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RANGELAND ENTOMOLOGY[1]

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PERSPECTIVES AND OVERVIEW

Rangeland is described as "land on which native vegetation (climax or natural potential) is predominantly grasses, grass-like plants, forbs or shrubs suitable for grazing or browsing . . ." (9). In this first Annual Review of the broad subject of rangeland entomology, reference is made to only a small fraction of the extensive pertinent literature, with principal but not exclusive reference to the most recent investigations. Our coverage of this subject will focus primarily on rangelands of the western United States, with only brief reference to corresponding problems in other parts of the world. Grassland, whether designated as "rangeland" or "waste grassland," was the origin of most cereal, feed grain, and grass forage insect pests. With a few exceptions the biology of most rangeland insects is at best poorly known. They inhabit a relatively undisturbed, mixed community of plants, which adds a complexity not found in a typical argicultural monoculture. Further, there is a relatively temporal stability in the perennial grassland system that is absent in annual cropping systems. Because of this, opinions have been expressed that integrated pest management (IPM) may be more successfully employed on rangelands than in an agroecosystem. Only recently has the concept of rangeland entomology emerged as a cohesive entity, though earlier Annual Reviews have touched upon parts of the subject (55, 93). Hewitt et al (62) previously published a book entitled *Rangeland Entomology.*

Grasshoppers, presently considered to be the most destructive group of insects on rangeland, periodically cause devastation within each of the six temperate zone continents. In some problem areas, particularly where locust swarming occurs, a single species may be primarily responsible for the

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devastation, such as *Schistocerca gregaria* whose range extends from southwestern Asia into Africa or *Nomadacris septemfasciata* in southern Africa. On the other hand, in the western United States an assemblage of 12 or even more species at any one location is often responsible for major damage, and the assemblage usually changes from region to region and year to year (104). Periodically, devastating plagues of the Mormon cricket, *Anabrus simplex,* destroy all vegetation along their line of march through the sagebrush-grassland community of the intermountain and far western regions of the United States. Careful monitoring in its mountain habitats and early control have probably contributed to its decline in importance in recent decades.

The insects on rangelands, however, extend beyond grasshoppers to include others that attack roots, stems, leaves, flowers, and seeds. One group of plant bugs (Miridae) damage range grasses through toxemia and loss of plant juices. Certain others feed on the panicle and seed head where a toxemia prevents seed maturation. Several grass-feeding caterpillars may denude heavily infested areas. Some, such as the range caterpillar, *Hemileuca oliviae,* are almost always range species, whereas others such as cutworms or armyworms are more often reported as pests in agroecosystems of cereal grains, hay, and pasture grasses. White grubs are widely distributed, yet often highly localized, and may cause total destruction of the grass stand. Termites, e.g. *Gnathamitermes tubiformans,* in the southwestern United States are presently regarded as minor but potential range grass pests; however, in Africa and Australia harvester termites do extensive damage to range grasses. Grasscutter ants in South America greatly reduce the carrying capacity of rangelands. The extent to which grass seed insects interfere with natural reseeding on range is largely unknown. Their importance is in commercial production of seed grown for revegetating rangeland and for seeding cultivated hay and pasture grasses.

Browse plants that provide forage for both livestock and big game are attacked by numerous insects most of which are root borers or lepidopterous defoliators. These destroy forage and sometimes threaten plant survival.

Weeds, particularly woody perennials, are probably the universal and paramount rangeland pest problem. Biological control with insects has been sought for many imported weeds with mixed success (36). Some of the most costly rangeland weeds are indigenous and are subjects of conflict of interest. The conflict may arise because certain species, e.g. sagebrush, mesquite, cactus, etc, are considered pests by some interest groups while others view them as beneficial. For these reasons their biological control has not been pursued in the United States.

The growing interest in IPM on rangelands was highlighted by an interdisciplinary workshop in June 1980 at Denver, Colorado. Participants included biological and agricultural scientists and economists from state and federal research agencies of the western United States.

ROLE OF RANGELAND INSECTS

The ecology of western rangeland is fragile. Stresses (drought) or abuses (overgrazing) repair slowly and produce bare spots that favor certain insects. Some grasshoppers are favored by a mosaic of vegetation and patches of bare ground; the latter is attractive for egg laying, and the vegetated areas provide food for the young (25).

Successful ranching in such a fragile ecosystem requires fine tuning of the bioeconomic balance. This necessitates the establishment, for each pest species, of an economic threshold at which appropriate management strategies should be implemented. However, these thresholds have been established for only a few of the world's pest insects, regardless of host. The closely associated term "action threshold" denotes the density at which controls should be considered (100). Establishment of the economic threshold must include the value of lost forage, cost of control, cost of undesirable side effects resulting from the use of insecticides, as well as the value of results that may last for more than one year.

The roles that insects play in biological processes on rangeland are numerous, but several specific ones are recognized as follows.

1. Herbivores that feed on forage species beneficial to man (e.g. grasshoppers, grass bugs, etc).
2. Herbivores that control plants undesirable to man (e.g. *Cactoblastis cactorum* on prickly pear and *Chrysolina* spp. on Klamath weed).
3. Parasitoids and predators of noxious and beneficial arthropods (e.g. the encytid parasitoid on Rhodesgrass mealybug and many other species of Hymenoptera, Coleoptera, Hemiptera, Diptera, etc).
4. Decomposers and soil aerators (e.g. all insects through feeding and digestion are decomposers; ants, termites, dung feeders, etc, are also soil aerators).
5. Herbivores that survive and multiply on rangeland and migrate to agroecosystems (e.g. most insects that attack grass and cereal crops: Hessian fly, many cutworms and armyworms, sod webworms, some mirids, grasshoppers, white grubs, false wireworms, etc).
6. Parasitoids and predators of arthropods that survive and multiply on rangeland and migrate to agroecosystems and vice versa (e.g. many species of families of Hymenoptera (*Trichogramma,* etc), Diptera (tachinids), Hemiptera (pirate bugs), Coleoptera (lady beetles), etc).
7. Herbivores that transmit the causal agents of plant diseases within and

between the rangeland and agroecosystems (e.g. aphids, leafhoppers, mites).

8. Hematophages that transmit the causal agents of animal diseases within and between the rangeland and agroecosystems (mosquitoes, horse flies, mites, ticks).
9. Pollinators (a number of families of Hymenoptera, some Diptera, etc).
10. Those that are recognized as neither harmful nor beneficial but that add stability to the system (e.g. all other rangeland insects).

