V. Rangeland Management

V.1 The Importance of Grazing Strategies to Grasshopper Management: An Introduction

Jerome A. Onsager

For some rangeland ecosystems, certain grazing-management strategies appear to offer great potential for reducing periodic grasshopper outbreaks. For most of the prairie grassland ecosystems, grasshopper densities tend to increase with drought and grazing intensity. In several different studies since 1940, grasshoppers have been reported as being most abundant during dry seasons in heavily grazed pastures. The study sites included mixed-grass prairie in Montana and Oklahoma, tall-grass prairie in Kansas, and fescue grassland in Alberta (see Onsager 1987 and Kemp 1992).

In the Montana studies, grasshopper densities generally were inversely proportional to plant height and amount of cover. Therefore, grazing strategies that manipulate the time, rate, and severity of forage harvest can, in turn, affect the time, rate, and degree to which prairie rangeland habitats are improved for grasshoppers.

For some rangeland ecosystems, an almost opposite situation appears to be true. Examples include short-grass prairie in Arizona (Nerney 1958) and Colorado (Capinera and Sechrist 1982) and Intermountain sagebrush-grass range in Idaho (see V.2), where food supply usually limits grasshopper density.

During dry or normal seasons in food-limited habitats, densities generally are low but tend to be highest in ungrazed or lightly grazed pastures. Infestations tend to increase during years with above-normal precipitation and above-normal forage production, but it is not practical to attempt grasshopper suppression through removal of forage with livestock (see V.6). Periodic grasshopper outbreaks, therefore, probably will continue in such habitats regardless of the presence or intensity of livestock grazing.

Hart et al. (1987) discuss some relationships between grazing management and pest management: The primary forage plant species determine to a large degree what pest species will be of most importance, the return from grazing management affects the resources available for pest management, and good grazing practices should maintain vigorous plant communities that resist pest outbreaks and recover from attack. Hart's team also discusses five "families" of grazing strategies, four of which involve systems for rotation or alternation of periods of grazing versus no grazing. The fifth strategy is continuous or season-long grazing.

Perhaps the primary criticism of continuous grazing is that the plant species most preferred by livestock tend to be grazed and regrazed at the same growth stages year after year. This repetitive selection favors growth of plant species that are less palatable or species with unique competitive advantages and, consequently, favors the same species of grasshoppers year after year.

The boundaries between proper, sustainable, season-long grazing and abusive grazing usually are not clear and can vary from season to season. Management options are largely limited to adjustments in herd size, an option that may or may not stop the abuse. (Reducing the herd size could simply alter the number, area, or distribution of patches where abuse continues unabated.) Because frequent lapses into an abusive scenario can favor undesirable plant species, such lapses can favor undesirable grasshopper populations as well. In fact, the ability to thrive in disturbed habitats is a prominent characteristic of many of the grasshopper species that cause the highest levels of damage. Therefore, the continuous grazing strategy does not seem to offer much opportunity for proactive grasshopper management.

Hart's four "families" of grazing systems include (1) rotationally deferred grazing (grazing is not allowed in selected pastures until after a certain interval, and the deferment is rotated among pastures), (2) rest-rotation grazing (rest periods with no grazing intended to allow seed production and seedling establishment are rotated among pastures), (3) high-intensity, low-frequency grazing (heavy, nonselective grazing is followed by a relatively long period of rest before the next grazing), and (4) high-intensity, short-duration grazing (relatively short periods of intense grazing are interspersed between relatively short periods of rest). Devised in different rangeland ecosystems to meet different goals and objectives, these four grazing systems seem to share some common goals. These include improvement of range condition, maintenance of plant diversity, and avoidance of repetition, all of which are compatible with sound grasshopper management.

Besides providing a food source, plant canopy can affect grasshopper microhabitat in many ways. Thanks to both direct experimentation and modeling studies, we can now predict some of the responses of grasshoppers to grazing. High diversity in canopy structure and plant species composition tends to support high diversity in grasshopper species (Joern 1979, Pfadt 1982). This diversity and composition tend to provide stability and to suppress pest species that exploit disturbance.

Canopy removal increases solar radiation of the soil surface and increases airflow over the ground. Thus, canopy removal increases both soil and air temperatures and decreases relative humidity for grasshoppers. All of this is favorable to pest grasshopper species because sunlight and low humidity discourage important grasshopper pathogens and because higher temperatures accelerate grasshopper egg development, growth, maturation, and egg production. Canopy removal also can affect basking sites, which provide for early morning thermoregulation (to hasten grasshopper warmup); perching sites, which provide for avoidance of high midday temperatures; and availability or frequency of sites favored for egg-laying (some species require patches of bare soil).

The preceding two paragraphs suggest that any range-management practice that significantly opens up the prairie grassland canopy will tend to favor one or more pest grasshopper species. Therefore, the possibility is unlikely that any grazing strategy, season-long or systematic, can negatively affect every pest grasshopper species in every pasture during every season. However, some attributes of grazing systems should provide some benefits in all pastures every year. Both deferment and alternation of grazing can manipulate the time, rate, and degree of defoliation, and these factors affect the timing, rate, and degree of improvement in habitat for discouraging increases in pest grasshoppers. Both strategies also can prevent repetitively favoring the same pest species for consecutive seasons. Even subtle changes in microhabitat can cause significant decreases in grasshopper development rates and survival rates, and reducing these rates can not only increase the interval between periodic outbreaks but also decrease their intensity and duration.

Different grazing systems can rely on different mechanisms to achieve similar goals. For example, in eastern Montana, Banister (1991) essentially uses periodic high-intensity grazing to increase his forage base (he forces utilization of unpalatable forage, which is about as nutritious as palatable forage). He then uses long periods (about 23 months) of rest to allow plant recovery and to generate plant litter and a tall, dense canopy, which discourage grasshoppers.

Meanwhile, in western North Dakota, Manske (see V.7) promotes use of a “twice-over” rotational grazing system that he developed specifically for use in the northern Great Plains. He allows grazing during a critical period of plant growth to induce subsequent increases in total forage production. The system increases cover and encourages the reproduction of preferred forage (the grasses that are preferentially grazed are selectively induced to produce tillers). The heavier canopy created by this rotation of grazing schedules discourages grasshopper populations.

All observations to date indicate that both systems have merit. Infestations on Banister’s lands seem to comprise mostly *Melanoplus sanguinipes* (a very mobile species), and the grasshopper densities seem to decrease with length of the rest period and with distance to adjacent cultivated crop- or rangeland under more traditional management.

Infestations affecting Manske’s land have been shown to suffer from unusually long periods for development of immature grasshoppers and from rather high daily mortality rates of all stages. Neither system supports pest species that need bare soil for egg-laying. The biggest difference seems to be that the former modifies grazing behavior of the animals while the latter increases production of preferred forage plants. Both systems are ingenious, and both represent creative approaches to the solution of complex, interrelated problems. I hope that their examples will inspire similar integrated management packages that will discourage grasshoppers in other rangeland ecosystems.

The chapters in this section provide an overview of grazing management and the role of grasshoppers in healthy range ecosystems. The introduction of nonnative rangeland plants in the rangeland States unquestionably has had an effect on grasshopper populations, and moisture is a key variable in any range management decision. Grasshopper management through controlled removal of vegetative cover appears to have promise in some situations and may prove to be a key approach to integrated grasshopper management in the future.

References Cited

Banister, R. 1991. Eight principles of range management. Rangelands 13: 85–86.

Capinera, J. L.; Sechrist, T. S. 1982. Grasshoppers (Acrididae)—host plant associations: response of grasshopper populations to cattle grazing intensity. Canadian Entomologist 114: 1055–1062.

Hart, R. H.; Samuel, M. J.; Waggoner, J. W., Jr.; Kaltenbach, C. C.; Smith, M. A. 1987. Grazing management systems for the shortgrass prairie. In: Capinera, J. L., ed. Integrated pest management on rangeland: a shortgrass prairie perspective. Boulder, CO: Westview Press: 9–24.

Joern, A. 1979. Resource utilization and community structure in assemblages of arid grassland grasshoppers (Orthoptera: Acrididae). Transactions of American Entomological Society 105: 253–300.

Kemp, W. P. 1992. Temporal variation in rangeland grasshopper (Orthoptera: Acrididae) communities in the steppe region of Montana, USA. Canadian Entomologist 124: 437–450.

Nerney, N. J. 1958. Grasshopper infestations in relation to range condition. Journal of Range Management 11: 247.

Onsager, J. A. 1987. Current tactics for suppression of grasshoppers on range. In: Onsager, J. A., ed. Integrated pest management on rangeland: state of the art in the sagebrush ecosystem. Washington, DC: U.S. Department of Agriculture, Agricultural Research Service; 60–65.

Pfadt, R. E. 1982. Density and diversity of grasshoppers (Orthoptera: Acrididae) in an outbreak on Arizona rangeland. Environmental Entomology 11: 690–694.

V.2 Historical Trends in Grasshopper Populations in Southern Idaho

Dennis J. Fielding and M. A. Brusven

Many people who live in the West want to know when the next grasshopper outbreak will occur. Currently, understanding of grasshopper population dynamics on rangeland is limited. While precise predictions of grasshopper densities cannot be made from place to place and year to year, examining historical records since 1950 reveals trends that may be valuable when managers need to predict when and why the next grasshopper outbreak will occur.

Each year, personnel of the U.S. Department of Agriculture's Animal and Plant Health Inspection Service, Plant Protection and Quarantine (APHIS-PPQ) conduct surveys of adult grasshopper populations. These survey records generally do not give information on species composition and do not represent intensive sampling, but they are useful in documenting large-scale, regional trends in overall grasshopper densities.

These records show that areas of high density (more than 8 grasshoppers/yd^2) occur somewhere in the State of Idaho nearly every year, but usually these areas are small. Most grasshopper problems occur in the southern portion of the State. Major outbreaks, covering large portions of southern Idaho, occurred in each decade since 1950: in the early 1950's, 1963–65, 1971–72, and most recently, in 1985.

Although we cannot detail the relative contribution of all factors influencing grasshopper populations, we believe that weather plays a very important role in grasshopper population fluctuations in southern Idaho. The historical records show that high grasshopper populations are associated with above-average precipitation at most locations in that area.

Figure V.2–1 shows the importance of adequate precipitation for grasshoppers by depicting the relationship between the number of acres sprayed for grasshopper control and the total precipitation of the 2 previous years. Since 1950, APHIS and its predecessors carried out spray programs covering more than 100,000 acres in southern Idaho in 7 years following the 15 wettest 2-year periods. No spray programs of more than 50,000 acres occurred following the 15 driest 2-year periods.

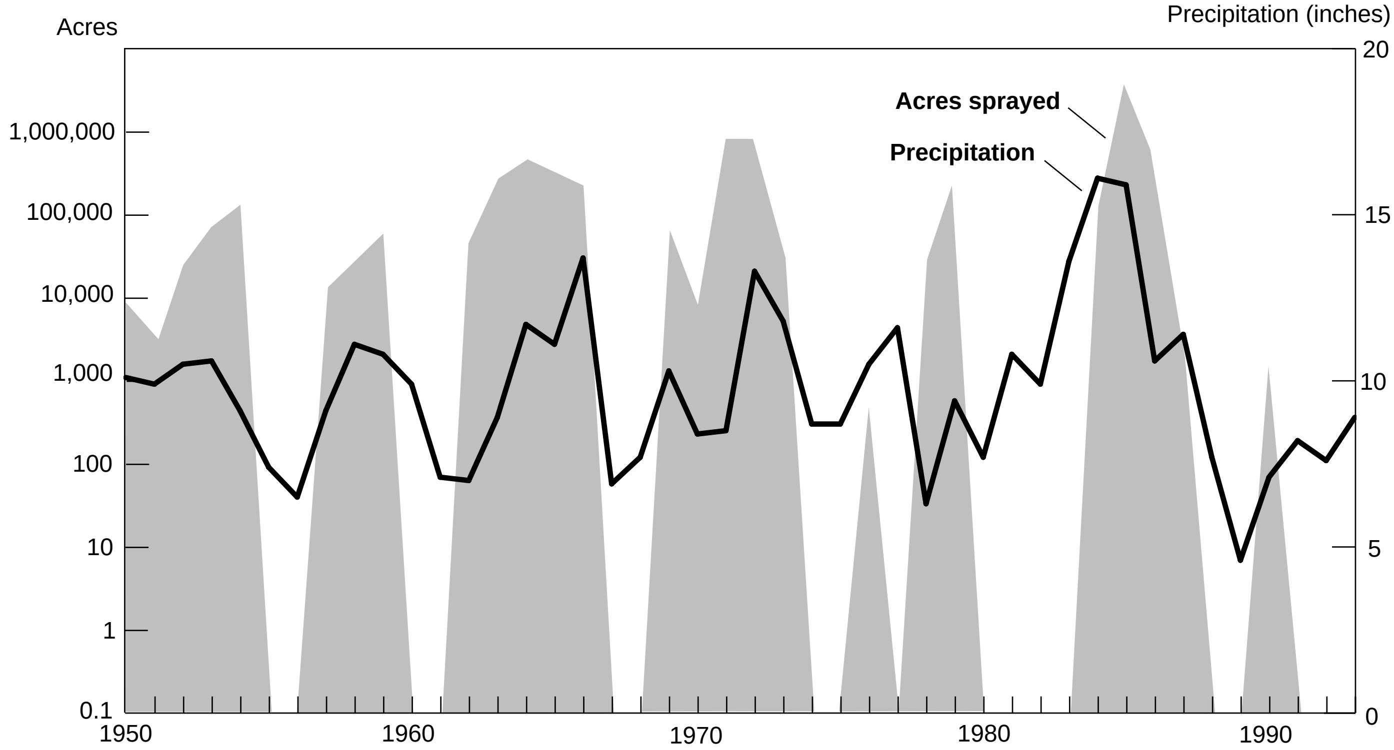

Figure V.2–1—Annual acreage treated for control of grasshoppers in southern Idaho, 1950–92. Precipitation is the average total for the 2 years prior to year of treatment.

Precipitation affects grasshoppers both directly and indirectly. In the Intermountain region, most precipitation occurs between October and April; rainfall in the summer is generally very scant and unpredictable. Grasshopper eggs may be susceptible to drying out during summer drought.

Precipitation also greatly influences the amount and quality of forage available to grasshoppers. As with any herbivore, grasshoppers require abundant energy and protein to achieve maximum reproduction. During drought episodes, rangeland in the Intermountain region provides little green forage in late summer, when many pest grasshopper species reach reproductive stages. Precipitation also may influence the incidence of grasshopper diseases.

Temperature is an important variable. Grasshoppers require a certain amount of heat units to complete development and reproduce. A short growing season at higher elevations may limit grasshopper populations. Cooler, high-elevation areas in southern Idaho usually have lower average grasshopper densities.

Varying 27-year-average densities of adult grasshoppers among 26 locations across southern Idaho reflect the importance of temperature and precipitation. The wetter and warmer locales of southwestern Idaho tend to have the highest average densities, and the cooler, drier areas of eastern Idaho, the lowest.

Biotic (living) factors also help regulate grasshopper populations. Predators, parasites, and pathogens may exert a significant influence on grasshopper population dynamics. Competition for limited resources, especially desired food plants, also may have an impact.

If weather is the primary factor controlling fluctuations in grasshopper populations in southern Idaho, we can do little to prevent occasional outbreaks. Anecdotal evidence from the 1800’s suggests that grasshopper outbreaks are a natural feature of southern Idaho rangeland. To date, evidence does not show whether the frequency of outbreaks has increased with the introduction of domesticated livestock or exotic plant communities. Our observations show that maintaining a shrub cover with a perennial grass understory will foster grasshopper populations that are more diverse with more species that are not prone to outbreaks. We therefore suggest that habitat management is the best long-term action to reduce grasshopper problems (see VII.12).

Acknowledgment

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V.3 Associations Between Grasshoppers and Plant Communities on the Snake River Plains of Idaho

Dennis J. Fielding and M. A. Brusven

A mosaic of vegetation exists across the landscape of the Intermountain region of Idaho (fig. V.3–1). Soils, elevation, and disturbance history strongly influence the mix of plant species growing on a site. Vegetation directly affects watershed functions, suitability of habitat for wildlife, livestock forage, and many recreational uses. Therefore, range managers are very concerned with vegetation management. They try to nurture plant communities that will provide an optimal balance among the multiple demands placed upon America's public rangelands.

The plants growing on a site also provide resources, such as food and shelter, critical to grasshoppers. Because plants define much of a grasshopper's environment, we may expect that different plant communities will harbor different grasshopper species. Our research on the U.S. Department of the Interior, Bureau of Land Management's Shoshone District in south-central Idaho has documented some dominant trends in the associations between grasshoppers and plant communities in the region.

Exotic and Native Plant Communities in Southern Idaho

Compared to some other grassland ecosystems, such as the short-grass prairie of the Great Plains, the sagebrush–grass ecosystem of the Intermountain region is very susceptible to disturbance. Evidence shows that this region did not support heavy concentrations of large, vertebrate herbivores before settlers introduced livestock. (The buffalo [American bison] did not inhabit the Snake River Plains in large numbers.) Grazing, especially during the spring and early summer growing season, easily depletes most of the native perennial grasses in this

Figure V.3–1—Undisturbed Idaho rangeland may contain many native plant species, such as sagebrush and bluebunch wheatgrass. Native plant communities often are host to grasshopper species different from species found in plant communities with introduced grasses. (U.S. Department of the Interior, Bureau of Land Management photo by Mike Pellant.)

region. With the introduction of large numbers of livestock in the 1800's, a substantial decline in the abundance of native perennial grasses occurred over large areas of the region.

Introduced from Eurasia, annual grasses such as cheatgrass *(Bromus tectorum)* and medusahead *(Taeniantherum asperum)* quickly spread through the region. These exotic species are often present in relatively undisturbed plant communities but usually become dominant only on disturbed sites.

Because annual grasses form a continuous, fine fuel that dries out early in the summer fire season, the presence of annual grasses on a site greatly increases the chances of wildfire. Most species of sagebrush are sensitive to fire and with repeated burning are lost from the community. Frequent burning perpetuates the dominance of cheatgrass and maintains these annual grasslands.

This process of shrub loss and conversion to annual grasslands is a key management problem that affects nearly every use of public rangelands on the Snake River Plains. Annual grasses are more susceptible to climatic fluctuations, such as drought, than perennial grasses, so forage production is less predictable on annual grasslands. Cheatgrass matures early in the season, so the grazing season is shorter than on perennial grasslands. The lack of shrub cover makes for poor-quality wildlife habitat, so annual grasslands have diminished plant and animal diversity. Finally, the increased frequency of fire on annual grasslands increases the costs of fire suppression. In the Shoshone District, about 240,000 acres have been converted from perennial to annual grasslands.

Because of the limited resource values of annual grasslands, efforts have been made to reconvert cover in some of these areas to perennial grasses. A primary strategy during the last 40 years has been to plant crested wheatgrass *(Agropyron cristatum),* an introduced perennial bunchgrass that is relatively easy to establish and exhibits competitive abilities against cheatgrass. Crested wheatgrass is often seeded as part of fire-rehabilitation projects or following removal of overabundant sagebrush stands in range-improvement projects. These seedings have typically been established as monocultures, although a new trend involves more diverse seed mixtures that include shrubs and forbs.

A crested wheatgrass monoculture usually has a large percentage of bare ground between the bunchgrasses and fewer annual grasses and weeds than other habitats. Where crested wheatgrass stands fail to become established, because of drought for instance, range-improvement projects can actually promote conversion to highly disturbed annual grassland. As of the mid-1980's, about 20 percent of the Shoshone District below 5,000-ft elevation consisted of crested wheatgrass stands.

Grasshopper Complexes and Principal Species of Southern Idaho

Only about 4 of the 40-plus common species of grasshoppers in southern Idaho attain pest status. The others seldom reach high densities and may be considered harmless or beneficial.

The spurthroated grasshoppers, subfamily Melanoplinae, include some of the most pestiferous species in southern Idaho. Most feed upon a wide range of plants, but some are more specialized. *Melanoplus cinereus,* for instance, feeds mainly on sagebrush and is found only where sagebrush is growing. *Hesperotettix viridus* feeds mainly on rabbitbrush (*Chrysothamnus* spp.) in southern Idaho.

The lesser migratory grasshopper, *M. sanguinipes,* is the number 1 grasshopper pest in southern Idaho. This species occurs in a wide variety of habitats across North America and it feeds upon many forbs and grasses. It has a high reproductive potential, and populations can reach outbreak status within a generation or two when conditions are favorable. This insect will readily migrate to irrigated crops when rangeland vegetation dries during summer droughts.

The valley grasshopper, *Oedaleonotus enigma,* also can reach outbreak densities. It feeds primarily on forbs but will feed extensively on cheatgrass in the spring and on sagebrush during summer droughts. From 50 to 95 percent of a population of this species have short wings and are flightless. Scientists do not know how commonly these grasshoppers migrate from rangeland to cropland. Depending on the proportion of flightless individuals in the population and the distance from cropland, this species is much less significant as a threat to crops than *M. sanguinipes.*

Members of the subfamily Gomphocerinae, the slantfaced grasshoppers, feed almost exclusively on grasses. Except for the bigheaded grasshopper, *Aulocara elliotti,* slantfaced grasshoppers are not major pests in southern Idaho, although *Ageneotettix deorum* and *Amphitornus coloradus* may be common pests elsewhere. *Aulocara elliotti* matures from mid-June to July, about the same time as the perennial grasses on which it feeds. Although it can attain high densities and can be very damaging to rangeland grasses, it does not seem to be a threat to cultivated crops in southern Idaho.

The lower elevations of the Intermountain region have many species in the subfamily Oedipodinae, the bandwinged grasshoppers. About half of the grasshopper species in south-central Idaho are included in this group. Most are large-bodied, generalist feeders, although *Trachyrachys kiowa* is a common, smaller grasshopper that feeds exclusively on grasses. High densities of the clearwinged grasshopper, *Camnula pellucida,* have been recorded at higher elevations in south-central Idaho.

Grasshopper Species Distributions Across Plant Communities in Southern Idaho

We established long-term grasshopper monitoring sites at 30 locations in the Shoshone District, representing annual grasslands, crested wheatgrass seedings, and sagebrush–grass areas. The sagebrush–grass sites covered a variety of vegetation types, with different species and subspecies of sagebrush represented. Dominant understory grasses included cheatgrass or native bunchgrasses, such as bluebunch wheatgrass *(Agropyron spicatum)* or Thurber's needlegrass *(Stipa thurberiana).*

During 5 years of monitoring grasshopper populations on these sites, we have observed differences in grasshopper species composition between exotic and native plant communities.

The annual grasslands had the highest grasshopper densities, along with the highest proportion of pest species, during the 5-year period. The annual grassland sites also had the lowest grasshopper species diversity and were clearly dominated by the Melanoplinae (fig. V.3–2). Other researchers have noted that these species are common in weedy, disturbed habitats.

