasshopper biology, found that the threebanded grasshopper preferred antelopehorns, milkweed, and narrowleaf bluet. As these plants grow in the optimum habitat of the grasshopper in northeastern Texas, he concluded that they were its host plants.

Several observations have been made of the threebanded grasshopper's method of feeding. A hungry grasshopper crawling on the ground often stops to feed on ground litter. This litter may consist of green or dry grasses, forbs, or dead insects. An interesting observation was made of a female *H. trifasciatus* and a male *Aulocara elliotti* that came across a dead adult grasshopper *(Trachyrhachys kiowa)* at nearly the same time. In the scramble that followed, the larger female won out and fed for approximately eight minutes on the cadaver before it was inadvertently frightened away.

Another female climbed 2 inches up a short forb stem, cut a 1 inch section, held on to it with the front tarsi, and then consumed it completely in approximately five minutes. This grasshopper then fed briefly on the stub and finally walked away.

An observation was made of a caged female feeding on a dandelion leaf. It perched diagonally on the leaf and fed on the leaf's edge. In a series of progressive ingestions it moved its head forward 1/4 inch on the edge and then ate back this distance. Dandelion appeared to be a relished food plant, but it is a rare species in the habitat of this grasshopper.

Dispersal and Migration

The threebanded grasshopper is a strong flier, possessing long wings that usually extend 6 to 10 mm beyond the end of the abdomen. Finding "accidentals" of the species in three Colorado mountain sites at altitudes of 6,700 to 10,000 feet provides evidence that it makes dispersal flights. The site of the highest elevation was 10 miles from the nearest known resident population.

Flushed flight is usually straight with a 90 degree turn at the end. Landing is soft as they normally flutter to the ground. Crepitating in flight, males travel distances of 9 to 24 feet and the heavier females 6 to 15 feet, both at heights of 12 to 18 inches. Flying with the wind (2 to 8 mph), a male was observed to travel a distance of 42 feet. A case of mass emigration of adults from a desert prairie site on the San Carlos Apache Indian Reservation, Arizona occurred during June 1980. A dense infestation

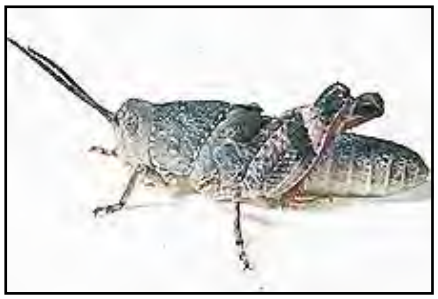
Instar 1

1. BL 5.2-10.4 mm FL 3.9-4.4 mm AS 13-14.

Instar 2

2. BL 7.9-12.5 mm FL 5.1-6.4 mm AS 17-19.

Instar 3



3. BL 12-16.7 mm FL 7.8-9.1 mm AS 20-21.

Instar 4

4. BL 19.5-22.5 mm FL 10.9-13 mm AS 23.

Figures 1-4. Appearance of the four nymphal instars of *Hadrotettix trifasciatus* - their sizes, structures, and color patterns. Notice progressive development of the wing pads. BL = body length, FL = hind femur length, AS = antennal segments number.

of grasshoppers, 36 per square yard, was recorded on May 30, 1980 in which the following grasshoppers (mainly ultimate instars) dominated: *Melanoplus cuneatus* (14 per square yard), *Aulocara elliotti* (13 per square yard), *Melanoplus sanguinipes* (4.4 per square yard), and *Hadrotettix trifasciatus* (3.8 per square yard). Sampling the site on June 26 revealed that the densities of adult grasshoppers were: *Aulocara elliotti* 15 per square yard and *Melanoplus cuneatus* 2.5 per square yard. No *Melanoplus sanguinipes* and no adult *Hadrotettix trifasciatus* were found. Only one ultimate instar of the latter species was found in 50 1-square-foot samples. Circumstantial evidence indicated that the forb feeders (all the adult *Melanoplus sanguinipes*, all the adult *Hadrotettix trifasciatus*, and 82 percent of the adult *Melanoplus cuneatus*) had emigrated from the site, ostensibly because of food shortage. The population of *Aulocara elliotti*, which uses grasses for food, remained high at 15 adults per square yard.

Identification

The threebanded grasshopper is a large rangeland species (Fig. 5 and 6). Antennae are long and dark, each segment often with a light anterior annulus. Pronotum has the median carina very low. Tegmen with three dark bands; hind wings with disk pale yellow or nearly white, outer dark band wide and located in the distal third (Fig. 7). Outer face of hind femur with an oblique dark band and an adjacent, distal light band; inner face mainly dark blue, adjacent distal light band, knee area dark blue; hind tibia orange or red (Fig. 8). The distal light bands of the outer and inner face meet and form a wide annulus around the hind femur.

The nymphs are identifiable by their color patterns, structures, and shape (Fig. 1-4).

1. Head with face vertical, antennae long and dark.
2. Pronotum with low median carina, uncut in instars I and II, cut near middle in instar III, cut in front of middle in instar IV.
3. Color patterns of hindlegs similar to adult, except hind tibia of instar I often gray and tan.
4. General body color brown or gray with dark brown spots.

Hatching

The threebanded grasshopper hatches early in the season along with *Ageneotettix deorum*, *Amphitornus coloradus*, and *Aulocara elliotti*. In the mixedgrass prairie of eastern Wyoming, eggs usually begin to hatch during the latter part of May. In 1992, however, first instar nymphs were collected on May 9, along with first and second instars of *Ageneotettix deorum* and *Amphitornus*

Figures 5-9. Appearance of the adult male and female of *Hadrotettix trifasciatus*, wings, hindleg, egg pod, and eggs.

coloradus. In the mixedgrass prairie of eastern Montana in 1950, hatching of the threebanded grasshopper and *A. coloradus* began on May 22. In the Southwest, hatching is earlier with first instar nymphs present in early May.

Nymphal Development

Development of the threebanded grasshopper begins with relatively large nymphs. The length of the hind femur of first instars averages 4.3 mm; by comparison, that of *Metator pardalinus*, another large bandwinged species, averages 3.6 mm.

Nymphal development of the threebanded grasshopper is relatively long. Based on dates of observations of first instar nymphs and of first adults, the length of the nymphal period was 56 days in mixedgrass prairies of southeastern Montana in 1950 and southeastern Wyoming in 1991. At the same site in Wyoming in 1992, the nymphal period was 62 days. Because the nymphs appeared three weeks sooner in 1992 than in 1991, they undoubtedly were exposed to lower temperatures early in development, which extended the nymphal period six days.

Surprisingly, only four instars are needed by this large grasshopper to reach the adult stage, as revealed by a study of the morphology of field-collected nymphs (the shape and size of the ovipositor and the wing pads, the length of the hind femur, and the number of antennal segments). Although females of *M. pardalinus* weigh only half as much as females of *H. trifasciatus*, the former species requires five instars to complete development. A comparison of these two species shows that nymphal, stepwise growth (metamorphosis), as gauged by the increase in length of the hind femur, of *H. trifasciatus* is greater than that of *M. pardalinus*. Measurements of the hind femur of the first four female instars of each species yield a growth factor of 1.43 for *H. trifasciatus* and 1.31 for *M. pardalinus*. This difference and the beginning larger size of first instars of *H. trifasciatus* readily account for the heavier adults of this species despite its having only four instars. Real growth (the daily increase in weight of nymphs) of both species is probably similar, but because the nymphal period of *H. trifasciatus* is longer, the adults become significantly larger.

Adults and Reproduction

Adults of the threebanded grasshopper usually remain in the same habitat in which the eggs hatch and the nymphs develop. Their preferred host plants remain green during the summer. However, if these plants dry up or are exhausted by intensive grazing of grasshoppers, the adults respond by emigrating and thereby finding, perhaps, a more viable habitat.

The adults appear in mid June in the shortgrass prairie of southwest Texas and the desert prairie of Arizona and a month later in the mixedgrass prairie of Montana and

Male

5. BL 24.5-27.5 mm FL 13.8-15 mm AS 23-24.

Female

6. BL 28-35.5 mm FL 14.5-18.3 mm AS 22-24.

Wings

7. Spread left wings of female.

Hindleg

8. Inner face of female, hind femur, tibia, and tarsus.

Egg pod

9. Egg pod and four loose eggs.

Wyoming. Although aggregating rituals of the sexes have not been seen, courtship has been observed several times. Males approaching a female may make tipping motions of the hind femora. As they come closer, they stridulate to attract her attention. Successful courtship has not been noted, but rejection by the female has been observed. Females may reject courting males by hopping away, raising the hind femora and holding the tibiae over the back while making slight upward kicking motions, tipping the hind femora, or kicking out with the hind tibiae.

Oviposition begins about one month after the fledglings appear. Females retreat into grass cover, often blue grama or buffalograss, and oviposit through plant litter into the ground. An interesting observation was made in the mixedgrass prairie of southeastern Wyoming of a female preparing an oviposition site. She crawled into a secluded spot among blue grama, then tipped the front of her head down and began to fashion a small depression in plant litter by bobbing her head up and down into the litter. After a few seconds she turned around and began to work her ovipositor into the depression, but was soon frightened by the observer attempting a closer look.

In the saltbrush-bunchgrass community of the Big Horn Basin (Big Horn County, WY) where bare ground prevails, a single observation was made of a female ovipositing in bare ground 2 inches southeast of a saltbrush. She was discovered at 12:12 p.m. DST with her ovipositor already inserted into the soil. She completed her laying between 12:45 and 12:50 p.m. but was not observed extracting her ovipositor nor covering the hole. Temperature of the soil surface ranged from 113° to 117°F and the air at the 1 inch level from 78° to 81°F. The sky was clear, the soil dry, and an east wind ranged from 0 to 6 mph. An examination of the position of the pod in the soil revealed that the top of the pod was 1/8 inch below the soil surface, the froth occupied 5/8 inch of the pod, was vertically oriented. Because of the sharp curve in the pod, the egg portion lay horizontally in the soil so that the eggs were oriented almost vertically. The eggs were at a depth of 1/2 to 3/4 inch.

The egg pod of the threebanded grasshopper is 1 inch long and strongly curved (Fig. 9). The egg section is 5/8 inch long and contains from 18 to 26 eggs. In Figure 9 the loose eggs are recently laid and tan, and those in the intact pod are older and have turned reddish-brown. Eggs are large, their lengths ranging from 7.2 to 8.7 mm.

Population Ecology

The center of distribution of the threebanded grasshopper appears to be in the Southwest's shortgrass and desert prairies. Although absolute densities were not determined, a study (1966-72) of grasshopper populations in the shortgrass prairie of the Texas Panhandle revealed that in two of the years (1970 and 1971) the threebanded grasshopper was the dominant species. In the other years *Mermiria picta* or *Syrbula admirabilis* was dominant. In the desert prairie of Arizona, the threebanded grasshopper occurs at densities of 1.3 to 4 per square yard and often ranks fourth in abundance after *Aulocara elliotti*, *Melanoplus cuneatus*, and *Melanoplus sanguinipes*.

In the extensive mixedgrass prairie of the West, the threebanded grasshopper is a common but not abundant species. Densities range from less than 0.1 to 0.3 grasshoppers per square yard. These low densities persist from year to year and do not appear to track the dynamic fluctuations of the dominant species or the assemblage.

Daily Activities

The threebanded grasshopper is a ground-dwelling species. At night it rests horizontally on the ground surface surrounded by a canopy of grasses. When the rays of the sun strike them, about two hours after sunrise, both nymphs and adults begin to bask. They sit horizontally on the ground and turn a side perpendicular to the sun and lower the flexed hindleg to expose the abdomen. Basking may last for two hours, until soil temperatures have risen to 80°F and air temperatures (1 inch high) to 72°F. Activities such as walking and feeding then begin. A mating pair was observed at 11:55 a.m., and attempts by two males to mate with a single female were noted at noon. Neither attempt was successful, although the female made no effort to dislodge them after they had mounted. A female was observed testing sites for oviposition in litter under a grass canopy at 12:42 p.m., when bare soil registered 130°F and air temperatures 95°F. Adults usually take evasive action from excessive heat when soil temperature reaches 120°F. Adults first stilt and then crawl away from hot bare ground. They evade the extreme heat by sitting on thick litter or by crawling atop blue grama. In either case they become elevated approximately 2 inches above ground. With further increase in temperature they may crawl into shade of vegetation or crawl up a plant to a height of 3 inches.

Few observations of the threebanded grasshopper were realized between 1 p.m. and sunset. At 5:40 p.m. a male and a female were discovered sitting horizontally and quietly on bare soil under a cloudy sky. Although still unknown, the threebanded grasshopper during clear weather probably basks before moving to its night resting locations.

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Snakeweed Grasshopper

Hesperotettix viridis (Thomas)

Distribution and Habitat

The snakeweed grasshopper has a wide geographic range in North America. Limited to areas where one or more of its host plants occur, its distribution is patchy, particularly in the East where it is less common than in the West. Host plants, usually certain low shrubs belonging to the composite family of plants, grow in numerous habitats including all grasslands, sagebrush and other shrub associations, and abandoned fields.

Economic Importance

The snakeweed grasshopper is a beneficial insect, as it feeds on rangeland plants with little or no forage value for livestock that intensively compete for soil moisture and hinder the growth of high quality forage plants. Some of the preferred host plants, such as the snakeweeds, are poisonous. Cattle, horses, sheep, and goats may ingest sufficient quantities of shoots and seedlings in the spring to cause illness and pregnant females to abort.

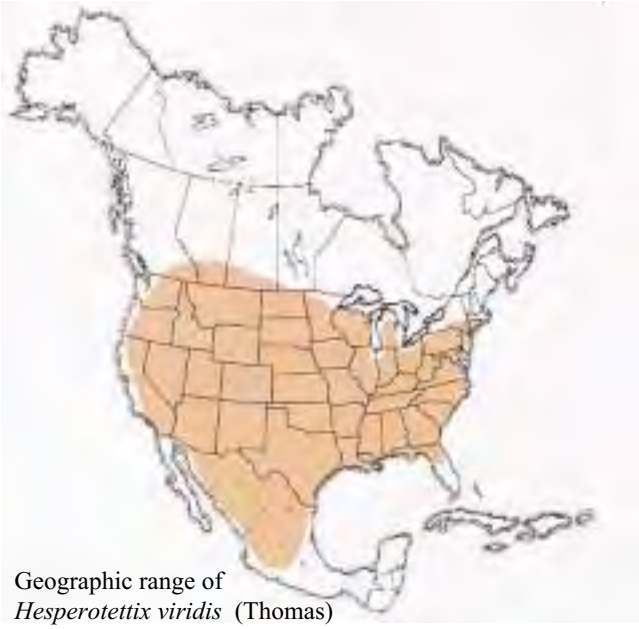
In New Mexico, feeding injury by this grasshopper has been shown to cause high mortality among seedlings and one-year-old plants of threadleaf snakeweed. As the plants age they become more tolerant to feeding damage, yet high densities of this grasshopper will consume all leaves and much of the stem cortex of older plants, contributing to their early death. A study is being undertaken in New Mexico to determine the feasibility of using this grasshopper as a biological control agent against broom snakeweed.

The snakeweed grasshopper is a medium-sized species. Average live weight of males from the mixedgrass prairie of eastern Wyoming is 212 mg and of females 344 mg (dry weight: males 66 mg and females 83 mg).

Food Habits

The snakeweed grasshopper feeds on a wide variety of host plants over its extensive geographic range. All are forbs and most are members of the composite family of plants. Common host plants include broom snakeweed, threadleaf snakeweed, Missouri goldenrod, western ragweed, Douglas rabbitbrush, gray rabbitbrush, and burroweed. Examination of crop contents and field observations have shown that this grasshopper ingests a minimum of 34 species of forbs over its range. It also feeds in trace amounts on grasses, flower petals, pollen, fungi, and arthropods. Food preference tests indicate that this grasshopper prefers the snakeweeds to rabbitbrush and burroweed.

Its method of feeding has been observed in New Mexico on one of its preferred host plants, threadleaf snakeweed. The grasshopper roosts in the low shrub most of the day and feed during daylight hours in short bouts of less than three minutes. It attacks the edges of leaves, stem cortex tissue, and flower buds.



Geographic range of *Hesperotettix viridis* (Thomas)

Dispersal and Migration

Wings of the snakeweed grasshopper are long; those of the females do not quite reach the end of the abdomen, while those of the males do. This grasshopper is able to disperse over long distances. A study in Colorado showed that the upper resident altitude of this species was 7,600 feet while “accidentals” were found in the mountains up to 11,500 feet. The distance between the highest resident altitude and the highest collection site of an accidental was approximately 12 miles.

Evasive flights begin about 9 a.m. DST on clear days when air temperature 1 inch above ground have risen to 68ºF. Because the adults usually roost 5 to 6 inches above ground level, they are resting at a lower ambient temperature. The flights are silent, straight, low (6 to 9 inches), and for short distances (2 to 6 feet). They usually begin from a perch on vegetation and end on vegetation, but they can begin from vegetation or ground and end on the ground.

Instar 1

1. BL 5.2-6.1 mm FL 2.4-3.1 mm AS 11-12.

Instar 2

2. BL 6-8 mm FL 3.7-4.2 mm AS 14-17.

Instar 3

3. BL 8.3-9.1 mm FL 4.9-5 mm AS 17-18.

Instar 4

4. BL 11-14.2 mm FL 6.3-7.7 mm AS 19-20.

Instar 5

5. BL 14.8-16 mm FL 7.7-10.4 mm AS 20-22.

Figures 1-5. Appearance of five nymphal instars of *Hesperotettix viridis* - their sizes, structures, and color patterns. Notice progressive development of the wing pads. BL = body length, FL = hind femur length, AS = antennal segments number.

Identification

The adult snakeweed grasshopper is a green, medium-sized, spurthroated grasshopper possessing wings that reach or nearly reach the end of the abdomen (Fig. 6 and Fig. 7). A median light line begins on the occiput and continues posteriorly on the pronotal disk (Fig. 8). The fore and mid femora are pink and green; the hind femora are green with cream and fuscous chevrons and a distal pink annulus. The male subgenital plate has a large truncated, preapical tubercle (Fig. 9). The hind tibiae are light blue, often with distal end light green in females.

The nymphs are identifiable by their shape, structures, and color patterns (Fig. 1-5).

1. Head: face moderately slanted; compound eyes with light spots on brown or burgundy background; fuscous antennae with segments having cream-colored rings anteriorly.
2. Thorax: pronotum with cream-colored median carina; pronotal disk rounded, lacking lateral carinae; hind femur green in instars I to III, instars IV and V also green but with fuscous and cream chevrons, hind tibia green in instars I and II, light green or blue in instars III to V.
3. General body color green with many fuscous spots. Median cream-colored line running from top of head to nearly end of abdomen, line at time absent from head.

Collections of grasshoppers from rangeland may include nymphs of *Hesperotettix viridis* and *Hypochlora alba*. Both species are spurthroated grasshoppers and green. The two can be separated by the following characteristics. 1. *H. viridis* is medium green, *H. alba* pale green. 2. Antennae of *H. viridis* are black with segments having a pale anterior annulus, *H. alba* have green antennae and may be spotted or suffused with brown in the older instars. 3. *H. viridis* has medial area of hind femur medium green and spotted black in instars I and II, and medium green with black chevrons in instars III to V, *H. alba* has the medial area of hind femur pale green and spotted brown or medium green.

Figures 6-10. Appearance of the adult male and female, dorsal view of head and pronotum of adult female, side view end of male abdomen, egg pod, and several loose eggs.

Hatching

Eggs of the snakeweed grasshopper hatch two to three weeks after those of the bigheaded grasshopper, placing it in the intermediate hatching group. In the northern mixedgrass prairie of eastern Wyoming, hatching occurs in the middle of June. In New Mexico, this event occurs six weeks earlier.

Nymphal Development

In both Wyoming and New Mexico the nymphs complete development in about 55 days. This is 12 to 15 days longer than the period needed by rangeland grasshoppers that dwell on the ground. Evidently the time spent perched in the host plant keeps the snakeweed grasshopper at a lower average temperature, resulting in slower growth. In the laboratory the nymphal period of grasshoppers fed broom snakeweed averaged 74 days and of those fed threadleaf snakeweed 68 days. They pass through five instars before molting to the adult stage.

Adults and Reproduction

The majority of adults remain in the same habitat in which the nymphs developed. There they continue to feed and live on the same species of host plant. In the West this is usually snakeweed or rabbitbrush. Little is known about the snakeweed grasshopper's reproductive biology, including time taken from fledging to mating, courtship, and time of first oviposition. Adults have a relatively long period in which to reproduce. In northern New Mexico mating and oviposition begin in late June and continue through early September. A gravid female ready to lay a clutch of eggs elects a site at the base of its host plant in bare ground or in a clump of shortgrass. The eggs are laid in the soil at a depth of 1 inch and are enclosed in a tough-walled pod that measure about one-half inch long. In the region of the eggs the pod is two-to-three-sixteenths inch in diameter. It contains ten, tan eggs 4.3 to 4.7 mm long (Fig. 10). Immediately above the eggs the pods cap consists of a thin layer of froth. Embryos of eggs laid and retained in the laboratory at warm temperature develop to stage 19, then dispause. This is the embryonic stage in which many grasshopper species diapause and overwinter. Evidently, the snakeweed grasshopper likewise overwinters in this embryonic stage at a depth of 1 inch in the soil. The species has one generation annually. Fed an exclusive diet of broom snakeweed in the laboratory, this

Male

6. BL 19-21 mm FL 9.8-11 mm AS 23-24.

Female

7. BL 20-22 mm FL 11-12.5 mm AS 22-24.

Head and Pronotum

8. Dorsal view of head and pronotum of adult female.

Preapical Tubercle

9. End abdomen showing preapical tubercle of male subgenital plate.

Egg pod

10. Egg pod and several loose eggs.

grasshopper produced approximately six eggs per female while those feed threadleaf snakeweed produce 28 eggs per female.

Population Ecology

Because the snakeweed grasshopper is an oligophagous species that restricts its feeding to several members of the Compositae, the existence of populations of this grasshopper depends on the presence of at least on of its host plants. In the West the host plants is often a single species of snakeweed or rabbitbrush.

Growth and size of populations are limited by the quality and the density of the host plants. Snakeweed grasshoppers feed and remain longer on threadleaf snakeweed plants that have not been damaged by herbivory or by lack of water. Nymphs grow more rapidly on undamaged, healthy plants.

The importance of density or amount of biomass of host plant in the habitat is indicated by a comparison of populations in eastern New Mexico and in eastern Wyoming. In New Mexico 50-acre islands of broom snakeweed infestation by two adult grasshoppers per plant represent a population density of approximately 15 grasshoppers per square yard, whereas in mixedgrass prairie of Wyoming two adult grasshoppers per plant represent only 1.2 to 1 grasshopper per square yard. This difference is obviously due to the lower host plant densities in the Wyoming habitat.

Densities of snakeweed grasshopper populations are known to vary annually. A population infesting threadleaf snakeweed in New Mexico reached a peak in 1980. The grasshoppers severely damaged their host plant, which not only suffered from the herbivory, but also from inadequate moisture during a drought. The following year, the population decreased to less than half its former density.

No comprehensive study of the population ecology of the snakeweed grasshopper has been made. Plans for an early use of this grasshopper as a biological control agent of broom snakeweed are hampered by the paucity of ecological information.

Daily Activity

The snakeweed grasshopper is a phytophilous species, as it spends most of its active live on the host plant. Both the nymphs and adults roost head up on stems of snakeweed during the nights. Shortly after sunrise they may begin basking by turning a side perpendicular to rays of the sun, still roosting vertically on the host plant. Later, by 8 a.m. DST, adults take basking positions on the soil surface. Resting horizontally, they expose a side perpendicular to ray of the sun and lower the exposed hindleg to the ground. Mating pairs take similar basking positions on the ground surface. Basking may continue on the ground until 10 a.m. after which other activities begin such as pottering and jumping back onto the host plant where feeding and mating occur. In the evening, individuals that are still on the ground eventually crawl to within 6 inches of their host plant and then jump into it and take roosting positions on stems. In late evening (8 p.m.) the grasshoppers may continue to feed on the foliage or they may bask as the sun wanes.

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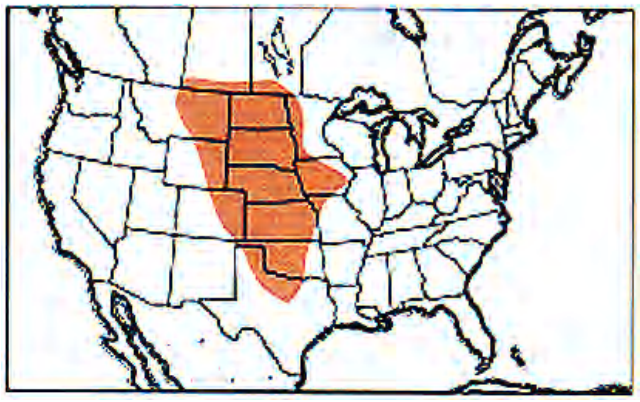
Cudweed Grasshopper

Hypochlora alba (Dodge)

Distribution and Habitat

The cudweed grasshopper inhabits grasslands east of the Rocky Mountains. It has an irregular distribution due to variations in distribution of its host plant, cudweed sagewort, *Artemisia ludoviciana*. The insect is not entirely coexistent with its host plant, which occurs farther in all directions and at altitudes considerably higher than the grasshopper. In Colorado the cudweed grasshopper has not been found higher than 6,000 feet.



Geographic range of *Hypochlora alba* (Dodge)

Economic Importance

The cudweed grasshopper feeds chiefly on the young leaves of cudweed sagewort. The plant is an herbaceous, perennial, native forb, which has fair to good forage value for sheep and fair for cattle in New Mexico. In states farther north, the plant has less forage value. It does serve to bind soil and prevent erosion and probably has other functions in the natural ecosystem. In the mixedgrass prairie, which constitutes the largest area of its distribution, cudweed sagewort is widespread but seldom abundant. It commonly occurs in patches of 10 to 50 square yards. In these patches, populations of the grasshopper may have a density of six young adults per square yard. Although at this density the grasshoppers cause minor damage to the plants, consumption of large sections of young leaves from the edge to the midvein and sometimes beyond is readily visible. The female cudweed grasshopper weighs three times as much as the male. Live weights of males collected from the mixedgrass prairie of northern Colorado averaged 122 mg and females 326 mg (dry weights: males 35 mg, females 107 mg).

Food Habits

The cudweed grasshopper feeds primarily on cudweed sagewort, *Artemisia ludoviciana*. Several other plants in the same genus are eaten in lesser amounts. Direct observations of feeding by this grasshopper in a Montana mixedgrass prairie habitat revealed that both nymphs and adults fed not only on the primary host but also on *A. frigida* and *A. cana*. In Kansas, crops of this grasshopper were found to contain trace amounts of *A. glauca*. Also, trace amounts of six grasses and nine forbs were found in crop contents of grasshoppers collected in Kansas, Nebraska, and North Dakota. The grasses included bluegrama, buffalograss, needleandthread, western wheatgrass, sand dropseed, and prairie sandreed. Identified forbs included western ragweed, leadplant, common yarrow, and wildindigo.

Of ecological interest is the observation that the cudweed grasshopper is the only species of grasshopper able to survive on cudweed sagewort. The leaves of this plant are pubescent, but the hairs do not interfere with the consumption and digestion of leaf tissue by the cudweed grasshopper. Although the hairs do not deter attack by polyphagous species, they apparently interfere with digestion of leaf tissue as indicated by the response of the migratory and twostriped grasshoppers. These two species are unable to grow normally on this plant because, it is suggested, digestion is abnormally energy-expensive.

Laboratory studies of Kansas populations revealed details of feeding by this grasshopper on its host plant. The younger nymphs (instar I to III) fed from the upper, less hairy surface of leaves by gouging out leaf tissue. This injury left thin areas and holes within the leaf margins. Older instars and adults fed on the edges of leaves. Samples of injured plants from rangeland 6 miles northwest of Fort Collins, Colorado indicated that cudweed grasshoppers preferred the young top leaves.

Dispersal and Migration

Little is known about the dispersal abilities of the cudweed grasshopper. It is a short-winged, flightless insect. Females infrequently possess long wings that extend 2 to 3 mm beyond the end of the abdomen. H.C. Severin (1885-1964), a renowned student of grasshoppers at South Dakota State University, collected six long-winged females from the mixedgrass prairie of South Dakota in four different years: 1924, 1927, 1930, and 1931. The long wings suggests that at times this grasshopper has the ability to fly and disperse. Its extensive geographic range east of the Rocky Mountains in 11 states and 3 provinces provides evidence for its dispersal in past times.

Identification

The cudweed grasshopper is a medium-sized, short-winged, pale green insect (Fig. 6 and 7). It matches the color of its host plant upon which it usually rests. Many small brown spots cover the body and are readily visible under a stereomicroscope. Color patterns of green hues adorn the body and legs. A characteristic broad green band

Instar 1

1. BL 5.5 mm FL 2.4 mm AS 11.

Instar 2

2. BL 5.2-8.3 mm FL 3-3.7 mm AS 13-15.

Instar 3

3. BL 8-10.5 mm FL 4.7-5.4 mm AS 17-18.

Instar 4

4. BL 9.6-12.6 mm FL 5.8-6.7 mm AS 18-20.

Instar 5

5. BL 11-18.2 mm FL 7.8-9.8 mm AS 21-22.

Figures 1-5. Appearance of the five nymphal instars of *Hypochlora alba* - their sizes, structures, and color patterns. Notice progressive development of the wing pads. BL = body length, FL = hind femur length, AS = antennal segments number.

runs behind the eye on the side of the head and continues onto the lateral lobe of the pronotum and the sides of the meso and metanotum. Dry, pinned specimens change color, turning dull yellowish tan. The male cercus is broad at the base and slender apically, the furcula is short and slender, and the subgenital plate bears an apical tubercle (Fig. 8). Infrequently the female is long-winged.

The nymphs are identifiable by their shape, structures, and color (Fig. 1-5).

1. Head pale green and spotted brown, antennae of instar I blue and each segment with anterior pale annulus, antennae of instars II to V green and segments with anterior pale annuli, segments of instars III to V with brown spots or suffusions of brown.
2. Pronotum pale green and spotted brown, median carina paler green, this dorsal line runs from median carina onto meso and metanotum and the abdomen; medial area of hind femur pale green and spotted brown or medium green; hind tibia pale green.
3. Abdomen pale green and spotted brown.

Collections of grasshoppers from rangeland may include nymphs of *Hypochlora alba* and *Hesperotettix viridis*. Both species are spurthroated grasshoppers and green. The two can be separated by the following characteristics. 1. *H. viridis* is medium green, *H. alba* pale green. 2. Antennae of *H. viridis* are black with segments having a pale anterior annulus, *H. alba* have green antennae and may be spotted or suffused with brown in the older instars. 3. *H. viridis* has medial area of hind femur medium green and spotted black in instars I and II, and medium green with black chevrons in instars III to V, *H. alba* has the medial area of hind femur pale green and spotted brown or medium green.

Hatching

Hatching about one month after *Ageneotettix deorum*, the cudweed grasshopper belongs to the late-developing group of grasshoppers. In the tallgrass prairie of eastern Kansas, eggs may begin to hatch as early as May 15 (Table 1). In southeastern North Dakota and in northern Colorado, they begin to hatch June 1. Hatching continues for approximately one month.

Nymphal Development

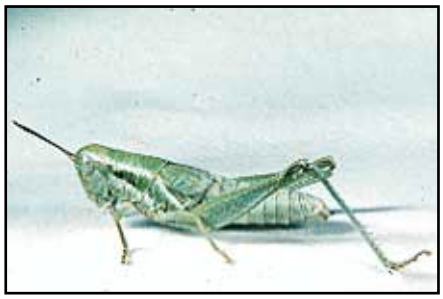
For a rangeland species that spends most of its time above ground on the host plant, the nymphs develop relatively fast. In a mixedgrass prairie site in northcentral

Figures 6-9. Appearance of the adult male and female of *Hypochlora alba*, end male abdomen, and egg pod and eggs.

Male

6. BL 14.5-16.6 mm FL 9.7-10.5 mm AS 21-25.

Female



7. BL 17-22 mm FL 10.1-11.7 mm AS 22-23.

Cercus

8. End of male abdomen showing cerci, furcula, and supraanal plate.

Eggs

9. Egg pod and three exposed eggs

Colorado, late instars and adults have been discovered from morning to evening sitting 5 to 11 inches above ground on stems of cudweed and fringed sagebrush. For many ground-dwelling grasshoppers this height serves as a refuge from extremes of high temperature.

As measured from first hatch to first adults, the nymphal period lasts 44 to 46 days (Table 1). Both males and females require five instars to achieve adulthood.

Adults and Reproduction

Adults remain in the same habitat in which the eggs hatch and nymphs develop. In the mixedgrass prairie the majority of adults congregate in patches of cudweed. Some adults, however, rest on isolated host plants and also on isolated non-host plants. This fact indicates limited dispersal and the mixing of individuals in a population among host-plant patches.

No investigation of maturation and courtship have been conducted. Observations of two pairs in copulo were made 12 August 1994 at 6:46 a.m. and at 9:25 a.m. DST in a mixedgrass prairie site of northcentral Colorado (altitude 5,400 feet). One pair rested 1.5 inches from the tip of a 10-inch tall cudweed plant; the other pair inhabited a cudweed patch, but its position was not noted. Adults were observed in this Colorado site from July 31 to October 4, 1993. The population dwindled in density as the season progressed. Females oviposit in the interspersed bare areas of grassland. During oviposition, the female holds on to an upright plant, and with hindlegs held high, works her ovipositor into the soil. A record of one complete oviposition revealed that drilling began at 3:10 p.m. and egg laying finished at 4:25 p.m. The female then devoted several minutes to movement of soil particles over the cavity with her ovipositor. The pod is slightly curved, 5/8 to 3/4 inch long, and contains 8 to 12 eggs (Fig. 9). The eggs are tan and 3.8 to 4.9 mm long. In the ground, the eggs are oriented nearly vertically.

Population Ecology

An important population characteristic of an organism is its dispersion. The term refers to the distribution or spacing of individuals in the habitat. Because in its nymphal and adult stages the cudweed grasshopper almost continually occupies the host plant, the dispersion of the plant determines that of the grasshopper. Where cudweed is abundant and scattered as in the tallgrass and sand prairies, the grasshopper is relatively abundant and scattered. But in the mixedgrass prairie, the cudweed plant is less abundant and grows chiefly in clumps in well-watered situations such as sandy loam slopes and ravine bottoms. These clumps of cudweed plants serve as the main residential sites of the grasshopper and cause the

dispersion of the grasshopper to be clumped. Measurements of density of young adults were taken both in patches of cudweed plants and in the general area of a sandy slope site in northcentral Colorado. The sampled density of cudweed grasshoppers in the general area amounted to 0.8 young adults per square yard but in clumps there were six young adults per square yard confirming the general impression of the clumped nature of cudweed grasshoppers.

The steady persistence of the cudweed grasshopper in sites with an abundance of their host plants was shown in a study of grasshopper assemblages inhabiting the sand prairie of southeastern North Dakota. The study revealed the presence of populations of the cudweed grasshopper every year from 1959 to 1969. The relative abundance of the species fluctuated from 7.3 percent of the grasshopper assemblage in 1959 to 2.2 percent in 1964. The study also showed that the cudweed grasshopper was an important member of the forb-feeding group in the sand prairie. Studies in Kansas have shown this species to be numerically important also in the tallgrass prairie. Of 8,100 grasshoppers collected methodically by sweep net from 1982 to 1986 at six sites in native tallgrass prairie (Konza Prairie Kansas), the cudweed grasshopper was fourth in abundance. Ranks of the five dominant species were the following: *Phoetaliotes nebrascensis* comprised 54 percent of the total; *Melanoplus scudderi*, 14 percent; *Orphulella speciosa*, 11 percent; *Hypochlora alba*, 7 percent; and *Melanoplus keeleri*, 6 percent. Of the forb feeders, *M. scudderi* ranked first, *H. alba* ranked second, and *M. keeleri* third.

Daily Activity

The cudweed grasshopper is a phytophilous species. Nymphs and adults spend almost all of their time on the primary host plant, cudweed sagewort. They may, however, also rest on other plants, particularly fringed sagebrush and silver sagebrush. Before sunrise, individuals have been observed resting vertically, head-up on main stems of cudweed at heights of 8 to 12 inches. They have occasionally been found on the top leaves resting in a horizontal position. Presumably both orientations are their nighttime positions.

As soon as the rays of the rising sun strike them, they adjust their positions on the plant to take full advantage of the warming rays. Still in a vertical, head-up orientation, they turn a side perpendicular to the sun's rays and lower the associated hindleg to expose the abdomen more fully. After basking for approximately two hours, they begin to stir, move, and feed. Although mating pairs have been observed as early as 6:45 a.m. DST, the specific time of courting and joining is unknown. Also unknown is the time of day in which oviposition occurs. During the day most individuals observed on the host plant are resting quietly. A few observations have been made of their movements. For example, a female was observed at 10:13 a.m. basking 6 inches above ground on the north side of a cudweed stem; at 10:15 a.m. she backed down 2 inches, then pivoted 45° to the east side of the stem and climbed 2 inches, and then she turned to the west side of the stem; at 10:17 a.m. she fed briefly; by 10:26 a.m. she had moved to the top of the plant (8 inches) in a vertical head-up orientation; at 10:30 she was flushed by the observer in attempting to get a closer look. Adults have also been observed to jump appetitively 2 to 8 inches from one stem to another or to a higher position on the same stem.

When disturbed, both nymphs and adults often jump 2 to 8 inches from one stem of cudweed to another, retaining a vertical head-up orientation. They may jump just once or several times before settling down. Occasionally they may jump as much as 2 feet and land on the ground, but then almost immediately they jump back onto a nearby host plant. Unlike *Chorthippus curtipennis*, they do not drop to the ground to evade a potential predator. To avoid overheating at high air temperatures (100°F and above) cudweed grasshoppers already several inches above the hot soil surface simply move to the shady side of the plant stem in their usual vertical, head-up orientation. For night shelter they stay and rest on the main stem of the host plant in the same characteristic orientation.

Table 1. Phenology of *Hypochlora alba* in selected sites of its geographic range.

Site	Altitude feet	First Numphs	First Adults	Nymphal period days
Kansas (eastern)	1,200	May 15	July 1	46
North Dakota (southeastern)	1,100	June 1	July 15	44
Colorado (Boulder)	5,450	June 1	July 15	45
Colorado (Chautauqua)	5,750	June 12	July 28	46

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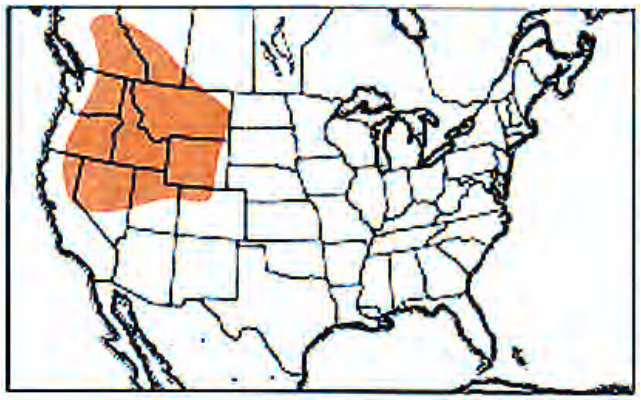
Alpine Grasshopper

Melanoplus alpinus Scudder

Distribution and Habitat

The geographic range of the alpine grasshopper is located in northwestern North America. It inhabits the grass-forb meadows and parklands of the Rocky Mountains and the Sierra Nevada Mountains. In the United States, altitudes of its habitats range from 6,400 feet in Montana to 11,000 feet in Colorado. In Canada, the species lives not only in mountain meadows and parklands but also in foothill habitats as low as 3,200 feet.



Geographic range of *Melanoplus alpinus* Scudder

Economic Importance

The alpine grasshopper, a common resident of mountain meadows, has a history of low densities and no documented outbreaks. Researchers of the species consider it to be a minor pest during some years and often a beneficial insect due to its feeding on competing weeds and poisonous plants such as locoweed and lupine. Populations in Wyoming meadows have ranged in density from less than 0.1 to 3.7 adults per square yard. Because the alpine grasshopper feeds readily on Idaho fescue, it is considered a potentially competitive pest with livestock on summer range, particularly during droughts when forage is in short supply.

Food Habits

The alpine grasshopper feeds on both forbs and grasses, and will eat fungi and injured or dead arthropods. About 26 species of forbs, 11 grasses, and 2 sedges are known to be ingested. Preferred forbs include *Arenaria congesta*, *Arenaria fendleri*, *Astragalus adsurgens*, *Lupinus laxiflorus*, *Oxytropis campestris, Musineon tenuifolium*, and *Taraxacum laevigatum*. Preferred grasses include *Poa* spp., *Elymus lanceolatus, Festuca idahoensis*, and *Stipa occidentalis*. Over its geographic range the alpine grasshopper subsists on different diets. In Canada it is reported to feed on grasses. In Idaho, crop content examinations show it to feed evenly on forbs and grasses; in Colorado, 69 percent of its diet is forbs and 18 percent grasses; in southern Wyoming, 77 percent forbs and 12 percent grasses; and in northern Wyoming, 93 percent forbs and 7 percent grasses.

Direct observations of the grasshoppers feeding in their natural habitat west of Laramie, Wyoming totaled 13 bouts on *Arenaria congesta*, 13 on *Poa* spp., and 9 on *Taraxacum laevigatum*. Average times spent feeding on these plants were *A. congesta*, 3 minutes; *Poa* spp., 1.8 minutes; and *T. laevigatum* 1.8 minutes. These results suggest that *A. congesta* was the preferred food plant. In a northern Colorado mountain meadow, *A. fendleri* served as the chief food plant. Crops of the alpine grasshopper contained 35 percent of this plant on both 10 and 23 August 1967 (Table 1).

The number of food items per crop is of importance to the nutrition of grasshoppers; laboratory tests have shown increased weight, survival, and egg production of individuals among several species of *Melanoplus* when fed more than one kind of food plant. Adults of the alpine grasshopper usually contain more than one species of host plant in their crops. Collected from a meadow of the Laramie range, males contained an average of 1.2 items and females 3.2 items. Collected from a meadow of the Big Horn Mountains, males contained an average of 1.8 items and females 2.4 items. These differences between the sexes were statistically significant.

Dispersal and Migration

Possessing long wings and developed wing muscles, the alpine grasshopper is able to fly evasively and to disperse. Within the center of its distribution in the Big Horn Mountains of northern Wyoming, the species inhabits a high percentage of the available montane meadows, which suggests effective dispersal. Additional evidence for dispersal was the collection of one adult male on 5 September 1995 in a bunchgrass-sagebrush habitat lying at an altitude of 7,300 feet - a foothill locale atypical for the species. None of the species was collected in this site on 3 August 1995 nor in the previous year on 25 July 1994. On the other hand, no adults have been found in grasshopper glaciers with other species that inhabit montane meadows, a fact suggesting that the alpine grasshopper disperses primarily by short, low flights.

When flushed, the adult alpine grasshopper appears more often to jump than to fly. Nymphs (instar V) and adults jump from 4 inches to 3 feet at air temperatures of 46° to 70°F. Adults fly short distances at

Instar 1

1. BL 4.5-5.2 mm FL 2.3-2.6 mm AS 13.

Instar 2

2. BL 5.1-7 mm FL 3.3-3.9 mm AS 15.

Instar 3

3. BL 8.1-9.2 mm FL 5-5.4 mm AS 17-18.

Instar 4

4. BL 9.2-12 mm FL 6.6-7.7 mm AS 18-21.

Instar 5

5. BL 13-15 mm FL 8.4-10.3 mm AS 21-23.

Figures 1-5. Appearance of the five nymphal instars of *Melanoplus alpinus* - their sizes, structures, and color patterns. Notice progressive development of the wing pads. BL = body length, FL = hind femur length, AS = antennal segments number.

temperatures of 54° to 70°F. The flight is low and silent.

Identification

The alpine grasshopper is a medium-sized, long-winged species (Fig. 6 and 7). Head, thorax, and tegmen are usually gray but may range in color to shades of light tan. The venter and sides of the abdomen are cream colored. The dark dorsal stripe of the hind femur is continuous and may fill most of the medial area, often the stripe has a wedge-shaped mark dorsally in the middle; the lower medial area is pale gray or tan (Fig. 8). The upper marginal area is tan and marked by three black transverse bars. The hind tibia is green, blue, or pink. The male cercus is bifurcate, the dorsal arm is stubby and blunt, and the ventral arm is sharply pointed and both arms bend medially (Fig. 9). The smaller *Melanoplus infantilis,* which often resides alongside the alpine grasshopper in mountain meadows, has a similar bifurcate cercus, but the lower arm ends in a rounded blunt tip and does not bend toward the median (compare the two).

The nymphs are identifiable by their color patterns, shape, and structures (Fig. 1-5). The early nymphs and some of the late nymphs are recognizable in the field by their green bodies, dark compound eyes, and prominent dark dorsal stripe of the hind femur.

1. Head with face nearly vertical and colored plain green, often tan in older instars; ridges of frontal costa and preocular ridges spotted brown; a black bar is present on the side of the head behind the compound eye.
2. Pronotal disk with dusky band, which is spotted brown and present on each side; the band continues onto the meso-and metanotum or the wing pads of older instars and to the end of the abdomen. The venter of the thorax and abdomen is green or pale tan, sometimes with pale brown spots.
3. The hind femur is green or tan and has a prominent dark dorsal stripe, often with a light dorsal wedge in the middle. The lower medial area and the lower marginal area are pale green or pale tan. The upper marginal area is green or tan.
4. Nymphs may change body color when they undergo metamorphosis. All specimens are green in instar I. In Instar II approximately 85

Figures 6-10. Appearance of the adult male and female of *Melanoplus alpinus*, left hindleg of adult female, male cercus, and eggs and egg pod.

percent are green and 15 percent are cream or pale tan; in instars III and IV approximately 52 percent are green and 48 percent are cream or pale tan; in instar V approximately 20 percent are green and 80 percent are tan.

Hatching

Before eggs of the alpine grasshopper will hatch, they require a long developmental period in the soil. A study of eggs laid in the Big Horn Mountains of Montana and Wyoming revealed that the majority of eggs (92 percent) required three years of development before hatching and a smaller number (8 percent), two years. None hatched in one year; the eggs laid in one summer were unable to hatch the following spring. The cause for the delay is unknown but may be due to both cold temperatures of mountain soils and to an extended diapause of the embryos.

In mountain meadows of Wyoming, eggs of the alpine grasshopper start hatching from early to late June. The precise time depends on seasonal temperatures that affect snow melt and the thawing and warming of the soil. The period of hatching is short, ranging from 6 to 17 days.

Nymphal Development

In spite of cold night temperatures and frequent cold rains in the mountain environment, nymphs of the alpine grasshopper develop rapidly to the adult stage. During the day in their meadow habitats, they bask in the warming rays of the sun and then at night they seek shelter in ground litter and crowns of grass insulating themselves from night air temperatures that range from 34° to 53°F. Nymphal periods have been found to last from 25 to 40 days. The shortest period of 25 days occurred in 1955 in a meadow lying at 9,800 feet in the Snowy Range west of Laramie, Wyoming. Daily scouting of the meadow revealed the first hatch of nymphs on June 21 and the first adult on July 16. In 1994 and 1995, slightly longer nymphal periods of 35 and 38 days were found to occur in a Pole Mountain meadow east of Laramie (altitude 8,600 feet). In 1994, in a Big Horn Mountain meadow of northern Wyoming (altitude 8,200 feet), the nymphal period took 37 days. Both male and female alpine grasshoppers have five instars.

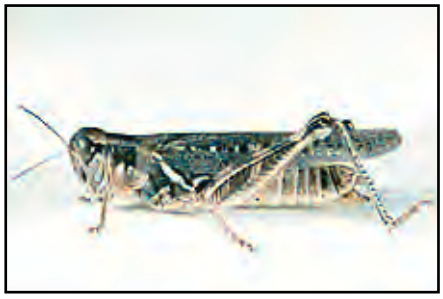
Adults and Reproduction

The alpine grasshopper reaches the adult stage by early July in the mountains of Wyoming . In 1994, adults were first discovered on July 8 in both northern and southern mountains. In the Snowy Range study meadow west of Laramie, Wyoming (altitude 9,800 feet), adults

Male

6. BL 17.5-18.5 mm FL 10.7-11.2 mm AS 23-25.

Female



7. BL 20.5-24 mm FL 12-13.2 mm AS 22-24.

Hindleg

8. Hindleg of female showing yellow wedge in dorsal stripe.

Cercus

9. End of male abdomen showing the cercus.

Eggs

10. Exposed eggs and egg pod.

were first observed on 16 July 1955. The first observation of mating in this site was noted on August 12, and the first oviposition a week later. Females select bare ground between clumps of grass to deposit groups of 8 to 12 eggs. Although populations of adults dwindle through the summer, residual individuals are still present in mid September. These individuals continue to mate and presumably to deposit eggs. Because alpine grasshoppers retreat into shelters when weather becomes inclement, early frosts do not affect their survival.

The pods are 1 to 1 1/8 inches long and curved at the bottom so that the terminal section with eggs, 3/8 inch long, lies diagonally in the soil. Offwhite froth fills the top section of the pod; tan froth surrounds the eggs at the bottom. Eggs are yellow or pale tan and 4.3 to 5.0 mm long (Fig. 10).

Population Ecology

The alpine grasshopper enjoys a high frequency of occurrence in mountain meadows of Wyoming. In the Big Horn mountains of northern Wyoming, 12 of 14 meadow sites (85 percent) surveyed in 1994 were inhabited by resident populations. Densities were low in all populations, ranging from less than 0.1 to 0.5 adult per square yard. The highest density of adults ever recorded in the Wyoming annual grasshopper survey (1988-94) was 3.7 adults per square yard in a meadow of the Big Horn Mountains (13 August 1991). The entire grasshopper assemblage living in this site numbered 16 adults per square yard. Densities of the six species were: *Bruneria brunnea*, 5.7; *M. alpinus*, 3.7; *M. bruneri*, 2.4; *M. borealis*, 2; *Camnula pellucida*, 2; and *Chorthippus curtipennis*, 0.2. The study of the alpine grasshopper in the Snowy Range in 1954-55 revealed densities ranging from 0.4 to 0.9 adult per square yard. To date, no irruptions of the alpine grasshopper have been observed even in years favorable for outbreaks of *M. borealis* and *M. bruneri*. The requirement of alpine grasshopper eggs to be in the soil for two to three years before hatching complicates the study of population ecology of this species.

Daily Activity

The alpine grasshopper is a geophilous species resting, walking, feeding, and performing other activities on the ground. At night, the grasshoppers rest deep in grass crowns or wedge themselves as much as 2 inches below the soil surface alongside a rock or boulder. Two hours after sunrise they emerge from their shelters and begin to bask, resting horizontally on bare ground or on litter. They turn a side perpendicular to the rays of the sun and lower the associated hindleg, exposing the abdomen. In meadows of the Big Horn Mountains of northern Wyoming, basking begins about 7:30 a.m. DST and may last for two to three hours. Feeding occurs in the forenoon and again in the afternoon. During a feeding observation in a Big Horn Mountain meadow at 9:51 a.m. DST, an adult male sitting horizontally on the ground was seen to feed on a short green sprout from its tip to base. Adults may remain inactive on the ground in sheltered spots for long periods of time during the day and may not move unless disturbed by roving insects, wind, or rain. A second period of basking occurs in late afternoon. Then as evening approaches and temperatures fall, the grasshoppers enter their nightime shelters.

Table 1. Mean percent dry weight of food items in the crops of *Melanoplus alpinus* in northern Colorado, Larimer County. (Adapted from Hansen and Ueckert, 1970.)

Item	8/10/67	8/23/67
Arenaria fendleri	34.9	34.7
Astragalus spp. and *Oxytropis lambertii*	19.7	15.8
Penstemon sp.	3.2	0.5
Taraxacum offinale	2.1	0.8
Antennaria parvifolia	2.1	0.5
Achillea lanulosa	2.1	0.0
Cryptantha virgata	2.1	0.0
Erigeron spp.	2.1	0.0
Poa spp.	4.6	2.6
Festuca idahoensis	2.1	9.5
Agropyron spp.	1.7	3.9
Muhlenbergia filiculmis	1.4	2.9
Danthonia parryi	0.3	3.9
Bouteloua gracilis	1.2	1.5
Arthropod parts	2.4	4.8
Fungi	10.2	8.3
Number Crops	23	40

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Narrowwinged Sand Grasshopper

Melanoplus angustipennis (Dodge)

Distribution and Habitat

Despite its local distribution in sand prairies and in smaller open tracts of sandy land, the narrowwinged sand grasshopper ranges widely in North America. It lives in vegetated sand dunes, blowouts, and banks of streams and lakes. Vegetation in the sand prairie consists of thin stands of tall, mid, and short grasses and a variety of forbs. Common species include sand bluestem and prairie sandreed (tall grasses); needleandthread, sand dropseed, little bluestem, prairie junegrass, and western wheatgrass (mid grasses); blue grama and sun sedge (short grass and sedge); scarlet globemallow, slimflower scurfpea, and western ragweed (forbs); and sand sagebrush (shrub). In regions of sand and sandy loam soils this grasshopper also inhabits roadsides, edges of crop fields, and weedy fields of the Conservation Reserve Program (CRP). Large populations may build up in these disturbed sites.

Economic Importance

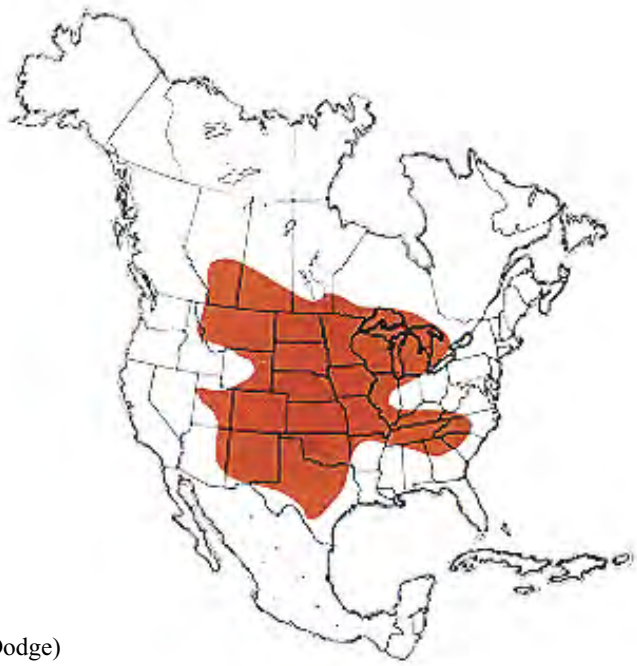
Damage to rangeland forage by this grasshopper has not been investigated quantitatively. However, in 1978 this grasshopper was the dominant species in high density assemblages in the Nebraska Sand Hills, which caused much concern among ranchers. Regrettably, no data on damage and absolute densities were obtained. The following year, densities were still high, but *M. angustipennis* dropped to second place while *Ageneotettix deorum* became the dominant species. In 1980 the outbreak ended and densities of the grasshopper assemblage fell, ranging from two to six per square yard with *M. angustipennis* averaging 0.3 per square yard.

Populations of this grasshopper, as well as certain other species of *Melanoplus*, build up in roadside vegetation and in abandoned fields, posing a hazard for adjacent fields of winter wheat. In Ontario, infestations have damaged grain crops grown in sandy soil.

Of the three size divisions of grasshoppers, the narrowwinged sand grasshopper belongs to the middle group. Live weight of males and females from a sand prairie of eastern Wyoming averaged 271 mg and 381 mg, respectively (dry weight of males averaged 82 mg and females averaged 121 mg).

Food Habits

The narrowwinged sand grasshopper is a polyphagous species. It feeds on forbs, grasses, shrubs, moss, and fungi, and also dead insects if available. Examination of crops of grasshoppers collected in three western states (Nebraska, North Dakota, and Colorado) indicates that this species feeds principally on forbs. Consumption of forbs ranges from 41 to 78 percent (average 62) and of grasses from 12 to 47 percent (average 21). A large number of plant species have been detected in crops: 21 grasses, 4 sedges, 47 forbs, and 2



Geographic range of
Melanoplus angustipennis (Dodge)

Instar 1

1. BL 3.9-4.5 mm FL 2.5-2.7 mm AS 13.

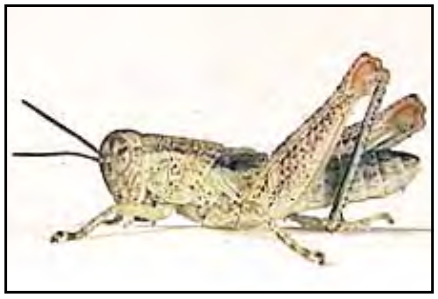
Instar 2

2. BL 5-6.4 mm FL 3.2-4 mm AS 15-17.

Instar 3

3. BL 7.2-10 mm FL 4.6-6.9 mm AS 20-21.

Instar 4



4. BL 10.5-13.5 mm FL 6.9-8.6 mm AS 21-23.

Instar 5

5. BL 13.5-18.6 mm FL 9-11.5 mm AS 23-25.

Figures 1-5. Appearance of the five nymphal instars of *Melanoplus angustipennis* - their sizes, structures, and color patterns. Notice progressive development of the wing pads. BL = body length, FL = hind femur length, AS = antennal segments number.

shrubs. The majority of these appear only in trace amounts (less than 1 percent). Native rangeland forbs eaten in substantial amounts include western ragweed, prairie sunflower, western sticktight, and cudweed sagewort, while rangeland grasses eaten in substantial amounts include blue grama, needleandthread, sand dropseed, and western wheatgrass. Sun sedge has been found in large amounts in crops of grasshoppers collected in the Nebraska Sand Hills.

In two-choice food tests, the narrowwinged sand grasshopper showed a preference for petals of sunflower, leaves of dandelion, downy brome, and alfalfa, and a lack of preference for blue grama, western wheatgrass, yellow sweetclover, kochia, lambsquarters, and tumble mustard. These results indicate that this grasshopper, although polyphagous, discriminates among food plants and may feed heavily on grasses only when preferred forbs are unavailable.

Few direct observations have been made of the feeding of the narrowwinged sand grasshopper. One female near the top of a lemon scurfpea plant was observed to feed on the edge and then the tip of the small lanceolate leaf. Another observation was made of two females with their heads buried in the composite center of common sunflower. They were presumably feeding on parts of the reddish brown disk flowers. Two observations were made of a fifth instar and an adult male feeding on ground litter. They crawled on the ground tasting litter and then stopped to feed. The fifth instar lifted a small piece of litter with the front tarsi and directed the food to its mouthparts.

Dispersal and Migration

The narrowwinged sand grasshopper possesses long wings that extend to the end of the abdomen or may surpass it by up to 4 mm. Evasive flight ranges from 2 to 8 feet, at heights of 4 to 10 inches. The flight is silent and usually straight. Landing may be on the ground or onto vegetation.

Evidence for dispersal is the discovery of “accidentals” at high altitudes west of Boulder, Colorado. A distance of 13 miles separated the habitat of a resident population near Boulder and the site at 8,500 feet. Circumstantial evidence of its ability to disperse is also found in its distribution in eastern Wyoming. The species is present in sandy roadside habitats and CRP land, while it is absent in surrounding mixedgrass prairie. Migrating swarms of this grasshopper have not been observed.

Figures 6-10. Appearance of the adult male and female of *Melanoplus angustipennis*, wings of female, end of male abdomen, and egg pod and eggs.

Identification

The adult narrowwinged sand grasshopper is a medium-sized spurthroated species. It may be dull gray or brightly colored yellow and tan (Fig. 6 and 7). Wings are long, extending as much as 4 mm beyond the abdomen. The hind tibiae are red or blue. The male possesses diagnostic characters of the species: the cerci are spatulate and the distal third of the supraanal plate narrows abruptly (Fig. 9). In a collection of grasshoppers one may identify the females by associating them with the males using size, markings, and color.

The nymphs are identifiable by their structure, color patterns, and shape (Fig. 1-5).

1. Head with face nearly vertical, head usually tan but sometimes green and usually with numerous brown spots; frontal costa without brown spots in center but with brown spots on the carinae; compound eye fuscous with numerous light spots; antennae filiform and fuscous, each segment ringed anteriorly pale yellow.
2. Pronotum with lateral lobes usually tan or cream (sometimes green) and with several to many brown spots; disk of pronotum tan or green with numerous brown spots imparting a dark contrast to the lighter lateral lobes, this dorsal dark band extends posteriorly to the end of the abdomen.
3. Outer medial area of hind femur with four to five rows of fuscous spots and two faint, irregular dark patches; spots of first row (below upper carinula) often enlarged, coalescing and forming a dark broken line; tibia mainly pale gray, fuscous on front edge.
4. General color: instars I and II tan, instars III to V pale tan, pale gray, or cream.

Hatching

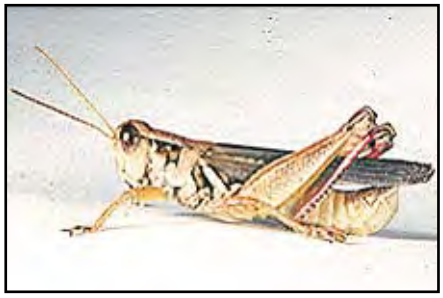
The narrowwinged sand grasshopper is an early developing species. First instars appear about the same time as those of *Ageneotettix deorum*, which is also a common member of the grasshopper assemblage in sand prairie. In eastern Wyoming, hatching begins in early to late May and continues for approximately two weeks.

Nymphal Development

Both male and female nymphs develop through five instars, taking from 36 to 42 days to reach the adult stage.

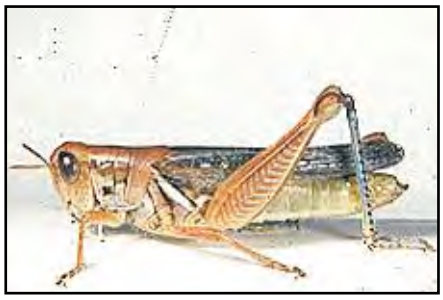
It is not surprising that the males and females have the same number of instars, as the sexes differ little in size.

Male



6. BL 19.7-22.2 mm FL 11-12.7 mm AS 23-26.

Female



7. BL 20.5-24.5 mm FL 12.2-13.5 mm AS 24-26.

Wings

8. Spread wings of an adult female.

Cercus

9. End of male abdomen showing shape of cercus and supraanal plate.

Egg pod

10. Egg pod (froth section broken off and missing) and exposed eggs.

The length of hind femur in male and female first instar nymphs is equal, while this part in the female fifth instar and the adult is only 1.1 fold longer than in the male.

Adults and Reproduction

The majority of adults remain in the same sandy soil habitat in which the nymphs hatched and developed. In eastern Wyoming, young adults appear during the first half of July, while a few old adults survive into October. The males fledge about one week before the females. Sexual maturation of the females occurs approximately two weeks after they fledge. Mating pairs may first be observed toward the end of July. An attempt at mating was observed in a laboratory terrarium. A male facing a female resting on vegetation stridulated several times and suddenly jumped and mounted her. Both fell to the sandy floor but failed to copulate.

Oviposition has not been observed in nature. Adults (four males and eight females) confined in a laboratory terrarium produced a total of 18 pods during October 1992. Examination of five of the pods revealed 12, 12, 14, 17, and 17 eggs. The females laid in bare sand that had been transported from their sand prairie habitat. Twice as many were laid close to vegetation (sand bluestem) as in the peripheral bare sand. This indicates that in their natural habitat the females prefer ovipositing close to vegetation.

The pods are 5/8 inch long, curved, and contain from 12 to 18 eggs each (Fig. 10). The egg portion of the pod is 3/8 inch long and is topped by a 1/4 inch section of froth. The bottom eggs lie 1/2 inch deep in the soil. Eggs are tan and range from 4 to 4.8 mm in length.

Population Ecology

Grasshopper outbreaks in the sand prairies consist of assemblages of species in which the narrowwinged sand grasshopper and A. deorum are often dominant. The absolute densities reached by the narrowwinged grasshopper during these outbreaks have been infrequently measured. In a Nebraska Sand Hills site it was the dominant species in 1978 during an outbreak that lasted at least two years. In 1979, the last year of outbreak, A. deorum became dominant while the narrowwinged sand grasshopper fell to second place.

A study of populations in a sand prairie of southeastern North Dakota from 1959 to 1968 revealed an outbreak of grasshoppers (25 per square yard) in one year of the ten. In this outbreak the narrowwinged sand grasshopper was a subdominant species with a density of 1.3 individuals per square yard. Density of this species, dominant in a sand prairie site in eastern Wyoming in a non-outbreak population, measured two young adults per square yard. Outbreak densities have been observed in ruderal habitats, but absolute densities have not been ascertained.

Daily Activity

In its sand prairie habitat, the narrowwinged sand grasshopper spends most of its day on the ground. Early in the morning before the sun strikes them, the grasshoppers emerge from their nighttime shelters. Because temperatures of the ground surface and 1 inch above may be as low as 50°F, the chilled grasshoppers do not fly evasively but are able to jump away from an intruder. They rest horizontally on the ground with no particular orientation to the sun. Flushed grasshoppers may land on vegetation, but the majority of these jump quickly to the ground.

Later (8 a.m. DST) as solar radiation increases the temperatures of the air (60°F) and ground (70°F), the grasshoppers begin to bask on the ground by turning a side perpendicular to the sun's rays and by lowering the associated hindleg. When grasshoppers have warmed sufficiently, they become active and begin to walk, feed, and mate. No observation has been made of their response to inimical high temperatures. In late afternoon as temperatures cool they again bask. Later (5:30-6:30 p.m. DST), adults seek shelter for the night by crawling under canopies of ground litter, mainly dry grass leaves. Although temperatures at these times are above 70°F and well within their normal activity range, the grasshoppers do not flush, even when one walks within 1 foot of them. In ruderal habitats most individuals climb on high vegetation, such as sunflower, western ragweed, and sweetclover, to spend the night vertically (head up) at heights of 10 to 40 inches.

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Twostriped Grasshopper

Melanoplus bivittatus (Say)

Distribution and Habitat

The twostriped grasshopper, *Melanoplus bivittatus* (Say), occurs widely in North America inhabiting tall, lush, herbaceous vegetation. Dense populations may reside in tallgrass prairie, wet meadows, roadsides, ditch banks, and crop borders.

Economic Importance

The twostriped grasshopper is a major crop pest causing much damage to small grains, alfalfa, and corn. During outbreaks, it may completely destroy crops. A population of 10 adults per square yard in a corn field will defoliate the crop. Sorghum plants over 6 inches tall, however, are nearly immune to attack. Experiments indicate that in feeding on spring wheat the twostriped grasshopper wastes six times as much foliage as it eats. In urban areas the twostriped grasshopper is a common pest of flowers and vegetables. It is a large grasshopper. Collected from a roadside in Platte County, Wyoming, males averaged 549 mg live weight and females 1,086 mg (dry weight: males 166 mg and females 341 mg).

