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The Economic Threshold for Grasshopper Control on Public Rangelands

Robert M. Davis, Melvin D. Skold, James S. Berry, and William P. Kemp

The U.S. Department of Agriculture's Animal and Plant Health Inspection Service (APHIS) is responsible for controlling grasshopper populations on public rangelands. Under current guidelines, control of grasshoppers on rangeland should occur if grasshopper densities are at least eight per square yard. This article evaluates the concept of an economic threshold relative to the value of forage saved from destruction during a grasshopper outbreak. It is shown that financial justification for treating grasshopper outbreaks depends upon grasshopper density, rangeland productivity, climatic factors, livestock cost and return relationships, and the efficacy of treatment options.

Key words: benefits and costs, economic threshold, grasshopper control, range economics.

Introduction

Recurring grasshopper outbreaks are a problem to rangeland management in the western U.S. Severe outbreaks can inflict damage on the quality of the rangeland and on cultivated crops as well. The persistence and severity of damage from grasshoppers has resulted in a U.S. Department of Agriculture (USDA) control program; the Animal and Plant Health Inspection Service (APHIS) is authorized to implement publicly supported control programs on rangelands. An average of over two million acres is treated annually; the acreage treated varies between zero and over 13 million acres per year. The area treated is about evenly divided between public and private land. Conditions favorable to large hatches of grasshoppers tend to be associated with dry years, but entomologists have not had much success in predicting the extent and location of any grasshopper outbreak (USDA).

APHIS intervention in the management of grasshopper populations is based on an economic threshold of eight grasshoppers per square yard, which has been applied for over 50 years (Parker). This nominal intervention level is applied regardless of the value of the crop to be protected or the productivity of the rangeland. Program managers do exercise a considerable amount of judgment and discretion before treatments are employed, however. If, in response to an inquiry from resource users or managers, APHIS personnel determine grasshopper densities exceed eight per square yard, the delimited area of the outbreak is considered for treatment with one of several approved control practices. For range forage protection, the area of outbreak generally must include at least 10,000 acres.[1] To date, most control options involve the application of chemicals. If treatments are on federal land, APHIS bears 100% of the treatment costs. If states have cost-share arrangements, APHIS will cost-share for one-half of the cost for treating state lands and one-third of the cost for private lands.

Publicly supported control programs were initiated to protect rangelands from degradation due to damage by grasshopper infestations. Because public costs are associated with controlling grasshopper populations, there is concern about environmental effects of chemical control practices. Special support has been directed toward a Grasshopper Integrated Pest Management (GHIPM) project (APHIS 1987). The GHIPM seeks more economically justifiable and less environmentally degrading grasshopper control practices. Consequently, the GHIPM must consider both (*a*) the adequacy of the economic thresholds for publicly supported control measures and (*b*) the extent to which all costs and benefits associated with

Robert Davis is a graduate research assistant and Melvin Skold is a professor in the Department of Agricultural and Resource Economics, Colorado State University. James Berry is a research ecologist and William Kemp is a research entomologist with the U.S. Department of Agriculture, Agricultural Research Service, Rangeland Insect Laboratory, Bozeman, Montana.

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those control practices are considered. The latter, specifically, includes evaluation of the environmental effects of grasshoppers and their control.

This article addresses only the economic threshold concept as it presently is applied. It is based on an analysis for the Little Missouri National Grasslands (LMNG) but the results can be extended to similar portions of the Northern Plains. The direct benefits (damage prevented) from treatment are contrasted with the direct costs of treatments. External benefits and costs, which may accrue over time and space, are not directly evaluated.

The analysis presented here does not consider the benefits of grasshopper control treatments to last beyond the current year. No empirical evidence exists to support multiple-year effects of treatments; in fact, the lack of multiple-year effects from control programs is reported (Blickenstaff, Skoog, and Daum; Hewitt and Onsager 1983). Even though other entomologists suggest that multiple-year effects are present (Pfadt) and that private landowners expect multiple-year suppression, only current-year mortality of treated grasshoppers is evaluated by existing control programs and by this analysis.

Costs also may involve damage to nontarget species, threats to human health, and imposition of an undesired imbalance in the ecosystem. While research on some of the external costs is being pursued, the current lack of data prevents the evaluation of grasshopper treatment effects on physical and biological systems.

Torell and Huddleston, and Mann, Pfadt, and Jacobs have reported economic evaluations of rangeland grasshopper control programs. Torell and Huddleston concluded that the economic basis for control depends on the potential value of forage saved, treatment cost, treatment life, treatment efficiency, and pest population dynamics. Mann, Pfadt, and Jacobs developed a simulation model to compare conventional insecticides with wheat bran treatments for controlling grasshoppers. This analysis builds on the contributions of these authors.