The grasshopper species commonly found in annual grassland habitats usually are generalist feeders that live in a variety of habitats, characteristics that make them well adapted to exploit unpredictable habitats like the annual grasslands. Two species, *M. sanguinipes* and *O. enigma,* accounted for most of the grasshoppers on the annual grassland sites. The presence of *M. sanguinipes* correlated positively with areas having a high percentage of ground cover of annual vegetation and correlated negatively with areas having sagebrush cover.

The crested wheatgrass seedings had a more even representation of grasshopper species, with the grass-feeding Gomphocerinae being the most abundant group in these habitats (fig. V.3–2). Most slantfaced grasshoppers are closely associated with perennial grasses, such as crested wheatgrass, using them for food and shelter.

The sagebrush–grass sites had an even distribution of grasshopper species across the three subfamilies (fig. V.3–2). Grasshopper assemblages of the sagebrush–grass habitats included a greater proportion of species with specialized habitat requirements. These species tended to be found at fewer sites and to have a more restricted diet.

Implications for Range Managers

We conducted our studies during years of low grasshopper densities. We expect that under outbreak conditions the observed relationships may change. For example, we expect *M. sanguinipes* to be a prominent species in all southern Idaho habitats during an outbreak. We need detailed observations during high-density years. Historical data from the last outbreak (1985) are consistent with our more recent observations in that, although we found high densities in all habitats, the annual grasslands had the highest average densities.

While one may argue that during a major outbreak all habitats will require control operations, we believe that outbreaks will be less frequent and of smaller extent in habitats characterized by sagebrush cover over a perennial grass understory. Moreover, we believe that efforts to prevent further shrub loss and to reconvert annual grasslands to perennial grasses should help restrain future grasshopper outbreaks.

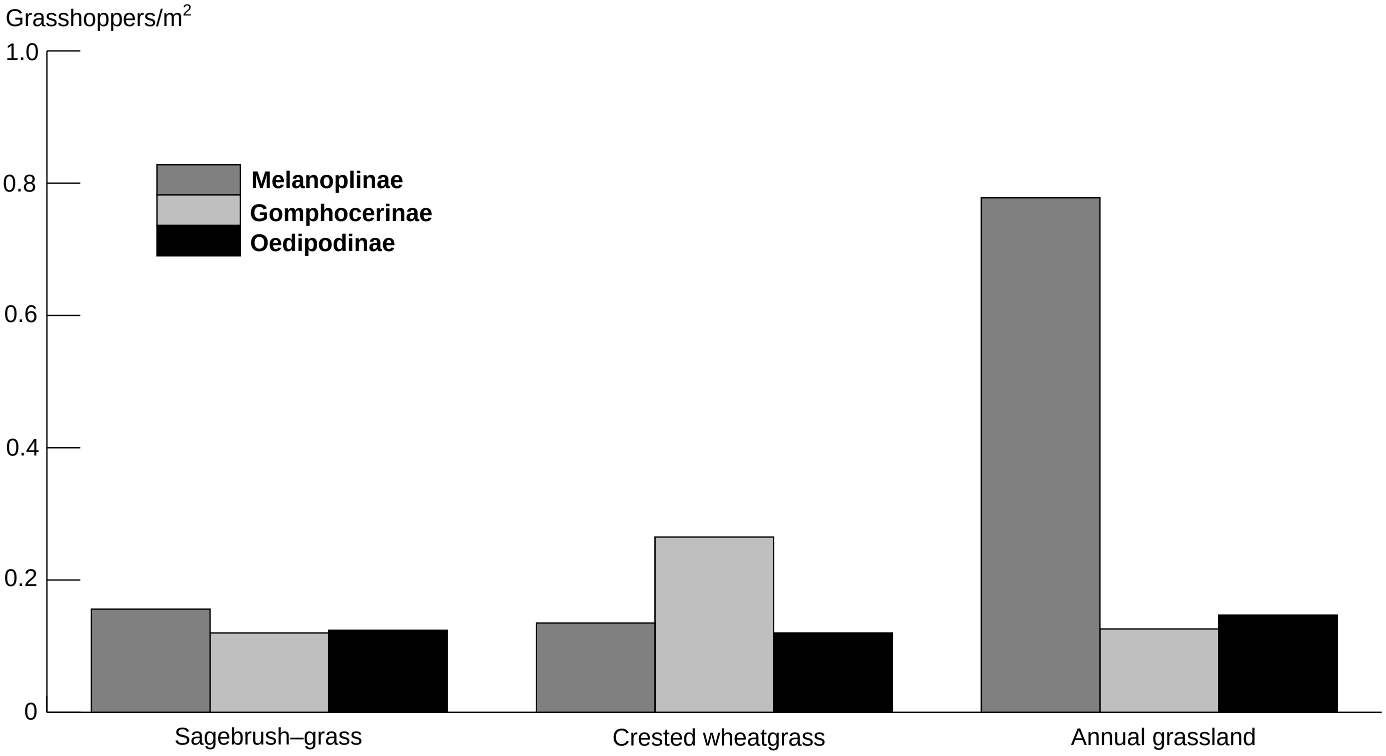

Figure V.3–2—Density distribution of grasshopper subfamilies by grassland sites on the Snake River Plains of southern Idaho.

Although the high cost of rehabilitating annual grasslands may not be justified by reduced grasshopper problems alone, the conversion of annual grasslands to a sagebrush–perennial grass vegetation type is consistent with many other goals of multiple-use management, such as the provision of wildlife habitat, livestock forage, and recreation.

Acknowledgment

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Selected References

Fielding, D. J.; Brusven, M. A. 1993. Spatial analysis of grasshopper density and ecological disturbance in southern Idaho. Agricultural Ecosystem Environment 43: 31–47.

Fielding, D. J.; Brusven, M. A. 1993. Grasshopper (Orthoptera: Acrididae) community composition and ecological disturbance on southern Idaho rangeland. Environmental Entomology 22: 71–81.

Fielding, D. J.; Brusven, M. A. 1994. Grasshopper community responses to shrub loss, annual grasslands, and crested wheatgrass seedings: management implications. In: Monsen, Stephen B.; Kitchen, Stanley G., comps. Proceedings—ecology and management of annual rangelands; 1992 May 18–21; Boise, ID. Gen. Tech. Rep. INT-313. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station: 162–166.

Tisdale, E. W.; Hironaka, M.; Fosberg, M. A. 1969. The sagebrush region in southern Idaho: a problem in range resource management. Bull. 512. Moscow, ID: University of Idaho, Idaho Agricultural Experiment Station.

Whisenant, S. G. 1990. Changing fire frequencies on Idaho's Snake River Plains: ecological and management implications. In: McArthur, E. D.; Romney, E. M.; Smith, S. D.; Tueller, P. T., eds. Proceedings of a symposium on cheatgrass invasion, shrub die-off, and other aspects of shrub biology and management. Gen. Tech. Rep. INT-276. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station: 4–10.

V.4 Utilization of Nonnative Rangeland Plants by Grasshoppers on the Snake River Plains of Idaho

Dennis J. Fielding and M. A. Brusven

The Intermountain region of Idaho is highly susceptible to invasions by exotic plant species. At many locations in southern Idaho, exotic plant species comprise 70 to 90 percent of the plant biomass. Cheatgrass *(Bromus tectorum),* medusahead wildrye *(Taeniantherum asper),* knapweeds *(Centaurea* spp.), tumblemustard *(Sisymbrium altissimum),* and Russian-thistle *(Salsola kali)* are widely distributed annual or biennial weeds. Other introduced weeds threatening rangelands in southern Idaho include leafy spurge *(Euphorbia esula)* and rush skeletonweed *(Chondrilla juncea).* The area infested by exotics continues to increase each year. Also, people intentionally have established crested wheatgrass *(Agropyron cristatum),* an exotic perennial bunchgrass, over vast acreages of the Intermountain West.

To learn about the relationship between such exotic plant species and grasshoppers, we investigated the food habits of the most common grasshopper species in southern Idaho. We wanted to gain some insight into the following questions: How palatable are these exotic plant species to native grasshoppers? Do these exotics provide a significant new resource for grasshoppers? Might grasshoppers limit the spread of these new weeds?

We used microscopic analysis of the crops of grasshoppers to learn about their food choices. By examining the contents of a grasshopper's crop under a microscope and comparing the surface characters (hairs, hair structure, arrangement of cells, etc.) of the plant fragments with known reference material, we were able to measure accurately the relative proportion of different plant species and parts of plants (stems, flowers, and leaves) ingested by the grasshopper.

Diffuse Knapweed

Diffuse knapweed *(Centaurea diffusa)* has spread rapidly and widely across Idaho. Knapweeds contain a chemical, cnicin, that is repellent to many herbivores. Concentrations of cnicin vary within the plant: leaves surrounding the flowers have the highest concentrations, and the stem epidermis and flowers have only trace quantities. Because of the unpalatibility of knapweed, infested rangeland has greatly reduced forage value for livestock and wildlife.

We used microscopic analysis to determine the use of diffuse knapweed by the common grasshopper species *Melanoplus sanguinipes.* A spurthroated grasshopper, *M. sanguinipes* is a very opportunistic feeder. Egg hatch in this species often spreads out over a long period, resulting in a highly variable life history. Much of a population of this species typically matures during late summer droughts common in southern Idaho. At such times, most late-maturing plant species that retain some greenness will be a primary food item for *M. sanguinipes.*

Our results showed that *M. sanguinipes* readily consumes knapweed but not in proportion to its availability. The insect prefers other plants, such as cheatgrass and tumblemustard, over knapweed. In late summer, though, when most other plant species are dead, knapweed comprises up to 50 percent of that species' crop contents (table V.4–1). Other plants that are still green then, such as rabbitbrush *(Chrysothamnus* spp.), sagebrush *(Artemesia* spp.), and certain lupine *(Lupinus)* species, also serve as food sources. After autumn rains caused cheatgrass, an exotic annual, to sprout in October, this grass comprised the bulk of *M. sanguinipes'* diet.

Cheatgrass and Crested Wheatgrass

Cheatgrass and another exotic grass species, crested wheatgrass, dominate much of the landscape at lower elevations on the Snake River Plains (figs. V.4–1 and –2). Crested wheatgrass, a perennial bunchgrass, stays green longer in the season than does cheatgrass. We investigated the food habits of *M. sanguinipes* and another common grasshopper species, *Aulocara elliotti*, regarding these two grasses.

A. elliotti, a slantfaced grasshopper, is mostly limited in its diet to grasses but is not selective among grasses. In southern Idaho, populations of *A. elliotti* hatch early and mature at the same time as the grasses on which they feed. In early summer, that species eats crested wheatgrass and cheatgrass equally (table V.4–2). However, as the season progresses and the cheatgrass dries, the diet of *A. elliotti* consists of proportionally greater amounts of crested wheatgrass.

Figure V.4–1—Cheatgrass, an introduced annual grass, can dominate disturbed sites and is widespread across Idaho and in other Pacific Northwest States (Photo by Dennis Fielding, University of Idaho).

Figure V.4–2—Land managers and ranchers often have used crested wheatgrass to reseed areas of Idaho rangeland to enhance forage for livestock and in doing so, sometimes create food sources for pest species of grasshoppers. (U.S. Department of the Interior, Bureau of Land Management photo by Mike Pellant.)

In contrast, *M. sanguinipes* eats mostly cheatgrass in the early summer. As the cheatgrass dries, the insect consumes greater proportions of weedy forbs, such as tumblemustard and Russian-thistle (table V.4–2). Crested wheatgrass did not comprise more than 20 percent of the insect's diet at any time.

Table V.4–1—Crop contents of *M. sanguinipes*, by percentage, on knapweed-infested rangeland east of Jerome, ID, on five different dates in 1989. Grasses were primarily cheatgrass with less than 5 percent western wheatgrass *(Agropyron smithii)*

	June 30	July 20	Aug. 14	Sept. 6	Oct. 13
Diffuse knapweed	18	30	32	55	12
Other forbs	65	48	29	31	1
Grasses	8	13	27	7	86
Litter, detritus	9	9	13	7	1

Note: Percentages may exceed 100 due to rounding.

Table V.4–2—Crop contents of *A. elliotti* and *M. sanguinipes*, by percentage, on a crested wheatgrass seeding north of Bliss, ID, in 1990

	Aulocara elliotti		*Melanoplus sanguinipes*		
	May 18	July 2	May 25	July 9	Aug. 13
Crested wheatgrass	37	75	16	16	19
Cheatgrass	60	17	56	22	17
Forbs	0	7	12	42	50
Litter, detritus	3	2	16	20	14

Note: Percentages may exceed 100 due to rounding.

Conclusions

The manner in which evolutionary history has molded a grasshopper's food habits and other life-history traits decides how a grasshopper will respond to exotic plants. On the Snake River Plains, the most abundant grasshopper species—the ones most likely to achieve outbreak densities—accept a variety of plants and will adapt readily to exotic plant species.

Certain introduced weeds, especially tumblemustard and cheatgrass, may represent a significant new resource for generalist feeders, such as *M. sanguinipes* and *Oedaleonotus enigma.* Rangeland dominated by these plants may provide a more favorable habitat for these grasshoppers, compared to rangeland dominated by native perennial grasses (see section IV, Modeling and Population Dynamics). Less palatable weeds, such as the knapweeds, probably do not provide a significant new resource for native grasshopper populations in southern Idaho; our findings indicate that diffuse knapweed may serve mostly as a survival food during summer droughts.

Our study of grasshopper food habits suggests that land managers should not count on these insects to slow the spread of noxious weeds. While it is conceivable that at high densities grasshoppers may eat large amounts of noxious weeds and reduce seed production, grasshoppers also will eat other plants at the same time, reducing competition to the weeds.

Grasshoppers with specialized feeding habits may offer a better chance of controlling certain weeds. *Hesperotettix viridis*, for example, feeds on broom snakeweed *(Gutierrezia sarothrae).* Such specialist feeders probably would eat mainly native weeds or exotics that are very close relatives of native plants. Specialist feeders would not recognize novel plants as potential food items.

Acknowledgment

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V.5 Local Movement of Grasshoppers Between Public Rangeland and Irrigated Pastures in Southern Idaho

M. A. Brusven, Dennis J. Fielding, Leslie P. Kish, and Russell C. Biggam

On the ground or in flight, grasshoppers have great powers of mobility that allow them to disperse in a way that aids their survival (Dingle 1980, Drake and Farrow 1988, Farrow 1990, Joern 1983, McAnelly and Rankin 1986, Parker et al. 1955). During major outbreak years, ranchers and farmers have noted "clouds" of grasshoppers migrating from one area to another. The exact origin of the migrating grasshopper bands, direction and distance traveled, and the reasons why they disperse are poorly understood for most North American grasshopper species (Riegert et al. 1954, Shotwell 1941). Chapman et al. (1978), Dingle (1972), Southwood (1981), and Uvarov (1977) have given general accounts of insect migration. Laboratory studies have been used to help understand grasshopper flight in confined environments (Riegert 1962).

But the study we conducted is about more localized movement of grasshoppers across the narrow transitions between public rangeland and privately owned, irrigated pastures. A general perception exists that grasshoppers migrate from highly disturbed, overgrazed public rangeland to the more lush, irrigated cropland–pastureland, causing considerable damage to the latter (fig. V.5–1). In southern Idaho, the boundaries between private and public lands, most of which are managed by the U.S. Department of the Interior's Bureau of Land Management (BLM), are long and irregular and usually marked by a fence. Nearly 2 million acres (809,717 ha) make up the BLM Shoshone District. This district is located in the sagebrush–grass ecoregion of southern Idaho. Areas having deeper and more productive soils are largely under private ownership.

The question of whether grasshoppers migrate from public to private land or vice versa and the reasons for localized movements formed the basis for our study. Numerous factors potentially influence the direction and extent of grasshopper migration. Some of these factors include soil moisture; plant composition, height, quality,

Figure V.5–1—An Idaho study provided new information on the belief that grasshoppers migrate from public rangelands to privately owned pastures.

and moisture; vegetative cover; wind velocity; grazing disturbance; predators, inter- and intraspecific competition; grasshopper age and physiological state; and genetically related behavior, such as egg-laying. Our investigations and interpretations were limited to plant cover, composition, moisture content, and height, particularly as they related to grazing of public rangeland and adjacent irrigated pastures.

The Study Area

We studied the lesser migratory grasshopper, *Melanoplus sanguinipes*, and used adults because they display the greatest powers of mobility. The study took place in and adjacent to a 321-acre (130-ha) sprinkler-irrigated pasture bordered on the north, east, and west by BLM rangeland. Studies centered on the west border in 1991 and east border in 1992 to test for directional movements of grasshoppers in response to different rest-rotation grazing regimes, range conditions, prevailing winds, and irrigated pasture conditions.

In 1991, 2 populations of 500 adult *M. sanguinipes* each were differentially marked with fluorescent markers and released in the centers of 2 adjacent 98.4×98.4-ft (30×30-m) plots separated by a fence. The west-side plot was on BLM rangeland that had been rested (not grazed) since the previous year. The east-side plot was on a well-utilized (currently grazed), legume–grass, irrigated pasture. In 1992, 2 populations of 400 grasshoppers each were marked and released in a similar manner, except the plots were on the east side of the irrigated pasture. Again, extensive grazing occurred on the sprinkler-irrigated pasture at the time of the study. Extensive grazing on the BLM pasture during early summer had resulted in a dry, depleted rangeland condition consisting mostly of heavily cropped crested wheatgrass. After releasing marked grasshoppers, we counted them during the night, thus minimizing movement resulting from investigator disturbance. We counted all the marked grasshoppers within the plot borders at 24, 48, and 96 hours after release.

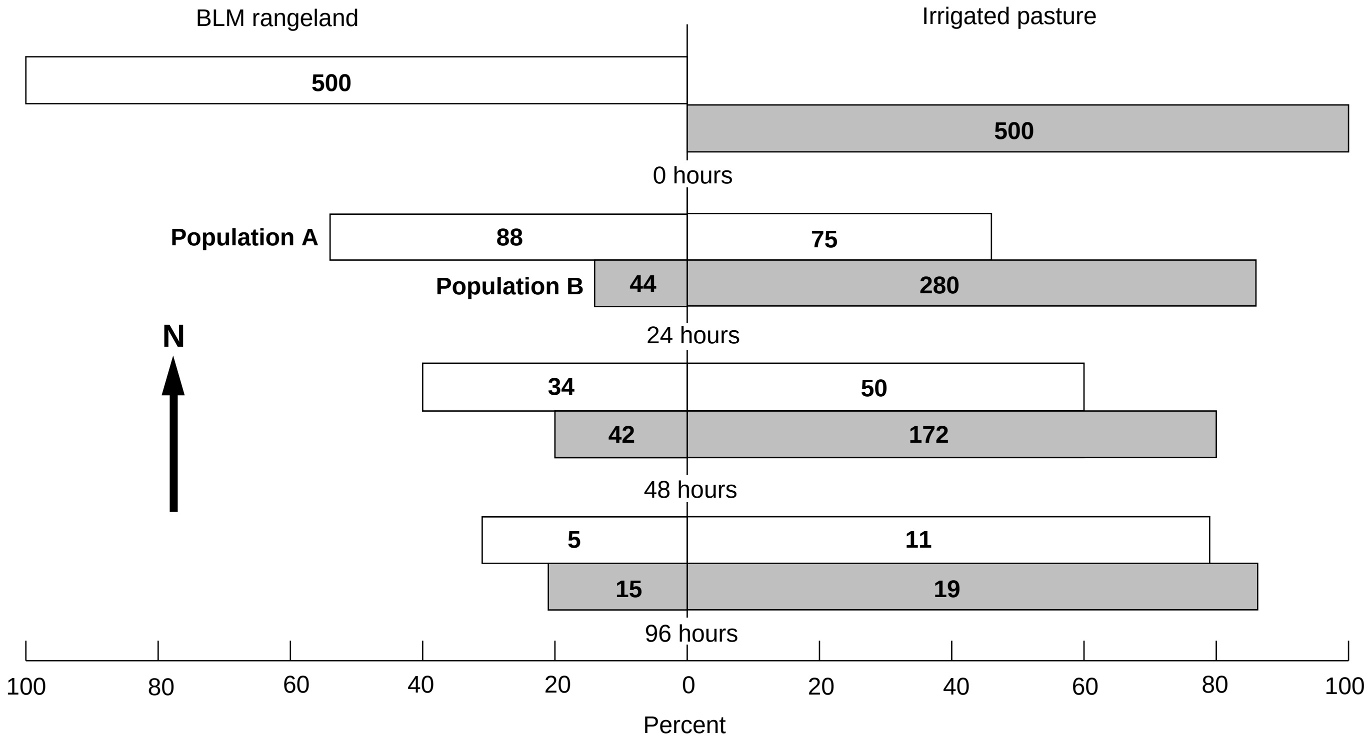

Figure V.5–2—Percent distribution of marked grasshoppers within adjacent rangeland and irrigated pasture plots at 24, 48, and 96 hours after their release, 1991. Numbers inside bars are actual counts.

What We Found

Grasshopper movement between private and public lands differed markedly between the 2 years with regard to "net" directional dispersal. Because the marked populations were not confined to specific plots, the insects' ultimate movement could be in any direction from the release point and could extend beyond the plot perimeters. For purposes of interpretation, we recorded only marked grasshoppers within adjacent plots. Figures V.5–2 and –3 graph the results on a relative basis (percent of total marked) for each time interval.

In 1991, with prevailing winds from the south to southwest ranging from 6 to 12 miles per hour (mi/hour) (10 to 19 km/hour), net movement of marked populations was easterly from the BLM rangeland to the irrigated pasture (fig. V.5–2). The grasshoppers released in the irrigated pasture showed a much higher affinity for that habitat than grasshoppers released in the BLM plot; however, there was a noticeable presence of grasshoppers from the irrigated pasture in the BLM plot at all times. Only 3 and 5 percent of the marked populations were accounted for in the adjacent plots after 96 hours, indicating a progressive outward dispersal from the release points in all directions.

Because the BLM plot was rested during the spring and summer months preceding the study, the vegetative condition was fair overall, with good plant height and fair cover. The irrigated plot had greater plant cover and moisture content than the BLM plot. Distribution of grasshoppers within the plots correlated significantly with plant height but not with the percent of moisture or cover (bare ground).