RANGELAND INSECTS OF MAJOR IMPORTANCE

Grasshoppers

Until further research indicates otherwise, it must be accepted that the Acrididae or grasshoppers surpass all other arthropods in their destructiveness to rangelands (7). In the western United States 26 species have been named as potential threats west of approximately the 100th meridian. Of these, 22 are a threat in the Great Plains states, 13 in the Intermountain region, and 6 in the Pacific Coastal region (61). Some are important interregionally. *Camnula pellucida* is a pest in all three regions (but it is not necessarily the most important), and 13 others are named in two regions. A number of incompletely understood factors such as weather, food availability, mismanagement and land use interact to bring a species to outbreak status.

Gangwere (52), expanding on Isely & Alexander's (72) pioneer work, did a landmark study of food selection in Orthoptera. Crop contents, fecal materials, and mouthparts were found to be useful in the study of food selection. Based on the availability of common food plants and demonstrated latitude in food selection of most groups and species, Gangwere concluded that food probably plays only a minor role in insects' habitat selection.

The broad range of feeding habits among grasshoppers makes it difficult to generalize about the economic significance of a particular population. The impact of populations is not a matter of mere numbers, since Anderson (5) found little correlation between the numbers of grasshoppers per unit area and the seasonal loss of vegetation. Mulkern et al (94) made a comprehensive study of the food habits and preferences of grasshoppers in the central Great Plains. Based upon the plant species found in the crop, they classified 62 Kansas, Nebraska, and North Dakota grasshopper species into five feeding preference categories as follows: forbivorous—20 species; mixed forbivorous—8; mixed herbivorous—9; mixed graminivorous—4; and graminivorous—28. As a group, they ranged from monophagous to polyphagous feeders, although most were oligophagous to polyphagous. When grouped phylogenetically, the slant-faced grasshoppers (Gomphocerinae) were found to be primarily grass feeders while spur-throated grasshoppers (Melonaplinae) fed predominantly on forbs; the banded-winged grasshoppers (Oedipodinae) showed less clear-cut tendencies (77). The feeding pattern of an individual species such as *Melanoplus sanguinipes* appears to be inconsistent. It is classified as mixed herbivorous (94), but under some circumstances it is almost omnivorous while at other times it is much more selective. Early instars feed more on forbs while later instars and adults feed increasingly on grasses. Thus, density per se of a population can be misleading without knowledge of the species involved and predominant food habits.

The territory selected by grasshoppers for occupancy (oviposition and feeding) is strongly influenced by vegetation and its density, varying inversely with plant height and shading (6). The Australian plague locust, *Chortoicetes terminifera,* selected ovipositional sites where vegetation did not exceed 15 cm in height and where there was about 50% bare ground and 50% low cover (25). Overgrazing may bring about this condition.

Acridologists agree that fluctuations in numbers of grasshoppers and weather conditions are in some way intrinsically related, notwithstanding the fact that all attempts to show a consistent, direct correlation have been largely unsuccessful. Gage & Mukerji (51) examined 32 years of grasshopper annual survey data in Saskatchewan and used it, along with selected weather variables, to establish trends in grasshopper numbers. Individual year's density ratings were most highly autocorrelated with the previous years' ratings. The correlation decreased the second year and became nonsignificant after three years. Despite differences among individual species, maximum correlation coefficients tended to occur with previous years' weather, and distribution of high density was related to heat units and precipitation. Heat accumulation above 1600° $days_{50}$ (daily maximums above 50°F are additive) during April–June and precipitation less than 10 inches (254 mm) favored higher grasshopper populations. Nerney & Hamilton (98) considered the influence of fall and winter precipitation and subsequent range conditions on spring hatch and survival of grasshopper populations over a 15-year period. In three separate two-year periods, above-average rainfall occurred and the resulting good range forage was accompanied by grasshopper population increases. In each case, during the dry year and particularly during the dry spring that followed, restricted plant growth occurred. Thus, a large spring population drastically decreased by summertime and remained low for two to four years regardless of subsequent condition of the range. Edwards (42) reported a high correlation between grasshopper densities and weather conditions—temperature and precipitation—but he readily concedes that a cause and effect relationship is not proven. Even if such a relationship is assumed, there can be no assertion as to whether it is a direct action of weather on the grasshopper's physiology, an indirect action on the food plants, a differential effect on their predators, parasites, and diseases, or a measure of each.

Surveys of current adult and egg populations have been used for many years in both Canada and the United States for mapping the potential of light, moderate, severe, or very severe outbreaks the following year. However, surveys have never provided the desired degree of accuracy in forecasting. Edwards' (43) critical appraisal of the accuracy of grasshopper forecast maps based on summer adult and fall egg surveys in Saskatchewan for the period 1936–1958 was tested against adult surveys, crop damage reports, and nymphal surveys (the latter for only three of the years). He found that the forecast maps achieved their greatest degree of accuracy (82%) when grasshopper populations were at low levels and the populations decreased slightly from year to year. When they were at the highest levels, the degree of forecast accuracy was no greater than that which could be expected to arise by chance. Nevertheless, a dependable forecast of grasshopper abundance has such profound beneficial implications that this should be a continuing goal of high priority.

In establishing an economic threshold it is important to know not only what but how much a grasshopper eats. When forage consumptions of a grasshopper and of domestic livestock such as a steer are compared, the problem assumes a more pragmatic character, even though many variables must be compromised to achieve a reasonably usable estimate. In caged plot experiments, Putnam (106) calculated that *C. pellucida* at 1/yd^2 (1.20/m^2) during the whole nymphal life destroyed 5.1 lb/acre (5.68 kg/ha) of *Poa pratensis* and that young adults at 1/yd^2 (1.20/m^2) destroyed 1lb/acre/day (1.11 kg/ha/day). However, a 1000-lb steer consuming grass at a rate of 2.0% of his weight per day (28) consumes 20 lb (9.1 kg)/day. According to Putnam's calculation that one adult *C. pellucida*/yd^2 destroys 1 lb/acre/day of grass, a density of 20 grasshoppers/yd^2 (24/m^2) is the grazing equivalent of one 1000-lb steer.

When chemical control of grasshoppers is considered, the final decision should be based on some measure of population density. For many years the Cooperative Grasshopper Control Program of the United States Department of Agriculture (USDA) Animal and Plant Health Inspection Service (APHIS) has employed an action threshold of 8 grasshoppers/yd^2 (9.57/m^2) (13). Therefore, a rapid estimate of population density is needed, even though it may be imprecise. One method used includes all instars of all species that depart from a visually estimated square foot on the ground several paces away. The possibility of considerable error is inherent in this method but is tolerated because of the relatively low cost and speed. For the past several years, grasshopper control programs have most often utilized low volume, aerial applications of malathion.