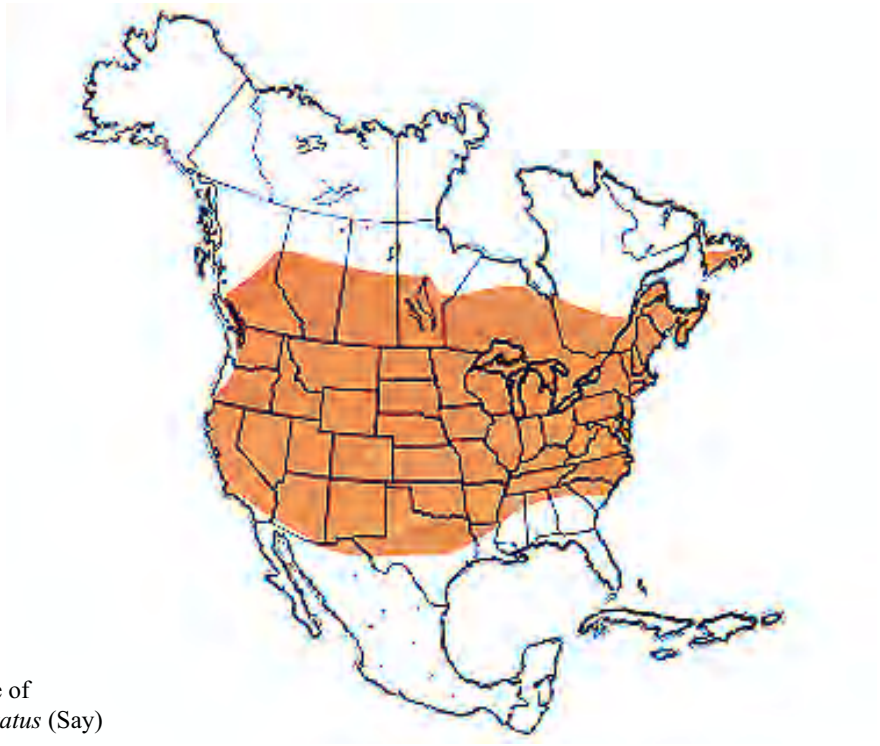
Food Habits

The twostriped grasshopper is a polyphagous species. It feeds on many kinds of plants. Although grasses and cereals are eaten and damaged, rearing experiments show that certain forbs furnish the nymphs with diets that promote high survival, fast growth, and heavy weights. These host plants belong to several plant families. Included are mustards, flixweed and pepperweed; a plantain (broadleaf plantain); legumes (alfalfa and red clover); and composites (greenflower, dandelion, chicory, prickly lettuce, giant ragweed, and arrowleaf butterbur). Microscopic examination of crop contents and field observations indicate that the following species may also be primary host plants: ball mustard, western ragweed, prairie sunflower, perennial sowthistle, kochia, and leadplant. The twostriped grasshopper feeds also on dry litter found on the ground.

A meal for the twostriped grasshopper may be a single species of plant but usually it consists of two or more species. Laboratory rearings demonstrate that a mixed diet is more nutritious than a single plant diet. The diets of particular populations vary depending on the kinds of plants present in their habitats.

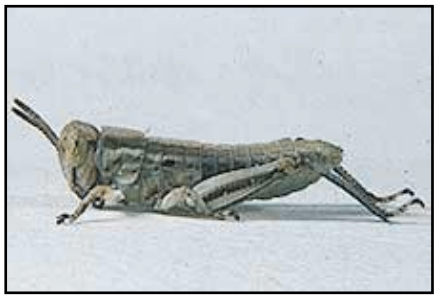
Migratory Habits

The twostriped grasshopper exhibits migratory behavior during both nymphal and adult stages. At high densities nymphs move in bands when they reach the third and older instars. Populations invade crops from crop borders and roadsides where eggs are concentrated and nymphs reach densities as great as 500 per square yard. Nymphs start migration around 10 a.m. when skies are clear and temperature has risen to 75°F. This activity may



Geographic range of
Melanoplus bivittatus (Say)

Instar 1



1. BL 5-6.6 mm FL 2.7-3 mm AS 12-13.

Instar 2

2. BL 7.4-10.4 mm FL 3.9-4.3 mm AS 17-18.

Instar 3

3. BL 9-14 mm FL 5.7-8.4 mm AS 19-22.

Instar 4

4. BL 15-21 mm FL 8.5-12 mm AS 23-24.

Instar 5

5. BL 20-27 mm FL 12-14 mm AS 24-26.

Figures 1-5. Appearance of the five nymphal instars of *M. bivittatus* - their sizes, structures, and color patterns. Notice progressive development of the wing pads. BL = body length, FL = hind femur length, AS = antennal segments number.

occur through the day until 6 p.m. Wind has little effect on movement.

Adults begin flying when temperatures reach 86° to 90°F. Flying with the wind at heights of 600 to 1,400 ft above ground level, they may travel long distances. Swarms of adults also move upwind by low, short flights in search of green food. At high densities, twostriped grasshoppers develop longer wings and slimmer bodies and are more adapted to flight than are low density, solitary individuals.

Identification

The twostriped grasshopper is one of the two largest species in the genus *Melanoplus*. The other is the differential grasshopper, *M. differentialis* (Thomas). Both species are often found together in the same habitat.

The nymphs of the twostriped grasshopper (Fig. 1-5) are identifiable by their spots, stripes, and color patterns:

(1) Compound eye brown with many light tan spots and no dark bands.

(2) Front of head tan or green with dark spots; line of dark spots on carinae (ridges) of frontal costa.

(3) Pronotum with light, horizontal stripe at top of lateral lobe; above the stripe a fuscous or brown band at the edge of pronotal disk.

(4) Gena colored tan or green and spotted, without light crescent below compound eye.

(5) Hind femur with black stripe entire, not interrupted by pale band. Stripe fills upper medial area of hind femur except at proximal end and encroaches slightly on the lower medial area.

(6) Hind tibia green or buff with spines or tips of spines black. Front (anterior edge) of tibia fuscous.

(7) General color green or tan.

The adult male (Fig. 6) is easily identified by the shape of the cercus (Fig. 9). Both the male and the female (Fig. 7) have two distinctive light yellow stripes running down the dorsum of the head, pronotum, and tegmina (Fig. 8). The stripes come together posteriorly on the tegmina forming a triangle.

Hatching

The twostriped grasshopper is an early-hatching species. It is one of the first species to appear in habitats of roadsides and field borders. Eggs (Fig. 10) begin embryonic growth in the summer of deposition and attain 60 to 80 percent development before they go into diapause for the winter. When soil temperatures rise in spring, the

Figures 6-10. Appearance of the adult male and female of *M. bivittatus*, two diagnostic characters, and the egg pod and several loose eggs.

embryos complete development and hatching begins. Eggs start to hatch eight to ten days ahead of those of the migratory grasshopper, *Melanoplus sanguinipes* (F.) The hatching period may last from four to six weeks depending mainly on soil temperatures in spring. Hatching may come in two or more bursts following rain and warm temperatures.

Nymphal Development

Nymphs develop and grow in spring when vegetation is young and green. It takes around 40 days for them to reach the adult stage. Dense populations of nymphs do much shifting about and often migrate into crops, particularly barley and wheat. Because of an extended period of hatching, nymphs may be present in the habitat for as long as 75 days.

Adults and Reproduction

Although the exact date of adult emergence may vary annually by as much as 50 days, this event usually occurs in the first part of summer. Grasshoppers that have moved into crops return to crop borders and roadside habitats for reproduction. Without signaling, a male will stealthily approach a female and make a copulatory leap. After mounting and while attaching his genitalia, the male performs a courtship ritual by shaking his hind femora for three or four seconds. Females have a preoviposition period of one to two weeks before depositing their first clutch of eggs. Favored sites for oviposition are ditch banks that face south and crop borders with compact drift soil. The females select crowns of grass or roots of weeds on which to deposit their clutch. Pods may contain from 50 to 108 eggs. Pods are curved, one and one-eighth to one and one-half inches inches long and one-quarter inch in diameter (Fig. 10) They are delicate and easily broken in sifting them from the soil. Eggs are olive and 5.1 to 5.3 mm long. Fed a nutritious diet of radish leaves, caged grasshoppers have averaged 450 eggs per female. The average number of pods and eggs produced in nature is unknown.

Most populations of the twostriped grasshopper have a one-year life cycle, but in mountain parks of British Columbia at altitudes above 3,000 feet, populations take two years to complete a life cycle. A two-year life cycle may also occur among populations inhabiting meadows of the Rocky Mountains.

Population Ecology

The twostriped grasshopper became a pest when agricultural development in the West fostered large populations of the insect. Early settlers unwittingly sowed

Male

6. BL 28-30 mm FL 15-16.5 mm AS 26-27.

Female

7. BL 36-41 mm FL 18.5-20.5 mm AS 27-28.

Note Two Stripes

8. Dorsal view of twostriped grasshopper.

Note Cercus

9. Side view end of male abdomen.

Egg pod

10. Egg pod and several loose eggs.

seeds of various weeds along with their crops, thus introducing nutritious new host plants for this grasshopper. The weeds also grew luxuriantly along crop borders, road sides, and ditch banks. This environment provided essential habitats, while south-facing ditch banks and compact drift soil at field margins furnished ideal egg laying sites.

These factors and favorable weather over a few consecutive years allow populations to irrupt. In eastern North and South Dakota such favorable conditions combined to precipitate one of the worst outbreaks of the twostriped grasshopper and differential grasshopper in agricultural history. Populations increased slowly for three years, 1928 to 1930. Both species reached phenomenal numbers in 1931 and 1932. They devastated fields of alfalfa, small grains, corn, vegetables, and a variety of fruit and shelterbelt trees. In 1933 and 1934 a severe drought not only ruined crops and other vegetation but also terminated the grasshopper outbreak.

Daily Activity

The twostriped grasshopper is a diurnal insect. Its activities occur during the daylight hours when weather is warm and the skies are clear (Table 1).

The tall vegetation of its habitat influences its behavior. In the evening before sunset as temperatures cool, both nymphs and adults climb the plants and rest, moving from halfway up to nearly the top of the vegetation. In these positions they rest through the night. Shortly after sunrise, the grasshoppers are warmed by the rays of the sun and begin to descend from their overnight perches. On the ground they may continue sunning themselves or begin to feed and then to migrate. Nymphs are usually on the ground from 6 to 11 a.m.

Table 1. Activity of nymphs and adults of the twostriped grasshopper, *Melanoplus bivittatus* (Say) correlated with air and soil temperatures (after Parker and Shotwell 1932)

Name of activity	Description	Average temperature °F			
		Nymphs		Adults	
		Air	Soil	Air	Soil
Beginning of activity	Start of descent from plants	65		65	
Beginning of normal activity	Start of feeding	68		68	70
	Start of migration	75		78	
	Start of oviposition			70	
Beginning of escape from heat	Climbing and seeking shade on plants	90	112	90	112
	Flying in circle or flying with wind			90	112

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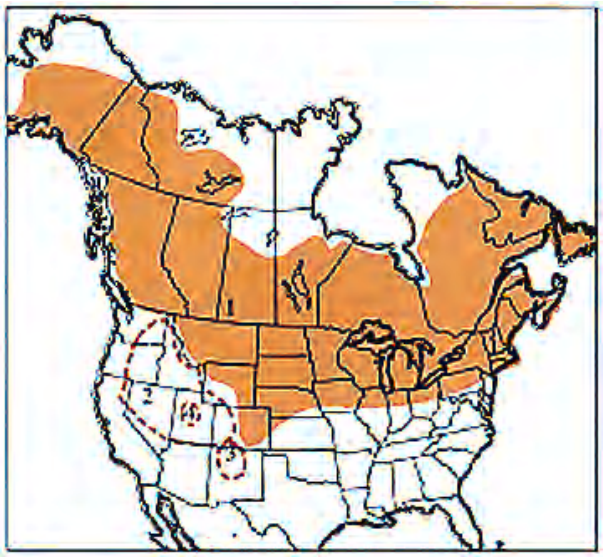
Northern Grasshopper

Melanoplus borealis borealis (Fieber)

Distribution and Habitat

The northern grasshopper, *Melanoplus borealis borealis*, ranges widely in the north of North America. The species inhabits both lowland and mountain sites, living in a variety of habitats that range from arctic tundra, wet bogs, and swamps to moist mountain meadows. In the latter, large populations consisting almost entirely of the northern grasshopper irrupt sporadically.



Geographic range of 1. *Melanoplus borealis borealis* (Fieber), 2. *Melanoplus borealis palaceus* Fulton, 3. *Melanoplus borealis stupefactus* (Scudder), 4. *Melanoplus borealis utahensis* Scudder.

Economic Importance

Because the northern grasshopper feeds preferentially on certain forbs and variably on certain grasses, a clear picture of its economic importance on grazing lands eludes precise description. In mountain meadows of Montana and Wyoming this grasshopper increases sporadically to densities as high as 60 young adults per square yard. It thus has the potential of damaging range forage; indeed, experienced entomologists have reported serious damage. In 1955 in Utah's Beaver Mountain, Fishlake National Forest, grasshopper survey entomologists reported a population of the subspecies *M. borealis palaceus*, estimated at 50 young adults per square yard, that destroyed reseeded meadow. High densities of this grasshopper have also been reported in the mountains of Idaho and Oregon. A small outbreak of the northern grasshopper in Wyoming occurred in 1995 in the Big Horn Mountains. One infested meadow of approximately 100 acres supported a population estimated at 20 young adults per square yard. A visual estimate of the vegetation indicated that 90 percent had been grazed by August 9. A method of sorting out the proportions consumed by each of the two chief herbivores, cattle and grasshoppers, appeared impossible. Observations of damage in nature are usually confounded by the presence of more than one herbivore. A study with adequate controls is needed to determine the exact impact under various circumstances. The problem is complex as the northern grasshopper is also beneficial when it feeds on its preferred host plants of lupine and loco. Grasshopper management specialists in Wyoming have postulated that in forb-rich meadows, damage to range grasses may be much less than might be expected from high densities of this species.

The northern grasshopper is a medium-sized species. Males collected from a meadow in the Big Horn Mountains of northern Wyoming averaged 231 mg live weight and females 392 mg (dry weight: males 68 mg, females 111 mg). Live weight of Alaskan males one to two days after emergence averaged 254 mg and females 377 mg.

Food Habits

Northern grasshoppers feed principally on forbs but they may also feed at times on certain grasses. In the crops of adults collected in the mountain meadows of Wyoming, high percentages of lupine and loco have been found (Table 1). Other forbs selected include dandelion, *Cerastium arvense*, species of thistle (*Cirsium*), and cinquefoil (*Potentilla*). As do many species of grasshoppers, the northern grasshopper will feed on arthropods, probably dead or dying grasshoppers, when they have the opportunity. A bluegrass, *Poa* sp, has been found in large amounts in crops of the northern grasshopper collected in one of three Big Horn Mountain sites (Table 1).

Near Fairbanks, Alaska, in an open field, the northern grasshopper has been observed feeding on four forbs: dandelion, red clover, *Parnassia palustris*, and *Petasites frigidus*. In laboratory tests these species were selected for food, confirming their status as preferred host plants in the Alaskan habitat.

In 1962 in the sand prairie of southeastern North Dakota, flood waters trapped a population of northern grasshoppers with a large number left in the center of an ongoing study area. Analysis of crop contents revealed that the grasshoppers were feeding on seven forbs, five grasses, and one sedge. Favored foods in the order of percent ingested were Kentucky bluegrass, 53; western ragweed, 21; Missouri goldenrod, 15; and leadplant, 9.

In two-choice food preference tests of adults collected from a heavily infested meadow in the Big Horn Mountains of Wyoming, the grasshoppers preferred dandelion to white clover, alfalfa, silky loco, young wheat plants, downy brome, Kentucky bluegrass, western wheatgrass, and Idaho fescue. Of particular interest is the result of pairing dandelion and western wheatgrass. After six hours, 75 percent of the dandelion was consumed but less than 1 percent of the wheatgrass. After 22 hours all of the dandelion had been consumed and 20 percent of the western wheatgrass. Evidently the grasshoppers will feed on wheatgrass when other food is lacking. After six hours 98 percent of dandelion and none of Idaho fescue were consumed. In contrast, Kentucky bluegrass and downy brome were consumed at the same time as dandelion but in unequal amounts. At the end of four hours, 90 percent of dandelion and 25 percent of Kentucky bluegrass were consumed; at the end of six hours 20 percent of dandelion and 10 percent of downy brome.

In its mountain meadow habitat a few observations have been made of the northern grasshopper's method of attacking its food plant. A male was seen to rise from a horizontal position on the ground onto the lower green leaves of field

Instar 1

1. BL 4-4.8 mm FL 2.2-2.6 mm AS 13.

Instar 2

2. BL 5.6-6.5 mm FL 3.1-3.7 mm AS 15-17.

Instar 3

3. BL 7.2-8.9 mm FL 4.5-5.1 mm AS 18-20.

Instar 4

4. BL 10.1-13.7 mm FL 5.2-7 mm AS 20-21.

Instar 5

5. BL 14-17.5 mm FL 9.2-10.1 mm AS 23-24.

Figures 1-5. Appearance of the five nymphal instars of *Melanoplus borealis borealis* - their sizes, structures, and color patterns. Notice progressive development of the wing pads. BL = body length, FL = hind femur length, AS = antennal segments number.

chickweed, *Cerastium arvense*. Resting diagonally on the plant with hindlegs on the ground supporting the body, the male consumed a half-inch long leaf from tip to base. Another observation was of a female attacking a forb sprout. Oriented horizontally on the soil surface and over the plant, the female ate in two minutes the entire sprout from tip to below ground level.

No observation of the grasshoppers feeding on lupine (*Lupinus wyethi*) was made, but damage to leaves showed feeding from tip to base and gouging from edges. Evidently the grasshoppers either climbed 3 to 10 inches on the stems or they jumped onto the plant to reach the leaves.

Dispersal and Migration

The northern grasshopper possesses long wings, enabling it to fly and disperse. Observations of the species in a 4 acre meadow near Fairbanks, Alaska, provide insights into its dispersal behavior. Nymphs were concentrated in loose groups around areas where the eggs had hatched, but upon the acquisition of wings, the grasshoppers dispersed progressively into wider areas. When temperatures rose from 74° F to 95° F, the adults flew frequently and covered wide areas in relatively short periods. Another example of this grasshopper's powers of dispersal happened fortuitously when one-half of the meadow (2 acres) was mowed in mid July, 1967. Five days later the density of adults in the unmowed half did not differ greatly from that in the mowed. Ten days later, however, the density in the mowed half more than doubled. Finally, 15 days after mowing the population was concentrated in the mowed section. Because of the very short vegetation in this section the ground temperature was 4 to 6° F higher than in the natural habitat. Presumably, the grasshoppers moved because they preferred the higher temperatures.

A record of dispersal or of migratory flight was the discovery of a male northern grasshopper on the ice of Grasshopper Glacier in the Crazy Mountains of Montana, August 1988. The wings of the male were long, surpassing the apex of the hind femur by 5 mm. Individuals of the species were present in the adjacent meadow, so it is unknown whether the male came from close by or from a distant meadow.

In meadows of the Big Horn Mountains, flushed flight by the northern grasshopper is silent, short (1 1/2 to 3 feet), and at heights of 2 to 4 inches. The flight starts usually from the ground and ends on the ground, with the grasshopper facing away from the intruder. In the meadow at Fairbanks, Alaska flushed grasshoppers flew a distance of 1.6 to 5 feet at heights of 1 to 2 feet. On very warm, dry, and windless days, some adults flew 3 feet high and covered a distance of 10 to 20 feet.

Identification

The northern grasshopper is a dark insect of medium size possessing wings of variable length. The wings of males usually range from slightly short of the apex of the hind femur to slightly beyond; the wings of females are usually shorter covering three quarters of the abdomen (Fig. 6 and 7). The shape of the male cercus is diagnostic of the species (Fig. 9). It is short, wide at the base, gently curved upward, and narrows toward a blunt apex. The arms of the furcula are long, reaching about halfway on the supraanal plate. The subgenital plate curves dorsally, terminating in a blunt truncate end. The medial area of the hind femur is usually entirely black, the upper marginal area is usually fuscous, the lower marginal area is red but sometimes yellow, and the hind

Figures 6-10. Appearance of the adult male and female of *Melanoplus borealis borealis*, left hindleg of male, end of male abdomen, and egg pod and exposed eggs.

tibia is red (Fig. 8). The abdominal venter is usually pale gray or pale green, but occasionally yellow or two-toned, each sternum being fuscous in the anterior half and olive in the posterior.

The nymphs are identifiable by their color patterns, shape, and structures (Fig. 1-5). The first instars are distinctively black except for a narrow mid dorsal brown band and a light crescent on the side of the head and pronotum. Figure 1 pictures an unusually light first instar.

1. Head with face nearly vertical and colored black, brown, tan, or green; yellow or ivory crescent on side of head and lateral lobe of pronotum; compound eye with many light spots, lower half darker than upper; narrow light line and broad black bar behind compound eye.
2. Pronotum brown or green and usually with dark brown or fuscous spots. Medial area of hind femur all black in instars I an II, broad dorsal stripe in instars III to V; inner medial area in instars I and II all black and occasionally marked by a light bar apically; in instar III like instar II or the black area may be interrupted by two light bars, an apical and a middle one; in instarts IV and V the inner black area becomes a dark dorsal ensiform stripe (elongate triangular with base toward apex of hind femur), light ventrally. Hind tibia is black in instar I with a light annulus proximally, in instar II hind tibia is black or fuscous and tan. In instars III to V hind tibia is usually dark tan with front fuscous.
3. General body color of instars II to V brown less often green, venter generally olive or each sternum of the abdomen with front half fuscous and rear half olive.

Hatching

In the grasshopper assemblages of mountain meadows, the northern grasshoper hatches relatively early along with several other high-altitude species, including *Aeropedellus clavatus*, *Bruneria brunnea*, *Camnula pellucida*, *Melanoplus alpinus*, and *M. bruneri*. Before hatching in spring, the eggs of the northern grasshopper require two winters in the soil to break diapause. The species is one of several the early 1950s field entomologists postulated that this grasshopper required more than one year to complete its life cycle when they observed reinfestations of areas a year after treatment and were unable to explain the results by poor kills or migration of adults. Subsequently, entomologists conducted field and laboratory experiments that showed the eggs required two years in the soil before hatching.

A study of the life cycle of the northern grasshopper in the Big Horn Mountains of Wyoming in 1994 and 1995 revealed that eggs begin to hatch from June 1 to July 1. The exact date depended on time of snow melt, warming of the soil, and elevation of site. On 4 May 1994, Powder River Pass (elevation 9,660) was 85 percent covered with snow. By May 24 the site became clear of snow, and exactly one month later the eggs of the northern grasshopper began to hatch. A late spring in 1995 delayed the start of hatch at this site until July 1. In this year hatching continued for two weeks.

In a meadow site near Fairbanks, Alaska (elev. 450 feet) eggs of the northern grasshopper began hatching June 10 in both 1967 and 1968 and continued for 10 to 15 days. The eggs did not hatch unless they were submerged in melt water in spring.

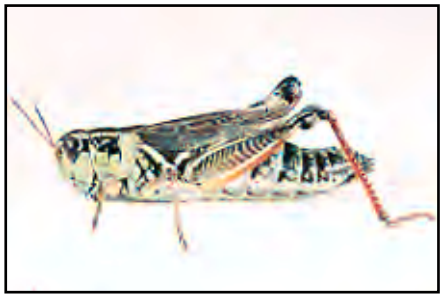
Nymphal Development

The nymphs grow rapidly, completing their development to the adult stage in about one month. Calculated from first hatch to first

Male

6. BL 19.5-21 mm FL 10.5-12 mm AS 24-26.

Female



7. BL 18.5-29 mm FL 10.5-13.8 mm AS 23-26.

Hindleg

8. Left hindleg of male.

Cercus

9. End of male abdomen showing the cercus and long arms of furcula.

Eggs

10. Egg pod and exposed eggs of opened pod.

adults, nymphs in the Bald Ridge site (elevation 9,185) of the Big Horn Mountains, completed development in 29 days; while in the Powder River Pass site (elevation 9,660 feet) they completed development in 31 days. In the meadow at Fairbanks, Alaska, nymphs took 30 to 32 days to become adults.

Adults and Reproduction

In meadows of the Big Horn mountains, adults may appear as early as the first week of July or as late as the first week of August. They usually remain in the habitat in which they developed as nymphs and some survive into mid September. Maturation in nature has not been studied but rearing of the species in a laboratory at Fairbanks, Alaska has provided information on this important feature of the adult life history. The adults emerged between July 10 and August 3; the first mating was observed on July 28 but mating did not become common until August 7. Sexual maturity was attained about three weeks after molting to adulthood. In laboratory cages mating usually occurred during the warmest part of the day and pairs remained in copulo for 10 to 15 minutes. Oviposition began 8 to 10 days after mating and lasted from mid August until October 1.

No record of females ovipositing in their natural habitat has been made. Under laboratory conditions females readily oviposit into bare soil. The pods, 3/4 to 7/8 inch long and slightly curved, contain 12 to 16 eggs (Fig. 10). The egg section is 3/8 inch long and lies in the soil at a depth equal to the length of the pod. Eggs are two-toned tan and yellow and 4 to 4.8 mm long.

Population Ecology

The northern grasshopper has a history of irrupting in meadows of the Rocky Mountains. Survey records from the Big Horn Mountains of Wyoming have revealed populations as dense as 60 young adults per square yard. The species enjoys a high frequency of occurrence in the many disjunct meadows of the Rocky Mountains. For example, of 19 meadow sites investigated in 1994 and 1995, nine harbored individuals of the northern grasshopper and ten were free of the species (47 percent frequency). Densities of three sites were estimated to be 20, 8, and 3 young adults per square yard while densities of the other six occupied sites were all less than 0.1 per square yard. In outbreak years the species appears to have a higher frequency of occurrence. In 1963, an outbreak year, all of 14 sites surveyed were infested and dominated by the northern grasshopper. The density of assemblages in these sites averaged 49 young adult grasshoppers per square yard. We may infer that the northern grasshopper comprised over half of these densities and it therefore comprised an average of 25 or more young adults per square yard. In 1964 the numbers of northern grasshopper were sparse and their dominance was relinquished to *Camnula pellucida* and *Melanoplus sanguinipes*.

Because only limited studies of the population ecology of the northern grasshopper have been conducted and none for more than three years, we do not know how many years it takes for populations to increase to outbreak numbers, nor how long outbreak populations persist after they appear. We also do not know how long the intervals of low numbers last. Survey data indicate that an infested site may have high densities in successive years or due to the biennial life cycle of the species particular sites may have high numbers one year and low or none the next. Evidently a multiplicity of physical factors are affecting the growth, survival, and decline of populations of the northern grasshopper.

Daily Activity

The northern grasshopper dwells chiefly on the ground in meadow habitats with adequate bare soil for basking. Its nightly refuge has yet to be determined with certainty. An observation made 10 August 1995 at 7:30 a.m. DST in a meadow of the Big Horn Mountains (sun hid by clouds, 40° F ground surface, 50° F air) revealed a female sitting quietly on and parallel to a dry stem of grass that leaned at a 10° angle to the ground. The female rested at a height of 2 inches above ground and was sheltered in a thick midgrass canopy. On clear days grasshoppers leave shelters early in the morning and move to sunny spots on bare soil or litter to bask. Observations made in August 1995 from 9 to 11 a.m. DST show that the basking grasshoppers orient themselves horizontally on the soil surface, turn a side perpendicular to the sun, and lower the associated hindleg to expose the abdomen fully to the sun's rays. On clear days basking ends between 10 and 11 a.m. when ground temperatures have increased to 85° F and air temperatures exceed 52° F. The grasshoppers may turn on the ground and face directly away or into the sun and rest, or they may become active—walking, searching, feeding, and mating. During rains the grasshoppers have been observed in the Alaskan meadow to take refuge by sitting vertically, head-up on vegetation. Activity, and much resting, may continue until 5 p.m. at which time the grasshoppers begin to bask for a second time. Basking then continues until nearly sunset when they disappear into their nocturnal shelters.

Table 1. Mean percent dry weight of food items in the crops of adult *Melanoplus borealis* collected from grass-herb meadows of the Big Horn Mountains, Wyoming.

Food item	Site 1 15 August 1994	Site 2 27 July 1989	Site 3 27 July 1989
Lupinus	6	50	68
Oxytropis campestris	58	0	0
Poa	0	26	8
Composite	6	8	17
Cirsium	0	10	5
Potentilla diversifolia	10	0	0
Astragalus	7	0	0
Achillea millefolium	6	0	0
Arthropod	6	0	0
Carex	0	4	0
Verbena	0	0	2
Grass seed	1	0	0
Other forbs	0.4	1.7	0.2
Total forbs	94.4	69.7	92.2
Total grasses	1.0	30.0	8.0
Number crops	**13**	**19**	**8**

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Sagebrush Grasshopper

Melanoplus bowditchi Scudder

Distribution and Habitat

The sagebrush grasshopper is distributed widely in western grasslands. It inhabits the mixedgrass, shortgrass, desert, and bunchgrass prairies, and certain desert shrub communities. In all of these vegetational units its distribution depends upon the presence of sagebrush.

Economic Importance

The preference of the sagebrush grasshopper for silver sagebrush, a plant that furnishes good to excellent browse in fall and winter for all classes of livestock and game animals, makes this insect a potentially damaging species. The low densities of this grasshopper, however, suggest economic damage does not occur. The sagebrush grasshopper is a medium-sized species of the diverse genus, *Melanoplus*. Live weights of males average 394 mg and of females 434 mg (dry weights males 80 mg, females 144 mg).

Food Habits

The sagebrush grasshopper feeds almost exclusively on several species of sagebrush. Two of the six species known to be ingested are evidently primary host plants, silver sagebrush, *Artemisia cana*, and sand sagebrush, *A. filifolia*. Crop contents of grasshoppers collected in western North Dakota contained 97 percent silver sagebrush and 5 percent fringed sagebrush, while crop contents of grasshoppers collected in western Nebraska consisted of 88 percent sand sagebrush and the remainder undetermined forbs and pollen. The geographic range of the two host plants taken together matches closely the range of the grasshopper. Four other species - big sagebrush, fringed sagebrush, tarragon, and cudweed sagewort - are ingested in small amounts. These occur in the mixedgrass prairie along with silver sagebrush, so the nearly exclusive consumption of the latter indicates that it is the preferred species. Sand sagebrush grows on sand dunes and sand hills where silver sagebrush frequently does not occur and serves as the host plant in these more limited habitats.

The sagebrush grasshopper often attacks silver sagebrush at the edge of leaves. It may also cut a leaf at its base and hold onto it with the front tarsi to consume

Geographic range of
Melanoplus bowditchi Scudder

Instar 1

1. BL 3.9-6.1 mm FL 2.4-2.5 mm AS 13.

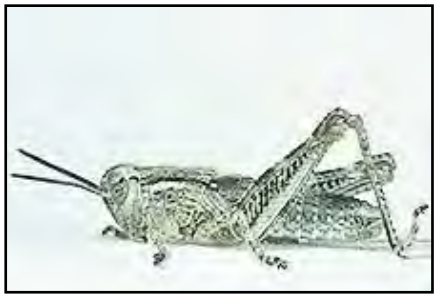
Instar 2

2. BL 6.5-7.5 mm FL 3.6-4.2 mm AS 16-18.

Instar 3

3. BL 8.1-9.4 mm FL 5.1-5.2 mm AS 19.

Instar 4



4. BL 12-14 mm FL 7.4-8 mm AS 20-21.

Instar 5

5. BL 14.5-20.5 mm FL 10-12 mm AS 22-24.

Figures 1-5. Appearance of the five nymphal instars of *Melanoplus bowditchi* - their sizes, structures, and color patterns. Notice progressive development of the wing pads. BL = body length, FL = hind femur length, AS = antennal segments number.

the entire leaf. In addition, this grasshopper feeds on the flowers of silver sagebrush when they become available. Adults have been observed feeding horizontally on a small mat-forming lichen on the ground.

Dispersal and Migration

Little is known about the dispersal and migration of the sagebrush grasshopper. Possessing long wings that extend beyond the end of the abdomen, the species evidently has the capacity to disperse and migrate. Observations have been made of its evasive flights. These are silent and usually straight at heights of 12 to 15 inches for distances of 1.5 to 12 feet. The flushed grasshopper takes off from its perch on silver sagebrush or from the ground and usually lands on vegetation, either its host plant or a grass culm.

Identification

The sagebrush grasshopper is a pale to dark gray, medium-sized, spurthroated grasshopper (Fig. 6 and 7). The wings are long, extending 3 to 5 mm beyond the end of the abdomen. The shape of the male cercus, an essential character for identifying and separating the numerous species of *Melanoplus*, is elongated and slender (Fig. 8). The medial area of the hind femur is marked by chevrons that are separated by white lines; chevrons are darker dorsally and lighter ventrally. The hind tibiae are light to medium blue.

Nymphs of the sagebrush grasshopper are identifiable by their shape, structures, and color patterns (Fig. 1-5).

1. Head. Face nearly vertical (slightly receding); compound eye with pale yellow spots; pale yellow crescent beginning on gena below compound eye and running onto lateral lobe.
2. Pronotum. Lateral lobes below crescent are light gray and weakly spotted; disk medium gray or brown, darker than lateral lobes and with many fuscous spots.
3. Hindleg. Femur with medial area having dark stripe centrally located in instars I and II and dorsally in instars III to V; tibia pale gray in instars I to IV, pale blue in instar V; front of tibia fuscous in all five instars.

Figures 6-9. Appearance of the adult male and female of *Melanoplus bowditchi*, the cercus of the male, and the egg pod and exposed eggs.

4. General body color pale gray with darker markings.

Specimens of this species may be picked up in a sweep net when a surveyor passes close to host plants.

Hatching

In the mixedgrass prairie of eastern Wyoming, eggs of the sagebrush grasshopper begin to hatch during the first week of June. Hatching occurs about three weeks after the bigheaded grasshopper begins to hatch, and places the sagebrush grasshopper in the intermediate-hatching group of species.

Nymphal Development

Nymphs develop rapidly, taking about 30 to 40 days to become adults. They are located close to their host plants: silver sagebrush or sand sagebrush.

Adults and Reproduction

Adults begin to appear in the habitat during the first week of July. Part of the nymphal population continues to molt to this final stage for as long as a month. Adults are present in the habitat for three months, July through September. No observations of courtship, mating, or oviposition in nature have been made. In the laboratory, females readily oviposit in bare soil. One caged female was observed ovipositing for at least 30 minutes. During this time she was attended by a male. Upon completion of oviposition and extraction of her abdomen, she covered the hole with soil by working her ovipositor back-and-forth and sideways. The pod is three-quarters inch long; froth surrounds a cluster of 12 to 13 eggs held together by scanty secretion of the accessory gland. The eggs are tan and 4.5 to 4.9 mm long (Fig. 9).

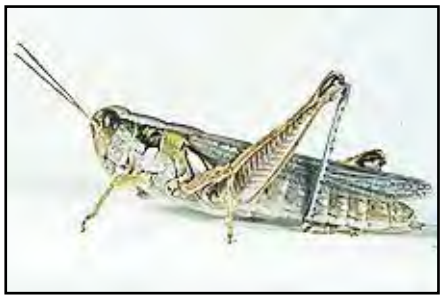
Population Ecology

The population ecology of the sagebrush grasshopper remains unstudied. We do know that it has an extensive range within which its dispersion is patchy and limited by the distribution of its host plants. Other important population characteristics such as density, fecundity, mortality, and capacity for increase are unknown. However, we know that it is an insignificant component of grasshopper outbreaks.

Male

6. BL 19-24.5 mm FL 11.5-12.5 mm AS 24-25.

Female



7. BL 22.5-26.5 mm FL 12-14.5 mm AS 24.

Cercus

8. End of adult male abdomen showing the cercus.

Eggs

9. Egg pod showing exposed eggs in bottom half of pod.

Daily Activity

The sagebrush grasshopper is a phytophilous species because it spends much of its daily life on the host plant. The precise proportion of time spent between the host plant and the ground, however, remains undetermined. During the night both nymphs and adults roost 6 to 16 inches high, head up, on stems of silver sagebrush. For about two hours after sunrise they remain on the host in these resting positions. Subsequently, they adjust their positions so that their sides or backs are exposed to the warming rays of the sun. By 9 a.m. many individuals have jumped to the ground and bask horizontally. On the ground, they turn a side perpendicular to rays of the sun and lower the exposed hindleg. About 10 a.m., when the soil surface temperature has risen to 70°F, they begin to stir and potter. Shortly afterwards they jump back into their host plant to feed. Method of mate location, courtship, and where the adults mate, either on the host plant or on the ground, are unknown. The grasshoppers again bask in late afternoon and by 6 or 7 p.m. most are roosting on the host plant where they remain overnight.

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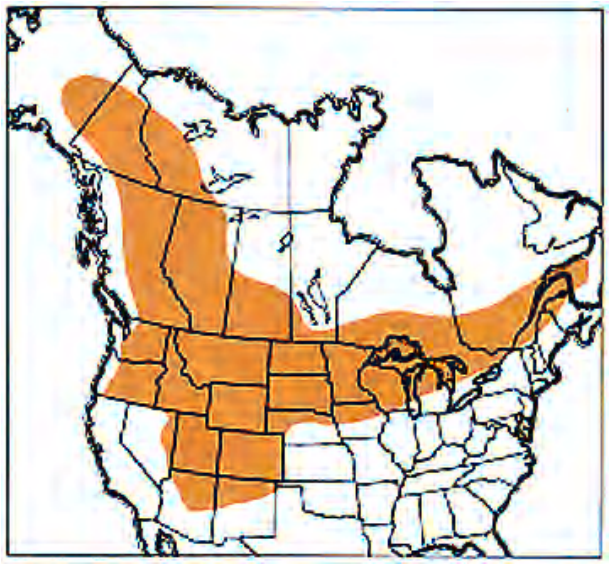
Bruner Spurthroated Grasshopper

Melanoplus bruneri Scudder

Distribution and Habitat

The Bruner spurthroated grasshopper ranges widely in North America, inhabiting arctic tundra, northern sections of western prairies, herb-grasslands of the Northeast, and mountain meadows of the West. In mountain meadows it often coexists with the northern grasshopper, *Melanoplus borealis*. The northern grasshopper characteristically resides in wetter, more luxuriant habitats while the Bruner spurthroated grasshopper lives in adjacent upland with drier conditions and thinner vegetation. Remarkably, the Bruner spurthroated grasshopper often inhabits the grass-herb undergrowth of quaking aspen groves and the adjoining open grassland.



Geographic range of *Melanoplus bruneri* Scudder

Economic Importance

The Bruner spurthroated grasshopper is primarily a pest of rangeland forage. A polyphagous species, it prefers to feed on forbs but also eats grasses. During outbreaks the grasshoppers may exhaust their preferred host plants of certain forbs by the end of the nymphal period and feed heavily on grasses as adults. Records of damage to forage appeared early in this century. In 1920 and 1921 huge numbers of this grasshopper and *Camnula pellucida* devastated grazing land of the Riske Creek Range of British Columbia. Surrounded by forests, the range is an undulating plateau of 300 square miles that lies between 3,000 and 3,500 feet elevation. In 1921 the Bruner spurthroated grasshopper was also reported as causing damage in the tallgrass prairie of northcentral Minnesota (near Grand Rapids, elevation 1,280 feet).

In the western United States, the species inhabits mountain meadows where populations irrupt at irregular intervals and cause severe damage to forage. An early record of forage destruction tells of the impact of a heavy infestation of *M. bruneri* in eastcentral Nevada in the Humboldt National Forest. The infested area consisted of tableland lying at an elevation of 11,000 feet, vegetated by bunch grasses and forbs, and grazed by sheep. High numbers of grasshoppers were reported from 1936 to 1938. In mid September 1937, densities were estimated at 20 adults per square yard. In an attempt to control this infestation, poison bait was transported to the sheep range by pack mules in 1937 and spread by hand. A large population, still present in 1938, was decimated by a midsummer hail storm. Records reveal outbreaks and damage in the mountains of Montana, Utah, and Wyoming. In the Crazy Mountains of Park County, Montana, severe damage to meadow grasses was inflicted by high numbers of *Camnula pellucida* and *M. bruneri* in 1954. This assemblage ranged from 15 to 50 adults per square yard. During the same year a study of food selection by *M. bruneri* was conducted in one of the infested meadows. A population of 15 adults per square yard exhausted the supply of preferred food plant, *Lupinus sericeus*, inducing the grasshoppers to feed on timothy and the heads of yarrow. Prolonged feeding on the leaves of timothy resulted in extensive damage to this grass. In 1962 and 1964, *M. bruneri* again irrupted in the mountains of Montana, this time in Madison County, and caused extremely heavy damage to meadow grasses. Utah records show populations of *M. bruneri* and *M. borealis* in excess of 100 adults per square yard infesting meadows of Fish Lake National Forest in 1959, 1961, and 1963. The meadows, lying at 10,500 feet elevation, were devastated by the grasshoppers. In 1963, 4,000 acres were baited to control a part of the infestation. In an adjacent area of Utah, the Manti-LaSal National Forest, *M. bruneri* was the dominant grasshopper infesting 75,400 acres on which controls were applied in 1959. Outbreaks of *M. bruneri* were discovered in meadows of the Big Horn Mountains of northern Wyoming in 1995. One of the infested sites was studied briefly on 10 August 1995. The site, called South Park and located on the western slope of the Big Horn Mountains in Big Horn County (T 50N R88W Sec23 SW), lies at an elevation of 8,600 feet and represents a typical mountain meadow vegetated by Idaho fescue and other high- altitude grasses. It was infested with weeds and forbs, many serving as preferred food plants for *M. bruneri* (See Table 1).

Cattle had not yet grazed the meadow. An examination of the vegetation revealed much consumption of forbs but none of grasses. Analyses of crop contents, however, showed that some feeding on grasses had occurred. Forbs comprised 68 percent of the diet and grasses 21 percent (Table 1). The evidence suggests that small numbers of the Bruner spurthroated grasshopper in a mountain meadow are beneficial as they feed principally on their preferred forbs, many of which are toxic to livestock, but that large numbers are destructive as they feed heavily on forage grasses and may devastate a meadow. The Bruner spurthroated grasshopper has occasionally infested fields of alfalfa in Saskatchewan and has caused harm to seed crops of alsike, timothy, and alfalfa in British Columbia and to oats in Alberta. The Bruner spurthroated grasshopper is a medium-sized species slightly larger than the migratory grasshopper, *M. sanguinipes*. In a collection from the South Park meadow of the Big Horn Mountains, live weight of males averaged 429 mg and females 535 mg (dry weight 120 mg and 160 mg, respectively).

Food Habits

The Bruner spurthroated grasshopper is a polyphagous species. Several studies reveal that it feeds on many kinds of plants growing in widespread habitats. It prefers certain forbs, but it also feeds on grasses. An analysis of crop contents of adults in the summer of 1995 from a heavily infested meadow of the Big Horn Mountains in northern Wyoming (South Park) indicated that the grasshoppers consumed 68 percent forbs, 21 percent grasses, 7 percent moss, 3 percent fungus, and 1 percent pollen (Table 1). Of 24 crops examined, 13 contained more than one food item and 11 contained a single item. The number of food items per crop ranged from 1 to 6 and averaged 2.3. Of the crops containing a single item, four contained common yarrow, two a perennial herb, *Arnica sororia*, and two a grass, Idaho fescue.

The diet of this grasshopper has been found to change with the advance of summer. In a mountain meadow of northern Colorado, this grasshopper in early August fed principally on *Astragalus*, but later in the month it consumed large amounts of *Astragalus* along with common dandelion and cinquefoil, *Potentilla* spp. (Table 1).

Instar 1

1. BL 4.4-5.8 mm FL 2.4-2.6 mm AS 12-13.

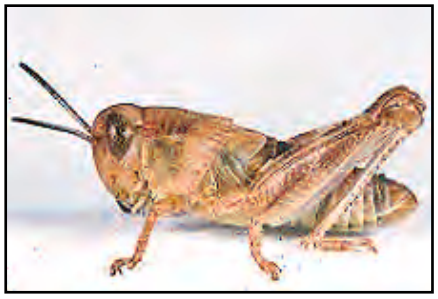
Instar 2

2. BL 5.6-8.3 mm FL 3.2-3.6 mm AS 16.

Instar 3

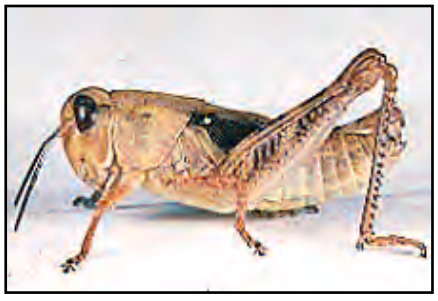
3. BL 7.7-9.4 mm FL 5-5.3 mm AS 18-20.

Instar 4



4. BL 10-11.6 mm FL 6.2-7.2 mm AS 20-21.

Instar 5



5. BL 15.5-27 mm FL 8.8-13.9 mm AS 22-24.

Figures 1-5. Appearance of the five nymphal instars of *Melanoplus bruneri* - their sizes, structures, and color patterns. Notice progressive development of the wing pads. BL = body length, FL = hind femur length, AS = antennal segments number.

A seasonal change of diet was likewise observed in the dense population inhabiting a meadow in the Crazy Mountains of southwestern Montana. The nymphs were observed to feed principally on *Lupinus sericeus*. This plant was almost completely defoliated by 22 July 1956, a time when nearly all the grasshoppers had molted to the adult stage. They then began to feed on common yarrow and timothy. When these plants became desiccated by 13 August, the grasshoppers began to feed on sticky geranium, *Geranium viscosissimum*, as a last resort.

Although in the Montana study dandelion was not seen to be a chosen food plant, observations of adults feeding in Wyoming mountain meadows and crop analyses of adults collected from a northern Colorado mountain meadow showed it was eaten in substantial amounts. Results of laboratory two-choice tests demonstrated that adults ate dandelion in preference to wheat, downy brome, Kentucky bluegrass, Idaho fescue, spike fescue, alfalfa, and red clover. The adults consumed false dandelion, *Agoseris glauca*, equally as well as common dandelion.

The method of attacking the host plant by the Bruner spurthroated grasshopper has received little attention. Three observations were made in 1996 in a mountain meadow of the Laramie Range (Pole Mountain). In late morning hungry grasshoppers were observed to stir, then to crawl along the ground surface in search of food. Possibly by chance, all three adults contacted dandelion plants. Still on the ground surface, they palpated the leaves and oriented themselves to feed on the leaf edges. No report has been make of how the grasshoppers feed on erect plants like lupine. They may crawl up the stem or jump onto the plant to reach the leaves on which they feed.

Dispersal and Migration

The Bruner spurthroated grasshopper possesses long wings and well-developed wing muscles enabling it to fly, disperse, and migrate. Only a small amount of information, however, is available on its flight behavior. A pertinent observation of migration by this grasshopper was made in the Big Horn Mountains of Wyoming on 15 August 1995 by grasshopper surveyor, Robert Stuckey. He monitored a large population of adults with a density ranging from 10 to 30 per square yard. The population was moving downwind and down slope in a southwesterly direction as the wind blew at 3 to 6 miles per hour. The grasshoppers were observed between 10 a.m. and 12 p.m. DST flying at heights of 2 to 10 feet and traveling 20 to 100 feet each time they flew. The morning was clear and air temperatures were estimated to range from 60° to 70° F. The grasshoppers were leaving a stock drive, 10 miles long and 3 miles wide lying at 6,700 to 7,800 feet, in which the vegetation was very short from heavy grazing by livestock and grasshoppers. The cessation of flight and the destination was not observed.

Further evidence of movement by flight was obtained upon the discovery in 1988 of 5 males and 18 females on the ice surface of Grasshopper Glacier in the Crazy Mountains of Montana. The preserved grasshoppers may have come from an adjoining mountain meadow, which harbored the species, or from a more distant meadow.

Flushed flight of the Bruner spurthroated grasshopper is silent, short, 3 to 4 feet in length, and at heights of 6 to 12 inches. In early morning when temperatures are low (less than 60°F), the adults jump to evade an intruder, but when morning temperatures have risen flushed adults usually take flight.

Identification

The Bruner spurthroated grasshopper is a medium-sized, fully winged, pale to dark brown species (Fig. 6 and 7). The wings reach or exceed from 1 to 3 mm the apex of the hind femur. Adult males possess a distinctive large, flat cercus; at its base the dorsal and ventral sides lie straight and parallel to each other, apically the cercus curves upward (Fig. 9). Arms of the furcula are large, reaching half the length of the supraanal plate and are nearly parallel. The subgenital plate of the male is long, the end curving noticeably upward; the apex is bilobed and shallowly notched. The mesosternum of the male has a prominent hump

Figures 6-10. Appearance of the adult male and female of *Melanoplus bruneri*, male hindleg, end male abdomen, and egg pod and exposed eggs.

like that of its close relative, *Melanoplus sanguinipes*. The medial area of the hind femur of both sexes is almost entirely fuscous or distinctively marked (Fig. 8 and see Fig. 4 for clear delineation of pattern). The hind tibia is usually pink or red; less often it is pale greenish yellow. The venter is usually bright yellow but may be pale or greenish yellow.

The nymphs are identifiable by their structures and color patterns (Fig. 1-5). Among montane *Melanopli* a distinctive characteristic of the nymphs is their body color, commonly brown and tan; however, some III to V female nymphs are green with faint, reduced dark markings.

1. Head with face nearly vertical; compound eyes brown with light tan spots; crescent faint or absent. Color bar behind eye is fuscous or brown, sometimes faint.
2. Pronotum with tail of crescent faint or completely absent. Medial area of hind femur with a distinctive color pattern; instar I frequently without this pattern, mainly fuscous but with light herring-bone stripes. Inner side of hind femur of instar I dark with three light bars; the light area increases in instars II to V with two dark patches remaining, one apically and one dorsally in the middle. Tibia in instar I is fuscous with a light basal annulus; in instars II to V it is tan or gray with front fuscous and spines black.
3. Venter of abdomen in instar I is shiny black, in instars II to V it is olive or yellowish green.
4. Body color brown and tan and spotted darker brown. Instar I often dark, chiefly fuscous. Some females of instars II to V are green.

Hatching

The Bruner spurthroated grasshopper is an early-hatching mountain species. Along with *M. alpinus*, *M. borealis*, and *Camnula pellucida*, first instar nymphs appear in the habitat during the first and second weeks of June in both Montana and Wyoming. A cool season, however, may delay hatching until the last week of June and first week of July. Normally hatching takes three weeks to complete, but if it is delayed by a late spring it may be concentrated into one week.

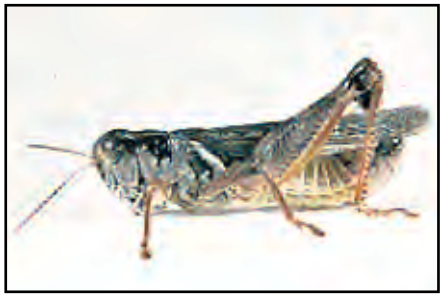
In mountain meadows, eggs of M. bruneri require two years of development in the soil before they hatch and some may even require three years. In a USDA study, eggs that did not hatch after two years contained fully developed embryos. These eggs required another exposure to a cold period before hatching when brought back to 85°F.

Results of laboratory rearing of this species at the Wyoming Agricultural Experiment Station suggest that under warmer conditions at low altitudes eggs may require only one year of development in the soil before hatching. A collection of three young males and seven young females was made on 29 July 1994 from a site in the Big Horn Mountains. On 31 July 1994 the grasshoppers were confined in the laboratory at an average temperature of 87°F for 12 hours during the day and 73°F during the night. The grasshoppers were fed dandelion and provided with a container (5 x 7 x 3 inches deep) of soil for oviposition. The adults were kept until all had died by 16 October 1994. Several pods were recovered from the oviposition container and placed in a mixture of sand and vermiculite. The eggs were exposed to cold, 36° to 40°F, for 83 days after which they were incubated at 82°F for 12 hours each day and 73°F for 12 hours at night. Emergence of 30 nymphs occurred after 8 days of incubation, 5 nymphs after 30 days, and 8 nymphs after 36 days. The results show that under favorable temperatures, some eggs can hatch in one year.

Nymphal Development

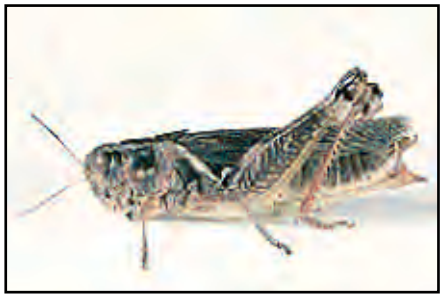
The nymphs make their appearance in the habitat usually by the first or second week of June. At this time they have available an abundance of preferred food plants. Although temperatures may be relatively low with peak air and soil surface temperatures of 71°F and 103°F, respectively, the nymphs' behavioral responses to temperature allow them to develop rapidly. Based on the time from first appearance of nymphs to first appearance of adults, the nymphal period lasts from 31 to 35 days. Both male and female nymphs require five instars to reach the adult stage.

Male



6. BL 18-22 mm FL 10-12.5 mm AS 24-25.

Female



7. BL 22-27 mm FL 11.8-13.9 mm AS 24-25.

Hindleg

8. Hindleg of adult male.

Cercus

9. End of male abdomen showing the cercus, long arms of the furcula, and subgenital plate.

Eggs

10. Egg pod and five loose eggs.

Adults and Reproduction

The adult stage of the Bruner spurthroated grasshopper is reached early in summer. In 1956 in the Crazy Mountains, Montana, adults began to appear July 16, while in 1994 in the Big Horn Mountains, Wyoming, they began to appear July 11. In the Pole Mountain study meadow in southeastern Wyoming, adults appeared 27 July 1996 but not until 5 August in 1995, a seasonally late year.

When food supply and other conditions are favorable, the adults remain in the habitat in which they have developed as nymphs. For example, the adults of a small population residing in the Pole Mountain meadow remained and survived well into October 1996, but none survived a hard freeze during the first week of November.

In habitats where the food supply of large populations becomes exhausted, adults are induced to disperse to "greener pastures." The emigrations usually occur after egg deposition has begun but not ended. The females continue to oviposit in the new habitat and thereby initiate new populations in areas previously devoid of the species. Such behavior apparently occurred in 1994 and 1995 between two study meadows lying 1 mile apart in the Big Horn Mountains.

Mating, gravid females, and egg laying were observed in the meadow in the Crazy Mountains of Montana by 1 August 1956. This evidence indicates maturation of females took approximately 16 days. A late observation of mating was made in a meadow of the Laramie Range in southeastern Wyoming on 1 October 1996. Presumably oviposition may likewise occur late in the season.

No description of where and how females oviposit in nature is available. In laboratory cages, females readily oviposit into bare soil. A female that had just finished ovipositing on 17 August 1995 at 3:51 p.m. DST was observed to brush soil particles over the resulting aperture with her ovipositor. At the same time, two other females were observed to be in the process of ovipositing into the bare soil. The pod, 1 to 1¼ inches long and curved at the bottom, contains 21 to 22 eggs (Fig. 10). The eggs are tan and 3.9 to 4.2 mm long.

Population Ecology

The Bruner spurthroated grasshopper is a common inhabitant of western mountain meadows with a high frequency of occurrence in the many disjunct meadows. This grasshopper was present in 14 of 19 study sites in the Big Horn Mountains indicating a 74 percent frequency. The species' ability and propensity to fly and disperse appear to account for its general distribution in mountain meadows.

The species develops particularly large populations in weedy mountain meadows. Observations have revealed that high-density populations deplete native host plants early in the grasshoppers' adult stage. The grasshoppers must then exploit other plants for food. Weeds such as dandelion and brome and forage grasses such as timothy provide the adults with a steady supply of nutritious food into late summer. Weedy sites are characterized by an abundance of interspersed bare ground providing the grasshoppers with another requirement for prolific reproduction—accessible basking spots. Sites with heavy populations of *M. bruneri* on which notes of vegetation and grasshopper densities have been noted were discovered 40 years apart in Montana and Wyoming. In 1956 a weedy meadow in the Crazy Mountains of Montana harbored a population estimated to have a density of 15 young adults per square yard. Three weedy meadows with 30 to 38 young adults of *M. bruneri* per square yard were discovered in 1995 in the Big Horn Mountains of Wyoming. For comparison, 15 well-vegetated sites surveyed in 1994 and 1995 in the Big Horn Mountains harbored from less than 0.1 to 1 young adult per square yard.

Several nymphal color forms of this grasshopper are present in populations. Of 87 nymphs collected from a mountain meadow (Pole Mountain) in 1996, 62 (71 percent) were of the normal pale brown or tan color, 11 (13 percent, all males) were dark (mainly fuscous), and 11 (13 percent, all females) were green. These forms have been found also in meadows of the Big Horn Mountains of northern Wyoming.

Daily Activity

The Bruner spurthroated grasshopper is a geophilous species, resting, basking, walking, feeding, and performing other activities on the ground. Around sunset it seeks shelter for the night to protect itself from cold mountain temperatures. In early morning before sunrise, no individuals are seen on vegetation or the ground surface. A search for their location in a low-density population of the Pole Mountain study meadow was largely unsuccessful except for the discovery of two adult males clinging to the underside of dry cattle dung. Grasshoppers of other montane species were discovered sheltered under dry dung in this meadow including *M. alpinus*, *M. infantilis*, and *Camnula pellucida*.

Bruner spurthroated grasshoppers begin to bask on bare ground approximately one hour after sunrise. They turn a side perpendicular to the sun's rays and lower the associated hindleg to expose the abdomen. Basking lasts from one to three hours depending on temperature, usually shorter in August and longer in September. At the end of basking, when temperatures of the soil surface have reached 93°F and air 65°F, they may continue to rest horizontally on the soil facing directly into the sun or directly away. At this time, approximately 10 to 11 a.m. DST, normal activities may start such as feeding, stridulating by males, mating, walking, and flying. If midday temperatures rise unusually high, the grasshoppers may climb vegetation to remove themselves from the hot soil surface. In the South Park study meadow on 10 August 1995 at 12:22 p.m. DST, a female was discovered vertically head-up on the shady side of the stem of *Arnica sororia* at a height of 12 inches (ground surface temperature 119°F and air 81°F). A second period of basking occurs during late afternoon before the grasshoppers seek shelter for the night near sunset.

Table 1. Mean percent dry weight of food items in the crops of adult *Melanoplus bruneri* from northern Colorado (adapted from Hansen and Ueckert, 1970) and from northern Wyoming (original).

Item	Colorado 8/10/67	Colorado 8/23/67	Wyoming 8/10/95
Achillea millefolium	0.1	3.2	26.7
Agoseris glauca	0.0	0.0	9.1
Arenaria fendleri	8.5	7.6	0.0
Arnica sororia	0.0	0.0	12.5
Artemisia frigida	2.5	0.0	0.0
Artemisia tridentata	0.0	0.0	4.4
Aster sp.	0.0	0.0	2.6
Astragalus spp.-*Oxytropis* spp.	70.4	18.6	6.2
Composite flower	0.0	0.0	0.9
Allium sp.	0.0	0.0	5.2
Lupinus argenteus	0.2	8.3	0.0
Orthocarpus luteus	0.0	4.8	0.0
Penstemon sp.	0.4	5.6	0.9
Potentilla spp.	2.9	11.9	0.0
Taraxacum officinale	0.1	17.9	0.0
Carex sp.	0.0	0.0	6.3
Danthonia parryi	0.1	2.3	0.0
Danthonia unispicata	0.0	0.0	1.9
Festuca idahoensis	0.1	2.2	12.1
Juncus confusus	0.0	0.0	0.2
Poe sp.	0.0	0.0	0.3
Fungi	5.5	4.7	3.0
Moss	0.0	0.0	7.3
Pollen	0.0	0.0	1.3
Arthropod parts	2.5	3.7	0.9
Number crops	**25**	**57**	**24**

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Pasture Grasshopper

Melanoplus confusus Scudder

Distribution and Habitat

The pasture grasshopper, *Melanoplus confusus* Scudder, ranges from the northeastern states to the western states and provinces. It inhabits the grass prairies of the West and the meadows and pastures of the Midwest and East.

Economic Importance

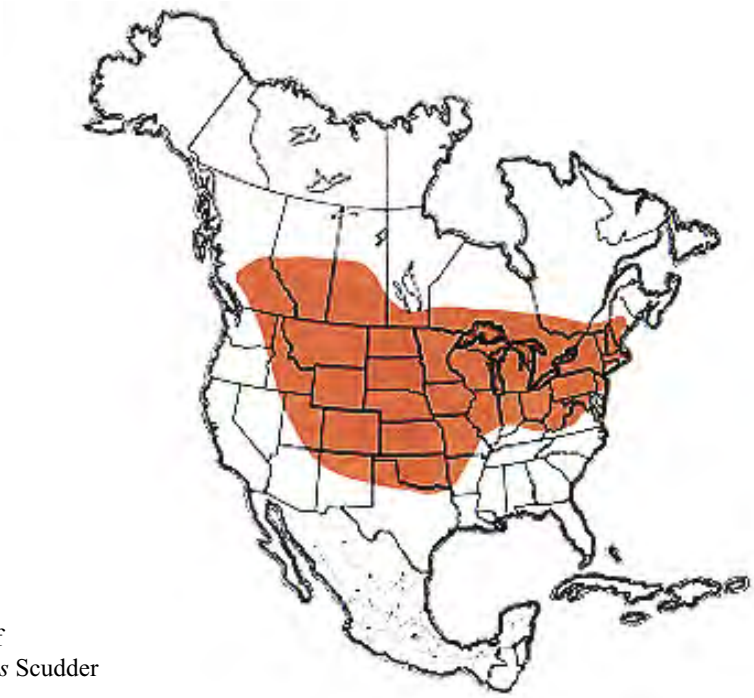
This species is commonly present at low densities in grassland habitats. It occurs early in the season when vegetation is green and abundant, causing little or no economic damage. There have been small outbreaks, however, in association with the clubhorned grasshopper in Saskatchewan that have caused damage to pastures and grain fields.

Food Habits

The pasture grasshopper is a mixed feeder consuming both grasses and forbs. Based on examination of specimens collected from several different states, grasses in crop contents have ranged from 22 to 49 percent and forbs from 45 to 100 percent. Thus, this grasshopper feeds more on forbs than grasses. Preferred species of forbs include western ragweed, spreading wildbuckwheat, cudweed sagewort, and western sticktight. Preferred grasses include early-season species, e.g., downy brome, Japanese brome, and Kentucky bluegrass. In addition, substantial amounts of other materials such as pollen, fungi, and arthropod parts have been found in crops. In Michigan a species of goldenrod is a favored host plant.

Migratory Habits

The pasture grasshopper is a strong flier with wings extending to or beyond the end of the abdomen. In the Rocky Mountains of Colorado it is a resident up to 9,000 feet and an “accidental” between 9,000 and 11,000 feet. It also appears as an “accidental” at montane elevations within its resident range before adults have matured at such elevations. Evidence of a mass emigration from a drought-stricken area of the mixedgrass prairie of Wyoming was observed in 1989. A heavy infestation of three species of grasshoppers had developed around an overflowing water tank and retaining pond in use the previous several years but shut off in 1989 because of absence of cattle in the pasture. On July 1 the three species - the clearwinged, migratory, and pasture grasshoppers - were present as adults even though the vegetation had started to dry because of drought and was nearly depleted due to the feeding of the grasshoppers. On visiting the area on July 20 few grasshoppers remained. Most had evidently emigrated from the site. Apparently all three species have the



Geographic range of
Melanoplus confusus Scudder

Instar 1

1. BL 3.6-5.6 mm FL 2.8-3 mm AS 13.

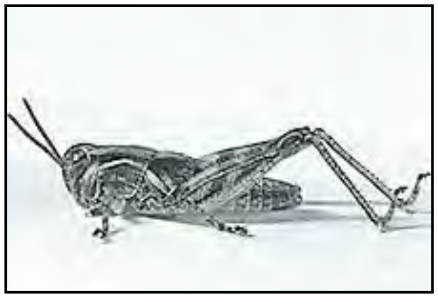
Instar 2

2. BL 6.8-7.7 mm FL 3.9-4.3 mm AS 16-17.

Instar 3

3. BL 7.1-8.1 mm FL 5.1-5.3 mm AS 20.

Instar 4



4. BL 9.1-13 mm FL 6.8-7.9 mm AS 21-22.

Instar 5

5. BL 14.5-16 mm FL 9-10.8 mm AS 24.

Figures 1-5. Appearance of the five nymphal instars of *Melanoplus confusus* - their sizes, structures, and color patterns. Notice progressive development of the wing pads. BL = body length, FL = hind femur length, AS = antennal segments number.

capacity to move when food becomes scarce. At that time they fly to more favorable habitats.

Identification

Adults of the pasture grasshopper (Figs. 6 and 7)are medium-sized and drab gray and brown. The underside of body is cream colored. A patch behind the compound eye on the side of the head and the pronotal lobe is usually solid black and shiny. The shape of the male cercus, twisted and bent medially, is diagnostic (Fig. 8). Wings are long. Underside of hind femur is orange, occasionally yellow. Hind tibia is greenish blue.

The nymphs (Figs. 1-5) are identifiable by their shape, stripes, and color:

1. Head with face nearly vertical; face colored tan or green and spotted; antennae filiform; compound eye with broad dark stripe running diagonally in center and a narrow light line on each side of this stripe. (This character is diagnostic. See Figure 5 for clear illustration).
2. Cream-colored crescent begins on side of head below compound eye and runs onto lobe of pronotum; however, side of head may be solid brown or green without crescent in instars III, IV, and V and a cream-colored line present only on pronotal lobe.
3. Medial area of hind femur variable - with fuscous stripe entire, with fuscous stripe cut, or with solid color and no fuscous stripe.
4. Body color is green or drab gray-brown; underside greenish.

Hatching

The pasture grasshopper is a very early hatching species. The first instar nymphs appear in early spring two to three weeks ahead of nymphs of *Aulocara elliotti* and *Melanoplus occidentalis*. First instars can be collected along with adults and late instar nymphs of overwintering species such as *Eritettix simplex* and *Psoloessa delicatula*. Hatching continues for a month.

Figures 6-9. Appearance of the adult male and female of *Melanoplus confusus*, male cercus, and the egg pod and eggs.

Nymphal Development

The pasture grasshopper develops through five nymphal instars, becoming an adult in 40 to 46 days. Rate of development appears to be similar to that of *M. occidentalis* in spite of the earlier hatching of the pasture grasshopper.

Adults and Reproduction

As long as rainfall keeps vegetation green, adults of the pasture grasshopper remain in the same habitat in which the nymphs hatch and develop. When rangeland becomes dry they may move short distances to low swales or they may emigrate from the area. In Michigan when upland grass-herb habitats become dry, populations move and congregate around edges of marshes.

Several observations of the courtship of the pasture grasshopper have been made. Although the males exhibit variations in this activity pattern, a courter usually approaches the female and when close enough pounces on her and attaches his genitalia. After attachment he jerks his hind femora forward and backward and his body from side to side for about one minute.

The pasture grasshopper is one of the earliest species to begin ovipositing. It prefers to oviposit in the shade of shrubs and tall herbs. Females deposit clutches of 10 to 15 eggs in bare ground or in the sod of buffalo grass (probably also blue grama). The eggs are laid deep into the soil - to a depth of one and one-quarter inches. On completion of laying the female withdraws her abdomen and then briefly brushes over the exit hole with her ovipositor and walks away. The pod (Fig. 9) is one to one and one-eighth inches long and one-eighth inch diameter at the level of the egg mass. Above the eggs, dried froth forms a plug one-half to three-quarters inch long. In this region the pod is narrowed. Eggs are yellow to tan and 4.4 to 4.8 mm long.

Male

6. BL 18-19 mm FL 11 mm AS 25.

Female

7. BL 23-24 mm FL 13.4-13.6 mm AS 24-25.

Cercus

8. Cercus of adult male pasture grasshopper.

Egg pod

9. Egg pod (bottom at right) and four eggs.

Population Ecology

Populations of the pasture grasshopper fluctuate at low densities over time in both the mixedgrass prairie of Wyoming and sand prairie of North Dakota. During a 12-year period in Wyoming, densities of adults ranged from less than 0.1 individual per square yard to 2.7 individuals per square yard. For nine of the years, densities were below 1 individual per square yard, during three of the years densities rose to 1.2, 1.8, and 2.7 individuals per square yard. During a ten-year period in sand prairie of North Dakota, densities ranged from 0.1 to 1.2 individuals per square yard. Evidently populations of the pasture grasshopper in these areas are able to maintain themselves year after year but do not irrupt.

Daily Activity

The pasture grasshopper is a diurnal insect, active during the day and inactive at night. Except for behavior during courtship and oviposition, its daily activity has not been studied.