In 1992, dispersal patterns were profoundly different from the previous year (fig. V.5–3). Strong, gusty winds from the west and southwest ranged from 14 to 24 mi/hour (23 to 39 km/hour) during the period of study. We recovered only two marked grasshoppers in the heavily grazed BLM plot during the 96-hour test and

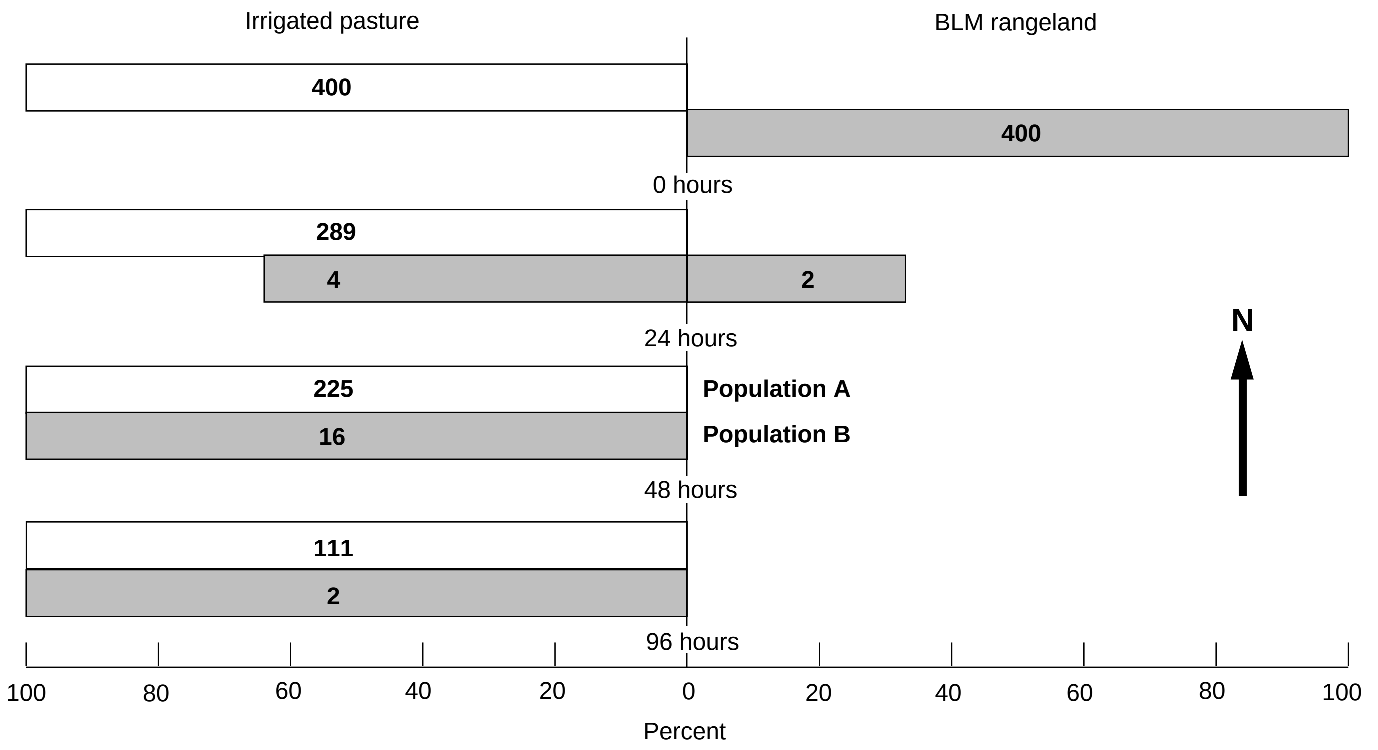

Figure V.5–3—Percent distribution of marked grasshoppers within adjacent BLM rangeland and irrigated pasture plots at 24, 48, and 96 hours after their release, 1992. Numbers inside bars are actual counts.

found 12 of the marked grasshoppers from the BLM plot in the irrigated pasture plot. Conversely, we found no grasshoppers from the irrigated pasture in the BLM plot and noted a very high level of retention of grasshoppers within the irrigated pasture with more than 25 percent still accounted for after 96 hours. The heavily grazed BLM plot was clearly unfavorable to the grasshoppers. Nearly all had moved from the plot within 24 hours or were lost to predation, a factor not readily measurable. The BLM plot was nearly a monoculture of heavily cropped crested wheatgrass. A diversity of weedy forbs was generally absent from the plot, undoubtedly contributing to its objectionable habitat quality for *M. sanguinipes*, which is a mixed feeder preferring forbs.

We believe that strong, westerly to southwesterly, gusty winds aided the dispersal of grasshoppers from the BLM plot in a general downwind direction (northeasterly), even though positive chemical cues were likely coming from the highly diverse, succulent, irrigated pasture to the west. Again, we emphasize the significance of much higher plant height (nearly 3 times greater), plant diversity (mixture of weedy, invasionary plants, grasses, and pasture legumes), and greater vegetative cover (about 2.5 times greater); all are contributing factors to the high retention of grasshoppers in the irrigated pasture compared to the heavily grazed BLM plot, in spite of high, gusty winds.

Conclusions

As to the question of whether grasshoppers migrate from public rangeland to adjacent irrigated pastures, the answer is “not always.” Numerous factors operate individually or together to influence the direction, distance, and magnitude of grasshopper migration. The present study addressed only public rangeland and irrigated pastures. Other types of crops adjoin public rangeland and provide interesting challenges for future studies. A basic axiom of life applies to grasshoppers as with most other mobile organisms on rangeland: When the requirements of survival are limiting (for example, depleted habitat) grasshoppers will migrate, either actively or passively, (wind-aided movement) in search of more favorable habitat conditions.

Acknowledgment

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References Cited

Chapman, R. F.; Cook, A. G.; Mitchell, G. A.; Page, W. W. 1978. Wing dimorphism and flight in *Zonocerus variegatus* (L.) (Orthoptera, Acridoidea). Bulletin of Entomological Research 68: 229–242.

Dingle, H. 1972. Migration strategies of insects. Science 175: 1327–1335.

Dingle, H. 1980. Ecology and evolution of migration. In: Gauthreaux, S. A., ed. Animal migration, orientation and navigation. New York: Academic Press: 1–101.

Drake, V. A.; Farrow, R. A. 1988. The influence of atmospheric structure and motions on insect migration. Annual Review of Entomology 33: 183–210.

Farrow, R. A. 1990. Flight and migration in acridoids. In: Chapman, R. F.; Joern, A., eds. Biology of grasshoppers. New York: John Wiley & Sons: 227–314.

Joern, A. 1983. Small-scale displacements of grasshoppers (Orthoptera, Acrididae) within arid grasslands. Journal of the Kansas Entomological Society 56: 131–139.

McAnelly, M. L.; Rankin, M. A. 1986. Migration in the grasshopper *Melanoplus sanguinipes* (Fab.). I. The capacity for flight in non-swarming populations. Biology Bulletin 170: 368–377.

Parker, J. R.; Newton, R. C.; Shotwell, R. L. 1955. Observations on mass flights and other activities of the migratory grasshopper. Tech. Bull. 110. Washington, DC: U.S. Department of Agriculture.

Riegert, P. W. 1962. Flight of grasshoppers in the laboratory. Nature 194: 1298–1299.

Riegert, P. W.; Fuller, R. A.; Putnam, L. G. 1954. Studies on dispersal of grasshoppers (Acrididae) tagged with phosphorus-32. Canadian Entomologist 5: 223–232.

Shotwell, R. L. 1941. Life histories and habits of some grasshoppers of economic importance on the Great Plains. Tech. Bull. 774. Washington, DC: U.S. Department of Agriculture. 48 p.

Southwood, T.R.E. 1981. Ecological aspects of insect migration. In: Aidly, D. J., ed. Animal migration. London and New York: Cambridge University Press: 196–208.

Uvarov, B. P. 1977. Grasshoppers and locusts, vol. 2. London: Centre for Overseas Pest Research.

V.6 Grazing Effects on Grasshopper Populations in Southern Idaho

Dennis J. Fielding and M. A. Brusven

Many investigators have examined the impact grasshopper populations exert on the availability of forage for livestock. Fewer studies have been done on the reverse relationship: the effects of livestock grazing on grasshoppers. No previous studies have addressed this topic within the Intermountain region of Idaho.

In any discussion of the effects of livestock grazing on grasshoppers, the distinction between long-term and short-term effects of grazing must be maintained. Long-term changes due to grazing may include alterations in the composition of the plant community and changes in soil properties. Short-term changes include reduced forage, altered chemical and physical characteristics of plants, reduced plant height, and possibly a warmer and drier microclimate (see V.1). Only short-term grazing effects will be considered here.

Field Studies

We compared grasshopper densities and species composition between grazed and ungrazed plots from 1990 to 1993. The results have been consistent: we have seen either lower densities on heavily grazed plots or no differences at all. Over the 4-year period, the grazed plots had an average of half as many grasshoppers as the ungrazed plots (fig. V.6–1). One species, *Melanoplus sanguinipes*, accounted for most of the difference in density. The subfamilies Gomphocerinae (slantfaced) and Oedipodinae (bandwinged), as a group, were relatively indifferent to grazing. This does not mean that grazing did not affect certain species within these subfamilies, but densities were too low to evaluate individual species.

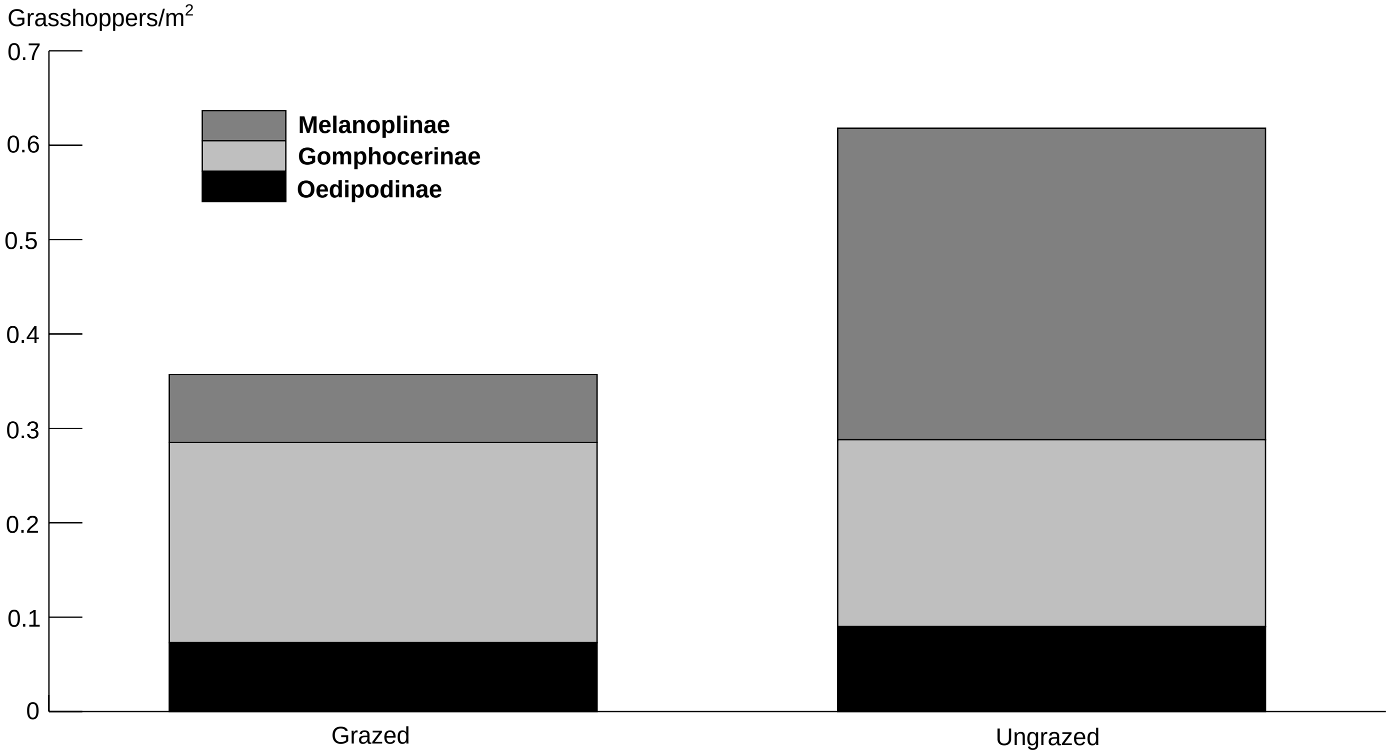

Figure V.6–1—Mean grasshopper densities from five pairs of grazed and ungrazed plots, 1990–93, within the Bureau of Land Management’s Shoshone District (N = 3 samples per year × 4 years × 5 plots = 60).

In 1993, a year of above-average precipitation and unusually high rangeland productivity, grazing effects on grasshopper densities were not as pronounced as in other years. These results suggest that by reducing the amount of forage available to grasshoppers, livestock are competing with them and reducing the carrying capacity of the rangeland for grasshoppers. To test this hypothesis under more controlled conditions, we conducted cage studies during 1992 and 1993.

Cage Studies

Cages covering 1 m^2 were set out in an area dominated by cheatgrass *(Bromus tectorum)* and tumblemustard *(Sisymbrium altissimum),* favored habitat of *M. sanguinipes.* We stocked the cages with 10 adult *M. sanguinipes* in July, shortly after adults were first observed in the field. Before we stocked the cages, we clipped half of the aboveground plant biomass (material) and weighed it to the nearest gram in half the cages. We counted grasshoppers within each cage weekly until no grasshoppers survived or until we finished the experiment in October. The remaining plants within the cages were clipped and weighed to the nearest gram after we terminated the experiment, and we sifted the soil to collect any grasshopper egg pods.

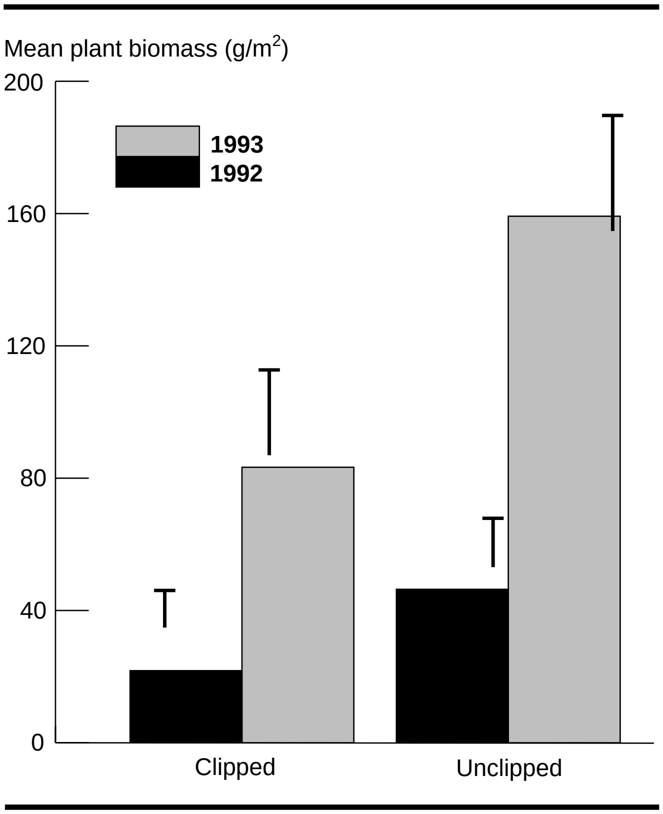

Figure V.6–2—Mean (N = 6 and 9, in 1992 and 1993, respectively) total dry weight of aboveground plant material in clipped and unclipped cages. Error bars indicate 1 standard error of mean. Plants consisted mainly of tumblemustard, cheatgrass, and Sandberg's bluegrass *(Poa sandbergii).*

Abundant precipitation generated much greater plant production in 1993 than the year before (fig. V.6–2). No differences in adult grasshopper survival (measured as total grasshopper-days) occurred between cages of clipped and unclipped plant biomass in either year (fig. V.6–3). However, dramatic differences in fecundity (reproductive capability—measured as eggs per female-day) occurred between the 2 years and between clipped and unclipped cages in 1993 (fig. V.6–4).

These field results suggest that fecundity of *M. sanguinipes* is strongly affected by host plant quality and/or quantity, although adult survival is not. Perhaps maintenance requirements for survival in adults of this species are quite low and can be met by low-quality food, such as dead plant litter. Egg production appears to be much more sensitive to diet.

As the previously cited chapter points out, other factors, besides forage availability, may also play a role in interactions between grazing and grasshoppers. Reduced plant height, increased bare ground, higher temperatures, and lower relative humidity are characteristic of grazed habitats. The behavioral responses of certain grasshopper species to these variables may affect population responses to grazed habitats. For instance, grasshoppers that take refuge in vegetation, such as many slantfaced grasshoppers, may actively seek habitats that provide a greater abundance of refuges, such as ungrazed habitats. Grasshoppers that escape predators by blending in with bare ground, such as many bandwinged species, may be indifferent to grazing-induced habitat changes. These sorts of habitat preferences could explain differing responses to grazing among species.

Concluding Statements

The effects of grazing on rangeland grasshoppers are dependent on so many factors (such as weather and plant community) that generalizations are difficult. Plant responses to grazing depend on the intensity and timing of grazing and the weather. For instance, younger plant tissue is generally more digestible and has higher protein levels than older tissue. In situations where plants can regrow following defoliation, the regrowth may provide higher quality forage for grasshoppers. In dry seasons or climates that do not allow for regrowth, defoliation results in less food, and probably food of lower quality, for grasshoppers. Similarly, the microclimate associated with grazed habitats (warmer and drier) may be beneficial to many grasshopper species during cool, wet spring weather but may be detrimental during summer droughts.

In summary, our observations suggest that livestock grazing often causes a short-term reduction in habitat quality for *M. sanguinipes* in southern Idaho. These observations suggest that grazing could be considered as a management tool for regulating grasshopper populations. However, we are skeptical of the practicality of using livestock grazing as a grasshopper management tool in southern Idaho. Rangeland productivity and the consequent carrying capacity for grasshoppers vary greatly from year to year within the Intermountain region. Livestock numbers are not flexible enough to permit land managers to respond to extreme fluctuations in carrying capacity of rangeland and grasshopper populations. During years of above-normal precipitation and high biomass productivity, grasshopper populations can increase tremendously. Grazing levels would have to be doubled or tripled to inhibit grasshopper reproduction appreciably.

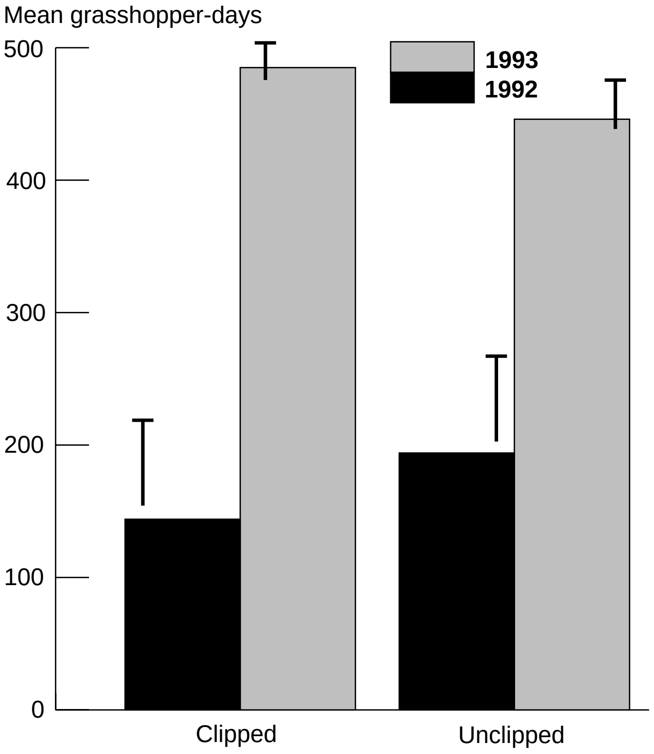

Figure V.6–3—Mean (N = 6 and 9, in 1992 and 1993, respectively) survival of adult grasshoppers *(Melanoplus sanguinipes)* within 1-m^2 cages. Error bars indicate 1 standard error of mean.

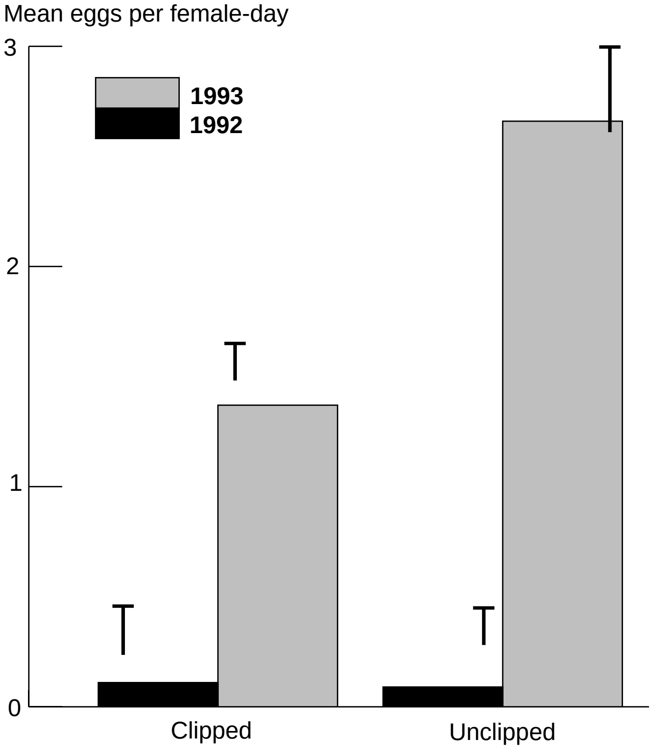

Figure V.6–4—Mean (N = 6 and 9, in 1992 and 1993, respectively) fecundity of female *Melanoplus sanquinipes* within 1-m^2 cages. Error bars indicate 1 standard error of mean.

Assuming that managers could increase livestock grazing to a point where it would reduce grasshopper populations, such levels of grazing could produce negative long-term effects. Chronic, heavy grazing could lead to long-term changes in vegetation toward more of the weedy annuals (fig. V.6–5) that promote high densities of pest grasshopper species (see V.3).

We expect grazing to have the greatest effect on grasshopper populations during drought episodes, when grasshopper populations are already low (see V.2). Under such conditions, grazing potentially could reduce already low grasshopper densities to the point of affecting creatures, such as nesting birds, that depend on grasshoppers for food. (For more information, see chapter I.9, “Birds and Wildlife as Grasshopper Predators.”)

The sustainable level of livestock grazing on public rangelands is an issue that is receiving increased scrutiny. Managers need information regarding ecosystem responses to grazing to manage rangeland resources properly. Presently, knowledge about grazing effects on grasshoppers is fragmentary and incomplete. These issues involve economics, politics, sociology, ecology, and environmental ethics. The full integration and balancing of these considerations leave fertile ground for more holistic studies in the future.

Figure V.6–5—Grazing can produce negative effects on rangeland by removing understory grasses and creating an opportunity for weedy annuals.

V.7 Beneficial Changes of Rangeland Through Proper Grazing

Llewellyn L. Manske

Introduction

Grassland ecosystems are diverse and complex, a fact that makes developing management recommendations difficult. However, increasing knowledge of ecological principles and the intricacies of the numerous mechanisms that function in the grassland ecosystem have allowed for improvements in management strategies.