RANGELAND INSECTS OF REGIONAL IMPORTANCE

Black Grassbugs and Other Plant Bugs

At least two genera, *Labops* and *Irbisia,* are commonly called black grassbugs. They emerged as pests of rangeland in the mountain-intermountain region of the western United States ca 1950 with the initiation of the practice of revegetating native rangeland with exotic grasses, especially wheatgrasses (*Agropyron* spp.). Since that time several species of these mirids have severely damaged the introduced grasses and occasionally the native grasses. They utilize the large plantings both as food and for oviposition. Significant damage by *L. hesperius* has occurred in all eleven western states plus North and South Dakota, the Canadian provinces of Alberta and British Columbia, and the Yukon Territory (123). The damage caused by toxemia and the extraction of plant juices (21) is most persistent in the Intermountain Region. The first record of damage to native grasses was in Montana in 1938 (91). Other species such as *L. tumidifrons, L. hirtus,* and *L. utahensis* are sometimes damaging.

L. hesperius activity occurs primarily during the first three months of spring grass growth. Within its distribution, dense populations as reflected by reported serious damage occur most often at higher elevations, 5000–10,000 ft (1500–3000 m), but sometimes occur as low as 3000 ft (900 m) in elevation. Populations are comparatively sparse on native grasses but may become phenomenally large in areas revegetated with wheatgrasses or other exotics, e.g. $1800/m^2$ in Oregon, $3500/m^2$ in New Mexico, and 990/sweep of a 15-inch sweep net in Utah. Wheatgrass pastures that are not fully utilized provide ovipositional material, winter protection, and a habitat that favors grassbug survival (82). Since most females are brachypterous, dispersal capabilities are limited (50, 58). Another species, *L. hirtus,* is a pest in wet meadows, a habitat entomologists have not examined in detail.

L. hesperius is easily controlled by several different insecticides (46). Management practices have been used experimentally to manipulate populations (82, 134). Parasites and predators have been reported but not yet evaluated (58). The herbicide paraquat, applied at low rates to cure the herbage prematurely in early May, also reduced the population of grassbugs by starvation. Because eggs are laid in dry grass stems, mechanical removal of herbage or selective and heavy grazing significantly reduced grassbug populations.

The occurrence and occasional damage by species of the genus *Irbisia,* including *brachycerus, pacifica,* and *shulli,* has been reported in the USDA Cooperative Economic Insect Report (CEIR)/Cooperative Plant Pest Report (CPPR),[2] but none of these species have approached the economic significance of *L. hesperius.*

The meadow plant bug, *Leptopterna dolobrata,* of European origin, has long been a pest of cultivated grass forage and seed production in the east and midwest United States (101). In 1970 this species together with *L. ferrugata* caused localized injury to range grasses in several Utah counties (115).

Range Caterpillar

The range caterpillar, *Hemileuca oliviae,* occurs at elevations between 4500 and 8000 ft (1350 and 2400 m) in south central and northeast New Mexico and adjacent fringe areas of Colorado, Oklahoma, and Texas. It feeds exclusively on grasses and was long regarded as reaching outbreak numbers only after long intervals, about ten to 30 years. These population explosions would persist for some five to ten years before fading again into obscurity (1, 148). This view has changed in recent years (143). Since an outbreak beginning ca 1960, heavy damage has occurred each year in some area of its distribution. Dense populations of V and VI instar larvae deplete their food supply and accumulate in dense bands as they search for additional food. These bands are referred to as "windrows," and where they occur the last vestige of green grass in their pathway is consumed. Thus, the limited distribution of the range caterpillar belies the total destruction of which it is capable and which it frequently accomplishes in limited areas. Cooperative (between ranchers, state, and federal governments) chemical control programs have been employed most years since 1966 on areas of up to a million acres (405,000 ha) in a single year.

Wildermuth & Caffrey (148) found range caterpillar larvae feeding on about 40 species of grasses. Capinera (24) noted that grasses "possessing the C_4-dicarboxylic acid pathway of carbon fixation (C_4 plants) were preferred and more suitable for larval growth than species possessing the C_3-Calvin cycle pathway (C_3 plants)." Huddleston et al (67) found that at a density of $2/yd^2$ the larvae consumed enough blue grama grass (*Bouteloua gracilis*) foliage to equal the 1975 cost of a chemical control program without assigning any value for a reduced population during the ensuing few years following treatment.

[2]CPPR and its predecessor CEIR published current (weekly) accounts of plant pest activity as submitted by workers in the field through December 1980. It is cited here in the text by year rather than in the *Literature Cited* section because of the excessive number of appropriate citations. This source is used because it related the subject to the rangeland and because it was often the only recent source of information or, in a few cases, the only source.

If the recent discovery of a *Hemileuca* sp. from north of Chihuahua, Mexico, some 400 miles south of the New Mexico infestation, is proven to be a specimen of the range caterpillar, the significance of this pest may increase substantially.

Cutworms, Armyworms, Sod Webworms

Cutworms and armyworms are serious pests of seeded pastures, hay meadows, cereal and feed grains and, to a much lesser extent, of native range grasses throughout the temperate and subtropical regions of the world. Collectively, they are judged to be second only to the Acrididae as competitors for the cultivated and native forage grasses. Unlike most Acrididae, their damage predominates in regions where rainfall is sufficient to support agriculture and the attending growth of seeded pastures, hay meadows, and cereal grains. On occasion, however, they significantly damage native range grasses in areas where rainfall is marginally insufficient for cultivated crops.

The genus *Spodoptera* is worldwide in distribution and may well be the noctuid genus most destructive to cultivated hay and pasture grasses and to a lesser extent to native grasses. *S. exempta* is of particular significance on cereal crops and grasses throughout East Africa (22, 41). Among the several pest species in the United States, by far the most important on cultivated and occasionally on native range grasses is the fall armyworm (*S. frugiperda*). This nondiapausing, tropical-subtropical species overwinters only where host plants are continually available. From points of permanent residence in south Texas and Florida it annually reinvades much of the continental United States and southern Canada, (129, 137).

The CEIR/CPPR each year carries numerous reports of cutworm damage to seeded pastures and meadows throughout the southeast United States and extending west into Kansas and Missouri. Some areas experience heavy damage almost annually and often require chemical control. In 1969, the CEIR carried a report of larval density of $5/ft^2$ $(54/m^2)$ on blue grama rangeland in northwestern Oklahoma. *S. praefica* was heavy on rangeland in Kern County, California (1976), and Malheur County, Oregon (1972). In North Dakota (1979) 610 ha of native prairie and hay meadows were treated for control of the armyworm (*Pseudaleita unipuncta*). This species often is reported to damage seeded pastures and hay meadows in most of the United States east of approximately the 104th meridian.