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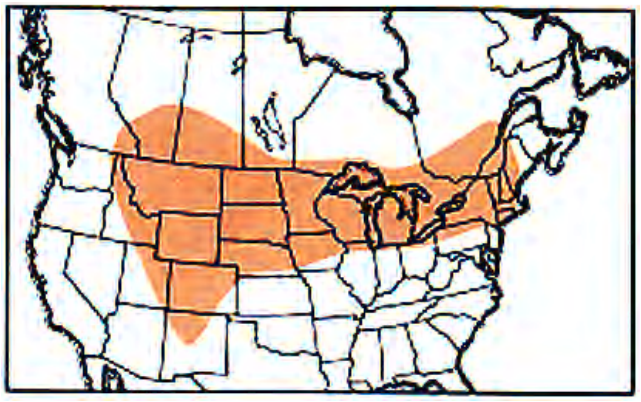
Dawson Grasshopper

Melanoplus dawsoni (Scudder)

Distribution and Habitat

The Dawson grasshopper is a small short-winged species that ranges in northern grasslands from the Atlantic coast to the Great Basin of the West. It is a common grasshopper in the mixedgrass prairie and in grass-forb parks at high altitudes (7,000 to 8,500 feet). In Colorado it is a rare resident at 10,000 feet. At lower altitudes it frequently inhabits the bottoms of ravines where grasses, forbs, and shrubs grow profusely.



Geographic range of *Melanoplus dawsoni* (Scudder)

Economic Importance

Some entomologists have concluded that the Dawson grasshopper is of little economic importance. Nevertheless, observed densities of 4 to 10 adult grasshoppers per square yard in the northern mixedgrass prairie indicate a potential for damage, especially to pastures in this region seeded to legumes.

Alfalfa fields in North Dakota are frequently infested with the Dawson grasshopper in addition to six other species of *Melanoplus*, namely, *M. bivittatus*, *M. femurrubrum*, *M. sanguinipes, M. packardii*, *M. gladstoni,* and *M. differentialis*. Of 12 counties surveyed in 1958 and 1959, two (Benson and Ramsey) harbored dominant numbers of the Dawson grasshopper (42 and 67 percent of the collected grasshoppers, respectively). Of 409 Dawson crops examined, 344 or 84 percent contained alfalfa fragments equalling the frequency of alfalfa in the crops of *M. femurrubrum*, a recognized serious pest of alfalfa.

Weights of the Dawson grasshopper are similar to weights of the little spurthroated grasshopper, *Melanoplus infantilis*. Live weights of males average 156 mg and females 238 mg (dry weights males 47 mg, females 73 mg). Weighed within 24 hours after molting into the adult stage, live weights of males averaged 94 mg and females 117 mg.

Food Habits

The Dawson grasshopper feeds principally on forbs. Forty species of forbs belonging to 13 plant families are known to be ingested. Two families, the bean and sunflower, appear to include the known principal host plants: western ragweed, leadplant, and milkvetches. Additionally, two introduced plants, both legumes, alfalfa and white clover, are among its host plants. White clover has become an important host plant due to its widespread invasion of pastures, foothill rangelands, mountain meadows, and roadsides. In cage tests the Dawson grasshopper has shown a marked preference for dandelion, an introduced weed that occurs in many of its habitats.

Fragments of 10 species of grasses, usually in small amounts, have been detected in the crops of this grasshopper. In the sand prairie of southeast North Dakota, Kentucky bluegrass besides three preferred forbs (leadplant, western ragweed, and wild rose) appeared to be consumed in substantial amounts. In a small overgrazed pasture that lies in a creek bottom in Johnson County, Wyoming, crops of adults collected late in the season (20 September 1994) contained chiefly fragments of grass seeds and brome leaves. In a foothill habitat of the Big Horn Mountains lying at an altitude of 7,190 feet, Dawson grasshoppers fed upon white clover, 43 percent; *Astragalus* sp., 25 percent; golden aster, 16 percent; common yarrow, 5 percent; grass seeds, 5 percent; and arthropods, 6 percent; as measured by analyses of crop contents.

Two observations were made of the Dawson grasshopper's method of attacking a host plant. A nymph (instar V) was observed walking on the ground in a searching mode. When it came across a sprouting 1-inch forb, it consumed it from tip to base. A female sitting diagonally head-up, 11 inches high, on a secondary stem of thistle (*Cirsium* sp.) crawled 2 inches to a leaf and began to feed on the edge. She fed for one minute until she was disturbed by the observer. This meager evidence suggests that the Dawson grasshopper feeds both by searching the ground and by attacking the leaves of a host plant close to where an individual may be resting or basking.

Dispersal and Migration

The wide geographic range of the Dawson grasshopper suggests that the species has both a long evolutionary history in North America and effective powers of dispersal. Although the majority of adults are short-winged, a few possess long wings. In a Colorado study, three of 952 adults (0.3 percent) collected in 14 study sites were long-winged. A specially relevant observation in this study was the discovery of one long-winged female at 12,200 feet indicating a flight distance of approximately 14 miles from the closest resident population. In 1995, three of 108 (2.8 percent) adults from six survey sites in Sheridan County, Wyoming possessed long wings.

Identification

The Dawson grasshopper is a small, short-winged species. A small proportion of the population, however, may possess long wings that extend 2 to 4 mm beyond the end of the abdomen. Adults are easily recognized by their small size, short wings, black and yellow ringed abdominal terga, canary yellow venter, and red hind tibia (Fig 6 and 7). The male cercus is short, slightly concave near the end, and rounded apically (Fig. 9).

The nymphs are identifiable by their color patterns, shape, and external structures (Fig. 1-5).

1. Head all black except conspicuous yellow band below compound eye and a median yellow line or

Instar 1

1. BL 4.5-5.1 mm FL 2-2.4 mm AS 13-14.

Instar 2

2. BL 5-6.9 mm FL 2.8-3.4 mm AS 17-18.

Instar 3

3. BL 6.9-8.8 mm FL 4.3-4.4 mm AS 19-20.

Instar 4

4. BL 8.7-12.5 mm FL 5.3-7.4 mm AS 21-23.

Instar 5

5. BL 10-13 mm FL 7.3-8 mm AS 22-24.

Figures 1-5. Appearance of the five nymphal instars of *Melanoplus dawsoni* - their sizes, structures, and color patterns. Notice progressive development of the wing pads. BL = body length, FL = hind femur length, AS = antennal segments number.

band on top. Compound eye is all black seen without magnification, but under magnification several scattered light spots are visible.

2. Pronotum mainly black; the yellow band below compound eye continues onto lateral lobe to form a conspicuous crescent; a large black band is centrally located on the lateral lobe; posteriorly below it is a yellow triangular marking; a median yellow line or band is present on the disk. The dorsal stripe of the hind femur is broad and continuous, a small dorsal yellow wedge in the middle of the stripe is sometimes present (Fig. 5). The tibia is tan.
3. Sides of abdomen are mainly fuscous or gray; in instars I and II the venter is tan; in instars III, IV, and V it is yellow; top of abdomen with median yellow band.
4. Body colors of black and yellow are shiny and appear polished.

Hatching

The Dawson grasshopper begins to hatch about one week after the migratory grasshopper, *Melanoplus sanguinipes*. Both belong to the intermediate-developing group of grasshoppers. In 1979 in northern Wyoming at an altitude of 3,700 feet, hatching of the Dawson grasshopper began the first week of June and continued until the first week of July. At higher altitudes in this region, hatching occurred later (e.g. at 4,100 feet hatching began on 19 June 1979). The effect of altitude on the life cycle of the Dawson grasshopper has been demonstrated nicely in a Colorado study. The study confirmed the applicability of Hopkin's bioclimatic law. The law, with reference to altitude in temperate North America, states that for every rise of 400 feet, events in the life cycle are delayed four days.

The start of hatching at a particular site depends on seasonal temperatures and precipitation and may vary from one year to another by as much as four weeks. The hatching period (duration) also varies, ranging from two to six weeks.

Nymphal Development

Both male and female nymphs require five instars to reach adulthood. Calculations of available data (days from first instars to first adults) indicate that at high altitudes the nymphal period is shorter than at low altitudes. For example, in northcentral Colorado nymphal development lasted 32 days at 5,750 feet, 28 days at 6,700 feet, and 20 days at 8,500 feet. In northern Wyoming, at 3,700 feet, the nymphal period lasted 45 days.

Reared in the laboratory at six different temperatures, the Dawson grasshopper developed at six different rates with nymphal periods ranging from 21 to 66 days. Up to a point, the higher the temperature the faster the growth. The highest-rearing temperature of 104°F, however, retarded development and increased mortality. Of the temperatures

Figures 6-10. Appearance of the adult male and female of *Melanoplus dawsoni*, hindleg of female adult, male cercus, and egg pod and eggs.

used in these tests, 95°F appeared most favorable, as the nymphs both developed fastest and survived in greatest numbers.

These experimental results suggest that temperatures in the habitat have a considerable influence on the rate of development and survival of this grasshopper. They do not explain, however, shorter life cycles at higher altitudes where temperatures are cooler. A hypothesis for variation in length of life cycles of the Dawson grasshopper living at different altitudes draws on one proposed to explain similar variation in populations of the migratory grasshopper, *Melanoplus sanguinipes*. Resident populations of a species may be genetically isolated, such that they adapt physiologically to the length of the growing seasons and other environmental exigencies of their habitat and pass on these adaptive characters to succeeding generations. Additionally, grasshoppers at high altitudes make behavioral adjustments that may equalize heat accumulation of individuals. They bask longer in the sun and remain longer in their thermal shelters under grass canopies, litter, and dry cow dung. Because of these responses, the most important physiological adaptations that grasshoppers at high altitudes make are to the shorter seasons.

Adults and Reproduction

First appearance of adults occurs from early to late July, with the precise time depending on seasonal temperatures and altitude. Transformation to the adult stage continues for four to five weeks; in mid to late August, only adults are present. The population then consists of adults of widely different ages. Maturation of adults has not been studied; however, courtship and copulating pairs have been observed. A male in search of a mate produces bursts of vibratory stridulation, and when close to a female he makes a sudden jump onto her back. He continues to produce bursts of vibratory stridulation as he attempts to engage her genitalia. If she is receptive, he succeeds in mating and the two remain in copulo for an undetermined period. Evidently copulation begins in the morning, as two pairs observed in a foothill habitat on 19 August 1994, were in copulo at 9:27 a.m. and at 11:41 a.m. DST.

One attempt at oviposition was observed on 5 August 1994 in a weedy grass-forb habitat. The female sitting horizontally on litter began to bore into the ground at 9 a.m. but withdrew her ovipositor five minutes later. She crawled 6 inches away and began to bore again into the ground at 9:06 a.m., but again withdrew her abdomen and crawled away into thick vegetation and became lost to view. Caged females readily oviposit into bare soil, but they often bore several times before finally depositing eggs.

Adults are present in habitats at low altitudes (3,500 to 6,000 feet) from mid-July to mid-October, a period of approximately 13 weeks. As long as the supply and condition of host plants persist, this extended presence of adults gives the species considerable time to reproduce. At higher altitudes (8,500 feet), the length of the adult period is shorter, but the species apparently reproduces as well in resident populations. Rapid development of nymphs at high altitudes has been documented and accelerated rates probably include maturation and egg production as well.

Male

6. BL 14.5-18.8 mm FL 8.7-9.5 mm AS 24-25.

Female

7. BL 17-22.5 mm FL 10-10.8 mm AS 23-25.

Hindleg

8. Outer face of left hindleg of female.

Cercus

9. End of male abdomen showing the cercus

Eggs

10. Egg pod and exposed eggs.

The egg pods are 3/4 inch long and slightly curved just above the eggs. In the region of the eggs, the pod has a diameter of 1/8 inch. The eggs occupy the lower 1/4 to 3/8 inch of the pod, with pale yellow or white froth comprising the top part. Pods contain 8 to 14 (average 10.8) tannish yellow eggs that measure 3.6 to 4.5 mm long (Fig. 10).

Population Ecology

Populations of the Dawson grasshopper enjoy the greatest frequency of occurrence and the highest densities in the northern part of their geographic range and at high altitudes in the south. The species occurs commonly in the northern mixedgrass prairie of the Canadian prairie provinces where populations may increase to 10 adults per square yard. It is occasionally the dominant species in an assemblage, but more often it is subdominant to *Melanoplus infantilis*, *M. sanguinipes*, *M. packardii*, or *Encoptolophus costalis*.

Results of grasshopper surveys in Montana and Wyoming show the influence of latitude on frequency of occurrence. The Dawson grasshopper was found in 9 of 55 sites (16 percent) in Montana, but only in 30 of 699 sites (4 percent) in Wyoming.

An important factor in fostering populations of the Dawson grasshopper appears to be quality and supply of host plants.

The species frequently inhabits abandoned fields and roadsides where dandelion, volunteer legumes, and other forbs grow abundantly. In Montana this grasshopper occupied 4 of 11 abandoned fields (36 percent).

A study of grasshopper ecology in the northern mixedgrass prairie of southwest Saskatchewan has shown that when environmental conditions become favorable for the Dawson grasshopper, populations can increase seven-fold over a period of four years. The densities during these years were low: 0.25 per square yard in 1968, 0.4 in 1969, 0.9 in 1970, and 1.7 in 1971.

In the south, favorable habitats of the Dawson grasshopper occur at high altitudes of 7,000 to 8,500 feet. An example of such a habitat was discovered in 1994 in the western foothills of the Big Horn Mountains, Washakie County, Wyoming. Located at an altitude of 7,200 feet, this grassland site was invaded by white clover that served as the grasshoppers' chief host plant. The density of all species in an assemblage of mainly young adults sampled on 19 August 1994 was estimated to be 16.5 grasshoppers per square yard. The Dawson grasshopper was the dominant species with 6.5 individuals per square yard.

The assemblage consisted of four other species: *Melanoplus sanguinipes*, 5 per square yard; *Camnula pellucida*, 3.5; *M. femurrubrum*, 1; and *M. infantilis*, 0.5. In Colorado, the Dawson grasshopper is a rare resident at 10,000 feet. Above this altitude the species is apparently unable to exist. Small populations of the Dawson grasshopper inhabit the sand prairie (altitude 1,075 feet) of southeast North Dakota. A 10-year study revealed low densities every season.

In its southern distribution, the Dawson grasshopper often inhabits the bottom of ravines from where, in outbreak years, they may disperse to surrounding mixedgrass prairie. When these large populations crash, the species disappears from the surrounding prairie but persists in the ravines.

Daily Activity

The Dawson grasshopper is a geophilus species living most of its life on the ground. In high-altitude habitats where soil and air temperatures fall below 50°F during the night, individuals rest in nocturnal shelters. One-half to one hour after the sun strikes the ground, they emerge from these shelters and begin to bask. Basking horizontally on the ground, they turn a side perpendicular to the sun's rays and lower the associated hindleg to expose the abdomen. The opposite hindleg is held in the normal position with the knee a few millimeters above the tegmen. They may also bask high on forbs, turning a side or their back to the sun. They bask for up to three hours until 10 a.m. DST. Some adults may become active before others have finished basking. Feeding has been observed as early as 9:30 a.m., courting 9:45 a.m., mating 9:27 a.m., and ovipositional probing 8:41 a.m. During the activity period many may just rest quietly occasionally stirring and preening. They sit on vegetation or horizontally on ground litter and usually face away from the sun.

All activity ceases if soil and air temperatures become too hot for the grasshoppers. Response of adults to soil surface temperature of 135°F and air 100°F was observed in a low-altitude (4,700 feet) habitat near Buffalo, Wyoming. The grasshoppers climbed forbs and grasses and rested vertically, head-up on the shady side of the plant at heights of 5 to 18 inches. The response of three adults flushed to the ground was observed. A female jumped 3 feet, landed on the ground, but almost immediately climbed up 15 inches on the stem of a wild licorice plant. A male jumped to the ground and after a few seconds crawled to a nearby grass plant and climbed up the stem. Another flushed male jumped onto a grass stem and landed 2 inches above ground and in the sun; after several seconds it moved to the stem of a slimflower scurfpea on which the grass leaned, crawled to a height of 5 inches, and came to rest vertically head-up on the shady side of the scurfpea.

When temperatures decline, a second period of activity occurs. As temperatures fall still further in late afternoon, the grasshoppers bask for a second time. Finally, just before sunset, they retreat to shelters. They have been observed to crawl into thick clumps of grasses and under dry cow dung. In the morning before sunrise, they have been discovered resting both horizontally on the ground and upside down on the underside of rocks or dry cow dung, often along with individuals of other species such as *Melanoplus sanguinipes* and *Camnula pellucida*.

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Devastating Grasshopper

Melanoplus devastator Scudder

Distribution and Habitat

The devastating grasshopper has a limited geographic range in the far west of North America. Its main distribution is in the coastal states, where it inhabits semiarid rangelands dominated by forbs and annual grasses at elevations from near sea level to over 5,000 feet.

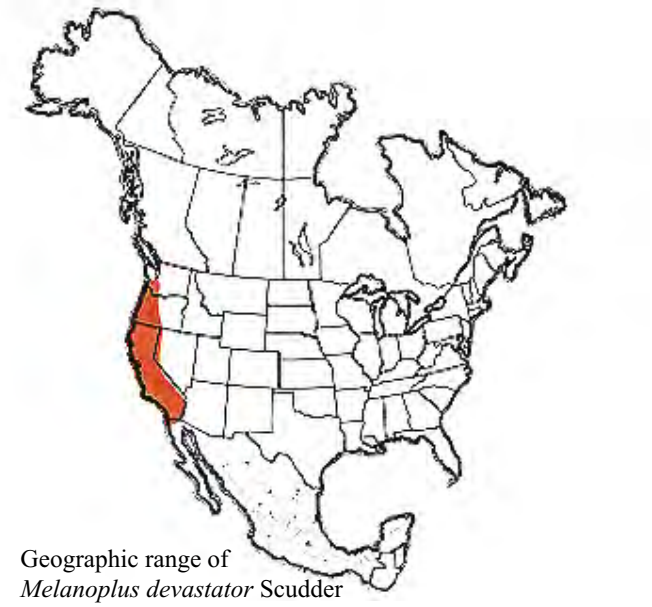
Economic Importance

The devastating grasshopper, a major pest in California and a minor one in Oregon and Washington, destroys rangeland forage, orchards, grains, vegetable crops, and gardens. Populations, ever present on rangeland in the coastal and Sierra Nevada foothills of California, fluctuate annually in size. Significant damage to rangeland occurs when densities rise to outbreak levels.

During a prolonged outbreak, more than 3 and 4.5 million acres of rangeland were infested in 1957 and 1958, respectively. Although several species were involved, the devastating grasshopper generally predominated in the assemblages. Forage of the infested rangeland, often harboring from 35 to 100 devastating grasshopper late nymphs and adults per square yard, became exhausted. The grasshoppers then moved to the valleys where green pastures, crops, and gardens flourished. The hungry marauders defoliated orchards and vineyards and destroyed fields of barley, corn, beets, vegetables, and many family gardens. The bark of young fruit trees and grape vines was frequently gnawed and consumed, killing terminals.

Depredations by this grasshopper have a long history beginning with the settling of California by the Spanish. Records as early as 1722 indicate destructive populations. In 1855 immense flights and severe damage occurred in California, Oregon, and Washington. The most recent general outbreak took place from 1955 to 1961 with annual infestations ranging from 580,000 to 4,523,000 acres. Irruptions since then have occurred on less than 500,000 acres each year.

Live weights of 20-day-old adult males reared from late nymphal instars averaged 280 mg and of females 341 mg (dry weights 103 mg and 125 mg, respectively). The nymphs were collected from a population inhabiting Jasper Ridge, Palo Alto, California on 5 July 1993 and reared on dandelion.



Geographic range of
Melanoplus devastator Scudder

Food Habits

The devastating grasshopper, a polyphagous insect, consumes a variety of grasses, forbs, shrubs, and trees. Under favorable spring conditions in their natural rangeland habitat, the nymphs feed preferentially upon various legumes, filaree, and brome and barley grasses. When these plants mature and become dry, late nymphs and adults survive on green but less palatable plants such as needlegrass, *Stipa* spp., tarweeds, *Hemizonia* spp. and wild lettuce, *Lactuca* spp. Favorite items of food at these times are grass seeds shed naturally or dropped by harvester ants (*Messor andrei*) on their mounds. The late nymphs and adults have been observed feeding on the epidermis of stems of the less palatable plants and on the edges of leaves. They may reject other drought-resistant plants that commonly grow in their habitat, such as turkey mullein. They also feed on stubble and ground litter. Late nymphs assume various orientations in feeding. Two common orientations are a nearly vertical head down position as they feed on epidermis of stems and a horizontal position on the ground as they feed on litter.

After rains start in fall and growth of preferred host plants begins anew, the adults mature and reproduce. Many observations have been made of the damage caused by the migrating swarms. Migrants have been observed to feed on the leaves of grape, citrus, apple, pear, cherry, peach, apricot, prune, plum, almond, avocado, and also on cabbage, tomato, beet, beans, marigold, alfalfa, clover, timothy, corn, and barley. The list is undoubtedly incomplete and could be lengthened considerably from experiences of California growers, entomologists, and horticulturists.

Identification

The devastating grasshopper is a medium-sized grasshopper with long wings that extend beyond the end of the abdomen (Fig. 7 and 8). Along with the migratory grasshopper, it is a member of the *mexicanus* group of the genus *Melanoplus*. The males have two diagnostic characters that distinguish this species from the migratory grasshopper, which it resembles. The cerci are elongated and slender; the furculae are long, extending halfway on the supraanal plate (Fig. 9).

Both males and females of the devastating grasshopper share several characteristics. The body color is pale gray and tan with fuscous maculations; the venter of the abdomen is pale greenish yellow. The tegmen is marked by a row of conspicuous black spots (Fig. 7). The color pattern of the

Instar 1

1. BL 3.4-4.6 mm FL 2-2.1 mm AS 13.

Instar 2

2. BL 4.8-6.6 mm FL 2.6-2.9 mm AS 14-16.

Instar 3

3. BL 5.9-6.8 mm FL 3.6-5.2 mm ASl 17.

Instar 4

4. BL 10.5-12.5 mm FL 6.1-6.7 mm AS 20-21.

Instar 5

5. BLl 13-15.2 mm FL 8.4-8.9 mm AS 22-23.

Figures 1-6. Appearance of the six nymphal instars of *Melanoplus devastator* - their sizes, structures, and color patterns. Notice progressive development of the wing pads. BL = body length, FL = femur length, AS = antennal segments number.

medial area of the hind femur consists of pale or reddish tan and fuscous patches. The hind tibiae are usually blue but may be red. In the Jasper Ridge, California site, 3 percent of males and 15 percent of females have red hind tibiae.

The nymphs are identifiable by their structure and color patterns (Fig. 1-6).

1. Head with face nearly vertical; antennae filiform, compound eyes brown with irregular ivory spots and occasional dark spots; a broad, ivory, or pale tan crescent begins on gena below compound eye and extends onto side of pronotum.
2. Hind femur with narrow dark stripe in center of medial area in instars I and II; in instars III to VI dark stripe cut in middle by wide (approximately two chevrons wide), diagonal, pale tan bar; a large pale tan patch interrupts the dark stripe at base of medial area.
3. General body color pale yellow, pale tan, or pale green.

Although the nymphs of the devastating grasshopper closely resemble those of the migratory grasshopper, they can be separated by differences in several characters that can be seen with either the naked eye or a 10x magnifier. Instar I of the devastating grasshopper is pale, has the ivory crescent clearly evident, and the medial area of the hind femur is pale yellow with a narrow dark stripe running down the middle. Instar I of the migratory grasshopper is dark with many fuscous spots, the crescent is faint, and the medial area of the hind femur is marked heavily with fuscous spots that partially conceal the dark stripe.

Two characters are useful in separating instars II-VI. The compound eyes of devastating grasshopper nymphs lack a diagonal dark bar, which is present in compound eyes of the nymphs of the migratory grasshopper. The medial area of the hind femur of the devastating grasshopper has the dark stripe interrupted by large ivory patches, while that of the migratory grasshopper has smaller light patches. (See illustrations of nymphs of the two species.)

Recent genetic studies of the two species suggest that *M. sanguinipes* and *M. devastator* are closely related and may be the same species or at least subspecies. However, because of clear structural, life history, and geographic differences, taxonomists continue to regard the two as related but separate species. Despite the controversy over species definition, the ecology and bionomics of the migratory and the devastating grasshoppers differ substantially. In California, the migratory grasshopper breeds and becomes a minor problem in irrigated alfalfa and permanent pastures (improved and irrigated), while the devastating grasshopper breeds in foothill rangelands and becomes a major problem when bands and swarms migrate into cropland.

Figures 7-10. Appearance of the adult male and female of *Melanoplus devastator*, end of male abdomen, and egg pod and eggs.

Dispersal and Migration

When populations irrupt and rangeland forage becomes depleted, the devastating grasshopper becomes a highly migratory insect. Bands of older nymphs crawl and hop while swarms of adults fly to the valleys. Nymphs usually migrate downhill toward more succulent green vegetation. They follow ravines and drainages toward cultivated crops, often migrating 5 miles or more during this stage. Extensive movements of nymphs took place in Alameda and Butte counties in California on 13 June 1957 when grass had dried on the hillsides but swales were still green.

Adult migrations are less predictable and may be delayed. Between 25 July and 8 August 1957, a spectacular migration of adults occurred from the California Range Experiment Station at Hopland. Adults are strong fliers and swarms migrate 15 or more miles in a single day. In this stage they have been observed to travel a distance of at least 30 miles. Attractive landing sites are fields of yellow stubble of barley, oats, and wheat. From these fields the devastating grasshopper disperses to fruit and vegetable crops. Even though the major pest status of this grasshopper results from its migrations, no special study of this behavior has been made. Some entomologists speculate that every year a part of each population migrates, but the migrants usually go unnoticed because of small numbers.

When flushed, nonmigratory adults travel 3 to 6 feet at heights of 4 to 12 inches. Their flight is straight and silent; however, flight noise or crepitation was heard once in San Mateo County, California.

Hatching

The hatching period, which ranges from 50 to 103 days, starts in late April and may extend to late July. This is a prolonged hatching period compared to that of several other species (e.g., *Camnula pellucida* and *Oedaleonotus enigma*) that occur in assemblages of California rangeland grasshoppers. The difference is probably due in part to the lateness of oviposition and greater depth of the eggs in the soil of the devastating grasshopper. The total heat units required for development and hatching of the eggs of all three species are probably similar.

Nymphal Development

The nymphs begin development when forage is green and succulent but a majority are often in the nymphal stage (instars IV, V, and VI) when the forage has matured and dried. Nutritional stress evidently prolongs the nymphal period as some nymphs may still be found in mid October. Both males and females require six instars to complete their nymphal development. The first nymphs that appear during the last week of April may become adult by July 1. This means that precocious adults take about 70 days to reach the fledgling stage.

Adults and Reproduction

Among rangeland species, the devastating grasshopper has a unique life history. Females enter a reproductive diapause during the summer months and must survive on less palatable forage to tide them over to the reproductive period, which

Instar 6

6. BL 15-19.5 mm FL 9.5-11.7 mm AS 24-25.

Male

7. BL 18.5-22 mm FL 10.3-11.5 mm AS 25-26.

Female

8. BL 21-23 mm FL 12-13.5 mm AS 25-26.

Cercus and Furcula

9. Side view of end of male abdomen.

Egg pod

10. Egg pod and group of exposed eggs.

begins in late September. Laboratory experiments have shown that development and maturation of eggs within the females are triggered by decreasing day length. Usually fall rains arrive at this time, stimulating sprouting and growth of preferred food plants. The usual coincidence of the breaking of reproductive diapause and the availability of nutritious host plants allows the females to oviposit prolifically. Dissection of females collected at the Hopland Range Experiment Station in Mendocino County, California and at Mission Peak study area in Alameda County, California, revealed that mature eggs were present in the ovaries at the end of September and in October, 1963.

The females oviposit in restricted locations within their normal rangeland habitat. They prefer well-drained hillocks, ridges, slopes, and banks of ravines where soil is gravelly. Many pods are deposited within relatively small areas (egg beds). Only a few pods are deposited in surrounding soil. Pods are deposited close to the basal growth of forbs such as tarweeds and Russian thistle. Some are laid among the roots of filaree or in small, well-drained bare spots. Pods are 3/4 to 7/8 inch long, slightly curved, and contain 20-31 eggs (Fig. 10). The eggs are pale yellow and 3.9-4.4 mm long.

No study of courtship of the sexes has been made nor is it known whether the males, like the females, have a reproductive diapause.

Population Ecology

In their natural rangeland habitats in the foothills of the coastal states, populations of the devastating grasshopper persist over many years. Astonishingly large changes in densities occur with time. Grasshoppers may increase from noneconomic numbers to as many as 100 per square yard in just three years. Before the severe outbreak of 1957-58, survey entomologists began to notice increases in densities in the Sierra Nevada foothills in 1952. In 1953 and 1954 the sizes of populations were rated about the same as in 1952, but in 1955 the densities of populations increased dramatically and the economically infested acres expanded by five fold, from 220,000 acres in 1954 to 1,264,000 acres in 1955. The sudden increases in both densities and infested acreage suggest that populations had experienced especially favorable conditions for growth. Although populations grew at a slower rate during the next three years, they continued to increase. Two other species, *Oedaleonotus enigma* and *Camnula pellucida*, contributed to the outbreak, but the devastating grasshopper was the primary pest. In 1959 a fungal disease (*Entomophaga grylli*) killed many grasshoppers, reducing some populations by as much as 90 percent. The disease and a subsequent drought led to a gradual decline of the outbreak during the next six years.

Like other rangeland grasshopper assemblages, those in the foothills of California consist of several species. The devastating grasshopper often dominates and coexists with *O. enigma*, *C. pellucida*, *Dissosteira pictipennis*, and several other species. In habitats less favorable for the devastating grasshopper, other species may dominate. In montane grasslands *C. pellucida* usually dominates, while in valley and low foothill habitats *O. enigma* often dominates. Migrants of the devastating grasshopper that invade crops do not successfully colonize these valley habitats, but the reason for this is unknown.

Daily Activity

Behavior of the late nymphs and young adults was observed on Jasper Ridge in a serpentine grassland habitat from the 3 to 5 July 1993. The ridge is a low-lying foothill (maximum elevation 620 feet) on the eastern side of the Santa Cruz mountains with a Mediterranean-type climate. Skies are generally clear and virtually no rains fall during the nymphal development of the devastating grasshopper. Sampling of the resident population of devastating grasshoppers indicated a density of eight per square yard (late nymphs and young adults).

In early July, ground temperatures during the night fall to 60°F and air temperatures to 50°F. Approximately one hour after sunrise the grasshoppers begin to move from overnight retreats and crawl to sunny spots to bask. Some crawl up stems of dead weeds or culms of grasses, while others stay on the ground. They turn a side perpendicular to the rays of the sun and lower the associated hindleg to expose the abdomen fully to the warming rays. They bask for a period of two hours from 7 to 9 a.m. DST. However, feeding may start as early as 8 a.m., and feeding of different individuals may be observed for two or more hours.

The feeding period ends when rapidly increasing temperatures of the habitat force them to take evasive actions. By mid morning, surface temperatures of the black, gravelly serpentine soils rise to over 130°F and later exceed 160°F. To avoid high ground temperatures the grasshoppers climb forb stems and grass culms and rest vertically head-up in the shade at heights of 2 to 9 inches. When temperatures moderate in late afternoon (5 p.m. DST), the grasshoppers feed again. This second period of feeding lasts for approximately two hours. The grasshoppers have no second daily period of basking. After feeding they seek shelter under canopies of vegetation and may back into small depressions. They begin this movement as early as 7 p.m. when ground surface temperatures are in the 80s and air temperatures are 67° to 71°F.

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Differential Grasshopper

Melanoplus differentialis (Thomas)

Distribution and Habitat

The differential grasshopper, *Melanoplus differentialis* (Thomas), ranges widely in North America. Originally restricted to tall herbaceous vegetation growing in wet meadows, swales, and creek bottom lands, the species spread into the weedy vegetation of crop borders, roadsides, and reversions brought about by settlement and agricultural development. In the United States large populations develop in extensive areas of cropland located between the Rocky Mountains and the Mississippi River. Populations east and west of these landmarks are spotty and discontinuous.

Economic Importance

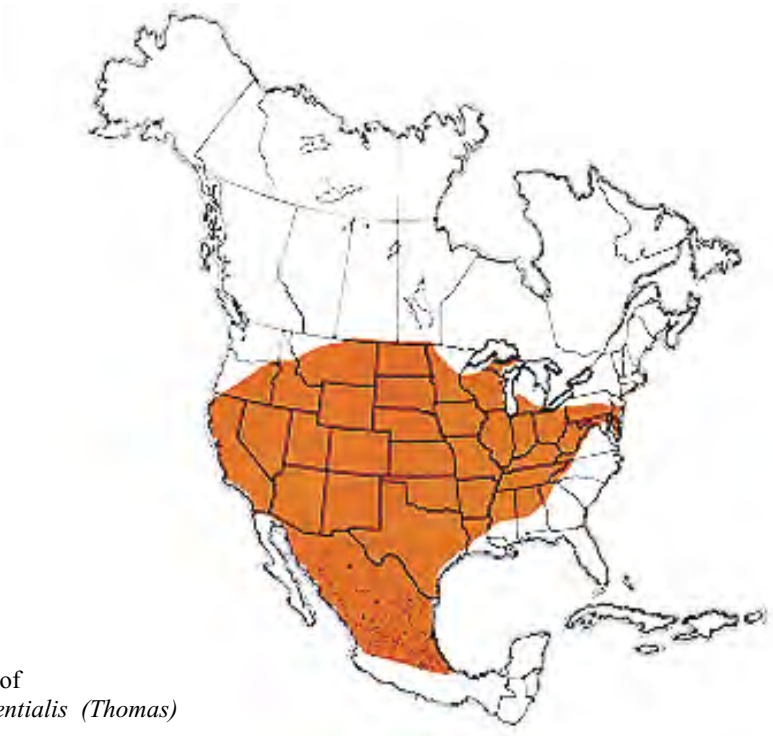
The differential grasshopper is a severe pest of crops including small grains, corn, alfalfa, soybeans, cotton, various vegetables, and deciduous fruit trees. During outbreaks in northern states such as Nebraska and South Dakota, it and the twostriped grasshopper may increase in nearly equal numbers. The nymphs attack small grains, alfalfa, and other hay crops. After they become adults and have destroyed these crops, the grasshoppers fly into corn. A dense swarm will destroy a young cornfield in just three or four days. In southern states, such as Oklahoma and Missouri, the differential grasshopper outnumbers the twostriped and is responsible for much damage of alfalfa, corn, and cotton.

Food Habits

The differential grasshopper is a polyphagous insect feeding on both grasses and forbs. Microscopic examinations of crop contents show that it usually consumes more forbs than grasses. When fed a mixture of forbs in the laboratory, the differential grasshopper develops faster, grows larger, and produces more eggs than when fed a mixture of grasses. It also does well on single plant diets of common sunflower, soybean, and wheat plants, but not alfalfa. In laboratory tests the differential grasshopper readily eats several species of forbs and grasses while it rejects others. Among its host plants are representatives from several plant families, but members of the Compositae appear to be the most important, including giant ragweed, blood ragweed, common sunflower, and prickly lettuce. The preference of the differential grasshopper for wilted or damaged sunflower, often observed in the field, is probably due to chemical changes in the wilted tissues such as increases in sugar and in amino acids.

Migratory Habits

The differential grasshopper is a mobile insect in both its nymphal and adult stages. After hatching from eggs concentrated in field borders and roadsides, the nymphs, third instars and older, often move into fields of barley,



Geographic range of
Melanoplus differentialis (Thomas)

Instar 1

1. BL 5.3-6 mm FL 2.2-2.4 mm AS 12-14.

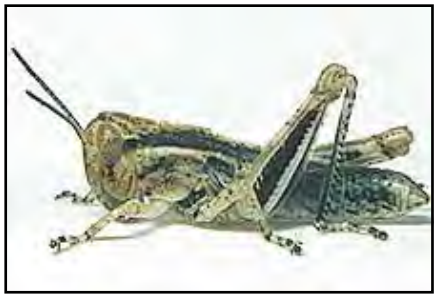
Instar 2

2. BL 5.2-6.8 mm FL 3.4-3.6 mm AS 14-17.

Instar 3

3. BL 9.4-12.6 mm FL 5.0-5.1 mm AS 19-20.

Instar 4



4. BL 12-14 mm FL 5.9-7.1 mm AS 21-22.

Instar 5

5. BL 18-21.5 mm FL 10.5-11 mm AS 25-26.

Figures 1-6. Appearance of the six nymphal instars of *M. differentialis* - their sizes, structures, and color patterns. Notice progressive development of the wing pads. BL = body length, FL = hind femur length, AS = antennal segments number.

wheat, and alfalfa by crawling and hopping. All go in the same direction as a cohesive band.

Adults display strong powers of flight. In search for green food, they may move upwind in short, low flights of 10 to 100 yards toward green corn. These flights begin around 9 a.m. and reach a peak when temperatures rise to 81°F.

Flight also provides escape from extreme heat of temperatures above 86°F. Grasshoppers rise and mill about in calm air or fly with the wind. They have been seen by airplane pilots as high as 1,400 feet above the ground, but most have been seen below 600 feet. In 1939 the differential grasshopper migrated northward by successive short flights from along the Missouri River in southeastern South Dakota to as far north as Pierre, South Dakota, a distance of 130 miles. In North Dakota one differential grasshopper of a marked group was recovered 20 miles from the point of release two days after its liberation. During outbreaks of this species adults have longer wings and slimmer bodies.

Identification

The adult differential grasshopper is a large yellow insect with black markings. The chevron-like markings on the hind femur are diagnostic as is also the shape of the male cercus. A few individuals in populations are melanistic (black) through their nymphal and adult stages (Fig. 8).

The adult male (Fig. 7) is identifiable by the shape of the cercus (Fig. 9) and both male and female by the black chevrons on the hind femur. A melanistic female is pictured in Figure 8. The majority of females are yellow with black markings like the male shown in Figure 7.

The nymphs (Fig. 1-6) are identifiable by their spots, stripes, and color patterns:

(1) Compound eye brown with light tan spots; lacking transverse dark band.

(2) Front of head green, yellow, or tan often with dark spots and a few larger markings.

(3) Pronotum with pale yellow, horizontal stripe at top of lateral lobe; brown band at edge of pronotal disk; narrow, median pale yellow stripe on pronotum, mesonotum, metanotum, and continuing on to abdomen various distances.

(4) Gena with short, pale yellow band below compound eye and continuous with pale yellow stripe of lateral lobe. Band faint or lacking in fifth and sixth instars.

Figures 7-10. Appearance of the adult male and a melanistic female of *M. differentialis*, the male cercus, a diagnostic character, and the egg pod and several loose eggs.

(5) Black stripe of hind femur occupying center of medial area in first to fourth instars; black chevrons beginning to be evident in fifth and sixth instars. Black stripe in first instar often interrupted by pale band.

(6) Hind tibia light green or light gray to gray.

(7) General color pale green, pale yellow, or tan; many fuscous markings.

Hatching

Eggs of the differential grasshopper begin to hatch in late spring about two weeks after eggs of the migratory grasshopper and three weeks after eggs of the twostriped grasshopper. The eggs start embryonic growth in the summer of deposition and attain a maximum development of 54 percent at which point they diapause. The majority of eggs hatch within a period of two weeks.

Nymphal Development

Exposed to high temperatures of early summer, the nymphs grow rapidly and become adult after about 32 days. Because development is well synchronized, a large percentage of the nymphs transform to winged adults in just a few days.

Adults and Reproduction

After fledging, the adults often fly into cornfields where for several weeks they feed and increase in weight. During this time their ovaries or testes mature. Pairs form in the morning and may often continue copulation for 20 to 24 hours. The females seek adjacent sod land or rank weeds for oviposition. A female ready to lay eggs may brace herself in a vertical position against a grass or weed stalk and work her ovipositor down into the soil. She then deposits from 45 to 194 eggs among the roots and forms a large pod for their protection (Fig. 10).

Egg pods of the differential grasshopper are curved, one and one-half inches long and one-quarter inch in diameter. They are fragile and easily broken in sifting them from the soil. The eggs are olive and 4.4 to 5.1 mm long. In separate laboratory experiments, females fed a single plant diet of soybeans averaged 305 eggs each while those fed common sunflower averaged 591 eggs each. The maximum number of eggs deposited by a single female fed soybean was 645 and the maximum number of pods was six. The number of eggs laid by females in nature is unknown. There is one generation annually.

Instar 6

6. BL 22-32 mm FL 13-15.5 mm AS 26.

Male

7. BL 30-33 mm FL 15-17 mm AS 27-28.

Female

8. BL 32-41 mm FL 16.5-19 mm AS 26-28.

Note Cercus

9. Side view end of male abdomen.

Egg pod

10. Egg pod and several loose eggs.

Population Ecology

Comparison of the differential grasshopper's ecology with that of the twostriped grasshopper indicates that for several reasons the differential is better adapted to warmer climates: (1) even though the distributions of the two species overlap extensively, the differential grasshopper ranges farther south while the twostriped ranges farther north; (2) outbreaks of the differential grasshopper occur more frequently in the south, the twostriped occur more in the north; (3) the differential grasshopper requires more heat units for its development and tolerates higher temperatures than the twostriped.

The high biotic potential of the differential grasshopper is evident in the records of an outbreak that occurred more than 50 years ago in Missouri. In 1934 the differential grasshopper was present in noneconomic numbers. In 1935 this species became more numerous, damaging fall wheat and alfalfa. The warm, dry summer and fall of 1935 provided favorable conditions for egg production. The next year, 1936, spring rains and warm temperatures allowed a successful hatch and nymphal development that precipitated the worst outbreak of grasshoppers in Missouri since the years of the Rocky Mountain locust. Favorable weather continued and allowed the differential grasshopper to stay at outbreak numbers in 1937; the fall egg survey that year showed the greatest density of eggs ever. In 1937 the eggs hatched but this period was followed by rains and cool weather. The emerged nymphs died ending the outbreak.

Daily Activity

The differential grasshopper is inactive at night resting high up on vegetation. When temperatures reach 65°F on clear mornings, nymphs descend to the ground and bask in the sun. Feeding begins when temperatures reach 68°F; general feeding starts at 75°F. This activity continues until air temperatures reach 90°F and the soil surface is 112°F. Then to escape the heat, the nymphs climb vegetation and seek shade. Usually the nymphs are on the ground from 6 to 11 a.m. They may migrate in bands at air temperatures between 77° and 99°F beginning at 10 a.m. Under cloudy skies, irrespective of temperature, the nymphs remain inactive.

Like the nymphs the adults rest high on plants at night and descend only when temperatures are 68°F or above and the sun rises and strikes both them and the ground. Upon descending they begin to feed. Feeding slackens at 86°F and ceases at air temperatures above 90°F and soil surface temperatures above 112°F. At these high temperatures, air 86° to 90°F, adults seek shade or rise in flight. Table 1 summarizes information on the influence of temperature upon activities of nymphs and adults.

Table 1. Activity of nymphs and adults of the differential grasshopper, *Melanoplus differentialis* (Thomas), correlated with air and soil temperatures (after Parker and Shotwell 1932).

		Temperature °F			
		Nymphs		Adults	
Name of activity	**Description**	**Air**	**Soil**	**Air**	**Soil**
Beginning of activity	Start of descent	65		68	
Beginning of normal activity	Start of feeding	68		68	70
	Start of migration	75		78	
	Start of oviposition			70	
Beginning of escape from heat	Climbing and seeking shade on plants	90	112	90	112
	Flying in circles or flying with wind			90	112

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Redlegged Grasshopper

Melanoplus femurrubrum (DeGeer)

Distribution and Habitat

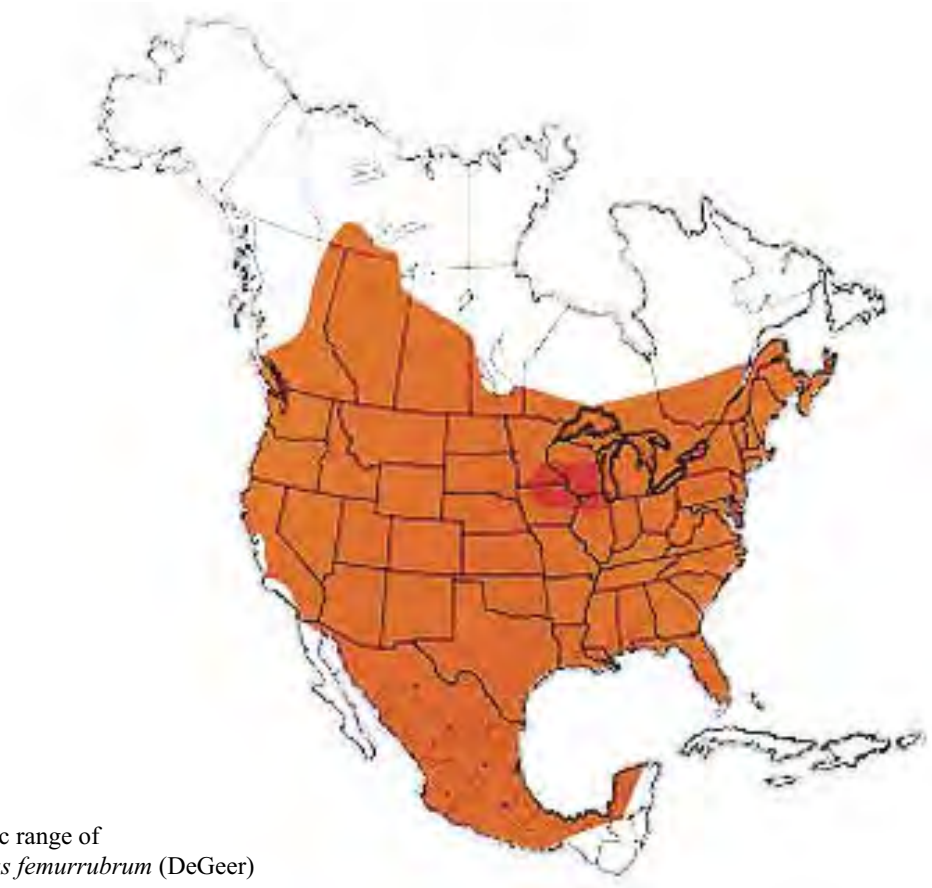
The redlegged grasshopper, *Melanoplus femurrubrum* (DeGeer), ranges over most of North America except for high mountain altitudes and the frigid north. It is the most widely distributed species of the major crop grasshoppers. Its favorite habitats include tall vegetation of grasslands, meadows, crop borders, reverted fields, Conservation Reserve Program lands, and roadsides. It favors low moist weedy areas where its host plants abound.

Economic Importance

The redlegged grasshopper is a crop pest. During outbreaks of the species, it may severely damage alfalfa, clover, soybeans, and small grains. It has destroyed second crops of clover and has caused losses of 20 to 25 percent to individual fields of oats. In the eastern United States and Canada, it is the most abundant species of grasshopper. It becomes a pest not only of legumes and small grains but also corn, tobacco, and vegetables - especially beans, beets, cabbage, and potatoes. Large numbers develop in meadows and damage forage grasses. In laboratory tests the redlegged grasshopper ingested 25 percent of the foliage that it removed from six different host plants and wasted 75 percent. It is a medium-sized grasshopper. Collected from a roadside in Platte County, Wyoming, males averaged 289 mg live weight and females 389 mg (dry weight: males 87 mg and females 126 mg).

Food Habits

The redlegged grasshopper feeds on a wide variety of forbs and on several kinds of grasses. Depending on availability of host plants in the habitat, it may be either forbivorous or a mixed feeder ingesting significant amounts of both forbs and grasses. Known host plants consist of legumes (birdsfoot trefoil, white and yellow sweetclover, lespedeza, milkvetches, and alfalfa); composites (dandelion, chicory, Canada goldenrod, kochia, and western ragweed); and grasses (Kentucky bluegrass, barley, oats, wheat, smooth brome, Japanese brome, timothy, and reed canarygrass).



Geographic range of
Melanoplus femurrubrum (DeGeer)

Instar 1

1. BL 4-5.6 mm FL 1.9-2.4 mm AS 12-14.

Instar 2

2. BL 6.2-7.2 mm FL 3.1-3.4 mm AS 15-16.

Instar 3

3. BL 7.4-9.7 mm FL 4.3-5.4 mm AS 17-19.

Instar 4

4. BL 10-15.5 mm FL 7.2-9.0 mm AS 22-24.

Instar 5

5. BL 16.5-22.5 mm FL 9.5-11.5 mm AS 24-26.

Figures 1-5. Appearance of the five nymphal instars of *M. femurrubrum* - their sizes, structures, and color patterns. Notice progressive development of the wing pads. BL = body length, FL = hind femur length, AS = antennal segments number.

Experiments show that host plants vary in their capacity to provide good nutrition. Although alfalfa is readily eaten, a sole diet of this plant causes a high nymphal mortality of 70 to 90 percent. Of three plants-corn, lettuce, and radish-tested for growth and performance of nymphs and adults, lettuce yielded the most favorable results which included high survival of nymphs, heavy weight of adults, and high egg production. A mixed diet of the three plants provided the best nutrition. This fact is significant because analyses of crop contents show that the majority of individuals collected from natural habitats consume two or more plant species in a single meal. Laboratory observation of the redlegged grasshopper has revealed that newly hatched nymphs do not begin to feed until three or more hours after eclosion. During the prefeeding time nymphs in the field climb nearby vegetation. Later they feed on a host plant that they have climbed and on which they have come to rest.

Migratory Habits

The redlegged grasshopper has strong powers of flight that allow the adults to disperse and find new habitats. In years of drought, the adults develop longer wings, fly more, and make lengthy flights often in company with the migratory grasshopper.

The flight of flushed individuals is swift, even, and 3 or 4 feet above the vegetation. The insects generally fly distances of 30 to 40 feet.

Identification

Adults of the redlegged grasshopper are medium size and have a bright yellow underside and bright red hind tibia (Fig. 6 and 7). Rarely, the hind tibia is colored yellowish-green or blue (Fig. 8). The bulbous subgenital plate and the shape of the cercus (Fig. 9) are diagnostic characters of the male. The nymphs (Fig. 1-5) are strikingly marked yellow and black. They are identifiable from their spots and color patterns:

(1) Compound eye brown to burgundy with light yellow or tan spots, more spots on dorsal half than ventral; lacking transverse dark band.

(2) Front of head with dark vertical band in center; light yellow band on each side of the center band; the two yellow bands come together below on the clypeus.

Figures 6-10. Appearance of the adult male and female, adult female of uncommon blue form, the male cercus, a diagnostic character, and the egg pod and several loose eggs.

(3) Gena with broad pale yellow crescent continuing on pronotal lobe to first abdominal segment and fading along the rest of abdomen.

(4) Dorsum of head to end of abdomen with median pale yellow stripe. Broad black stripe on either side of the median pale yellow stripe. Pronotal lobe with black band or markings below the yellow crescent.

(5) Hind femur with black stripe entire, not interrupted by pale band. Stripe fills upper medial area of hind femur except at proximal end. Stripe encroaches a third or more on the lower medial area.

(6) Hind tibia mainly pale yellow or pale gray, front black; tips of spines black.

(7) General color contrasting yellow and black.

Hatching

Eggs of the redlegged grasshopper begin to hatch three weeks after the eggs of the twostriped grasshopper. The period of hatching lasts approximately 52 days. Because females oviposit throughout the habitat in a scattered pattern, the eggs are subjected to a range of soil temperatures and moisture conditions.

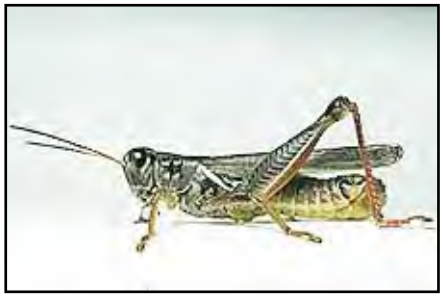
Nymphal Development

Nymphal development begins in late spring and in early summer when host plants are usually green and succulent. In approximately 40 days the nymphs become adult, developing at rates approximately the same as the twostriped. When reared in cages at a constant temperature of 85°F, the redlegged requires a nymphal period of 28 days and the twostriped 29 days. Because of the extended period of hatching, some nymphal grasshoppers can be found nearly all summer long.

Adults and Reproduction

Adults of the redlegged grasshopper are active from early summer to the middle of fall. Although dispersal flights occur, most individuals stay close to where they hatch. There they feed, reproduce, and face many mortality factors throughout the summer. After fledging, caged females require a preoviposition period of 9 to 15 days at 86°F before beginning to lay eggs. In nature the females have been observed ovipositing into sod. The pods

Male

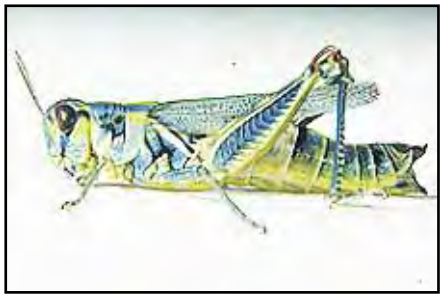


6. BL 17.5-23 mm FL 10.5-13 mm AS 25-28.

Female

7. BL 24-28 mm FL 14-14.5 mm AS 26-27.

Female



8. Uncommon blue form of redlegged grasshopper.

Note cercus

9. Side view end of male abdomen.

Egg pod

10. Egg pod and several loose eggs.

are distinctly curved, three-quarters to one inch long and one-eighth to three-sixteenth inch in diameter (Fig. 10). The top third is dried froth, the bottom two-thirds contain 20 to 26 eggs. The eggs are 4.1 to 4.4 mm long and pale yellow. Caged redlegged grasshoppers fed a nutritious mixed diet of green leaves produced 336 eggs per female. Under similar conditions twostriped grasshoppers produced 412 eggs per female. The redlegged grasshopper has one generation annually.

Population Ecology

Historical records from the late 1800s till the 1980s indicate that a center of distribution of the redlegged grasshopper is present in a 78,000 square mile area composed of sections of Iowa, Illinois, Minnesota, and Wisconsin. A center is an especially favorable zone where the redlegged grasshopper is abundant and outbreaks are frequent. In such a distribution zone, populations respond quickly during spring and summer to reduced rainfall and warm temperatures. Within one to two years small populations may increase to outbreak numbers. Densities in these years reach peaks of 200 to 500 nymphs per square yard. Outbreaks last for two to three years until normal rainfall and cool spring temperatures reduce populations back to low noninjurious numbers. The periods of low densities range from two years to over five years.

In western states densities of the redlegged grasshopper fluctuate widely, apparently in response to annual changes in weather. Large populations develop in irrigated fields of alfalfa and along roadsides, particularly in patches of sweetclover. This species may also add considerably to the density of outbreak assemblages of the migratory, twostriped, and differential grasshoppers.

Daily Activity

The redlegged grasshopper is active during the day. At night adults roost on the tops of grasses and weeds. Close to 6:30 a.m. they begin to move from their perches and begin feeding about 7 a.m. Between 4:30 and 5 p.m. they start crawling up vegetation to roost. By 5:30 p.m. the majority are roosting and have settled down for the night. In marshes this grasshopper has been observed at times to feed between 8 p.m. and midnight. Correlations of these activities with temperature have not been made.

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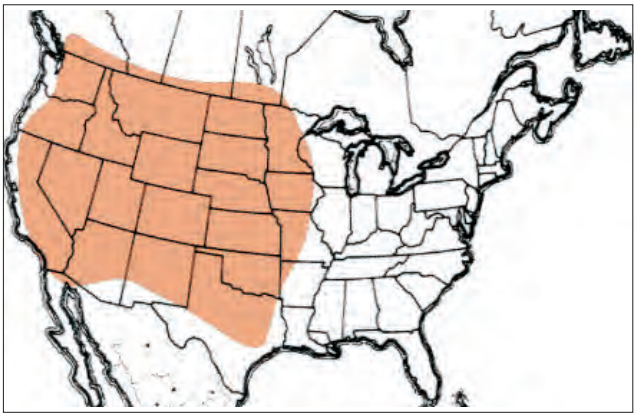
Striped Sand Grasshopper

Melanoplus foedus Scudder

Distribution and Habitat

The striped sand grasshopper, *Melanoplus foedus*, ranges widely in western North America, nearly coextensive with the range of *Melanoplus packardii* which it closely resembles. The habitats of these two species within their common geographic ranges differ remarkably. The striped sand grasshopper inhabits vegetated areas of sandy soils while the Packard grasshopper inhabits vegetated areas of loamy soils. Both species feed principally on forbs and both conduct most activities on the preponderant bare ground of their habitats.

A distinctive community of native plants grows in sandy soils. In addition to the widely distributed and tolerant grasses blue grama, western wheatgrass, and needleandthread, two species of tall grass are prominent, prairie sandreed and sand bluestem and one midgrass, sand dropseed. Of the many forbs, western ragweed, several species of sunflower, and several species of scurfpea are commonly present.



Geographic range of *Melanoplus foedus* Scudder

Economic Importance

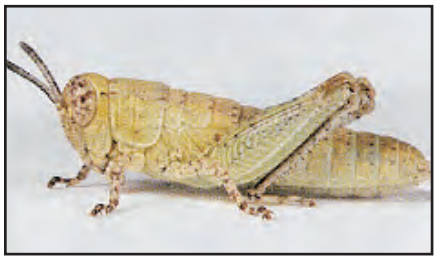
Because of its preference for "weeds" and its normally low density in the assemblage of grasshoppers inhabiting sandy rangeland sites, the striped sand grasshopper is of minor economic importance. Nevertheless, damaging densities irrupt on the sandy rangeland of western Idaho and eastern Oregon. This species also increases to outbreak numbers in weedy land adjacent to crop land. After becoming adult the grasshoppers invade and damage fields of wheat, barley, corn, and alfalfa.

The Cooperative Economic Insect Report recorded severe infestations in five states: Idaho, Nebraska, Kansas, Oklahoma, and Texas. In western Idaho an assemblage of species, mainly *Melanoplus sanguinipes*, *M. bivittatus*, and *M. foedus*, irrupted in 1957 reaching densities of 100 per square yard. In eastern Idaho in 1961, the striped

Table 1. Percent fragments of important food plant species found in crops of *Melanoplus foedus*.

Family Names Species	North Dakota Mulkern et al 1969	Colorado Ueckert et al 9172	Idaho Banfill/Brusven 1973	Colorado Pfadt/Lavigne 1982	Nebraska Joern 1985
Asteraceae					
Ambrosia psilostachya	19	11			3
Artemisia drunculus			4		
Artemisia ludoviciana	15				6
Helianthus petiolaris	5	3			t
Chrysopsis villosa			20		
Cirsium undulatum		7		t	
Tragopogon dubius			2		
Fabaceae					
Amorpha canescens	19				
Psoralea tenuiflora		7		24	
Medicago sativa		2	14	41	
Malvaceae					
Sphaeralcea coccinea		5		4	11
Brassicaceae					
Eryssimum asperum	4				5
Convolvulaceae					
Evolvulus nuttallianus		10			
Poaceae					
Bouteloua gracilis		8		1	7
Bromus tectorum			25		
Stipa comata				8	
Calomovilfa longifolia		6			
Phleum pretense			5		
Poa sp			6		
Sporobolus cryptandrus			1		

Instar 1



1. BL 5.4 mm FL 3.2 mm AS 13.

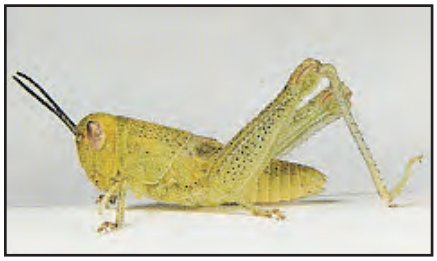
Instar 2

2. BL 5.7-7.8 mm FL 3.4-4 mm AS 16-18.

Instar 3

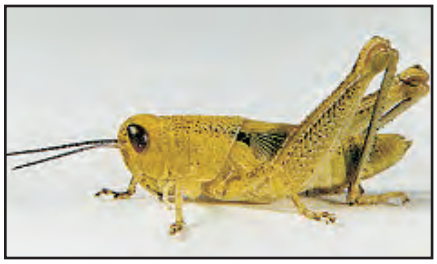
3. BL 8-13.1 mm FL 5.8-8.4 mm AS 19-23.

Instar 4



4. BL 14-16 mm FL 9.5-10.5 mm AS 23-25.

Instar 5



5. BL 18.2-20.2 mm FL 12-13.5 mm AS 25-26.

Figures 1-5. Appearance of the five nymphal instars of *Melanoplus foedus* - their sizes, structures, and color patterns. Notice progressive development of the small wing pads. BL = body length, FL = hind femur length, AS = number of antennal segments.

sand grasshopper increased along roadsides to numbers averaging 8 per square yard. In 1958 in southwestern Nebraska, an assemblage of species, mainly *Melanoplus sanguinipes*, *M. angustipennis*, and *M. foedus*, infested margins of wheat fields at densities of 5 to 54 per square yard. No follow-up reports were made of this infestation. Presumably the grasshoppers were either controlled or they dispersed into the wheat and caused damage.

As no quantitative study of this grasshopper's impact on rangeland and crops has been made, we may estimate its importance based on its weight. It belongs to the largest third of North American grasshopper species. Live weights of five males and six females collected in sandy rangeland of southeastern Wyoming averaged 450 and 725 mg, respectively (dry weight: males 143 mg, females 238 mg).

Food Habits

The striped sand grasshopper is a highly polyphagous species that feeds on a variety of forbs, grasses, and sedges. Fifty-six species of forbs, 19 species of grasses, and 2 species of sedges have been detected in crop contents of specimens collected from sites in four states. Table 1 shows the common food plants of grasshoppers collected in Colorado, Idaho, Nebraska, and North Dakota. Crop analyses of specimens captured in two rangeland sites in southwestern Idaho revealed that common plants ingested were downy brome, thickspike wheatgrass, sunflower, redstem filaree, tumblemustard, and western salsify (*Tragopogon dubious*). Two-choice laboratory tests of striped sand grasshoppers from Wyoming showed that dandelion and green young wheat are also among its preferred food plants.

Dispersal and Migration

The striped sand grasshopper is a long-winged species with good capacity for flight. Adults observed in Idaho are wary and commonly fly 30 to 60 feet when disturbed. In this state during the dry period of summer when upland vegetation desiccates, the adults move into more mesic, ravine habitats. Movement of adults from weedy rangelands, CRP land, and field margins into crops have been reported in three western states — Idaho in 1957 and 1961, Texas Panhandle in 1959, and Oklahoma in 1973. The details of these dispersals were not investigated and mass migrations have never been reported.

Observations of flushed flight in sandy native grasslands of southeast Wyoming, indicated shorter distances than in Idaho. Flight distances were 2 to 9 feet at heights of 4 to 10 inches. The flights were straight and silent with the landed grasshoppers facing in the direction of flight.

The nymphs have not been observed to disperse extensively or to migrate. Apparently they complete nymphal development in the habitat of their hatching.

Identification

The striped sand grasshopper is a large, usually colorful species equaling in size and resembling in color patterns the closely related Packard grasshopper, *Melanoplus packardii*. A broad brown band runs down the top of head and center of the pronotum. On each side of this band is a pale yellow stripe (Fig. 8) to which the common name refers. Variations in color, however, occur among populations of adult striped sand grasshoppers. In the sandy sites of eastern Wyoming and Colorado adults are bright yellow and brown with contrasting bars and stripes (Fig. 6 and 7); in the rangeland of eastern Oregon, adults are dull pale tan with faint bars and stripes. The wings are long and extend

Figures 6-10. Appearance of the adult male and female of *Melanoplus foedus*, dorsal view of head and pronotum, cercus of the male, egg pod and eggs.

1 to 4 mm beyond the apex of the hind femora. Tegmina are usually unspotted. The outer medial area of the hind femur is either solid fuscous or pale yellow and spotted fuscous; the inner medial area is bright yellow. In Wyoming and Oregon the hind tibia is usually red but farther north it is blue. As the striped sand grasshopper and the Packard grasshopper are superficially alike, definite identification depends on differences of the aedeagus. The valves of the Packard grasshopper are equally short; the outer valve of the striped sand grasshopper is short, the medial valve is long, clearly extending beyond the tip of the outer valve (Fig. 11).

The nymphs are identifiable by their structures, color patterns and shape (Fig. 1-5).

1. Head with face nearly vertical, color green, sparsely spotted fuscous, spots more numerous on top and front of head; compound eye with relatively large tan spots; antennae filiform and predomin antly fuscous, each segment ringed anteriorly pale gray.
2. Pronotum mostly green, disk of pronotum green or pale tan and spotted fuscous, lobes unspotted or sparsely spotted.
3. Outer medial area of hind femur green with three rows of spots or nearly spotless; hind tibia pale green or pale gray.

Apparently the color of nymphs varies, as those collected in Colorado and Wyoming are green, while those found in western Idaho are predominantly pale brown or tan and only a few are green. Because of the difficulty of separating nymphs of *M. foedus* from *M. packardii* one may tentatively call nymphs collected in sandy soil *M. foedus* and then return later to the site to capture adult males for confirmation using the distinguishing structure of the aedeagus.

Hatching

The striped sand grasshopper is an early hatching species. Nymphs first appear about two weeks after *Cordillacris occipitalis* and about the same time as *Melanoplus sanguinipes*. All three species often occupy the same sandy soil habitat. In southeastern Wyoming (elevations 4,100 to 5,000 ft), hatching begins usually in mid May, however, actual dates of hatching have ranged from May 1 to 29. After the first nymphs appear, hatching continues for two weeks. In southwestern Idaho and in the sandhills prairie of southeastern North Dakota hatching occurs in late May and early June.

Nymphal Development

Nymphs develop in late spring when temperatures are mild and cool-season grasses and forbs are still green and nutritious. In southeastern Wyoming, the nymphal period lasts approximately 40 days from mid May to late June. Based on initial appearance of instar I and first adults, the nymphal stage has been estimated to range from 34 to 42 days. In the sandy study site 5 mi south of Guernsey, Wyoming, calculated nymphal periods were 34 days in 1975 and 1981, 37 days in 1977, and 42 days in 1979.

Adults and Reproduction

In sandy soil habitats of southeastern Wyoming, adults are present during the summer months from late June through September. In favorable rangeland sites, they appear to remain lifelong, but whenever the habitat deteriorates due to drought, they move to nearby areas with green vegetation such as swales, ravines, and irrigated land.

No special studies of maturation, courtship, or fecundity of this grasshopper have been made. A few field observations have been noted that provide incidental information. In a study site in northeast Laramie County, Wyoming on 18 August 1999 at 8:17 am DST (soil 81°F, air 76°F, sky

Male

6. BL 25-28 mm FL 13.5-14.8 mm AS 25-27.

Female

7. BL 26-35 mm FL 14.5-17.5 mm AS 26-27.

Dorsum

8. Dorsal view of head and pronotum of a female.

Cercus

9. End of male abdomen showing cercus, furcula, and supraanal plate.

Eggs

10. Egg pod and three loose eggs.

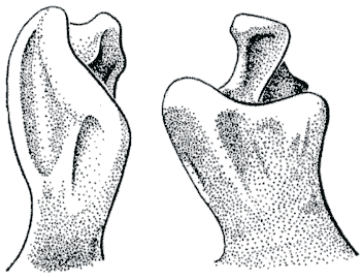


Figure 11. Valves of aedeagus of *Melanoplus packardii* equally extending (left); aedeagal valves of *Melanoplus foedus* inner valve extends beyond outer valve (right). Drawings by J.L. Capinera and T.S. Sechrist.

clear), a male made courtship overtures of femur shaking as he faced a female 6 inches away. Before the male could make contact, the female was frightened away by an inquisitive cowboy on horseback.