Several greenhouse and laboratory studies within the last 10 to 12 years have enabled scientists to begin to understand how grassland plants react to being grazed. Grassland plants and herbivores have evolved together for 20 million years. During this long period of coevolution, grassland plants have developed mechanisms to compensate for defoliation from herbivores and fire. These adaptive tolerance mechanisms can be separated into two main categories, but they do not function independently. The first mechanism involves numerous changes in the physiological growth processes within the grassland plant itself, and the second involves numerous changes in the activity levels of the symbiotic (mutually beneficial) soil organisms in the rhizosphere, which is the narrow zone of soil around perennial plant roots.

The physiological responses within the plant caused by defoliation have been reviewed and grouped into nine categories by McNaughton (1983). Physiological responses to defoliation do not occur at all times, and the intensity of the response varies. Grass plants have different physiological responses at various stages of growth. The key to ecological management by defoliation is to match the timing of defoliation events to the appropriate stage of growth that triggers the desired outcome.

All possible combinations of relationships between the physiological responses and the application of the defoliation-management treatment have not yet been quantitatively evaluated with scientific research. One of the main physiological effects of defoliation is the temporary reduction in the production of the blockage hormone auxin in young, developing leaves and within the meristem (the growth point where tissue is formed by cell division). The reduction of plant auxin in the lead tiller allows either for the synthesis of cytokinin (a growth hormone) in the roots or crown or its utilization in axillary buds, which are growth points with potential to develop into vegetative tillers, resulting in the production of new plants (Murphy and Briske 1992). Partial defoliation of young leaf material reduces the hormonal effects of apical dominance (hormonal suppression of growth of other buds by the lead tiller) and allows secondary tillers to develop from the previous year’s axillary buds. Secondary tillers can develop without defoliation manipulation after the lead tiller has reached the flowering growth stage. Usually, only one secondary tiller develops from the potential of five to eight buds because this secondary tiller also suppresses additional axillary bud development hormonally. When the lead tiller is partially defoliated between the third leaf stage and flowering, several axillary buds can develop subsequently into secondary tillers. No single secondary tiller is apparently capable of developing complete hormonal apical dominance following defoliation of the lead tiller at that time. Some level of hormonal control from the older axillary buds still suppresses development of some of the younger axillary buds. This mechanism is not completely understood, and scientists have not been able to manipulate the hormone levels so that all of the axillary buds develop into secondary tillers.

Besides encouraging grassland plants to tiller, defoliation also stimulates soil organism activity in the rhizosphere. The rhizosphere is that narrow zone of soil around living roots of perennial grassland plants where the exudation (leakage) of materials like sugars, amino acids, glycosides, and other compounds affects micro-organism activity. Bacterial growth in the rhizosphere is stimulated by the presence of carbon from the exuded material (Elliott 1978, Anderson et al. 1981). Protozoa and nematodes graze increasingly on the multiplying bacteria and accelerate the overall nutrient cycling process through the “fast” pathway of substrate decomposition proposed by Coleman et al. (1983). The activity of the microbes in the rhizosphere increases the amount of nitrogen available for plant growth (Ingham et al. 1985, Clarholm 1985). The presence of mycorrhizal fungi (those that live in association with plants) enhances the absorption of ammonia, phosphorus, other mineral nutrients, and water.

Rhizosphere activity can be manipulated by defoliation at early growth stages, when a higher percentage of the total nitrogen of the plant is in the aboveground parts and a higher percentage of the total carbon of the plant is in the belowground parts. At that time, partial defoliation disrupts the plant’s relationship of carbon to nitrogen, leaving a relatively high level of carbon in the remaining plant. Some of this carbon is exuded through the roots into the rhizosphere in order to readjust the carbon–nitrogen ratio.

Because of limited access to simple carbon chains, bacteria in the rhizosphere are restricted in growth and activity levels under conditions when defoliation is absent. When defoliation management is used, rhizosphere bacteria increase in activity in response to the increase in exuded carbon. The increases in activity by the bacteria trigger increases in activity levels in the other micro-organisms that make up the nutritional food chain of the rhizosphere. These increases in activity levels ultimately increase available nutrients for the defoliated grass plant. The relationship between grassland plants and organisms in the rhizosphere is truly symbiotic with both entities receiving benefit from their association.

Rhizosphere activity can be stimulated by disrupting the carbon–nitrogen ratio through plant defoliation at early growth stages. During middle and late growth, carbon and nitrogen are distributed fairly evenly throughout the plant, and at these stages defoliation does not remove a disproportionate amount of nitrogen, and very little or no carbon is exuded into the rhizosphere. Also, water levels in the soil generally decrease during the middle and late portions of the grazing season and limit the activity levels of rhizosphere organisms.

The adaptive tolerance mechanisms that pertain to the changes in physiological growth processes within grassland plants, and to the changes in activity levels of the symbiotic organisms in the rhizosphere following defoliation, are the key to understanding the manipulation of beneficial effects from defoliation management under field conditions. Manipulation of these mechanisms by defoliation is also key to the development of ecologically sound recommendations for management of North America’s grassland natural resources. Contributions to the development of biological and ecological foundations for grazing management recommendations were major goals of a research project developed to study the ecological effects of defoliation at the Dickinson Research Center in western North Dakota from 1984 to 1992. This study was expanded in 1990 to include sites in McKenzie County, ND.

The objectives of this study were to evaluate changes in plant-exuded material, soil organism activity and biomass, tiller development of grass plants, aboveground and belowground plant biomass, and livestock weight performance among twice-over rotation-grazing treatments, a 4.5-month seasonlong treatment, a 4-month deferred seasonlong treatment, a 6-month seasonlong treatment, and a long-term nongrazed treatment.

The Study Area and Methods

The long-term study site is located 20 miles north of Dickinson in southwestern North Dakota (lat. 47°14' N., long. 102°50' W.) on the Dickinson Research Center operated by North Dakota State University. The McKenzie County sites are located 21 miles west of Watford City (between lat. 47°35' and 47°50' N. and long. 104°00' and 103°45' W.) in the McKenzie County Grazing District of the Little Missouri National Grassland. The National Grassland is administered by the U.S. Department of Agriculture’s Forest Service and managed in cooperation with the McKenzie County Grazing Association.

Soils are primarily dark in color and developed under grassland vegetation having cool, continental climate and moderate moisture levels. Average annual precipitation is 14 inches (356 mm) with 80 percent falling as rain between April and September. Temperatures in summer average 66 °F (19 °C) with average daily maximums of 80 °F (27 °C). Winter average daily temperatures are 13 °F (–11 °C) with average daily minimums of 2 °F (–17 °C). The vegetation is the wheatgrass–needlegrass type (Barker and Whitman 1988) of the mixed-grass prairie. The dominant native range species are western wheatgrass *(Agropyron smithii)*, needle-and-thread *(Stipa comata)*, blue grama *(Bouteloua gracilis)*, and threadleaved sedge *(Carex filifolia)*.

The treatments on native range were organized as a paired-plot design with two replications. The twice-over rotation grazing treatments at the Dickinson Research Center had three pastures with each grazed for 15 days between June 1 and July 15 and for 30 days after mid-July and prior to mid-October for a total of 4.5 months. Three seasonlong treatments were used: a 4.5-month seasonlong grazing between mid-June to early November, a 4-month deferred seasonlong grazing between mid-July to mid-November, and a 6-month seasonlong grazing between mid-May and mid-November. The long-term nongrazed treatment areas had not been grazed, mowed, or burned for more than 30 years prior to the start of data collection.

The McKenzie County sites had two grazing treatments. The rotation-grazing treatment had four pastures with each grazed for two periods. The other treatment had a traditional seasonlong grazing method. A long-term nongrazed exclosure was available for nondestructive sampling of control sites. Commercial crossbred cattle were used on all treatments in this trial.

Each of the treatments was stratified on the basis of three range sites (sandy, shallow, and silty). Samples from the grazed treatments were collected on both grazed and ungrazed (protected with cages) quadrats (plots). Aboveground plant biomass was collected on seven sampling dates from May to October. Belowground plant biomass and soil micro-organism data were collected on four sampling periods. Aboveground and belowground net primary productivity (NPP) were determined by methods outlined by Sala et al. (1981) and Bohm (1979), respectively. The major components sampled were live material (by species), standing dead material, and litter.

Plant materials were analyzed for nutrient content using standard procedures (Association of Official Analytical Chemists 1984). Plant species composition was determined between mid-July and mid-August using the 10-pin point frame method as described by Cook and Stubbendieck (1986). Root exudates were determined using procedures outlined by Haller and Stolp (1985). A standard paired-plot t-test (Mosteller and Rourke 1973) was used to analyze differences between means.

Individual animals were weighed on and off each treatment and on each rotation date. Mean weights of cows and calves were adjusted to the 8th and 23d day of each month of the grazing period. Biweekly live-weight performance periods of average daily gain and accumulated weight gain for cows and calves were used to evaluate each treatment. Response surface analysis (Kerlinger and Pedhazur 1973) with a repeated observation design was used to compare animal response curves among treatments and was reported by Manske et al. (1988).

Findings

Percent basal cover of grasses increased 25 percent (from 15 percent to 19 percent basal cover) on the rotation-grazing treatments compared to seasonlong treatments (table V.7–1). Basal cover of sedges and forbs decreased by 4 percent and 36 percent, respectively, on the rotation treatments compared to seasonlong treatments. Plant community relative percent composition changed, with grasses increasing by 14 percent, sedges decreasing by 14 percent, and forbs plus shrubs decreasing by 40 percent, on the rotation treatments compared to seasonlong treatments (table V.7–2).

The amount of herbage that remained standing on September 1 after the rotation treatments was greater than the amount of total current-year's growth on the long-term nongrazed treatments (table V.7–3). These data do not account for the amount of vegetation removed by livestock on the rotation treatments. During the entire grazing season, an average of 15 percent more herbage biomass was standing after each grazing period on the rotation treatments compared to long-term nongrazed treatments. Seasonlong treatments averaged 8 percent and 29 percent less herbage biomass standing after grazing than on the nongrazed and rotation treatments, respectively. The relatively greater amount of photosynthetic leaf area remaining on the rotation treatments at the end of the grazing season was beneficial for the continued development of the grassland ecosystem at a higher production level. This remaining herbage also provided a benefit as wildlife habitat.

Tiller development of grass plants and the resulting increase in aboveground herbage biomass were greater on the rotation treatments than on the nongrazed and seasonlong treatments. These increases in the vegetation suggest that removal by defoliation of some young leaf material early in the growth cycle has some effect on the

Table V.7–1—Mean percent basal cover, by vegetative growth form categories

	Treatments		
	Season-long	Rotation	Percent difference
Grass	14.7	18.6	+25.2
Sedge	7.7	7.6	–3.8
Forb	3.8	2.4	35.9
Shrub	0.1	0.1	—

Table V.7–2—Mean relative percent composition of plant communities

	Treatments		
	Season-long	Rotation	Percent difference
Grass	55.1	63.2	+14.1
Sedge	30.6	28.0	–13.6
Forb and shrub	14.5	8.7	–39.6

Table V.7–3—Mean monthly aboveground herbage biomass, in pounds per acre, remaining after grazing on three range sites

	Monthly sample periods				
Treatments	1June	1July	1Aug.	1Sept.	1Oct.
Nongrazed	822*a*	1,010*a*	1,144*a*	888*a*	—
Seasonlong	974*a*	1,017*a*	785*b*	717*a*	—
Rotation	990*a*	1,211*b*	1,231*a*	993*b*	987

Means of same column followed by the same letter are not significantly different ($P<0.05$).

reduction of auxin and the subsequent stimulation of cytokinin, which causes axillary buds to develop into secondary tillers. Thus, defoliation of grass plants at an early growth stage exerts beneficial effects on vegetative tiller development.

Preliminary interpretation of the rhizosphere data collected so far indicates that greater amounts of exuded material were released into the rhizosphere on the rotation treatments than on nongrazed or seasonlong treatments. These data also indicate that the biomass of soil mites was greater on the rotation treatments compared to the nongrazed or seasonlong treatments. This information suggests that removal of some young leaf material by defoliation at early growth stages has some effect on increasing exuded material, which in turn presumably stimulates activity of the bacteria. Greater bacterial activity stimulates activity of subsequent organisms in the nutritional food chain of the rhizosphere. Activity levels were increased in protozoa, nematodes, and mites. Increasing the activity levels of organisms in the rhizosphere increases the amount of nitrogen available for plant growth. Thus, defoliation of grass plants at an early growth stage has beneficial effects on symbiotic rhizosphere organism activity and results in greater amounts of nutrients available for growth by those plants.

The period when defoliation of grass plants showed beneficial effects on the increases in vegetative tillers and symbiotic rhizosphere organism activity occurred between the third leaf stage and the flowering period during this study.

The increase in grass tiller development and symbiotic rhizosphere activity on the twice-over rotation treatments allowed a mean increase in stocking rate of 40 percent greater than on the 4.5-month seasonlong treatments, 96 percent greater than on 6-month seasonlong treatments, and 9 percent greater than the 4-month deferred seasonlong treatments.

Accumulated weight performance of individual cows and calves (table V.7–4), their average daily gain (table V.7–5), and weight gain per acre (table V.7–6), were greater on the rotation treatments compared to the seasonlong and deferred seasonlong treatments. Weight performance of cows and calves on the three grazing treatments was

Table V.7–4—Mean annual accumulated weight gain in pounds for cows and calves

	Treatments		
	Deferred season-long	Season-long	Rotation
		Pounds	
Cows	34	40	107
Calves	204	284	309

Table V.7–5—Mean annual average daily weight gain in pounds for cows and calves

	Treatments		
	Deferred season-long	Season-long	Rotation
		Pounds	
Cows	0.32*a*	0.34*a*	0.62*b*
Calves	1.80*a*	2.09*a*	2.21*b*

Means of same row followed by the same letter are not significantly different (P<0.05).

Table V.7–6—Mean annual weight gain in pounds per acre for cows and calves

	Treatments		
	Deferred season-long	Season-long	Rotation
		Pounds per acre	
Cows	2.6*a*	2.9*a*	8.1*b*
Calves	20.4*a*	20.5*a*	28.5*b*

Means of same row followed by the same letter are not significantly different (P<0.05).

generally not significantly different during the first grazing period of June and July. During the second grazing period, after early August, the animal weight performance on the rotation treatments was significantly greater than on the seasonlong and deferred seasonlong treatments (Manske et al. 1988). Individual animal performance improved on the twice-over rotation-grazing system with an increase in calf average daily gain of 6 percent greater than 4.5-month seasonlong and 23 percent greater than deferred seasonlong grazing treatments. Average daily weight gain of cows improved on the twice-over rotation system by 82 percent greater than 4.5-month seasonlong and 94 percent greater than deferred seasonlong grazing treatments.

The combination of increases in stocking rate and individual animal performance gave the twice-over rotation system a considerable increase in animal weight gain per acre over the other grazing treatments. Calf weight gain per acre on the twice-over rotation system was 39 percent greater than 4.5-month seasonlong and 40 percent greater than deferred seasonlong treatments. Cow weight gain per acre on the twice-over rotation system was 179 percent greater than 4.5-month seasonlong and 212 percent greater than deferred seasonlong grazing treatments.

The improved livestock weight performance during the later portion of the grazing season on the rotation treatments was primarily attributed to the increase in available nutrients from the addition of secondary tillers. These tillers had developed from axillary buds and were at an early growth stage during the second rotation period. Generally, the available herbage on the rotation treatments was 1.5 and 2.5 percentage points greater in crude protein content than the herbage on the seasonlong and deferred seasonlong treatments during the later portion of the grazing season.

The grassland plant community can be changed beneficially when grazing defoliation is properly timed to coincide with the appropriate growth stage of the grass plants (fig. V.7–1). Grass plant density is increased, and total herbage production is increased when defoliation by grazing is timed to occur between the third leaf stage and the flowering stage. A greater amount of vegetation can remain at the end of the grazing season, which causes a noticeable change in the vegetation canopy cover. There

Figure V.7–1—Land managers and ranchers can create beneficial changes on rangeland by using proper and timely grazing systems. Changes in turn can affect the habitat for some grasshopper species, offering another possible tool for long-term grasshopper management.

is a decrease in the amount of bare ground present in the pastures. These changes in plant structure and density should be unfavorable for most troublesome rangeland grasshopper species. Most rangeland pest grasshopper species are favored by open vegetation canopy and bare areas. These open areas in the vegetation structure are used by the grasshoppers to provide access to solar radiation during nymphal development for body temperature regulation and by some species for egg-laying sites.

Grassland areas that have higher percentages of open canopy should have relatively higher grasshopper populations. Grassland areas that have had beneficial changes in the structure and density of the vegetation as a result of the manipulation of the adaptive tolerance mechanisms of the grass plants by the twice-over rotation treatment should show negative effects on grasshopper populations. The changes in vegetation structure and density should lower air and soil temperatures, raise relative humidity, and reduce the level of irradiation within the grasshopper microhabitat. These changes in grasshopper microhabitat should lengthen the time required for nymphal development, exposing the nymphs to numerous causes of death, which would raise the average daily mortality rate and reduce the density of individuals. Lowering the number of nymphs will reduce the number of grasshoppers that develop into adults. This, in turn, will reduce the number of eggs laid. All of these factors should cause an overall reduction in the population of grasshoppers on grassland areas managed with twice-over rotation treatments.

The other characteristic of the twice-over rotation treatment that would negatively affect grasshopper populations is that the sequence of grazing periods on the rotation-system pastures is never the same in consecutive years. This variation should alter the vegetation growth patterns enough so that no single pest grasshopper species would consistently be favored.

Conclusions

Additional research would help quantify exuded material, soil organism activity and biomass, axillary bud development into tillers, and nitrogen, carbon, and phosphorus cyclic flows. These additional findings would allow scientists to understand more completely the adaptive tolerance mechanisms developed by grassland plants to compensate for defoliation. Grassland managers then could manipulate these mechanisms more precisely and be able to use the beneficial defoliation effects on a finer level and further improve the grassland ecosystem. Additional research also needs to document relationships between the changes in vegetation structure and density and the effects on grasshopper population dynamics.

Data collected to date have shown that defoliation of grass plants between the third leaf stage and flowering stage has beneficial effects on the physiological responses within the plant. These effects allow for greater tiller development and beneficial effects on the symbiotic rhizosphere organism activity, which is believed to increase the amount of nitrogen available for plant growth. Deliberate and precise manipulation of these adaptive tolerance mechanisms can increase secondary tiller development and total herbage biomass. The secondary tillers increase the nutrient content of the herbage, and that increase enhances individual animal weight performance during the latter portion of the grazing season.

The increase in herbage biomass permits an increase in stocking rate and leaves a greater amount of herbage after grazing. This increase in residual herbage is beneficial for grassland wildlife habitat. Plant density, canopy cover, and litter cover increase as a result of increased tiller growth, which in turn, reduces the impact of raindrops, reduces and slows runoff, reduces erosion, and increases water infiltration. These improvements in the vegetation density and canopy cover should have negative impacts on grasshopper populations. Grazing management recommendations of systematically rotating 7- to 15-day periods of defoliation between the third leaf stage and flowering growth stage (June 1–July 15 in western North Dakota) on each pasture should maximize beneficial effects on the adaptive tolerance mechanisms of grassland plants.

References Cited

Anderson, R. V.; Coleman, D. C.; Cole, C. V.; Elliott, E. T. 1981. Effect of nematodes *Acrobeloides* sp. and *Mesodiplogaster iheritieri* on substrate utilization and nitrogen and phosphorus mineralization. Ecology 62: 549–555.

Association of Official Analytical Chemists. 1984. Official methods of analysis (14th ed.). Washington, DC: Association of Official Analytical Chemists.

Barker, W. T.; Whitman, W. C. 1988. Vegetation of the northern Great Plains. Rangelands 10: 266–272.

Bohm, W. 1979. Methods of studying root systems. Berlin: Springer-Verlag.

Clarholm, M. 1985. Interactions of bacteria, protozoa, and plants leading to mineralization of soil nitrogen. Soil Biology and Biochemistry 17: 181–187.

Coleman, C. D.; Reid, C.P.P.; Cole. C. V. 1983. Biological strategies of nutrient cycling in soil ecosystems. Advancements in Ecological Research 13: 1–55.

Cook, C. W.; Stubbendieck, J. 1986. Range research: basic problems and techniques. Denver, CO: Society of Range Management. 317 p.

Elliot, E. T. 1978. Carbon, nitrogen, and phosphorus transformations in gnotobiotic soil microcosms. M.S. thesis. Ft. Collins, CO: Colorado State University.

Haller, T.; Stolp, H. 1985. Quantitative estimation of root exudation in maize plants. Plant and Soil 86: 207–216.

Ingham, R. E.; Trofymow, J. A.; Ingham, E. R.; Coleman, D. C. 1985. Interactions of bacteria, fungi, and their nematode grazers: effects on nutrient cycling and plant growth. Ecological Monographs 55: 119–140.

Kerlinger, F. N.; Pedhazur, E. J. 1973. Multiple regression in behavioral research. New York: Holt, Rinehart, and Winston.

Manske, L. L.; Biondini, M. E.; Kirby, D. R.; Nelson, J. L.; Landblom, D. G.; Sjursen, P. J. 1988. Cow and calf performance on seasonlong and twice-over rotation grazing treatments in western North Dakota. In: North Dakota cow/calf conference; [month and dates unknown] 1988; Bismarck, ND. Bismarck, ND: North Dakota Cow/Calf Conference: 5–17.

McNaughton, S. J. 1983. Compensatory plant growth as a response to herbivory. Oikos 40: 329–336.

Mosteller, F.; Rourke, R.E.K. 1973. Sturdy statistics. [City of publication unknown], MA: Addison–Wesley Publishing Co. 395 p.

Murphy, J. S.; Briske, D. D. 1992. Regulation of tillering by apical dominance: chronology, interpretive value, and current perspectives. Journal of Range Management 45: 419–429.

Sala, O. E.; Deregibus, V. A.; Schlichter, T.; Alippe, H. 1981. Productivity dynamics of native temperate grassland in Argentina. Journal of Range Management 34: 41–48.

V.8 Herbage Production, Phenology, and Soil Moisture Dynamics for Plant Communities in Western North Dakota

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Increasing demand for intensive management of rangelands requires improved methodologies for classifications, descriptions, and monitoring of plant communities. It is important to document vegetation characteristics of plant communities for a reference point in order to determine how herbivory (the consumption of all or part of a plant by consumers, including cattle, wildlife, insects, etc.) affects vegetation composition and production, insects, and wildlife. An understanding of plant characteristics (production, species composition, canopy cover, phenology, degree of utilization by grazers, and abiotic factors) is important for correlation with grasshopper populations and their dynamics. Knowledge gained from the plant component will be useful in determining grasshopper relationships with vegetation characteristics. Previous vegetation studies describing habitat types and communities in western North Dakota have been limited to subjective evaluations (Hanson and Whitman 1938, Redmann 1975, Lauenroth and Whitman 1977, Hansen et al. 1984, Hansen and Hoffman 1988).