The sod webworms or grassworms are commonplace on range, pasture (107), hay (110), and turf grasses but are a relatively unknown economic factor on native range grasses. Eight species are associated with grasses grown for seed in eastern Washington (33); the buffalograss webworm, *Surattha indentella,* sometimes causes damage in the Great Plains (127, 128). The 1974 CEIR noted widespread damage by sod webworms to range and pastures. A massive population explosion of *Crambus* spp., including

C. trisectus, occurred in 1974 over much of South Dakota and adjacent parts of North Dakota and Nebraska. Two generations destroyed at least the current year's production on thousands of acres of native range grass and heavily damaged additional hundreds of thousands of acres.

The lesser cornstalk borer, *Elasmopalpus lignosellus,* a sporadic pest of numerous crops, is at least an occasional pest of pasture grasses. The CEIR (1972) reported losses to grass stands from this species in Texas pastures, heavy damage "to 1700 acres (690 ha) of Bahia grass" in California (1970), to "coastal bermuda in Oklahoma" (1977), and "destruction" of 250 acres (100 ha) of ryegrass in Alabama (1968).

Mormon Cricket

Anabrus simplex, an omnivorous feeder, has periodically devastated rangeland and cultivated crops in the western united States since early frontier days. It is essentially an insect of the rugged mountains; however, during outbreaks when unknown factors incite it to aggregate, it moves in great bands into range and crop land (30, 32). It has been reported from all states and Canadian provinces west of approximately the 96th meridian and also from Minnesota. However, as gathered from the various reports in the literature, heaviest damage generally occurs within a radius of ~ 600 km from a point in southeastern Idaho.

Cowan & Shipman (31) calculated that at a density of 0.3 adults/yd^2 (0.36/m^2) the crickets would eat as much per day as ten mature cattle. Presented differently, a band of crickets at 2.27/yd^2 (2.71/m^2) will consume in four months enough forage to carry ten mature cattle for nine months. In outbreak situations they move in bands containing both sexes and all ages. This movement occurs irrespective of food availability or other known stimuli. The bands are variously described as "ten miles long and ¼ mile deep" or from the "area of a city block up to a square mile" (2.59 km^2) at densities ranging up to 500/ft^2 (5400/m^2).

Outbreaks of record, some 26 between 1848 and 1930, have extended mostly over a period of five to ten years. The last major outbreak commenced about 1930, peaked about 1940, diminished through 1949, but began to increase again in 1950 (139). Subsequent potential outbreaks are judged to have been averted by almost annual surveys and follow-up control of nuclei of potential outbreaks. As with other insects that become stimulated to aggregate and migrate, the question remains: Why do they exist as solitary, often harmless, individuals for years and then increase in numbers to form vast migratory bands?

The coulee cricket, *Peranabrus scabricollis,* looks, develops, and behaves much like the Mormon cricket, but its distribution is restricted to Washington, Oregon, Idaho, and Montana and reported outbreaks are less frequent (139).

Beetles

The Coleoptera, the insect order with the largest number of species, are notable in the rangeland ecosystem in that they are relatively uncommon as economic pests. However, their diversity and omnipresence is mute evidence of a substantial, though usually subtle, role.

White grubs, *Phyllophaga* spp., are well-known pests of agriculture in the eastern United States and Canada (105) but are among the most poorly known of the sometimes destructive insects of western rangeland. Over a period of years the CIER/CPPR have occasionally reported white grub damage to range grasses along the broad juncture of the Rocky Mountain region and the western Great Plains from the Canadian to the Mexican borders. It is believed that white grubs are underestimated as range pests. Several possible reasons include (*a*) the multi-year cycle of development and little overlapping of broods, (*b*) the period of apparent inactivity following heavy destruction by last instar grubs, which leaves a feeling of false security, (*c*) the remoteness of many small outbreaks that are not observed by specialists or reported by ranchers, and (*d*) the relatively small area involved at any one location. At least six species are known to cause damage to western range grasses. Heavy damage rarely exceeds several thousand acres (a few thousand hectares) at one location.

Phyllophaga crinita reduced the ground cover of perennial grasses by 88% in localized areas of a shortgrass community in Scurry County, Texas; however, revegetation occurred within three years with good rainfall conditions (136). In a 1980 unpublished report (E. W. Huddleston and others), *P. koehleriana* was found to have heavily damaged some 30 to 50,000 acres (12 to 20,000 ha) and noticeably damaged an additional 200,000 acres (81 thousand ha) of mixed short grass prairie on the San Augustin Plains in Catron County, New Mexico. In this arid region, revegetation by desirable species may require many years, if it occurs at all. The intensity of damage appears to be strongly influenced by drought stress.

Ataenius and *Aphodius* are scarab genera most often thought of as dung feeders, but each contains one or more species that occasionally seriously damages turf grasses in the United States and seeded pastures in Australia. Densities as high as 6000–7000/m^2 have been reported (4, 64, 114).

Termites

Termite occurrence on North American rangeland is restricted to the southwestern United States and adjacent areas of northern Mexico where significant grass defoliation is occasionally encountered. The diet of *Gnathamitermes tubiformans* in a short grass prairie in western Texas consisted primarily of red threeawn (*Aristida longiseta*), buffalograss (*Buchloe dactyloides*,) and blue grama. Living plants were the major food component in spring and early summer, whereas in late summer and fall standing dead plants were the principal components (3). When termites were controlled by spraying ungrazed plots with chlordane, grass production increased by 22% and litter by 50% one year and by 7% and 300%, respectively, two years later (19).

Overgrazing by livestock was found to promote increased termite abundance and damage in South Africa to the point that practically all grass was destroyed (27). In Australia, grass-eating termites are of economic importance only where rainfall is less than 25 inches (635 mm) annually (119).

Harvester and Other Ants

Expectations of greater production from western United States rangelands aroused concern about the consequences of seed harvesting and vegetation clearing around the mounds of harvester ants, especially *Pogonomyrmex occidentalis*. The investigations that grew out of this concern did not agree either on the factors that influence ant abundance or on their general economic significance. For example, Lavigne et al (88) found that colony density was higher on light use and lowest on heavy use pastures. Subsequent findings at a different location in Wyoming showed no significant change in colony abundance at four grazing intensities over a ten-year period; it was shown that soil texture, which facilitated colony establishment, was the most important factor in harvester ant abundance (84). Although seeds comprised 39% of forage particles brought into the colony from a shortgrass prairie, this amount represented only 2% of the available seed biomass (116) and the cleared area around the mound accounted for only a small fraction of the potential plant cover. In one study the maximum cleared area was 27.3 m^2/ha, which was 0.3% of the total (117), and an increase in vegetation around the cleared disk partially compensated for the clearings.