In a study site 5 miles west of Torrington, Wyoming, a female was observed on 27 July 1991 at 11:24 am (soil 120°F, air 86°F, sky clear) to begin boring into bare ground but after 1 minute she ceased and walked away. The number of days from fledging to this ovipositing behavior was estimated to be 26. In a study site of southeast Goshen County, Wyoming, two females were observed ovipositing into bare soil at the side of a ranch road on 25 August 1993 at 12:30 pm. In a study site south of Guernsey, Wyoming, a female was discovered ovipositing into bare soil at 4:06 pm, 17 August 1990 (soil 101°F, air 86°F, sky clear).

Females confined with males in laboratory cages were provided plastic trays of sandy soil for oviposition. The females readily found the sandy soil and deposited most eggs into this medium. A few eggs however, were deposited on the screen floor of the cage. One female was discovered ovipositing into the soil at 11:15 am on 3 August 1992. After removing her ovipositor from the soil she moved the end of her ovipositor sideways and back and forth to brush soil over the exit hole.

The pods contained from 16 to 30 tan eggs (Fig 10). Eggs were 4.8 to 5.1 mm long, the pods 1/2 to 3/4 inch long.

Population Ecology

The striped sand grasshopper fluctuates in density over the years much like other pest grasshoppers of the genus *Melanoplus*. Recorded outbreaks usually consisted of several species in the assemblage. Prominent coinhabitants include *Melanoplus bivittatus*, *M. sanguinipes*, and *M. angustipennis*. The absolute density of each species in these assemblages has not been reported. At times *M. foedus*, essentially alone, may irrupt and become the sole cause of a moderate outbreak. Such an outbreak occurred in 1961 in the vicinities of Victor and Swan Valley, Idaho. The grasshoppers increased along roadsides to densities averaging 8 per square yard.

In Wyoming native grassland, densities of *M. foedus* have remained low, even during years of outbreaks. In the longest studied site, a sandy soil habitat 5 miles south of Guernsey, Wyoming, monitored for 12 years, 1975 to 1986, populations of *M. foedus* fluctuated in density from less than 0.1 to 1.0 per square yard. At its highest density of 1 per square yard *M. foedus* was subdominant to *M. sanguinipes* which had risen to a density of 3.6 per square yard. Populations of *M. foedus* in a study site of northeast Laramie County have remained small with estimated densities of 1.3 per square yard for three years, 1999 to 2001.

Over their large geographic ranges the two closely related species *M. foedus* and *M. packardii*, do not, as a rule, occupy the same habitats. Exceptions, however, occur. In the Pine Ridge of the Nebraska Panhandle, pure populations of *M. foedus* were found on grass covered ridges while at the bottom this species was often mixed with *M. packardii*.

Although how populations of the striped sand grasshopper grow to outbreak densities remains undocumented, the reports of damaging assemblages of grasshoppers in Idaho and Nebraska indicate that under environmental condition fostering increases of other species of the genus, especially *M. bivittatus* and *M. sanguinipes* which have been studied thoroughly, *M. foedus* is similarly affected. By inference, mild spring weather, adequate but gentle rainfall, a steady supply of preferred food plants, few predators, and little disease all interact to promote population growth of *M. Foedus*.

Daily Activity

At night in its native rangeland habitat, the striped sand grasshopper shelters on the ground under canopies of grasses and forbs. In disturbed weedy sites, however, it climbs tall plants such as kochia, Russian thistle, sunflower, and sweet clover; it rests vertically, head-up, usually on the main stem, at heights of 12 to 24 inches.

In early August in rangeland of southeast Wyoming, adults emerge from shelter and begin to bask 1 hour after sunrise (soil and air temperatures 50°-60°F). They continue basking for about 3 hours (at end of basking: soil 100°-110°F and air 80°-85°F). In basking they sit horizontally on bare ground and take a flanking posture by turning a side perpendicularly to rays of the sun and lowering the hindleg to expose the abdomen. On sunny days, adults spend most of their morning basking, but during this period they also conduct other activities. They have been observed to crawl, feed, court, and oviposit. They discontinue basking at high temperatures but remain on the soil surface and assume a variety of postures to reduce further insolation. As temperatures rise still higher (soil 115°F air 95°F), the grasshoppers take evasive action by climbing grass or forb stems to heights of 2 to 6 inches or they crawl into the shade of vegetation. When temperatures ameliorate in late afternoon, the grasshoppers resume daily activities. As temperatures cool still further, they bask for a second time. Finally around sunset, they retreat to their nighttime shelters.

The daily routine of activities of adults roosting on tall plants is remarkably different from that of ground residents. In the morning they bask by adjusting their positions on the plants and adopting a flanking posture or a dorsal posture, remaining vertical, head up. Later they feed on the host plant and when temperature of the habitat rises above their preferendum, they adjust their positions on the plant. At times they move to the ground, particularly for oviposition, but evidently also for other purposes. In the site 5 miles west of Torrington, Wyoming, between 6 and 6:34 am on 26 July 1991, one adult was discovered on the ground while five adults were found roosting on tall vegetation.

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Gladston Grasshopper

Melanoplus gladstoni Scudder

Distribution and Habitat

The Gladston grasshopper ranges widely in the rangelands of western North America. It inhabits the mixedgrass, shortgrass, tallgrass, bunchgrass, desert, and sand prairies and also lives in grass-shrub habitats of the intermountain basins. It is a common species in the grasslands east of the Rocky Mountains and is also present in the foothills and mountain parks as high as 8,500 feet.

Economic Importance

Because of its usually low densities and its preference for poor forage plants, the Gladston grasshopper is not a serious pest of native rangeland. Under some circumstances, it may even be a beneficial insect as it voraciously attacks the developing seeds of Russian thistle and perhaps other weed species. Although this grasshopper inhabits alfalfa fields and feeds on this crop, as shown by a study in North Dakota, the species represents only 5 percent of the average infestation. In fall, adults of the Gladston grasshopper, with other late-maturing grasshoppers of the rangeland assemblage, may invade fields of winter wheat in the green seedling stage. As a group these late-maturing species can cause complete destruction of edge rows of the crop. The Gladston grasshopper is a large species. Live weight of young males and females collected from the mixedgrass prairie of southeastern Wyoming averaged 446 mg and 509 mg, respectively (dry weight 127 mg and 134 mg, respectively).

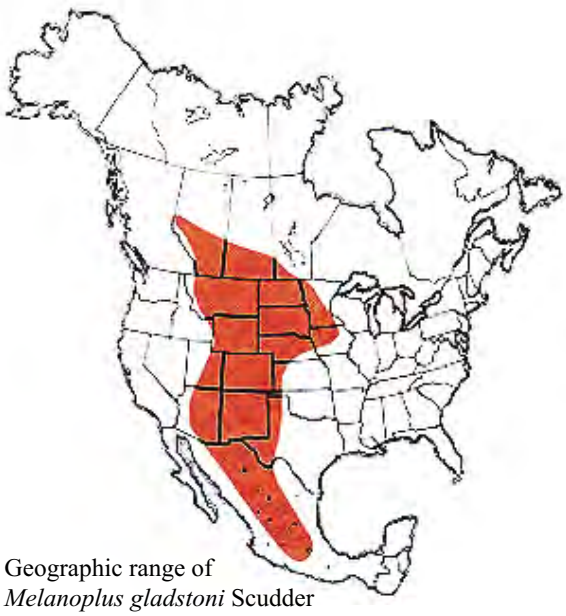
Food Habits

A polyphagous species, the Gladston grasshopper feeds on a variety of forbs, grasses, sedges, and several miscellaneous foods including seeds, moss, fungi, and dead arthropods. Forty-three species of forbs, eleven grasses, and two sedges have been detected in crops of this grasshopper collected from the mixedgrass, shortgrass, and sand prairies. The Gladston grasshopper apparently prefers forbs, as they constitute 70 to 85 percent of crop contents. In the natural grassland habitat this grasshopper has been found to feed extensively on scarlet globemallow, fringed sagebrush, Missouri goldenrod, and *Astragalus* sp. Among grasses, fragments of blue grama, Kentucky bluegrass, little bluestem, needleandthread, and sand dropseed have been found in substantial amounts in crops. Where blue grama is dominant, this grass has contributed from 9 to 25 percent of crop contents. Penn sedge made up 17 percent of crop contents of grasshoppers collected from the sand prairie of southeast North Dakota, and needleleaf sedge made up 4 percent of crop contents of grasshoppers collected from the shortgrass prairie of northern Colorado. In the desert prairie of southwest Texas, crop contents of this grasshopper consisted of 24 percent *Cryptantha* sp., 20 percent *Croton* or *Solanum* sp., 13 percent other forbs, and 23 percent grasses.

A dietary study of grasshoppers inhabiting alfalfa fields in North Dakota revealed that the Gladston grasshopper ingested plants in direct proportion to their abundance. Crop contents consisted of 75 percent alfalfa, 14 percent kochia, 10 percent smooth brome, and smaller amounts of nine less common plant species.

Several direct observations of the method of feeding of this grasshopper have been made at a study site of the mixedgrass prairie of eastern Wyoming. Adults attracted to isolated plants of Russian thistle climbed the plants and, from various orientations, fed upon the growing tips, small leaves, and especially the developing seeds, which were soft and juicy. A female was observed to crawl up an unidentified forb and feed, vertical, head up, on the edges of the green leaves. A female in a horizontal position on the ground was observed feeding on plant litter, and another female fed on a dead female grasshopper, *Trachyrhachys kiowa*.

An interesting observation was made of two adult Gladston grasshoppers that had moved from adjacent mixedgrass prairie into a winter wheat field during late October 1992. The wheat was 6 to 8 inches tall, but the first 16 rows had been eaten by grasshoppers that had migrated from the adjacent mixedgrass prairie, and only green stubs of wheat remained in these rows. One female Gladston grasshopper, horizontal on the ground, was observed feeding on the cut end of a green wheat stub. A male on the ground was observed feeding in the middle of a recumbent wheat leaf. This grasshopper chewed intermittently on the leaf with a peculiar up and down motion of its head. Close inspection of the leaf revealed that it was not being consumed but only chewed. Probably the grasshopper was seeking moisture but ingesting some leaf tissue.



Geographic range of
Melanoplus gladstoni Scudder

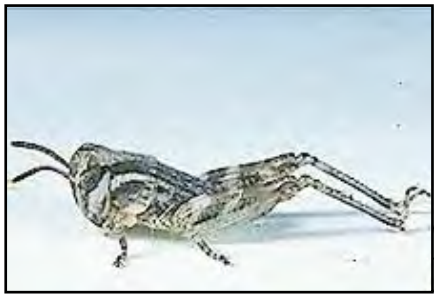
Dispersal and Migration

The Gladston grasshopper is a strong flier possessing long wings. Dispersal flights of young adults may occur soon after they fledge. A male and female were captured in the

Instar 1

1. BL 3.7-4.5 mm FL 2.2-2.4 mm AS 13.

Instar 2



2. BL 4.3-7.8 mm FL 3-4.4 mm AS 16-18.

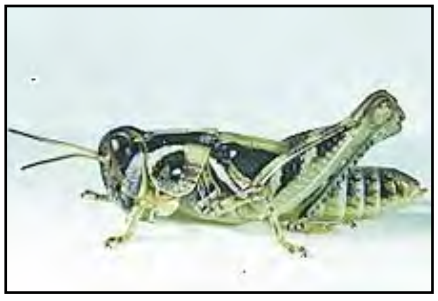
Instar 3

3. BL 6.4-9.6 mm FL 5.1-6 mm AS 20-21.

Instar 4

4. BL 11-13 mm FL 7.1-8.4 mm AS 21-23.

Instar 5



5. BL 13.7-15.5 mm FL 8.6-10.1 mm AS 23-24.

Figures 1-5. Appearance of the five nymphal instars of *Melanoplus gladstoni* - their sizes, structures, and color patterns. Notice progressive development of the wing pads. BL = body length, FL = hind femur length, AS = antennal segments number.

center of Laramie in early September 1991. They probably came from mixedgrass prairie that surrounds the city. Of interest is the fact that the two migrants possessed wings 2 to 3 mm longer than nonmigrant specimens in a general collection from the mixedgrass prairie.

Mass migration into Cheyenne, Wyoming became apparent during the last week of August 1991, when hundreds of young adults were seen on asphalt and concrete, in downtown doorways, and in grassy lots. Further evidence of mass migration was deduced from results of sampling densities of grasshoppers in the mixedgrass prairie of eastern Wyoming (Platte County). A population of late instars and adults declined suddenly from 0.7 to 0.2 per square yard between August 13 and 26, 1969. During the same interval no decline in the migratory grasshopper, *Melanoplus sanguinipes*, occurred. This fact implied that no epizootic, intensive predation, or other severe mortality factor was present on the site. The previous year, survival of the Gladston grasshopper was high in August. Only a 2 percent per day mortality occurred in 1968, while in 1969 the decrease due to the apparent mass emigration amounted to 11 percent per day.

Flushed flights range from 2 to 9 feet at heights of 4 to 8 inches. The flight is silent and usually straight, but occasionally curved. The grasshopper lands face away from the intruder.

Identification

The adult Gladston grasshopper is a dark brown, moderately large, long-winged species (Fig. 6 and 7). A broken line, fuscous alternating with ivory, runs longitudinally down the middle of the tegmen (Fig. 9). The male cercus is uniquely shaped; it is undivided and bent inward at the apical quarter (Fig. 8). This characteristic is diagnostic of the species. A second diagnostic character, holding good for both males and females, is the curvature of the lower carina of the hind femur (Fig. 11). In profile the basal third is straight or flat. In other species of *Melanoplus* this carina is gently curved over its entire length. The hind femur is notably robust; the fuscous stripe of the medial area is broken by two light patches. The hind tibiae are usually red, but may be blue in some southern specimens (Arizona).

The nymphs are identifiable by their structures, color, and shape (Fig. 1-5).

1. Head with face nearly vertical; frontal ridge either light or fuscous; frontal view of lower mouthparts fuscous or black. Antennae filiform and fuscous dorsally, each segment ringed anteriorly in ivory. Compound eye brown with many light spots; a diagonal dark bar crosses middle.
2. A distinct yellow or ivory crescent begins on gena below compound eye and runs onto lateral lobe of pronotum. Dorsal stripe of hind femur interrupted

Figures 6-10. Appearance of the adult male and female of *Melanoplus gladstoni*, male cercus, wings, egg pod and eggs.

in middle by light patch. Hind tibia pale yellow or pale gray in instars I to IV; pale blue in instar V; front edge fuscous.

3. Body color pale gray and light brown marked with fuscous; bottom of thorax and abdomen usually bright yellow but in a few specimens pale yellow or olive.

Many of the described nymphal characters of *M. gladstoni*, *M. infantilis*, and *M. occidentalis* are similar, yet nymphs of these species can be separated easily by color and by their seasonal appearance. The venter (ventral side of both thorax and abdomen) of nymphs of the Gladston grasshopper is usually bright yellow, while the venter of nymphs of *M. infantilis* is usually white and of *M. occidentalis* pale gray. Nymphs of *M. infantilis* and *M. occidentalis* are present in the grasshopper assemblage early in the season along with nymphs of *M. sanguinipes* and *M. packardii*, while those of the Gladston grasshopper are present late when all four of the former species are adults.

Hatching

The Gladston grasshopper hatches late in the season compared with most other rangeland species. In the mixedgrass prairie of eastern Wyoming and in the shortgrass prairie of northcentral Colorado the start of hatch may begin as early as June 13 or as late as July 2. In Montana, hatching begins about one week later. The period of hatching lasts for one to two weeks. In laboratory cages females oviposit to a depth of 5/8 inch, which is not as deep as is oviposition of the migratory grasshopper, *Melanoplus sanguinipes*. Yet the latter grasshopper hatches in early June, about two to three weeks ahead of the Gladston. No studies of egg development have been made to explain the delay of hatching of the Gladston grasshopper.

Nymphal Period

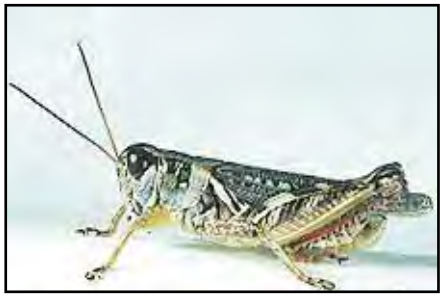
Based on the date of first appearance of instar I and the first appearance of adults, the nymphal period averages 56 days in length (range 42 to 70). Both males and females have five instars. The nymphs are present in July and August when most other species of rangeland grasshoppers are adult, some even at the end of their life cycle. Metamorphosis of the fifth instars to adults begins the middle of August and continues for three to four weeks.

Adults and Reproduction

Adults usually remain in the same habitat in which they developed as nymphs. In the mixedgrass prairie of southeast Wyoming mating pairs have been observed eight days after the first adults appear. The females begin to lay eggs about 21 days after becoming adult. Survival rate of adults is high through September and October. Freezing temperatures in November appear to bring an end to the adult stage.

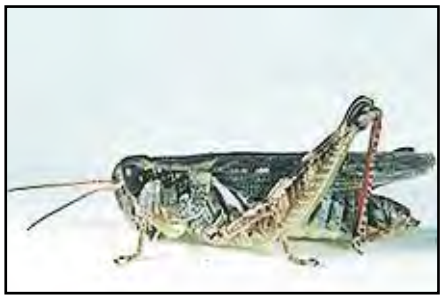
Oviposition has not been observed, but females confined in a laboratory terrarium with sandy loam soil and sod in the center laid in the bare soil, which was interspersed in the sod, and in

Male



6. BL 19-22.5 mm FL 11-12.3 mm AS 24-27.

Female



7. BL 20.1-25.2 mm FL 11.5-13.5 mm AS 25-27.

Cercus

8. End of male abdomen to show shape of cercus.

Wings

9. Spread wings of female.

Eggs

10. Two egg pods, one broken open to expose eggs.

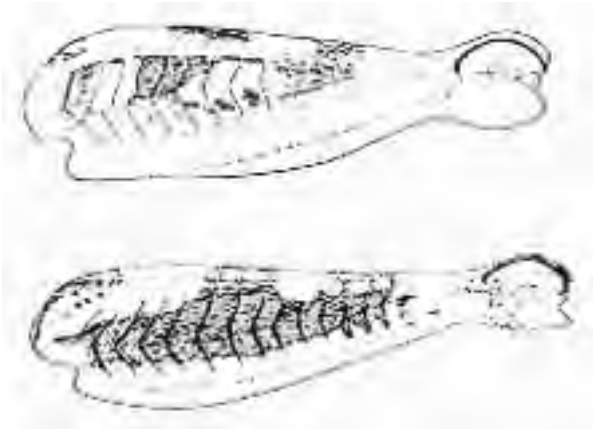


Figure 11. Left hind femur of *Melanoplus gladstoni* (above) showing the straightened lower carina of basal third and the gentle curve of the entire lower carina in *M. keeleri* (below). (From Brooks 1958).

the peripheral soil. Pods are 1 to 1 1/8 inches long and notably curved (Fig. 10) and contain 16 to 29 eggs. The eggs are tan and 4 to 4.9 mm long. Eggs are contained in the bottom section of the pod and because of its diagonal orientation, the eggs lie in the soil at a depth between 5/16 to 10/16 inch. The top section of pod consists of dry froth.

Population Ecology

The Gladston grasshopper's center of distribution appears to be in the mixedgrass prairie where it is a common inhabitant. Densities of young adults are usually low, ranging from less than 0.1 to 1.0 per square yard. It may reach a density of four per square yard during an outbreak. Even at this density the species is a subdominant; other species are more abundant and the dominant species may number 20 or more per square yard.

In the shortgrass prairie of northeastern Colorado, the Gladston grasshopper is a principal member of the assemblage. It may range from less than 0.1 to 1.1 per square yard. The latter number is reached during a peak in density of the assemblage (Table 1). From 1980 to 1985 populations of the Gladston grasshopper at this site fluctuated between 0.1 and 1.1 individuals per square yard, making it the primary or secondary species in five of the six years.

Daily Activities

The Gladston grasshopper dwells chiefly on the ground. During the night it rests horizontally on bare soil or litter under canopies of short grasses such as blue grama. Occasionally adults rest overnight vertically, head up on forbs. On plants of Russian thistle, 20 to 23 inches tall, the grasshoppers cling to stems at heights of 15 to 21 inches.

Early in the morning before the rays of the sun strike them, the grasshoppers emerge from their nighttime shelters. They rest horizontally on the ground facing in various directions. When the rays eventually reach them, about one hour after sunrise, they begin to bask by turning a side perpendicular to the rays and by lowering the hindleg to maximize exposure of the abdomen. They bask from one to two hours at soil temperatures that range from 59° to 103°F and air temperatures (1 inch high) from 59° to 76°F. Some individuals, however, become active at a soil temperature of 85° and an air temperature of 65°F. The peak of activity comes between 10 a.m. and noon, at which time they feed, mate, and walk about on the ground. When temperatures rise above their tolerance level, they cease activity and take evasive actions. First they may face the sun or face directly away and stilt; as temperatures increase they climb vegetation to heights of 4 inches or more.

They again bask in the afternoon from 4 to 7 p.m. on bare soil. When shadows engulf these spots, they crawl into their nighttime shelters under canopies of grasses, usually blue grama.

Table 1. Population fluctuations of grasshoppers in a shortgrass prairie site, northeastern Colorado. (Adapted from Capinera and Thompson)

	Number per square yard					
	1980	1981	1982	1983	1984	1985
Melanoplus gladstoni	0.2	0.3	0.9	1.1	0.7	0.1
Assemblage of 5 common species	0.4	0.9	2.4	4.0	3.1	1.6

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Little Spurthroated Grasshopper

Melanoplus infantilis Scudder

Distribution and Habitat

The little spurthroated grasshopper has a wide geographic range in Western North America. It occurs in grasslands, often as the dominant grasshopper, from the Canadian provinces to northern New Mexico. It is common in clearings of montane coniferous forest and in the parklands of the Canadian northern forest. In Colorado, it is found in montane grasslands as high as 10,000 feet. Its northern geographic range and its distribution in montane habitats indicate tolerance for colder temperate climates and intolerance for warmer conditions.

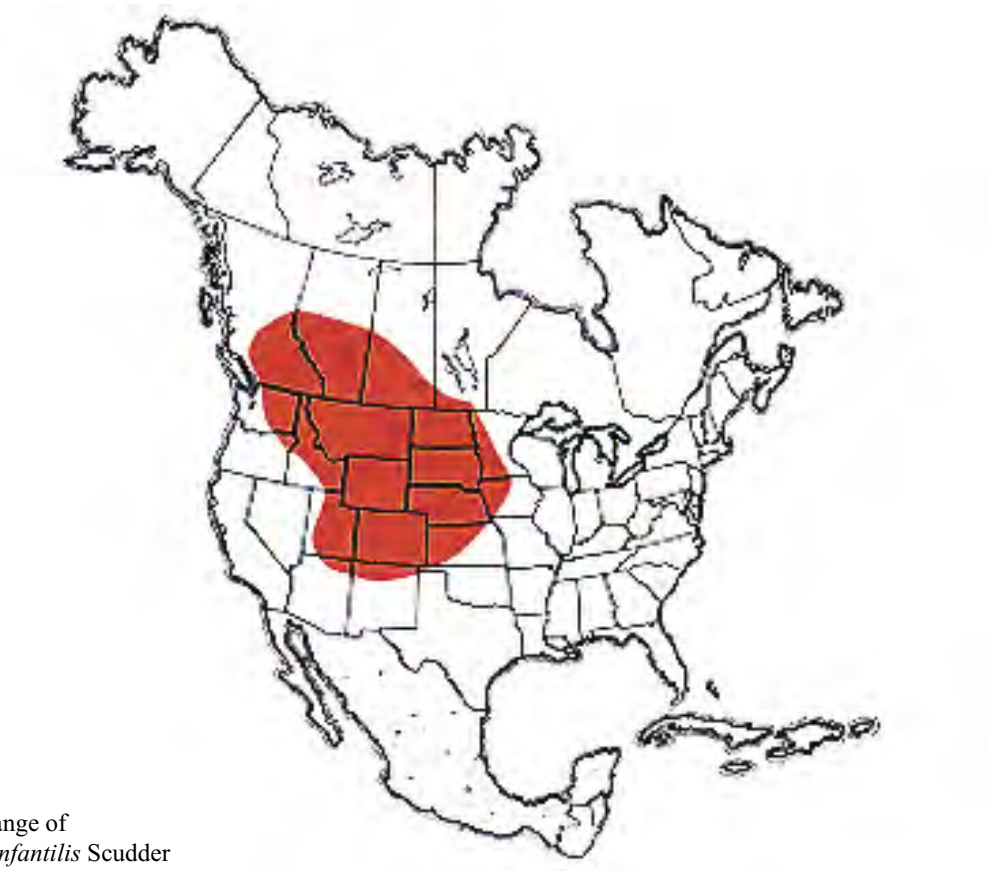
Economic Importance

This grasshopper is an economically important species, becoming abundant in grasslands and feeding on both grasses and forbs. In a rangeland assemblage it is sometimes the dominant grasshopper. During 1953 it was the dominant species in 11 of 42 sites sampled in the mixedgrass prairie of Montana. A small species, the live weight of males averages 157 mg and of females 236 mg (dry weight males 53 mg, females 63 mg).

Large populations infest regions of bunchgrass-sagebrush in Idaho where densities may reach 20 to 40 per square yard in outbreak years. This species confined in field cages on western wheatgrass in Montana, caused a loss of 35 mg dry weight of forage per adult grasshopper per day. This amount was less than that caused by an adult big-headed grasshopper, *Aulocara elliotti*, which caused a loss of 62 mg per day. The reason for this difference is no doubt related to the difference in weight of the two species. The larger grasshopper, which requires more food, caused the greater damage. Unconfined in its natural habitat, the little spurthroated grasshopper may be even less damaging because it feeds on forbs as well as grasses.

Food Habits

The little spurthroated grasshopper feeds on both grasses and forbs. No primary host has been revealed from three studies that have examined crop contents. Rather the studies indicate that the diet varies with the kinds of vegetation growing in the habitat and with the time of season. Populations may be either mainly gram-inivorous or forbivorous. Direct observations of feeding and



Geographic range of
Melanoplus infantilis Scudder

Instar 1

1. BL 4.2-5.2 mm FL 2.1-2.3 mm AS 13.

Instar 2

2. BL 4.6-7.2 mm FL 3-4.3 mm AS 15-18.

Instar 3

3. BL 7.1-10.1 mm FL 4.9-5.7 mm AS 19-20.

Instar 4

4. BL 9.1-12.1 mm FL 6.3-7.8 mm AS 20-22.

Instar 5

5. BL 12-15 mm FL 8.4-9.2 mm AS 22-25.

Figures 1-5. Appearance of the five nymphal instars of *Melanoplus infantilis* - their sizes, structures, and color patterns. Notice progressive development of the wing pads. BL = body length, FL = femur length, AS = antennal segments number.

examinations of crop contents provide records of feeding on ten species of grasses, three species of sedge, and 16 species of forbs. Major grass hosts include blue grama, western wheatgrass, needleandthread, sand dropseed, Idaho fescue, parry oatgrass, and several species of bluegrass. Threadleaf sedge and needleleaf sedge, grass-like rangeland plants, are also major foods. Major forb hosts include scarlet globemallow, woolly plantain, broom snakeweed, fringed sagewort, Fendler sandwort, dandelion, and several species of milkvetch.

Even though results from the field indicate that the little spurthroated grasshopper is a polyphagous feeder, laboratory tests of food preference show that it discriminates between paired species of plants. It prefers dandelion to blue grama, western wheatgrass, and alfalfa, but it eats equal amounts of dandelion and downy brome.

No field observations have been made of how this grasshopper attacks a food plant; however, several observations have been made of its feeding in a laboratory terrarium. In feeding on needleandthread grass, a hungry female crawled on the soil surface until she contacted the food plant. She then reached up and cut a green leaf about one-half inch above the ground level and held onto the cut section, approximately 1 to 2 inches long, with the front tarsi and consumed the entire section from the cut end to the tip. She repeated this procedure five times on leaves of the same plant. The sixth time she cut another leaf but did not continue feeding, probably having been satiated. Adults were also observed feeding on ground litter such as fallen leaves of needleandthread and scarlet globemallow. In their natural habitat in Montana, adults have been observed feeding on ground litter.

Dispersal and Migration

Dispersal and migration of the little spurthroated grasshopper have been recorded several times. It has been recorded flying into cities and towns. Recently four males and eight females were found on Grasshopper Glacier of Montana along with several other migratory species. Two carbon-dated specimens of this species were determined to be less than 40 years old.

Evasive flights of the little spurthroated grasshopper are straight, silent, and low (4 to 9 inches above ground), and for short distances (3 to 10 feet).

Figures 6-10. Appearance of the adult male and female of *Melanoplus infantilis*, front of head, end male abdomen, and egg pod and eggs.

Identification

The adult of the little spurthroated grasshopper is a small, long-winged member of the genus *Melanoplus*. The hind femur has the medial area distinctively patterned with dark chevrons and light patches (see figures 6 and 7). The upper marginal areas of the hind femur are marked by three dark bands. The hind tibia is usually light blue. A diagnostic character of the species is the shape of the male cercus (Fig. 9). It is forked with the lower arm curving down and ending in a blunt tip (the alpine grasshopper, *Melanoplus alpinus*, has a similarly shaped cercus, but the lower arm curves decidedly downward and narrows to an acute point).

The nymphs are identifiable by their structures, color patterns, and shape (Fig. 1-5).

1. Head with face nearly vertical; frontal ridge distinctively black (Fig. 8), vertical black band running from bottom of compound eye down to mouthparts. Antennae filiform, each segment ringed anteriorly in white. Compound eye brown with many light spots.
2. Cream-colored crescent beginning on gena below compound eye and running onto lateral lobe. Dorsal stripe of hind femur usually interrupted near middle by cream-colored band. Hind tibia pale yellow or pale gray, front edge fuscous.
3. Body color is cream and tan with fuscous lines and marks. Bottom of thorax and abdomen usually white, occasionally pale yellow.

Many of the described nymphal characters of *M. infantilis, M. gladstoni*, and *M. occidentalis* are similar, yet nymphs of these species can be separated easily by color and by their seasonal appearance. The venter (ventral side of both thorax and abdomen) of nymphs of *M. infantilis* is usually white, while the venter of nymphs of *M. gladstoni* is usually bright yellow and of *M. occidentalis* pale gray. Nymphs of *M. infantilis* and *M. occidentalis* are present in the grasshopper assemblage early in the season along with nymphs of *M. sanguinipes* and *M. packardii*, while those of the *M. gladstoni* are present late when all four of the former species are adults.

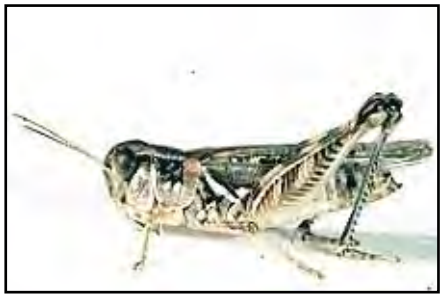
Hatching

The little spurthroated grasshopper is an intermediate-hatching species appearing two to three weeks after the bigheaded grasshopper. In the northern mixedgrass prairie the eggs may hatch from late May to mid June.

Male

6. BL 16.5-17 mm FL 9.6-10.7 mm AS 25-26.

Female



7. BL 16-19 mm FL 10.5-11.2 mm AS 24-25.

Frontal Ridge

8. Distinctively black color of frontal ridge of nymphs.

Cercus

9. End of male abdomen showing shape of male cercus.

Eggs

10. Egg pod and loose eggs.

Nymphal Development

Nymphs develop and grow during late spring and early summer when weather is usually warm and food plants are green and abundant. Under these favorable conditions the young grasshoppers develop through the nymphal stage in 27 to 34 days. Of six common species inhabiting Montana mixedgrass prairie (*Ageneotettix deorum*, *Amphitornus coloradus*, *Aulocara elliotti*, *Melanoplus infantilis*, *Melanoplus packardii*, and *Melanoplus sanguinipes*), the little spurthroated grass-hopper developed most rapidly.

Adults and Reproduction

Adults remain in the same habitat in which they develop as nymphs. There they feed, mature, mate, and reproduce. No special study has been made of their courtship or reproduction. Four observations of pairs in copulation have been made between the hours of 8:30 and 10:30 a.m. DST. One pair, which was first observed at 10:10 a.m. on 14 August 1990, disengaged after 20 minutes. In the northern mixedgrass prairie the adults are present from mid July to mid September or mid October, a period of 60 to 90 days. Longevity of individual adults is much less, however, ranging from 15 to 22 days on the mixedgrass prairie of Montana.

On South Dakota rangeland, females have been observed ovipositing to a depth of 1 inch in clumps of buffalo grass. Caged females oviposit readily into bare soil. Upon withdrawing their abdomen, females brush soil and litter over the exit holes with their ovipositor. The pods are curved, seven-eighths to 1 inch long, and contain 10-13 light tan eggs in the bottom half (Fig. 10). The eggs are 3.9 to 4.2 mm long. The top half of the pod consists of dry froth. There is one generation annually.

Population Ecology

Population densities of the little spurthroated grasshopper fluctuate in a habitat over time. In the northern mixedgrass prairie where this grasshopper is usually subdominant, it may persist at low adult densities of 0.1 to 0.5 per square yard for six or more years. During a favorable period for growth of grasshopper populations, it may increase with other species of an assemblage and reach densities of one adult per square yard. No study has been made of its rate of increase to outbreak numbers when it becomes the dominant species. The fecundity of this species is unknown. In a three year study on Montana mixedgrass prairie, mortality of nymphs has ranged from 3 to 11 percent per day and mortality of adults from 4 to 6 percent. These rates are similar to mortality rates of other species of *Melanoplus* at the study site.

Daily Activity

Because of low densities of the little spurthroated grasshopper in study sites during the last three years, only a small number of observations of daily activity are available. This grasshopper appears to spend the night either on the ground or on small shrubs. These conclusions are based on the location of adults in early morning before activity began. On the ground they sit horizontally on bare ground or in clumps of blue grama. On shrubs, such as silver sagebrush or broom snakeweed, they sit on a stem vertically, head up, and at heights of 5 to 10 inches.

Both nymphs and adults began to bask about one hour after sunrise by sitting horizontally on bare ground or on the crown of blue grama grass. At this time, temperatures of the soil surface and at 1 inch high were below 60°F. They turned one side perpendicular to the rays of the sun and often lowered the exposed hindleg to the ground. They frequently stirred and raised and lowered their flexed hindlegs during basking. Adults were observed basking till 10 a.m. when soil surface temperature was 80°F. and air temperature 1 inch above the ground was 68°F. Exactly when these grasshoppers start morning activities has not been determined.

Two fifth instar nymphs were observed in the afternoon sitting vertically head up, 2 inches high on the leaves of needleandthread grass when soil surface temperature was 115°F. This behavior was ostensibly to escape ground heat.

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Keeler Grasshopper

Melanoplus keeleri (Thomas)

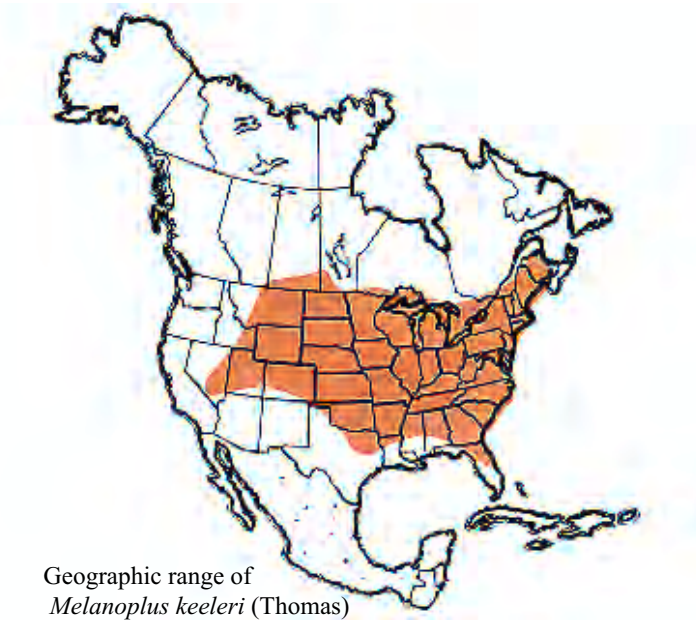
Distribution and Habitat

The Keeler grasshopper ranges widely in North America inhabiting upland grasslands from the Atlantic coast to the Great Basin and from southern Canada to southern United States. In the west it is a common inhabitant of the tallgrass prairie and the taller types of the mixedgrass prairie.

Economic Importance

The Keeler grasshopper is a minor pest of rangeland forage. When present, populations occur at low densities in the mixedgrass, tallgrass, and sand prairies. Furthermore, the nymphs and adults do not consume native grasses in significant amounts, preferring to eat forbs of low forage value. Because several forages in the bean family are among its preferred food plants, the Keeler grasshopper may become a pest in pastures seeded to mixtures that include legumes. In such situations it is usually subdominant to major pest species such as the migratory, redlegged, and twostriped grasshoppers. The Keeler grasshopper merely adds a small amount to the more serious damage of the others. Likewise, this grasshopper does not appear to be a serious pest of cultivated crops. It has been discovered in small numbers in North Dakota alfalfa fields ranking eighth in abundance after seven other melanoplines. It did feed on the alfalfa, however, as 19 out of 26 crops examined contained fragments of this legume.

The Keeler grasshopper is a medium-sized species. Live weights of males average 252 mg and of females 343 mg (dry weights: 73 mg and 100 mg, respectively).



Geographic range of *Melanoplus keeleri* (Thomas)

Food Habits

The Keeler grasshopper feeds on a wide variety of forbs. Field observations and examinations of crop contents reveal that a minimum of 52 species are consumed in variable amounts. These belong to 17 plant families. Additionally, records show that a small amount of feeding occurs on seven species of grasses and one sedge. The Keeler grasshopper has also been observed to feed on cabbage and the leaves of apple and plum. Only two plant families embrace the primary host plants: the sunflower family (Asteraceae) and the bean family (Fabaceae).

The kinds of plants present in the habitat influence greatly the diet of this grasshopper. In the tallgrass prairie of eastern Kansas, three species serve as the chief host plants: western ragweed, cudweed sagewort, and Missouri goldenrod; four species in the mixedgrass prairie of central Nebraska: breadroot scurfpea, aromatic aster, common sunflower, and prickly lettuce; four species in the sand prairie of southeast North Dakota: green sagewort (*Artemisia glauca*), western ragweed, leadplant, and cudweed sagewort; and four species in the mixedgrass prairie of northcentral Colorado: *Astragalus flexuosus*, cudweed sagewort, scarlet globemallow, and undetermined species of the sunflower family. Different host plants and dietary combinations no doubt occur in other sites. Of economic interest is the fact that several introduced forages belonging to the bean family - alfalfa, lespedeza, sweetclover, and probably others - are among this grasshopper's preferred food plants.

Although primarily a forb feeder, the Keeler grasshopper ingests small or trace amounts of grass. Examination of crop contents reveals fragments of western wheatgrass, blue grama, needleandthread, downy brome, Japanese brome, smooth brome, and Kentucky bluegrass. Cage tests show that among six species of grasses occurring in eastern Kansas, tall fescue was preferred, followed closely by smooth brome. Fragments of Penn sedge have been found in crops of Keeler grasshoppers collected in southeast North Dakota.

One observation was made of this grasshopper feeding on the host plant, *Penstemon glaber*. A female sitting diagonally head-up on the dry culm of Japanese brome that leaned on the host plant fed on the stub of a leaf that had been previously fed upon across its entire width. Observations of *P. glaber* plants revealed more injury to top leaves than the low, rosette leaves lying near ground level. Lateral edges of top leaves, which are about 3 inches long, exhibited uneven gouges 3/8 to 5/8

Instar 1

1. BL 4-5.4 mm FL 2.4-2.6 mm AS 12-13.

Instar 2

2. BL 6-8.3 mm FL 3.7-5.7 mm AS 16-17.

Instar 3

3. BL 8.9-10.5 mm FL 5.1-5.8 mm AS 18-19.

Instar 4

4. BL 11.8-15 mm FL 6-8.7 mm AS 20-23.

Instar 5

5. BL 13.7-22 mm FL 9.1-11.5 mm AS 23-24.

Figures 1-5. Appearance of the five nymphal instars of *Melanoplus keeleri* - their sizes, structures, and color patterns. Notice progressive development of the wing pads. BL = body length, FL = hind femur length, AS = antennal segments number.

inch long and 1/8 inch deep. Some leaves had been attacked from the tips and only basal stubs remained. This limited evidence suggests that this grasshopper feeds close to where it perches on the plant. In the case of *Penstemon glaber*, the grasshopper fed primarily on leaves 4 to 10 inches high.

Dispersal and Migration

Western specimens of the Keeler grasshopper possess long wings that range from nearly reaching the end of the abdomen to 4 mm beyond. Despite having the structures necessary for flight, they do not appear to disperse much but remain most often in the relatively thick vegetation of midgrasses and forbs within their habitat. However, some evidence for dispersal exists. Two adult accidentals were collected in a montane site northwest of Boulder, Colorado at an altitude of 7,600 feet. In this area the species is resident up to 6,700 feet. Other evidence for dispersal comes from the collection of two fifth-instar nymphs in a mixedgrass study site (Platte County, Wyoming) on 25 July 1992 where previously the species had not been seen or collected for a period of 13 years (1968-81). Evidently, adults dispersed into the site between 1982 and 1991. Further evidence for dispersal comes from the George Reserve in Michigan, where accidentals (erratics) have been taken in nonresident habitats such as shady oak-hickory woodland and semipermanent marsh.

Adults that are flushed jump or more often fly short distances of 2 to 4 feet at heights of 8 to 12 inches. The flight is straight and silent and the landing is on vegetation or bare ground. On vegetation they land vertically head-up and on bare ground they land horizontally facing away from the intruder.

Identification

In the west, the Keeler grasshopper is a colorful long-winged, medium-sized grasshopper (Fig. 6 and 7), in contrast to many eastern specimens that are dark brown and dull. Males are recognizable by the distinctive shape of the cercus, which is bifurcate with the dorsal arm larger than the ventral (Fig. 9). Both sexes possess a distinctively shaped femoral stripe. Located on the outer face of the hind femur, the stripe is solid fuscous (not cut by any light band) and narrows

Figures 6-10. Appearance of the adult male and female of *Melanoplus keeleri*, hindleg of female adult, male cercus, and egg pod and eggs.

toward the base (Fig. 8). The hind tibiae are red and the body is brown and yellow.

The nymphs are identifiable by their structures, color patterns, and shape (Fig. 1-5).

1. Head with face nearly vertical and colored fuscous except frequently yellow around base of antenna; compound eye brown or fuscous and marked distinctively by two parallel transverse yellow stripes (See Figure 2 for clear picture); sides of head yellow, top of head yellow in instars I and II, reduced to median yellow band or all black in older instars.
2. Pronotum with disk fuscous, divided by yellow median band, lobes yellow and marked by an anterior diagonal dark stripe in instars I and II, faint or lacking in instar III, solid cream or yellow in instars IV and V.
3. Hind femur yellow with solid black femoral stripe; hind tibia gray.
4. General body color yellow and black. Venter often canary yellow.

Hatching

The Keeler grasshopper is a late-hatching species. Depending on the year, it begins to hatch from early to late June in the mixedgrass prairie of Colorado, hatching about three weeks after the migratory grasshopper, *Melanoplus sanguinipes*, which often shares the same habitat. In Larimer County, Colorado, first instars were collected on June 4 in 1992 and on June 22 in 1993. Limited data indicate that the hatching period is short - from one to two weeks.

Nymphal Development

In their natural habitat within the mixedgrass prairie, Keeler grasshoppers develop through five instars in approximately 46 days. In Larimer County, Colorado, the first adults were observed July 31 in 1993 and July 27 in 1994. On these dates the majority of the population consisted mainly of instars IV and V.

Adults and Reproduction

Adults begin to emerge during the latter part of July and continue emerging for approximately three weeks in the mixedgrass prairie of northcentral Colorado. By mid

Male

6. BL 18.5-21.7 mm FL 11-11.5 mm AS 25-26.

Female

7. BL 19-22.5 mm FL 11-12.8 mm AS 24-26.

Hindleg

8. Outer face of left hindleg of female.

Cercus

9. End of adult male abdomen showing the cercus.

Eggs

10. Egg pod and loose eggs.

August, 85 percent of the population is fledged. At lower altitudes emergence of adults occurs earlier. In eastern North Dakota, adults are present during the first week of July; in Iowa, adults have been found as early as June 23. Although maturation of adults has not been studied, a few facts are known. Courtship in this species is brief. Without preparatory signals, the male jumps on a female. A nonresponsive female shakes her hindlegs and kicks away the unwanted suitor, but a responsive female scarcely struggles while the male produces bursts of femur shaking and attaches his genitalia. The duration of copulation is unknown. Two observations of pairs in copulo were made in the mixedgrass prairie of Colorado, one on 9 August 1994 at 11:45 a.m. DST and another three days later at 10:31 a.m. Adults peak numerically in mid August. They then gradually dwindle, but a fair number are still present and active in October. In southeast North Dakota the females have been observed to oviposit in small, bare or sparsely vegetated areas. The egg pods are 3/4 to 1 inch long, curved, and contain 20 to 22 light tan eggs 4.0 to 4.3 mm long (Fig. 10).

Population Ecology

The center of distribution of the Keeler grasshopper appears to be in the midwest where it is common in upland grass-herb habitats and at times becomes the dominant species in the grasshopper assemblage. In the western peripheral zone of its geographic range, it is rare in the normal mixedgrass and shortgrass prairies. In this zone it occupies edaphic habitats characterized by relatively tall grasses and herbs that occur on well-watered slopes and along roadsides. An edaphic site in the mixedgrass prairie of northcentral Colorado affords a favorable habitat in which populations of the Keeler grasshopper have persisted for at least eight years: 1987 to 1994. In 1994 it was the dominant species in an assemblage of nine species with a total density of eight grasshoppers per square yard. On 11 August 1994, the Keeler population measured four individuals per square yard. At this time 75 percent were adult and 25 percent were late instars. By 29 September 1994, the population had decreased to 0.2 adults per square yard, indicating a 6 percent daily mortality over the adult period.

A study site in the sand prairie of southeastern North Dakota (Sheyenne National Grasslands) harbored populations of the Keeler grasshopper for at least ten years, 1959 to 1968. Measurements of relative abundance indicated a subdominant position throughout this period. In 1960, however, it ranked second after Eritettix simplex and then decreased in density through 1962 and fluctuated in abundance to 1968.

Daily Activity

Inhabiting sites of thick, tall and mid grasses and tall forbs, the Keeler grasshopper spends most of its time perched on vegetation. At night, individuals usually rest vertically, head-up on stems of forbs at heights of 8 to 14 inches above the ground. An occasional individual may rest diagonally or horizontally on the stem of a fallen, dead forb or on the cladode of a prickly pear cactus. In the morning when rays of the sun strike them, they begin to bask. In the study site on August 9 to 12, 1994, a hill to the east hid the rising sun until 7:33 a.m. DST. Basking grasshoppers were noticed an hour later. Still on the vegetation, they turned a side perpendicular to the sun and lowered the hindleg to expose the abdomen. They basked for two hours or longer and some fed during this time on leaves of the host plant. One observation was made of a female feeding on ground litter at 11:05 a.m. Shortly before sunset, the grasshoppers settled on their host plants and presumably stayed at rest until morning.

Temperatures declined from 80°F at sunset to 60°F at sunrise, at which time the grasshoppers were quietly roosting.

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Kennicott Grasshopper

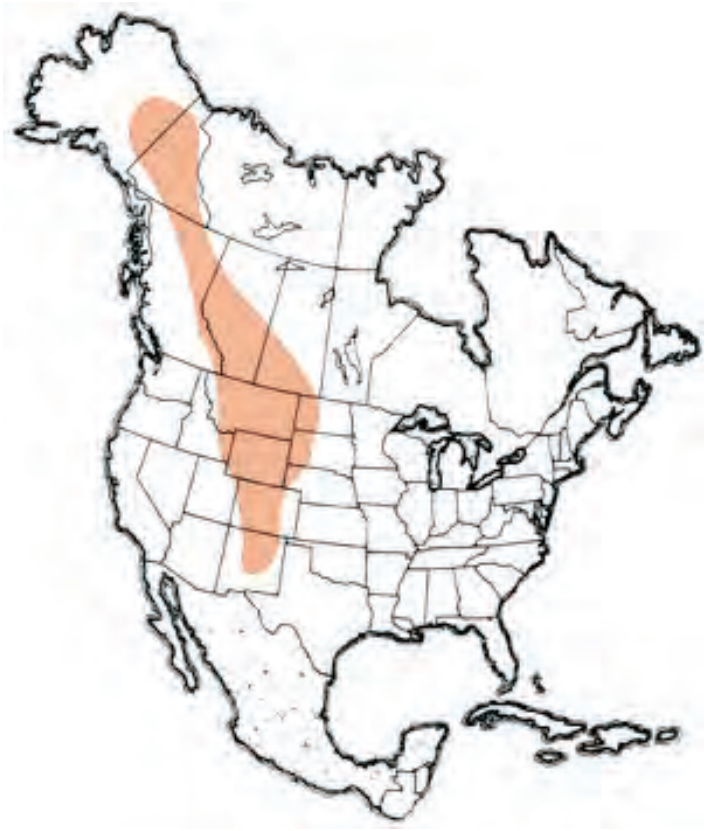
Melanoplus kennicotti Scudder

Distribution and Habitat

The Kennicott grasshopper, *Melanoplus kennicotti*, ranges in a wide band along the Rocky Mountains from Alaska to New Mexico. It inhabits the grasslands of mountain meadows and parklands and the western edge of the northern mixedgrass prairie. The species resides at elevations ranging from 100 feet in Alaska to 11,060 feet in the Absaroka Range in Wyoming. In Alaska the species inhabits open areas of the mixedgrass-forb-moss association at elevations of 100 to 450 feet.

Economic Importance

A feeder on forbs and grasses, the Kennicott grasshopper is a potential pest of forage in mountain parklands. It is a small species that during years of outbreaks, makes up for its size by large numbers. Adding its impact to the damage caused by other pest species during outbreaks, it contributes to the depletion of livestock and wildlife forage in parklands. Occasionally, it is the predominant species of the grasshopper assemblage, but no quantitative studies of its damage have been made. Live males weigh an average of 173 mg and live females 285 mg (dry weight males 60 mg, females 100 mg).



Geographic range of *Melanoplus kennicotti* Scudder

Food Habits

The Kennicott grasshopper feeds on a variety of forbs and grasses. Observations of released adults in their natural habitat in early fall revealed that they fed upon several forbs: dandelion, a sagebrush (*Artemisia tripartita*), prairie chickweed (*Cerastium arvense*), and an unidentified forb sprout approximately 1 inch tall. The latter plant was consumed to ground level in 6 minutes. One adult was observed to feed on prairie junegrass which had greened up after late summer rains. It ate the distal 1 inch of a 2-inch-tall leaf. Field observations were limited both by time spent watching individual grasshoppers and by the short window of adult life scrutinized in fall. Observations should be made ideally from late spring to early fall so that grasshoppers may encounter all kinds and stages of plants in the habitat. This mountain study site had a rich floral diversity including a minimum of 20 forbs, 9 grasses, and 2 sedges.

Confined in cubic-foot cages on transplanted sod from the study site west of Tie City, Wyoming, adults were observed to feed on dandelion, prairie chickweed, prairie junegrass, wild buckwheat (*Eriogonum umbellatum*), *Arenaria fendleri*, and *Poa cusickii*.

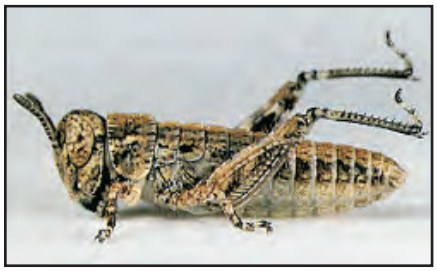
Laboratory two-choice tests showed that dandelion, alfalfa, *Cryptantha thyrsiflora*, and downy brome were preferred; *Erigeron eatoni*, *Heterotheca villosi*, *Kochia scoparia*, and *Poa pratensis* were rejected. Adults consumed some of *Astragalus* sp. but results were unclear.

Although these observations and others of feeding by the Kennicott grasshopper show that it is a polyphagous species consuming both forbs and grasses, they do not provide vital information about its diet. Such observations fail to reveal the proportions of food items ingested and the changes in diet that are sure to occur seasonally. Only a detailed study by quantitative analysis of gut contents of grasshoppers taken from several habitats at different densities and times of the season will disclose fully the Kennicott grasshopper's food habits.

Dispersal and Migration

Flushed flight of the Kennicott grasshopper is short (4 to 5 feet) and low (6 to 8 inches above the ground surface). The flight is silent and usually straight but may be circuitous. Direct evidence for voluntary flight is lacking. No migrating swarms have been seen and reported and no frozen specimens have been found on glaciers. Likewise no appetitive flying has been observed in study sites of the Laramie Range. Nevertheless, a study of population densities in the infested square mile area west of Tie City, Wyoming,

Instar 1



1. BL 4-5.9 mm FL 2.2-3.3 mm AS 12-14.

Instar 2

2. BL 6.3-7.2 mm FL 3.5-3.6 mm AS 14-16.

Instar 3

3. BL 7.8-9.6 mm FL 4.4-4.9 mm AS 16-19.

Instar 4

4. BL 10.5-15.5 mm FL 6.5-7.8 mm AS 19-21.

Instar 5

5. BL 13.5-18 mm FL 7.7-9.1 mm AS 21-22.

Figures 1-5. Appearance of the five nymphal instars of *Melanoplus kennicotti* - their sizes, structures, and color patterns. Notice progressive development of the wing pads. BL = body length, FL = hind femur length, AS = number of antennal segments.

provide circumstantial evidence for a slow dispersal from the center where densities were highest to the edges where densities were lowest. Less likely is the possibility that of apparently uniform parkland the central area was a more favorable habitat than all four perimeter sites.

Identification

The Kennicott grasshopper is a small, dark gray member of the species-rich genus, *Melanoplus*. The body patterns are dark gray with contrasting pale gray and tannish gray areas (Figure 6 and 7). The wings are long reaching approximately the end of the abdomen and the apices of the hind femur (male wings terminate from 1 mm before to 1.5 mm beyond the hind-femur apex, female wings end 0.5 to 1.5 mm before the apex). The hind femur is yellow ventrally and the medial area is marked by three dark gray bands; the middle one has a feather-and-shaft appearance; occasionally the pattern is indistinct when the medial area is entirely dark. The tibia are olive, buff, or blue. The distinctive male cerci are rectangular and stubby (Fig. 8). The furcula is short with acutely pointed processes. The end of the subgenital plate bears a nipple. The venter of the abdomen is cream or pale gray and spotted fuscous.

The nymphs are identifiable by their color and color patterns (Fig. 1-5).

1. Head tan or pale gray, each ridge of frontal costa with a row of 8-12 fuscous spots; antennal segments black with anterior annulus cream-colored; compound eye brown with tan spots, a transverse dark bar crosses center of eye, each side of dark bar with adjacent tan bar; top third of eye pale brown, bottom third dark brown.
2. Crescent on side of head and pronotal lobe cream-colored or tan, crooked on lobe (Fig. 1-4 and 9), may be interrupted on lobe (Fig. 5), or entirely absent.
3. Hindleg: medial area of femur with light and dark transverse bars and areas, middle dark bar shaped like feather and shaft of arrow (See Fig. 3 for clear depiction); marginal area with 2 tan and 2 black transverse bars in instar I, 3 tan and 4 black transverse bars in instars II to V; hind tibia with side black or gray in instar I, gray or tan in instars II to V, front of tibia and spines black in all instars.
4. Venter of thorax and abdomen pale gray or tan, spotted brown.
5. General color gray, tan, or cream with many fuscous spots, a few specimens melanistic.

Figures 6-10. Appearance of the adult male and female of *Melanoplus kennicotti,* end of male abdomen, side of head and thorax of male instar V, and eggs and pod.

Two characters useful in identifying the nymphs of the Kennicott grasshopper are the crooked crescent and the feather-and-shaft marking on the medial area of the hind femur.

Hatching

From eggs that overwinter in the soil, the Kennicott grasshopper hatches in late spring. It is one of the early hatching species in the montane environment along with *Melanoplus alpinus*, *Bruneria brunnea*, *Camnula pellucida*, and several others. These early species hatch about one month after snow melt exposes parkland vegetation. In the mountain study site west of Tie City, Wyoming (Laramie Range T15N, R72W, Sec 15 NW, elevation 8,600 feet), the Kennicott grasshopper along with *M. alpinus* and *B. brunnea* began to hatch 6 June 1994 and 24 June 1995. In the same site, the hatching of *M. infantilis* and *M. sanguinipes* did not begin until 5 July 1994 and 5 August 1995. This would place these two species in the intermediate hatching group of montane species. However, at lower elevations as in the grasslands of the High Plains, they belong to the early hatching group. The length of time that the hatching eggs of the Kennicott grasshopper have lain in the soil is unknown. The eggs may have been laid the previous summer or two or more summers earlier.

Nymphal Development

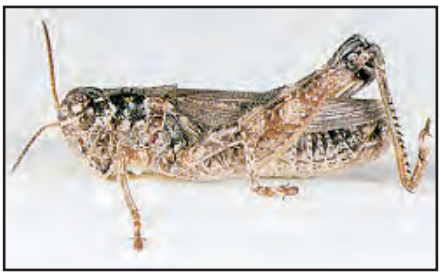
The nymphs develop early in summer when montane weather is variable but vegetation is green and nutritious. A few days of cold rain or snow may occur but most days are sunny and warm. The length of the nymphal development, as measured from first hatch to first adult, is short. In the parkland west of Tie City, Wyoming, this period was calculated to be 29 days in 1994 and 38 days in 1995. The length of the latter figure may be an over estimate due to difficulties in netting the first adults.

Adults and Reproduction

In mountain habitats the adult stage of the Kennicott grasshopper is reached in early summer. In the parkland west of Tie City, Wyoming, adults appeared 2 July 1994 and 29 July 1995. For comparison, adults of *M. infantilis* appeared 7 August 1994 and 29 August 1995. Survival of adults of the Kennicott grasshopper was high through August and the first half of September, but declined noticeably by late September. A small number of hardy adults survived into October. Sampling of the population in 1995 showed that in 200 semicircular sweeps of a 15-inch diameter insect net, an average of 3 adults were captured in August but by 18 September only one adult was captured.

Females caged with males oviposited into containers of bare soil. Pods were curved and 3/4 to 1 inch long. Three pods

Male



6. BL 15.5-17.5 mm FL 9.7-10 mm AS 23-24.

Female

7. BL 20-32 mm FL 10.5-12.3 mm AS 23-25.

Cercus

8. End of male abdomen showing the cercus.

Crescent

9. Side of head and pronotal lobe showing crescent, instar V.

Eggs

10. Exposed eggs and egg pod.

contained 12 eggs each. Eggs were pale tan and 4.2 to 4.6 mm long (Fig. 10).

Population Ecology

The Kennicott grasshopper maintains a low frequency of occupation of mountain meadows and parklands in Wyoming, as indicated by results of the Wyoming Grasshopper Survey. From 1991 to 1994, 256 sites in the Rocky Mountains were investigated. In only 35 sites was the Kennicott grasshopper collected (14 percent frequency). For comparison, the alpine grasshopper, *M. alpinus*, occupied 83 of the 256 sites (32 percent frequency) and the Bruner slantfaced grasshopper, *B. brunnea*, occupied 95 sites (37 percent frequency). The low frequency of the Kennicott grasshopper is probably a biased account of its presence due to this species' behavior on being disturbed. When flushed, individuals either fly low a short distance or hunker down and become quiescent. Thus, at low densities it may be under sampled by scouts using insect sweep nets. A more reliable method of documenting the presence of the Kennicott grasshopper is to visually search and capture grasshoppers by hand. This method was begun in 2001 in the parkland west of Tie City, Wyoming. In this area in mid September, sampling with an insect net yielded no Kennicott grasshopper specimens in the first 100 sweeps and one female in the second 100 sweeps. However, in two 10-minute search-and-capture samples, four specimens were caught in the first search and three in the second.

Like most pest species of grasshoppers, populations of the Kennicott grasshopper may range numerically between years and among locations. The Wyoming Grasshopper Survey has recorded densities ranging from 0.02 to 12 adults per square yard. The latter density of the Kennicott grasshopper was discovered in 1995 in parkland on the western slope of the Big Horn Mountains (Big Horn County, Wyoming T51N R88W Sec 33 SE). The density of the assemblage of three species was estimated at 36 adults per square yard, *B. brunnea* was dominant at 18 adults per square yard, the Kennicott grasshopper was next at 12 adults, and *Melanoplus bruneri* was last at 6 adults. In 1995 another heavily infested site was discovered. This time in parkland of the eastern slope of the Big Horn Mountains (Washakie County, Wyoming T42N R86W Sec 23 NW) in which the Kennicott grasshopper was the dominant species at 5 adults per square yard in an assemblage of 5 species numbering 15 adults per square yard. No long-term study of these or any sites has been made to determine how many years are needed for the Kennicott grasshopper to reach outbreak densities nor how long outbreaks last.

Important characteristics of local grasshopper populations are the sizes of inhabited areas and the density of individuals. An opportunity to determine these parameters for the Kennicott grasshopper arose in the summer of 2001 in the infested parkland west of Tie City, Wyoming. The area of habitation measured approximately 1 square mile (0.5 x 2 miles). The absolute density was less than 0.1 adult per square yard throughout the inhabited area. Because of the low numbers, relative densities were taken at 12 stops, 0.2 to 0.3 miles apart, along gravel and dirt roads by the 10-minute search-and-capture method. Results showed that the relative densities were highest near the center with 4 to 5 adults and lowest at the edges with 1 adult per 10-minute-search-and-capture. The evidence suggests gradual dispersal from the center and slow expansion of the inhabited area.

Daily Activity

Observations reveal that the Kennicott grasshopper is a highly geophilous species. It rests, basks, feeds, and shelters on the ground. Due to low densities in the study site, field observations were made of adults caught and released in their natural habitat. During basking the adults sit on bare ground or litter, turn a side perpendicular to rays of the sun, and lower the associated hindleg to expose the abdomen (flanking). Air and soil surface temperatures in mountain parklands fall very low during the night at times reaching 35°F. Because cold body temperatures result in cold stupor of grasshoppers, movement from shelters to basking places may not begin until 1 hour after sunrise. Basking lasts from 2 to 3 hours.

To determine how the Kennicott grasshopper responds to high temperature, adults were released in native grassland in an outskirt of Laramie, Wyoming (elevation 7,165 feet). At 11:35 a.m. DST when the soil surface temperature reached 120°F and air 85°F, a female crawled from bare ground to the partial shade of blue grama and reared up diagonally to face the sun directly, thereby minimizing radiant heating. There she remained quiescently, even refusing to flush.

Basking begins again in the afternoon when ground surface temperatures have fallen to 72°F and air temperatures to 60°F. Basking continues until nearly sunset. Close to sunset adults crawl several inches to choose a shelter on the ground that is surrounded by vegetation. They sit horizontally on bare ground or litter and remain quiescent, presumably through the night as it becomes darker and colder.

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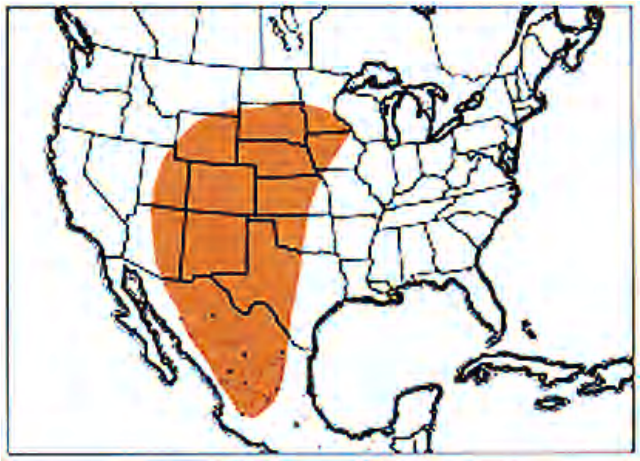
Lakin Grasshopper

Melanoplus lakinus (Scudder)

Distribution and Habitat

The Lakin grasshopper ranges widely in western North America inhabiting several types of grasslands and desert shrub regions. Its occupancy of a site depends on the presence of a good supply of food plants, especially several members of the goosefoot family (Chenopodiaceae). Native host plants include species of *Atriplex* and probably species of other genera. In recent times this grasshopper has been aided in its population growth by the invasion of exotic weeds, principally kochia and Russianthistle. Roadsides and fence rows, as well as weedy rangeland, often harbor large numbers of the Lakin grasshopper.



Geographic range of *Melanoplus lakinus* (Scudder)

Economic Importance

The Lakin grasshopper does not cause much damage to rangeland forage and in certain circumstances may be a beneficial species. Although it has a wide geographic range on western grasslands, its distribution is largely limited to disturbed areas vegetated by preferred host plants of kochia, Russianthistle, and other weeds. It is absent or rare in prairies in good condition, but it thrives in weedy rangeland. A seven-year study (1966-72) on three land types in the Texas Panhandle—shortgrass prairie, revegetated land, and cultivated land—revealed that Lakin grasshoppers were only present in the weedy revegetated land. In 1959, Arizona populations of the migratory and Lakin grasshopper infested weedy rangeland and together averaged 20 to 50 adults per square yard.

During outbreaks the Lakin grasshopper occasionally becomes a pest of alfalfa, wheat, vegetables, and ornamental flowers. Dense populations inhabiting field margins, fence rows, and roadsides may move into crop land and cause severe damage. When border weeds dried up in 1966, an assemblage of the twostriped, redlegged, and Lakin grasshoppers invaded alfalfa fields in Colorado inflicting considerable damage. Weedy city lots provide favorable breeding areas from which the grasshoppers may move into vegetable and flower gardens.

The Lakin grasshopper is a medium-sized species. Collected from a patch of kochia and Russianthistle on 1 August 1996, 8 miles east of La Junta, Colorado, short-winged males averaged 222 mg live weight and females 331 mg (dry wt 62 mg and 97 mg, respectively).

Food Habits

The Lakin grasshopper feeds preferentially on plants in the goosefoot family, Chenopodiaceae. Native host plants include species of *Atriplex* (saltbush) and probably species of other genera in this family. The native plants are prevalent in both grassland and desert shrub habitats and appear to support small populations. The invasion of kochia and Russianthistle in the late 1800s into the West provided the Lakin grasshopper with an abundant and steady supply of nutritious host plants. Observations in a tourist rest area 8 miles east of La Junta, Colorado revealed that the nymphs inhabited patches of kochia in early July 1996 and were feeding almost entirely on the leaves of this plant. At this time, Russianthistle plants were just beginning to grow while kochia plants were 8 to 14 inches tall. A month later nearly all the Lakin grasshoppers were adults and Russianthistle had grown tall enough (10 to 33 inches) to equal kochia in height. From their roosting positions high on these two plants the grasshoppers fed on the young leaves and flower buds.

Examination of crop contents of Lakin grasshoppers collected from a weedy pasture near North Platte, Nebraska showed 94 percent of fragments to be kochia and 1 percent each of lambsquarters, western wheatgrass, and downy brome. In a study of grasshoppers inhabiting desert prairie near Alpine, Texas, crop examinations revealed that Lakin adults were feeding on several species of grasses and forbs, utilizing approximately 40 percent grasses and 60 percent forbs.

Confined in laboratory cages, Lakin grasshoppers fed well on dandelion and young wheat plants. On these host plants, the nymphs survived and developed through the nymphal stage, and the adults matured and reproduced. Surprisingly, in two-choice preference tests, Lakin adults selected greater amounts of dandelion than kochia as their food.