Phenology is the study of the relationship between seasonal climatic changes and plant development. Knowledge of the seasonal timing of flowering events (phenological phases) is useful information for resource managers. This information can be used to determine when to graze livestock on native pastures (Frank and Hofmann 1989), when to burn for enhancement and/or control of plant growth, and when to implement insect control measures (Hewitt 1980, Kemp et al. 1991).

An understanding of soil moisture regimes for native plant communities on the northern Great Plains is basic for improvement of rangeland productivity and development of ecological management practices for each community. On the northern Great Plains, soil moisture is one of the major factors that influence plant growth. Soil types and other factors, including plant composition, plant production, litter, grazing, rocks, and soil nutrients, influence the soil moisture (Rauzi 1960, Smika et al. 1961, Houston 1965, Goetz 1975, Cline et al. 1977, Benkobi et al. 1993). Models have been developed for plant growth at individual or homogeneous (similar) sites as related to soil moisture, precipitation, and temperature (Uresk et al. 1975 and 1979, Wight and Hanks 1981, Wight et al. 1986). However, over large areas, successful attempts to model soil moisture and plant growth relationships have been limited (Rauzi 1960). For additional information, see Branson et al. (1981) for an excellent overview of rangeland hydrology.

The objectives of this study were (1) to classify and describe plant communities quantitively by species using canopy cover, frequency of occurrence, production, and utilization of plants by herbivores in western North Dakota over a 5-year period, (2) to identify the most useful plant species for discriminating, classifying, and monitoring plant communities, (3) to provide information on phenological (growth) development for 10 native plant species, and (4) to determine seasonal trends in soil moisture for native plant communities throughout the study area.

Study Area

The study area was located on the Little Missouri National Grassland and privately owned rangelands in western North Dakota. Climate is semiarid and continental, characterized by long, cold winters and short, warm summers. The coldest month is January with an average low of 10.5 °F (–11.6 °C) and the monthly high for July is 71.6 °F (22 °C). Most of the precipitation falls as rain in early summer. Approximately 75 percent of the precipitation falls during April through September (Hansen et al. 1984, Hansen and Hoffman 1988). Yearly precipitation totals over the 5-year period for four sites within the study area are presented in table V.8–1. Vegetation is dominated by western wheatgrass *(Agropyron smithii)*, blue grama *(Bouteloua gracilis)*, needle-and-thread *(Stipa comata)*, and scarlet globemallow *(Sphaeralcea coccinea)*, with scattered dwarf sagebrush *(Artemisia cana)* and fringed sagebrush *(A. frigida)* (fig. V.8–1).

Study Methods

Plant Communities.—In all, 30 sites were selected throughout the Little Missouri National Grassland. Vegetative characteristics sampled included canopy cover and frequency of occurrence by species (Daubenmire 1959) and plants harvested at peak production. Twenty sites were sampled in 1987–88, and an additional 10 sites were added in 1989. All 30 sites were sampled in 1989–91. Each site had four replicated areas. Three transects were randomly located on each of the four replicates at each site from 1987–89. Sample size estimates for num-

Table V.8–1—Yearly precipitation, in inches, over a 5-year period for four U.S. weather service stations within the western North Dakota study area

Year	Watford City	Trotter's store	Fairfield store	Medora
1987	11	12	13	18
1988	[1]9	[1]6	8	9
1989	14	12	[1]15	[1]13
1990	11	11	12	11
1991	18	18	19	13
Average[2]			16	15

[1] Incomplete or missing data for the year.

[2] Thirty-year station average; similar measurements are not available for Watford City or Trotter's store.

Figure V.8–1—Rangelands support a variety of plant communities. Understanding how plant communities function is important for increasing knowledge about how grasshoppers interact with those communities.

ber of transects and quadrats (plots) were then determined, and for 1990–91, two 98.4-ft (30-m) permanent transects were located at random on each of the replicated sites. Canopy cover and frequency of occurrence by species were estimated at 1-m intervals within 7.9-×19.7-inch (20-×50-cm) frames along each transect (Daubenmire 1959). Data were summarized as means by site for all analyses.

Classification of Communities.—Plant communities were classified and defined by plant canopy cover and frequency of occurrence collected on the 30 sites for 1990 and 1991. Canopy cover times frequency of occurrence (index) of the 10 major plant species were subjected to data reduction (Uresk 1990) and cluster analyses (ISODATA) to determine groupings of similar plant communities (Ball and Hall 1967). Original data reductions to define the 10 major plant species were based on Soil Conservation Service range site classifications. Stepwise discriminant analysis was used to estimate the compactness of the clusters, to identify key variables that accounted for community differences, and to develop Fisher classification coefficients (Uresk 1990). Plant production estimates and utilization were summarized by plant communities.

Plant Production and Utilization.—Plant biomass at time of peak production was determined by harvesting all plants inside cages. The difference between plant biomass harvested inside and outside the cages is expressed as utilization by herbivores. Each site was comprised of four replicated areas. Prior to initiation of spring growth, 10 wire cages measuring 3.3×6.6 ft (1×2 m) were randomly located on each of the 4 replicates for a total of 40 cages/site. Plants were harvested at ground level inside each cage within one 2.69-ft^2 (0.25-m^2) randomly placed circular hoop and sorted by grasses (sedges were included in this category), forbs, and shrubs. Approximately 10–20 ft (3–6 m) from the cages, six 7.9-×19.7-inch (20-×50-cm) quadrats were harvested on each of three transects. In 1990, 5 of the 1.08-ft^2 (0.1-m^2) quadrats were harvested on each of 2 transects/replicate for a total of 10 quadrats. During 1991, a total of 10 2.69-ft^2 (0.25-m^2) circular hoops were harvested along the 2 transects. All plant material was oven dried at 140 °F (60 °C) for 48 hours and weighed to the nearest 0.1 g. Weights were expressed as a mean per site in pounds per acre.

Phenology.—Phenological development was divided into five stages: (1) vegetative, (2) flowering, (3) seed set, (4) seed drop, and (5) dormancy (Sauer and Uresk 1976). Biweekly measurements of 10 plant species were made to determine the timing of developmental stages (phenophases). For each species, 40 plants/site were randomly selected within each of 30 sites in 1989 and were monitored from mid-May through mid-August. In 1990 and 1991, 2 plants of each of the 10 species were located within each of the 4 replicates on each site for a total of 240 plants/species/year. The individual plants were permanently marked with flags in late April on each of 30 sites and were monitored through September. Although some plant species were not found on all sites, a minimum of 192 individual plants was evaluated. New plants were selected each year. Data were summarized for all sites for each of 3 years.

Soil Moisture.—In all, 28 of the study sites were sampled: 18 in 1987–88 and an additional 10 in 1989–91. At each site, four replicates were systematically selected and sampled for soil moisture at a 12-inch (30-cm) depth. On each replicate, three 40-inch soil-moisture access tubes were randomly installed in early June 1987. Neutron soil moisture probes were used and recalibrated each year. Soil samples were collected at the time of installation to determine gravimetric soil moisture. Regression analyses permitted calibration of actual gravimetric soil moisture with estimated soil moisture at each site with value converted to volume percent. Data were summarized as means per site and summarized by plant community.

Results of the Study

Plant Communities.—Cluster analyses on cover and frequency of native plant species separated the 30 sites into 4 native plant community types. Discriminant analyses indicated significant separation (P=0.001) among the plant communities. Five plant species—western wheatgrass, dwarf sagebrush, blue grama, threadleaf sedge *(Carex filifolia)* and needle-and-thread were required to separate the four native communities. The five species accounted for 97 percent of the total variation in three canonical discriminant functions.

These five major plant species were used in the discriminant procedure in SPSS/PC (1990) to develop Fisher classification coefficients to predict the four plant communities (table V.8–2). Needle-and-thread had a greater weighting for community 1, dwarf sagebrush had a greater weighting for communities 2 and 3, and western wheatgrass, a greater weighting for community 4. Based on substitution error rates in SPSS/PC (1990), the four plant communities could be classified with 96-percent accuracy given just these five species.

The four plant communities are (1) needle-and-thread/blue grama/threadleaf sedge, (2) blue grama/western wheatgrass/needle-and-thread, (3) dwarf sagebrush/blue grama/western wheatgrass, and (4) western wheatgrass/blue grama/needle-and-thread. Two additional plant communities with limited sample sizes were defined in this study but not included in the above analyses. These are (5) crested wheatgrass *(Agropyron cristatum)* and (6) dwarf sagebrush/leafy spurge *(Euphorbia esula)*. The sites for each plant community by number and name are listed in table V.8–3.

Table V.8–2—Fisher classification coefficients for plant communities in western North Dakota

	Plant community			
Plant	1	2	3	4
Western wheatgrass	0.00145	0.00306	0.00384	0.00649
Dwarf sagebrush	0.00561	0.01048	0.01443	0.00417
Blue grama	0.00203	0.00649	0.00494	0.00285
Threadleaf sedge	0.00637	–0.00049	–0.00059	0.00006
Needle-and-thread	0.01095	0.00360	0.00234	0.00152
Constant	–17.48374	–17.82723	–14.53323	–13.43716

1. Needle-and-Thread/Blue Grama/Threadleaf Sedge Community.—This plant community is dominated by needle-and-thread (table V.8–4). Canopy cover for this species ranged, over a 5-year period, from 18 to 39 percent. Blue grama is the second most abundant grasslike, with canopy cover that varied from 10 to 22 percent. It was followed by threadleaf sedge, which extended from 7 to 20 percent over the 5-year period. Western wheatgrass is common in this plant community, with an overall average cover of 8 percent. Dwarf sagebrush is present only in trace amounts.

Total plant production estimated inside cages ranged from 584 lb/acre in 1988 to 1,165 lb/acre in 1991 (table V.8–5). Grasses and sedges comprised a major portion of the production in this plant community and ranged from 532 to 1,026 lb/acre. Forb production was variable and extended from 49 to 276 lb/acre. Shrubs were not dominant in this plant community; production varied from 3 to 20 lb/acre.

The difference between plant production estimated inside and outside cages (utilization) over the 5-year period is shown in figure V.8–2. In 1987, no forage utilization was evident. Utilization from 1988 to 1991 averaged 12 percent when sampled at the peak of the growing season in July.

2. Blue Grama/Western Wheatgrass/Needle-and-Thread Community.—This plant community was dominated by blue grama followed by western wheatgrass and needle-and-thread (table V.8–4). Canopy cover for blue grama ranged from 21 to 60 percent over a 5-year period. Canopy cover varied from 7 to 19 percent for western wheatgrass and from 5 to 13 percent for needle-and-thread during this study. Threadleaf sedge averaged 5 percent over the 5-year period. Dwarf sagebrush was present in only trace amounts.

Table V.8–3—List of Grasshopper Integrated Pest Management Project sites and identification number sampled, 1987–91, by plant communities in western North Dakota

1. Needle-and-thread/blue grama/threadleaf sedge	
7	101-Exclosure
15	East Twin Butte (natural)
16	Buffalo Gap
19	Dantz Creek
20	Van-Vig Ranch
22	Flat Top Butte
24	Charbonneau Creek
28	Road 881
2. Blue grama/western wheatgrass/needle-and-thread	
1	Tobacco Garden
2	Lone Beaver
3	Christ Springs
4	Bear Butte
5	Horse Creek
10	Grassy Butte
11	Devils Pass
18	Kinley Plateau
23	Valley Enclosure
26	French Creek
29	Klandl Springs
30	Bartall Creek
3. Dwarf sagebrush/blue grama/western wheatgrass	
8	Prairie Dog Enclosure
9	Little Beicegal
13	Government Creek
17	Tracy Mountain
21	Icebox Canyon
4. Western wheatgrass/blue grama/needle-and-thread	
12	Whitetail Creek
25	Bowline Creek
27	Cheney Creek
5. Crested wheatgrass	
6	Crested wheatgrass
31	East Twin (crested wheatgrass)
6. Dwarf sagebrush/leafy spurge	
14	Wannagan Creek

Table V.8–4—Mean canopy cover (percent) ± standard error for key species, by plant community and year (n=number of sites)

	1987	1988	1989	1990	1991
1. Needle-and-thread/blue grama/threadleaf sedge					
	n=5	n=5	n=8	n=8	n=8
Western wheatgrass	7.6 ± 1.4	6.9 ± 1.8	6.7 ± 1.7	5.6 ± 1.4	17.3 ± 3.3
Blue grama	13.6 ± 3.7	16.5 ± 4.2	10.0 ± 2.4	9.5 ± 2.2	22.2 ± 5.0
Threadleaf sedge	6.7 ± 2.7	11.3 ± 4.6	12.1 ± 4.2	7.3 ± 2.0	19.8 ± 8.0
Needle-and-thread	27.0 ± 8.4	17.5 ± 3.9	19.1 ± 3.6	20.3 ± 5.2	39.2 ± 6.0
Dwarf sagebrush	0.2 ± 0.2	0.1 ± 0.1	0.1 ± 0.1	0.2 ± 0.1	0.4 ± 0.2
2. Blue grama/western wheatgrass/needle-and-thread					
	n=8	n=8	n=12	n=12	n=12
Western wheatgrass	8.4 ± 2.1	6.6 ± 1.4	9.5 ± 1.5	10.1 ± 1.1	19.0 ± 3.5
Blue grama	29.5 ± 2.1	24.8 ± 2.4	21.3 ± 2.2	32.3 ± 2.3	59.9 ± 3.2
Threadleaf sedge	2.1 ± 0.7	2.0 ± 0.7	4.3 ± 1.2	2.8 ± 0.6	5.0 ± 1.4
Needle-and-thread	5.6 ± 1.2	4.9 ± 1.1	4.7 ± 1.0	6.0 ± 1.5	12.5 ± 2.8
Dwarf sagebrush	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0
3. Dwarf sagebrush/blue grama/western wheatgrass					
	n=4	n=4	n=5	n=5	n=5
Western wheatgrass	19.7 ± 5.8	11.0 ± 2.1	15.4 ± 2.8	13.9 ± 2.0	26.4 ± 3.8
Blue grama	15.4 ± 3.9	20.0 ± 5.0	19.1 ± 3.7	19.8 ± 5.6	38.9 ± 8.3
Threadleaf sedge	0.2 ± 0.1	0.7 ± 0.4	1.1 ± 1.0	0.5 ± 0.3	0.3 ± 0.1
Needle-and-thread	7.1 ± 1.0	5.3 ± 1.8	3.7 ± 1.0	4.1 ± 1.5	7.7 ± 3.6
Dwarf sagebrush	10.0 ± 5.3	6.4 ± 3.6	9.6 ± 3.8	9.2 ± 3.3	13.5 ± 4.9
4. Western wheatgrass/blue grama/needle-and-thread					
	n=1	n=1	n=3	n=3	n=3
Western wheatgrass	14.2	9.3	20.2 ± 3.5	20.2 ± 4.9	41.5 ± 6.5
Blue grama	24.4	37.3	14.7 ± 3.7	10.2 ± 2.8	33.5 ± 8.7
Threadleaf sedge	1.7	0.4	4.4 ± 2.5	1.1 ± 0.5	1.0 ± 0.7
Needle-and-thread	2.3	0.8	5.0 ± 2.4	6.2 ± 2.7	11.3 ± 5.8
Dwarf sagebrush	0.0	0.0	0.9 ± 0.8	0.3 ± 0.2	0.5 ± 0.4

Table V.8–5—Plant production, in total and by grasses, forbs, and shrubs (in lb/acre), over a 5-year period for six plant communities (mean ± standard error)

	1987	1988	1989	1990	1991
1. Needle-and-thread/blue grama/threadleaf sedge					
	n=5	n=5	n=8	n=8	n=8
Total	1,165 ± 96	584 ± 86	1,042 ± 102	1,113 ± 139	1,159 ± 127
Grasses	959 ± 119	532 ± 92	747 ± 75	896 ± 89	1,026 ± 120
Forbs	208 ± 40	49 ± 10	276 ± 84	207 ± 64	118 ± 24
Shrubs	7 ± 4	3 ± 2	20 ± 7	10 ± 5	16 ± 8
2. Blue grama/western wheatgrass/needle-and-thread					
	n=8	n=8	n=12	n=12	n=12
Total	984 ± 60	449 ± 18	889 ± 64	1,021 ± 57	1,144 ± 85
Grasses	733 ± 63	372 ± 19	530 ± 4	826 ± 63	1,019 ± 78
Forbs	249 ± 41	77 ± 15	351 ± 59	194 ± 28	122 ± 22
Shrubs	2 ± 1	<0.1	9 ± 4	1 ± 1	3 ± 1
3. Dwarf sagebrush/blue grama/western wheatgrass					
	n=4	n=4	n=5	n=5	n=5
Total	1,604 ± 244	401 ± 62	1,320 ± 108	1,157 ± 115	1,140 ± 112
Grasses	1,210 ± 195	334 ± 56	853 ± 98	860 ± 80	986 ± 105
Forbs	179 ± 61	30 ± 11	279 ± 96	148 ± 60	72 ± 17
Shrubs	216 ± 107	38 ± 20	289 ± 141	148 ± 73	82 ± 57
4. Western wheatgrass/blue grama/needle-and-thread					
	n=1	n=1	n=3	n=3	n=3
Total	1,271	513	1,332 ± 278	1,167 ± 183	1,308 ± 226
Grasses	878	452	825 ± 148	895 ± 112	1,154 ± 182
Forbs	390	46	459 ± 146	260 ± 96	91 ± 29
Shrubs	3	16	47 ± 45	12 ± 9	63 ± 57
5. Crested wheatgrass					
	n=2	n=2	n=2	n=2	n=2
Total	292 ± 69	391 ± 62	1,170 ± 17	1,167 ± 62	1,366 ± 249
Grasses	1,056 ± 11	377 ± 55	1,120 ± 0	1,091 ± 121	1,316 ± 285
Forbs	101 ± 51	22 ± 1	46 ± 15	72 ± 55	45 ± 30
Shrubs	16 ± 7	5 ± 5	4 ± 3	5 ± 4	6 ± 5
6. Dwarf sagebrush/leafy spurge					
	n=1		n=1	n=1	n=1
Total	2,503		2,089	1,660	2,242
Grasses	197		207	333	182
Forbs	2,055		1,405	127	1,893
Shrubs	251		477	309	168

This community was the least productive of the four major types: total plant production fluctuated from 449 to 1,144 lb/acre over the 5-year period (table V.8–5). Total production of grasses and sedges showed a range of 372 to 1,019 lb/acre. Forbs were less productive and varied from 77 to 351 lb/acre. Shrub production was very limited and averaged 3 lb/acre.

Plant production and herbivore utilization for this plant community is presented in figure V.8–3. Forage used by herbivores during the first 2 years of the study was nominal. However, plant utilization increased the last 3 years from 18 to 28 percent in July.

3. Dwarf Sagebrush/Blue Grama/Western Wheatgrass Community.—Blue grama was the dominant understory grass in this community (table V.8–4). It ranged from a low of 15 percent to a high of 39 percent canopy cover. This was followed by western wheatgrass, which varied from 11 to 26 percent cover. Dwarf sagebrush was the dominant overstory plant with canopy cover values that ranged from 6 to 14 percent over the 5-year period. Needle-and-thread averaged 6 percent canopy cover. Least abundant was threadleaf sedge, which averaged less than 1 percent cover.

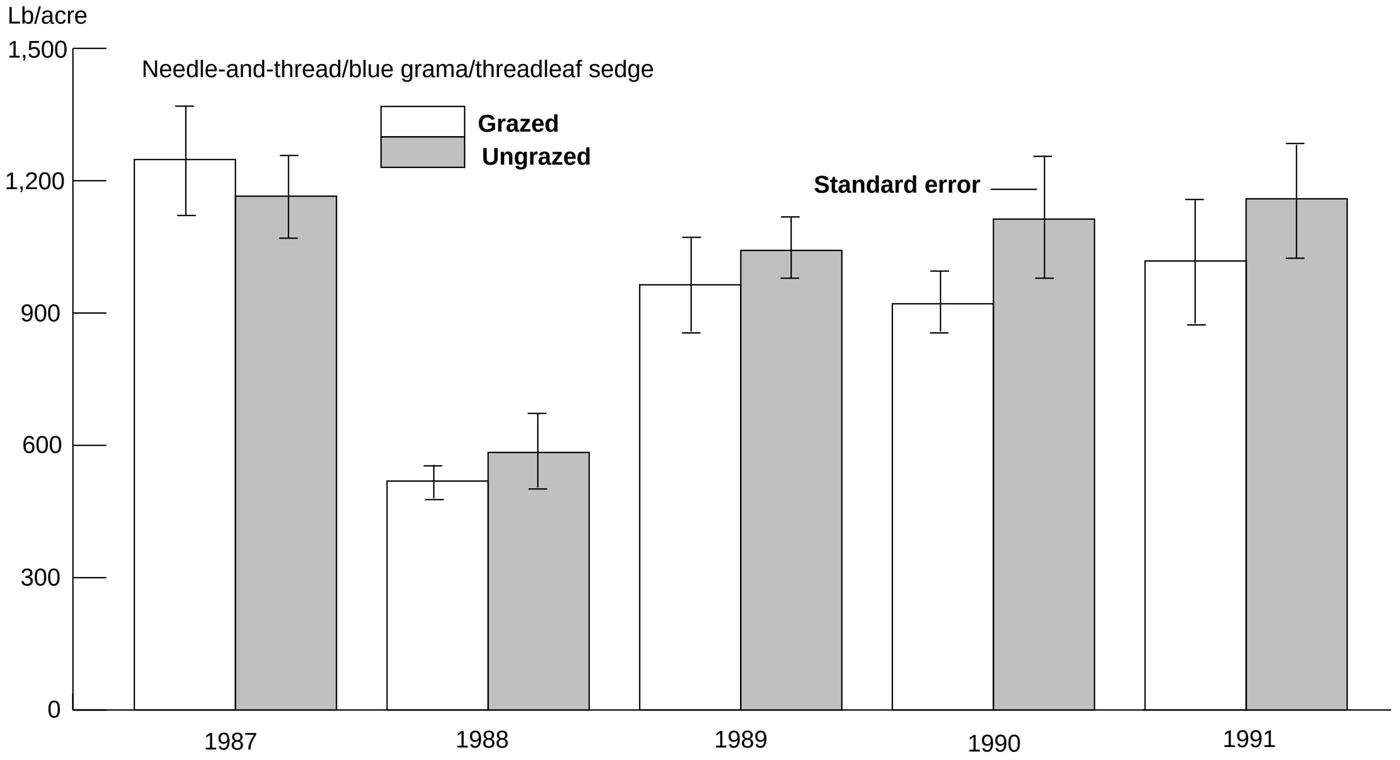

Figure V.8–2—Comparison of plant biomass in July over a 5-year period on ungrazed (inside cages) with grazed (outside of cages) habitats.