Grass-cutter ants, such as *Atta capiguara* and *Acromyrmex landolti fracticornis*, constitute a significant threat to the cattle industry over much of South America through harvest of grass foliage (47). The range of one species, *Atta texana*, extends into the Edwards Plateau of Texas but is of little economic consequence there.

Thief ants of the genus *Pheidole* are pests of newly seeded pastures in New South Wales (78); funnel ants *Aphaenogaster pythia* and *A. longiceps* hasten the deterioration of overgrazed or otherwise poor pastures and encourage invasion of inferior grasses and deep rooted weeds in Queensland, Australia (118). The imported fire ants, *Solenopsis* spp. (59, 65), are primarily insectivorous, but their powerful sting and sizable mounds, up to a meter in height, make their presence on pasture or crop land highly objectionable.

Range Crane Flies

The larvae of the range crane fly, *Tipula simplex,* have been a localized but intense rangeland problem since frontier days (71, 103), primarily in California where they sometimes denude large areas of grassland. As the value of grazing on rangeland increased during recent decades, accounts of the range crane fly have appeared more frequently, primarily in the CEIR/CPPR. Outbreaks are sporadic, and an extensive one occurred in 1971–1973 in Tulare County, California. In 1978 considerable damage, with larval densities up to 400/ft^2 (3900/m^2), was reported on 40,000 to 50,000 acres in a three-county area in the foothills surrounding the Sacramento Valley.

The European crane fly, *Tipula paludosa,* and other species have long been a problem on pastures in northern Europe where much has been written on their biology, ecology, and control (10). This species was introduced into the United States in the 1960s and has become a pest of pasture and turf in the state of Washington (73).

Grass Seed Insects

Published research has not shown seed insects to be a significant deterrent to the natural reseeding of most perennial rangeland grasses, although some writers (145) have suggested this possibility. However, commercial production of grass seeds for range revegetation and other uses has resulted in a monoculture in which incidental insect species have gained pest status (142). "Grass seed insects" as here interpreted is limited to those that attack the caryopsis or the panicle, to the exclusion of vegetative tissue, and thus excludes most grasshoppers and caterpillars. Four families of insects are credited with most economic damage to grass seeds: plant bugs (Miridae) (81), midges (Chironomidae), fritflies (Chloropidae), and thrips (Thripidae) (141). Plant bugs are implicated as the principal cause of "silver top" or "white ear" (15, 138), although thrips also produce a silver top of a slightly different kind (80).

INSECTS OF BROWSE PLANTS

In rangeland of western North America, browse plants including species of *Artemesia, Amelanchier, Atriplex, Ceanothus, Cercocarpus, Eurotia, Prunus,* and *Purshia* are vital to larger wildlife and are sometimes important for livestock grazing. Moreover, browse plants are an integral component of the range ecosystem, exerting a major influence on the occurrence of native and introduced grasses.

Browse plants have constituted a poorly defined natural resource that has occupied an unclear role in the ranching economy. This fact may account for the absence of detailed biological literature on potentially damaging insects. Control of browse plant insects has not been necessary on a regular or sustained basis. Nevertheless, in specific instances of pest outbreaks, e.g. the mountain mahogany looper (*Anacamptodes clivinaria profanata*) the sagebrush defoliator (*Aroga websteri*), and *Orthezia* scales on *Atriplex* spp., emergency controls, if available, would be justified. Perhaps equally important are insects such as the introduced snailcase bagworm (*Apterona crenulella*), which is sometimes abundant, widely distributed, and locally devastating. Also present are numerous borers, defoliators, and gall formers that impact local browse plant populations and influence the composition of plant communities without causing noticeable pest outbreaks. Insects of all three categories have been reviewed by Furniss & Barr (49). Where browse plants become significant in mine spoils revegetation, insects that destroy their seeds may become important.

MAJOR INTERACTIONS BETWEEN RANGELAND INSECTS AND OTHER ORGANISMS IN THE RANGELAND ECOSYSTEM

Herbivorous insects compete directly and successfully with large wild and domestic herbivores for palatable forage. For example, populations of range caterpillar commonly achieved densities of 5 larvae/yd^2 on range with a grazing capacity of one animal unit/40 acres. Using the average weight of 2 gm/VI instar larva, the weight of larvae, at peak size, on the 40 acres is 4260 lb (1936 kg), a weight near four times the recommended stocking rate of cattle in the infested area. Because of their small size and inconspicuous nature, some plant-feeding insects may be ignored in the assessment of forage consumption. However, Bowers (20) found that insects consumed or destroyed more crested wheatgrass than did cattle present at normal stocking rate. Furthermore, chewing insects frequently clip grasses much closer to the crown than large herbivores, thus reducing carbohydrate storage to critical levels.

The grazing regime may have a significant effect on the numbers and types of insects in a given year and in successive years. A rest rotation grazing system may favor the black grassbug and, in effect, be equal to a year of overgrazing. This can happen because the abundance of old stems provides numerous egg deposition sites and the lack of grazing permits increased survival (82). Because of the high biotic potential of insects, survival rates cannot exceed 1–2% in a population that remains stable from year to year. Thus, a moderate percentage change in survival may result in an explosive population increase in one generation. For example, the range caterpillar has a 1:1 sex ratio and the female lays an average of 120 eggs.

Thus, 60, or one half of the eggs, are female, but in order to maintain a stable population 59, or all but 1.67% of these, must perish. If two females (instead of one), or 3.33% survive, the population doubles in one generation. Whereas rest rotations may enhance populations of some insects, overgrazing may enhance populations of others such as grasshoppers. As a result, grazing studies are incomplete when viewed only in light of livestock numbers and gains, with forage consumption by invertebrate herbivores disregarded.