Dispersal and Migration

Populations of the Lakin grasshopper consist mainly of short-winged individuals, a morphological characteristic that limits the species' capability to disperse and migrate. Long-winged forms, however, are not uncommon in populations and as many as 47 percent long-winged individuals have been observed in Arizona in at least one population. The large increase in wing length of macropterous individuals occurs during development of the last or fifth instar, but no external difference in length of the wing pads nor other structural differences exist to identify which nymphs are to become long-winged adults and which short-winged. Mating of long-winged forms among themselves in the laboratory has increased their frequency from less than 4 percent to 39 percent in the F_1 generation.

Studies of movement by short-winged species of grasshoppers indicate that distances traveled vary significantly. For example, short-winged adults of *Phoetaliotes nebrascensis* exhibit daily displacements of 3 to 13 feet and may travel

Instar 1

1. BL 3.9-4.2 mm FL 2.1-2.5 mm AS 12-13.

Instar 2

2. BL 4.9-6.2 mm FL 2.9-3.2 mm AS 15-16.

Instar 3

3. BL 6.9-10 mm FL 4.2-5.9 mm AS 17-20.

Instar 4

4. BL 10-14 mm FL 5.8-7.5 mm AS 19-21.

Instar 5

5. BL 12.5-14.7 mm FL 7.5-9.4 mm AS 21-23.

Figures 1-5. Appearance of the five nymphal instars of *Melanoplus lakinus* - their sizes, structures, and color patterns. Notice progressive development of the wing pads. BL = body length, FL = hind femur length, AS = antennal segments number.

distances of 90 feet or more to reach a better food supply. But a species such as *Hypochlora alba*, which is mainly short-winged and a faithful occupant of its host plant, *Artemisia ludoviciana*, exhibits a shorter daily displacement of 0 to 10 feet. A few individuals, both nymphs and adults, remain on the same plant for an entire day. One fifth instar was observed to remain on its host plant for five consecutive days. Regrettably, a review of the latter significant research by Smith and Grodowitz (1987) was omitted in the fact sheet of H. alba (Pfadt 1996). No similar research of movement of the Lakin grasshopper has been done. Its present distribution, however, provides circumstantial evidence that the species has strong powers of dispersal. The common presence of this species in patches of kochia and Russianthistle growing in roadsides, fence rows, city lots, and other isolated areas suggests dispersal into these sites. Probably long-winged individuals colonize new habitats and start an infestation. In subsequent generations, perhaps because of reproductive advantage, short-winged individuals come to outnumber long-winged individuals.

Identification

The Lakin grasshopper is a medium-sized species, brown with fuscous and yellow markings, and typically with short wings (Fig. 6 and 7). Occasionally a small percentage of a population develops long wings that may extend 1 to 3 mm beyond the apex of the hind femur. The cercus of the male is distinctive (Fig. 9); the base is bulbous and at its posterior edge, carinate, the apical end is finger-like. Arms of the furcula are short, broad basally, and finger-like apically. The medial area of the hind femur is tan with three dark dorsal markings; the lower marginal area of the hind femur is orange, the upper marginal areas are tan with three dark markings. The hind tibia is blue. The venter is frequently yellow or pale tan.

The nymphs are identifiable by their color patterns, shape, and external structures (Fig. 1-5). The head and lobes of the pronotum are noticeably and distinctively striped yellow or tan. In instars I and II the stripes are conspicuous and extend onto the sides of the thorax. In older instars the stripes begin to fade; some may continue to sport stripes while others may lack them except for the crescent.

1. Head in instar I shiny black, yellow or tan line below eye (part of crescent); yellow markings on face; compound eyes with two or three diagonal yellow lines. In instars II to V, head brown or green; crescent yellow or tan, eyes brown with two to three diagonal tan or yellow lines.
2. Pronotal lobes of instars I and II with three curved yellow or tan stripes. Instars III to V may retain the three stripes, but some individuals may have only the crescent stripe.
3. Instar I with medial area of hind femur crossed completely (from top to bottom) by three dark bars.

Figures 6-10. Appearance of adult male and female of *Melanoplus lakinus*, detached wings of male, male cercus, egg pod, and three loose eggs.

In instars II to V three dark bars located in dorsal half of medial area. Tibia pale gray, tan, green, or blue.

4. Body color is black or fuscous in instar I and brown or green in instars II to V.

Hatching

A late-developing species, the Lakin grasshopper begins to hatch three to four weeks after *Melanoplus sanguinipes* and *Ageneotettix deorum*. In 1992 the Lakin grasshopper started to hatch in southeastern Colorado (tourist rest area 8 miles east of La Junta, elevation 4,100 feet) on 1 June while at Cheyenne, Wyoming (elevation 6,100 feet) on 9 June. In 1993 the species began to hatch 10 days earlier than in 1992. At the La Junta site hatching began on 21 May 1993 and in southwestern Kansas (elevation 2,000 feet) on 19 May. Surprisingly, hatching in Chino Valley, Arizona (elevation 4,600 feet) begins usually about July 3, a month later than in any of the northern sites. The difference appears to be due to the timing of seasonal rainfall. In the mixedgrass prairie of Colorado, Kansas, and Wyoming rains are prevalent in spring while in Arizona substantial rains do not fall until the monsoons arrive in summer. Apparently the Lakin grasshopper has adjusted its life cycle in Arizona to fit the regimen of soil moisture. The eggs retain the characteristic of hatching late and remain viable in the dry soil until moisture conditions become favorable, requiring at least 1 inch of rainfall.

No study has been made of egg development in nature. Laboratory research in Arizona has shown that a diapause occurs and that exposure to a cold period is necessary before the eggs complete embryonic development. In nature the hatching period in northern sites appears to extend over approximately five weeks.

Nymphal Development

Because of the extended hatching period in habitats of kochia and Russianthistle patches, all instars of the Lakin grasshopper may be present by early summer. The nymphs inhabit their host plants day and night, adjusting their positions vertically to suit environmental conditions (mainly temperature). Both male and female nymphs develop through five instars to reach the adult stage. In a laboratory study at the University of Arizona, nymphs subjected to favorable temperature varying between 95° and 104°F completed the nymphal stage in 28 days. Duration of the instars was I, 5 days; II, 4.5 days; III, 4.5 days; IV, 5.5 days; V, 8.5 days.

Adults and Reproduction

In southwest Kansas and southeast Colorado the adults begin to appear in early July, but in Chino Valley, Arizona not until mid August. Although maturation of the adults has not been directly studied, several events in the life cycle have been observed. In 1996 at the rest area east of La Junta, Colorado on 5 July, in addition to 79 nymphs, two male and one female adults were captured in sweeping. A mating pair was observed roosting on the host plant, kochia, in this site 30 July, providing evidence of maturation in 25 days or less. No oviposition was observed by 1 August. In southeast Colorado the adults survive for at least two

Male

6. BL 17.5-19.5 mm FL 9.8-11 mm AS 23-26.

Female

7. BL 18.5-22 mm FL 10-12.4 mm AS 23-25.

Wings

8. Detached wings of male.

Cercus

9. End of male abdomen showing cercus, furcula, and subgenital plate.

Egg pod

10. Egg pod and three exposed eggs.

months, August and September. Collection of adults were made from 16 to 19 September 1991 in Kit Carson, Lamar, and La Junta, Colorado. The adults, like the nymphs, spend their whole life on their host plants; only the females appear to come down to the ground in order to oviposit. In a grassland area 30 miles southeast of Tucson, Arizona, a collection of egg pods was made from the crown and upper roots of a bluestem grass, *Andropogon* sp.

The egg pods, deposited by females from La Junta, Colorado into bare soil in the laboratory, were 5/8 to 7/8 inch long, slightly curved, and contained 18 to 22 cream-colored eggs, 3.9 to 4.2 mm long (Fig. 10). In Arizona females oviposit among grass roots and the base of stems. Length of pods is short, 3/8 inch long, and pods contained from 20 to 25 eggs.

Population Ecology

Populations of the Lakin grasshopper often increase to high densities. From 1956 to 1978 the Cooperative Economic Insect Report recorded large numbers of this grasshopper in 11 years out of 13 in the western region, encompassing the states of Colorado, Kansas, Nebraska, Oklahoma, Arizona, and New Mexico. The majority of these records describe the densities of assemblages of grasshopper species. One record, however, made by USDA entomologists in a research project distinguished the densities of individual species. In 1956, an infestation of grasshoppers on rangeland in southern Arizona (San Rafael Valley, south of Tucson) was dominated by the Lakin grasshopper, which numbered 19 young adults per square yard. The entire assemblage of grass- and forb-feeding species numbered 46 per square yard. A report made in 1973 in Grant County, New Mexico, describes an infestation of only the Lakin grasshopper that numbered 12 to 15 adults per square yard.

In the Texas panhandle, the Lakin grasshopper in 1972 outnumbered other species in a study of weedy rangeland and was present in smaller numbers in 1967 and 1970. No specimens were collected in 1966, 1968, 1969, and 1971. Probably the species was present these years, but in numbers too low to be collected by routine sweeping with an insect net. These data indicate that the density of populations of the Lakin grasshopper fluctuate, but give no hint as to causes.

Patches of kochia and Russianthistle foster and support dense populations of the Lakin grasshopper. In the La Junta site on 4 July 1996, nymphs (III to V instars) numbered 91 per square yard. Four weeks later the density of the population, which consisted now mainly of young adults, decreased to 16 per square yard. Observation showed that the number and volume of kochia and Russianthistle patches had increased. The circumstantial evidence indicated dispersal as well as normal mortality of the population.

Daily Activity

Lakin grasshoppers inhabiting patches of kochia and Russianthistle conduct nearly all activities on the host plants, behaving as phytophilous insects. For 24 hours of the day they feed, grow, molt, mate, bask, and roost on the host plants.

In the disturbed site near La Junta, Colorado in July and early August, 1996, Lakin grasshoppers moved vertically on plants in response to environmental conditions. During the night nymphs sat vertically 1 inch below the plant tips, head-up on stems and leaves of kochia. In early July, kochia plants ranged from 8 to 14 inches in height, while Russianthistle plants were just starting to grow. Temperatures during the first week of July were unusually high, reaching 105°F during the early afternoon and decreasing to 70°F by early morning. A month later the majority of nymphs had become adults and both kochia and Russianthistle had grown to 12 to 24 inches in height. During the night the adults rested vertically, head-up on the main and secondary stems 1 to 13 inches below the tips. Temperatures were cooler in early August than in early July with early morning temperatures dipping to 65°F.

One to two hours after sunrise, nymphs and adults climbed and adjusted positions to begin basking in the sun. Oriented vertically and head-up, the majority turned a side perpendicular to the rays of the sun and lowered the associated hindleg. After basking for one to two hours, the grasshoppers backed down 4 to 6 inches. A few crawled with head pointed down, but as soon as they reached the desired lower level, they turned around and faced upward. Many roosted quietly, some stirred and changed position on the host plant, and a few jumped 5 to 6 inches to another host plant.

Feeding began early in the morning from 7 to 8 a.m. when air temperatures ranged from 70° to 75°F. The nymphs fed on the edge of young kochia leaves while adults fed on terminal tissues and leaves of kochia and Russianthistle.

When air temperatures in the afternoon became unusually high, 105°F in early July, the grasshoppers took evasive action. The nymphs rotated on the stems to be in the shade. Further research of the behavior of Lakin grasshoppers is needed to disclose their activities on rangeland.

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Flabellate Grasshopper

Melanoplus occidentalis (Thomas)

Distribution and Habitat

The range of the flabellate grasshopper includes nearly all of the grasslands of the western United States and Canadian provinces. The species inhabits the natural prairies as a common member of grasshopper assemblages. Densities are greatest in the mixedgrass prairie.

Economic Importance

The flabellate grasshopper feeds on grasses and forbs. It competes for food with both cattle and sheep, because cattle are generally graminivorous and sheep forbivorous. By itself the species rarely reaches an economic level of eight individuals per square yard, but it frequently contributes one to three adults per square yard to heavy infestations of rangeland grasshoppers. Adult weights are at the light end of the large third of grasshopper size. Collected in Big Horn County, Wyoming, 22 July 1993, males averaged 280 mg live weight and females 567 mg. (dry weight: males 86 mg, females 174 mg).

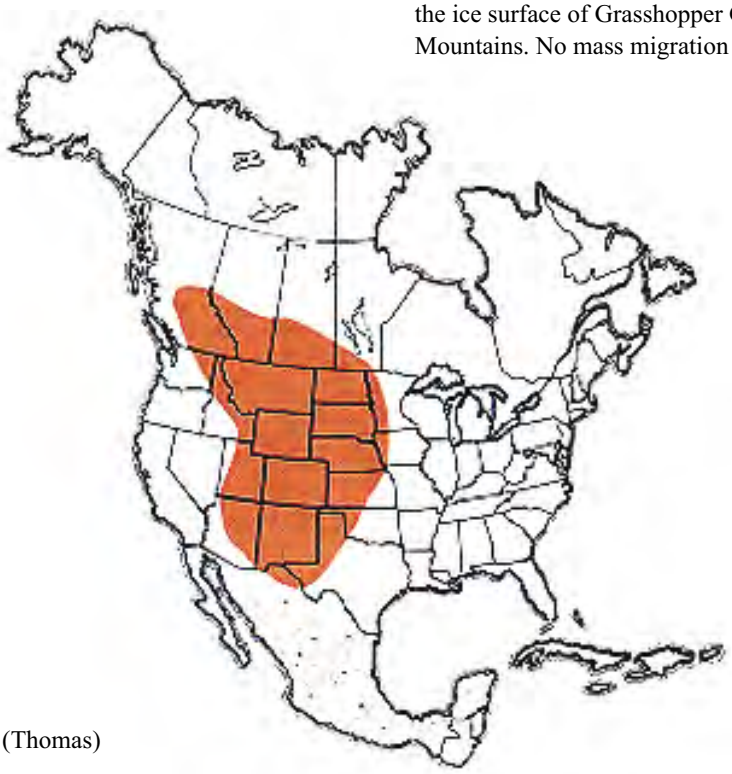
Food Habits

The flabellate grasshopper is a polyphagous insect. It feeds chiefly on the leaves of forbs but it also consumes substantial amounts of grasses, moss, roots, seeds, and dying or dead arthropods. Crop contents of grasshoppers collected in the mixedgrass prairie of Nebraska and Wyoming consisted of 70 to 90 percent forbs, 8 to 15 percent grasses, and 1 to 10 percent arthropod parts. Favored host plants are scarlet globemallow, wildbuckwheat, and milkvetch. Grasses on which it is known to feed include blue grama, needlandthread, western wheat-grass, and bluegrasses. It also consumes needleleaf sedge.

The flabellate grasshopper feeds both while on the ground, ingesting moss and litter, and on plants, climbing to feed on leaves and bark.

Migratory Habits

The flabellate grasshopper is a strong flier with long wings extending to or beyond the end of the abdomen. Relatively frequent “accidentals” of this species have been found above 7,000 feet in the Rocky Mountains of Colorado. In Montana two long-winged individuals, a male and a female, were collected from the ice surface of Grasshopper Glacier in the Crazy Mountains. No mass migration of the flabellate



Geographic range of
Melanoplus occidentalis (Thomas)

Instar 1

1. BL 3.8-4.9 mm FL 2.6-2.9 mm AS 13.

Instar 2

2. BL 5.7-6.5 mm FL 3.6-3.9 mm AS 15-16.

Instar 3

3. BL 6.1-8.6 mm FL 4.5-5.6 mm AS 18-19.

Instar 4

4. BL 9.4-13.3 mm FL 6.8-7.4 mm AS 21.

Instar 5

5. BL 15-16.5 mm FL 8.4-10.2 mm AS 22.

Figures 1-5. Appearance of the five nymphal instars of *Melanoplus occidentalis* - their sizes, structures, and color patterns. Notice progressive development of the wing pads. BL = body length, FL = hind femur length, AS = antennal segments number.

grasshopper has been observed but it appears likely that such behavior occurs.

When flushed, flabellate grasshoppers fly distances of 2 to 7 feet at heights of 3 to 6 inches. The evasive flight is straight, silent, and usually across the wind.

Identification

Adults of the flabellate grasshopper are brightly colored (Fig. 6 and 7). The lower and inner surfaces of the hind femora are bright orange. The hind tibiae are light blue. The middle fuscous patch on the medial area of the hind femur is V-shaped. The cercus of the male is diagnostic, appearing ear-like or fan-shaped (Fig. 9). The latter description of the cercus gives this grasshopper its common name (flabellate = fan-shaped). The body is gray with bright orange patches. The wings are long, reaching the end of the abdomen or extending beyond.

The nymphs (Fig. 1-5) are identifiable by their shape, spots, and color patterns:

1. Head with face nearly vertical and solid tan or green; frontal costa sometimes darker (Fig. 8); antenna filiform; compound eye spotted and with a diagonal fuscous line on posterior half near middle (See Figure 5 for clear illustration).
2. Prominent cream colored crescent beginning on gena below compound eye and running onto pronotal lobe.
3. Hind femur with fuscous stripe interrupted (cut completely across) three times.
4. Body brightly colored gray, tan, or green; underside of body pale gray.

Many of the described nymphal characters of *M. occidentalis*, *M. infantilis*, and *M. gladstoni* are similar, yet nymphs of these species can be separated easily by color and by their seasonal appearance. The venter (ventral side of both thorax and abdomen) of nymphs of *M. occidentalis* is pale gray, while the venter of nymphs of *M. infantilis* is usually white and of *M. gladstoni* usually bright yellow. Nymphs of *M. occidentalis* and *M. infantilis* are present in the grasshopper assemblage early in the season along with nymphs of *M. sanguinipes* and *M. packardii*, while those of the *M. gladstoni* are present late when all four of the former species are adults.

Figures 6-10. Appearance of the adult male and female of *Melanoplus occidentalis*, diagnostic characters, and the egg pod and eggs.

Hatching

Eggs of the flabellate grasshopper hatch in mid-spring at almost the same time as the bigheaded, striped, and spottedwinged grasshoppers with which it consorts. The period of hatching lasts approximately 25 days.

Nymphal Development

The flabellate grasshopper passes through five instars, becoming an adult in 40 to 45 days. Nymphal development proceeds at approximately the same rate as the bigheaded grasshopper. As with most grasshoppers the adult males appear before the females.

Adults and Reproduction

Adults of the flabellate grasshopper remain in the same habitat in which the nymphs hatch and develop. This habitat of the mixedgrass prairie continues to furnish green host plants for their food and a favorable place for them to live and reproduce. Observations of their courtship have not been made. Mating pairs, however, have been observed frequently during the morning, as early as 30 minutes after sunrise, and less often in the afternoon.

About two weeks after fledging, the female deposits her first clutch of eggs. She selects a bare spot and works her ovipositor into the soil to a depth of approximately 1 inch. She deposits eight to ten eggs, which lie in two columns at depths between one-half inch and 1 inch. Upon withdrawing her abdomen she briefly brushes soil over the exit hole with her ovipositor and walks away. A female will continue to reproduce for the length of her short life. The fecundity of females is unknown. There is one generation annually.

The pod is 1 inch long and one-eighth inch in diameter (Fig. 10). The bottom half contains the egg mass and is curved. The top half, vertically oriented just below the surface of the soil, is dried froth. Eggs are pale yellow and 4.5 to 5.3 mm long.

Population Ecology

Populations of the flabellate grasshopper fluctuate in a habitat with time. In a favorable habitat of mixedgrass prairie in Wyoming, densities ranged from 0.1 to 7.3 adults per square yard over a period of 10 years. During half of this time the population was below one adult per square yard. In some habitats of the mixedgrass prairie this species appears to be absent, as is often the case in Montana.

Male

6. BL 19.2-21 mm FL 10.2-11.4 mm AS 24-25.

Female

7. BL 22-24 mm FL 11.5-12.6 mm AS 24.

Faces

8. Front of head of nymphal flabellate grasshoppers.

Cercus

9. Cercus of adult male flabellate grasshopper.

Egg pod

10. Egg pod (bottom at right) and four eggs.

Daily Activity

The flabellate grasshopper is a diurnal insect being inactive at night and active during the day. Both nymphs and adults rest horizontally on bare ground at night. They move to basking positions, usually with their side perpendicular to rays of the sun, about 45 minutes after sunrise. They bask for about two hours before they start their normal activities of pottering, feeding, and egg laying. At this time temperatures have risen to about 70°F (air) and 90° to 100°F (soil). Activity ends when temperatures in midsummer reach 90°F (air) and 130°F (soil). Flabellate grasshoppers, adult by this time, climb small shrubs to heights of 3 to 6 inches and rest in the shade. When temperatures decline in late afternoon, they return to normal activities. Two hours before sunset, with further decline in temperature, they again begin basking. As the sun begins to set and shadows cover the ground, they assume their nocturnal resting positions.

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Packard Grasshopper

Melanoplus packardii Scudder

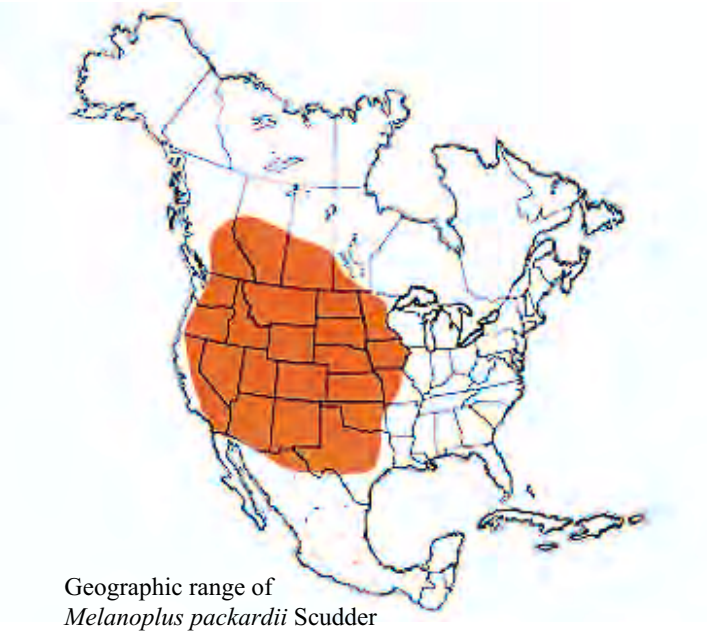
Distribution and Habitat

The Packard grasshopper ranges widely in western North America. It is primarily a rangeland species inhabiting the tallgrass, shortgrass, mixedgrass, bunchgrass, and desert prairies. The species also lives in ruderal habitats and has become recognized as an important cropland grasshopper. It reaches high densities in the northern part of its geographic range and lives in mountain meadows at altitudes as high as 9,000 feet.

Economic Importance

Because of its usual low densities on rangeland and its preference for poor forage plants, such as the scurfpeas, the Packard grasshopper in its natural habitat causes little damage. Nevertheless, in the northern region of the mixedgrass prairie, the Packard grasshopper is an important member of the rangeland assemblage, and it is often second in density after the dominant species, *Melanoplus infantilis*.

This grasshopper has adapted well to cropland and ruderal habitats including roadsides, fence rows, edges of cultivated fields, abandoned farm land, and Conservation Reserve Program land. In certain years it develops large populations that cause serious damage to small grains and alfalfa. Grasshopper surveys conducted in cropland areas of Saskatchewan from 1931 to 1966 reveal that the Packard grasshopper often adds substantially to the damage of cereal crops as an important member of an assemblage along with *Melanoplus sanguinipes* and *M. bivittatus*. In certain years the Packard grasshopper is the dominant species, making up 50 percent of the total population. As one moves south the Packard grasshopper becomes less important. It is mentioned as a minor pest in Kansas, although in Oklahoma it has been recorded as damaging cotton, vegetables, small grains, and legumes. The Packard grasshopper is a large species. Live weight of males and females collected from rangeland and roadsides in eastern Wyoming averaged 571 mg and 639 mg, respectively (dry weight: males 141 mg, females 208 mg).



Geographic range of *Melanoplus packardii* Scudder

Food Habits

The Packard grasshopper feeds on both forbs and grasses. Examinations of crop contents of grasshoppers collected from the mixedgrass and shortgrass prairies indicate that the scurfpeas, *Psoralea tenuiflora* and *P. esculenta*, are fed upon preferentially. Although the contents of the majority of crops consist of more than one species of plant, a sizeable number consist of only fragments of scurfpea. Several other legumes that grow in the mixedgrass prairie serve as host plants including Missouri milkvetch, woolly loco, and peavine (*Lathyrus polymorphus*). When available in improved grassland, sweetclover and smooth brome serve as preferred host plants.

A total of seven grasses and 26 forbs have been recorded from crops of Packard grasshoppers collected from the shortgrass and mixedgrass prairies. The average consumption of forbs from both mixedgrass and shortgrass prairies equaled 85 percent, while grasses equaled 7 and 13 percent, respectively. Among seven grasses found in crop contents, blue grama, sand dropseed, and needleandthread were present in greatest amounts. The Packard grasshopper also fed on ground litter including dead arthropods. In ruderal habitats a variety of weeds serve as host plants including brome grasses, sweetclover, prickly lettuce, western ragweed, and sunflower. In cropland this grasshopper has fed upon winter wheat, barley, fall rye, and alfalfa.

Several direct observations have been made of feeding. On July 11, 1990 at 10 a.m. DST one female was seen crawling on the ground, then stopping to feed a few seconds on plant litter. She then moved to a small peavine plant and reached up her full length to feed on a leaflet. In a roadside habitat, a male (oriented vertical head up) and a female (oriented vertical head down) were observed feeding on the petals of yellow sweetclover. A female on the ground was observed to feed on a dead darkling beetle. In a study area of the mixedgrass prairie, two females on the ground surface were observed feeding on an unidentified small lichen growing among moss.

Dispersal and Migration

The Packard grasshopper is a strong flier possessing long wings. In Colorado where the species is regularly resident up to 8,500 feet, “accidentals” have been found at altitudes in excess of 11,000 feet, evidently dispersing a minimum of 10 miles in one season. Further evidence for dispersal consists of the discovery of five males and eight females on the ice of Grasshopper Glacier in the Crazy Mountains of Montana. These may have originated in a mountain meadow about one mile below the glacier where a resident population lived at an altitude of approximately 9,000 feet. But it is also possible that they originated from a distant area along with *M. sanguinipes* and *Aulocara elliotti*, which were also present on the glacier.

Instar 1

1. BL 4.6-5.6 mm FL 2.7-3.1 mm AS 13.

Instar 2

2. BL 5.1-7.3 mm FL 3.4-4.1 mm AS 17-18.

Instar 3

3. BL 7.9-10 mm FL 5.6-6 mm AS 19-21.

Instar 4

4. BL 14-18.7 mm FL 8.2-10.2 mm AS 22-24.

Instar 5

5. BL 19-25.7 mm FL 10.8-13.5 mm AS 24-26.

Figures 1-5. Appearance of five nymphal instars of *Melanoplus packardii* - their sizes, structures, and color patterns. Notice progressive development of the wing pads. BL = body length, FL = hind femur length, AS = antennal segments number.

Identification

Of the three size divisions of grasshoppers, the Packard grasshopper is in the large category. It is, however, smaller than the two largest species of *Melanoplus,* the twostriped grasshopper and the differential grasshopper. The adults have bright color patterns of tan, brown, and yellow (Fig. 6 and 7). Two conspicuous light tan stripes run down the occiput of the head and disk of the pronotum (Fig. 8). Wings are long, reaching to at least the end of the abdomen and extending as much as 6 mm beyond. The hind tibiae are red or blue. The male possesses diagnostic characteristics of the species: the cerci are spatulate (Fig. 9) and the lobes of the aedeagus project nearly equally (Fig. 11). This species cannot be separated with certainty from *M. foedus* without exposing the aedeagus, accomplished by lifting and moving the pallium back. The supraanal plate narrows gradually to the pointed end. In a collection of grasshoppers one may identify the females by associating them with the males using size, markings, and color. The nymphs are identifiable by their structures, color patterns, and shape (Fig. 1-5).

1. Head with face nearly vertical; color of head in instars I and II greenish tan, instars III to V green; heads of all instars sparsely spotted brown; compound eye fuscous with many light spots; antennae filiform and fuscous, each segment ringed anteriorly pale yellow.
2. Pronotum with lateral lobes greenish tan in instar I, greenish tan or green in instar II, green in instars III to V; lateral lobes with few to many brown spots in all instars; disk of pronotum somewhat darker than the lobes and spots more dense.
3. Outer medial area of hind femur with three to four rows of spots, first row of spots (below upper carinula) separate, not coalescing into lines. Hind tibia pale gray in instar I, pale green in instar II, green in instars III to V; tibia with front edge fuscous in all instars.
4. General color: instar I greenish tan, instar II green or greenish tan, instars III to V green, occasionally tan.

Hatching

The Packard grasshopper is an early-hatching species. First instars appear in the mixedgrass prairie at the same time as those of the bigheaded grasshopper, *A. elliotti*. Although eggs of the Packard grasshopper lie deeper in the soil than eggs of the bigheaded grasshopper and receive less heat in spring, they hatch at the same time due to their advanced development in fall. In nature, diapause of eggs is broken during winter and only a few days of warm ground temperatures are required for an embryo to reach the final embryonic stage 27, which then must wait for hatching thresholds of temperature and moisture.

In the mixedgrass prairie of eastern Montana and Wyoming, eggs of the Packard grasshopper hatch from May

Figures 6-10. Appearance of the adult male and female of *Melanoplus packardii*, dorsal view of head and pronotum, end of male abdomen, and egg pod and eggs.

to early June depending on seasonal weather. In different years first instars may appear as early as May 1 or as late as May 30.

Nymphal Development

Nymphs develop at nearly the same rate as the bigheaded grasshopper. Based on dates of first appearance of nymphs and adults in the mixedgrass prairie, the nymphal period of the Packard grasshopper ranges from 47 to 63 days. Both males and females develop through five instars to become adults. Rearing nymphs in the laboratory at constant temperatures has shown that the Packard grasshopper completes the nymphal period in 47 days at 77°F and in 70 days at 70°F.

Adults and Reproduction

Although emigration of some adults may occur, the majority remain in the same habitat in which the nymphs develop. In the mixedgrass prairie of Colorado, Wyoming, and Montana, both male and female adults begin to appear in early July. Only a few observations have been made of maturation and reproduction of this species. In a study site of the mixedgrass prairie in eastern Wyoming the first adults of both sexes were seen 11 July 1990. Courting by a male was observed on 30 July 1990, approximately 20 days after adults began to emerge. The first observation of oviposition was made 16 August 1990, 36 days after adults began to emerge; however, examination of ovaries indicates a maturation period of 21 days.

Longevity of adults is relatively long, as decline of densities in summer are almost imperceptible. An average adult longevity of 50 days has been estimated from sampling populations in the mixedgrass prairie. A large part of the adult population of the Packard grasshopper lives through the months of August and September.

Females oviposit in bare ground and lay a clutch of 16 to 29 eggs. Laboratory rearing of adult Packard grasshoppers resulted in an average fecundity of 153 eggs per female at 33°C and 94 eggs at 27°C; the average numbers of pods was 7.7 and 4.8 per female, respectively.

The pod is slightly curved and 1 1/4 inches long and 3/16 inch in diameter (Fig. 10). The eggs lie in the bottom 3/4 inch; froth occupies the top part of the pod. Eggs are tan and 4.7 to 5.1 mm long.

Population Ecology

Small numbers of the Packard grasshopper commonly inhabit grasslands of the West. Densities usually range from less than 0.1 to 0.4 per square yard. Sampling in the mixedgrass prairie of eastern Wyoming indicates that although the species is one of the least abundant members of the rangeland grasshopper assemblage, it persists from year to year at low densities and does not track the fluctuations of the dominant species or that of the assemblage (Table 1).

However, the Packard grasshopper's abundance in Alberta and Saskatchewan and its residency in meadows of the Rocky Mountains at relatively high altitudes indicate a center of distribution for the species in the colder regions of its geographic range. A summary of relative densities from 1928-44 in a mixedgrass prairie of southeastern Alberta shows

Male

6. BL 27-32 mm FL 13.8-15.5 mm AS 25-27.

Female

7. BL 32-35.5 mm FL 15.5-18 mm AS 25-27.

Dorsum

8. Dorsal view of head and pronotum of a female.

Cercus

9. End of male abdomen showing cercus and supraanal and subgenital plates.

Egg pod

10. Egg pod and exposed eggs in bottom of broken pod.

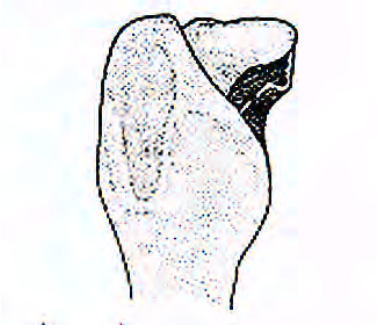


Figure 11. Shape of male aedeagus, view of left side. Drawing by Arthur R. Brooks.

that populations fluctuate and that in certain years the species may occur in outbreak numbers, but no absolute densities are available for these populations.

A Montana study ascertained that the Packard grasshopper occupied nine of 38 sites in the mixedgrass prairie and in one site, consisting of 19 species with a density of 10 grasshoppers per square yard, it was second in abundance to *M. infantilis*. The same study found the Packard grasshopper occupied eight of 11 abandoned fields. In one of the sites the Packard grasshopper was the dominant species at approximately five per square yard.

In ruderal habitats and cropland the Packard grasshopper may be a serious pest. The ecological changes brought about by crop agriculture have created ideal habitats for no less than six species of grasshoppers including the Packard grasshopper. Crop damaging outbreaks in Alberta and Saskatchewan have often consisted of three species: the Packard grasshopper, the migratory grasshopper *M. sanguinipes*, and the twostriped grasshopper *M. bivittatus*. In certain localities the Packard grasshopper becomes the dominant species, but more often the migratory grasshopper is dominant, the twostriped is second, and the Packard is third. Factors that appear to have made ruderal tracts more favorable for these species include the formation of better egg-laying sites of drift soil and south-facing slopes, and the introduction of succulent weeds and cereal crops that serve as reliable, abundant, and nutritious sources of food. Estimates based on relative densities indicate that the Packard grasshopper may increase to six adults per square yard in weedy roadsides.

Daily Activity

In its natural habitat in the mixedgrass prairie, the Packard grasshopper spends most of its time on the ground. Nights are passed resting horizontally on the ground surface on bare soil or litter. Early in the morning before the sun has risen, late instar nymphs and adults may sit under canopies of grasses or close to vegetation. A few individuals rest vertically, head up, on stems of slimflower scurfpea and silver sagebrush at heights of 8 to 12 inches.

As soon as the rays of the sun strike their resting places, the grasshoppers orient a side perpendicular to the rays and may tilt in the direction of the sun and lower a hindleg to expose more of the abdomen. Individuals that have spent the night on vegetation turn their back or a side to the sun. After basking for two to three hours (soil surface temperatures usually have risen to 80°F and air temperatures to 70°F), the grasshoppers become active. A few adults may become active sooner in courting and mating activities.

When temperatures become too hot, soil above 120°F and air above 90°F, grasshoppers cease activities and take evasive actions. They climb vegetation and rest vertically, head up, 2-10 inches high. They may spread their flexed hindlegs and hold onto a grass stem or leaves with their fore and midlegs. There has been one observation of basking in the evening at 4:55 p.m. DST in which an adult male and female resting on the ground turned their sides perpendicular to the rays of the sun.

Table 1. Population fluctuations of grasshoppers in a mixedgrass prairie site of eastern Wyoming (Platte County). P = present but not found in 200 1-square foot samples.

	Number per square yard						
	1968	1969	1970	1971	1972	1973	1974
Melanoplus packardii	0.1	0.1	0.1	0.1	0.2	P	0.2
Ageneotettix deorum	3.4	2.2	0.8	1.2	0.8	1.3	3.3
Assemblage of 19 species	12.8	6.1	2.9	5.6	4.0	3.3	10.5

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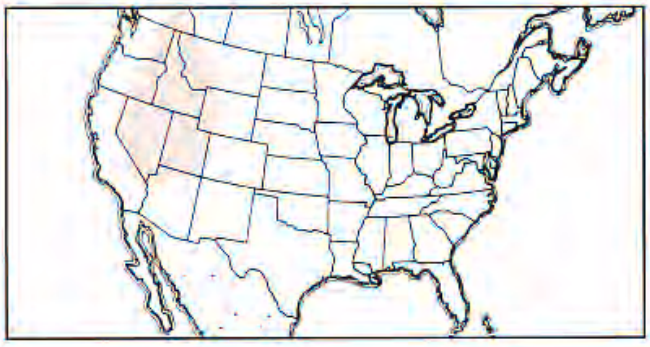
Nevada Sage Grasshopper

Melanoplus rugglesi Gurney

Distribution and Habitat

The Nevada sage grasshopper inhabits the deserts of the far West. It is distributed mainly in Nevada and Utah, but also occurs in adjacent states and the province of British Columbia. The preferred location of the species is in cold desert shrub areas where a variety of shrubs dominate the flora with several subdominant forbs and grasses growing in the understory. These diverse plants appear to serve as food at different times in the season for the Nevada sage grasshopper.



Geographic range of *Melanoplus rugglesi* Gurney

Economic Importance

High densities of nymphs (100 to 3,000 per square yard) and of adults (no absolute figures available) during the outbreak of 1938-51 in Nevada caused serious damage to shrubs, the dominant vegetation in the habitat of the Nevada sage grasshopper. The grasshoppers defoliated, barked, and killed host plants. Eleven species of native shrubs were fed upon, as well as forbs and grasses. The grasshoppers disrupted the natural biodiversity of the plant community by killing the shrubs and opened the land to soil erosion and invasion of noxious weeds. Extensive damage to vegetation reduced the amount of winter forage for livestock and wildlife. Several cases of severe damage to big sagebrush, budsage, and silver sagebrush occurred. Additionally, soils within and adjacent to the egg beds were denuded by the feeding of nymphal bands. Despite attempts to control outbreaks of this pest grasshopper, populations persisted for years. In Nevada the outbreak that began in 1938 lasted until 1951, a total of 14 years, while in western Utah an outbreak that began about 1989 did not end until 1996, a total of seven years.

Swarms in Nevada that landed in garden crops completely destroyed plantings of corn, lettuce, onions, radishes, beets, and potatoes. The grasshoppers were not recorded as entering grain fields, but invasion of alfalfa and sweet clover fields caused minor damage.

The Nevada sage grasshopper is a medium-sized species. The live weight of eight migratory phase males collected in Millard County, Utah in 1995 averaged 290 mg and eight females 565 mg (dry weight of males 96 mg, females 186 mg). Live weight of two solitary males collected in Millard County, Utah in 1998 averaged 264 mg and five solitary females 552 mg. Differences in live weight between migratory and solitary grasshoppers of the same sex were statistically insignificant.

Food Habits

Observations of feeding of the Nevada sage grasshopper during the Nevada outbreak of 1938-51 revealed that migratory phase nymphs and adults were primarily shrub feeders. Of the shrubs attacked, five were preferred: big sagebrush (Artemisia tridentata), black sagebrush (A. nova), Douglas rabbit brush (Chrysothamnus viscidiflorus), spiny hopsage (Grayia spinosa), and shadscale (Atriplex confertifolia). Five less preferred shrubs included silver sagebrush (A. cana), bud sagebrush (A. spinescens), littleleaf horsebrush (Tetradymia glabrata), antelope bitterbrush (Purshia tridentata), and gray rabbitbrush (C. nauseosus). In addition, sporadic feeding was observed on 14 forbs and five grasses. Heavy feeding, however, occurred on downy brome, a common and abundant invader plant of western deserts.

An interesting observation was made in the desert of Millard County, Utah of a solitary phase female that fed upon scarlet globemallow. On 19 June 1998, 10:34 a.m. DST (soil surface 105° F, air 68° F, clear), this grasshopper hopped from the ground onto globemallow and crawled around the plant tasting leaves and stems. It finally tasted and fed upon a young fruit for 9 minutes and then hopped back to the ground. This observation prompted examination of eight globemallow plants, all of which exhibited grasshopper injury to leaves, flowers, stems, and fruits. As the Nevada sage grasshopper was the only species of grasshopper feeding on forbs and shrubs inhabiting the site, its feeding on scarlet globemallow, a common plant in the Utah desert, provided evidence that this plant may be an important host.

Unexpected results were obtained in laboratory food preference tests of the Nevada sage grasshopper involving 12 species of plants (two-choice tests). Four plants were preferred: young wheat leaves, dandelion, downy brome, and white sage (Ceratoides lanata). The ubiquitous downy brome, green in spring but dry and brown in summer, may serve as an important host plant for the nymphs. Seven less-preferred (less eaten) species were big sagebrush, gray rabbitbrush, scarlet globemallow, Gardner saltbush, kochia, alfalfa, and barley. One species, tansy mustard, was not fed upon at all.

A definitive study of the food habits of the Nevada sage grasshopper has yet to be made. Results of the food preference tests and several field observations of feeding by adults and of damage by nymphs (dense bands of gregarious nymphs baring the ground of vegetation) provide evidence that the Nevada sage grasshopper is not solely a feeder of shrubs. Like dense hordes of several other species of grasshoppers, they exploit nearly all plants in the habitat rather than starve for lack of a preferred food. Shrubs appear to be a second choice of the Nevada sage grasshopper.

Instar 1

1. BL 4.2-5.2 mm FL 2.3-2.4 mm AS 12.

Instar 2

2. BL 4.9-7.5 mm FL 3.5-3.7 mm AS 14-15.

Instar 3

3. BL 6.6-9 mm FL 4.2-5.4 mm AS 18-19.

Instar 4

4. BL 10-11 mm FL 6.4-8 mm AS 20.

Instar 5

5. BL 15-18.5 mm FL 8.7-10.5 mm AS 22-23.

Figures 1-5. Appearance of the five nymphal instars of *Melanoplus rugglesi* - their sizes, structures, and color patterns. Notice progressive development of the wing pads. BL = body length, FL = hind femur length, AS = antennal segments number.

Dispersal and Migration

Dense populations of the Nevada sage grasshopper are extremely migratory. In Nevada in the summer of 1948, close observations revealed that swarms of adults traveled 2 to 4 miles in a day and from 40 to 75 miles during a season. After feeding in the morning, adults began migration whenever conditions were favorable for flight: clear sky, minimum temperatures of 70° F air and 85° F soil, and air movement of about 2 mph. A wind of 15 mph held swarms on the ground. The first flights of young adults were erratic and short and were interspersed with periods of crawling and resting. After several days of undirected flights, swarms began to move as coherent groups chiefly in a northerly direction and at heights of a few hundred feet. One closely observed swarm moved about 2 miles each day and traveled a total distance of 40 miles. Another swarm was observed to have flown a record distance of 15 miles in one day. Daily termination of flights was not observed. Swarms may be lifted several thousand feet in the air by warm summer updrafts. Sudden strong winds aloft may then transport the grasshoppers long distances. The presence of specimens of this grasshopper on Grasshopper Glacier in Montana in 1949 suggested that a long flight had occurred; the closest outbreak population in that year was in southwestern Oregon 600 miles west of the glacier.

Flushed adults of dense populations have been observed to fly off beyond the observer's vision, but flushed adults in sparse populations usually fly short distances of 1 to 9 feet and at heights of 4 to 18 inches. The adults take off from the ground and usually land on the ground. They fly silently and straight but a few may turn at a right angle near the end of flight. The grasshoppers fly at various orientations to the wind: into the wind, with the wind, and crosswind.

Like the adults, the nymphs of the Nevada sage grasshopper have notable migratory habits. Observations of their migrations were made in 1948 in Nevada. The young nymphs, instars I to III, moved erratically and independently of one another. The older nymphs, instars IV and V, migrated as coherent bands and usually moved northerly in the same direction as the previous year's adults. One band of nymphs was observed to have traveled 200 yards in one day and one-half mile in two weeks.

Identification

The Nevada sage grasshopper is a brightly colored species (Figs. 6-8). The inner and lower areas of the hind femur are bright orange. The upper marginal and medial areas are tan and crossed transversely by three dark bars. The middle bar of the medial area is usually chevron-shaped. The hind tibia is blue. Diagnostic characters of the species are the

Figures 6-10. Appearances of the adult female and solitary and migratory males of *Melanoplus rugglesi*, cercus, and egg pod and exposed eggs.

large size and quadrate shape of the male cercus (Fig. 9) and the corkscrew twist of the lateral appendage of the aedeagus. In the closely related *Melanoplus occidentalis,* the cercus is slightly smaller and triangular with apex evenly rounded and the lateral appendage of the aedeagus is straight (needle-shaped).

Adults possess long wings that extend 1 to 7 mm beyond the apex of the hind femur. Ashley Gurney described this grasshopper in 1949 and named it in honor of the late professor of entomology, Arthur G. Ruggles, University of Minnesota. Gurney recognized solitary and migratory phases that differ in body size and wing length with the migratory individuals having larger bodies and longer wings. Small differences in the color of adults exist between the phases. Markings of pronotum and hind femur of solitary adults tend to be gray rather than the bright orange of migratory adults.

The nymphs are identifiable by their structures color, and shape (Fig. 1-5).

1. Head with face nearly vertical, and colored usually solid tan, antennae filiform; compound eye with diagonal dark bar, light bar on each side of dark bar that extends nearly full width of eye; dorsal area of eye with relatively few large pale tan spots, ventral area with numerous small dark spots.
2. Prominent white or cream-colored crescent beginning on gena below compound eye and extending onto pronotal lobe.
3. Medial and upper marginal areas of hind femur crossed by three alternating dark and light bars. Hind tibia gray and fuscous.
4. Body marked by black stripes and cream and tan patches.

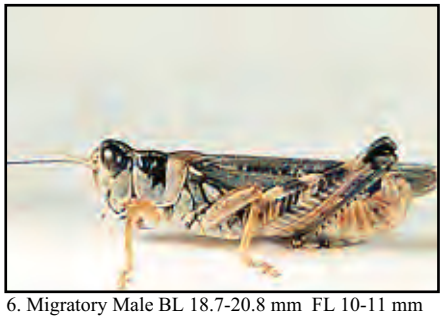
Hatching

The Nevada sage grasshopper is an early-hatching species. Observations made in Nevada from 1940 to 1951 revealed that hatching began in years of normal weather as early as April 10. In a warm year in Smoky Valley, Nye County, Nevada, hatching began 1 April, 1938. Below normal temperatures delay hatching as much as 20 days. In 1998 in western Utah (Millard County, Steamboat Pass, elevation approximately 4,800 ft.) hatching was calculated to have begun on April 19 and continued until May 14. The hatching period ranged from two to three weeks.

Nymphal Development

In the field the Nevada sage grasshopper develops through five instars and becomes an adult in approximately six weeks. Because of the early hatch, the grasshoppers are exposed at times to periods of cold weather which cause delays in their development. Reared in the laboratory at a constant 90° F, the

Male



6. Migratory Male BL 18.7-20.8 mm FL 10-11 mm AS 22-24.

Male

7. Solitary Male BL 19.5-21 mm FL 10-11.3 mm AS 23-24.

Female

8. BL 23-28.5 mm FL 12-13.5 mm AS 24.

Cercus

9. End of male abdomen showing the cercus, tiny furcula, and subgenital plate.

Egg pod

10. *M. rugglesi* egg pod and three exposed eggs.

Nevada sage grasshopper developed at the same rate as *M. bivittatus* and *M. sanguinipes,* approximately 23 days.

Adults and Reproduction

The first adults of the Nevada sage grasshopper may appear as early as mid May or as late as mid June. A population near Carson City, Nevada (elevation 4,675 ft) on 19 May 1943 consisted of 60 percent nymphs and 40 percent adults; 75 miles north at Sand Pass, Nevada first adults did not appear until 15 June 1948. In Millard County, Utah, a population on 2 June 1995 consisted of 81 percent nymphs and 19 percent adults.

Maturation was studied in the laboratory beginning with adults newly emerged on June 12 to 15, 1995. Source of the nymphs was a population of the migratory phase infesting Millard County, Utah. Two males and seven females were confined in a large cage (11 3/8 in cubed) furnished with a 15 W incandescent bulb turned on during the day and off at night. Day temperatures averaged 82° F and night 72° F. Eight days after becoming an adult a male was observed attempting to mate, but mating was not observed until the 11th day. After 21 days of adulthood, the first egg pod was sifted from the oviposition tray.

Observations of life history made in Smoky Valley, Nye County, Nevada in 1938 revealed eggs of the Nevada sage grasshopper hatching on April 1. By the third week in May practically all of the grasshoppers were adult. Two weeks later (June 1) egg deposition began and continued until the latter part of July when few adults survived. The eggs overwintered and hatched the following spring. The eggs are pale yellow or pearl gray and 4 to 5 mm long. Pods are 1 to 1 3/4 inches long, and contain from 14 to 25 eggs (Fig. 10).

Population Ecology

Ecological studies of the Nevada sage grasshopper have been limited mainly to outbreak populations. Early in adult life, the grasshoppers in dense populations begin to migrate 2 to 4 miles each day. In 1948 a closely monitored swarm located a few miles southwest of Denio, Nevada and measuring 2 miles wide and 8 miles long, began to migrate north early in July at a rate of 2 miles per day. The swarm traveled a total distance of 40 miles crossing into Oregon and colonizing an area on the eastern shore of a dry lake on July 21. There the grasshoppers lived out the rest of their lives. Published articles do not mention any dropouts from the migrating swarms. It is likely, however, that dropouts occur especially toward the end of the migratory period when some of the older females become gravid. These dropouts appear to disperse the species over wide areas of western deserts. Once a population increases to outbreak numbers, it survives at high densities for a relatively long time. In Nevada an outbreak continued for 14 years from 1938 to 1951; in Millard County, Utah an outbreak continued for a minimum of 7 years from 1989 to 1995, ending only because of a severe drought. Evidently the migration into new habitats each year safeguards the grasshoppers from buildups of predators and pathogens.

Sparse populations of the Nevada sage grasshopper have been briefly studied in Millard County, Utah. Densities of six populations observed along a 30-mile transect south and east of Sevier Lake in 1998 were estimated to range from less than one to one young adult per square yard. The grasshopper's high frequency of occurrence indicated a low density infestation of 250 square miles; perhaps under favorable conditions the grasshoppers will again increase to outbreak proportions. This area was infested by the outbreak of 1989-95, which ended when a severe drought began in July 1995 and lasted through 1996. The nymphs were not observed in the spring of 1996. Presumably most of the eggs laid in the summer of 1995 desiccated and died from lack of water. A few eggs evidently survived in drainages, as small numbers of nymphs were found in such areas in 1997 but none in the upland, which in 1995 was heavily infested with both nymphs and adults.

Daily Activities

The Nevada sage grasshopper is a geophilous species, spending most of its time on the ground. In spring when nighttime temperatures often dip to 45° F, nymphs sit horizontally on ground litter sheltering under shrub canopies. On summer nights, the adults at night appear to rest horizontally on the ground without seeking special places for shelter. About an hour after sunrise both nymphs and adults begin to bask by "flanking." They turn a side perpendicular to the rays of the sun and lower the associated hindleg to expose the abdomen. During cool weather (50° to 70° F air temperature), the grasshoppers may bask for three hours. General activities begin after the basking period. Some grasshoppers, however, may begin certain activities sooner. In Nevada, migratory phase nymphs were observed to feed from 7:30 a.m. to 5 p.m. at air temperatures of 50° to 80° F. After feeding in the morning, the migration of nymphal bands began when soil surface temperatures reached 80° to 85° F. Also swarms of adults fed heavily in the morning before migrating. Reproduction began when the migratory period ended and the majority of females were ready to deposit eggs. The females oviposited from 8 a.m. until noon at soil temperatures of 85° to 130° F. Ovipositing females exhibited a high degree of gregariousness; often more than 100 simultaneously deposited their eggs in a small area.

In western deserts, summer temperatures often exceed 100° F air and 140° F soil surface. To avoid temperatures above their preferendum and tolerance, adults of the Nevada sage grasshopper make behavioral adjustments. In Millard County, Utah, adult grasshoppers in sparse populations were observed to crawl on the ground into the shade of shrubs or to climb several inches into the canopy of shrubs. In dense populations adults climbed to various heights and covered much of a shrub, which often had been defoliated and barked. After temperatures decline in late afternoon, the grasshoppers become active and remain so at the normally and relatively high evening temperatures. At sunset they sit horizontally on bare ground and plant litter. Night activity has not been observed, but it is probable that some adults may move about and even feed.

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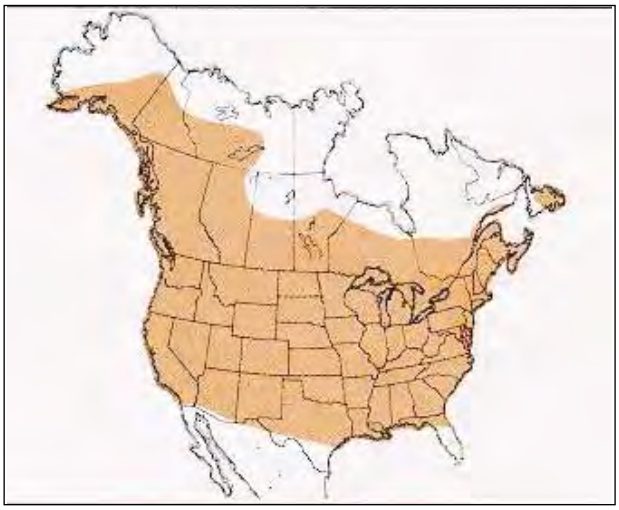
Migratory Grasshopper

Melanoplus sanguinipes (Fabricius)

Distribution and Habitat

Widely distributed in North America, the migratory grasshopper, *Melanoplus sanguinipes* (Fabricius), lives in a multitude of habitats. It is a common inhabitant of grasslands and meadows. Host plants include many kinds of forbs and grasses. Depending on availability of plant species, it may be either a mixed herbivorous or a forbivorous feeder.



Geographic range of *Melanoplus sanguinipes* (Fabricius)

The migratory grasshopper has adapted exceedingly well to western agriculture. The inadvertent introduction of weeds, plowing of sandy loam soils of the prairie for the planting of crops, and overgrazing of rangeland sites have created especially favorable habitats. Introduced weeds have furnished a nutritious and steady supply of food, plowing of sandy soils has resulted in wind-blown drifts that have proved favorable for oviposition, and overuse of rangeland by livestock has reduced grass cover and led to the invasion of weeds. A more recent cause of dense populations are the fields of abandoned cropland that rapidly convert to weeds. All of these sources of outbreaks make the migratory grasshopper a prime candidate for integrated pest management. Suggested methods of control include combining clean culture (weed-free) of crops, elimination of weedy fence rows and roadside strips, judicious use of herbicides and insecticides, planting thick stands of grasses in idle cropland, restoring grasses in depleted rangeland, protecting healthy rangeland from overuse, and annual monitoring of habitats and populations of the migratory grasshopper.

Economic Importance

The migratory grasshopper, a mixed feeder of grasses and forbs, is a serious pest of both crops and grasslands. It causes more crop damage than any other species of grasshopper in the United States. High densities damage and may even destroy fields of wheat, barley, oats, alfalfa, clover, corn, vegetables, and ornamentals. It also attacks vines, bushes, and trees, feeding on foliage, fruit, and bark. Populations that irrupt on weedy rangeland and in idle cropland may migrate in massive swarms to infest land miles away. After flight, the migrants may number from 60-140 per square yard, wreaking havoc on the vegetation of the landing area - rangeland, crops, or urban gardens.

Small grains are especially vulnerable to depredations of the migratory grasshopper. Losses of a wheat crop may occur in several ways. An early hatch of grasshoppers may completely destroy newly germinated seedlings of spring wheat. This occurs when the grasshoppers invade the crop from heavily infested stubble or roadside. Grasshoppers may also hatch within the field of growing plants when the crop is seeded in infested stubble. Gradual defoliation through the growing season reduces yield and quality of the wheat by depressing weight of the kernels. Toward the end of the season, defoliated plants become susceptible to head clipping by grasshoppers, further decreasing yield. The grasshoppers feed on green areas of the stem close to the head, causing the head to fall to the ground. A fourth way in which the migratory grasshopper damages wheat is the invasion in late summer of second generation nymphs and adults into the edges of newly emerged winter wheat. The grasshoppers consume the young plants to ground level. Row after row of seedlings are killed as the grasshoppers eat their way from the edge toward the center of a strip or field. This sort of damage occurs in western Kansas and surrounding regions where strip cropping of winter wheat is practiced. Dispersal of a light infestation of one grasshopper per square yard in a fallow strip of wheat stubble to an adjoining field margin of young growing wheat concentrates the infestation to 55 grasshoppers per square yard.

High densities of the migratory grasshopper infesting rangeland seriously deplete forage for both livestock and wildlife. The grasshoppers not only feed on native forbs and introduced weeds but also on valuable forage grasses. In the desert prairie of Arizona where this species frequently reaches outbreak numbers, the grasshoppers damage blue grama, curly mesquite, red sprangletop, squirreltail, and stinkgrass as well as a variety of forbs and weeds. In the mixedgrass prairie the migratory grasshopper attacks several native grasses including blue grama, western wheatgrass, bluegrasses, and sand dropseed. A severe outbreak of the migratory grasshopper occurred in the mixedgrass prairie of South Dakota from 1937 through 1939 and an unusual but severe outbreak occurred in the bunchgrass prairie of British Columbia during 1944. In the latter case populations destroyed 70 to 80 percent of grasses on the open range.

Much variation in size of the migratory grasshopper exists among specimens taken from different habitats and regions. Live weights of males collected from a ranch roadside in eastern Wyoming averaged 338 mg and of females 442 mg (dry weights 112 mg and 151 mg, respectively).

Food Habits

Examinations of gut contents show that the migratory grasshopper is usually feeding on several species of plants growing in its habitat. This behavior is important in its ecology because laboratory studies have demonstrated that a mixed diet affords individual grasshoppers better nutrition. Although

Instar 1

1. BL 4-6 mm FL 2-2.9 mm AS 12-13.

Instar 2

2. BL 6-8 mm FL 3-4.3 mm AS 15-17.

Instar 3

3. BL 8-11 mm FL 5.5-6.1 mm AS 18-20.

Instar 4

4. BL 11-16 mm FL 7.6-8.6 mm AS 21-22.

Instar 5

5. BL 16-23 mm FL 10-13 mm AS 22-24.

Figures 1-5. Appearance of the five nymphal instars of *M. sanguinipes* - their sizes, structures, and color patterns. Notice progressive development of the wing pads. BL = body length, FL = hind femur length, AS = antennal segments number.

polyphagous, the migratory grasshopper selects host plants from its habitat. Preferred foods include dandelion, tumble mustard, wild mustard, pepperweed, western ragweed, downy brome, Kentucky bluegrass, barley, and wheat. Nymphs and adults ingest dry materials lying on the ground surface including plant litter, cattle manure, and bran flakes.

Dispersal and Migration

The migratory grasshopper, as the common name implies, often disperses and migrates. Many accounts of adults swarming have been published, although there are few records of nymphal migration and still fewer accounts of adult migration in the absence of mass swarming. Recent research has revealed that migratory behavior is inherent and regularly displayed, although considerable variability occurs among populations. The greatest degree of migration has been found in populations inhabiting areas where resources are patchy and unpredictable, as in Arizona and New Mexico. The least degree of migratory behavior was detected in a population inhabiting a relatively lush and stable environment in Colorado.

The older nymphs, third to sixth instars, may migrate as far as 10 miles but usually the distance is less than 5 miles. The nymphs travel together in a band at rates of around 0.1 mile per hour.

Adults are highly migratory in their prereproductive stage. Swarming occurs on clear days when temperatures approach 80½F and winds are gentle and intermittent. Migrants take off into the wind and then turn around and fly with the wind at speeds of 10 to 12 miles per hour. They usually begin flight in late morning, fly during the middle of the day, and alight in the afternoon to feed and rest. With favorable conditions the following morning, they continue their migration. From trials of marked adults, individuals are known to travel 30 miles in a day and probably fly much farther. In 1938 one record of migration indicated a swarm averaged 66 miles per day for four days, flying from Highmore, South Dakota to Beach, North Dakota. The longest migrations recorded in 1938 were made by swarms that traveled from northeastern South Dakota to the southwestern corner of Saskatchewan, a distance of 575 miles.

Flights of the migratory grasshopper have been designated as low flights (25 feet or less above the ground) or high flights (more than 25 feet above ground). The high flights occur at various elevations. Pilots of observation aircraft in the grasshopper control program have encountered swarms flying 1,000 feet above ground and pilots of ferrying aircraft have encountered swarms 2,000-3,000 feet above ground. Pilots of commercial aircraft have reported encountering swarms at all elevations up to 13,000 feet above sea level (about 8,000-9,000 feet above ground).

Migrating or milling swarms can be observed by cupping a hand over one eye and looking toward the sun with the other. The flying grasshoppers reflect the sun's rays and this shimmer of light can be seen at great distances.

Figures 6-10. Appearance of the adult male and female of *M. sanguinipes* and two diagnostic characters of the male — the shape of cercus (Fig. 8) and the notch in the apex of the subgenital plate (Fig. 9) and egg pods. Notice the two different color forms of hind tibia — red and pale blue.

Identification

The migratory grasshopper, *Melanoplus sanguinipes* (Fabricius), is a medium-sized representative of this large genus. Adult males (Fig. 6) are easily identified by the shape of the cercus (Fig. 8), the notch of the subgenital plate (Fig. 9), and the node or bump on the mesosternum. The females (Fig. 7) are slightly larger than the males and can be associated with them and distinguished by their similar color patterns. The hind tibiae are blue green or red.

The nymphs (Fig. 1-5) are identifiable by their color patterns:

1. Compound eye with many light spots, narrow brown bar across middle.
2. Narrow pale yellow crescent on gena below eye and continuing on pronotal lobe to principal sulcus.
3. Hind femur with dorsal black stripe cut in middle by light bar; a light bar on each end.
4. Hind tibia of first instar fuscous with pale basal ring; hind tibia of other instars pale blue green or reddish without pal e ring.
5. General color of body tan or gray, few light green.

Hatching

The migratory grasshopper is an early-hatching species, appearing on rangeland about one week after the bigheaded grasshopper begins to hatch. Several environmental factors, especially soil temperature and moisture, affect the exact timing and duration of hatching. Hatching starts first along open south slopes, in fields and rangeland with little vegetative cover, and in sandy soils. The duration of hatching is shortened by uniform soil and vegetation and high temperatures, and may be completed in three weeks. Hatching is retarded by heavy clay loam soils and by tall vegetation that shades the ground. A mosaic of these conditions in an area, as well as below-normal temperatures, may extend the hatching period to six weeks. For complete embryonic development the eggs require 527 day-degrees above a threshold of 50°F soil temperature. Under favorable conditions 80 percent of development occurs during the summer that the eggs are laid and 20 percent the following spring. In warmer areas of the West, as in Kansas, the migratory grasshopper produces a smaller (less numerous) second generation each year. The majority of eggs of the first generation enter diapause and hatch the following year.

Duration of embryonic development and stage of embryonic diapause are greatly influenced by the climate of the occupied area. Grasshoppers from warmer environments tend to diapause at early stages of embryonic development while grasshoppers from cooler environments diapause at later stages. This seeming paradox is due to populations evolving adaptations to prevailing lengths of season.

Nymphal Development

Nymphs grow and develop during late spring when days are long, weather is usually warm, and food plants are green and abundant. Under these favorable conditions the young grasshoppers pass through the nymphal stage in 35 days. Cool weather, however, may lengthen the nymphal stage to 55 days. Nymphal instars range from five to six; the females usually require the larger number.

Male

6. BL 20-26 mm FL 11-12.5 mm AS 24-27.

Female

7. BL 20-29 mm FL 12.3-14 mm AS 25-27.

Note Cercus

8. Side view of end of male abdomen.

Note Notch

9. End view of male abdomen, showing notch in the subgenital plate.

Egg pod

10. Egg pod and exposed eggs in bottom of broken egg pod.

A study of six populations of the migratory grasshopper residing in habitats lying along an altitudinal gradient in California revealed significant variations in nymphal period and other life cycle parameters. Both nymphal development and adult maturation were accelerated at high altitudes relative to sea level. The phenological differences were attributable partly to environment and partly to genetic divergence of the populations.

Adults and Reproduction

Emergence of adults begins the first part of summer and may continue for three or four weeks. The first adults to emerge have the best chance for reproductive success. At this time there is likely to be an abundance of green food plants to provide the nourishment necessary for rapid egg production. In addition, the first eggs laid will usually experience more favorable soil moisture and have a longer time to reach an advanced developmental stage before entering diapause.

The females have a preoviposition period of two to three weeks. During this time they increase in weight, mate, and mature their first group of 18 to 24 eggs. The male is able to recognize a mature, virgin female and performs a short courtship in which he waves his antennae and vibrates his hind femora before he makes a sudden copulatory leap onto the female. A mated female oviposits about six days later and takes nearly an hour to lay a clutch of eggs. Healthy adults copulate many times during the reproductive period.

The females deposit their eggs on rangeland among the roots of blue grama or other grasses. In cropland they often deposit them around the base of wheat stubble or alfalfa. Pods are curved, one inch long and one-eighth inch in diameter. The top half of the pod, containing dried froth, is oriented vertically in the soil and the bottom half, containing the eggs, is oriented diagonally. The midpoint of the clutch is three-fourths inch below the soil surface. Eggs have a banana-like shape, are 4.5 mm long, and pale yellow or cream colored (Fig. 10). Under laboratory conditions, a long-lived female may produce as many as 20 pods and a total of 400 eggs. The average fecundity in nature is unknown, but it may not be more than 20 eggs.

Population Ecology

The population ecology of the migratory grasshopper has received much study by scientists in Canada and the United States. Their findings indicate that the two most influential factors affecting population growth of this grasshopper are weather and food plants. Although the species feeds on a large variety of plants, a limited number are particularly favorable for survival, growth, and reproduction.

The migratory grasshopper has a great capacity for increase. Large populations develop in disturbed or cultivated land such as weedy rangeland, stubble of small grains, reverted fields, and roadsides. In a favorable year, a noneconomic population of three adults per square yard can reproduce exponentially so that in the next year the population may reach an outbreak density of 30 adults per square yard. Over a period of several favorable years, densities may reach enormous levels. In 1938 in northeastern South Dakota, densities of the migratory grasshopper reached 1,500 to 8,000 nymphs per square yard in cropland, idle land, and weedy rangeland. Less than ideal weather and natural enemies (predators, parasites, and diseases) usually keep populations from increasing to such an extent. Densities normally range from zero to nine nymphs and zero to three adults per square yard.

Weather is important to the health of this grasshopper and consequent population growth. An early, mild spring allows the nymphs to flourish and a large percentage to become adults. On the other hand, cool wet weather and heavy rains in spring cause much mortality among young nymphs. A mild fall with intermittent rains keeps food plants growing and lengthens the longevity of adults, which allows them to continue reproducing.

The migratory grasshopper resides, usually in small numbers, in all types of grassland habitats. During outbreaks of grass-feeding species on good-condition rangeland, the migratory grasshopper is present in the assemblage at subdominant densities of 0.1 to 3 young adults per square yard. This is in contrast to its often dominant position in weedy depleted rangeland, where it reaches densities of 20 to 60 or more young adults per square yard. The latter densities exhaust the forage, inducing the grasshoppers to take wing and migrate to “greener pastures.”

A study of a severe outbreak of the migratory grasshopper in northeastern South Dakota revealed a gradual increase in density from 1934 to 1936. In the spring of 1937 very severe infestations of nymphs (80 plus per square yard) hatched and survived in many sites. From these sites adults spread throughout the area. Unusually warm weather in September and October allowed the females to lay over an extended period, producing as many as 8,000 eggs per square yard in idle land and depleted rangeland. This extraordinary reproduction resulted in an enormous outbreak during 1938 that eventually led to mass flights of the young adults. Because of the migrations, the outbreak expanded and continued through 1939. It ended in 1940, due, at least in parts of the extensively infested area, to a cool, wet spring that caused high mortality among the nymphs.