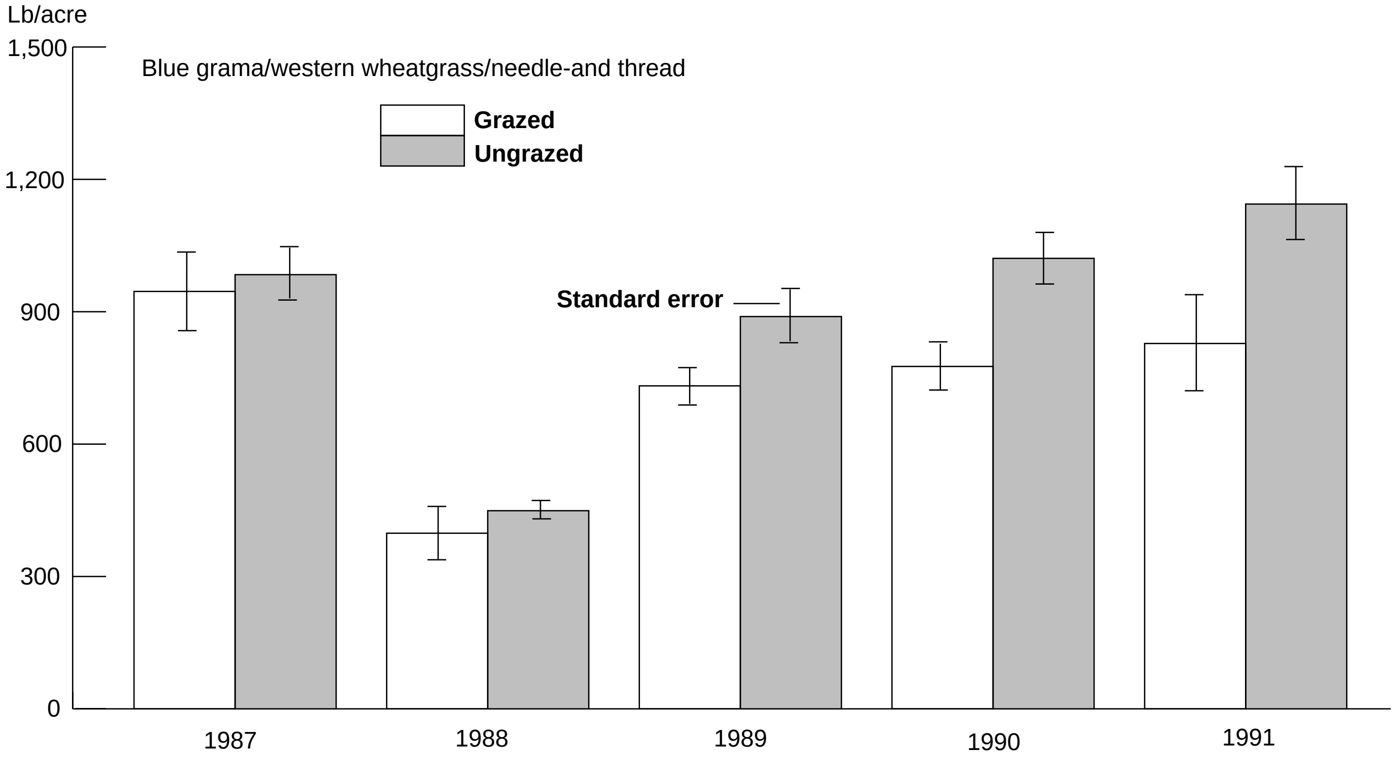

Figure V.8–3—Comparison of plant biomass in July over a 5-year period on ungrazed (inside cages) with grazed (outside of cages) habitats.

Total production ranged from 401 to 1,604 lb/acre over the 5-year period (table V.8–5). Production of grasses and sedges varied from 334 to 1,210 lb/acre. Grass and sedge production was followed by forbs with 30 to 279 lb/acre, and shrubs, with 38 to 289 lb/acre. Shrub production was greater in this community than in the other three native plant communities.

Plant utilization was nominal in light of total production estimates throughout the 5 years; however, estimates of dwarf sagebrush production were highly variable and masked utilization of grasses (and sedges) and forbs. Herbivore utilization of grasses (and sedges) and forbs is comparable to utilization in other plant communities. Utilization of grasses (and sedges) and forbs was minimal during the first 2 years (fig. V.8–4). Greatest utilization of plants occurred in 1991.

4. Western Wheatgrass/Blue Grama/Needle-and-Thread Community.**—**Western wheatgrass was the dominant plant species in this community (table V.8–4). Canopy cover ranged from 9 to 42 percent over the 5-year period. Western wheatgrass was followed by blue grama, which ranged from 10 to 37 percent. Needle-and-thread expressed itself less (less than 1 percent cover) during the drier years early in the study; however, when more moisture was available for growth during the last 3 years, canopy cover reached a high of 11 percent. Threadleaf sedge averaged approximately 2 percent cover over the 5-year period, and dwarf sagebrush was present only in trace amounts.

Total plant production on this community ranged from 513 to 1,332 lb/acre over the 5 years (table V.8–5). Grasses and sedges showed similar trends among years, with production varying from 452 to 1,154 lb/acre. Forb production showed a range from 46 to 459 lb/acre over the study period. Shrubs were a minor component and averaged only 28 lb/acre.

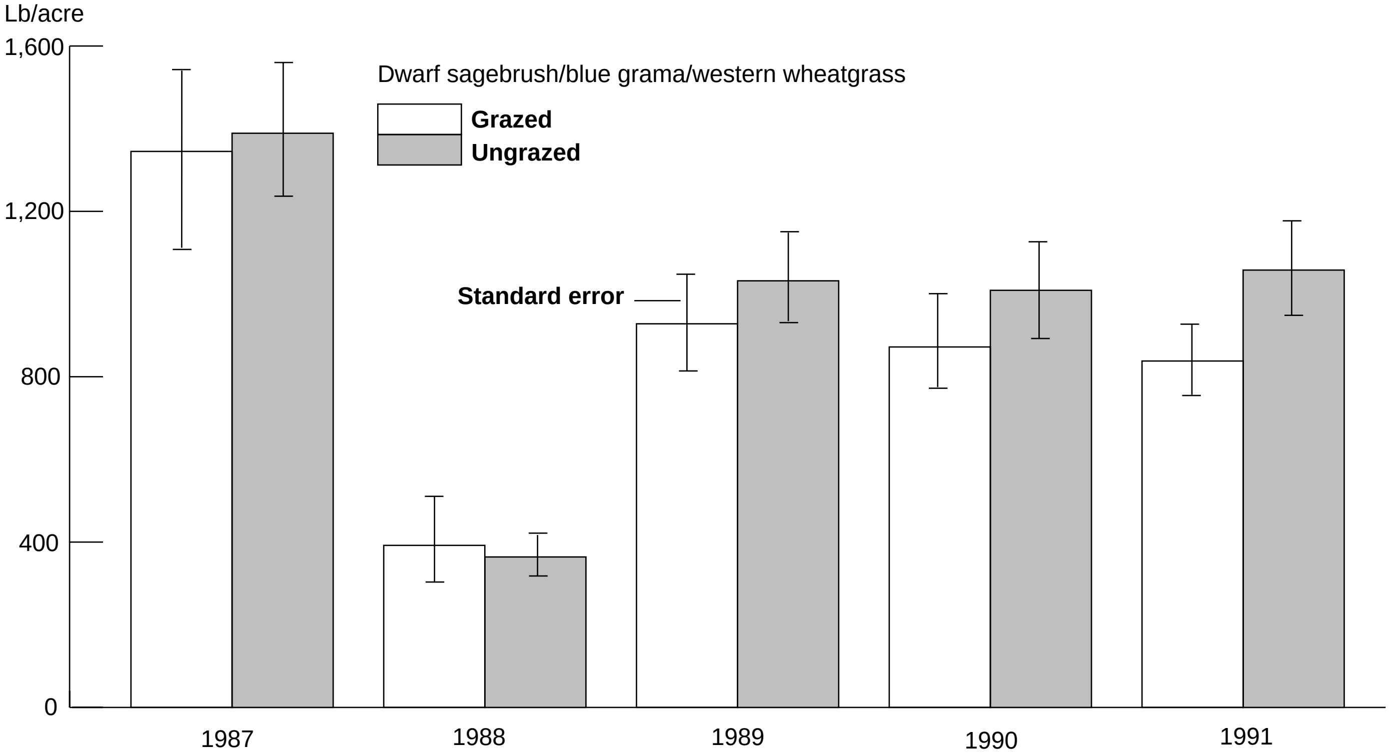

Figure V.8–4—Comparison of plant biomass in July over a 5-year period on ungrazed (inside cages) with grazed (outside of cages) habitats. Shrubs are excluded from this comparison.

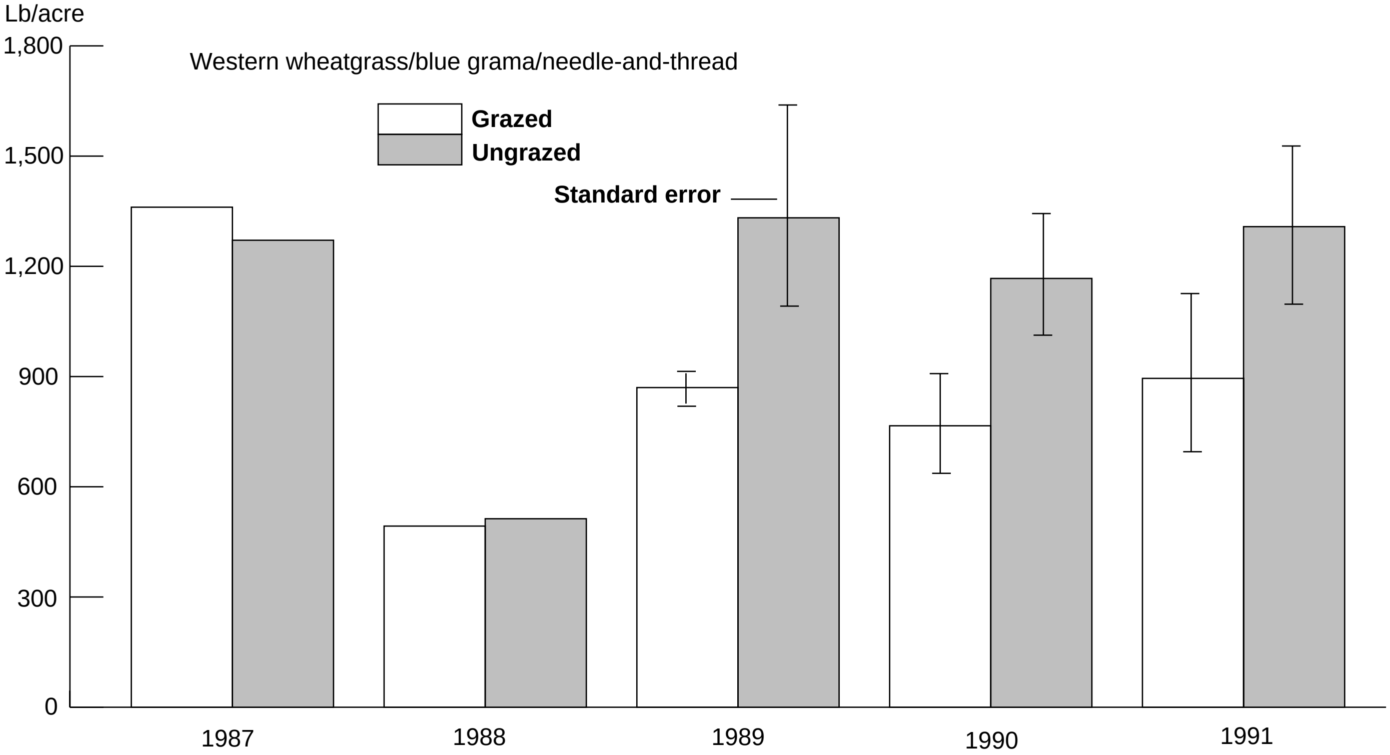

Figure V.8–5—Comparison of plant biomass in July over a 5-year period on ungrazed (inside cages) with grazed (outside of cages) habitats. For the years 1987 and 1988, n=1.

Limited sample size constrained estimates of plant utilization the first 2 years on this community (fig. V.8–5). Nominal utilization occurred in the latter 3 years. Total plant production was low during the first 2 years, but from 1989 to 1991, plant production and utilization were greater. Utilization of forage was similar during the last 3 years, averaging 34 percent. Of the four native plant communities, this one showed the greatest use by herbivores.

5. Crested Wheatgrass Community.—This plant community, represented by two sites, was dominated by the non-native crested wheatgrass, whose canopy cover ranged from 33 to 72 percent. Needle-and-thread was the next most dominant grass, ranging from 5 to 11 percent canopy cover.

The community had been seeded to crested wheatgrass, and total plant production was less variable among years (table V.8–5). Total production for this community ranged from 391 to 1,366 lb/acre. Grass and sedge production, primarily crested wheatgrass, varied from 377 to 1,316 lb/acre. Forbs ranged in production from 22 to 101 lb/acre. Shrubs were a minor component in the community at 7 lb/acre.

Utilization of crested wheatgrass was nominal and variable throughout the study (fig. V.8–6). Livestock generally use crested wheatgrass early in the spring before native plants start to grow and then switch to native species as they turn green.

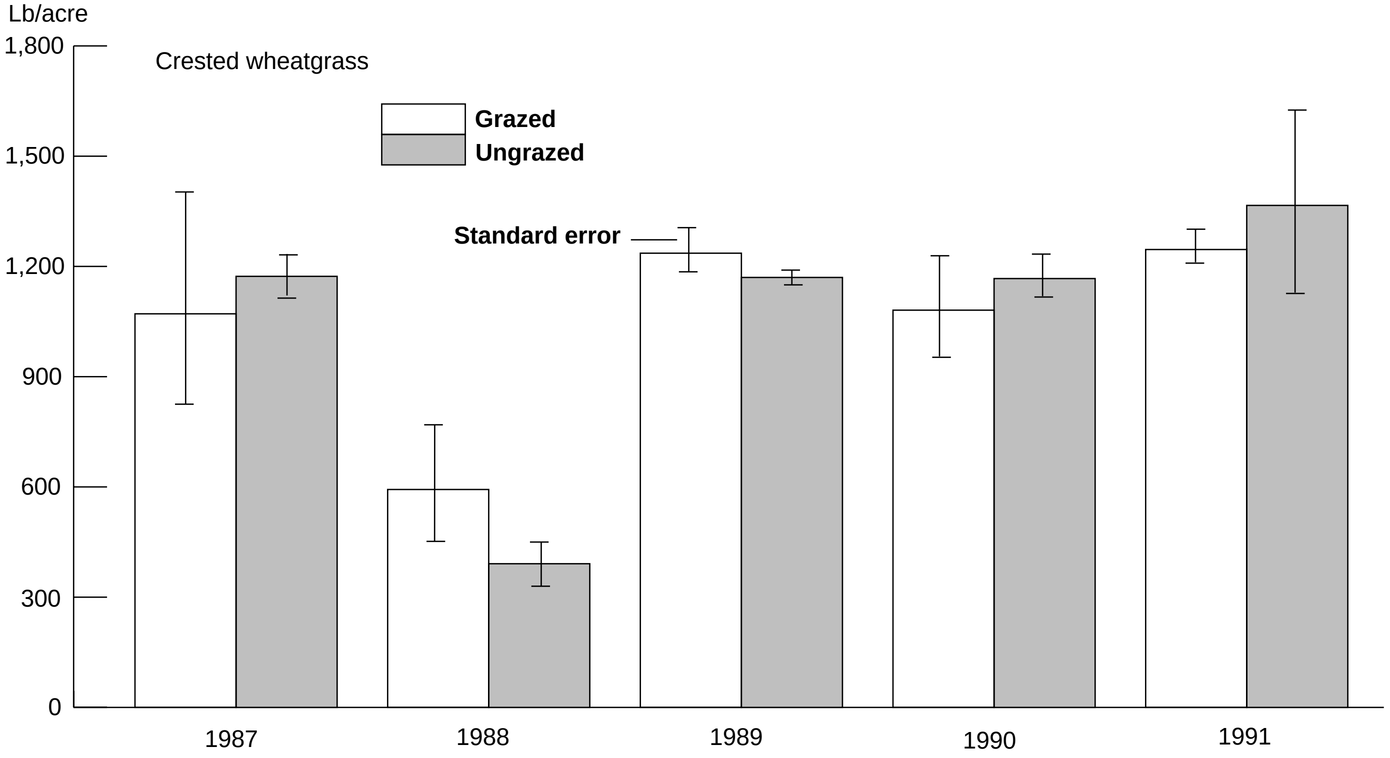

Figure V.8–6—Comparisons of plant biomass in July over a 5-year period on ungrazed (inside cages) with grazed (outside cages) habitats.

6. Dwarf Sagebrush/Leafy Spurge Community.—Only one site dominated by leafy spurge was sampled throughout the 5-year period; its total understory canopy cover ranged from 50 to 77 percent. Dwarf sagebrush was the dominant shrub, and canopy cover varied from 5 to 11 percent. Some western wheatgrass (2 percent) and needle-and-thread (3 percent) was present. Total production over a 4-year period averaged 2,123 lb/acre, with forbs averaging 1,593 lb/acre, shrubs 301 lb/acre, and grasses and sedges 229 lb/acre. Plant utilization was not determined.

Phenology.—Phenological progression through the three seasons for each species is shown in figure V.8–7. These species vary in growth form and include a woody shrub, perennial grasses, *Carex* species, and a forb. The 10 species differed in the timing of their development among years. Western wheatgrass was in a vegetative stage throughout 1991; however, this plant completed all phases of development in 1990. In 1989, when other species were flowering early, fringed sagebrush remained in the vegetative state through the first week in August, when sampling was terminated. Needle-and-thread and green needlegrass *(Stipa viridula)* were similar in phenological development for all 3 years. Blue grama, junegrass *(Koeleria pyramidata),* and Sandberg's bluegrass *(Poa sandbergii)* varied greatly among years in phenophases. Both threadleaf sedge *(Carex filifolia)* and needleleaf sedge *(C. eleocharis)* initiated flowering and seed-set early in the growing season, although length of flowering varied among years. Scarlet globemallow, a forb, flowered longer in 1989 than in the other 2 years; however, other phases of development were similar among all years. In 1991, most species entered the dormancy phase 2–4 weeks later than in 1989–90.

Extensive examination with multivariate analyses, regressions, and correlations of developmental phases through the season for the 10 plant species in our study produced no relationships with degree days, soil moisture, air temperatures, soil temperatures, or precipitation.

Soil Moisture.—Seasonal and yearly amounts of soil moisture are presented in figure V.8–8 and table V.8–6. Overall, soil moisture varied among years. When considering spring moisture available for plant growth, 1988 was the driest year and 1989 the wettest (fig. V.8–9). All years exhibited seasonal variation in soil moisture content among the four native plant communities. Generally, western wheatgrass/blue grama/needle-and-thread community (type 4) was the most moist of the four plant communities (fig. V.8–8). The driest was generally needle-and-thread/blue grama/threadleaf sedge (type 1). Soil moisture trends throughout the growing seasons differed among years. Usually soil moisture decreased on all plant communities as the growing season progressed. Soil moisture and plant production were very low in 1988. Early spring moisture content ranged from 9 to 15 percent among the four plant communities. Years showing greater amounts of soil moisture early in the growing season also showed greater plant production.

Discussion

Plant Community Classification.—The procedures developed in this study to define and classify native plant communities by methods outlined by Uresk (1990) used cover-frequency index for grouping plant communities. Individual plant communities are homogeneous, with minimal variance within each of the communities. Discriminant analyses allowed for identification of groups of variables (species) that collectively were important in separating the major communities.

Five species accounted for most of the variation (97 percent) in separating the four native plant communities in western North Dakota. The plant communities were quantitatively identified with an estimated 96 percent predictability, based on cover-frequency estimates for western wheatgrass, blue grama, threadleaf sedge, needle-and-thread, and dwarf sagebrush. Variation in species composition on a site can be used by resource managers to classify plant communities once canopy cover and frequency-of-occurrence data are collected.

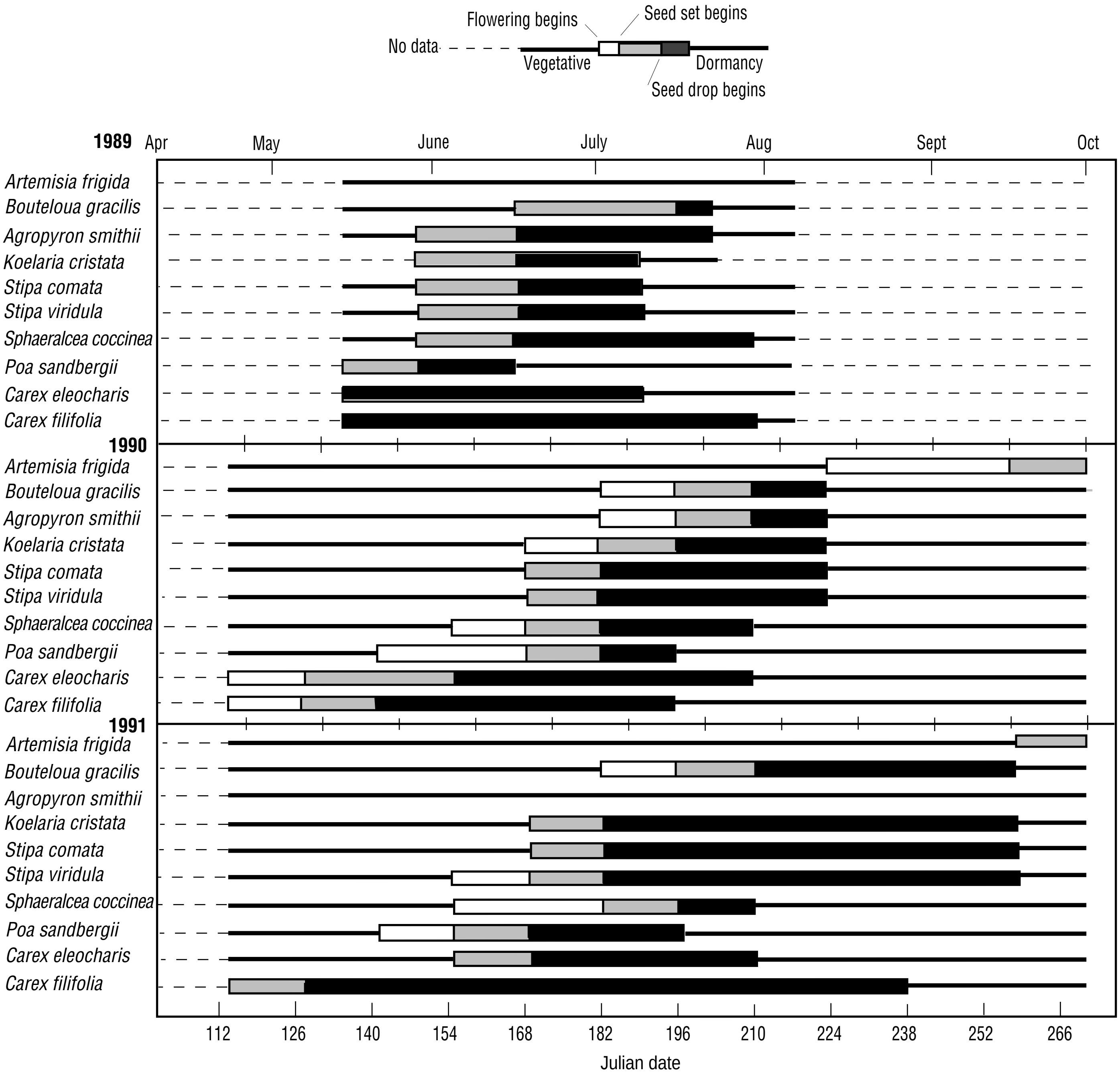

Figure V.8–7—Phenological development for 10 plant species over the 1989–91 growing seasons in western North Dakota.