Because they are closely associated with plants in the evolution of rangeland, insects may have played a significant role in succession and plant species composition. In addition to direct feeding and indirect effects on primary and secondary succession, insects undoubtedly transmit agents of diseases that reduce vigor or kill range plants. As in agronomic crops, insects and nematodes cause both direct damage by feeding on the roots of range plants and indirect damage by facilitating invasion by plant pathogens. This area is almost totally unexplored (125, 131). White grubs, especially in the ecologically fragile rangelands of arid regions, may influence weed and brush invasion by reducing or eliminating competing grasses. If this occurs at a time of drought, noxious plants probably will increase with the advent of increased moisture (23). Recovery from white grub damage may be compared to recovery of abandoned farmland. In a northeastern Colorado mixed prairie, natural revegetation following farm abandonment was described as occurring in 5 stages, and requiring from 29 to 61 years for return to a near climax, mixed prairie association (29). The recovery from white grub damage may be equally slow.

The impact of insects on certain range plant species can produce conflicts of interest, and circumstances that are advantageous to one segment of society may prove detrimental to others. Mesquite, the major factor in reduced grass production on millions of acres in the Southwest, is important as a source of nectar for bees and of domestic firewood, and as a cover for wildlife. Big sagebrush is beneficial as browse and is necessary for survival of the sage hen or sage grouse, *Centrocercus urophasianus,* but it may reduce the carrying capacity of sagebrush-infested ranges by 20–95%. Salt cedar, a phreatophyte, drastically reduces forage production along river bottoms, transpires large amounts of surface and ground water, and serves as food and harborage for grasshoppers that later invade croplands. However, benefits of salt cedar include nectar for honey production and shelter for birds and wildlife. Plant species selected for biological control programs must be reviewed carefully to determine the benefits and losses that would be derived from a successful program.

The amount and frequency of pesticide use in the rangeland ecosystem has been limited when compared with croplands. However, when used, pesticides usually are applied to large areas ranging from 10,000 to 1,000,000 or more acres. Resurgence of the primary pest or emergence of secondary pests has not presented a problem (18). The subtle and long-term effects of pesticide use are unknown; however, no significant adverse effects have been reported in the literature.

MAJOR INTERACTIONS BETWEEN RANGELAND INSECTS AND OTHER ORGANISMS IN AGROECOSYSTEMS

Migratory locusts or grasshoppers are the best known insect pests that multiply on rangeland and migrate to cropland. The disastrous results of locust migrations from the late nineteenth century (113) to the present (CIER/CPPR 1950–1980) are well documented. On a smaller scale, the Mormon cricket is just as destructive. Chinch bugs in the prairie states and false chinch bugs found further west breed and overwinter in range grasses near cultivated crops and migrate to crops during the growing season. Another rangeland insect, the army cutworm (*Euxoa auxiliaris*), plays a unique nuisance role for homeowners, quite apart from the economic destruction of both range grasses and crops by developing larvae. The nuisance occurs when adults are attracted in large numbers to lights in homes.

Certain aphids and leafhoppers that feed on range plants transmit plant virus diseases when they move to and feed on cultivated crops. Sugarbeets, tomatoes, and peppers are susceptible to a disease known as curly top. The virus pathogen is transmitted by the beet leafhopper, which overwinters and multiplies in the spring on range host plants such as saltbush (*Atriplex* spp.), Russian thistle (*Salsola kali*), greasewood (*Sarcobatus vermiculatus*), and filaree (*Erodium* spp.). In May and early June the adults of the first generation may migrate hundreds of miles in great swarms that are attracted to beet fields. Although the insects are easily killed by insecticides, prevention of disease transmission is very difficult because individual insects may inoculate one or more plants upon arriving at a field before the insecticide residue on the plant takes effect (140). Certain aphids, such as the greenbug (*Schizaphis graminum*) and the English grain aphid (*Macrosiphum avenae*), spend the summer on rangeland grasses and return to the grain fields when the crops begin growing in the fall (34, 144).

Wireworms, false wireworms, and white grubs are rangeland species that become especially troublesome when agronomic crops are planted following the breaking of sod.

Blister beetles, the adults of which attack many agronomic crops, are beneficial insects in the larval stage as predators of grasshopper eggs. Controlling grasshopper nymphs on rangeland near agronomic crops has been recommended to reduce the potential for poisoning of horses by blister beetle adults whose larvae feed on grasshopper eggs. The presence of as few as two to five dead blister beetles per bale of hay is sufficient to cause death in horses (120).

The classic example of a rangeland insect that adapted to the agroecosystem is the Colorado potato beetle (*Leptinotarsa decemlineata*), which was described in 1824 from the eastern slopes of the Rocky Mountains where it fed on buffalo bur (*Solanum rostratum*). It remained an obscure insect until the 1850s, when pioneer settlers introduced potatoes to the region. Moving from field to field this insect spread to the Atlantic at a rate of about 85 miles per year (90). The wheat stem sawfly, another native insect of range grasses, also adapted to agronomic crops. It gained pest status on small grains in the northern wheat belt where it has been reported to destroy up to 50% of the crop in certain years (2).

The Hessian fly, an introduced pest of small grains, especially winter wheat, has adapted to *Hordeum pusillum,* a native grass with life habits similar to winter wheat. *H. pusillum* may be capable of maintaining Hessian fly populations in the absence of wheat (79).

Many species of insects that attack crops have a wide host range that includes plants considered to be weeds in the agroecosystem. Although much of the feeding on the undesirable plants may be minor, some of these insects undoubtedly exert a degree of biological control on their weed hosts.

Conversely, many beneficial insects of importance in agroecosystems utilize adjacent rangeland or other uncultivated land for overwintering. These sites are especially important where annual crops are grown in clean culture during the winter months. On the rolling plains of Texas, beneficial insects migrate from cotton fields as the plants mature in the fall and return to the fields early the next summer. Because of this pattern of movement, the fall diapause program of spraying with insecticides for the cotton bollweevil was not found to adversely affect beneficial insect populations (69).

Livestock insects continually interact between the rangeland and the agroecosystems (12). This is manifested both by the insect deriving sustenance, usually blood, from its host, and by transmission of disease-causing organisms. Domestic animals, especially horses, sporadically experience epidemics of such diseases. A classic example is the transmission of the encephalitis virus by mosquitoes that breed in playa lakes, prairie pot holes, etc (68). Other insects, such as black flies and horse flies, transmit disease organisms of certain big game animals in higher elevations of the Southwest (63).