Daily Activity

The migratory grasshopper is normally active during the day and inactive at night. In rangeland habitats most nymphs and adults spend the night resting horizontally on the ground. A few, however, climb vegetation and rest vertically head up at heights of 8 to 24 inches. When the rising sun strikes them in the morning, they adjust their positions to receive the full benefit of the warming rays. They may bask either on the ground or on vegetation. The common orientation is to turn a side perpendicular to the sun’s rays and lower the associated hindleg to expose the abdomen. After basking for approximately two to three hours they become active, walking about and feeding. Later in the day they have been observed to mate and oviposit. When soil temperatures rise, those occupying bare ground may stilt. As temperatures rise still further (soil approximately 130°F, air 90°F at 1 inch level) many individuals climb vegetation, often the stems and culms of western wheatgrass, to heights of 2 to 8 inches. When temperatures moderate in late afternoon, they again become active, pottering, feeding, mating, and ovipositing. Before taking their nighttime positions, they bask for a second time. J. R. Parker (1884-1972), a renowned student of grasshopper biology, has described in detail the influence of temperature on the daily activities of the migratory grasshopper (Montana Agr. Exp. Stn. Bull. 223, 1930).

References

See list of selected field guide references. In grasshopper literature the scientific name of the migratory grasshopper has been given as *Melanoplus mexicanus* (Saussure), later *Melanoplus bilituratus* (Walker), and finally *Melanoplus sanguinipes* (Fabricius).

Twostriped Slantfaced Grasshopper

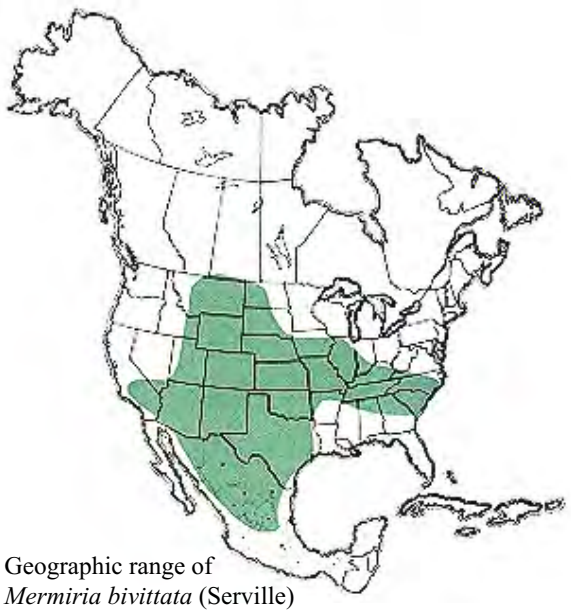
Mermiria bivittata (Serville)

Distribution and Habitat

The twostriped slantfaced grasshopper is widely distributed in North America. Its center of distribution is in the tallgrass prairie where it may reach densities of one adult per square yard in unplowed native grassland. Its habitat consists primarily of tall grasses: big bluestem, yellow indiangrass, and switchgrass, and it frequently inhabits these grasses on slopes and hills. Small, edaphic stands of tall grasses in the mixedgrass, shortgrass, bunchgrass, and desert prairies also provide suitable habitats for the species. In addition, this grasshopper may live in luxuriant stands of midgrasses in the mixedgrass prairie.

Economic Importance

The twostriped slantfaced grasshopper is a frequent and common species in the tallgrass prairie and is a potentially damaging pest. It feeds on valuable forage grasses and occasionally reaches outbreak densities, as it did in native grass pastures of eastern Kansas in 1939. It is a large grasshopper; live weights of males from eastern Wyoming average 222 mg and females 784 mg (average dry weight of males 63 mg, females 204 mg). An estimate of damage indicates that an individual consumes 3.4 gm dry weight of grass during its lifetime, an amount greater than the bigheaded grasshopper, *Aulocara elliotti*, which consumes 2.0 gm. Nevertheless, it rarely becomes a significant pest because densities usually remain light and grass production plentiful in the tallgrass prairie.



Geographic range of
Mermiria bivittata (Serville)

A quantitative study of the impact of grasshoppers on tallgrass prairie disclosed no significant differences in above ground biomass of vegetation between plots with five grasshoppers per square yard and plots with 11 grasshoppers per square yard (early instars). In these studies the twostriped slantfaced grasshopper was a subdominant in an assemblage of 15 species in which *Phoetaliotes nebrascensis*, a grass feeder, was the dominant species. These data indicate that in the tallgrass prairie where grasshopper densities are lower and vegetation production higher than in the drier western grasslands, the impact of grasshoppers is slight and often unmeasurable.

Food Habits

The twostriped slantfaced grasshopper is a grass feeder. Enjoying a wide distribution in North America, the species exploits a variety of grasses that grow in its diverse habitats. In the tallgrass prairie of eastern Kansas, examination of crop contents has shown that it feeds upon sideoats grama, tall dropseed, and yellow indiangrass; in the northern mixedgrass prairie of western Nebraska, it feeds upon prairie sandreed, western wheatgrass, big bluestem, and on eight other grass species; in the blackland (tallgrass) prairie of northeastern Texas, it feeds upon big bluestem, silver beardgrass, prairie dropseed, and several species of grama. This grasshopper has been found to feed on a total of 18 species of grass and on threadleaf sedge. Its dietary, in addition to the grasses already mentioned, includes little bluestem, sand bluestem, blue grama, downy brome, smooth brome, sand dropseed, needleandthread, and hairy grama. Preference tests of caged individuals in a Texas insectary showed that the grasshoppers chose Bermuda grass, an introduced species, and prairie dropseed for food in preference to big bluestem and silver beardgrass.

The twostriped slantfaced grasshopper feeds on green leaves of its host plant. It may attack a plant in three ways. First, sitting vertically, head- up, and near the middle of a wide leaf (sand bluestem), it holds onto its food with the front tarsi and eats from the edge to the midrib, progressing toward the tip. Nymphs and young adults consume lengths of leaf 1 to 2 inches long, causing characteristic semi-elliptical damage. In the second method of attack, the grasshopper, also in a vertical, head-up position, cuts a narrow leaf (needleandthread) near the tip and holds onto a 1 to 2 inch section with the front tarsi and consumes the whole section. The third method of attack involves the grasshopper feeding on a bent over or recumbent leaf

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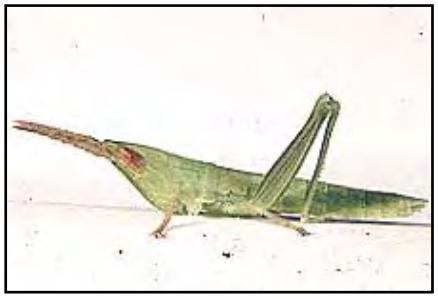
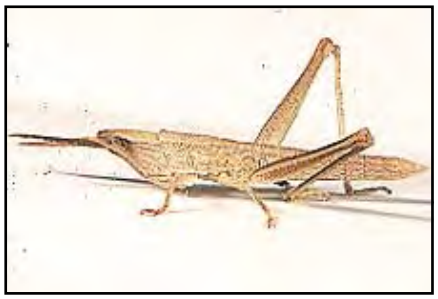
1. BL 9.5-10.4 mm FL 4.3-4.7 mm AS 13.

Instar 2



2. BL 12-13.8 mm FL 6.1-6.9 mm AS 16-19.

Instar 3

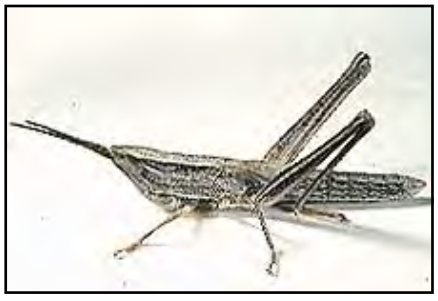


3. BL 16-18.5 mm FL 9.2-9.5 mm AS 21.

Instar 4

4. Males: BL 21.5-24 mm FL 12.5-12.7 mm AS 22-23.
Females: BL 24-24.7 mm FL 12.5-13.5 mm AS 22-23.

Instar 5



5. Females: BL 28-30 mm FL 16.8-18 mm AS 23-24.

Figures 1-5. Appearance of the five nymphal instars of *Mermiria bivittata* - their sizes, structures, and color patterns. Notice progressive development of the wing pads. BL = body length, FL = hind femur length, AS = antennal segments number.

from a horizontal orientation. It then progresses from the middle of the leaf for a short distance toward the base. Feeding bouts of the adults last as long as 7 to 10 minutes. By the end of the season the culms of sand bluestem are stripped of nearly all their leaves and the bunch-like leaves of young plants are partially consumed.

During feeding, the twostriped slantfaced grasshopper may cut and drop sections of leaf, which can still be found on the ground around each plant at the end of the season. In the tallgrass habitat, unlike the mixedgrass prairie, the cut leaves remain uneaten by grasshoppers and become part of the ground litter.

Dispersal and Migration

The twostriped slantfaced grasshopper has long wings that extend to the end of the abdomen. It is a strong and adept flyer. In flushed flights it flies distances of 2 to 12 feet at heights of 9 to 36 inches. The flight is silent and may be straight or sinuous. The grasshopper usually takes off from vegetation and lands on vegetation, but it may also land on plant litter or bare ground. It is able to turn at the end of a flight to land vertically on an upright culm or stem. It can also veer in flight to land within vegetated areas, although many individuals occasionally land in inimical bare areas.

No special study of its dispersal or migration has been made. It has not been found as an “accidental” in the mountains west of Boulder, Colorado, even though it inhabits the adjacent plains and foothills. Although direct evidence of its dispersal is lacking, we may speculate that the species does disperse for the following reasons: 1) good capacity for flight; 2) extensive range in North America; and 3) occupation of small edaphic habitats in the drier grasslands.

Identification

The twostriped slantfaced grasshopper is a large, long-winged, colorful insect (Fig. 6 and 7). It has a strongly slanted face; the antennae are ensiform. A brown stripe beginning behind the compound eye runs along the side of the head and onto the lateral lobe of the pronotum. Four diagnostic characters of this species are: 1) the disk of the pronotum rounds off onto the lateral lobe, i.e., it lacks lateral carinae (Fig. 8); 2) the pronotal disk margin is cut by three sulci; 3) sides of occiput and pronotal disk without ivory stripe; and 4) one longitudinal white or ivory streak on tegmen. The

Figures 6-9. Appearance of the adult male and female of *Mermiria bivittata*, dorsal view of head and pronotum of female, and view of eggs and pod.

hind tibiae are orange and the body is tan, often densely spotted brown (visible under low magnification). In the West, this grasshopper broadly overlaps geographically and seasonally with two other species of the genus - *M. picta* and *M. texana*. All three look superficially alike, but adults can be easily separated by a few distinguishing characters.

Mermiria texana has an ivory stripe on sides of occiput and pronotal disk and it has two longitudinal white streaks on the tegmen, one above base of hindleg and one above abdomen. *Mermiria picta* lacks the ivory stripes on the occiput and pronotal disk and the streaks on tegmen (*M. bivittata* has one streak), and it has well-developed lateral carinae on pronotal disk and the lateral carinae are cut by two posterior sulci (the anterior sulcus is visible on pronotal disk but does not cut the carinae). One other species is known, *M. intertexta*. It is distributed in the eastern United States along the Atlantic and Gulf coasts.

The nymphs (Fig. 1-5) are identifiable by their color patterns, structures, and shape:

1. Head with face strongly slanted; antennae ensiform with proximal segments triangular in cross section, distal segments tubular; lateral foveolae triangular, invisible from above; narrow brown band beginning behind compound eye runs along side of head and continues on dorsal edge of lateral lobe; band faint in early instars.
2. Pronotum with lateral margin of disk rounding off onto lateral lobe; margin of disk cut by three sulci; sulci weak in instar I.
3. Hind femur with upper medial area darker than the lower; hind tibia yellow or pale gray.
4. Body yellow, tan, or green and densely spotted brown (visible with low magnification).

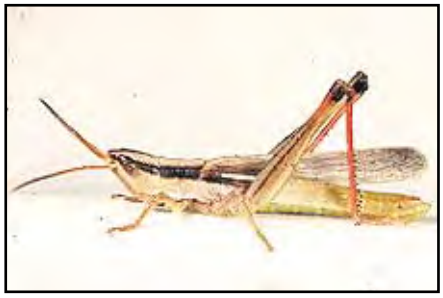
Hatching

The twostriped slantfaced grasshopper is a late-hatching species. In the tallgrass prairie of eastern Kansas, first instars appear in early May, while in the mixedgrass prairie of eastern Wyoming they do not appear until early to mid June. The period of hatching in a habitat may last two weeks or longer.

Nymphal Development

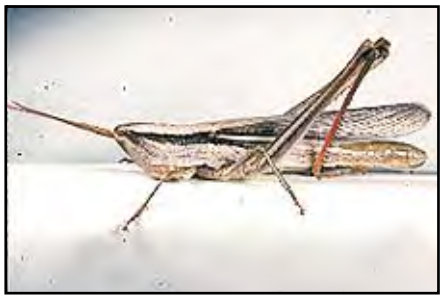
Although nymphs hatch late and normally experience warm conditions and favorable food supply, they develop at a relatively slow rate. Their minimum nymphal period, completed by the males, is 40 days. The slow development is probably due to exposure to the cooler temperatures of their

Male



6. BL 25-29 mm FL 14-16.8 mm AS 22-24.

Female



7. BL 35.5-39.8 mm FL 20.5-24.5 mm AS 23-24.

Head and pronotum

8. Dorsal view of female's head and pronotum showing ensiform antennae, sulci of pronotal disk, and color patterns.

Egg pod

9. Egg mass at bottom of pod (left) and froth plug above (right).

luxuriant grass habitat and their above-ground location on tall grass. Studies carried out in eastern Wyoming indicate that the males have four instars and the females five. Because of their smaller size, the males apparently require fewer instars to achieve the weights necessary to metamorphose to the adult stage than do the much larger females. This proposition suggests that the males have a shorter nymphal period and thus emerge before the females.

Adults and Reproduction

Most adults remain in the habitat in which they hatched and developed as nymphs. There they have the tall grasses for feeding, roosting, and shelter and bare ground for oviposition. Several observations of male courtship have been made. On approaching a female, a male stridulates with a burst of two to five strokes of the femora. No information is available on mounting and copulation nor on how soon adult females mate and lay eggs. The females oviposit in bare ground near their host plant. Eggs are placed deep in the soil, lying at depths between one and one-quarter and one and three-quarters inches. The egg mass, which consists of 14 to 18 eggs, has no pod wall; the eggs are held together by spots of froth (Fig. 9). The egg mass itself is one-half inch long. Eggs are tan or two-toned tan and yellow and are 7.2 mm long. A long froth plug of one and one-quarter inches lies above the eggs. The diameter of the plug measures one-eighth inch or slightly more.

Population Ecology

Studies on the population ecology of the twostriped slantfaced grasshopper have been conducted in the tallgrass prairie where the species finds extensive areas of its preferred habitat of tall grasses. These studies show that populations fluctuate around low densities, rarely exceeding one adult per square yard. Food supply is not the limiting factor, as the luxuriant grass foliage of the tallgrass prairie remains plentiful except in cases of heavy use by livestock. Elegant studies of the impacts of burning, which occurs regularly via humans and lightning, show that the grass habitat is maintained by reducing competition or invasion by forbs and shrubs thereby favoring the graminivorous grasshoppers over the forb- or mixed-feeders. A problem that still remains unsolved is the discovery of the factor or factors that limit the size of populations of the twostriped slantfaced grasshopper.

Daily Activity

The twostriped slantfaced grasshopper is a phytophilous species spending most of its days and nights perched on grass. At night, nymphs and adults rest vertically head-up on leaves or culms at heights of 8 to 12 inches. As the sun rises and rays strike their perches, the grasshoppers begin to bask by adjusting their positions so that one side receives the full benefit of the radiant heat. They may bask for two to four hours before they begin to feed or move about on host plants. Movement consists of descent by backing down from their perches, crawling onto another leaf, or jumping from one plant to another. If in jumping they land on the ground, they immediately crawl up on a nearby grass plant. As do grasshoppers of other species, they frequently preen their antennae and compound eyes, presumably to remove dust particles that settle on these organs. High temperatures cause them to change their positions on grass plants to the shady side. When temperatures subside they again become active, feeding and moving about. As evening approaches, they become quiescent and remain largely immobile from 8:30 p.m. to 7 a.m. DST. Rain and cool temperatures extend quiescence. Individuals continue to rest on their nocturnal perches until the sun again shines on them.

In the sandhills grassland of central Nebraska, a study of time and activity budgets of this grasshopper showed that in the daylight hours (13.5 hours), the twostriped slantfaced grasshopper remained quiescent 88 percent of the time, fed 10 percent, and moved 1 percent.

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Bluelegged Grasshopper

Metator pardalinus (Saussure)

Distribution and Habitat

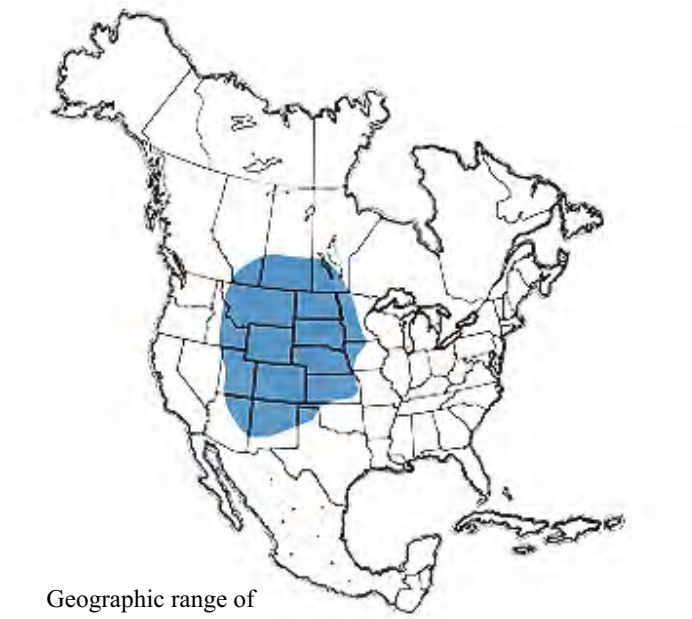
The bluelegged grasshopper, a large bandwinged species, has a wide geographic range in western North America. It inhabits the shortgrass, mixedgrass, bunchgrass, desert, and tallgrass prairies. In the northern mixedgrass prairie, where populations reach their highest densities, the species prefers to live in areas dominated by western wheatgrass. These are mesic habitats commonly occurring on clay soil flats, in valley bottoms, and in old dry lake beds. The close plant-insect relationship is probably the main reason for a patchy distribution of this grasshopper.

Economic Importance

The bluelegged grasshopper is a heavy feeder on native grasses, particularly western wheatgrass, which abounds in its preferred habitats. Calculations made from a quantitative study of damage in Montana indicate that a density of one bluelegged grasshopper per square yard causes a loss of approximately 100 pounds (air-dry weight) of grass per acre. This figure appears unusually high, suggesting the need for further study of damage by this grasshopper.

The damage is usually done in participation with other rangeland species, often with the bigheaded grasshopper, *Aulocara elliotti*, or the whitecrossed grasshopper, *Aulocara femoratum*. The densities of the bluelegged grasshopper in assemblages occupying its preferred habitats usually range from one to four adults per square yard, but in some situations densities may reach ten per square yard.

The bluelegged grasshopper is a large species. Live weights of males from northern mixedgrass prairie average 294 mg and of females 828 mg (dry weights: males 97 mg, females 236 mg).



Geographic range of *Metator pardalinus* (Saussure)

Food Habits

The bluelegged grasshopper feeds almost exclusively on grasses and sedges. It has been observed to feed on the green leaves of western wheatgrass, bluebunch wheatgrass, needleandthread, green needlegrass, sand dropseed, prairie junegrass, and blue grama. Microscopic examination of crop contents of late instars (IV and V) and adult males collected from a western wheatgrass habitat in the northern mixedgrass prairie of eastern Wyoming revealed that these grasshoppers were ingesting two host plants exclusively - western wheatgrass and needleleaf sedge in nearly equal amounts. In a Nebraska study, crops of two specimens from a site near Scottsbluff contained solely prairie sandreed fragments. The bluelegged grasshopper also feeds on both green and dry grass litter and on dry cattle droppings. Although this habit suggests the species should eat bran bait, insecticidal tests indicate otherwise, as only a 2 percent reduction was achieved in a population treated with carbaryl bran bait. Adults have been observed feeding ravenously on a small matforming lichen. This behavior sometimes gives the appearance that the grasshoppers are eating soil.

The method of attacking a host plant by this grasshopper is unusual. Crawling on the ground, a hungry adult contacts a host plant such as western wheatgrass or needleandthread, climbs the plant, and cuts a 3 to 4 inch terminal section of leaf, which falls to the ground. The grasshopper immediately drops to the ground and recovers the cut section. Handling the cut terminal with its front tarsi, the grasshopper devours it from one end to the other. While searching for food, a hungry grasshopper may instead contact a green section of leaf lying on the ground or an attached recumbent leaf and feed on it. The method of attack used by instars II to V is similar to the adults; they climb and cut terminal sections of leaves and feed on them from a horizontal position on the ground or they feed on ground litter, both green and dry grass leaves. No observations of feeding of instar I have been made.

Dispersal and Migration

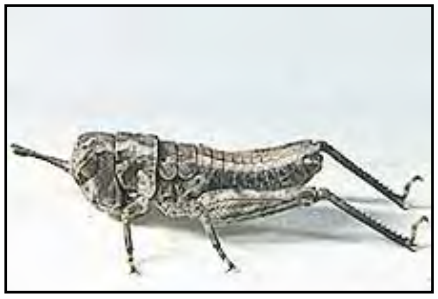
Possessing long wings that extend beyond the end of the abdomen and strong powers of flight, the bluelegged grasshopper is well known for its vagrant tendencies. In Colorado its upper resident altitude is 5,800 feet at the western edge of the plains, but adult “accidentals” have been collected farther west at several locations in the mountains, the highest at 11,400 feet.

Evasive flights begin about 8:30 a.m. DST on clear days when soil temperatures have risen above 60°F. These

Instar 1

1. BL 5.9-7.6 mm FL 3.5-3.7 mm AS 9-10.

Instar 2



2. BL 7.4-9.3 mm FL 4.5-5 mm AS 11-14.

Instar 3

3. BL 9.5-11.9 mm FL 5.8-6.2 mm AS 16-17.

Instar 4

4. BL 10.9-15 mm FL 6.4-9.3 mm AS 17-18.

Instar 5

5. BL 12.5-20 mm FL 8.4-11.9 mm AS 19-20.

Figures 1-5. Appearance of the five nymphal instars of *Metator pardalinus* - their sizes, structures, and color patterns. Notice progressive development of the wing pads. BL = body length, FL = hind femur length, AS = antennal segments number.

flights are straight and 6 to 12 inches high, the adults softly crepitating and travelling distances of 3 to 15 feet.

Although no direct observations of group migratory flights have been made, circumstantial evidence indicates that such behavior occurs. In eastern Wyoming a preferred habitat dominated by western wheatgrass became drought stricken in July 1989, and the usually luxuriant grasses stopped growing and turned brown. Where both the bigheaded grasshopper and the bluelegged grasshopper occurred in economic densities on 1 July 1989, only the bigheaded grasshopper remained at high densities 20 July 1989. The bluelegged grasshopper had disappeared and presumably emigrated to more favorable habitats that had received spotty rainfall during the summer. Two possible stimuli for the emigration of the bluelegged grasshopper were the exhaustion of its preferred food plants and the deterioration of the microhabitat. On the other hand, the bigheaded grasshopper, with less stringent ecological requirements, chose to remain in the deteriorating habitat.

Identification

The bluelegged grasshopper is a large, tan and brown grassland species (Fig. 6 and 7). The posteroventral angle of the pronotal lobe is acute and drawn down. The tegmen has numerous dark brown spots and a pale streak on the outer edge of the dorsal field. The streaks of the folded tegmina converge posteriorly. The hindwings are marked by a wide outer dark band and the inner or basal area is colored yellow, orange, or red (Fig. 8). The inner face of the hind femur has alternating bands of light and dark blue; the band next to the knee is sometimes tan (Fig. 9). The hind tibia of the male is medium blue, that of the female is light blue on the outer face and medium blue on the inner face. The male often has top and sides of the abdomen (the terga) colored blue.

The nymphs are identifiable by their shape, structures, and color patterns (Fig. 1-5).

1. Head: face nearly vertical, a diagnostic light band beginning from near top of compound eye and running diagonally backwards on the occiput, the band from one eye converges on the other but the bands do not meet, bands sometimes faint. Figures 1-5 show side view of left band beginning above compound eye and running diagonally on occiput.
2. Pronotum with disk wrinkled; median carina distinct and elevated higher on the prozona than the metazona, cut twice, in front of middle and

Figures 6-10. Appearance of the adult male and female, the hindleg, the left wings, and the eggs.

near middle; lateral lobe with posteroventral angle acute and drawn downward.

3. Hind femur with sparse hairs on lower carina; this characteristic separates bluelegged nymphs from Kiowa grasshopper nymphs (*Trachyrhachys kiowa*), which possess a thick fringe of hairs on the lower carina. Color of hind tibia of instars I and II is fuscous, of instars III and IV fuscous and gray, of instar V pale blue or pale blue, tan, and fuscous.
4. General body color tan to brown with many dark brown maculations imparting a dark brown aspect to all instars.

Hatching

Eggs of the bluelegged grasshopper hatch two to three weeks after those of the bigheaded grasshopper, placing the former species in the intermediate-hatching group. Although egg development of the bluelegged grasshopper has yet to be investigated, we may speculate from its seasonal development and from the results of studies of other rangeland species that the embryos begin to develop in summer, shortly after the eggs are laid, and continue developing until they diapause in an undetermined embryonic stage in fall. Sheltered in soil cells at depths of 1 to 2 inches, the eggs pass the winter and then complete development the following spring. We postulate that eggs of the bluelegged grasshopper diapause in approximately the same developmental stage as eggs of the bigheaded grasshopper, but because of greater depth in the soil eggs of the former species take longer to accumulate the required heat units for completion of their embryonic development and hatching.

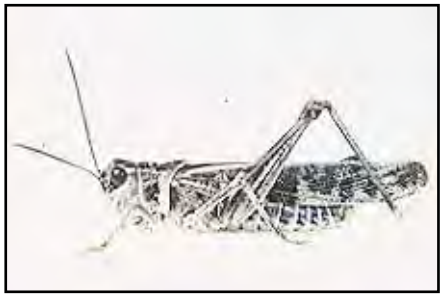
Nymphal Development

In the northern mixedgrass prairie, nymphs emerge in June over a short period, possibly as short as one week. They feed and develop in the same habitat as they hatch and dwell on the ground surface. Their nymphal development consists of five instars and takes about 36 days to complete.

Adults and Reproduction

Adults of the bluelegged grasshopper may disperse to new areas, but the majority remain in the same favorable habitat in which the nymphs hatched and developed. There they feed, mature, reproduce, and eventually are eaten by a predator or die from other causes. Observations have not been made of the courting and mating behavior of this grasshopper, but several observations of oviposition in northern mixedgrass prairie have been made. A gravid female

Male

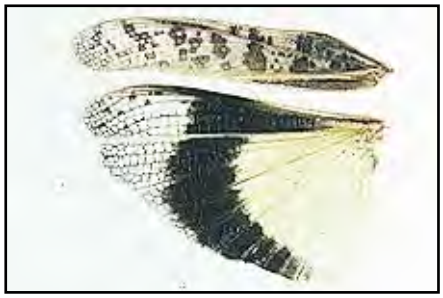


6. BL 22-25 mm FL 13.5-14.5 mm AS 20.

Female

7. BL 30-34 mm FL 15.2-18 mm AS 21-13.

Wings



8. Spread wings from left side.

Hindleg

9. Inner face of female hindleg.

Eggs

10. Loose eggs from single pod.

ready to lay selects either bare ground or ground covered by litter among shortgrass, if available, and works her ovipositor 2 inches deep into the soil. The time taken to begin and end oviposition has not been observed, but one female with her ovipositor already inserted took 32 minutes until withdrawal. A female covers the hole by tamping with her hindlegs and brushing with her ovipositor. A clutch consists of 14 large reddish brown eggs measuring 6.3 to 7.3 mm in length (Fig. 10). There is one generation annually.

Population Ecology

Populations of the bluelegged grasshopper reach their highest densities in habitats dominated by western wheatgrass. These habitats commonly occur under mesic conditions, as in dry lake basins (playas), valley bottoms, and on clay soil flats. In especially favorable habitats, populations may reach a peak density of ten adults per square yard, but usually densities are much less. In a 15 acre playa in the northern mixedgrass prairie of eastern Wyoming, where from 1981 to 1985 adults of the bigheaded grasshopper ranked first in abundance (adult densities of 18, 26, 17, 14, and 9 per square yard in the successive years), the bluelegged grasshopper ranked second (1.7, 1.1, 1.8, 1.8, and 2.8 per square yard). Populations of both species were still high in the spring of 1989, but a severe summer drought caused the vegetation to desiccate and the adults of the bluelegged grasshopper to emigrate. Thus, the bluelegged grasshopper appeared to be more sensitive to conditions of the vegetation and to moisture than the bigheaded grasshopper. Under favorable moisture conditions populations of both species remained high but did fluctuate. The rises and falls of the populations of the two species were not synchronous. In given years the population of one species increased while the other decreased.

A biological control factor affecting populations of the bluelegged grasshopper is parasitism by the tangleveined fly, *Trichopsidea clausa*. In some years 80 percent of females in a population are infested with parasitic larvae. A parasitized female is unable to reproduce, as all eggs and soft tissues are consumed by an invading larva. Upon developing to maturity a larva leaves its host, which then dies. Interestingly, the bigheaded grasshopper is not affected by this parasite. The tiny larva, 0.5 mm in length, may invade an individual but it is sealed off and killed by the resistant host.

Daily Activity

The bluelegged grasshopper is a ground-dwelling insect. Both nymphs and adults sit horizontally on the ground through the night. Many take positions on ground litter among grasses or on bare ground under canopies of grasses. Others may just sit on bare ground unprotected and exposed to the chilling night temperatures. At sunrise the grasshoppers are found facing in various directions. About two hours later they begin to bask by exposing a side perpendicular to the rays of the sun and lowering the hindleg of the exposed side to the ground. They may also lower both hindlegs to the ground while basking. In both postures the hindlegs are flexed. Some may bask for as long as three hours until 10:30 a.m. (DST), but normal activities of feeding, walking and seeking a mate usually begin about 10 a.m., when ground temperature reaches approximately 80°F and air temperature reaches 67°F 1 inch high above ground.

In the afternoon, activity ceases when temperatures of the soil surface rise to 120°F. The nymphs may rest horizontally on the ground in shade of vegetation or may climb on grasses to a height of 2 inches. Adults may rest horizontally on the ground in the shade of vegetation or they may move into the crowns of grasses and rest diagonally on leaf stems in the shade. Later, when temperatures decline the grasshoppers become active again and begin normal activities. In the evening they bask in the waning rays of the sun and eventually select their night-time locations.

Observations of the species in Montana have revealed that older nymphs and the adults are gregarious. Older nymphs were found in small aggregations while the adults were found in large aggregations.

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Valley Grasshopper

Oedaleonotus enigma (Scudder)

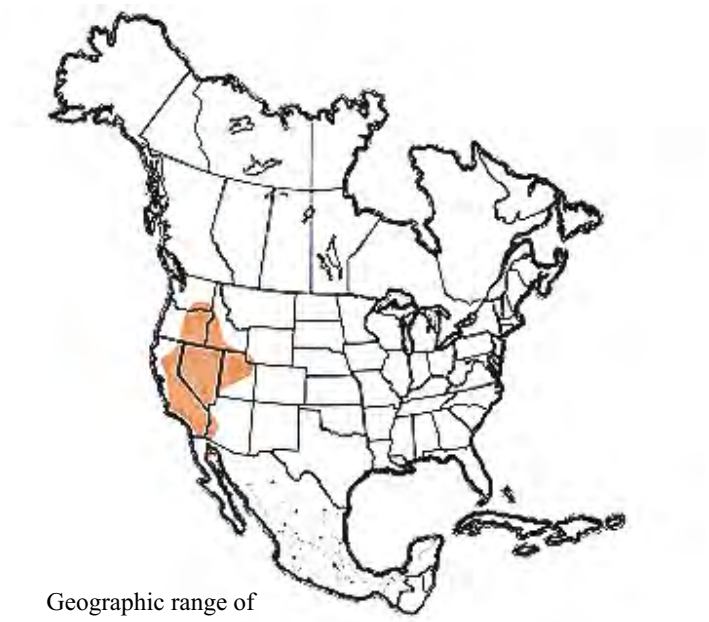
Distribution and Habitat

The valley grasshopper is a rangeland species, inhabiting the sagebrush-grass and other semiarid associations of the west. Native host plants include springparsley, balsamroot, big sagebrush, and rabbitbrush. The valley grasshopper has found several introduced weeds to its liking: redstem filaree, flixweed, and downy brome. The increase in number of favorable food plants appears to be an important factor in outbreaks of the species due to better nutrition. Abandoned farmland, Conservation Reserve Program (CRP) land, and foothills of the California coastal and Sierra Nevada ranges are especially favorable sites for development of large populations.

Economic Importance

High densities of the valley grasshopper on rangeland cause severe injury to forage plants. These grasshoppers are particularly damaging to young grasses and legumes in newly reseeded rangeland. The species has a high reproductive capacity. Density of adults may reach 20 per square yard and higher. Nymphs and adults in outbreak populations often migrate into alfalfa, cotton, grains, and vegetables, causing serious damage. The valley grasshopper may be beneficial at low densities as it prefers weeds for food, thereby thinning and reducing these strong competitors of valuable forage plants. No quantitative study of damage or benefits of this grasshopper, however, has been made.

The sizes attained by adults from one population to another are highly variable and are probably due to variations in environmental factors among habitats, such as temperature and quality and supply of food. Weights of adults collected in a drought-stricken habitat 12 miles south of Mountain Home, Idaho, and then caged and fed downy brome for 11 days averaged 365 mg for live males and 530 mg for live females (dry weight: males 110 mg, females 165 mg).



Geographic range of *Oedaleonotus enigma* (Scudder)

Food Habits

The valley grasshopper is primarily a forb and shrub feeder, but it also feeds to some extent on grasses. It has been observed to feed heavily on introduced weeds that often grow abundantly in its habitat. These include redstem filaree, tumble mustard, draba mustard, pepperweed, and downy brome. It likewise feeds heavily on lichen. In summer, when annual weeds have matured and dried, big sagebrush becomes an important host plant. In abandoned fields and CRP fields where big sagebrush no longer occurs, Russianthistle is often the only green plant available to the valley grasshopper in mid-summer. It does not feed upon this plant, but it does use it for roosting. Adult grasshoppers have been observed nibbling on the leaves of Russianthistle but never found to ingest any substantial amount of the plant. This may indicate that other members of the goosefoot family, including the sugar beet, are essentially immune to attack. Under drought conditions the grasshoppers resort to feeding on ground litter and dead or dying grasshoppers, and they will skirmish over an apple core thrown on the ground.

Direct observations and examination of crop contents have provided records of the valley grasshopper feeding on seven species of forbs, four shrubs, two grasses, one sedge, and one lichen. This list of food plants is undoubtedly incomplete.

To learn how the valley grasshopper attacks food plants, twigs of miniature rose (variety Meiponal) bearing leaves and blooms were transplanted 2 August 1991 in an abandoned field 12 miles south of Mountain Home, Idaho. Except for Russianthistle, the field contained only dry vegetation and ground litter. Shortly after being transplanted in the morning, the rose began to attract the adult grasshoppers. Some grasshoppers jumped onto the stem before making direct contact, while others kept crawling until making contact and then began to feed on lower leaves. In either case, individuals fed on the leaf edge beginning at the base or at the tip and often consumed the entire leaf before attacking another. A feeding grasshopper either stood on the ground or held onto the plant with the midlegs and hindlegs and used the front tarsi to hold the leaf and direct it to the mouthparts. Some grasshoppers cut through the petiole of leaves, which fell to the ground. Fallen leaves were eaten by grasshoppers still crawling on the ground. The grasshoppers also fed on the bracts and petals of flowers.

Valley grasshoppers were also offered transplanted spearmint. They fed on this plant in essentially the same way as on rose. They were observed walking to the mint and beginning to feed on the edge of the leaf down to mid rib and beyond. They also climbed the plant and began to feed. Grasshoppers on the rose and mint assumed various

Instar 1

1. BL 4-4.8 mm FL 2.4-2.7 mm AS 13.

Instar 2

2. BL 4.9 mm FL 3.2-3.3 mm AS 17.

Instar 3

3. BL 7.7-8.9 mm FL 4.4-4.9 mm AS 18-19.

Instar 4

4. BL 8.3-10.5 mm FL 6.1-6.5 mm AS 20.

Instar 5

5. BL 12-15.5 mm FL 8.6-9.3 mm AS 22-24.

Figures 1-6. Appearance of the six nymphal instars of *Oedaleonotus enigma* - their sizes, structures, and color patterns. Notice progressive development of the wing pads. BL = body length, FL = hind femur length, AS = antennal segments number.

orientations suited to their feeding on the edges of leaves. At times they fed on the centers of leaves by folding them.

Dispersal and Migration

Slow dispersal of older nymphs and adults occurs almost daily. During an outbreak nymphs tend to migrate in concentrated bands of 20 to 30 per square yard. The grasshoppers may move in one direction while following or entering a draw with greener vegetation or they may spread out in all directions. Populations are known to move from abandoned fields and rangeland into irrigated crops.

Long-winged adults may disperse by flight. They are able to fly from deteriorating habitats into more favorable areas. Evidence for such flights comes from a drought-stricken habitat 12 miles south of Mountain Home, Idaho. On 24 June 1991 a dense population of young adults consisted of 54 percent macropterous and 46 percent brachypterous individuals. Sixteen days later the population had significantly decreased in density and consisted of only 18 percent macropterous and 82 percent brachypterous, indicating emigration out of the area by a majority of the long-winged adults.

Evasive flights of adults are straight, silent, and range from 4 to 8 feet in distance and 4 to 10 inches in height. On landing they face directly or diagonally away from the intruder. Brachypterous adults evade an intruder by jumping distances of 2 to 8 feet. The larger, stronger adults jump farther than the smaller ones.

In spite of its importance to integrated pest management of destructive populations, no special study of the dispersal and migration of the valley grasshopper has been made. We do not know the length nor height of flights, nor whether macropterous adults leave their original habitat individually, in groups, or en masse.

Identification

The adult valley grasshopper is a large, colorful, spurthroated grasshopper (Fig. 7 and 8). The tegmina range from short to long. Short tegmina are as long or longer than the pronotum. Seven other species of the genus *Oedaleonotus* can be distinguished by their possession of tegmina shorter than the pronotum, and the tegmina are usually narrow and widely separated. These seven species are distributed mainly in California.

Valley grasshoppers with long tegmina also have long hindwings that are functional organs of flight. Adults with short tegmina have even shorter, nonfunctional hindwings.

The anterior edge of the pronotum has a narrow, conspicuously white to cream-colored band, giving this grasshopper the appearance of wearing a clergyman's collar.

Figures 7-10. Appearance of the adult male and female, the male cercus, and the egg pod and eggs.

The medial area of the hind femur is marked with fuscous chevrons separated by light tan lines. The proximal end of the inner medial area and the lower marginal area are colored orange. The hind tibiae are blue. The cercus of the male is broad basally with apex abruptly narrowed and fingerlike (Fig. 9).

Nymphs are identifiable by their color patterns, structures, and shape (Fig. 1-6).

1. Head. Face slightly slanting, vertex and occiput with fuscous band down middle divided by narrow cream-colored line. Antennae filiform, first two segments pale tan or yellow with several darker spots, remainder of segments fuscous, each with narrow light ring on anterior edge. Compound eye with many cream-colored spots in brown reticulum, relatively large dark spot near center.
2. Thorax. Disk of pronotum dark brown with longitudinal cream-colored, narrow, fusiform band down middle. The entire dorsal light band begins on head and extends onto abdomen becoming faint posteriorly.
3. Hindleg. Medial area of hind femur with fuscous chevrons that are broken in middle at proximal half; hind tibia light gray with fuscous maculations.
4. General color light tan with fuscous spots and maculations. Shape is robust, pronotum widens posteriorly, matching wide meso- and metathorax.

Hatching

Overwintering as eggs in an advanced embryonic stage, valley grasshoppers hatch early in spring. Hatching may start in early April in California, Nevada, and Idaho and continue for a month or longer. Hatching usually occurs in the morning when air temperatures are between 45° and 90°F and soil temperatures are between 76° and 98°F.

Nymphal Development

Upon hatching in early spring the nymphs usually have a plentiful supply of food, but because of cool weather during this time of year they develop slowly, becoming adults in about 42 to 50 days. Compared with later-hatching species, the valley grasshopper has a long nymphal period, due to both the cooler temperatures and to the greater number of nymphal instars, six instead of the usual five. The proportion of males to females is nearly 1:1. In different years, the proportion of short-winged adults to long-winged adults ranges from all short-winged to over 50 percent long-winged. Laboratory tests indicate that temperature may be one factor that influences this proportion. Cooler developmental temperatures (constant 80°F) result in greater proportions of long-winged adults, while warmer temperatures (constant 100°F) result in more short-winged adults.

Instar 6

6. BL 15-21.5 mm FL 9.5-11.7 mm AS 23-25.

Male

7. BL 17.5-21.5 mm FL 11-13.5 mm AS 24-26.

Female

8. BL 19-24 mm FL 11-15 mm AS 24-26.

Cercus

9. Side view end of male abdomen showing shape of cercus.

Egg pod

10. Egg pod and eggs.

Adults and Reproduction

Although many adult valley grasshoppers disperse from their nymphal habitats, variable numbers remain and reproduce, even in a deteriorating habitat. In a north-central Nevada site in 1954 when average temperatures were slightly above normal, the first adults appeared on 22 May, mating pairs were noted 20 days later, and egg deposition began two weeks after mating. Eggs begin development upon being laid in summer; by fall they reach an advanced developmental stage (after blastokinesis, stage 23), and then go into diapause. During winter the diapause is broken and warming weather in spring enables the eggs to complete embryonic development.

Females oviposit in bare ground adjacent to the base of shrubs and weeds, under cover of low growing forbs, such as turkey mullein, and around and under rocks. The pods, placed horizontally one-eighth to one-quarter inch below the soil surface, contain 16 to 22 eggs each. Anterior ends of the eggs face diagonally toward the soil surface. On hatching, the nymphs emerge from the side of the pod rather than through the end as is usually the case with other species of grasshoppers. The pods are slightly curved, short, and wide - one-half to five-eighths inch long and one-eighth to three-sixteenths inch diameter. Eggs are olive tan and 4.8 to 5.2 mm long (Fig. 10).

Population Ecology

The valley grasshopper has the capacity to increase to high numbers on rangeland and cause serious outbreaks. Densities may rise to over 20 adults per square yard. Outbreaks may be terminated by drought. At these times vegetation turns brown and desiccates, causing nutritional problems for the grasshoppers. Older instars and adults may disperse to survive in other areas with green host plants. Predation may also effectively end an outbreak. During June of 1954 three species of digger wasps (Tachysphex), which provision their offspring with nymphs of the valley grasshopper, reduced a population in south central Idaho from 25 per square yard to 3 per square yard. Large numbers of wasps emerged in June 1955 but they had virtually no grasshoppers on which to prey. Field studies indicate that the principal dipterous parasite is the tangleveined fly, *Neorhynchocephalus sackenii* (Williston); rate of parasitism during four years of study was variable, ranging from 0 to 24 percent.

Regrettably, no population has been studied for more than three years, a period too brief to gain useful information and insights into the population ecology of this grasshopper. Important questions for integrated management remain unanswered - how long outbreaks last, how long populations remain at low densities, and how many years are required for populations to grow from low to high numbers.

Daily Activity

The behavior of adults inhabiting a drought-stricken abandoned field 12 miles south of Mountain Home, Idaho was observed for three days in August 1991. Early food plants, tumble mustard and downy brome, had matured and dried and only Russianthistle remained green. Valley grasshoppers refused to eat this plant but regularly used it for roosting.

The majority of valley grasshoppers spent the night roosting head-up on the main or secondary stems of Russianthistle plants, but a small number rested on the ground exposed or under a canopy of Russianthistle. At daybreak, before the sun had risen, the adults were quietly resting in different orientations. At this time (6 a.m. DST), surface soil temperatures ranged from 52° to 64°F and air temperatures 1 inch from the ground ranged from 52° to 62°F. An hour later the vertically roosting grasshoppers assumed a basking orientation by adjusting their position so that the sun's rays shone perpendicularly on their sides. They remained quietly basking on the Russianthistle plants for an hour, then began to climb down to the ground, head first, where they again basked by turning a side perpendicularly to the sun's rays and lowering the exposed hindleg to the ground. A few spread this hindleg to the side, exposing even more of the abdomen.

Regular activities of pottering, feeding, and mating began at 8:30 a.m. when surface soil temperatures had risen to 82°F and air temperature 1 inch above ground level to 67°F. The grasshoppers fed on ground litter and on dead or dying bigheaded grasshoppers, Aulocara elliotti. By 10:45 a.m. ground temperatures rose to 110°F, inducing grasshoppers to elevate their bodies off the soil surface by stilting (raising up on their legs). By noon the soil surface temperature was 130°F, and the majority of the grasshoppers had climbed or jumped into Russianthistle, resting at heights of 4 to 7 inches. A few crawled into the shade of Russianthistle and remained on the ground. When temperatures moderated in late afternoon the grasshoppers again became active pottering, feeding, and mating. By 8 p.m., an hour before sunset, the majority of grasshoppers were roosting on Russianthistle and remained in these positions for the night.

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Obscure Grasshopper

Opeia obscura (Thomas)

Distribution and Habitat

The obscure grasshopper is widely distributed in the grasslands of North America. It thrives in habitats of short grasses and mid grasses, preferring blue grama, a short grass, for food and patches of mid grasses for roosting and basking. On stems of the latter, grasshoppers rest vertically head up for the greater part of the day. In the tallgrass prairie, scattered populations may occupy upper ridges vegetated by short grasses.

Economic Importance

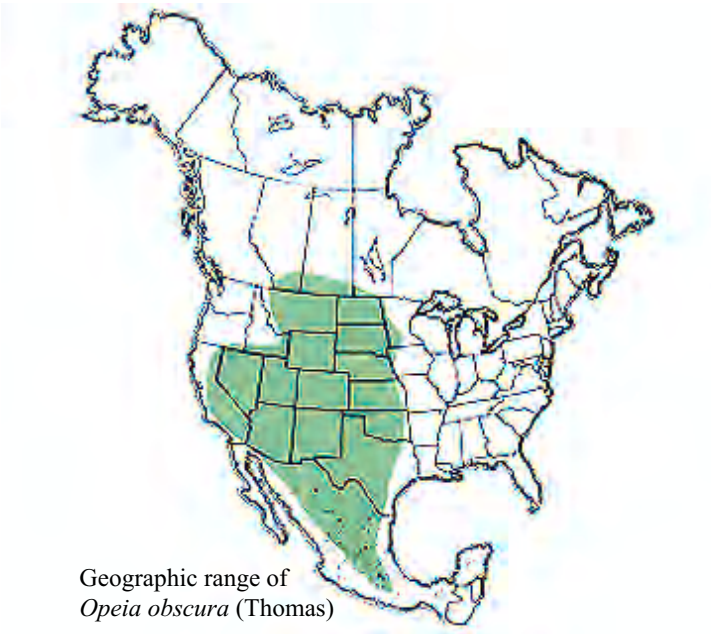
The obscure grasshopper concentrates its feeding on blue grama, an important forage grass for livestock on western grasslands. It ingests the green leaves and occasionally cuts and drops them. As a result it has two habits that make it a potentially damaging pest on rangeland. However, past records show that populations of the species do not reach outbreak numbers, but may add from 0.3 up to 3 grasshoppers per square yard to the density of an outbreak to slightly increase the overall damage. In low density assemblages (less than eight per square yard), the obscure grasshopper may become the dominant species, reaching peak densities of four per square yard.

Of the three weight divisions of range grasshoppers, the obscure grasshopper is in the lightest group. Live weights of males from the mixedgrass prairie of eastern Wyoming average 66 mg and females 143 mg (dry weight males 21 mg and females 48 mg).

Food Habits

The obscure grasshopper is a grass feeder and prefers blue grama. Examination of crop contents of grasshoppers collected from grasslands of Colorado, Kansas, Nebraska, and North Dakota revealed that diets consisted of 85 to 100 percent blue grama. Nineteen other species of grasses were found in crop contents. Usually in small amounts, these grasses included needleandthread, buffalograss, sand dropseed, little bluestem, and western wheatgrass. In addition, small or trace amounts of threadleaf sedge, needleleaf sedge, eight forbs, fungi, and arthropod parts were found. In a desert prairie of Texas, crop contents consisted of 78 percent blue grama, 13 percent buffalograss, 4 percent fall witchgrass, 2 percent Aristida sp., and 2 percent Muhlenbergia sp. Although a few observations have been made of nymphs feeding on dry cattle droppings, this grasshopper has not been observed to feed on plant litter or bran bait.

The obscure grasshopper feeds chiefly on the green leaves of grasses. The usual method of attack is to sit vertically, head up, on a leaf of blue grama, cut it near the middle, hang on to the cut portion with the front tarsi, and devour it to the tip. From a horizontal position on bare ground, this grasshopper may also feed on a recumbent leaf of blue grama. Feeding toward the base, it leaves a narrow section of leaf. Occasionally a grasshopper may feed head down on a green leaf of needleandthread, but this orientation is not maintained long before it turns around to its usual head up direction.



Geographic range of *Opeia obscura* (Thomas)

Dispersal and Migration

Little information is available on the capacity of the obscure grasshopper to disperse and migrate. Adults have long wings that range in length from nearly reaching the end of the abdomen to surpassing it by 3 mm. They are able to make short evasive flights. Available information indicates that their vagility is less than that of most long-winged rangeland species such as Aulocara elliotti and Ageneotettix deorum. Obscure grasshopper adults have not been found in the mountains west of Boulder, Colorado, which indicates little or no movement from their natural grassland habitats. In Wyoming's mixedgrass prairie where outbreaks of grasshoppers have been sprayed with insecticide, this species has virtually been eliminated for periods of four years. In one case, a male was found late in the season of the second year after treatment of an area, but the population did not subsequently make a comeback. The male evidently arrived from surrounding untreated rangeland, indicating that despite low vagility there is some dispersal.

Evasive flight is straight and silent for distances of 2 to 5 feet at heights of 3 to 6 inches. Flying grasshoppers may alight on vegetation or on the ground surface.

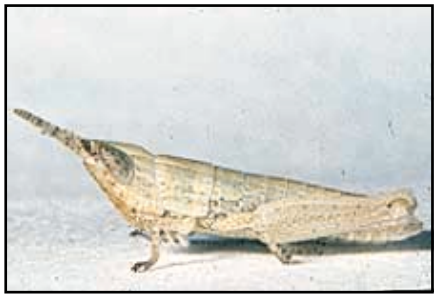
Identification

The adult obscure grasshopper is colored pale tan, sometimes pale green (Fig. 6 and 7). The males are small; the females are medium sized. Head has face strongly slanted; lateral foveolae of vertex invisible from above, top of head with single median carina. Antennae are ensiform. Except for carinae, the disk of pronotum is solidly colored (without dark stripes or triangles); lateral carinae nearly parallel; median carina cut once behind the middle (Fig. 8). Genae of head

Instar 1

1. BL 5.3-5.8 mm FL 2.2-2.5 mm AS 13.

Instar 2



2. BL 7.0-7.9 mm FL 3.3-3.6 mm AS 15-16.

Instar 3

3. BL 7.6-9.7 mm FL 4-4.8 mm AS 18-19.

Instar 4

4. Males: BL 8.2-11 mm FL 4.4-6.1 mm AS 21-22.
Females: BL 11.2-12.9 mm FL 6..5-7 mm AS 21.

Instar 5

5. Males: BL 11.5-12.2 mm FL 6.5-7 mm AS 22.
Females: BL 16-16.3 mm FL 9 mm AS 23.

Figures 1-5. Appearance of the nymphal instars of *Opeia obscura* - their sizes, structures, and color patterns. Notice progressive development of the wing pads. BL = body length, FL = hind femur length, AS = antennal segments number.

and lateral lobes of pronotum variably colored and marked with stripes and bands. Tegmina with longitudinal, dark brown, broken band in center (Fig. 9). Hind femur with a dark stripe in upper part of medial area, the stripe varies in width and darkness. Hind tibia colored pale tan or gray.

The nymphs are identifiable by their shape, external structures, and color (Fig. 1-5).

1. Head with face strongly slanted, antennae ensiform; lateral foveolae triangular, invisible from dorsal view.
2. Pronotum with distinct, parallel lateral carinae and distinct median carina. The median carina is entire (uncut) in instars I to III; slightly cut in instar IV and more so in instar V.
3. General color pale tan, markings present but pale with little contrast to the general color. Dark markings becoming more evident in instars IV and V. Hind femur with dark stripe on upper part of medial area, stripe faint in earlier instars. Hind tibia pale yellow; gray in front in instars IV and V.

Early instars of three species, *Opeia obscura, Eritettix simplex*, and *Psoloessa delicatula*, often occur together and may cause a problem in identification. They hatch late in the season and appear superficially similar. *O. obscura*, however, begins to hatch a month earlier than the other two species. A few distinct characters separate them readily. Nymphs of *P. delicatula* have the face nearly vertical, while the faces of *O. obscura* and of E. simplex are strongly slanting. The latter two can be separated by the differences in color patterns of the pronotal disk; *E. simplex* has a dark velvet band along each side, while *O. obscura* is entirely pale tan.

Hatching

The obscure grasshopper is a late-hatching species. In both the shortgrass prairie of Colorado and the mixedgrass prairie of Montana and Wyoming, eggs may begin to hatch as early as the first week of June or as late as the last week of June. The period of hatching is usually short, two weeks, but may occasionally be as long as four weeks. No study has been made of its embryology and egg development. The eggs, which lie relatively deep in the soil between depths of five-eighths and seven-eighths of an inch, are not exposed to extremes of soil temperature as the eggs of some other species of rangeland grasshoppers, such as *A. elliotti* and *A. deorum*.

Nymphal Development

Living under warm conditions of late spring and early summer, nymphs of the obscure grasshopper require 36 to 50 days to pass through five instars and become adults.

Figures 6-10. Appearance of the adult male and female of *Opeia obscura*, dorsal view of head and pronotum of adult female, fore and hind wings, egg pod and eggs.

When weather conditions delay hatching until the first of summer, nymphs then develop more rapidly in the warmer weather that follows. Adult males usually appear first, followed within a week by the females.

Adults and Reproduction

The adults generally remain at the same site in which the eggs hatched and the nymphs developed. There they have plenty of blue grama for food and patches of midgrasses for refuge and roosting. First appearance of adults in the mixedgrass prairie of Montana and Wyoming and the shortgrass prairie of Colorado occurs during late July or early August. In Arizona adults appear as early as April. The attrition of adults by parasites and predators goes on daily, and by October few individuals are left alive.

No special study of the obscure grasshopper's mating behavior has been made. In a laboratory terrarium, one observation was made of a male mounting a female and attempting, unsuccessfully, to engage his genitalia with the female's.

Females deposit their eggs deep in the soil and form a pod with weak earthen walls (Fig. 10). The eggs themselves are held together tightly and covered by cementing secretions of the female. An observation of oviposition was made of a caged female in a laboratory terrarium that contained mixedgrass sod and bare ground. The female chose bare ground beneath a 15-watt incandescent bulb. She worked her ovipositor into the soil to the full length of the abdomen and took 100 minutes to complete oviposition, after which she took 20 minutes to withdraw her abdomen and 90 seconds to brush loose soil over the hole with her hind tarsi. Following this parental care she walked away.

Pods of the obscure grasshopper are seven-eighths inch long and contain eight to ten small (4 to 4.3 mm long), pale tan eggs. The eggs overwinter, but no study of their embryology has been made. The species has one generation annually.

Population Ecology

The obscure grasshopper is a frequent inhabitant of sites in the mixedgrass and shortgrass prairies. It is usually a subdominant member of an assemblage in mixedgrass prairie and often a dominant member in shortgrass prairie. In both cases densities are low, ranging from less than 0.1 to 2.2 per square yard. Occasionally in the mixedgrass prairie the species becomes the dominant one of an economic infestation (greater than eight young adults per square yard) and it may reach a density of three per square yard.

The fluctuations of population densities of the obscure grasshopper were recorded in an assemblage of 19 species in the mixedgrass prairie of eastern Wyoming (Table 1). An increase took place over a two-year period just before a sudden five-fold increase occurred from 1973 to 1974. The assemblage tripled at the same time, indicating favorable conditions for

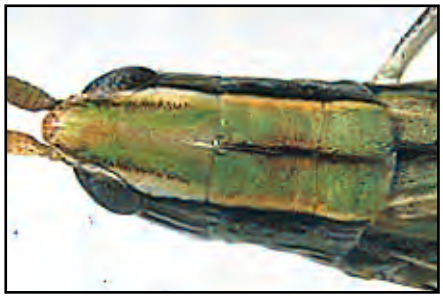
Male

6. BL 13.5-15 mm FL 7.9-8.9 mm AS 21-23.

Female

7. BL 18-19.7 mm FL 10.5-11.5 mm AS 23-24.

Dorsum



8. Showing ensiform antennae, the condition of lateral foveolae of vertex invisible from above, and parallel lateral carinae of pronotum.

Wings

9. Spread left tegmen and hind wing of female.

Eggs

10. Egg pod and clutch of eggs removed from pod

nearly all of the species. The response of the obscure grasshopper and the dominant species of the assemblage, Ageneotettix deorum, followed Parker's model of gradual increase for a period of a few years, then a large increase of numbers in the following year. The assemblage, however, was decreasing until the final year, but the rate of increase of some species was great enough to cause the whole population to go from noneconomic to economic without reaching outbreak proportions (25 or more young adults per square yard).

On the shortgrass prairie of northeastern Colorado, increases in a population of the obscure grasshopper, as the dominant species in an assemblage of five species, did not appear to follow Parker's model. Rather, this species increased by 1.7 to 2.7 fold over a period of four years to reach a peak density of 2.2 adult grasshoppers per square yard. On the other hand, this peak density may be less than the density possible under more favorable conditions.

Prevalence of the obscure grasshopper in the mixedgrass prairie of eastern Wyoming is moderate as indicated by the results of the 1991 grasshopper survey. The species was found in 77 of the 419 sites examined (18 percent). It occurred chiefly as a subdominant in assemblages of grasshoppers. In the mixedgrass prairie of Montana, a study of the grasshopper fauna in 1953 and 1954 showed that the obscure grasshopper was present in ten sites out of 38 (26 percent) and dominant in one of these. In the latter site, the assemblage consisted of nine species with a total density of three per square yard.

Daily Activity

The obscure grasshopper is a phytophilous species, spending most of each day sitting vertically head up on the stems and leaves of grasses. Observations made shortly after sunrise and before the grasshoppers became active indicate that the night is spent 1 to 2 inches above ground on both grasses and sedges. When the rays of the sun have struck their perches, about one hour after sunrise, both nymphs and adults begin to bask by adjusting their positions so that they directly expose a side or sometimes their back. They may also expose their back by taking diagonal positions on blue grama plants or small soil mounds. Occasionally they are found basking on bare ground, in which case they expose a side and often lower the associated hindleg. During the basking period, ground temperatures range from 70° to 100°F and air temperatures 1 inch above ground level range from 64° to 83°F. Activities such as feeding begin when ground temperature has risen to 85°F and air temperature to 70°F. No observations of their mating have been made in their natural habitat. In the mixedgrass prairie of western South Dakota females have been observed ovipositing into soil adjacent to buffalograss.

Because of their habit of sitting vertically on grasses, they are prone to remain inactive. When nymphs are flushed from their perches, they usually jump onto another plant. Occasionally they land on bare ground but quickly climb a grass leaf or stem. Adults may jump and behave like the nymphs or fly evasively. High soil temperatures of 110° to 130° and air temperatures at or above 90°F induce the grasshoppers to seek protection. They react in three main ways: they climb up to 4 inches on midgrasses, or they take diagonal positions on blue grama facing the sun to expose less of the body surface, or they rest in the shade under a canopy of vegetation above ground level on blue grama.

Their day ends with basking in the evening rays of the sun while resting vertically on grasses. As sunlight dims and temperatures cool, they eventually assume their nighttime positions.

Table 1. Population fluctuations of grasshoppers in a mixedgrass prairie site of eastern Wyoming (Platte County T28N R66W Sec 34 NE).

	Number per sq yd and (increase rate)						
	1968	**1969**	**1970**	**1971**	**1972**	**1973**	**1974**
Ageneotettix deorum	3.4	2.2 (0.6)	0.8 (0.4)	1.2 (1.4)	0.8 (0.7)	1.3 (1.6)	1.3 (2.6)
Opeia obscura	1.9	0.6 (0.3)	0.1 (0.2)	0.1 (1)	0.1 (1)	0.2 (2)	0.2 (4.5)
Assemblage of 19 species	12.8	6.1 (0.5)	2.9 (0.5)	5.6 (1.9)	4.0 (0.7)	3.3 (0.8)	10.5 (3.1)

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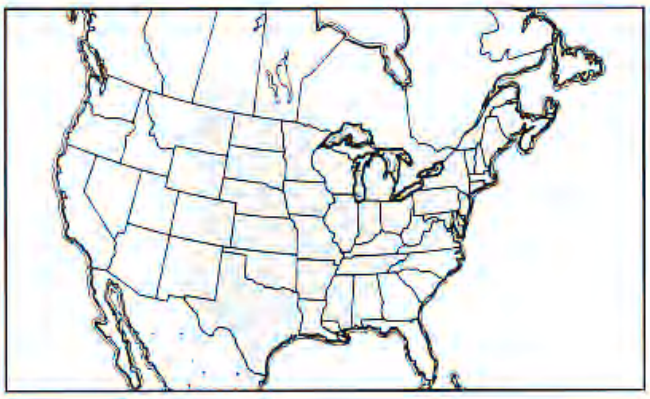
Slantfaced Pasture Grasshopper

Orphulella speciosa (Scudder)

Distribution and Habitat

The slantfaced pasture grasshopper ranges widely in North American grasslands from east of the Rocky Mountains to the Atlantic Coast and from southern Canada to northern Mexico. The species is most abundant in upland areas of short grasses in the tallgrass and southern mixedgrass prairies. In the shortgrass prairie of Colorado and New Mexico, it inhabits mesic swales. Generally preferring mesic habitats, its center of distribution appears to be in the tallgrass prairie where its populations often become numerically dominant. In eastern states this grasshopper occurs principally in relatively dry upland and hilly pastures with sandy loam soil and often becomes abundant and the dominant species.



Geographic range of *Orphulella speciosa* (Scudder)

Economic Importance

The slantfaced pasture grasshopper is a common, often numerically dominant, species in the tallgrass prairie region. Populations fluctuate in density increasing during a series of dry years along with other grassland species. Because it feeds almost exclusively on grasses, it contributes to the overall damage of forage by an assemblage of grass-feeding grasshoppers. In western Iowa during the outbreak of 1934 to 1937, it, in concert with *Ageneotettix deorum* and a few less numerous species, destroyed all green vegetation in bluegrass pastures. Assemblages ranged from 30 to more than 100 per square yard. Because the slantfaced pasture grasshopper is a small species, about half the size (weight) of *A. deorum*, it presumably eats less and causes less damage to forage. Live weight of adult males collected in Comanche County, Kansas, 29 August 1997, averaged 86 mg and adult females 173 mg (average dry weight of males 28 mg, and of females 58 mg).

Food Habits

The slantfaced pasture grasshopper is a general grass feeder, exhibiting some preferences among species of grasses. It usually feeds on grasses in proportion to their availability. Examination of crop contents of grasshoppers collected in the tallgrass prairie of eastern Kansas revealed that the common plants ingested were blue grama, sideoats grama, Kentucky bluegrass, little bluestem, and big bluestem. Because this grasshopper prefers to inhabit areas of short grasses, mowed fields, and heavily grazed pastures, a large proportion of crops, 16 to 27 percent, contained blue grama and Kentucky bluegrass. Fragments of other grasses detected in crops included buffalograss, hairy grama, prairie junegrass, western wheatgrass, tall dropseed, sand dropseed, Leibig panic, Scribner panic, switchgrass panic, prairie sandreed, reed canarygrass, prairie threeawn, stinkgrass, and yellow bristlegrass. Fragments of three species of sedges were also found: Penn sedge, needleleaf sedge, and fieldclustered sedge. Unidentified fungi were present in 6 percent of the crops of grasshoppers from Kansas and 8 percent from North Dakota. A few crops contained forbs and arthropod parts. Because of this grasshopper's wide distribution, it no doubt feeds on many other species of grass. In Michigan it has been observed to feed on Canada bluegrass (*Poa compressa*), arrowfeather threeawn (*Aristida purpurascens*), and poverty oatgrass (*Danthonia spicata*).

In a small patch of short grass within the tallgrass prairie of Comanche County, Kansas, two observations were made of method of feeding. On 24 August 1997 at 10:30 a.m. DST (temperature 1 inch above the ground was 79°), a pair in copulo hopped onto the top of blue grama and landed horizontally. After five minutes of basking, the female cut through a leaf, held onto the detached portion, and began to feed on the cut end. She fed briefly, crawled a short distance on top of the grass, and began to bask again. A second female was discovered resting horizontally on the top of a blue grama plant, stirred and oriented itself diagonally, and then began to feed on the tip of a leaf.

Because of the scant number of observations of feeding in nature, several observations were made in a terrarium stocked with turf of blue grama, western wheatgrass, and bare soil. Adults jumped or climbed onto the blue grama and fed vertically, head-up on the edge of a leaf, and moved up the leaf ingesting about 1/8 inch of leaf edge at a time. Thin edges of the attacked leaves were left standing. In another cage a female jumped onto the base of an 8-inch green leaf of downy brome and began to feed from a vertical head-up position on the edge of the leaf. Eating upward on the leaf, the grasshopper continued feeding for 18 minutes and then ceased. During this time the female consumed green leaf tissue 2 3/8 inches long by 1/8 inch deep and caused a gouge in the leaf of these same dimensions. A residual edge of 1/8 inch width was left standing. Occasionally a leaf was cut through; the grasshopper held onto the detached section with the front tarsi, eating the green material completely and dropping the

Instar 1

1. BL 4.3-4.8 mm FL 2.2-2.4 mm AS 11.

Instar 2

2. BL 5.8-6.2 mm FL 3-3.1 mm AS 14-15.

Instar 3

3. BL 8.7-9 mm FL 5.7-6.2 mm AS 17-18.

Instar 4

4. BL 9.3-12.5 mm FL 5.4-7.9 mm AS 18-20.

Instar 5

5. BL 9.9-14 mm FL 7.5-9.4 mm AS 19-22.

Figures 1-5. Appearance of the five nymphal instars of *Orphulella speciosa* - their sizes, structures, and color patterns. Notice progressive development of the wing pads. BL = body length, FL = hind femur length, AS = antennal segments number.

yellow, dry tip. Adults were also observed to feed head-down on leaf edges.

Dispersal and Migration

The slantfaced pasture grasshopper possesses long wings that allow it to disperse widely. In Lincoln, Nebraska one male and seven females were captured at night at electric lights 1 July 1921 indicating that these adults dispersed from surrounding tallgrass prairie. As valuable as such collections are in providing evidence of dispersal and migration, they leave several pertinent questions unanswered, especially grasshopper densities and meteorological data of the beginning, duration, and ending of flight. Of considerable significance is the swarming of populations in the New England states.

Flushed flight is silent, often straight, but sometimes circular, for distances of 1 to 4 feet and usually at heights of 4 to 12 inches. Flushed flight, however, may be as high as 5 feet (1 of 16 observations). Flights were chiefly crosswind but one was into a variable wind that ranged from 3 to 10 mph.