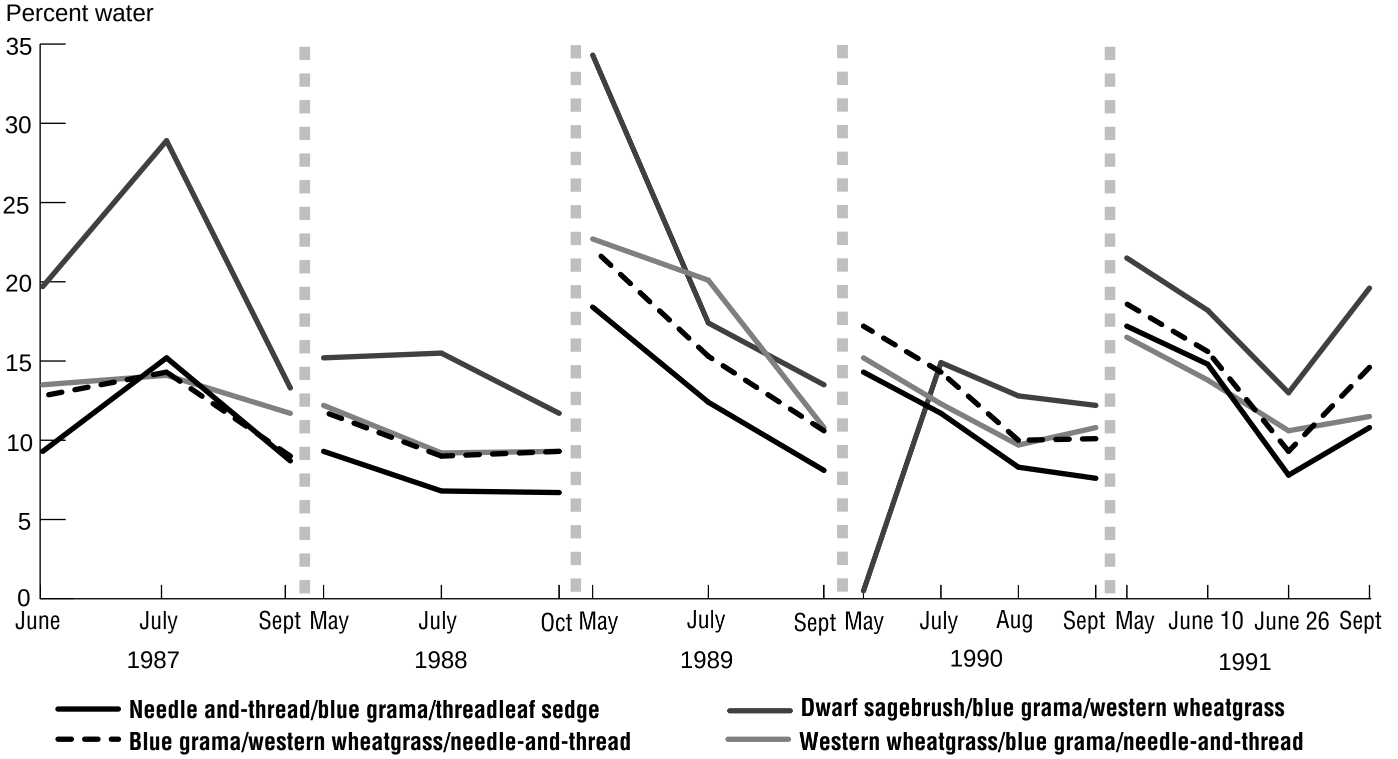

Figure V.8–8—Soil moisture content in percent, at 12-inch depth, by plant community, over a 5-year period.

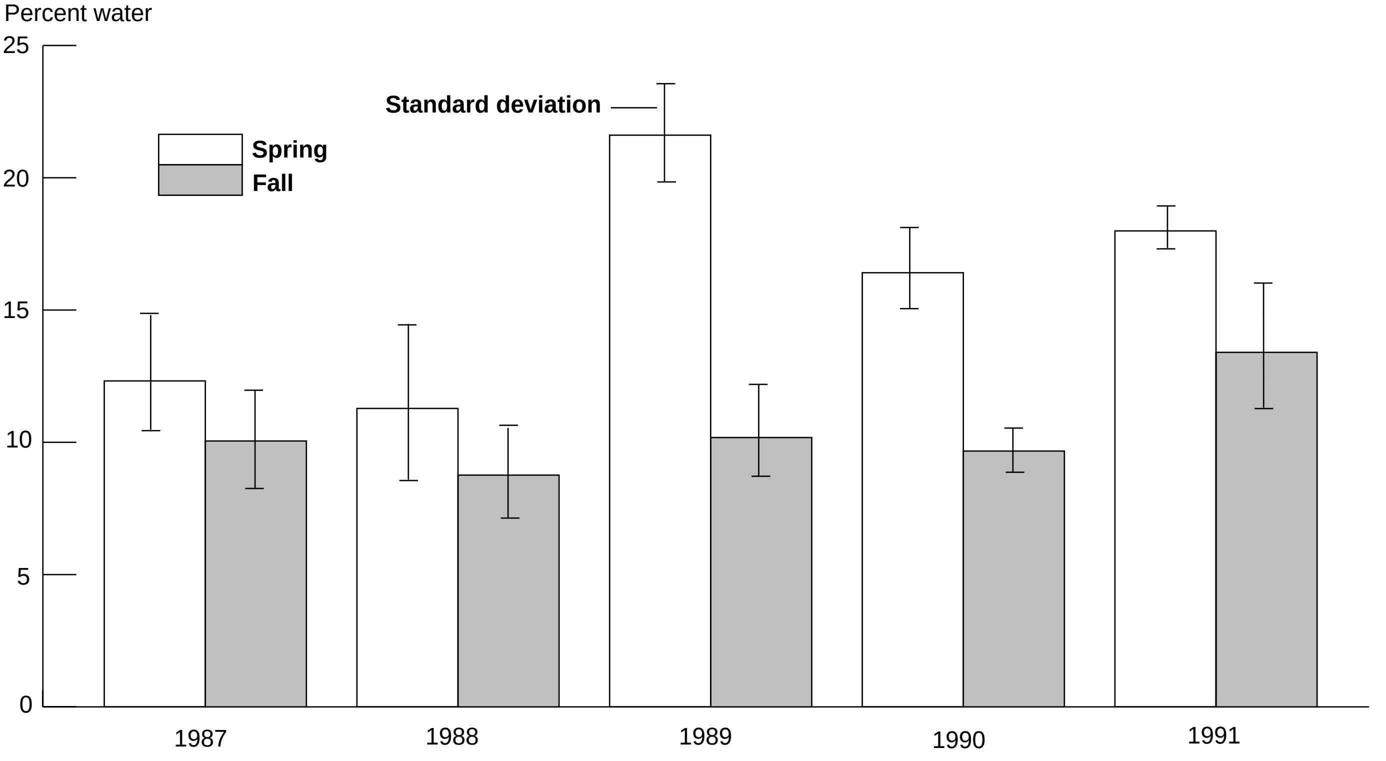

Figure V.8–9—Soil moisture content in percent, at 12-inch depth, across all sites, over a 5-year period.

Table V.8–6—Mean soil moisture (in percent; ± standard error), by plant community, over a 5-year period in western North Dakota

	[1]Type 1	Type 2	Type 3	Type 4
1987	n=5	n=8	n=4	n=1
June	9.3 ± 1.3	12.8 ± 1.9	13.5 ± 1.9	19.7
July	15.2 ± 1.7	14.3 ± 1.6	14.1 ± 2.1	28.9
Sept.	8.7 ± 0.6	9.9 ± 1.5	11.7 ± 1.5	13.3
1988	n=5	n=8	n=4	n=1
June	9.3 ± .7	11.8 ± 1.9	12.2 ± 1.6	15.2
July	6.8 ± 1.0	9.0 ± 1.6	9.2 ± 1.2	15.5
Oct.	6.7 ± .8	9.3 ± 1.7	9.3 ± 1.2	11.7
1989	n=5	n=8	n=4	n=1
1May	18.4 ± 2.7	22.1 ± 2.3	22.7 ± 3.0	34.3
July	12.4 ± 2.0	15.3 ± 2.2	20.1 ± 6.0	17.4 ± 2.4
Sept.	8.1 ± .9	10.6 ± 1.1	10.8 ± 1.2	13.5 ± 0.5
1990	n=8	n=12	n=5	n=3
May	14.3 ± 1.6	17.2 ± 0.9	15.2 ± 1.5	0.5 ± 2.0
July	11.7 ± .9	14.3 ± .9	12.3 ± 1.0	14.9 ± 1.1
Aug.	8.3 ± 1.2	10.0 ± 1.1	9.7 ± 1.1	12.8 ± .4
Sept.	7.6 ± 1.0	10.1 ± 1.1	10.8 ± 1.7	12.2 ± .6
1991	n=8	n=12	n=5	n=3
May 24	17.2 ± 1.4	18.6 ± 2.4	16.5 ± 1.0	21.5 ± 4.7
June 10	14.8 ± .6	15.6 ± 1.2	13.8 ± 1.7	18.2 ± 3.0
June 26	7.8 ± 2.5	9.3 ± 2.2	10.6 ± 2.8	13.0 ± 6.9
Sept. 18	10.8 ± 2.0	14.6 ± 1.5	11.5 ± 2.8	19.6 ± 2.9

[1] Plant community types:
1 = Needle-and-thread/blue grama/threadleaf sedge,
2 = Blue grama/western wheatgrass/needle-and-thread,
3 = Dwarf sagebrush/blue grama/western wheatgrass, and
4 = Western wheatgrass/blue grama/needle-and-thread.

Minimum requirements for data collection to classify plant communities would be to sample on two 98.4-ft (30-m) transects with a minimum of 30 frames (7.9×19.7 inches [20×50 cm]) per transect (Daubenmire 1959) for canopy cover and frequency of occurrence on each site for each of the 5 plant species. Data must be expressed as means for each of the five species. The index is obtained by multiplying canopy cover (percent) and frequency of occurrence (percent) corrected from 30 quadrats to a base of 100.

Once data are obtained for each of the five species, the method to classify a site to a plant community involves multiplying the index for each species with the appropriate Fisher classification coefficients (table V.8–2). All values are summed for each plant community, and the highest score to the positive end indicates the assigned plant community. This method, once developed, provides resource managers with a reliable quantitative tool with replicable results to classify a site to a plant community. With other methods, data sets can be interpreted subjectively to yield different results.

Monitoring Plant Communities.—The five plant species identified in the classification procedures (table V.8–2) can be used to monitor rangelands with respect to herbivory, fire, drought, and disease within these four plant communities. Monitoring can be conducted with canopy-cover and/or frequency-of-occurrence estimates with a minimum of 2 permanent transects and 30 canopy-cover and/or frequency estimates (Daubenmire 1959) per transect on each site. The index (cover × frequency) is the best plant variable to monitor changes (Uresk 1990), but either cover or frequency will do an adequate job for monitoring rangelands. Changes in direction (+/–) from the base data can be used for monitoring purposes with the five species defined for trend. Minor species are too variable for monitoring, and quantitative results are extremely limited. The five species can be easily identified and measured by resource managers in the field. Further refinement for monitoring is discussed by Uresk (1990).

Needle-and-Thread/Blue Grama/Threadleaf Sedge Community.—The eight sites assigned to this community were generally found on upland plateaus and gentle slopes. Soils were primarily sandy. Soil moisture for this community was lowest among the four communities throughout the study. In years of increased precipitation, canopy cover of some species may increase by two- or threefold. When summing canopy cover for individual species, we found that grasses and sedges ranged from 57 percent in a dry year to 125 percent in a wet year. Hansen and Hoffman (1988) reported 90 species in this community. We identified 28 grasses and sedges, 87 forbs, and 9 shrubs in this plant community, for a total of 124 species. Community and soil descriptions are similar to those provided by Hanson and Whitman (1938), Hansen et al. (1984), and Hansen and Hoffman (1988). Under heavy livestock grazing, threadleaf sedge increases and blue grama becomes dominant (Hansen and Hoffman 1988).

Plant production varied considerably from a dry year (1988) to a wet year (1991). Overall this is a very productive community. Eight species of plants make up most of the plant production for this community, with grasses (and sedges) and forbs the major components of production. Forb production showed a tremendous increase in 1989, following the dry year, possibly due to the release of nutrients available for plant growth. Hanson and Whitman (1938), Redmann (1975), and Hansen et al. (1984) described similar trends for canopy cover and production estimates for this community type.

Blue Grama/Western Wheatgrass/Needle-and-Thread Community.—Twelve sites were assigned to this community. Soils for these sites were clayey and silty. This plant community is generally found on drier upland slopes, and the period of optimum moisture for growth is shorter than that of the other communities. We found that blue grama was clearly the dominant vegetation in this plant community, similar to results reported by Hanson and Whitman (1938). Grasses and sedges ranged from 47 to 115 percent canopy cover in this community. In all, 29 grass and sedge species, 89 forbs, and 10 shrub species were identified. Redmann (1975) identified 21 species but sampled only 1 site, which produced 686 lb/acre. Overall plant production on our study ranged from 449 to 1,144 lb/acre. Forbs exhibited a 4.5-fold increase in production following 1988, the dry year. Approximately eight plant species made up the majority of the production.

Dwarf Sagebrush/Blue Grama/Western Wheatgrass Community.—This plant community was made up of five sites dominated by an overstory of dwarf sagebrush and an understory of blue grama and western wheatgrass. The community occupies floodplains and alluvial fans in valleys and is subjected to flooding, erosion, and deposition from storms or minor climatic events (Hanson and Whitman 1938). Soils were silty. Hansen et al. (1984) and Hansen and Hoffman (1988) described this as a dwarf sagebrush/western wheatgrass habitat type. Blue grama becomes the dominant understory plant when heavily grazed, with a reduction in western wheatgrass and needle-and-thread (Hansen et al. 1984). In the present study, grasses and sedges ranged in canopy cover from 44 to 101 percent. The number of grass and sedge species was 30; there were 69 forb species and 9 shrub species. Total production was greatest on this plant community when compared to other native plant communities; however, shrub production was highly variable. Forb production increased following the dry year.

Western Wheatgrass/Blue Grama/Needle-and-Thread Community.—Three sites were assigned to this plant community with western wheatgrass being the dominant plant. Soils were thinbreaks and found on slopes. Throughout the study, soil moisture was greatest for this community. Grasses and sedges ranged from 57 to 120 percent canopy cover. There were 22 grass and sedge species, 67 forb species, and 9 shrub species. Heavy livestock grazing reduces the amount of western wheatgrass and needle-and-thread and increases blue grama and buffalo grass (Uresk 1990). Grasses (and sedges) and forbs were the major component of production. Forb production increased after the dry year, 1988. Hanson and Whitman (1938) described this as a miscellaneous vegetation component in western North Dakota.

Crested Wheatgrass Community and Dwarf Sagebrush/Leafy Spurge Community.—Both of these communities were limited in the number of sites sampled. The crested wheatgrass community had a total of 79 plant species—23 grasses and sedges, 51 forbs, and 5 shrubs. Plant production was primarily from crested wheatgrass. Generally, in 20–30 years crested wheatgrass will decrease and native species become dominant. The dwarf sagebrush/leafy spurge site was dominated by dwarf sagebrush for the overstory plant and had an understory of leafy spurge, which land managers in the West consider a noxious weed. Total number of species in this community consisted of 10 grasses and sedges, 25 forbs, and 4 shrubs.

Phenology

Phenological change has been related to genetics, daily air temperatures, soil moisture, and nutrients (Bassett et al. 1961, Sauer and Uresk 1976, Idso et al. 1978, White 1979, Frank and Hofmann 1989, Callow et al. 1992). Plants on the northern Great Plains are dormant during winter. Seasonal development does not begin until temperatures and daylength exceed dormancy thresholds, adequate moisture is available, and no adverse conditions exist.

Most plants generally initiated flowering earliest in 1989 (fig. V.8–7) with the exception of fringed sagebrush, which remained in a vegetative state through the first week of August. In 1990, most plants were generally later in phenological development. The phases of development in 1991 exhibited a greater range for most plants throughout the season. However, western wheatgrass remained in a vegetative state. Callow et al. (1992) found that flowering events for 97 species varied by year and that temperature seemed more important than precipitation in the flowering dates of spring and early summer plants. They found that midsummer species did not show relationships to climatic effects.

Soil Moisture

Soil moisture could not be used as a variable to model plant growth and development over all 28 sites. Variation among sites was high due to variable precipitation, soil types, grazing, range condition, plant community differences, species composition, litter, and topography. Rauzi (1960) showed that correlations of soil moisture with plant production over several widely spaced sites were lower than for localized sites. Most modeling efforts in western North Dakota with acceptable results have been in homogeneous areas and with individual sites (Rauzi 1960, Wight and Hanks 1981, Wight et al. 1984 and 1986). Tools allowing management decisions to be applied over larger rangeland tracts are needed; unfortunately, it is difficult to model plant growth and development with high reliability over large areas that are highly variable.

As reported by the Agricultural Research Service in Sidney, MT, precipitation was highly variable over the study area. Effective precipitation directly influences soil moisture. Because most summer thunderstorms are localized, some areas may receive precipitation while others remain dry. However, effective thunderstorm events that recharge soil moisture were evident in some seasonal soil-moisture trends in midsummer or fall (fig. V.8–8).

Moisture-holding capacity in soil is a function of particle size. Fine soils generally accumulate and hold greater amounts of moisture; coarse-textured soils, less moisture (Houston 1965). Each plant community in our study was associated with a different soil type—a fact that accounted for some differences in soil moisture. Grazing intensity also influences the amount of moisture. Throughout the 28 sites, grazing, which varied from heavy to light, accounted for some of the variability in soil moisture among the four plant communities. Rangelands in a more productive condition with increased litter absorb greater amounts of moisture as compared to rangelands in poorer condition (Rauzi 1960, Houston 1965, Goetz 1975, Benkobi et al. 1993).

Most soil-moisture changes occur near the surface. Smika et al. (1961) and Cline et al. (1977) found that most variability in soil moisture occurred in the upper 12 inches (30 cm) with little change at the 35-inch (60-cm) depth and below. Soil moisture varied greatly among the 5 years for the four plant communities at the 12-inch depth.

Summary

The 30 sites in our study were classified into six plant communities. Multivariate analyses using the index (cover × frequency) provided a quantitative method to classify four native plant communities with key plant species for separating the communities. These plant species were western wheatgrass, blue grama, threadleaf sedge, needle-and-thread, and dwarf sagebrush. These plants may be used to monitor changes on the rangeland due to management practices, grazing, drought, fire, insects and disease.

Plant communities defined in this study were (1) needle-and-thread/blue grama/threadleaf sedge, (2) blue grama/western wheatgrass/needle-and-thread, (3) dwarf sagebrush/blue grama/western wheatgrass, (4) western wheatgrass/blue grama/needle-and-thread, (5) crested wheatgrass, and (6) dwarf sagebrush/leafy spurge. The latter two communities were limited to just a few sites.

The native grassland communities varied in soils and location. Plant community 2 showed the greatest species richness with 128 species, followed by 124, 108, and 98 for communities 1,3, and 4, respectively. Canopy cover for grasses and sedges ranged from 101 to 125 percent and was greatest on community 1, followed by 4, 2, and 3. Total production on the native communities was similar for all communities with the exception of community 2, which had lower total production. Shrub production in community 3 was highly variable. After a dry year, forb production dramatically increased the following year. Utilization was greatest on plant community 4 and least on community 3. Overall, western wheatgrass and dwarf sagebrush exhibited the greatest variability in phenological development among the 10 plant species over the 3-year period. However, yearly differences in phenological development were evident for all species. Timing for a particular developmental stage (e.g., flowering) varied by 2-4 weeks in some species over the 3 years. The wide range and variability in sites and climatic conditions did not produce definitive models for phenological development.

Soil moisture varied among years, seasons, and plant communities. Seasonal differences were pronounced in most years, with soil moisture decreasing as the growing season progressed. Plant communities dominated by western wheatgrass, blue grama, and needle-and-thread usually showed the greatest soil-moisture content; the needle-and-thread/blue grama/threadleaf sedge community showed the least over the 5-year period.

Acknowledgments

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References Cited

Ball, G. H.; Hall, D. J. 1967. A clustering technique for summarizing multivariate data. Behavioral Science 12: 153–155.

Bassett, I. J.; Holmes, R. M.; MacKay, K. H. 1961. Phenology of several plant species at Ottawa, Ontario, and an examination of the influence of air temperatures. Canadian Journal of Plant Science 41: 643–652.

Benkobi, L.; Trlica, M. J.; Smith, J. L. 1993. Soil loss as affected by different combinations of surface litter and rock. Journal of Environmental Quality 22: 657–661.

Branson, F. A.; Gifford, G. F.; Renard, K. G.; Hadley, R. F. 1981. Rangeland hydrology. Range Sci. Ser. No. 1, (2d ed.). Denver, CO: Society of Range Management. 340 p.

Callow, J. M.; Kantrud, H. A.; Higgins, K. F. 1992. First flowering dates and flowering periods of prairie plants at Woodworth, North Dakota. Prairie Naturalist 24: 57–64.

Cline, J. F.; Uresk, D. W.; Rickard, W. H. 1977. Comparison of soil water used by a sagebrush–bunchgrass and a cheatgrass community. Journal of Range Management 30: 199–201.

Daubenmire, R. 1959. A canopy-coverage method of vegetation analysis. Northwest Scientist 33: 43–64.

Frank A. B; Hofman, L. 1989. Relationship among grazing management, growing degree-days, and morphological development for native grasses on the northern Great Plains. Journal of Range Management 42: 199–202.

Goetz, H. 1975. Availability of nitrogen and other nutrients on four fertilized range sites during the active growing season. Journal of Range Management 28: 305–310.

Hansen, P. L.; Hoffman, G. R. 1988. The vegetation of the Grand River/Cedar River, Sioux, and Ashland Districts of the Custer National Forest: a habitat type classification. Gen. Tech. Rep. RM-157. Ft. Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 68 p.