INTEGRATED PEST MANAGEMENT

Throughout history man has benefited from naturally occurring biological control (parasitoids, predators, diseases, natural plant resistance). It remains a principal, though passive, control for most rangeland pest insects (26). Although such controls are insufficient to prevent periodic grasshopper outbreaks (54), they exert a continuing pressure that undoubtedly suppresses potential outbreaks. Agricultural entomology has set the pace for supplemental rangeland insect controls. A long procession of cultural controls (timely cultivation, crop and farm sanitation, crop rotation, improved varieties, etc) emerged as a part of cultivated crop production, but these controls have not been evaluated extensively in rangeland (83, 124). Chemical pest control was developed for agricultural crop production but was easily applied to rangeland insect control. Likewise, the manipulation of heritable characteristics in plants, the foundation of modern agricultural crop production, has wide potential application to range grasses. The idea eventually emerged of combining these approaches, natural, cultural, chemical, and genetic manipulation, into a unified and coordinated effort that became known as IPM. As with its many component parts, IPM was first implemented in cultivated crops. Its application to complex and ecologically fragile rangeland will require an expanded ecological knowledge of and sensitivity to the system (89).

Biological Control

Microbials are particularly attractive for use in rangeland IPM, and encouraging progress is being made in a few areas (132). In USDA studies in Montana, the microsporidian *Nosema locustae* shows great promise against various species of grasshoppers. This pathogen of the fat bodies, pericardial tissues, and neural tissues has been found to infect at least 55 species of grasshoppers (60). Research is progressing on improved formulations, carriers, and methods of application (44, 60, 100). The bacterium *Bacillus thuringiensis* has proven effective against the range caterpillar in New Mexico. Epizootics of the fungi *Entomophthora* (92) and *Empusa* on grasshoppers are reported from widely separated regions of the world, but the environmental requirements for survival and infection are quite restrictive.

There is a wealth of literature, worldwide, on parasitoids and predators of rangeland insects, particularly grasshoppers. Of the many species of parasitoids and predators (108), few have responded to manipulations for rangeland insect control. Perhaps the most notable exception in the United States is the introduced chalcid *Neodusmetia sangwani* in the successful control of the Rhodesgrass mealybug, *Antonina graminis,* in south Texas (35).

Spiders are recognized as generalist predators of insects but because they have not adapted to the oscillations of an individual pest species, they have not distinguished themselves in limiting pest outbreaks. Furthermore, their inability to share a limited space with other spiders of their own or a different species makes them ineffectual in bringing dense populations under control (112). Despite the paucity of measurements on the predatory value of spiders on rangelands, they unquestionably impart a stabilizing influence (135).

Mites of the family Phytoseiidae are widespread and effective predators of phytophagous mites, particularly in fruit culture (76). Since they occur from the arctic to the tropics, it is probable that they inhabit and benefit the rangeland ecosystem.

Many vertebrates (birds, small mammals, reptiles, and amphibians) feed on one or more life stages of a variety of rangeland insects. Most of the available data, on birds for example, are small parts of broader studies (147) and are not presented in such terms as insects consumed/animal/day. Consequently, it is difficult to assign such data an actual or relative value, despite their potentially great impact. Birds are more often reported as insect predators than are other vertebrates, which may be due partly to their higher visibility and aesthetic attributes. Some birds, such as the California gull (*Larus californicus*) in outbreaks of the Mormon cricket and grasshoppers (85) or the starling (*Sturnus vulgaris*) on the grass grub in New Zealand (40), appear to be opportunistic insectivores; even so, they serve, like spiders, as general population moderators.

Mice, shrews, and bats are among the most effective mammal insectivores. The white-footed mouse (*Peromyscus maniculatus osgoodi*), although primarily a vegetarian, is reported to seek out and feed upon egg pods of *Melanoplus differentalis* in North Dakota; the ground squirrel (*Citellus tridecemlineatus tridecemlineatus*) feeds heavily in egg beds of *Camnula pellucida* in Canada. Skunks, coyotes, and badgers are also insectivores, feeding, for example, on the range caterpillar (148).

Reptiles and amphibians are general feeders on ground-dwelling insects. Although their role in insect population dynamics is poorly known, Whitford & Bryant (146) noted that densities of the Texas horned lizard (*Phryonosoma cornutum*) were regulated by the availability and productivity of harvester ants, *Pogonomyrmex* spp.

Cultural Control

Experimental cultural control procedures are being developed for certain rangeland insects. As mentioned earlier, Kamm & Fuxa (82) found several such procedures to reduce black grassbug damage. Conversely, an application of nitrogen resulted in increased numbers (134). Bellows et al (17) found that range caterpillar eggs decreased by 82% when grazed by 0.10 sheep/ha during December–March and 1.2 sheep/ha during April. This compared to only 44% disappearance on an ungrazed exclosure and suggested that winter grazing should be considered as a feature of IPM. Dixon & Campbell (38) found fewer grass grub (*Costelytra zealandica*) larvae where animals had grazed and trampled the soil than in ungrazed pastures. Jensen (75) and Ostlie (102) reported finding fewer injurious insects in heterocultures than in monocultures of grassland.

Biological Control of Weeds

Weeds are widely accepted as the paramount pest problem in successful ranching. Chemical or mechanical control are options for certain areas, but as a general range improvement practice the cost effectiveness may become critical. Biological control through the importation of host-specific insects and plant pathogens is a viable alternative in numerous instances, particularly against introduced or naturalized weeds (8, 150). It is essential, however, that the target plant be regarded as undesirable throughout the potential distribution of the biological control agent, because the agent's spread and abundance cannot be controlled once it has been introduced. Some of the most costly range weeds, e.g. sagebrush, mesquite (*Prosopis juliflora*), broomweeds (*Gutierrezia* spp.), creosotebush (*Larrea tridentata*), and juniper, (*Juniperus* spp.), are native but are not regarded as undesirable throughout their range. Broom snakeweed (*Gutierrezia sarothrae*) is attacked by borers and other insects (111) and is considered by DeLoach to be the most acceptable native weed for biological control (37).

Classic examples of biological weed control include the control of *Opuntia* spp. in Australia by *Cactoblastis cactorum*, an introduced caterpillar from South America (39), and St. Johnswort or Klamath weed (*Hypericum perforatum*) by *Chrysolina* spp. in California where complete success occurred (70). Variable success has been experienced in neighboring states and provinces to the north and northeast (56, 133). Active research is under way on a number of other introduced range weeds, e.g. release and successful establishment of a gall-producing fly, *Urophora affinis*, on spotted knapweed (*Centaurea maculosa*) in Montana (11, 130) and release, successful establishment, and promising results from three seed-head weevils (Curculionidae) against several species of *Carduus* and *Silybum* (14, 86, 109). Two lepidopterons were successfully established and aggressively attacked Russian thistle (*Salsola iberica*); however, the host density was not reduced (53).