Identification

The slantfaced pasture grasshopper is a small, long-winged species with a variety of color patterns of brown, tan, and green (Fig. 6 and 7). Specimens are usually spotted and marked with brown and black. Some individuals bear much green while others are entirely tan and brown. The face is strongly slanted. The antennae are filiform. Compound eyes are tan with fuscous spots and markings. Behind each eye on the side of the head is a broad fuscous band, above it a thin black line, and above the latter a light line often colored ivory. A second species, *Orphulella pelidna*, inhabits the prairies east of the Rocky Mountains in greater abundance than *0. speciosa*. The two species can be distinguished from one another by structural differences. The slantfaced pasture grasshopper, *0. speciosa*, has a small semicircular depression of the vertex that is closer to the front and the lateral carinae of the pronotum incised once (Fig. 8 and Fig. 10). *0. pelidna*, a larger species, has a larger semicircular depression set farther back and the lateral carinae incised twice, occasionally three times (Fig. 10).

The nymphs are identifiable by their shape, structures, and color patterns (Fig. 1-5).

1. Head. Compound eyes tan and spotted brown; face strongly slanted; antennae of instar I terminally expanded, antennae of instar II flat and terminally pointed, antennae of instars III to V filiform; semicircular depression of vertex located close to front of fastigium; head of instars I and II with patterns of green, of instars III to V with patterns of tan, brown, green, and fuscous.
2. Lateral carinae of pronotum incised once, colored ivory, sometimes green on metazona in older instars; hind femur with medial and upper marginal areas of

Figures 6-10. Appearance of the adult male and female of *Orphulella speciosa*, pronotum, and the egg pod and eggs.

instars I and II tan, of instars III to V fuscous; lower part of medial area and lower marginal area pale gray. Thorax of instars I and II with patterns of green, of instars III to V patterns of tan, brown, green, and fuscous.

3. Abdomen in instars I and II green with darker green band on each side that runs forward on lateral lobe and side of head to eye, in instars III to V the lateral band is fuscous.

Hatching

The slantfaced pasture grasshopper is a late-developing species hatching about the same time as *Phoetaliotes nebrascensis*, a common coinhabitant of the tallgrass prairie. In the Flint Hills, Kansas (elevation 1,200 ft), hatching of the slantfaced pasture grasshopper began 16 May 1957-59 and 22 May 1976-78. The hatching continued for four to six weeks. In Comanche County, southcentral Kansas (elevation 2,000 ft), hatching began 10 June 1993. In northcentral Colorado (elevation 5,750 ft), hatching began in mid June 1958-60 and in eastem Montana (elevation 2,000-3,000 ft), 25 June 1950-51. In the Flint Hills in 1976-78 the period of hatching ranged from 20 days in the south to 47 days in the north. In the north some eggs were still hatching when some instar-V nymphs were nearly ready to become adults.

Nymphal Development

Nymphs of the slantfaced grasshopper develop through five instars to reach the adult stage. Several studies of the life history conducted in the Flint Hills of Kansas indicate a nymphal period of 42 to 48 days, as determined from date of first hatch to first adults.

Adults and Reproduction

Adults usually remain in favorable habitats of short grasses where they have developed as nymphs. Here they mature, mate, and reproduce, persisting generation after generation, frequently fluctuating in density. In the Flint Hills of Kansas adults first appeared 2 July 1957-59 and 5-9 July 1976-78 and in Comanche County, Kansas 17 July 1997. Near Boulder, Colorado adults first appeared by mid July 1958-60 and in eastern Montana by 5 August 1950-51. The peak of abundance of adults in the Flint Hills occurred in August.

Courtship of females by males was observed on the George Reserve, Michigan and in Southwestern Quebec. Males may court females by stridulating, making a faint ticking sound, repeated three to ten times. Males stalk moving females slowly and stealthily and when close enough, pounce on them without signaling. After the pair coupled, any disturbance or stirring of the female induces the male to stridulate, which keeps the mating pair together. In Comanche County, Kansas, 23-25 August 1997, pairs in copulo were observed from 9:22 a.m. to 2:20 P.M. (the time limits of the observations). The grasshoppers appeared to be in a mating frenzy. Of 60

Male

6. 7. BL 13-15 mm FL 8.7-10 mm AS 19-22.

Female

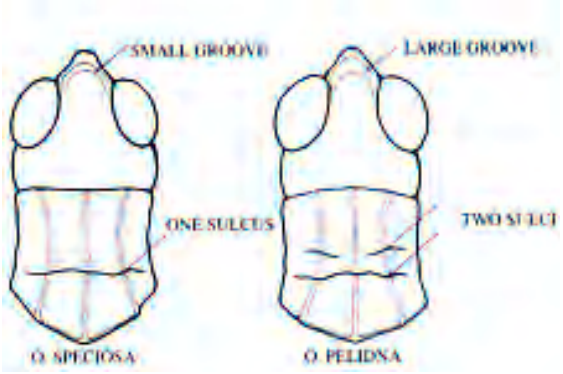
7. BL 16.5-19.5 mm FL 9.5-11.7 mm AS 21-22.

Pronotum

8. Lateral carina of pronotum incised once.

Eggs

9. *O. speciosa* egg pod and broken pod to show eggs.



Cutline: Dorsal view of head and pronotum of *Orphulella speciosa* and *O. pelidna* showing two characteristics for separating the two species. (Adapted from a drawing by Daniel Otte).

grasshoppers observed 18 were of single individuals and 21 were of copulating pairs.

Oviposition has not been observed in nature. A clue to location of pods was obtained in a laboratory terrarium furnished with buffalograss turf and bare soil. Three females deposited six pods in the small bare spaces between grass plants and none in the large bare areas. None of the pods was attached to roots of the grass. This location of pods among shortgrass plants would make the discovery of ovipositing females in nature difficult. The pods measure 13/16 inch long and contain from 10 to 13 eggs each (Fig. 9). Eggs measure 3.5 to 4.1 mm long and are pale yellow when laid becoming brown as they age. The eggs are deposited in summer, overwinter, and hatch the following year in late spring.

Population Ecology

In favorable dry years, populations of the slantfaced pasture grasshopper increase to outbreak densities. The shortgrass upland areas of the tallgrass prairie are especially prone to harbor large numbers. In 1935-36 this grasshopper and *Ageneotettix deorum* irrupted in pastures of western Iowa. Populations of the two ranged from 30 to more than 100 per square yard. In many of the pastures all green vegetation was eaten to the ground by the first of July and all new shoots were consumed as fast as they appeared. The scarcity of food induced populations to disperse, presumably to seek better grazing. Several studies of grasshopper populations inhabiting the tallgrass prairie of the Flint Hills, Kansas, revealed that the slantfaced pasture grasshopper is a characteristic species. Frequently it is the most abundant species of assemblages, at other times the second most abundant after such species as *Ageneotettix deorum*, *Mermiria bivittata*, *Melanoplus femurrubrum*, *Melanoplus sanguinipes*, or *Phoetaliotes nebrascensis*. The studies revealed that the peak of adult density of the slantfaced pasture grasshopper occurred the first or second week of August and then declined at a high rate of daily mortality (approximately 9 percent). In contrast, daily mortality rate of younger grasshoppers (late nymphal and early adult) amounted to only 2 percent.

That this grasshopper prefers to inhabit sites of short grass was evident in grassland of Comanche County, Kansas. On 25 August 1997 a population inhabiting a 300 square foot patch of blue grama and buffalograss reached 14 adults per square yard. In surrounding tallgrass the adults numbered less than one per square yard. The predominant tall grasses were interspersed with other patches of short grasses, which were also populated abundantly with adults of the slantfaced pasture grasshopper. In Oklahoma and South Dakota, entomologists have observed the dispersal of large numbers of adults into freshly mowed roadsides. These tracts of land bear not only shorter, but also greener and more succulent vegetation.

Daily Activities

The slantfaced pasture grasshopper is a phytophilous insect preferring to rest on vegetation, principally grasses, day and night. At night in its preferred habitat of short grasses, it appeared to rest 2 to 3 inches high on stems and leaves of blue grama and buffalograss (4 to 6 inches tall). Hidden by the dense grass leaves, the grasshoppers are difficult to locate and to observe their positions and orientations. Approximately two hours after sunrise, about 9 a.m. DST, they climb up grass stems and bask. Their usual position is resting on grass leaves at a 45° angle with their dorsum and a side in the sun. A few individuals have been found sitting in the sun on dry cattle dung. Basking may last for two hours before other activities begin. Pairs in copulo have been observed all day long from 9 a.m. to 2 p.m. As temperatures rise, the grasshoppers require little adjustment in orientation since they normally reside in cooler locations on the tops of short grasses. Some individuals may, however, rest on tall grass at heights of 9 inches. Presumably at sunset, the grasshoppers crawl or shinny down on short grasses to their night time resting places.

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Fourspotted Grasshopper

Phlibostroma quadrimaculatum (Thomas)

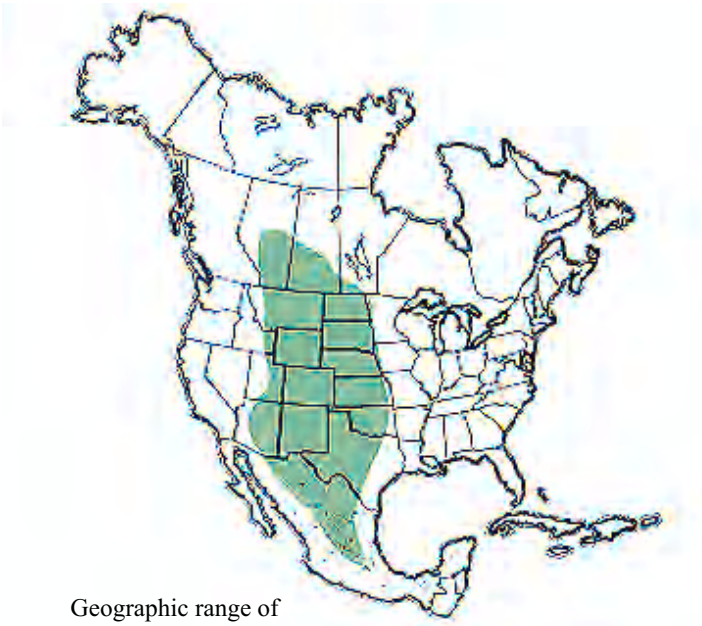
Distribution and Habitat

The fourspotted grasshopper has a wide distribution in western grasslands. It inhabits the shortgrass, mixedgrass, desert, and bunchgrass prairies. It prefers to feed on blue grama and is commonly found where this and other shortgrasses are the dominant vegetation. In the mixedgrass prairie where mid grasses and short grasses grow in mosaic patches, the fourspotted grasshopper occupies the patches of short grass. It has been recorded infrequently from the tallgrass prairie but with no description of the specific habitat in which it occurs.

Economic Importance

The fourspotted grasshopper lives in assemblages of grasshoppers inhabiting mixedgrass, shortgrass, and desert prairies of the West. It is usually a subdominant member of the assemblages, but it occasionally becomes the dominant species. Because it feeds principally on blue grama, a preferred forage plant of livestock, it can become a serious pest during grasshopper outbreaks. Estimates based on body weight indicate that an individual of this species ingests 1.4 gm of grass dry weight during its lifetime, an amount less than that eaten by the bigheaded grasshopper, *Aulocara elliotti* (2.0 gm). The fourspotted grasshopper is a thrifty feeder, cutting down little if any grass. It does much less clipping of forage than the bigheaded grasshopper. Because it does not increase to the high densities reached by the latter species, it is not as serious a pest.

The fourspotted grasshopper is a medium-sized rangeland species. Average live weights of males from the mixedgrass prairie of eastern Wyoming average 110 mg; females are much larger weighing an average 300 mg (dry weight: males 35 mg, females 90 mg).



Geographic range of
Phlibostroma quadrimaculatum (Thomas)

Food Habits

The fourspotted grasshopper feeds almost exclusively on grasses. Blue grama and buffalograss are its preferred food plants, but other species of grasses and sedges are ingested, usually in small amounts. Examinations of nymphal and adult crop contents show that blue grama makes up 89 to 100 percent of the diet. Six other species of grasses (buffalograss, needleandthread, western wheatgrass, sand dropseed, sideoats grama, and prairie sandreed) have been found in crop contents. In a desert prairie of Texas, crop contents consisted of 48 percent buffalograss, 21 percent blue grama, 19 percent burrograss, 5 percent fall witchgrass, 5 percent *Muhlenbergia* sp., and 2 percent of an undetermined grass. When given a choice of blue grama and western wheatgrass, caged adults ate only the blue grama.

Individual grasshoppers in the field, however, may contain a substantial amount of other grasses. For example, one female inhabiting the shortgrass prairie of Colorado had 40 percent western wheatgrass in its crop contents while another had 43 percent buffalograss. In addition to grasses, a few grasshopper crops have been found to contain small amounts of two sedges (needleleaf sedge and threadleaf sedge) and five species of forbs (prairie onion, fringed sagebrush, hairy goldaster, spreading fleabane, and scarlet globemallow).

The fourspotted grasshopper selects green leaves for its food. This species has not been observed to feed on dry plant litter in its natural habitat. Tests of caged grasshoppers indicated that only 6 percent of the insects had fed on bran bait.

Several observations of the feeding of this grasshopper in the mixedgrass prairie of eastern Wyoming indicate that it attacks grass in two chief ways. A grasshopper may climb up a green leaf of blue grama, turn around and feed about 1 inch from the tip, and proceed toward the base, ingesting the whole width and hanging onto adjacent leaves. The end pieces are cut off and fall. The second method is for a grasshopper sitting in a horizontal or diagonal position on the plant to begin feeding on the end of a leaf and progress toward the base.

Dispersal and Migration

The fourspotted grasshopper possesses functional wings, which range in length from being just short of the end of the abdomen to extending beyond the abdomen by as much as 5 mm. Specimens with longer wings occur commonly in the southern range of the species, as in Texas. Evasive flight is straight, silent, and extends for distances of 2.5 to 5 feet at heights of about 6 inches. The flying

Instar 1

1. BL 4.8-6.2 mm FL 3-3.2 mm AS 12-13.

Instar 2

2. BL 6.8-7.5 mm FL 4-4.4 mm AS 15-16.

Instar 3

3. Females: BL 8-9.1 mm FL 5.2-5.4 mm AS 18-19.

Instar 4

4. Females: BL 10.7-12 mm FL 7-7.6 mm AS 21-22.

Instar 5

5. Females: BL 14.5-18.5 mm FL 9.3-10.2 mm AS 23.

Figures 1-5. Appearance of the five nymphal instars of *Phlibostroma quadrimaculatum* - their sizes, structures, and color patterns. Notice progressive development of the wing pads. BL = body length, FL = femur length, AS = antennal segments number.

grasshopper usually lands on bare ground and faces away from the intruder.

Little is known about its dispersal and migration. Where the bigheaded grasshopper, *A. elliotti*, has often appeared as accidentals in the mountains west of Boulder, Colorado, no fourspotted grasshopper has ever been found there. However, evidence that the species occasionally disperses comes from a mixedgrass prairie of eastern Wyoming in which this grasshopper occurred at a density of 7 nymphs per square yard. An area of 840 acres was sprayed in 1970 with an insecticide resulting in the virtual elimination of this species. Not until 1973 was the species found again when one female was encountered in 100 square-foot samples. The following year two nymphs were found in 100 square-foot samples. The population evidently gained a new foothold in the area from dispersing adults and began once more to increase.

Identification

Adults of the fourspotted grasshopper are medium sized and strikingly colored (Fig. 6 and 7). Lateral foveolae are invisible from above. Side of head has a vertical ivory stripe below compound eye. Four diagnostic marks are on the median area of tegmen (Fig. 9). The hind femur has medial area crossed by three dark oblique bands. Hind tibiae are orange. The pronotal disk has the median carina cut once near the middle; the lateral carinae are distinct and constricted in the central region.

The nymphs are identifiable by their shape, external structures, color, and color patterns (Fig. 1-5).

1. Head is relatively large, face moderately slanting; antennae filiform. Instar I with dark brown vertical stripe below compound eye and with dark brown horizontal band behind compound eye that extends onto lateral lobe of pronotum, background color of head ivory. Postgena of head and anteroventral region of lateral lobe colored dark brown forming a vertical band that runs nearly parallel with the dark vertical band below compound eye. Instars II to V background color of head mainly green, dark brown band below compound eye becomes faded and broken; a vertical ivory band below compound eye is evident.
2. Pronotum with lateral carinae ivory-colored and constricted in central region (Fig. 8), constriction increases as nymphs molt from one instar to the next. Pronotal lobe with diagonal ivory ridge on anterior central region.

Figures 6-10. Appearance of the adult male and female of *Phlibostroma quadrimaculatum*, dorsal view of nymph, fore and hind wings, egg pod and group of eggs.

3. Hind femur with medial area almost entirely fuscous in instars I to III, partly green in instar IV and V. Hind tibia tan and gray or pink in late instars.
4. General color pattern of instar I ivory with fuscous band extending from behind compound eye to end of abdomen; instars II to V green or occasionally tan, the fuscous band entire on side of head and abdomen, broken on lobe of pronotum.

Hatching

The fourspotted grasshopper begins to hatch 15 to 25 days after the bigheaded grasshopper, A. elliotti, placing it in the intermediate hatching group. Hatching continues for two to three weeks. In the mixedgrass prairie of eastern Wyoming and shortgrass prairie of eastern Colorado hatching usually occurs during the first two weeks of June. Depending on the weather, actual dates of hatching in a site may differ by as much as 15 days between years.

Nymphal Development

Nymphs on the mixedgrass prairie of eastern Wyoming develop slowly, taking an average of 48 days to become adults. At some sites and in certain years the nymphal period may be as short as 33 days or as long as 55 days. There are five nymphal instars in females and usually four, but occasionally five, in males.

Adults and Reproduction

Adults of the fourspotted grasshopper remain in the same habitat in which the nymphs hatched and developed. The preferred host plant, blue grama, remains green and palatable through the summer and fall, even during most dry years. In the mixedgrass prairie of eastern Wyoming and shortgrass prairie of eastern Colorado, the adults appear during the latter part of July. Two weeks later, males begin to attempt copulation with the females. The males are attracted to moving females and may chase after them. Females that stop are courted by males, which tip their hind femora and stridulate. After closing in, the males mount and attempt to engage their genitalia with those of the females. Females may reject mounted males by producing vibratory stridulation or by shaking the hind femora in a vertical position. The initiation of successful copulation has not been observed, but copulating pairs have been seen in the morning between 9:45 and 11:45 MDT in late August and early September.

In western South Dakota, females have been observed to oviposit into soil next to buffalograss at maximum depths of 1 inch. The eggs are laid in clutches of 6 to 14 eggs and are contained in a tough pod seven-eighths to one inch long (Fig. 10). The eggs are tan and 4.8 to 5.2 mm long. The eggs pass the winter in the soil, but no study has been made of their embryology. The species has one generation annually.

Male

6. BL 14.5-15 mm FL 9.3-9.9 mm AS 22-24.

Female

7. BL 18.5-21.5 mm FL 11-13 mm AS 23-24.

Dorsum

8. Dorsal view of fifth instar female.

Wings

9. Spread left wings of female.

Eggs

10. Egg pod and group of exposed eggs.

Population Ecology

The fourspotted grasshopper is a common grasshopper, enjoying a relatively high frequency of occurrence in the mixedgrass and shortgrass prairies. Of 419 sites surveyed in 1991 in the mixedgrass prairie of eastern Wyoming, this species was encountered in 94 locations (22 percent). It occurred mainly as a subdominant in rangeland assemblages of grasshoppers, but in five of the 94 sites it was the dominant species. A study of the grasshopper fauna in the mixedgrass prairie of Montana in 1953 and 1954 disclosed the presence of the fourspotted grasshopper in 16 of 38 sites (42 percent) and dominance in two locations.

Densities of fourspotted grasshoppers, when subdominant in grasshopper assemblages, usually range from 0.2 to 1.5 young adults per square yard. When the species is dominant, densities may be as great as five per square yard. No information is available on how rapidly and under what conditions populations of this grasshopper rise to high densities and dominance.

In a population inhabiting the mixedgrass prairie of eastern Wyoming, the fourspotted grasshopper persisted for at least eight years at fluctuating, low densities. Densities of this species and the entire assemblage are shown for five years in Table 1.

A potentially significant mortality factor of fourspotted grasshoppers is parasitism by dipterous larvae. In populations of this species on the shortgrass prairie of northcentral Colorado, 12 percent of adults have been found to be parasitized by flesh fly larvae. Of these larvae, 64 percent were killed by the host and melanized, thereby reducing the negative impact of the parasite on population growth of the host.

Daily Activity

The fourspotted grasshopper is a ground-dwelling insect. At night both nymphs and adults sit horizontally on small areas (1 to 8 square inches) of bare ground or litter that are surrounded by blue grama and threadleaf or needleleaf sedge. They may also rest under a canopy of mid grasses. One to two hours after sunrise, they begin to bask horizontally on the ground by exposing a side perpendicular to the sun's rays. They usually enhance exposure of the abdomen by lowering the associated hindleg, which is held flexed and parallel with the abdomen. Basking lasts for one or two hours. When temperatures of the soil and air have risen above 70°F, the grasshoppers gradually become active and begin to potter, feed, and mate. They continue these activities until temperatures become too hot. When soil surface temperature reaches 100°F, grasshoppers horizontally positioned on bare ground assume a stilt posture in which they raise their bodies as high as their legs will extend. When temperatures rise still further (120°F soil surface), they take positions 1/2 to 4 inches above ground level on blue grama plants and face the sun. In this orientation they have moved away from the hot bare ground and expose a minimum of body surface to the sun's rays; they may also spread apart the hindlegs to increase cooling. Two hours before sunset the grasshoppers again bask. After basking and before sunset they move to their nighttime positions.

Table 1. Densities of late nymphs and adults of *Phlibostroma quadrimaculatum* in an assemblange of grasshoppers inhabiting a mixedgrass prairie site in eastern Wyoming (Platte County T28N R66W Sec 34 NE).

	Number per sq. yd.				
	1968	**1969**	**1970**	**1971**	**1972**
P. quadrimaculatum	1.4	1.0	0.5	0.6	0.6
Assemblage of 19 species	12.8	6.1	2.9	5.6	4.0

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Largeheaded Grasshopper

Phoetaliotes nebrascensis (Thomas)

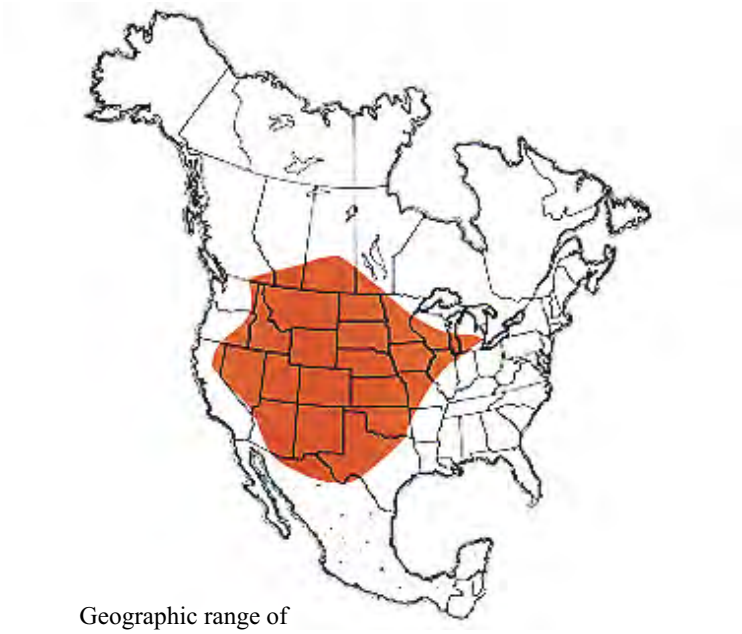
Distribution and Habitat

The largeheaded grasshopper ranges widely in the grasslands of North America. Preferring a habitat of tall, lush grasses, it is often the dominant grasshopper species in the tallgrass prairie and is a common inhabitant in taller types of the mixedgrass prairie. In shorter types it may be locally abundant in patches of tall grass growing in swales, ravines, along streams, and in roadsides.

Economic Importance

Feeding mainly on grasses, the largeheaded grass-hopper adds to the damage caused by infestations of rangeland grasshoppers. In the lush, tallgrass prairie, damage is visible but of little economic importance. Measurements of damage have not been successful in showing any statistical significance between treated and control plots. In the mixedgrass prairie, this grasshopper congregates in swales, especially during droughts, and consumes much of the forage that is in short supply for livestock and wildlife. In fall, adults may invade fields of winter wheat and feed on the seedlings, consuming the entire plant to ground level.

The female weighs twice as much as the male. Live weights of males collected from the mixedgrass prairie of southeastern Wyoming averaged 206 mg and females averaged 419 mg (dry weights: males 63 mg, females 137 mg).



Geographic range of
Phoetaliotes nebrascensis (Thomas)

Food Habits

The largeheaded grasshopper feeds almost exclusively on grasses, an unusual habit for a spurthroated grasshopper. It feeds heavily on little bluestem, big bluestem, and Kentucky bluegrass in the tallgrass prairie, while in the mixedgrass prairie it feeds principally on western wheatgrass. Populations in the bunchgrass prairie of west-central Idaho feed on bluebunch wheatgrass, but in its absence they feed on sand dropseed.

Extensive laboratory feeding tests reveal that largeheaded grasshoppers surprisingly prefer several species of grasses and forbs to their usual host plants. The preferred plants in the laboratory include the grasses: downy brome, Scribner panicum, barnyardgrass, witchgrass, junegrass, and foxtail barley; and the forbs: dandelion, meadow salsify, and skeletonweed. Plants as acceptable as the natural host plants include green bristlegrass and smooth brome, both introduced species. Smooth brome grows profusely in roadsides and often harbors dense populations of the largeheaded grasshopper. Less attractive grasses include blue grama, buffalograss, sand dropseed, needleandthread, prairie sandreed, and Kentucky bluegrass. The latter grass, however, is ingested in considerable amounts when it occurs in the habitat.

In tall, lush grasses, the largeheaded grasshopper rests vertically head-up on the host plant. During feeding, it may remain in this position or it may turn around and face vertically head-down. In either orientation it eats the edge of the leaf, creating a long gouge along one side and leaving a narrow edge of the leaf intact. The feeding of a nymph (instar IV) on western wheatgrass resulted in a 30 mm long, 2 mm wide gouge in the middle of the leaf, with 1 mm wide edge left standing. As soon as a head-down individual finishes a feeding bout, it turns around and again rests vertically head-up.

Dispersal and Migration

Because the majority of adults of the largeheaded grasshopper develop short wings unsuited for flying, this form of the species cannot disperse or migrate very far. When the need arises, however, adults readily disperse within the locale of their habitats. On Montana rangeland in midsummer, they have been observed to move from drying vegetation to nearby green vegetation. When these green areas became dry, they moved to adjacent gullies where the grasses still remained green. In southeastern Wyoming short-winged adults moved from a draw that had dried out in October to nearby seedling winter wheat, a distance of 30 to 90 feet. A mark-and-recapture study of movement of short-winged adults in the Nebraska sand prairie indicated a net displacement of individuals 3 to 13 feet from one day to the next. The distance for an individual (a male) with the

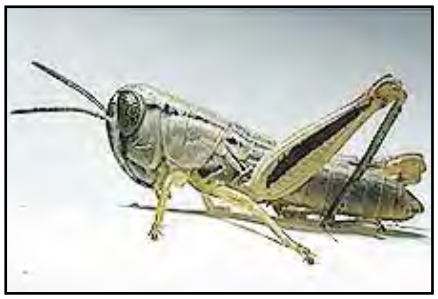
Instar 1

1. BL 2.3-4.6 mm FL 2.1-2.4 mm AS 13.

Instar 2

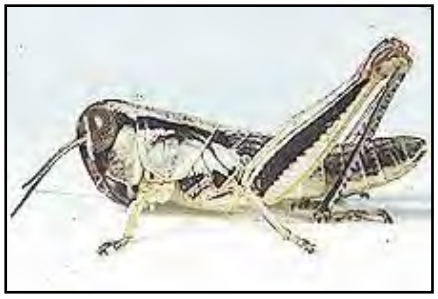
2. BL 6.3-7.1 mm FL 3.3-3.6 mm AS 16.

Instar 3



3. BL 7.9-10.7 mm FL 4.6-6.8 mm AS 18-20.

Instar 4



4. BL 12-13.5 mm FL 6.5-8.7 mm AS 21-23.

Instar 5

5. Males: BL 13.7-15.2 mm FL 8.7-9.9 mm AS 23-25.
Females: BL 17.2-18.5 mm FL 10.7-11.8 mm AS 24-25.

Figures 1-5. Appearance of the five nymphal instars of *Phoetaliotes nebrascensis* - their sizes, structures, and color patterns. Notice progressive development of the wing pads. BL = body length, FL = hind femur length, AS = antennal segments number.

longest period between marking and recapture (14 days) amounted to 135 feet.

The less common long-winged adults have strong powers of flight and no doubt are able to disperse considerable distances. Perhaps during past times, development of large numbers of long-winged adults with subsequent dispersal resulted in the widespread geographic range of this species.

Identification

The largeheaded grasshopper, slim and medium-sized, possesses a very large head relative to the rest of the body. The face is slanted. Most adults have short wings that extend only to the second or third abdominal segment and end in a point (Fig. 6 and 7). The rarer long-winged individuals (0.5 to 5.5 percent in a population) have wings extending a few millimeters beyond the end of the abdomen. Infrequently, as much as 25 percent of a population is long-winged. The body color of live adults is primarily light gray, the venter is often yellow. Dried specimens usually turn tan. The dorsal stripe of the hind femur is brown or fuscous and invades the lower medial area. The hind tibia is blue. The male cercus is triangular, ending in a blunt point (Fig. 9).

The nymphs are distinguishable by their structure, color, and shape (Fig. 1-5).

1. The head is large relative to the rest of the body, face is slanted; antennae are filiform; fuscous vertical stripe below and horizontal stripe behind compound eye, both stripes contrasting noticeably with light gray of head; compound eye brown with white to pale tan spots.
2. Edge of pronotal disk with fuscous wedge-shaped stripe, wide anteriorly, narrowing posteriorly, faint in instar I.
3. Hind femur with pronounced dorsal stripe that extends into ventral half of medial area; hind tibia pale yellow with front fuscous in instars I to III, blue in instars IV and V.

Hatching

Hatching about one month after *Ageneotettix deorum*, the largeheaded grasshopper belongs to the late-developing group of species. In the tallgrass prairie of eastern Kansas, eggs may begin to hatch as early as May 22. In the mixedgrass prairie of southeastern Montana hatching begins as early as June 8 and in southeastern Wyoming as early as June 13. Hatching continues for a period of four

Figures 6-10. Appearance of the short-winged adult male and female, wings of a long-winged female, end of male abdomen, and egg pod and loose eggs.

Male

6. BL 17.8-19.4 mm FL 10.6-11.4 mm AS 25-26.

Female

7. BL 20.5-22.5 mm FL 12.1-13.1 mm AS 25-26.

Long Wings

8. The wings of a long-winged female.

Cercus

9. End of male abdomen showing cercus, furcula, and other structures of terminus.

Egg pod

10. Egg pod and several loose eggs.

weeks or longer. Possible abiotic reasons for the late hatch include the relatively deep location of the eggs in the soil (an inch or more) and the cool soil temperatures of the lush habitat. In newly burned tallgrass prairie, eggs hatch two weeks earlier than in unburned tallgrass prairie due to the exposed soil warming more quickly in the spring than soil covered by deep litter of the unburned prairie.

Nymphal Development

The nymphs of the largeheaded grasshopper develop slowly. As measured by the time from first appearance of instar I to the first appearance of the adult, the nymphal period requires 55 days both in Kansas and Wyoming. The probable cause of this extended period is the habitual perching of nymphs on tall grasses. This location is usually several degrees cooler than the ground location of most rangeland species. Development of both males and females requires five instars for completion of the nymphal period.

Adults and Reproduction

Short-winged adults remain in the same general area in which the nymphs developed, but do move short distances to track greener and more nutritious host plants. The first adults appear in mid to late July in Kansas, while in southeastern Wyoming they appear during the first week of August.

Little is known about the maturation and reproduction of this grasshopper in nature. Laboratory cage tests suggest a high rate of fecundity. Short-winged females produced 120 eggs per capita during a reproductive period experimentally set at 25 days. Long-winged females produced fewer eggs because of the apparent necessity to divert part of the nutrient intake to the production of flight muscles and long wings.

No observations of courtship have been made, and published observations of mating are zilch. One mating pair was seen in the mixedgrass prairie of eastern Wyoming at 9:15 a.m. DST on 1 August 1968 and another in a roadside habitat dominated by smooth brome and western wheatgrass at 9:30 a.m. DST on 26 August 1993. In the latter case, the pair, which was basking vertically head-up 6 inches high on a smooth brome leaf, had assumed the usual mating position of grasshoppers (i.e., the male clinging on top of the female). The male's head rested immediately behind and above the female's. Because of the smaller size of the male, the female's genitalia had to curve up to meet the male's curving down.

The oviposition sites selected by females are uncertain. In a published study of grasshopper biology conducted in the sand prairie of southeastern North Dakota, females were said to oviposit in vegetated sites. However, it is not clear whether

the females oviposited into or close to crowns or into small bare areas interspersed among the plants. The egg-laying behavior of females confined in a laboratory terrarium of sandy loam soil and mixedgrass prairie turf further confuses the issue. During ten days of confinement, five short-winged females deposited five pods in the bare soil and none in the turf.

The pods are 1 to 1 1/4 inches long and slightly curved in the region of the eggs (Fig. 10). The pods of short-winged females usually contain 28 eggs, equaling the total number of ovarioles, while the pods of long-winged females usually contain from 20 to 24 eggs. Eggs range in color from olive to brownish yellow and measure from 4.1 to 4.4 mm in length.

Population Ecology

Populations of the largeheaded grasshopper reach their highest densities in habitats of lush tall grasses. In the Flint Hills, a tallgrass prairie region of eastern Kansas extending into Oklahoma and Nebraska, the species is common and often dominant. This large natural grassland, over 200 miles long from the north to the south and as much as 50 miles wide, appears to be the species center of distribution. Densities regularly number three to four young adults per square yard and probably increase to much higher densities during outbreaks.

The distribution of the largeheaded grasshopper extends west into the mixedgrass prairie, where the species occupies the more luxuriant aspects, particularly swales, riparian areas, and roadsides. In these sites, stands of western wheatgrass grow tall and rank, providing favorable habitats and an abundance of food. Populations aggregate in these habitats reaching densities as high as 12 young adults per square yard and often achieve dominance in the grasshopper assemblage. In contrast, surrounding mixedgrass prairie usually harbors less than one young adult per square yard, and the species occupies a low rank in the assemblage.

This grasshopper inhabits other grasslands of the West, usually in limited areas and at low densities. In the shortgrass prairie the species is rarely a member of the grasshopper assemblage, but in northwestern Texas it was a common species on rangeland in two out of seven years (1966-72). The desert prairie does not often harbor the largeheaded grasshopper, but south of Tucson in an ungrazed sanctuary of the Audubon Society it inhabits level uplands covered by luxuriant stands of blue grama, plains lovegrass, and wolftail grass. Average seasonal densities from 1985 to 1989 ranged from 0.1 to 0.3 per square yard. In 1989, at 0.3 per square yard, the largeheaded grasshopper became the dominant species in a low-density assemblage of nine species. This grasshopper is rarely found in sites of the bunchgrass prairie, but in Idaho it is one of the major species living on steep hillsides vegetated with bluebunch wheatgrass. Densities, however, are low, usually less than one per square yard.

Daily Activity

In its preferred habitat of tall grasses the largeheaded grasshopper behaves as a phytophilous species, sitting on stems and leaves for most of the day and night. Warm nights are spent resting vertically, head-up on grass leaves and stems at heights of 6 to 12 inches. Cold nights are spent lower down on the grass or under litter.

In the morning on a clear day, two to three hours after sunrise, the nymphs and adults, resting vertically head-up on tall grasses, begin to bask by turning a side perpendicular to the rays of the sun and lowering the associated hindleg. This orientation raises their body temperature, which has fallen during the night, to that of the habitat, which in Wyoming ranges from 50 to 60½F. They remain quietly basking, occasionally stirring, for two to three hours and eventually become active in mid morning. Individuals in habitats of short and mid grasses usually spend the night under litter. In the morning they bask sitting horizontally on bare ground.

After basking, the grasshoppers infrequently move about on the tall grasses by crawling or jumping from one plant to another. They may also back down a grass stem or turn around and crawl head-down to reach the ground. On the ground they crawl and hop intermittently, moving a net distance of 15 feet in 30 minutes. Grasshoppers perched on tall grass have been observed to feed from early morning to evening (7 a.m. to 6 p.m. DST). More observations of feeding, however, have been made from 9 to 11 a.m. DST than during any other two-hour period.

A second period of basking occurs in late afternoon. At this time the grasshoppers bask for approximately two hours. Near sunset, when shadows engulf their habitat, they take nighttime positions. Those basking vertically head-up on tall grasses may remain there, or back down several inches, while others may find shelter under ground litter.

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Brownspotted Grasshopper

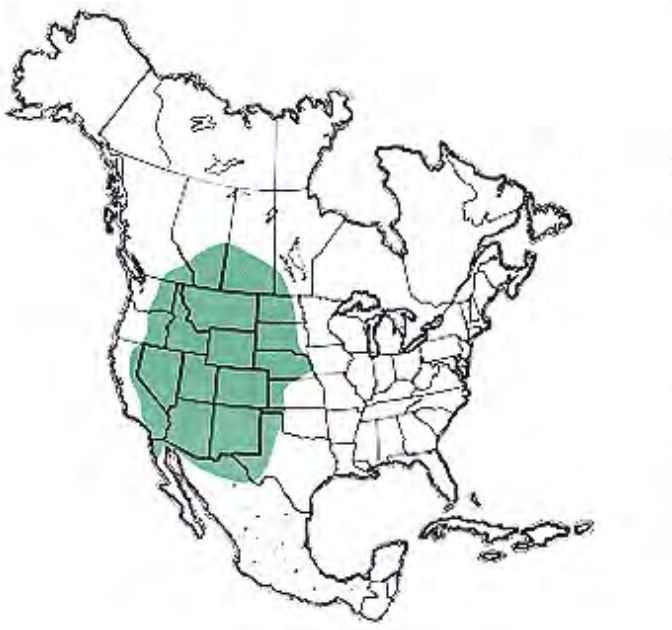
Psoloessa delicatula (Scudder)

Distribution and Habitat

The brownspotted grasshopper inhabits the grasslands of the western states and provinces. It is a common early denizen of desert shortgrass, mixedgrass, and bunchgrass prairies and extends its distribution into western desert shrub communities where grasses form a sparse understory. It does not invade mountain grasslands, but is present in foothill habitats as high as 8,076 feet.

Economic Importance

The brownspotted grasshopper feeds on grasses and sedges. When adults are abundant in spring, they cause some of the first grasshopper damage to rangeland. Populations of adults in the mixedgrass prairie may reach densities of 30 grasshoppers per square yard and maintain high densities for three or more years. Normally, populations of adults range from 0.5 to 1 grasshopper per square yard and cause no significant damage. This grasshopper is in the smallest group of the three size divisions of rangeland grasshoppers. Live weights of males average 99 mg and of females 284 mg (dry weight: males 32 mg, females 90 mg). Quantitative assessment of damage by this species has not been undertaken.



Geographic range of
Psoloessa delicatula (Scudder)

Food Habits

Host plants of the brownspotted grasshopper consist almost entirely of grasses and sedges. When the overwintered nymphs become active in early spring, they feed mainly on needleleaf and threadleaf sedges, plants that start seasonal growth very early. The nymphs feed also on cool- season grasses: western wheatgrass, downy brome, and sixweeks grass. As the season progresses and the grasshoppers become adults, they feed more on warm-season grasses, especially blue grama and sand dropseed. Examination of gut contents and direct observations have provided records of the brownspotted grasshopper feeding at various times and places on two species of sedges and 14 species of grasses. It may ingest in minute amounts forbs, lichens, moss, and arthropods.

The brownspotted grasshopper has two methods of attacking a grass or sedge. The first approach is to climb a short distance up the leaf and start cutting the leaf by eating through it. The grasshopper then holds onto the cut portion with the front tarsi and feeds on the entire leaf to the tip. The second method is for the grasshopper to raise its head and cut through a leaf, recover the fallen leaf on the ground, and then feed on it from the cut end to the tip. In the first method the grasshopper is upright, clinging to the leaf with mid- and hindlegs, and in the second method the grasshopper sits horizontally on the soil surface and litter, the mid and hind tarsi in contact with the ground, while the front tarsi handle the cut leaf. This grasshopper also feeds on ground litter, usually green or dry grass leaves, and on recumbent attached grass leaves.

Dispersal and Migration

Adults of the brownspotted grasshopper possess long wings that extend beyond the end of the abdomen. These provide the adults with strong powers of flight for evasion of predators and for dispersal. After sunrise, three to four hours of basking are required before flight is possible. Evasive flights are silent and sinuous for distances of 5 to 9 feet at heights of 4 to 6 inches. The end of a flight often comes with a quick turn in direction and sudden drop to the ground. The grasshopper lands horizontally on the surface and may face the intruder. No records of this grasshopper migrating have been published. Collection of a solitary female on a lawn in Laramie, Wyoming, at a distance of 1 mile from the nearest rangeland habitat provides some evidence that dispersal occurs.

Identification

Adults of the brownspotted grasshopper are small and colored dull gray and brown with dark brown spots and maculations (Fig. 6 and 7). Head with face slightly slanted; frontal costa grooved (Fig. 9); lateral foveolae well-defined and square to oblong. Pronotum with distinct median carina

Instar 1

1. BL 4.4-5.3 mm FL 2.4-2.7 mm AS 13-14.

Instar 2

2. BL 5.1-6.1 mm FL 3.3-4.1 mm AS 15-16.

Instar 3

3. BL 6.0-7.5 mm FL 4.1-4.9 mm AS 17-20.

Instar 4

4. BL 8.7-11.6 mm FL 5.7-7.2 mm AS 21-23.

Instar 5

5. BL 10.8-15 mm FL 7.2-9.4 mm AS 23-24.

Figures 1-5. Appearance of the five nymphal instars of *Psoloessa delicatula* - their sizes, structures, and color patterns. Notice progressive development of the wing pads. BL = body length, FL = femur length, AS = antennal segments number.

cut once in front of middle; lateral carinae constricted in middle, deeply cut, and strongly depressed in region of cut; lateral lobes with rounded broad ridge that runs diagonally upward; lower on the lateral lobe, a smaller, oblique ridge is present; it runs in the opposite direction and is often conspicuously colored ivory. Hind femur with triangular marking on upper marginal area; hind tibia proximally pale gray with brown spots, distally orange.

Nymphs (Fig. 1-5) are identifiable by their shape, external structures, and color patterns:

1. Head with face slightly slanted and with front of fastigium appearing rounded; frontal costa grooved; lateral foveolae square to oblong; each side of vertex with a curved brown stripe that ay extend short distance on pronotum (Fig. 8). Antennae filiform (threadlike).
2. Pronotum with definite median carina, entire (uncut) in instar I, cut in instars II to V; lateral carinae distinct and slightly constricted in instar I, strongly constricted, cut and depressed in instars II to V; lateral lobe with rounded broad oblique ridge faintly evident in instar I and becoming larger in subsequent instars; usually a distinctive pale yellow, oblique ridge present on lower rear of lobe (see Figure 4 for a clear picture).
3. Hind femur with rudimentary triangular maculation on upper marginal area. Hind tibia pale gray and brown.
4. General body color of nymphs is pale tan to brown with dark brown markings and with a light band on dorsum from head nearly to end of abdomen (Fig. 8). Older instars become darker, colored brown and gray with dark brown markings (Fig. 1-5).

Hatching

Rearing the brownspotted grasshopper in outdoor cages indicates that this species has a two-year life cycle in central Saskatchewan (Fig. 11). The eggs remain viable but unhatched during the summer in which they are laid, and hatch during the second summer at a time when most rangeland grasshoppers are mature and reproducing. The eggs are exposed to warm soil temperatures of their first summer and to low soil temperatures of winter. They perhaps break diapause during the winter cold period. The presumed timing of this event raises the question as to why

Figures 6-10. Appearance of the adult male and female of *Psoloessa delicatula*, diagnostic characters, and the egg pod and several loose eggs.

hatching is delayed during their second summer. In the southern range of the species, eggs appear to hatch the same summer in which they are laid. Unknown is the location of the line or zone between life cycles of one year and two years. Further study of the embryological development and life cycle of this grasshopper is desirable. For a small grasshopper, eggs lie relatively deep in the soil (three-quarters to one and one-quarter inches). The period of hatching lasts from two to six weeks.

Nymphal Development

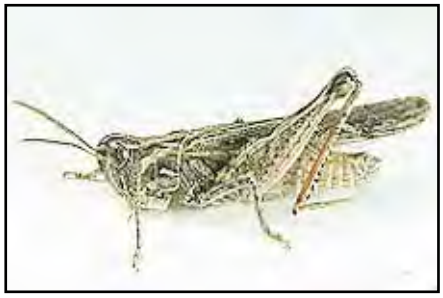
Nymphal development is slow and extended. In the Pawnee National Grassland of northeastern Colorado, for example, eggs start to hatch in early July and nymphal development proceeds through summer and fall for about 120 days. As temperatures decrease and days become shorter in fall, greater numbers of nymphs take shelter and begin winter dormancy. Cold weather in November compels all nymphs, mainly fourth and fifth instars by this time, to seek refuge under ground litter and bury shallowly in the soil. Spells of unseasonably warm weather in winter cause some individuals to become active for brief periods. After hibernating through the winter, the nymphs resume development in April and reach adulthood during this and the next month.

Adults and Reproduction

The adults remain in the same habitat in which the eggs and nymphs develop. Even though the first group of host plants mature and dry, food resources remain plentiful. The adults feed increasingly on the vigorously growing warm-season grasses as summer progresses. A few weeks after fledging, the grasshoppers mate. Observations of mating pairs have been made during morning hours (9 to 11 a.m. DST), in June and early July. A male seeking a mate stridulates, sending two to four acoustical signals, while advancing on a female. When close, he mounts and attempts to copulate. The female may accept him or reject him by emitting a series of ticking sounds (produced by the hind tibiae kicking out and striking the ends of her tegmina).

A gravid female ready to oviposit selects a site of bare soil. Boring over an inch into the soil, she deposits 18 eggs and surrounds them with very little froth but forms a three-quarter inch froth plug above them. The whole pod measures around one and one-half inches (Fig. 10). The eggs are yellow and 4.9 mm long.

Male



6. BL 12.5-15.5 mm FL 7.9-9.3 mm AS 23-25.

Female

7. BL 17-21 mm FL 10.5-12.5 mm AS 23-27.

Dorsal view

8. Shape and color pattern of instar 2.

Head

9. Note square lateral foveolae and grooved frontal costa.

Egg pod

10. Egg pod and several loose eggs.

Population Ecology

Although densities of the brownspotted grasshopper usually remain low (0.5 to 1.0 adults per square yard), they occasionally become very high in habitats of the mixedgrass prairie (25 to 30 adults per square yard). Heavily infested sites may encompass as much as four square miles. Causes of these population outbreaks are unknown as no detailed studies of population dynamics have been made over a sufficiently long period. Limited data indicate that mortality rates of 5 to 6 percent per day of adults at both low and high densities are similar to mortality rates of other rangeland grasshoppers. Large variations in survival of overwintering nymphs have been observed, ranging from 46 to 100 percent.

Daily Activity

The brownspotted grasshopper is a ground-dwelling insect with an array of behavior patterns that allow it to cope with both cold and hot temperatures in its environment. During early spring, temperatures decline rapidly in the evening, causing the nymphs to seek cover under grass litter where they spend the night. In the morning, two to three hours after sunrise, they begin to emerge from their shelters and bask on the soil surface by exposing their sides to the warming rays of the sun. The nymphs bask for long periods, three to four hours. During the latter part of this time they may feed on ground litter, when the soil temperature has reached 70°F, even if air temperature an inch above the ground is still low (54°F). Normal activity of the nymphs begins late in the morning and ends early in the afternoon. They may begin basking by 3:30 p.m. and start taking cover by 5:30 p.m. DST.

Although the adults experience warmer weather in May and June, their body temperatures fall at night and may be no greater than 40°F at sunrise. Under these cold conditions they sit immobile on the surface of the soil or litter. When the sun strikes the habitat, they turn their sides perpendicular to the sun's rays and bask for as long as three hours. When soil temperatures reach 75°F they may begin normal morning activities of feeding, mating, and ovipositing. Air temperatures above 77°F cause them to begin moving into shade, while air temperatures above 90°F cause them to actively seek shade. They rest on the ground surface in the shade of small shrubs or clumps of grass, and assume a "straddle" position in which the hindlegs are spread away from the body. Six thermoregulatory postures assumed by adults of this grasshopper have been described under different environmental conditions. A seventh may be added, termed "squat," in which the basking grasshopper lowers its body and both flexed hindlegs onto the soil surface. Adults end their day like the nymphs, basking in the rays of the sun. Finally, they crawl under canopies of grasses in the habitat for shelter during the night.

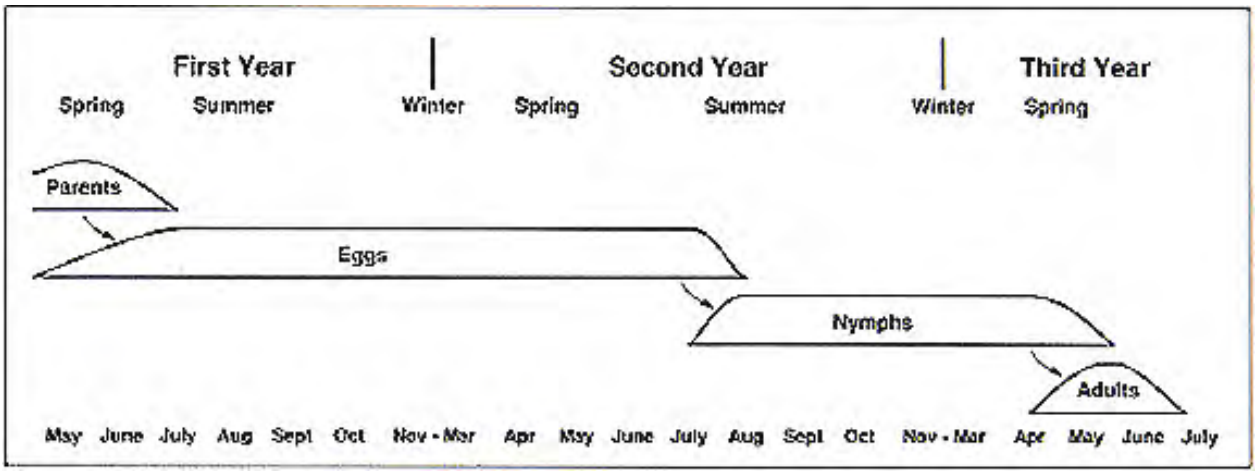


Figure 11. Diagram of the two-year life cycle of the brownspotted grasshopper, *Psoloessa delicatula* (Scudder) in central Saskatchewan. The species has a one-year life cycle in its southern range.

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Mottled Sand Grasshopper

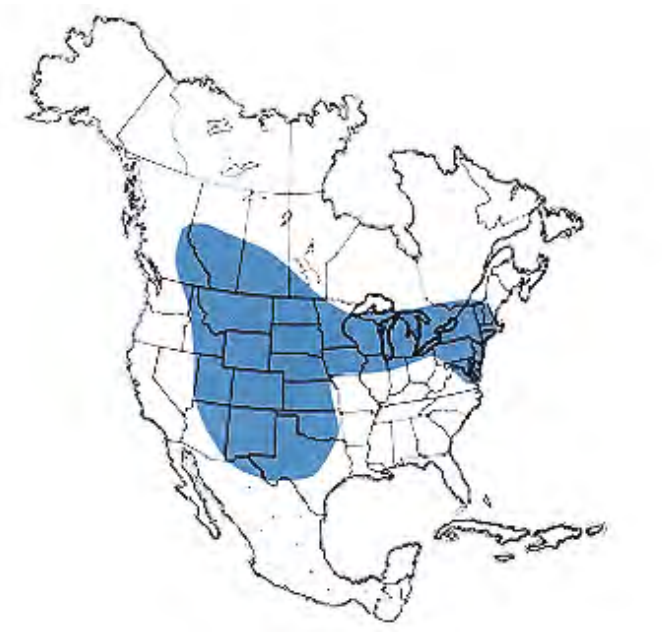
Spharagemon collare (Scudder)

Distribution and Habitat

Although locally distributed, the mottled sand grasshopper has a wide geographic range in North America. Its preferred habitat consists of sandy soil covered by sparse grasses and forbs. In the West it inhabits the sand prairie where the characteristic vegetation consists of the tall grasses, sand bluestem, and prairie sandreed, as well as several short and mid grasses and numerous species of forbs. Although the mottled sand grasshopper is prevalent in grassy areas with sandy soils, it is a rare species in grasslands with loam to clay soils such as in the mixedgrass prairie. Here, the closely related species, *Spharagemon equale*, is common. Yet, ruderal sandy loam sites (e.g., edges of wheat fields, roadsides, and other disturbed areas) provide favorable habitats for the mottled sand grasshopper where it may build up to unusually high densities.

Economic Importance

The mottled sand grasshopper is not a serious pest. Its usually low densities (less than 0.1 to 1 per square yard) cause only minor damage to forage. It may, however, increase to greater densities in disturbed areas of sandy loam soil and cause damage to wheat and other grains. In Idaho, densities of nymphs may reach 10 per square yard and present a hazard to newly seeded crested wheatgrass.



Geographic range of *Spharagemon collare* (Scudder)

Food Habits

The mottled sand grasshopper is a polyphagous species that feeds on grasses, sedges, and forbs. Examination of crop contents of grasshoppers collected in Colorado and Nebraska revealed that the species had fed upon 12 grasses, three sedges, and 13 forbs. Grasses and sedges consumed in large amounts were blue grama, needleandthread, western wheatgrass, sand dropseed, witchgrass, and threadleaf sedge. Grasses, sedges, and rushes ingested in lesser amounts included sand bluestem, little bluestem, prairie sandreed, buffalograss, hairy grama, junegrass, sun sedge, and baltic rush. Among forbs, kochia and Missouri milkvetch were heavily consumed. Other forbs eaten in greater than trace amounts were sand sagebrush, western sticktight, sunflower, redroot pigweed, bracted spiderwort, prairie spiderwort, rusty lupine, and western ragweed. In Michigan this grasshopper has been observed to feed on Kentucky bluegrass and on three forbs: type penstemon, lettuce, and an undetermined tall composite.

In an eastern Wyoming sand prairie, observations were made of adults feeding on grass and ground litter. A summary of these observations attests to the geophilous behavior of this species. Crawling on the ground, a hungry grasshopper contacted a recumbent grass leaf and began to feed. Handling the leaf with the front tarsi, it consumed the entire leaf from tip to base. If the contacted leaf was upright, the grasshopper raised up on its hindlegs and pulled the leaf down with the front tarsi. In both cases the grasshopper fed while resting horizontally on the ground. Another hungry grasshopper contacted a cut leaf and ground litter as it crawled on the ground and fed on these items while handling them with the front tarsi.

On a dirt roadside, two IV instars were observed feeding horizontally on the ground. One fed upon a fallen seed of downy brome and the other on ground litter.

Several observations of feeding adults confined in a terrarium have been made. In addition to the feeding methods described above, adults have been seen to climb grasses to a height of 1/2 inch, cut through the stem, and consume the cut piece while holding onto it with the front tarsi. During the feeding bout, the hindlegs may be extended to rest on the ground. Although cut pieces are usually held and consumed, they may occasionally fall to the ground. These are fed upon by the same individual after descending or by other individuals encountering them. Adults have been seen to feed on stubs of grasses or on short grasses, such as blue grama, from their normal horizontal position on the ground.

Instar 1

1. BL 4.5-5.8 mm FL 2.6-3mm AS 10-11.

Instar 2

2. BL 3.6-4.1 mm FL 3.6-4.1 AS 14-15.

Instar 3

3. BL 8.2-11 mm FL 5.2-6.2 mm AS 17-19.

Instar 4

4. BL 11-14.7 mm FL 6.6-7.8 mm AS 20-22.

Instar 5

5. Males: BL 15.2-15.5 mm FL 9-9.7 mm AS 22-23.
Females: BL 17.5-21.5 mm FL 11-12 mm AS 23.

Figures 1-5. Appearance of five nymphal instars of *Spharagemon collare* - their sizes, structures, and color patterns. Notice progressive development of the wing pads. BL = body length, FL = hind femur length, AS = antennal segments number.

Two-choice tests using 10 species of plants have shown that adults of the mottled sand grasshopper preferred dandelion and downy brome. Second-choice plants included: needleandthread, western wheatgrass, blue grama, kochia, and alfalfa. Least preferred but ingested in small amounts were tumble mustard and common lambsquarters. Flixweed appeared to be least preferred, as it was only nibbled upon. The tests indicate that the mottled sand grasshopper, even though a polyphagous feeder, discriminates among available food plants.

Dispersal and Migration

The mottled sand grasshopper is a strong flier, possessing long wings that extend 6 to 9 mm beyond the end of the abdomen. In the sandy grass-herbaceous habitats of the George Reserve, 25 miles northwest of Ann Arbor, Michigan, males have been seen to fly 50 to 100 feet when flushed and females even farther. Distances of flushed flights from a dirt road in eastern Wyoming were not nearly as far. Males have flown 3 to 8 feet and females 9 to 10 feet. These flights begin on the ground; reach heights of 4 to 30 inches, and end on the ground. The grasshopper flies straight or makes a right angle turn either near the start or near the end of flight. Crepitation may or may not occur during flight. Few appetitive flights have been observed and no study of their significance has been undertaken.

Evidence of dispersal comes from collection of “accidentals” at high altitudes west of Boulder, Colorado. Resident populations occur at 6,700 feet near Boulder, while “accidentals” have been collected several times up to 12,200 feet, at a distance of approximately 22 miles from the nearest resident population. Whether the distance covered is by a single flight or by a succession of short flights and whether flights in other directions and distances are taken is unknown.

Identification

The mottled sand grasshopper, a bandwinged species, occurs in the grasslands of sand dunes. Localized populations may be found in sand blowouts and sandy banks of lakes and streams. The adult is tan to gray and strongly spotted brown. It is a relatively large rangeland species (Fig. 6 and 7). The median carina of the pronotum is high and is cut once and deeply in front of the middle. The tegmina are speckled but occasionally the spots coalesce to form faint bands. The hindwings have a yellow disk and a dark broad central band (Fig. 9). The hind tibia is deep orange or red; the inner face of the hind femur is yellow and crossed by four fuscous bands (Fig. 8).

Figures 6-10. Appearance of the adult male and female of *Spharagemon collare*, hindleg of female, wings of female, egg pod, and several exposed eggs.

The nymphs are identifiable by their color patterns and external structures (Fig. 1-5).

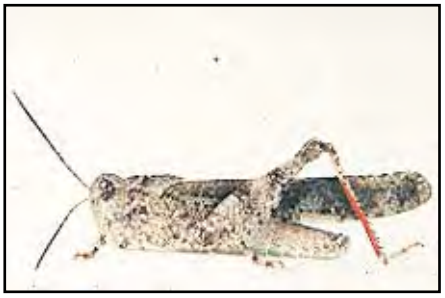
1. Head with face nearly vertical, lateral foveolae triangular.
2. General color tan profusely spotted brown.
3. Instar I
   (a) Pronotum with median carina strongly elevated; shallow notch in carina about one-third distance from posterior end.
   (b) Hind femur with outer face fuscous for distal three-fourths, proximal one-fourth tan with brown spots. Hind tibia fuscous. Hind tarsus with first segment white, second segment fuscous, and third segment white except fuscous at distal end.
4. Instar II
   (a) Pronotum with median carina strongly elevated; shallow notch in carina slightly more than one-third distance from posterior end.
   (b) Hind femur with outer face tan and spotted fuscous; outer face often with two faint brown bands, one in middle, the other distal. Hind tibia usually orange, occasionally proximal end yellow.
5. Instars III, IV, V
   (a) Pronotum with median carina strongly elevated and arcuate; deeply incised posterior to middle in III, anterior to middle in IV and V.
   (b) Hind femur with outer face tan or gray, heavily spotted brown on chevron ridges and on lower and upper keels, two or three dark transverse bands often present. Hind tibia usually orange.

Two other species of *Spharagemon* with elevated median carina occur in the West. The nymphs of *S. bolli* and *S. cristatum* are probably similar to those of *S. collare*, but they have not been collected or studied. Adults of *S. bolli* are normally found in sunny meadows and openings of ponderosa pines and other woodlands. Adults of *S. cristatum* are found in the grasslands of Kansas, Oklahoma, Texas, eastern New Mexico, and southeastern Colorado.

Hatching

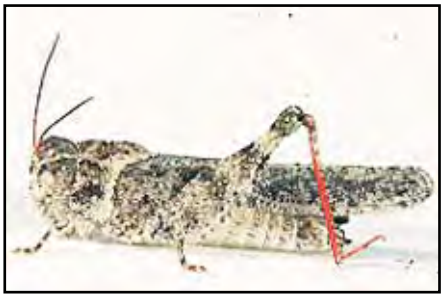
The mottled sand grasshopper hatches two to three weeks after *Ageneotettix deorum*, a species that often lives in the same sandy soil habitats. The eggs lie about 1/2 inch deep in the soil and are probably exposed to somewhat lower temperatures and greater moisture than the eggs of *A. deorum*. The greater depth may account, at least in part, for the later hatching of the mottled sand grasshopper. In the sand hills of

Male



6. BL 21-23.5 mm FL 12.5-14.5 mm AS 24-25.

Female



7. BL 24.5-27.5 mm FL 14.7-16 mm AS 25-26.

Hindleg

8. Inner face of female hindleg showing general yellow color, four fuscous bands of femur, deep orange of tibia.

Wings

9. Spread wings of female showing speckled tegmen and colors and dark band of hind wing.

Eggs

10. Egg pod and several exposed eggs

eastern Wyoming, hatching occurs during the last week of May and first half of June, over a period of 23 days.

Nymphal Development

The nymphs develop slowly in their warm, sandy habitat, reaching adulthood in a minimum of 42 days. Males have a shorter nymphal period than females. Both males and females have five nymphal instars. Because of the extended hatching period, nymphs are often present in various stages of development.

Adults and Reproduction

Adults of the mottled sand grasshopper remain in the sandy soil habitat in which the eggs hatched and the nymphs developed. Although no information is available on maturation of the adults and the start of oviposition, pair formation and courtship have been studied. Standing on open ground for long periods, males are attracted to moving grasshoppers, including males and females of their own species and even individuals of other species. Males make one and two pulse stridulations as they approach the potential mate. In the case of a female of their own species, pair formation and mating may occur, but other relationships result in aggression or repulsion. Unresponsive females of their own species repel courting males by shaking their hind femora and striking the ground with the hind tarsi.

Females ready to oviposit select bare areas of sandy soil close to vegetation. After completing oviposition and withdrawing her ovipositor from the soil, she covers the hole by brushing sand and soil litter over it with her hind tarsi. Males have not been seen attending ovipositing females. The whole act of oviposition was timed in Manitoba by Norman Criddle, an early investigator of grasshopper biology. Observations of two females revealed that they took 34 minutes to oviposit and produce 12 eggs per pod. This number is considerably less than that found in more recent research, indicating a wide range of clutch size. Pods of the mottled sand grasshopper are 3/4 inch long and 3/16 inch in diameter and contain from 21 to 28 eggs (Fig. 10). Eggs are tan and 5 to 5.2 mm long.

Population Ecology

Observations from the late 1800s to the present reveal that populations of the mottled sand grasshopper usually remain at low densities. A study in the Nebraska Sand Hills showed that populations of this grasshopper fluctuated over four years at densities of less than 0.01 to nearly 0.2 per square yard. Although the majority of factors governing population numbers have not been investigated, the study did show that predation by birds, chiefly the grasshopper sparrow and the meadow lark, had a significant depressing effect on population size. In a sand hill habitat of eastern Wyoming, the mottled sand grasshopper had a density of one young adult per square yard in 1992. Even greater densities, up to five young adults per square yard, have been found in small (300 square feet) ruderal areas in eastern Wyoming.

Daily Activity

The mottled sand grasshopper is a geophilous species, spending its active and quiescent hours on the ground. At night it rests horizontally on ground litter, sheltered closely under a canopy of grasses. In a roadside habitat, however, it may spend the night on bare ground or it may sit horizontally on the leaf of a broadleaf weed as high as 12 inches above ground.

After sunrise, the grasshoppers gradually emerge from their shelters. They remain quiescent on bare ground or litter until the sun's rays strike them. Then they begin to bask by turning a side perpendicular to the sun's rays and by lowering the associated hindleg, which exposes the abdomen to the warming rays. During this period they often stir, preen, and turn around to expose the opposite side to the sun. The basking period may last for one to two hours before they start walking, feeding, and mating. They continue these activities for several hours until temperatures of the habitat become too hot for them, at which point they begin to stilt on bare ground (soil surface temperature 105°F). As temperatures increase further, they leave the bare ground and crawl into the shade of plants resting horizontally on ground litter.

In the afternoon when temperatures moderate, they again become active walking about, feeding, flying appetitively, and seeking mates. As temperatures in late afternoon cool further they bask again. When shadows engulf the habitat, the grasshoppers crawl into shelters under canopies of vegetation and rest horizontally on ground litter. Although temperatures are still relatively warm and within their normal activity range (70°F soil surface and 65°F 1 inch above ground), they are not easily flushed from their hide-outs. One may walk within a foot of them and they will not flush.

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Orangelegged Grasshopper

Spharagemon equale (Say)

Distribution and Habitat

The orangelegged grasshopper is widely distributed in the grasslands of the western United States and Canada. It inhabits the tallgrass, mixedgrass, shortgrass, bunchgrass, and desert prairies and also shrub-grass communities of the Great Basin.

Economic Importance

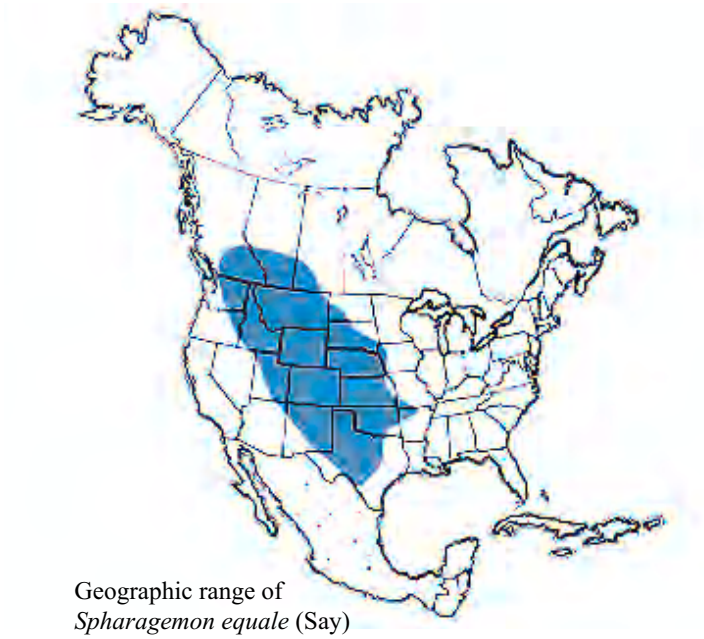
The orangelegged grasshopper occurs as a subdominant species in rangeland assemblages of grasshoppers. Because of the usually low densities (0.1 to 0.3 young adults per square yard), its feeding on both grasses and forbs is usually of minor economic importance. On bunchgrass prairie of British Columbia, however, it and *Metator nevadensis* caused considerable damage to cattle ranges in 1921. The adults are conspicuous and relatively large compared with the majority of rangeland grasshoppers. Live weight of males and females captured in the mixedgrass prairie of eastern Wyoming averaged 403 mg and 980 mg, respectively (dry weight: males 123 mg and females 299 mg).