Hansen, P. L.; Hoffman, G. R.; Bjugstad, A. J. 1984. The vegetation of Theodore Roosevelt National Park, North Dakota: a habitat type classification. Gen. Tech. Rep. RM-113. Ft. Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 35 p.

Hanson, H. C.; Whitman, W. C. 1938. Characteristics of major grassland types in western North Dakota. Ecological Monographs 8: 57–114.

Hewitt, G. B. 1980. Plant phenology as a guide in timing grasshopper control efforts on Montana rangeland. Journal of Range Management 33: 297–299.

Houston, W. R. 1965. Soil moisture response to range improvement in the northern Great Plains. Journal of Range Management 18: 25–30.

Idso, S. B.; Jackson, R. D.; Reginato, R. J. 1978. Extending the “degree day” concept of plant phenological development to include water stress effects. Ecological Society of America 59: 431–433.

Kemp, W. P; Berry, J. S.; Caprio, J. M. 1991. Use of ornamental lilac and honeysuckle phenophases as indicators of rangeland grasshopper development. Journal of Range Management 44: 583–587.

Lauenroth, W. K.; Whitman, W. C. 1977. Dynamics of dry matter production in a mixed-grass prairie in western North Dakota. Oecologia 27: 339–351.

Rauzi F. 1960. Water-intake studies on range soils at three locations in the northern plains. Journal of Range Management 13: 179–184.

Redmann, R. E. 1975. Production ecology of grassland plant communities in western North Dakota. Ecological Monographs 45: 83–106.

Sauer, R. H.; Uresk, D. W. 1976. Phenology of steppe plants in wet and dry years. Northwest Scientist 50: 133–139.

Smika, D. E.; Haas, A. J.; Rogler, G. A.; Lorenz, R. J. 1961. Chemical properties and moisture extraction in rangeland soils as influenced by nitrogen fertilization. Journal of Range Management 14: 213–216.

SPSS, Inc. 1990. SPSS/PC+ advanced statistics 4.0. Chicago: SPSS, Inc. 369 p.

Uresk, D. W. 1990. Using multivariate techniques to quantitatively estimate ecological stages in a mixed grass prairie. Journal of Range Management 43: 282–285.

Uresk, D. W.; Cline, J. F.; Rickard, W. H. 1979. Growth rates of cheat grass community and some associated factors. Journal of Range Management 32: 168–170.

Uresk, D. W.; Sims, P. L.; Jameson, D. A. 1975. Dynamics of blue grama within a shortgrass ecosystem. Journal of Range Management 28: 205–208.

White, L. M. 1979. Relationship between meteorological measurements and flowering of index species to flowering of 53 plant species. Agricultural Meteorology 20: 189–204.

Wight, J. R.; Hanks, R. J. 1981. A water-balance, climate model for range herbage production. Journal of Range Management 34: 307–311.

Wight, J. R.; Fissler, H. G.; Hanson, C. L. 1986. Biology and ecology of sagebrush in Wyoming: IV. Validation of a rangeland production model (ERHYM) for sagebrush sites. In: McArthur, E. D.; Welch, B. L., comps. Proceedings—symposium on the biology of *Artemisia* and *Chrysothamnus;* 1984 July 9–13; Provo, UT. Gen. Tech. Rep. INT-200. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station: 320–325.

Wight, J. R.; Hanson, C. L.; Whitmer, D. 1984. Using weather records with a forage production model to forecast range forage production. Journal of Range Management 37: 3–6.

V.9 Simulation of Near-Surface Soil Temperature on Rangelands

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To effectively control grasshoppers and the damage they cause requires information about when the potential for grasshopper outbreaks exists, the age structure of grasshopper populations, and how grasshopper population densities will change over time. Central to all these objectives is the ability to predict the timing of hatch and the rate of nymphal (immature) development for different species of grasshoppers. Recent Grasshopper Integrated Pest Management (GHIPM) Project results have shown that the growth and development of grasshoppers can be adequately predicted once the time of hatch has been determined (Dennis et al. 1986, Dennis and Kemp 1988). However, predicting the timing of grasshopper hatch is very difficult.

In late summer and fall, most grasshoppers lay eggs that then hatch the following spring. Several weeks after the eggs are laid, they enter what is called an embryonic diapause until the temperature gets very cold later in the fall or winter. Diapause is a state in which the eggs will not develop beyond a certain stage until the right environmental conditions exist. Diapause prevents the eggs from developing and hatching too early during an unfavorable or inappropriate season of the year. After the eggs experience a period of extreme cold, they begin to develop at a rate governed by the amount of heat they receive. Eggs that receive more heat hatch earlier in the year than eggs in cooler locations. Therefore, to predict grasshopper hatch accurately, scientists must first accurately predict soil temperature conditions that exist in the near-surface soil layers, where grasshopper eggs are laid.

Because continuous monitoring of environmental conditions in the soil is time-consuming and costly, computer simulation of soil temperature is the most practical alternative. However, temperature and moisture conditions near the soil surface change quite rapidly and are strongly influenced by small changes in weather patterns and soil types. Vegetation also strongly influences soil water and temperature conditions by controlling how much sunlight reaches the soil surface and how much heat is lost from the soil at night, when the air is cooler. Soil under a shrub receives much less sunlight than bare soil or soil covered by a grass plant immediately adjacent to the shrub. This causes a great deal of variation in how much heat is accumulated at different locations across a landscape. Pierson and Wight (1991) reported that at 1 cm below the surface, soil temperatures varied by as much as 31 °F between soils under a sagebrush plant canopy and a bare soil in the interspace between the shrubs. Their measurements reflect soil temperature conditions in March, when grasshopper eggs are still in the ground and are just beginning rapid development. Near-surface soil temperatures can be equally influenced by grasses or shrubs. In particular, bunch grasses insulate the soil surface like a shrub canopy does and can cause temperature differences of up to 36 °F between locations only a few centimeters apart.

The SHAW Model

The Simultaneous Heat and Water (SHAW) model was modified to estimate near-surface soil temperatures under varying types of rangeland vegetation (Flerchinger and Pierson 1991). The model simulates the movement of water and heat through the vegetation, snow, soil surface residue, and the soil profile. The model includes the influence of soil freezing and thawing, evaporation, transpiration, infiltration, and surface runoff. SHAW provides hourly predictions of soil temperature and water potential at any specified point throughout the plant canopy or soil profile. The model can simultaneously simulate the influence of several plant species as well as dead plant material on soil water and temperature conditions.

The model looks at the plant–soil system as a series of layers starting from the top of the plant canopy and extending down through the soil to a depth of just over 13 ft (4 m). The model requires weather information to tell it how much water and heat are being received into the top layer of the system. Data requirements include hourly estimates of air temperature, precipitation, solar radiation, windspeed, and relative humidity. The model then predicts how much heat and water will move between layers or will be lost out the bottom of the soil profile or back into the atmosphere.

Model Operation

A great deal of descriptive information about the vegetation and soil is needed before the SHAW model can be used to simulate soil water and temperature conditions at a specific site. Supplying this information in terms the model can use is referred to as the model parameterization process. To facilitate this process, there is a user interface that steps the user through each parameter and allows the user either to enter a value or have it estimated by the model. The interface then formats all the information into the proper computer file formats.

The model interface comprises a series of formatted computer screens that a user can select from a menu. Each screen steps through a variety of related parameters and, where applicable, provides helpful information on estimating a proper value. The menu consists of the following screen options, which allow the user to:

FILE: Recall parameter information from a previous simulation or to save the current parameter values,

CONTROL: Input dates of simulation and location of input and output files,

SITE: Input general information for the site (e.g., latitude, slope, aspect and elevation),

VEGETATION: Input data for plant characteristics,

SOILS: Input data for soil characteristics,

SURFACE: Input data for residue, snow, and surface characteristics,

RUN MODEL: Input data to create model input files using current data values and execute SHAW model simulation, and

EXIT: Exit the model interface.

In addition to parameterizing the model, the user must also supply a computer data file of weather information before a model simulation can be conducted. Values of air temperature, precipitation, solar radiation, windspeed, and relative humidity must be supplied on an hourly or daily basis. If weather data are available only on a daily basis and hourly output is desired, the model will estimate hourly weather values based on the daily values provided. Weather data specific to the site provide the most accurate model simulations, but weather data are not always available for all locations. In such situations, weather data can be computer generated using information from nearby weather stations. A climate generator called CLIGEN (Nicks and Gander 1993 and 1994) has been adapted to provide weather data in the proper format needed to run SHAW for many locations throughout the world.

Model Testing

To test how well the model predicts soil water and temperature conditions under different rangeland vegetation and soil conditions, model-predicted values were compared to measured values taken in the field (Pierson et al. 1992). Measurements of soil water and temperature conditions were taken at several depths in the soil within three different rangeland plant communities. One site was a sagebrush *(Artemisia tridentata tridentata)*–grass plant community, where measurements were taken directly under the shrubs and in the bare-soil interspaces between shrubs. The other two sites were shortgrass prairie plant communities dominated by blue grama grass *(Bouteloua gracilis)*, a sod-forming grass, and a stand of seeded crested wheatgrass *(Agropyron cristatum)*, a bunchgrass. The two sites were close to one another but differed in soil characteristics and elevation. Measurements of soil water and temperature were collected directly under the sodgrass and bunchgrass plants and in the bare-soil interspaces between the grass plants.

At the sagebrush site, SHAW predicted hourly soil temperatures at a depth of 1 cm during the spring growth period with average errors of only 4 °F (2.2 °C) for sagebrush locations and 5.8 °F (3.2 °C) for interspace locations. The model performed well throughout the year except for the hot summer months, when it consistently underestimated soil temperatures near the soil surface. SHAW did not simulate soil moisture conditions as well as it did soil temperature. It predicted soil moisture adequately under the sagebrush canopy but predicted drydown too early in the interspace locations.

On the shortgrass prairie sites, SHAW simulated 1-cm and 2-inch (5-cm) soil temperatures quite well under all conditions. For bare soil conditions, SHAW consistently underestimated soil temperatures during the hot summer months at the 1-cm depth but was much closer at the 5-cm depth. SHAW slightly overestimated soil temperatures during the cooler months, particularly at the 5-cm depth. SHAW predicted periods of wetness very well at both the 1-cm and 5-cm depths but predicted too rapid a dry-down period compared to measured values. Both measured and predicted soil temperature and moisture responses under the sodgrass were similar to those for the bare soil condition.

Under bunchgrass, SHAW simulated 1-cm and 5-cm soil temperatures better than it did under bare-soil conditions. The seasonal problem of underestimating summer soil temperatures exhibited for the bare soil was much less evident. For certain conditions throughout the year, SHAW seemed to overpredict temperatures at both the 1-cm and 5-cm depths, but the errors were generally small. SHAW simulated soil moisture conditions significantly better under the bunchgrass than under bare-soil conditions at both tested depths. Rather than predicting dryness too quickly as SHAW did for the bare soil, the model generally overpredicted the length of the wet periods at both depths.

Testing the SHAW model has shown that it is quite capable of simulating small-scale variations in soil temperature and moisture conditions induced by vegetation. The model performed particularly well under the sagebrush and bunchgrass conditions compared to bare-soil conditions, indicating SHAW's strength at simulating the insulating effect of the plant canopy and the evapotranspiration process.

Model Applications

The ability to simulate the soil water and temperature regimes of the top inch or so of the soil profile will significantly enhance the simulation of grasshopper growth dynamics and the development of management strategies. Simulated soil temperatures can be used to drive other models, such as the grasshopper hatch model developed as part of the GHIPM Project (see IV.2, "Grasshopper Egg Development: the Role of Temperature in Predicting Egg Hatch"). Together these models can be used to develop regional and geographic information systems data bases of the expected time of occurrence of various stages of grasshopper development.

SHAW-simulated soil temperatures were used to drive the grasshopper hatch model and predict grasshopper hatch dynamics at a site near Three Forks, MT. The results were compared against predictions of hatch based on measured soil temperatures and actual field measurements of grasshopper hatch (fig. V.9–1). Early in the season, predictions of grasshopper hatch based on SHAW soil temperatures were very close to those for measured soil temperatures, but both slightly overpredicted the proportion of grasshoppers hatched compared to measured populations. The timing of 50-percent hatch was predicted quite well based on both SHAW-simulated and measured soil temperatures. Later in the season, the hatch model slightly underestimated the proportion of grasshoppers hatched, particularly based on SHAW-simulated soil temperatures. Overall, the grasshopper hatch model performed very well and lost little accuracy when SHAW-simulated soil temperatures were substituted for measured values.

This type of modeling approach can also be used with historical climate information to explore management questions such as how the timing of grasshopper hatch might vary from year to year for different grasshopper species. The SHAW model was used to simulate annual near-surface soil temperatures within a sagebrush–grass plant community for a period of 100 years using simulated climate information. The model output was then used to determine the probability of occurrence of specific temperature conditions that might be associated with the timing of grasshopper hatch. For the purposes of this example, grasshoppers were assumed to hatch when the eggs had accumulated 300 growing degree-days (GDD).

Figure V.9–2 shows the frequency of occurrence of 300 GDD under both sagebrush shrubs and the interspace locations between shrubs. Notice that the distribution of possible hatch times for the entire site covers about 5 weeks (Julian date 124–161) and that there is no overlap of distributions between the two locations. The frequency distribution for the interspace location is only 1 week in length, indicating that there is a very high probability that grasshopper eggs within the interspace locations will hatch every year within 3 days of Julian day 126.

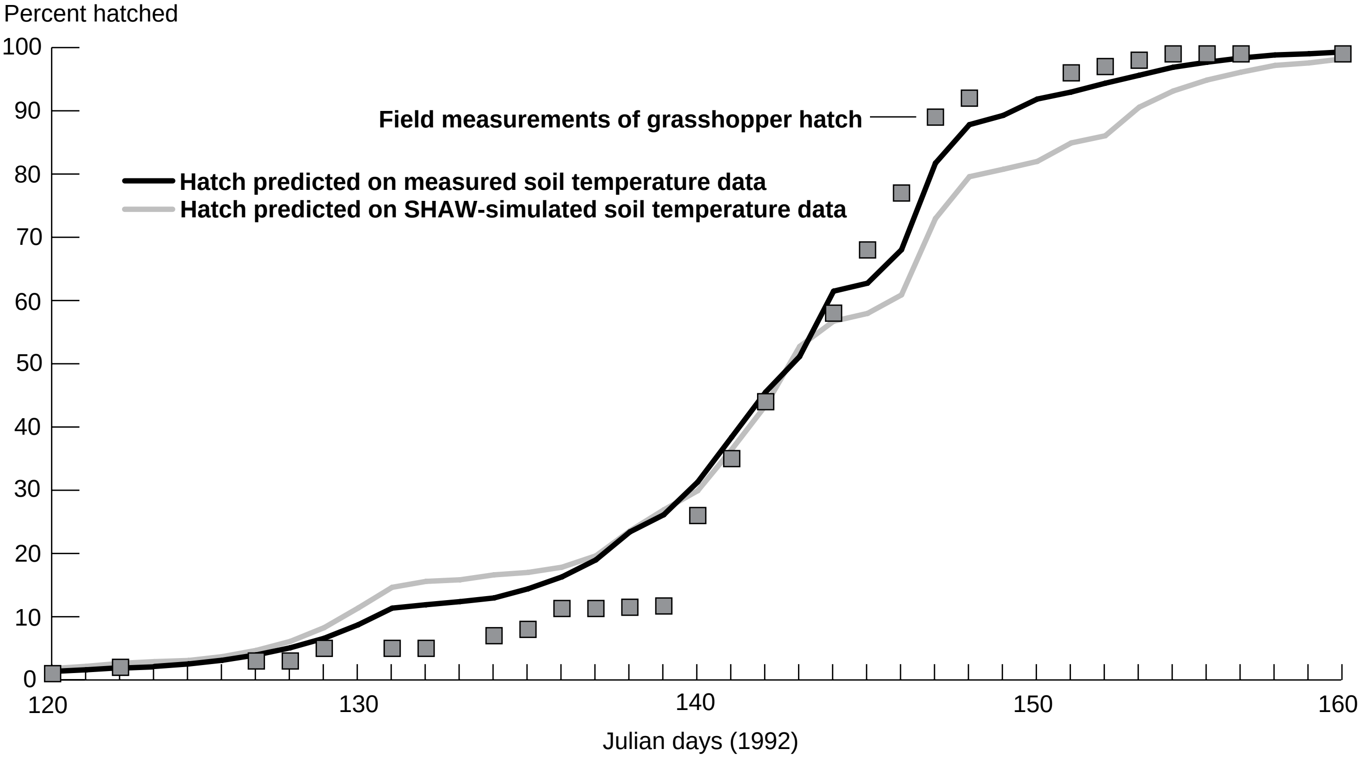

Figure V.9–1—Comparison of measured and predicted proportions of the population of *Aulocara elliotti* grasshoppers hatched for each day during the spring of 1992 near Three Forks, MT.

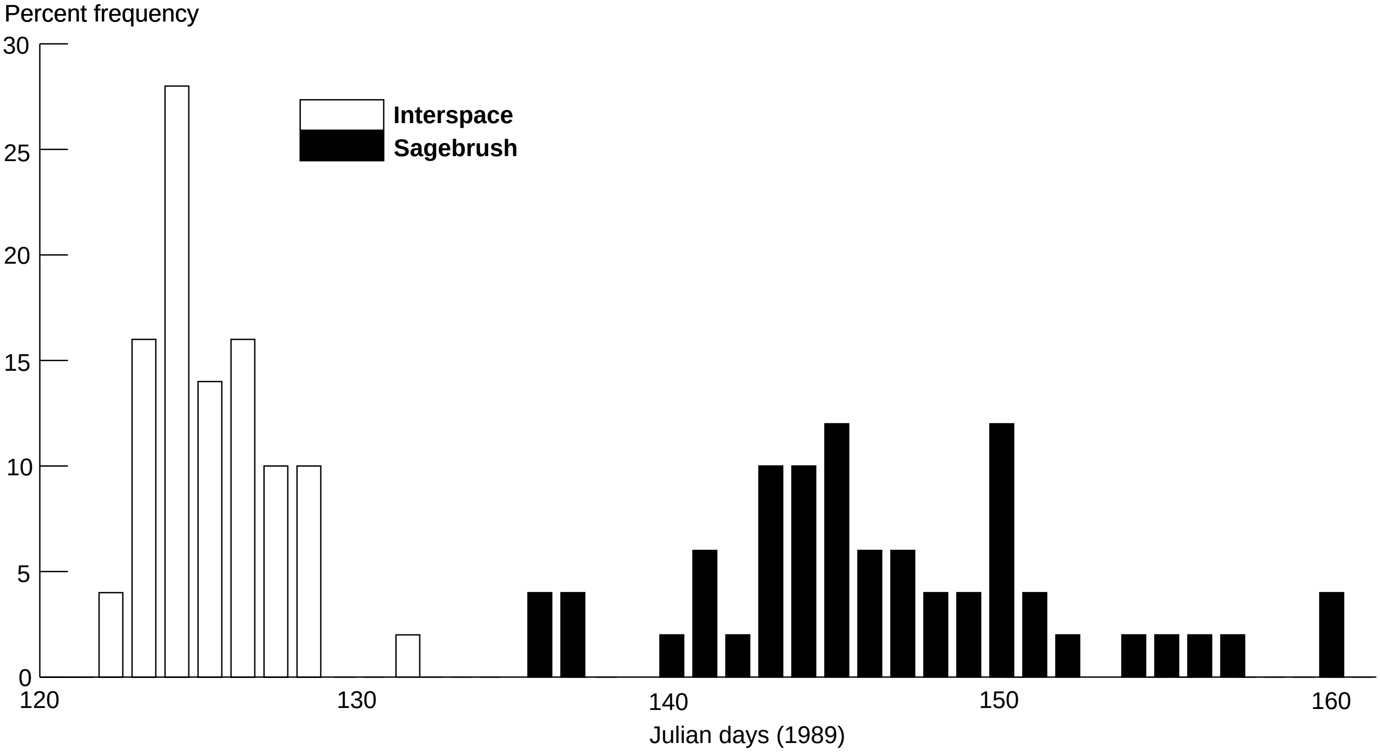

Figure V.9–2—Percent frequency of the timing of the accumulation of 300 degree-days of heat under sagebrush plants and the interspace locations between sagebrush plants at the Quonset site on the Reynolds Creek Experimental Watershed, Reynolds, ID (Wight et al. 1992).

So what does this information mean to grasshopper management? If grasshoppers lay their egg pods at random across the landscape, then the variation in hatch time across the site could be as much as 5 weeks. This variation would result in a very mixed-aged population of grasshoppers. However, research has shown that certain species of grasshoppers do not lay their eggs at random across the landscape but selectively choose specific sites (such as directly under a shrub or in full sunlight between shrubs). Thus, the model results can tell managers when to look for hatch to begin for different grasshopper species. For example, if grasshopper species "X" lays its eggs under shrubs and grasshopper species "Y" lays its eggs in the interspaces, then the entire population of grasshopper X will always hatch before grasshopper Y begins to hatch. This kind of information can be useful for improving resource planning and enhancing the efficiency of grasshopper control applications.

References Cited

Dennis, B.; Kemp, W. P.; Beckwith, R. C. 1986. A stochastic model of insect phenology: estimation and testing. Environmental Entomology 15: 540–546.

Dennis, B.; Kemp, W. P. 1988. Further statistical inference methods for a stochastic model of insect phenology. Environmental Entomology 17: 887–893.

Flerchinger, G. N.; Pierson, F. B. 1991. Modeling plant canopy effects on variability of soil temperature and water. Agriculture and Forest Meteorology 56: 227–246.

Nicks, A. D.; Gander, G. A. 1994. CLIGEN: a weather generator for climate inputs to water resource and other models. In: Watson, D. G.; Zarzueta, F. S.; Harrison, T. V., eds. Proceedings of the fifth international conference on computers in agriculture; 6–9 February 1994; Orlando, FL. [Place of publication unknown]: American Society of Agricultural Engineers: 903–909.

Nicks, A. D.; Gander, G. A. 1993. Using CLIGEN to stochastically generate climate data inputs to WEPP and other water resource models. In: Proceedings of the Federal interagency workshop on hydrologic modeling demands for the 90's. Water Resour. Invest. Rep. 93-4018. Fort Collins, CO: U.S. Geological Survey: 7-14–7-21.

Pierson, F. B.; Flerchinger, G. N.; Wight, J. R. 1992. Simulating near-surface soil temperature and water on sagebrush rangelands: a comparison of models. Transactions of the American Society of Agricultural Engineers 35: 1449–1455.

Pierson, F. B.; Wight, J. R. 1991. Variability of near-surface soil temperature on sagebrush rangeland. Journal of Range Management 44: 491–497.

Wight, J. R.; Pierson, F. B.; Hanson, C. L.; Flerchinger, G. N. 1992. Influence of sagebrush on the soil microclimate. In: Symposium on ecology and management of riparian shrub communities; 29–31 May 1991; Sun Valley, ID. Gen. Tech. Rep. INT-289. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station: 181–185.