The introduction of insects for the biological control of *Lantana camara* has proceeded intermittently since 1902 at widely separated points around the world, e.g. Hawaii, Australia, and South Africa, with varying degrees of success. Also, since 1935, efforts have continued to establish biological control of tansy ragwort (*Senecio jacobaea*), a range/pasture pest found in New Zealand, Australia, Canada, and the United States. Interest has focused largely upon the cinnabar moth, *Tyria jacobaeae,* and the ragwort seed fly, *Hylemya seneciella,* but success has been limited (48). The fleabeetle (*Longitarsus jacobaeae*) in conjunction with these other species has given good control in areas of California and Oregon (57). The rush skeletonweed (*Chondrilla junceae*), an aggressive composite of Eurasian steppe origin, has gained entry into and is widely distributed in Australia and the northwestern United States. Biocontrol agents under study in both countries include a gall midge, *Cystiphora schmidti,* an erophyid gall mite, *Aceria chondrillae,* and the plant pathogen *Puccinia chondrillina* (149). These are part of an IPM research project currently underway in Idaho, Oregon, and Washington (45, 126).

Host Plant Resistance to Insects

Heritable genetic variation, a major resource for the improvement of insect resistance in range grasses, remains largely untapped. Variations in resistance to range and pasture grass insects have been observed and reported over many decades (96, 97). Considerable effort has gone into selecting for agronomic qualities among native and exotic range grasses, but any resistance to insects that may have resulted was largely incidental to other objectives. Evidence in the literature of a major commitment to breeding for insect resistance among range grasses has yet to emerge; however, greater emphasis is beginning to be devoted to this area (16). The rewards for such a commitment should be fruitful because within the past decade the occurrence of resistance among grasses to no less than 26 pest species representing seven orders of insects has been reported in the entomological literature.

Chemical Control

Chemical insecticides have been used on rangeland largely to control grasshoppers and, to a lesser extent, such species as the Mormon cricket, range caterpillar, and black grassbug. Highly persistent insecticides have given way in recent years to those with a short residual (74, 99, 122).

The use of broad spectrum insecticides, even nonpersistent ones, in an IPM program calls for a deeper commitment to the establishment of the economic threshold for the various destructive range insects. When this is accomplished, several advantages emerge; possible avoidance of an unneeded application of insecticide, the opportunity to limit treatment to "hot spots," savings on insecticide use, and protection of beneficial and other nontarget organisms. Various natural and synthetic repellents and attractants have been investigated in rangeland pest control research; for example, adult grass grub attraction in New Zealand (87) and sex pheromones for the fall armyworm in the United States (121). Attractants and phagostimulants for control and population estimation of grasshoppers are being studied in North Dakota (95). These and other innovative approaches to control are still experimental.

None of the innovative approaches to rangeland insect control—fungal, bacterial, viral, attractants, repellents, genetic, etc—have been fully exploited, nor is it likely that any one or even a combination of them will completely replace chemical insecticides. However, the application of IPM principals to rangeland appears to be environmentally safe and both economically and scientifically sound. Such an IPM program was initiated on 760,000 acres infested with range caterpillar in northeastern New Mexico in 1980 (66). The program utilized intensive scouting, cooperation of ranchers and Cooperative Extension Service personnel, evaluation of biotic components, population dynamics models, and pesticide application based on economic thresholds and coordinated by the New Mexico Department of Agriculture and USDA APHIS. Pesticide use was reduced and low density populations of range caterpillars were preserved as potential hosts for continuing biotic control agents. Application of the IPM approach to grasshopper management is a logical extension of this work.

CONCLUSIONS

Rangeland insects belong to numerous taxa with diverse food habits and niche adaptations that only recently have been looked upon as a coherent entity. The rangeland ecosystem, when compared with an agroecosystem, is both complex and fragile. Grasshoppers are a worldwide problem on rangelands, and the need continues for a means of successful outbreak forecasting. A refined understanding of host plant selection and of the influence of weather and climate, not only on the grasshopper itself but also on its host plants, parasitoids, and predators, is central to that question. The present need for major reliance on chemicals for grasshopper and other pest insect control is tenuous, and alternatives and supplemental control methods are being pursued. Progress is being made in the use of microbials, and the many faceted array of parasitoids and predators would seem to offer further opportunity for favorable manipulation to suppress the major population fluctuations commonly experienced.

Most other pest insects are of regional or local importance and sporadically are quite devastating. Effective chemicals for many of these are available. Research on integrated contol techniques for some pests (range caterpillar, black grass bug, and Rhodesgrass mealybug, for example) has been sufficiently promising to encourage further development of these management techniques. Some pests, such as armyworms, cutworms, sod webworms, and white grubs never have had an adequate appraisal of their long-term impact on rangeland, which may be quite substantial. The role of others, such as leafhoppers and root- and crown-feeding aphids, mealybugs, etc, never has been appropriately evaluated, although these insects are sometimes present in very large numbers.

Grass seed insects occupy a unique position because their influence on the range is largely indirect. They are in fact not so much rangeland as crop insects where grass seed is produced in monoculture to revegetate depleted rangeland.

Browse plants fill a critical role in the modern range ecosystem, and insects influence these plants at various levels of intensity and in a variety of ways. IPM programs for rangeland must consider the browse plant component, the inclusion of which will require a greatly expanded biological and ecological data base.

Rangeland weeds present an enduring problem of encroachment on rangeland. Although chemical and mechanical controls may be useful in restricted areas, they are not broadly cost effective as a range improvement practice. Biological control (with insects, mites, plant diseases etc) has been employed with considerable success against some introduced weeds. Research in this area should be continued; in addition, control of native weeds needs to be explored and selective controls sought for those weeds where there are conflicts of interest.

Genetic manipulation of range grasses for pest resistance is now emerging to take advantage of a resource long observed to exist. This resource, together with the prudent use of selective insecticides and the preservation and enhancement of natural enemies, offers new scope for integrating management practices for the suppression of insect pest populations.

Both the removal of undesirable plants and the overseeding of desirable grasses may be expected to upset certain self-regulating balances and to lead to different pest problems. Such possibilities should not discourage innovation but should encourage more exhaustive investigation.

Public rangelands are now called upon to serve numerous diverse and sometimes conflicting interests. Each interest that is recognized as legitimate must be allowed appropriate representation and integrated with the interests of traditional ranching. In addition, these interests must be integrated with existing and evolving IPM strategies for the fullest use of rangelands. The building and employment of predictive models are likely to find broad application for both resource production and allocation and pest management. To enhance multiple land use goals it is essential to move from a single control strategy, often introduced in response to pest outbreaks, to one that maintains pest populations at noneconomic levels with minimal environmental impact. The basic structure of IPM, as developed for crop systems, can be adapted to this end.

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