Food Habits

A polyphagous species, the orangelegged grasshopper feeds on diverse grasses and forbs. Examination of 91 crops of grasshoppers collected in the sand prairie of southeastern North Dakota revealed that the species had fed upon 12 species of grasses, four sedges, and 11 forbs with no plant being clearly preferred. Crops of 18 grasshoppers collected in western Nebraska indicated a clear preference for blue grama. Two other grasses, needleandthread and prairie sandreed, were contained in the crops as well as one forb, lotus milkvetch, all in much smaller amounts than blue grama. Crops of 18 grasshoppers collected in the shortgrass prairie of north central Colorado (Pawnee Study Site) contained a preponderance of milkvetch (*Astragalus* sp.) and small amounts of four other forbs and three grasses.

Food preference tests of caged adults indicated that dandelion, blue grama, needleandthread, and downy brome were preferred food plants. Western wheatgrass, alfalfa, tumble mustard, kochia, and common lambsquarters were fed upon but not preferred. Flixweed was only nibbled upon. Early reports that this grasshopper prefers mustards have not been confirmed.

Five observations of the orangelegged grasshopper's method of attacking grass and sedge have been made in the mixedgrass prairie. At least two methods appear to be used. One is to raise up on the hindlegs and cut through a leaf 1/2 to 1 inch above its base, hang onto the cut section of 1 to 3 inches with the front tarsi, and consume all of it. The other method is to remain in a horizontal position on the ground, raise up on all legs over a leaf stub, and consume it to the base.



Geographic range of *Spharagemon equale* (Say)

Dispersal and Migration

The orangelegged grasshopper is a strong flier possessing long wings that extend 5 to 10 mm beyond the end of the abdomen. Distances of flushed flight range from 3 to 60 feet at heights of 4 inches to 6 feet. Patterns of flight may be straight or sinuous with either a gradual linear descent before landing or a right angle turn near the end of flight, followed by a gradual or steep descent. Both males and females usually crepitate in flight. Appetitive flight (unflushed flight) is common in the habitat; however, observations have been too few to determine what needs of the grasshopper are being met by these flights. Several investigators have noted aggregations of adults on bare soil in an otherwise vegetated habitat; perhaps both flight and walking are involved in movement to these spots, which may be important in pair formation and courtship.

A few observations provide evidence for dispersal by this species. West of Boulder, Colorado, where resident populations occur up to 7,200 feet, two "accidentals" were found at 8,500 feet. On sidewalks and pavement in downtown Billings, Montana on 1 August 1986, one male was collected along with seven specimens of the migratory grasshopper, *Melanoplus*

Instar 1

1. BL 4.5-5.9 mm FL 3-3.2 mm AS 13.

Instar 2

2. BL 6.6-8.5 mm FL 3.8-4.9 mm AS 15-17.

Instar 3

3. BL 9-10 mm FL 5.1-6.1 mm AS 18-20.

Instar 4

4. BL 10.5-15 mm FL 6-7.8 mm AS 20-21.

Instar 5

5. Males: BL 15.8-19.7 mm FL 9.2-10 mm AS 23.
Females: BL 19-24 mm FL 10-11.6 mm AS 23-24.

Figures 1-5. Appearance of five nymphal instars of *Spharagemon equale* - their sizes, structures, and color patterns. Notice progressive development of the wing pads. BL = body length, FL = hind femur length, AS = antennal segments number.

sanguinipes. In the city of Boise, Idaho, on 22 July 1923, five males and five females were collected at lights during the night along with specimens of *Dissosteira spurcata* and *Conozoa sulcifrons*. Migrating swarms of the orangelegged grasshopper have not been observed.

Identification

The orangelegged grasshopper is a relatively large bandwinged species. The adult is tan with brown bands and maculations (Fig. 6 and 7). The median carina of the pronotum is low and cut once in front of the middle; occasionally it is cut twice. The tegmina are crossed by three bands, the distal band sometimes being faint. The hindwings have a pale yellow disk and are crossed in the center by a broad, dark band (Fig. 9). The hind tibia is orange. The inner face of the hind femur is likewise orange and crossed with two or three fuscous bands (Fig. 8).

The nymphs are identifiable by their color patterns and external structures (Fig. 1-5).

1. Head with face nearly vertical, lateral foveolae triangular.
2. General color pale tan to brown.
3. Instar I

   (a) Pronotum with median carina distinct and slightly elevated; carina entire or faintly incised about one-fourth distance from posterior end.

   (b) Hind femur with outer face fuscous for distal three-fourths, proximal one-fourth tan and unspotted. Hind tibia fuscous. Hind tarsus with first and second segments white, third segment white except distal third fuscous.
4. Instar II

   (a) Pronotum with median carina distinct and slightly elevated; median carina faintly incised, slightly more than one-third distance from posterior end.

   (b) Hind femur with outer face pale tan to tan crossed by two fuscous bands. Hind tibia fuscous or fuscous and orange.
5. Instars III, IV, V

   (a) Pronotum with median carina distinct and slightly elevated, weakly incised near middle in instar III and anterior to middle in instars IV and V.

Figures 6-10. Appearance of the adult male and female of *Spharagemon equale*, hindleg of female, wings of female, egg pod, and exposed clutch of recently laid eggs.

(b) Hind femur with outer face pale tan or pale gray, sparsely spotted brown and fuscous, two dark transverse bands usually present, knee usually dark as well. Hind tibia orange.

Hatching

The orangelegged grasshopper is an intermediate-hatching species. In the mixedgrass prairie of eastern Wyoming, first hatch of eggs depends on seasonal weather and may occur as early as the last week of May or as late as mid June. Hatching ensues two to three weeks after eggs of *Aulocara elliotti* have begun to hatch. Field data indicate that the period over which hatching takes place in a particular year is brief, ranging from 7 to 11 days.

Nymphal Period

When nymphs emerge in spring, grasses, sedges, and forbs are young and nutritious. These supply an abundance and variety of host plants. The nymphal period ranges from 49 to 64 days and averages 55 days. Both male and female nymphs pass through five instars to reach the adult stage.

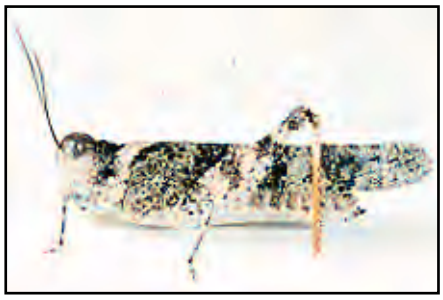
Adults and Reproduction

Depending on seasonal weather, adults may begin to appear in the mixedgrass prairie of eastern Wyoming as early as mid July or as late as early August. Remaining in the same habitat in which the nymphs developed, the adults are present during August and September, and may survive into early October when weather stays mild. Inspection of ovaries and field observation of oviposition indicate that egg laying begins three to four weeks after the adult stage is reached. No observation of courtship has been made, and there has been only one observation of a pair *in copulo* (13 August 1969 at 9:15 a.m. DST). Gravid females deposit their eggs into bare soil. These bare areas interspersed among the grasses range from 4 square inches to much larger areas, such as cattle trails. Caged females readily oviposit into containers of bare soil. They take 38 to 43 minutes from the start of boring into the soil to extraction of the ovipositor. Females then spend 90 seconds brushing soil over the hole with the hind tarsi, using one leg at a time. After this final act of protecting the eggs, the females walk away. No males have been observed attending ovipositing females.

Male

6. BL 22-28.8 mm FL 13-15.2 mm AS 25-26.

Female



7. BL 28.5-33.5 mm FL 14-17.5 mm AS 24-27.

Hindleg

8. Inner face of female hindleg showing general orange color and fuscous pattern.

Wings

9. Spread wings of female.

Eggs

10. Egg pod and part of a recently laid clutch of eggs. Note definitive egg color of two eggs showing through top left of pod.

The pods range from 1 1/8 to 1 1/4 inches long (Fig. 10). The section of pod containing eggs is 3/4 inch long and 3/16 inch in diameter. One-half inch above the eggs, the pod consists of light brown froth. The pod contains 24 to 26 light brown eggs, 5 to 5.5 mm long. Recently laid eggs are pale yellow. They eventually turn a light brown during their early development.

Population Ecology

The orangelegged grasshopper is a subdominant member of rangeland grasshopper assemblages. Where they occur in the mixedgrass prairie of Wyoming, densities of young adults usually range from 0.1 to 0.3 per square yard. In spite of low numbers, populations survive from year to year and appear to be influenced by the same factors that affect other rangeland grasshoppers (Table 1). When economically damaging grasshoppers increase to outbreak numbers, the orangelegged grasshopper may reach densities as high as two young adults per square yard.

Daily Activities

A geophilous species, the orangelegged grasshopper lives most of its life on the ground. At night, both nymphs and adults sit horizontally on the ground under a canopy of grasses. Before the sun's rays strike the ground early in the morning, a few individuals can be found sitting on small bare areas of 2 to 6 square inches interspersed among mats of blue grama. They face various directions with no particular orientation relative to the sun.

One to two hours after sunrise, the majority of individuals have emerged from their nighttime shelters and bask on bare ground. By turning a side perpendicular to the sun's rays and lowering the associated flexed hindleg, they expose the abdomen to the warming rays of the sun. The majority bask from 7 to 9 a.m. DST at ground temperatures of 60° to 90°F and air temperatures of 60° to 70°F (1 inch level). A few adults may bask longer, and they appear to reach body temperatures above their preference. These individuals then turn from the basking posture to face into or away from the sun and assume a stilt posture.

Daily activities of feeding, mating, and ovipositing follow the basking period and usually begin about 9:30 a.m. DST. When temperatures of bare ground exceed 100°F and air temperatures exceed 90°F (1 inch level), the adults leave bare ground and climb on top of blue grama or threadleaf sedge, and face the sun directly to expose the least body surface. At these times the grasshoppers are quiescent. When temperatures moderate later in the day, they again become active. In the evening, activity ceases and they again bask until nearly sunset at which time they seek shelter for the night under canopies of grasses.

Table 1. Growth of a rangeland grasshopper population and of *Spharagemon equale*, a subdominant member, in a mixedgrass habitat of eastern Wyoming (Platte County T27N R67W Sec 36 SE).

	Number per square yard				
	1970	1971	1972	1973	1974
Spharagemon equale	0.1	0.1	0.2	0.5	1.0
Assemblange of 16 species	3.7	5.1	8.7	15.3	48.6

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Finned Grasshopper

Trachyrhachys aspera Scudder

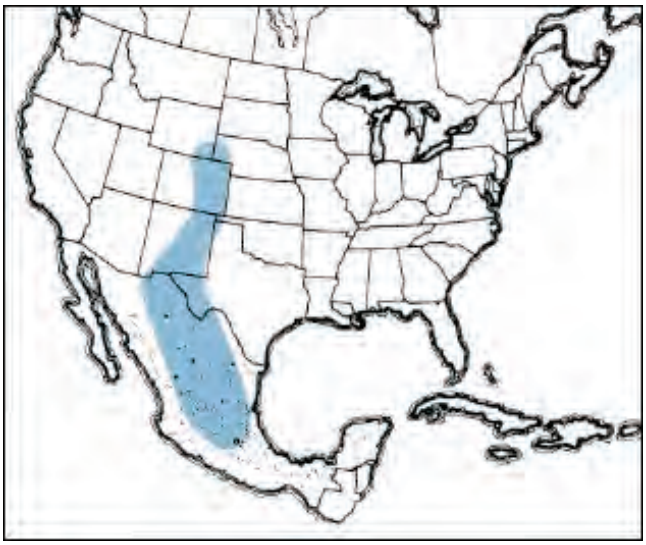
Distribution and Habitat

The finned grasshopper inhabits the shortgrass prairie and to a limited extent the desert prairie and the western edge of the mixedgrass prairie, ranging from Wyoming and Nebraska to central Mexico. Vegetation of these grasslands consists of the dominant plant, blue grama grass, several subdominant grasses, forbs, small shrubs, and much bare ground. During daylight hours, the finned grasshopper rests and conducts its activities on blue grama plants and on bare ground; at night it rests on bare ground and ground litter under canopies of blue grama.

Economic Importance

Finned grasshoppers feed almost entirely on blue grama grass, the dominant plant in their habitats and a primary forage plant of livestock. In recent years, population densities have been low and no known outbreaks have occurred. Although the Cooperative Economic Insect Survey recorded damaging numbers of the Kiowa grasshopper, *Trachyrhachys kiowa*, for 19 years between 1951 and 1980, the finned grasshopper was not mentioned once.

Collected from a mixedgrass prairie site in southeast Wyoming, live weight of six males averaged 202 mg and six females 461 mg (dry weight: males 59 mg, females 140 mg). The average dry weight of males and females are similar to those of the bigheaded grasshopper, *Aulocara elliotti*, a large and injurious rangeland species. Assuming an equal impact by grasshoppers of the same size and a density of one young adult finned grasshopper per square yard, we can estimate an annual loss of 20 pounds (dry weight) of forage per acre. During an outbreak, rangeland sites harbor assemblages of grasshopper species in which the finned grasshopper may be present as a subdominant member. Even the low density of the finned grasshopper during an outbreak contributes to serious damage of forage.



Geographic range of *Trachyrhachys aspera* Scudder

Food Habits

The finned grasshopper feeds almost exclusively on blue grama grass. A thrifty feeder, this grasshopper devours green leaves of blue grama from tip to base. If a leaf is clipped, the grasshopper holds onto the detached section and consumes it entirely. A study of the food habits of this grasshopper in the shortgrass prairie of Colorado revealed that of 13 adults, the crop contents of 12 consisted entirely of blue grama; a single crop had 99 percent blue grama and 1 percent sand dropseed. In the desert prairie of western Texas, crop contents consisted of 80 percent blue grama and 20 percent hairy grama, a closely related species. Two-choice food preference tests of adults collected from a mixedgrass prairie site in southeast Wyoming showed that blue grama was clearly preferred to western wheatgrass, red threeawn, downy brome, and threadleaf sedge.

Observations of feeding behavior of the finned grasshopper were made in a laboratory cage (1 ft^3) provided with sod translocated from the mixedgrass prairie of southeast Wyoming. A typical observation was made of a female starved for 19 hours and placed on bare soil in the cage. She crawled around on the bare soil for three minutes before she contacted a blue grama plant. She raised up diagonally on the plant and fed on a green leaf three inches long from tip to base, handling the leaf with her front tarsi while resting on bare soil with mid and hindlegs. She repeated this behavior five times. The sixth leaf she cut at one inch level, held onto it, fed on all of the green portion, and dropped the dry yellow tip. Finally she fed on the stub of blue grama. The time expended searching and feeding on six leaves and one stub was 28 minutes. Another female fed in the same manner, except for picking up an inch section of a fresh blue grama leaf from the soil surface and consuming all of it. She took 18 minutes from start to end of feeding.

Dispersal and Migration

The finned grasshopper's widespread presence in the shortgrass prairie where it inhabits patches of blue grama grass indicates effective dispersal. No doubt the species had many centuries to disperse slowly north upon retreat of the last ice sheet as the climate started to warm some 18,000 years ago. Nevertheless, this grasshopper appears to be a relatively sedentary species that exhibits faithfulness to favored habitats. Flushed flight is short (3 to 4 ft), low (4 to 6 in), and silent. Appetitive flights have never been observed in the two study sites of Colorado and Wyoming. Because these observations lack sufficient replication and completeness, conclusions remain tentative until more is learned about this grasshopper's habits of dispersal.

Instar 1

1. BL 5.1-5.7 mm FL 2.9-3.2 mm AS 12.

Instar 2

2. BL 5.7-6.5 mm FL 3.7-4.3 mm AS 14-15.

Instar 3

3. BL 7.5-9 mm FL 4.4-4.5 mm AS 16-17.

Instar 4

4. BL 9-11 mm FL 5.7-7 mm AS 17-18.

Instar 5

5. Males BL 13 mm FL 8-8.5 mm AS 20.
Females BL 16.7-17 mm FL 8.7-8.8 mm AS 19-20.

Figures 1-5. Appearance of the five nymphal instars of *Trachyrhachys aspera* – their sizes, structures, and color patterns. Notice progressive development of wing pads. BL = body length, FL = hind femur length, AS = number of antennal segments.

Identification

The finned grasshopper is a medium size, brown, mottled gray and black grasshopper (Fig. 6 and 7). It often occupies the same habitat as the Kiowa grasshopper which it closely resembles. Several characters serve to separate the two species. The hindwing of the finned grasshopper is marked by a large black band that often extends to the apex (Fig. 9), while the hindwing of Kiowa is mainly transparent. The posteroventral angle of the pronotal lateral lobe of the finned grasshopper approximates a right angle, while that of the Kiowa grasshopper is acute and the lobe distinctly drawn down. The inner (medial) side of the hind femur of the finned grasshopper is chiefly black marked by one light transverse bar (Fig. 8), while the Kiowa grasshopper is marked by two light transverse bars. The hind femur of the finned grasshopper has a high dorsal keel (fin) (Fig. 7), while the Kiowa grasshopper has a low dorsal keel. The finned grasshopper has a thin brush of hairs on the lower keel (Fig. 7), while the Kiowa grasshopper has a dense brush.

The nymphs are identifiable by their shape, structures, and color patterns (Fig. 1-5).

1. Head: face nearly vertical; compound eye with bottom third dark brown and black, upper two-thirds tan with three dark, diagonal stripes; antennae filiform, proximally gray, distally black.
2. Pronotum: median carina distinct, incised twice; posteroventral angle of lobe approximating a right Angle.
3. Hind femur with inner face mainly black, one pale yellow bar in front of knee (Fig. 8); in instar I the outer surface of the hind femur is strikingly black except for a light area proximally (Fig. 1); hind tibia usually black, sometimes gray.
4. Body short and robust; color brown with black markings, venter generally yellow or pale tan, and Unspotted.

Nymphs of the finned and Kiowa grasshoppers occupying the same habitat present a problem of identification. The easiest way of telling the nymphs apart is to examine the inner face of the hind femur. Nymphs of the finned grasshopper have the inner face chiefly black with one pale bar in front of the knee, while the inner femur of the Kiowa grasshopper is less black and has two pale bars. Also the phenologies of the two species are different; the finned grasshopper hatches and develops about four weeks later in the season, but some of the instars overlap.

Hatching

The finned grasshopper hatches late in the season, approximately four weeks after Kiowa with which it often shares the same habitat and overlaps phenologically. In the

Figures 6-10. Appearance of the adult male and female of *Trachyrhachys aspera,* inner side of hind femur of *T. aspera* above and *T. kiowa* below, spread wings of male *T. aspera*, clutch of 14 eggs.

shortgrass prairie of north central Colorado (Central Plains Experimental Range, elevation 5,400 ft), hatching usually begins the first week of July and continues for 7 to 10 days. Farther south in Trans-Pecos, Texas, hatching occurs at the same time. This event is delayed in southwest Texas by the sparse amount of spring rainfall and triggered by adequate amounts falling in June and July.

Nymphal Development

In Colorado the nymphs develop during July and the first half of August when temperatures are at their hottest. The host plant of this grasshopper, blue grama, remains green and succulent even though other native grasses may have cured or desiccated. Based on the times of appearance of first instars (hatching) and first adults, the nymphal period lasts 47 to 58 days (average 51 days, 1972 to 1975).

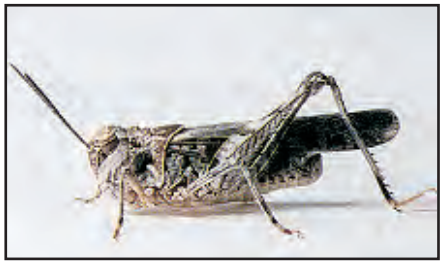
Adults and Reproduction

In northern Colorado the finned grasshopper molts to the adult stage during the last two weeks of August, the males fledging one week ahead of females. At this time, the adult stage is also reached farther south, in Trans-Pecos, Texas (Marathon, Texas elevation 4,121 ft). The adults are present in their habitats from mid August through October.

Oviposition was not observed in nature and rarely in cages, presumably because of the secretive behavior of females. In a cubic foot cage into which blue grama sod had been translocated from the natural habitat, a female was observed drilling and attempting to oviposit for 60 minutes into a small bare area (2 sq in) among grama plants. Search of the soil, however, revealed no eggs. At the end of life of six pairs that had been held individually in six cages in the laboratory, the sod and soil were examined for eggs. Production ranged from 1 to 48 eggs per female and averaged 30. The females laid in the small bare areas between grama plants at depths of 1/4 inch (top eggs of a clutch) to 1 1/4 inches (bottom eggs). No pod was formed, but a very light coating of froth enveloped some of the eggs. Number of eggs in a clutch ranged from 12 to 18. Eggs were 4.6 to 5.2 mm long and yellow to dark brown, some were two-toned yellow and dark brown (Fig. 10).

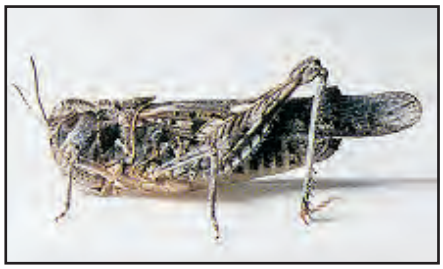
An interesting result of the cage studies was the lack of oviposition by females in the summer of 1999 when they were exposed daily to 12 hours of light and heat by a 25 watt incandescent bulb and to daylight entering through south-facing windows. In 2000, the 25 watt bulb of each cage was programmed for 7 hours on and 17 hours off with light coming through south-facing windows. Under these conditions each female produced eggs. We venture that like *Melanoplus devastator*, maturation of *T. aspera* is triggered by declining day lengths of late summer. Apparently the stimulus of declining photoperiod is also required by *Cordillacris crenulata* to develop eggs and oviposit, as this species did not produce eggs under 12 hours of daily light during adulthood.

Male



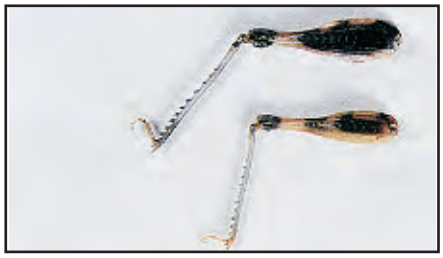
6. BL 16.5-17.5 mm FL 10.7-11 mm AS 21-22.

Female



7. BL 22.5-24.8 mm FL 11.8-13.5 mm AS 21-23.

Hindlegs



8. Inner side hindlegs *T. aspera* above, *T. kiowa* below.

Wings

9. Spread wings of male *T. aspera.*

Eggs

10. Clutch of eggs of *T. aspera.*

Population Ecology

Collections and observations of the finned grasshopper in Colorado, Texas, and Wyoming indicate that the species is a subdominant member of rangeland grasshopper assemblages and survives perennially at low densities in favorable habitats of shortgrass prairie where blue grama is the dominant grass. In the longest studied site, the Central Plains Experimental Range in north central Colorado, sparse populations inhabited shortgrass prairie annually from 1968 to 1978. From 1972 to 1975 recorded densities ranged from 0.27 to 0.72 young adults per square yard (Table 1), demonstrating that like other species of grasshoppers, fluctuations in population density occur. Subsequent research detected populations from 1980 to 1986 and in 1989 and 1999. In intervening years this rangeland was not searched for grasshoppers. The evidence indicates a permanent occupation of this shortgrass prairie site by sparse populations of the finned grasshopper.

Distribution of the finned grasshopper is spotty in the north of its range, with populations inhabiting limited acreage of shortgrass prairie. In the study sites in southeast Laramie County, Wyoming, the population was localized in an apparently favorable habitat of several acres. In contrast to other species of grasshoppers, such as *Trachyrhachys kiowa* which inhabited a much larger area outside this favorable site, *T. aspera* was notably absent. A New Mexico dot map indicates that near the center of its geographical range this grasshopper is widely distributed over shortgrass prairie, however even here densities have remained low.

Calculated daily mortality rates of adults were low (approximately 2 percent) allowing this stage to survive into late fall—through September and October. Why the species remains numerically low and a subdominant member of the grasshopper assemblage is an interesting and important question. One possibility is that females have a low fecundity in nature like in our cage study. Another possibility is that high egg mortality may occur during the period following deposition, a time of minimal rainfall. Because the eggs lie loosely in the soil unprotected by a pod, they may be at great risk of desiccating.

Daily Activities

At night finned grasshoppers take shelter on the ground surface under canopies of blue grama grass. In late August they remain hidden until two hours after sunrise at which time they crawl out onto bare ground and begin to bask turning a side perpendicular to the rays of the sun and lowering the hindleg to expose the abdomen. They bask for 90 minutes to two hours. During this time, approximately 8 to 10 am DST, the temperatures of the ground surface may rise from 50°F to 115°F. Still on the bare soil, they continue sitting, but take postures that reduce insolation and may even begin to stilt. In the laboratory study, males during late morning were observed crawling about on blue grama while females usually remained quiet and hidden from view in the thick of the grass. At various times during the day, caged males were observed mounted on females and in copula. Courtship was brief; stridulating males approached females and when close, approximately 1/2 inch away, they jumped onto the back of females and attempted to mate. When receptive females were mounted, mating followed. In the southeast Wyoming study site, a male was observed having mounted a female on 21 August 2000 at 11:27 am. A caged pair was observed in copula on 26 August 2000 at 11:30 am.

Finned grasshoppers appear to have low heat tolerance. On clear days they begin to stilt at 10:40 am (ground temperature 115°F, air 73°F). Soon afterwards they climb on top of grama grass, approximately 1 inch above the soil surface; then face the sun directly so that only the front of the head is impinged while the rest of the body is shaded. They were observed to avoid high temperatures from morning to late afternoon (10:40 am to 4:30 pm). During this time no other voluntary activities were observed. The question arises: when do these grasshoppers feed? A female translocated onto rangeland grama grass fed after sunset (6:56 pm, 14 September 2000, soil temperature 68°F, air temperature 67°F). Evidently finned grasshoppers can make adjustments in the time of their feeding to the temperature flux of their habitat. Intensive investigation will be required to discover all the details of their daily activities.

Table 1. Density of *T. aspera, Opeia obscura,* and assemblage of grasshopper species in shortgrass prairie of Colorado (Central Plains Experiment Range). Results calculated from 100 1-sq. ft. samples taken in late August.

	Number grasshoppers per sq. yd.		
Sampling date	*T. aspera*	*Opeia obscura*	Assemblage
29 Aug 1972	0.45	0.54	1.98
25 Aug 1973	0.63	0.81	1.98
22 Aug 1974	0.72	1.26	3.51
29 Aug 1975	0.27	0.27	0.90

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Kiowa Grasshopper

Trachyrhachys kiowa (Thomas)

Distribution and Habitat

The Kiowa grasshopper ranges widely in North America, occupying sparse grassland areas. Preferred habitats are dominated by short grasses, especially blue grama. The largest populations develop in the mixedgrass, shortgrass, and desert prairies. In the tallgrass prairie, the Kiowa grasshopper frequents sites of shorter, sparser grasses that occur on hilltops and in overgrazed or disturbed land.

Economic Importance

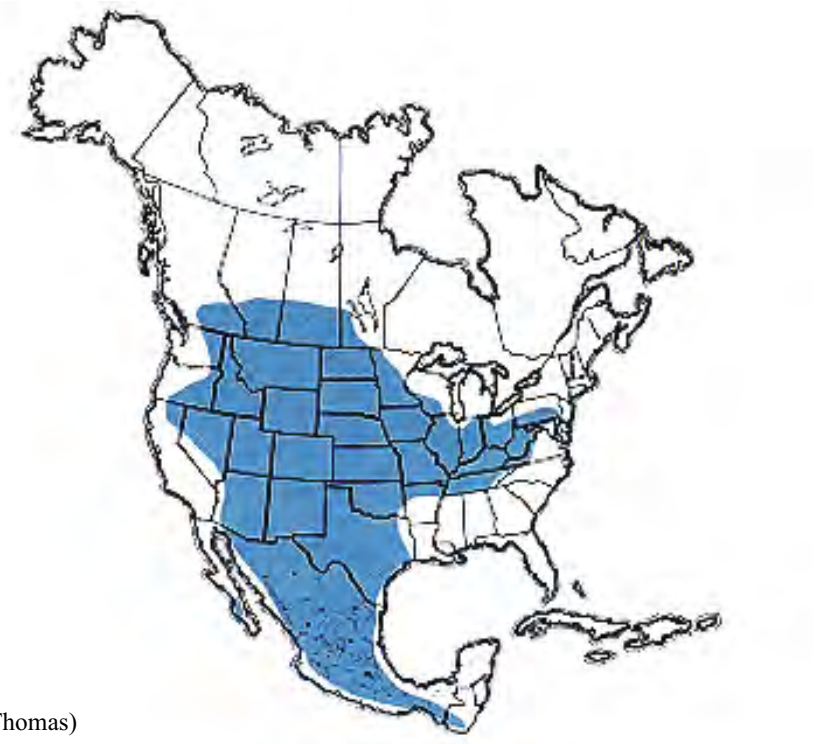
The Kiowa grasshopper feeds on high-quality forage grasses and sedges. It often becomes an injurious component of outbreak populations in the mixedgrass prairie. Its representation in these populations usually ranges from 1 to 13 percent, while densities range from 0.1 to 2 adults per square yard. Although rarely the dominant species, it may become the second most abundant species in an assemblage. In 1957 a "moderate" infestation was recorded from rangeland in British Columbia.

The Kiowa grasshopper is a medium-sized species. Live weight of males from mixedgrass prairie averages 148 mg and of females 303 mg (dry weight: males 44 mg, females 80 mg).

Food Habits

The Kiowa grasshopper feeds almost exclusively on grasses and sedges. In the mixedgrass and shortgrass prairies blue grama is its principal host, making up 84 to 100 percent of the diet. In other grasslands where blue grama occurs, it is again the preferred host plant. A total of twelve grasses and three sedges have been found in crop contents. In addition to blue grama, plants eaten in substantial quantities include western wheatgrass, needle-andthread, Kentucky bluegrass, threadleaf sedge, needle-leaf sedge, and Penn sedge. Due to its wide distribution, this grasshopper probably feeds on many more species of grasses and sedges than have been reported. Laboratory and field evidence indicate that it does not feed on bran bait. Nymphs have never been observed eating plant litter and adults infrequently.

The Kiowa grasshopper usually attacks a leaf at the tip and eats toward the base. It may feed on a green leaf of blue grama that is oriented horizontally about one-half inch above the soil surface, or it may raise on its hindlegs and bring an erect leaf down to feed while resting on the ground. The front tarsi handle the leaf while the mid- and hindlegs support the body. It may also feed head down at the base of grasses. Adults have been observed feeding on a small lichen that grows in mats on the soil surface.



Geographic range of
Trachyrhachys kiowa (Thomas)

Instar 1

1. BL 4-4.3 mm FL 2.3-2.5 mm AS 9-11.

Instar 2

2. BL 4.9-5.9 mm FL 3.1-3.4 mm AS 12-13.

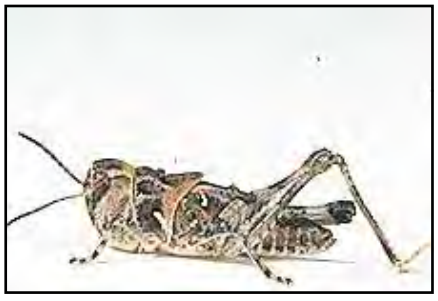
Instar 3

3. BL 5.8-7.9 mm FL 3.6-4.5 mm AS 14-15.

Instar 4

4. BL 7.6-12.1 mm FL 4.7-6.5 mm AS 16-18.

Instar 5



5. BL 11-16 mm FL 7.8-9.4 mm AS 20-21.

Figures 1-5. Appearance of five nymphal instars of *Trachyrhachys kiowa* - their sizes, structures, and color patterns. Notice progressive development of the wing pads. BL = body length, FL = hind femur length, AS = antennal segments number.

Dispersal and Migration

Possessing wings that extend considerably beyond the end of the abdomen, the Kiowa grasshopper is known as an inveterate wanderer. An investigation of resident and nonresident populations inhabiting sites at different altitudes in Colorado shows that dispersal of this species is a common phenomenon. In Nebraska a migratory swarm was observed flying over Overton on 8 July 1936. One male and two females from the swarm were caught and identified.

In evasive flights the adults take off from the ground and land on the ground. Distances range from 4 to 12 feet at heights of 6 to 18 inches. Crepitating softly, the adults fly straight or curved, often taking a right angle turn near the end so that a side is presented to the intruder.

Identification

The Kiowa grasshopper, a medium-sized rangeland species, becomes adult two to three weeks after the bigheaded grasshopper, *Aulocara elliotti*. General body color is tan, occasionally pale green, with maculations (Fig. 6 and 7). The tegmen has two or three large, dark brown markings in the middle and numerous dark brown spots at each end; the hindwing is mainly colorless and usually without a dark band (Fig. 9). Lateral lobe of the pronotum has the posteroventral angle drawn acutely downward. The hind femur has the lower carina with a fringe of long (male 3-4 mm, female 4-5 mm) hairs (Fig. 8). Hind femur with inner medial area fuscous and two pale yellow bands, one located in center and the other next to knee; hind tibia blue, especially inner face, with proximal end usually tan and spotted brown.

The nymphs are identifiable by their shape, structures, and color patterns (Fig. 1-5).

1. Head: face nearly vertical; dark narrow band on upper edge of fastigium running transversely between top of compound eyes; dark band often becomes broken and less distinct in instars IV and V.
2. Pronotum with disk wrinkled, median carina distinct, cut twice, elevated full length but slightly higher on prozona than metazona; lateral lobe with posteroventral angle drawn acutely downward.

Figures 6-10. Appearance of the adult male and female of *Trachyrhachys kiowa*, left hind femur of adult female, left wings of female, and eggs and egg pod.

3. Hind femur with diagnostic fringe of hairs on lower carina, more clearly evident in instars III to V.
4. General body color tan with dark brown markings; some individuals pale green with fewer but highly contrasting dark markings (see Figure 2).

Hatching

The Kiowa grasshopper begins to hatch 15 to 17 days after the bigheaded grasshopper, Aulocara elliotti, placing it in the intermediate-hatching group. In the mixedgrass prairie of eastern Wyoming and the shortgrass prairie of eastern Colorado, first hatch normally occurs sometime during the first half of June. Depending on heat accumulation of the soil, actual dates of hatching in a site may differ by as much as 15 days between years and the period of hatching may last from two to four weeks.

Nymphal Development

The nymphal period ranges from 37 to 53 days in the mixedgrass prairie of eastern Wyoming. In years of an early hatch the nymphal period is extended, while in years of a late hatch it is shortened. Like several species of grasshoppers that have been reared in laboratories at selected temperatures, nymphs of the Kiowa grasshopper undoubtedly develop slower under cooler conditions and faster under warmer.

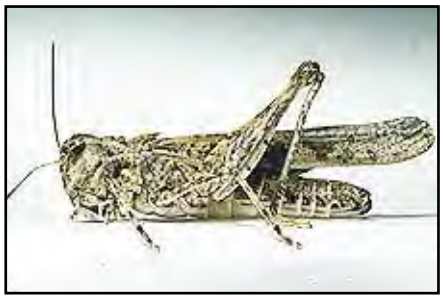
Adults and Reproduction

Although the adults are dispersive, the majority appear to remain in the habitat in which they developed as nymphs. Food generally stays green and abundant through their adult life, and the nymphal habitat contains the bare areas in which females prefer to oviposit. Courtship by the males is carried out on the ground. While approaching a female, the male makes single stridulating strokes of both hind femora. As a male mounts a female, he taps her head with his antennae. Copulation lasts from 25 to 40 minutes. Gravid females deposit their eggs close to vegetation in bare ground. Females take from 40 to 60 minutes to complete an oviposition. After extracting the ovipositor, they brush soil over the hole with their hind tarsi. The pod is an inch and one-eighth to an inch and one-quarter long and contains eight to ten eggs. The eggs lie in a soil cell

Male

6. BL 15-18 mm FL 9.4-11.5 mm AS 21-23.

Female



7. BL 17-24 mm FL 12-14 mm AS 21-22.

Femur

8. Left hind femur of adult female showing fringe of hairs.

Wings

9. Tegmen and hindwing of female.

Eggs

10. Pod and cluster of eggs in soil cell.

with slight protection by a minute amount of surrounding froth; a definite froth plug, however, lies above them (Fig. 10). Eggs are 4.4 to 5 mm long and two-toned, brown and tan. When digging pods from the soil, the cluster of eggs invariably falls apart. The species has one generation annually.

Population Ecology

Populations of the Kiowa grasshopper in the mixedgrass prairie may remain at low densities, from 0.2 to 0.5 adults per square yard, for periods of five years or more. Under favorable conditions population densities suddenly increase from three- to as much as seven-fold from one year to the next. This increase comes when other rangeland grasshoppers, such as the bigheaded grasshopper, *Aulocara elliotti*, and the whitewhiskered grasshopper, *Ageneotettix deorum*, make similar increases, and together the species assembled in a habitat reach outbreak proportions. Maximum adult densities of the Kiowa grasshopper during an outbreak reach 2.5 per square yard. Scientists doing research on population ecology of grasshoppers have yet to discover the causes of these outbreaks and their eventual collapse.

In the bunchgrass prairie of southern Idaho where the Kiowa grasshopper inhabits areas lacking blue grama, populations rarely reach densities exceeding one nymph per square yard.

Daily Activity

The Kiowa grasshopper is a ground-dwelling insect with activities greatly influenced by temperature and light. Both nymphs and adults rest horizontally on the ground at night and do not appear to seek protection from the low nightly temperatures of summer on the high plains (48 to 55°F at the soil surface and 1 inch above). In early morning shortly after sunrise they continue to sit quietly on the ground in no particular orientation to the sun. Two hours later they begin basking by orienting a side perpendicular to the rays of the sun and lowering the flexed hindleg on the sunny side of the grasshopper to the ground to expose the abdomen. Occasionally a basking individual will lower both hindlegs or take a diagonal position pointing the dorsum to the rays of the sun. Basking may continue until 10 or 11 a.m. DST.

On warm, clear days feeding begins at 9 a.m. with some individuals feeding as late as 11 a.m. After noon when temperatures rise excessively (about 130°F at the soil surface), the Kiowa grasshopper climbs grasses and forbs to rest 1/2 to 1 inch above ground level. Some individuals may crawl on the ground into the shade of vegetation. As temperatures moderate in the afternoon they descend to the ground and may begin to feed once more. Later, around 6 p.m. when temperatures drop to 90°F at the exposed soil surface and 80°F 1-inch high in shade, they begin basking and continue basking until sunset. They evidently shift positions during the night since individuals are found at dawn in various orientations and locations.

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Pallidwinged Grasshopper

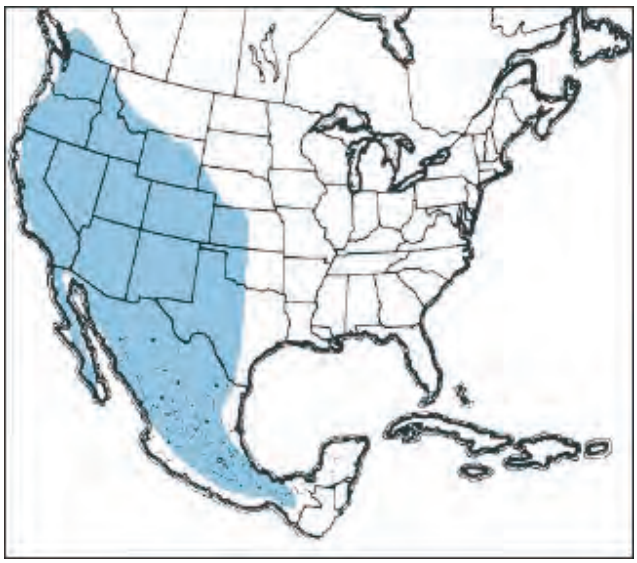
Trimerotropis pallidipennis (Burmeister)

Distribution and Habitat

The pallidwinged grasshopper, *Trimerotropis pallidipennis* (Burmeister), ranges from southwestern Canada to Argentina, making it the most widely distributed bandwinged grasshopper in the New World. In North America the primary habitats of this grasshopper lie in the deserts of the West where populations irrupt sporadically to damaging numbers. Vegetation of habitats consists of shrubs, forbs, and grasses with a preponderance of bare ground on which these grasshoppers commonly bask and rest. Outside their usual rangeland habitats, pallidwinged grasshoppers find favorable environmental conditions in weedy city lots.

Economic Importance

Outbreak numbers of the pallidwinged grasshopper damage the forage of their habitats. In Arizona in 1958 populations of nymphs residing in low areas and along washes numbered from 50 to more than 100 per square yard. They fed upon both annual grasses and forbs. Later in spring, the late nymphs and adults migrated into irrigated crops. In small grains, populations of 25 to 50 adults per square yard defoliated wheat and cut off heads. In cotton fields, the grasshoppers numbered 5 to 10 per square yard and consumed seedling plants to ground level. This damage compelled growers to replant large acreages. Some growers found it necessary to replant twice because of persistent grasshopper invasion. Other Arizona crops damaged in 1958 included carrots, sugarbeets, barley, milo, and corn. During outbreaks in California, pallidwinged grasshoppers have invaded and damaged fields of safflower and grapes as well as cotton, sugarbeets, barley, and corn.



Geographic range of *Trimerotropis pallidipennis* (Burmeister)

Over a period of 29 years, 1952 to 1980, six outbreaks of the pallidwinged grasshopper occurred in Arizona. These outbreaks have been brief, one lasted two years and the other five lasted only one year. Similar short outbreaks have occurred in the deserts of New Mexico, Utah, and California.

The most recent outbreak took place in west central Arizona in 1998. During the night of April 19 swarms attracted to city lights landed from Lake Havasu City to Bullhead City, a distance of approximately 50 miles. Crushed by traffic on streets and highways, the grasshoppers caused cars and trucks to skid and slide. Accumulations of the grasshoppers around buildings reached a depth of 2 inches.

The pallidwinged grasshopper is a relatively large rangeland grasshopper, but one that varies in weight depending on environmental conditions of its habitat. Live weight of males collected in the Sonoran Desert west of Phoenix, Arizona averaged 268 mg and females 565 mg while males collected in a sagebrush habitat along a hillside above the Gunnison River in Colorado (elevation 1,746 ft.) averaged 175 mg and females 429 mg. Live weight of six young males caught 14 May 2001 in the desert near Mesa, Arizona averaged 261 mg and four immature females 399 mg (dry weight: males 100 mg, females 145 mg).

Food Habits

The pallidwinged grasshopper feeds on a variety of forbs and grasses. Daily diets depend on availability and quality of food plants in the habitat. When eggs hatch in early spring, annual grasses such as downy brome and needle grama (*Bouteloua aristioides*), are lush and green and serve as the chief food plants. Later in spring the annual grasses become dry and brown, inducing the grasshoppers to switch to green perennial grasses and certain green forbs.

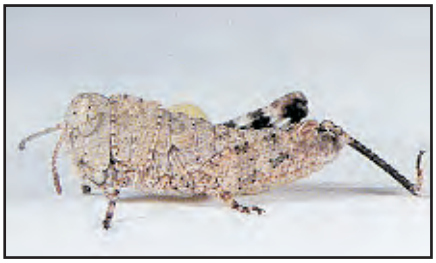
A variety of diets has been revealed by several studies of crop contents. In a four-year study, 1966-1969, in south-central Idaho, examination of 153 crops of the pallidwinged grasshopper revealed that 63 percent of crops contained fragments of downy brome and 22 percent tumblemustard. Other plants detected in the crops ranged from a trace to 11 percent. The grasses included crested wheatgrass, thickspike wheatgrass, and Sandburg bluegrass. The forbs included milkvetch, western salsify, big sagebrush, hoary aster, Greene rabbitbrush, and gray rabbitbrush. Also found in crops were fragments of arthropod parts, fungi, and pollen.

Crop analysis of adults collected in southwestern Texas near Alpine in the summer of 1974 showed that forbs were more frequently ingested (64 percent) than grasses (36 percent). However, blue grama grass was the most often ingested single plant, 23 percent, followed by a forb, *Cryptantha* sp, 16 percent. Other grasses found in crops included *Leptoloma cognata* (7 percent) and *Setaria* sp (1 percent); other forbs included *Solarium* sp (11 percent), *Iva* sp (10 percent), with smaller percentages of *Croton* sp, *Gaura* sp, and *Ratibida* sp.

Instar 1

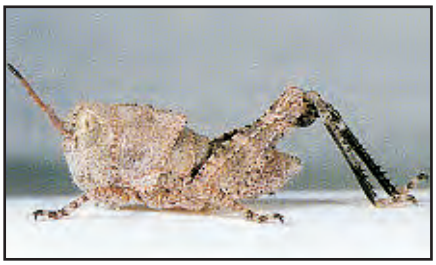
1. BL 4.6-6.8 mm FL 2.7-3 mm AS 12-13.

Instar 2



2. BL 6.7-8.1 mm FL 3.6-3.9 mm AS 14-15.

Instar 3



3. BL 9.2-10.8 mm FL 5.4-5.8 mm AS 17-19.

Instar 4

4. BL 13.8-15.5 mm FL 7.5-7.9 mm AS 22-23.

Instar 5

5. BL 13.7-20 mm FL 8.5-11.2 mm AS 22-24.

Figures 1-5. Appearance of the nymphal instars of *Trimerotropis pallidipennis* - their sizes, structures, and color patterns. Notice progressive development of wing pads. BL = body length, FL = hind femur length, AS = number antennal segments.

In the Sonoran Desert, 30 miles west of Tucson, Arizona, 68 of 126 crops (54 percent) contained needle grama, six crops contained the forb *Allionia incarnata*, four crops contained the forb *Franseria deltoidea*, and three crops contained arthropod parts.

Although these studies indicate a high degree of polyphagy by the pallidwinged grasshopper, two-choice tests demonstrate that the species has food preferences. Laboratory tests of 15 plant species offered in pairs to adults collected in Millard County, Utah in 1998 revealed preferences for dandelion, kochia, downy brome, crested wheatgrass, and needleandthread.

Dispersal and Migration

The pallidwinged grasshopper possesses remarkably strong powers of flight allowing the species to disperse widely and to escape deteriorating desert habitats as vegetation senesces and dries. Attracted by city lights, flying swarms land at night piling up on streets and sidewalks in enormous numbers. In Arizona during outbreaks, numerous adults have often been recorded as invading crops. Unfortunately, no detailed study has been made of the flights. We do not know the meteorological conditions, the time of day, direction, duration, and distance of flights. Small-scale displacement of the pallidwinged grasshopper was studied in a 2.5 acre plot in 1975 in western Texas, 15 miles east of Alpine. Of the four grasshopper species marked and recaptured, the pallidwinged grasshopper moved the farthest, an average distance of 27 feet per day. Recovery of this grasshopper was low, 25 percent, compared with the other two long-winged species, 36 and 53 percent, indicating that after two weeks a large number of pallidwinged grasshoppers had flown out of the plot area.

One of the few observations of actual flight of this species was made in Nevada; where flights were often of long duration, individuals commonly ascending well out of sight. In one case, a male circled about a sagebrush slope for 17 minutes in a single flight before finally coming to rest. In the Phoenix, Arizona area (altitude 1083 feet), pilots have reported swarms at altitudes of 3,000 to 5,000 feet. Flushed grasshoppers fly swiftly at heights of 2 to 3 feet often going more than 100 feet and beyond sight.

A remarkable dispersal record of the species was made 7 September 1966 when adults were discovered along roadsides bordering a sugar plantation at Ewa, Oahu, Hawaii. Specimens sent to the U.S. National Museum were identified by A. B. Gurney. The Hawaiian infestation persisted in 1967 and 1968. Probable source of the infestation was western North America indicating wind transportation of a swarm.

Identification

The pallidwinged grasshopper belongs to the diverse bandwinged genus *Trimerotropis* which encompasses more than 40 described species and several yet undescribed. The

Figures 6-10. Appearance of the adult male and female of *Trimerotropis pallidipennis*, spread wings of female, inner face of hindleg of female, and pod and opened pod.

large number of species with many shared color patterns and structural characteristics present a challenge for accurate identification. Nevertheless a combination of characters make possible the identification of the species.

The pallidwinged grasshopper is a moderately-sized tan or gray insect (Fig. 6 and 7) found chiefly in desert and semidesert habitats. The tegmen bears two transverse dark bands that cross its entire width; the distal end bears numerous brown spots. The center of the hindwing has a relatively narrow but conspicuous black band; the wing disk ranges from white to pale yellow, and the apical area is transparent (Fig. 8). Incised twice near the front, the median carina of the pronotum is high on the prozona and low but distinct on the metazona. The ventral edge of the pronotal lobe is straight, bearing no tooth. The inner medial area of the hind femur is black, broken by two yellow bars (Fig. 9). The hind tibia is yellow. The venter is solid cream to pale yellow.

The nymphs are identifiable by their structures and color patterns (Fig. 1-5).

1. Head with distinct triangular foveolae; carinae of frontal costa straight in instar I and II, carinae slightly incurving at level of antennal sockets in instars III to V; carinae connected by a bridge-like ridge approximately at level of antennal sockets in all instars.
2. Pronotum with distinct median carina feebly incised twice in instar I, becoming more strongly elevated and clearly incised in instars II to V; disk rugose on prozona, smooth on metazona; median carina elevated on prozona, low on metazona.
3. Hindleg: in instar I mainly black except basal fourth of femur (outer area) pale, inner medial area black with pale distal bar; hind tibia black with pale basal annulus; tarsus white except segment two and distal half of last segment black. In instar II medial area of hind femur pale tan, two dark bars on upper marginal area, inner medial area of hind femur with three black and three pale tan bars; hind tibia black or pale tan. In instars III to V outer and inner surface of hind femur pale tan with two or three black bars; hind tibia yellow.
4. Ground color tan spotted brown; venter yellow or olive.

Hatching

The pallidwinged grasshopper hatches early in spring from eggs that have overwintered in the soil. In south-central Arizona the species starts to hatch in late February and continues hatching through March. In west-central Utah (Millard County), hatching begins in late April. Based on the appearance of adults and a nymphal period of 45 days, hatching in late April occurs in southeastern Colorado (Bent County) and in eastern Wyoming (Goshen County). In south-central Arizona a second generation begins to hatch in early June. Only one generation develops in northern Arizona and northern states such as Colorado, Utah, and Wyoming. The evidence suggests that several days after being laid, the eggs cease development and enter a diapause. Yet in an insectary at Mesa, Arizona, eggs kept under moist conditions in a

Male

6. BL 20.5-24 mm FL 12-13.5 mm AS 24-26.

Female

7. BL 27-33 mm FL 13.5-16 mm AS 25-28.

Wings

8. Spread wings of female.

Hindleg

9. Inner face of female hindleg.

Eggs

10. Egg pod and opened pod showing eggs.

mixture of silt and sand hatched without a diapause in 13 to 21 days (mean 15.5 days) of incubation (air 82° to 104°F, mean 93°F).

In nature rainfall appears to be a critical factor for eggs to survive and hatch. In the Tule Hill site of Millard County, Utah, a moderate population of adults inhabited the site in the summer of 1998, but no eggs hatched by 22 June 1999 apparently having died because of drought.

Nymphal Development

Nymphs appear early in spring when weather is variable but food plants are usually green, nutritious, and plentiful. At this time the length of the nymphal period of individuals ranges from 42 to 48 days. In southern Arizona the nymphs develop during March and April, while in Colorado, Utah, and Wyoming they develop in May and June. A second generation develops in southern Arizona during June; and, under favorable conditions of moisture, additional generations may develop later in the season.

In a study conducted in an outdoor screened insectary at Mesa, Arizona, researchers found that female nymphs have five or six instars, while the males usually have five but a few have six. The study also found that the nymphal period of grasshoppers reared at relatively low temperatures in the laboratory (range 70° to 84°F, mean 77°F) averaged 50 days for males and females with five instars and 60 days for females with six instars. The nymphal period of grasshoppers reared during mid summer in the outdoor insectary at relatively high temperatures (range 81° to 101°F, mean 91°F) averaged 31 days for the males and 33 days for the females.

Adults and Reproduction

Depending on the location of the habitat, the adult stage of the pallidwinged grasshopper is reached in mid to late spring. In southern Arizona adults appear in mid April, while in Colorado, Utah, and Wyoming they appear in early June.

During the day adults fly about and may disperse widely. In the Alpine, Texas study marked adults were recaptured for only 14 days. On the other hand, in a small favorable habitat of about one acre in the desert of Millard County, Utah, adults have been found in residence from 19 June to 29 August 1998, indicating a habitat fidelity of at least 67 days.

Males make frequent local flights in which they crepitate (snapping sounds produced by the hind wings). Observations indicate that crepitation initiates pair formation of the sexes. Upon landing, the male walks in a straight line to a resting female. Courtship consists of ordinary stridulation which resembles a trilling sound to the human ear. One to eight trills in quick succession are produced by males advancing toward females. A receptive female remains still as the male approaches, mounts, and attaches his genitalia to consumate mating.

Reproductive maturation of females in nature has not been closely followed. However, in south-central Arizona adults that fledged by the end of April in a habitat of succulent vegetation bore well-developed eggs a week later, but no eggs were found in females inhabiting dry desert.

Caged in pairs and sheltered in a screened insectary during mid summer (76° to 101°F, mean 88°F), and fed a mixed diet of four species of host plants, pallidwinged grasshoppers exhibited a high fecundity, comparing favorably with other pest species of grasshoppers. Sixteen females averaged 386 eggs each. One female laid a record 27 pods containing 955 eggs. The preoviposition period was long with a minimum of 26 days and an average of 43 days. Average longevity of these females was 80 days. In nature the eggs are laid in bare soil to a depth of approximately 1 inch. The pod is slightly curved, narrow (1/8 inch in diameter), and 1 inch long (Fig. 10). Each pod contains an average of 34 pale yellow eggs, 4.5 to 5 mm long.

Population Ecology

Irruptions of the pallidwinged grasshopper occur sporadically in the deserts of western North America. In Arizona outbreaks have been associated with above normal, well-distributed rainfall during the preceding fall, winter, and early spring. The ample moisture provides favorable soil conditions for the eggs and a steady supply of nutritious food plants for the nymphs and adults. Populations inhabiting specific sites, however, have not been monitored to determine the time required for the pallidwinged grasshopper to reach high densities. In Idaho dense populations have numbered five adults per square yard. Outbreaks are of short duration, usually only one year, at most two. Evidently individuals of swarms that alight in cities die for lack of food, while those that migrate into crops are destroyed with insecticides or cultural practices. Between outbreaks, periods of usually three to four years, pallidwinged grasshoppers are rare in desert habitats. Apparently, favorable weather and the great fecundity of the species foster a rapid growth of populations.

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Redshanked Grasshopper

Xanthippus corallipes (Haldeman)

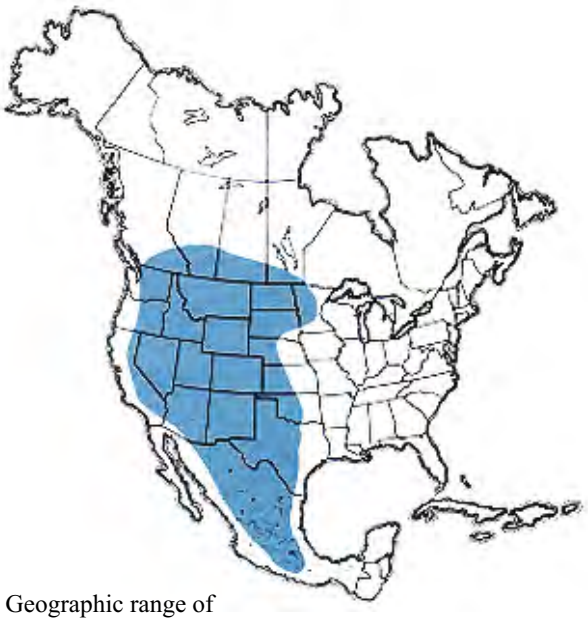
Distribution and Habitat

The redshanked grasshopper ranges widely in western North America, inhabiting the grasslands and shrub-grass communities. The species is also present in clearings of montane forests and in open vegetated areas above timberline.

Economic Importance

This grasshopper feeds on quality forage grasses and is a potentially damaging species. Because the adults are usually present in low densities (from less than 0.1 up to 0.2 grasshoppers per square yard) in spring at a time when grasses have adequate moisture, most populations do no measurable damage to forage. Occasionally populations erupt as in 1989 in western Utah, where densities of 18 to 20 adults per square yard damaged not only rangeland grasses but also cultivated crested wheatgrass. In several rangeland areas they literally ate everything green, both grasses and forbs, down to the ground. A year later in Utah the outbreak persisted, and in certain areas adults flew from drought-stricken grassland to alfalfa fields where they fed on the crop.

The redshanked grasshopper is a large species. Live weights of males from mixedgrass prairie average 607 mg and of females 1,352 mg (dry weight: males 117 mg, females 442 mg).



Geographic range of
Xanthippus corallipes (Haldeman)

Food Habits

The redshanked grasshopper feeds almost exclusively on grasses and sedges. In spring both the nymphs and the adults feed heavily on the green, early growth of cool-season plants: western wheatgrass, needleandthread, junegrass, needleleaf sedge, downy brome, and sixweeks fescue. In May when the foliage of blue grama, a warm-season grass, has grown plentiful, this species becomes an important item in the diet. After seeding early in the season, downy brome and sixweeks fescue die, turn brown, and become unpalatable. In late summer and early fall the new generation of nymphs feed heavily on blue grama.

A total of 22 species of grasses, two species of sedges, and one rush have been found in crop contents of the redshanked grasshopper. Because of its wide distribution in diverse habitats, known host plants are undoubtedly far short of the actual numbers eaten. Trace quantities of forbs (29 species), fungi, and arthropod parts have been found in crop contents. An apparent exception is the large quantity (17 percent dry weight) of the forb, woolly plantain, found in the crops of ten adults in July on the shortgrass prairie of northeastern Colorado.

Observation of the feeding of one adult female in the mixedgrass prairie of eastern Wyoming suggests that this grasshopper feeds on the ground in a horizontal position. The female fed on four western wheatgrass plants from 10:53 to 11:03 a.m. DST. Crawling and foraging on the ground, she raised her head upon contacting a host plant and cut a leaf an inch above ground level, then fed on the felled leaf from the cut end to the tip. She handled the leaf with her front tarsi from a horizontal position on the ground. Laboratory observations were made of late instar nymphs feeding from a horizontal ground position on dry fallen leaves of downy brome while housed in a gallon cage with soil as the floor. These observations indicate that the redshanked grasshopper may feed on ground litter as well as on green leaves that they cut.

Dispersal and Migration

The redshanked grasshopper has strong powers of flight. Wings of both males and females extend beyond the end of the abdomen. Evasive flights range from 4 to more than 30 feet. The flights are straight or sinuous at heights of 1 to 3 feet. They are accompanied by loud crepitation. The fleeing grasshopper lands horizontally on the ground and faces away from the intruder.

Instar 1

1. BL 4.9-5.8 mm FL 2.9-3.4 mm AS 12-14.

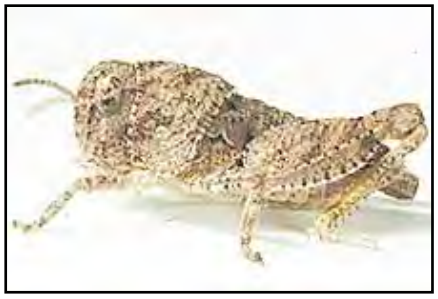
Instar 2

2. BL 6.8-8 mm FL 4.4-4.7 mm AS 15-17.

Instar 3

3. BL 7.7-11.3 mm FL 5.2-5.8 mm AS 18.

Instar 4



4. BL 10-14.5 mm FL 6.3-8 mm AS 19-21.

Instar 5

5. BL 13.5-19 mm FL 8-10 mm AS 21-23.

Figures 1-5. Appearance of five nymphal instars of *Xanthippus corallipes* - their sizes, structures, and color patterns. Notice progressive development of the wing pads. BL = body length, FL = hind femur length, AS = antennal segments number.

Little information is available on its dispersal and possible migration. Populations in habitats at different altitudes west of Boulder, Colorado did not disperse into nonresident habitats. In the recent outbreak in Utah, however, adults were observed to fly from denuded grass habitats to nearby alfalfa fields.

Identification

The redshanked grasshopper, a large rangeland species (Fig. 7 and 8), is present as an adult in spring. The adults are conspicuous in the habitat, as they crepitate loudly during evasive flight and reveal their yellow, dark-banded wings. A diagnostic character is the clearly defined dark brown maculations of the tegmina (Fig. 9).

The pronotum is heavily nodulate and rugose; the median carina is low and cut twice in front of the middle. The hind femur has three diagonal dark brown bands on its outer face and a solid bright red or deep blue inner face. The hind tibia is either entirely red or is yellow on the outer face and red on the inner face.

The nymphs are identifiable by their shape, structures, and color patterns (Fig. 1-6).

1. Head rounded with face nearly vertical; lateral foveolae triangular; vertex with integument wrinkled except smooth in instar I. Maxillary and labial palps with segments pale gray and proximal ends ringed black, terminal segment with an additional black ring near tip; rings fading in instars IV to VI.
2. Pronotum with integument smooth in instar I, nodulate and wrinkled instars II to VI; median carina of disk low but equally elevated throughout, entire in instar I, cut twice in instars II to VI, principal sulcus deeply cut, front sulcus often faintly cut; lateral carinae of disk pale yellow; a light V-shaped figure on anterior half of disk; light lateral lines on posterior half extend to arms of V (see Figure 2 for side view).
3. Hind femur with lower carina expanded into a conspicuous keel (instars III to VI); outer face tan with three diagonal brown bands, inner face dark blue with pale yellow band next to knee, sometimes a smaller second band near middle,

Figures 6-10. Appearance of the sixth instar, the adult male and female of *Xanthippus corallipes*, the left wings, and the egg pod and several loose eggs.

orange or red interfusions on inner face in instars V and VI. Hind tibia shiny dark blue to black in instars I and II, orange or dark blue with orange patches in instars III to VI.

4. Body color brown or gray with many dark brown spots; individuals developing on red soils become red and lose color patterns and majority of markings in instars III to VI (see Figure 4).

Hatching

Studies of egg development indicate that northern populations of the redshanked grasshopper have a two-year life cycle while southern populations have a one-year life cycle. In central Saskatchewan eggs laid in spring develop to an advanced stage by fall, at which time they go into diapause. The diapause is broken during winter and the eggs hatch the following summer. Eggs laid in the laboratory by females originating from a population in Pima County, Arizona hatched at room temperature in five weeks. This result indicates a one-year life cycle for southern populations.

In southern populations eggs of the redshanked grasshopper hatch in mid-summer, two to four weeks after the hatching of the brownspotted grasshopper, *Psoloessa delicatula*, and the specklewinged grasshopper, *Arphia conspersa*. In the mixedgrass prairie of western North Dakota at altitudes of 2,000 feet, hatching of the redshanked grasshopper begins in mid-July; in the shortgrass prairie of northeastern Colorado at altitudes of approximately 5,400 feet, hatching begins the last week of July; while in the mixedgrass prairie of eastern Wyoming at altitudes of 4,400 feet to 5,300 feet, hatching begins in mid-August. The period of hatching lasts approximately four weeks.

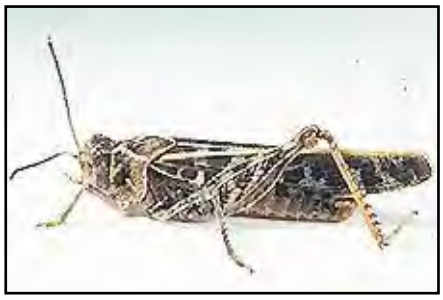
Nymphal Development

The redshanked grasshopper develops steadily during the warm weather of summer and early fall. In the mixed-grass prairie of western North Dakota the nymphs become third instars by the first of August, while in the prairies of eastern Wyoming and Colorado, they become third instars by the end of August. Males of this species have five or six instars and females have six. By the end of October nymphs have reached the overwintering instars, mainly fifth and sixth. They may take shelter on the ground surface under litter and in small soil depressions.

Instar 6

6. BL 18-24 mm FL 11-14 mm AS 24-25.

Male



7. BL 24-30 mm FL 14.5-15.2 mm AS 25-26.

Female

8. BL 35-41 mm FL 18-20 mm AS 26-28.

Wings

9. Forewing (tegmen) and hindwing.

Eggs

10. Egg pod and four loose eggs.

During unseasonably warm weather in winter, some nymphs become active and are able to evade an intruder by jumping. For example, three late instars were caught on 7 February 1991 after they jumped in a habitat of mixedgrass prairie on the outskirts of Laramie, Wyoming. As the sun waned during the 15-minute search (2:45 to 3:00 p.m.), the soil surface temperature decreased from 66 to 62°F and air temperature 1-inch high in shade decreased from 51 to 50°F. The nymphs emerge from their overwintering quarters in March and develop to the adult stage in April and May.

Adults and Reproduction

The adults, prevalent in May and June, remain in the same habitat in which they develop as nymphs. Late metamorphosing adults may survive well into August. Little is known about the maturation of adults. Courtship apparently occurs without flight displays and is mediated by stridulation of the males. The male rubs a ridge on the inside of the hind femur against a linear series of nodes on a raised vein of the tegmen. To the human ear, the sound produced is a chirp and is the primary courtship signal of the male. A visual signal may also be involved when a stridulating male raises his hindlegs and exposes the bright red or dark blue inner surfaces of the tibiae and femora.

Although the act of oviposition in the natural habitat has gone undescribed, circumstantial evidence indicates the female selects bare ground for this purpose. In a laboratory terrarium transplanted with vegetation from the mixedgrass prairie, females chose to oviposit in bare soil. Over one hour was required to complete an oviposition. After extracting her abdomen, a female takes a minute to brush soil over the hole with her hind tarsi. Females deposit eggs deeply in the soil; eggs lie at a depth of 2 to 3 inches.

The egg pod is two and three-quarters inches long and slightly curved (Fig. 10). The diameter of three-eighths inch in the bottom region containing the eggs is greater than in the top region of froth. Eggs are brown and 6 to 6.5 mm long and number about 32 per pod.

Population Ecology

Little information is available on the population ecology of the redshanked grasshopper, however, it is known that populations normally fluctuate at low densities, increasing from less than 0.1 adult per square yard in some years up to 0.2 adult per square yard in others. Populations have also been observed to increase explosively as in the recent outbreak in Utah, where adults have reached densities up to 20 per square yard.

Daily Activity

Observation of daily activity of the redshanked grasshopper has been limited because of low population densities in study sites. In spring and in fall the nymphs endure freezing temperatures during the night. They may find shelter in the litter or in small soil depressions or may sit exposed on the soil surface. They assume a posture that appears to keep them as warm as the environment allows by minimizing the area of exposure to the cold air. They sit horizontally on the ground surface with body appressed to the soil, legs flexed and held close to the body, and the antennae turned back and against the sides of the head.

Like the nymphs, adults appear to rest horizontally on the soil surface at night. Adults have been flushed from the ground surface and may jump to evade capture in the morning (8:30 a.m. DST) when ground surface temperature is 60°F. Later (9:30 a.m.), at soil surface temperature of 76°F, flushed adults fly evasively from the ground. One observation was made of a female basking late in the morning (10:45 a.m., soil temperature 80°F) with her left side perpendicular to the sun's rays. This same female began to feed at 10:55 a.m.

When temperatures rise above tolerable levels, greater than approximately 130°F at the soil surface, females have been observed to move across the ground to the shady side of shrubs and males have been observed to climb plants, such as western wheatgrass, to 3 to 6 inches above the soil surface and then rest on the shady side of the plant.

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