Under the GHIPM project, a prototype expert system (HOPPER 1.0) for treatment selection was developed by Kemp, Onsager, and Lemmon to assimilate and integrate current information into a useful management tool. This expert system used a simple economic analysis based on pesticide efficacy, grasshopper densities, and forage value. Berry, Kemp, and Onsager refined the expert system for treatment selection and enhanced the economic analysis with simulation models in a decision support system (DSS) called HOPPER (version 3.0).

Grasshoppers have only one generation per year in the Northern Plains of the United States. Adults of entomologically defined species of economic importance lay eggs in the soil in late summer and early fall; nymphs hatch from these eggs in late spring and early summer of the following year. The newly hatched nymphs are very small, do not consume much forage, and are very susceptible to mortality factors. Grasshopper densities decline through the summer as the nymphs mature through five development stages and reach the adult stage. Their development rates are faster at higher temperatures. Grasshoppers consume increased amounts of forage per day as the insects develop into the larger life stages. Also, consumption varies with grasshopper and plant species. Therefore, forage destruction depends on the number of grasshoppers present, grasshopper life stage, when grasshoppers appear in relation to forage growth, and grasshopper mortality (Onsager).

The inherent productivity of rangeland is quite variable in an area as vast as the Northern Plains. Because costs for a given treatment vary in almost direct proportion to the area treated, it is important to recognize the forage-producing capacity of the rangeland.

Given the inherent productivity of rangelands, the primary determinant of the forage production is precipitation (Wight and Hanks; Wight, Hanson, and Whitmer). An infestation of grasshoppers during a year in which precipitation and range forage are ample has less impact on the ranch operation and profitability than an equal infestation in a year of limited rainfall and forage. The analytical system applied here utilizes a simulation model of the range forage–grasshopper–ranch system that includes the effects of site potential and precipitation. It serves to demonstrate how the financial criteria for initiation of APHIS action to control grasshopper populations on public lands depend on a combination of physical, biological, and economic conditions.

The simulation of the range forage–grasshopper–ranch system is designed to facilitate the management of public rangelands and the application of grasshopper control programs. Resource managers can use the simulation model to evaluate whether or not a given circumstance of range forage availability, livestock cost and return relationships, grasshopper densities, and the cost of alternative sources of forage can justify initiation of treatments to control grasshoppers. Further, given the species and age composition of grasshoppers present, evaluation can be made to determine which of the several treatment options is most financially justified.

The incidence of grasshoppers, the damage grasshoppers cause to the resource base, the benefits which users of the resource receive from its use, and the efficacy of treatments applied to a grasshopper population are dependent on a large number of deterministic and random variables. The analytical system described here is capable of addressing most of the important variables in the forage–grasshopper–ranch system. Climate, which is one of the parameters allowed to vary here, is but one of a number of random variables. Other important random variables include: grasshopper species composition (different species have varied eating habits), treatment efficacy, percent calf crop, and soil water.

Because precipitation is so important to determining year-to-year variation in production from western rangelands, it is the variable chosen to be varied. Climate affects range forage production, grasshopper egg hatch, natural grasshopper mortality, and the efficacy of alternative treatments. Several climate and climate-related variables enter the analysis including: quantity of precipitation, frequency of precipitation, degree days, soil temperature, and soil water. Of these, only the quantity and frequency of precipitation are varied; simulations show the model to be most sensitive to these variables. All other climate-related variables are held at their 40-year mean values. When below normal precipitation is simulated, the frequency of significant precipitation is reduced to a situation for which accumulated precipitation is 21% less than the 40-year mean value.

Purpose

This paper proposes a new method for evaluation of public agency intervention in the control of grasshoppers on public lands. As an alternative to the discrete-choice threshold of eight grasshoppers per square yard, an analytical system was developed to evaluate suitable treatment options which are dependent upon the set of climatic, biological, and economic conditions prevailing at the time a treatment decision is being considered. The analytical system is a simulation model that can be used by a manager of a unit of public land or by an individual in charge of implementing the control program. The analytical system will be used to demonstrate how inherent rangeland productivity, climate, and grasshopper densities do affect the benefits and costs of treatment alternatives. The analytical system is capable of simulating the effects of a large number of other important variables which are not discussed here. While consideration of these variables would serve to further demonstrate the usefulness of the analytical system over the discrete-choice criterion, the sensitivity of financial justification for treatment to several important factors is demonstrated by the results presented.

Economic Threshold

The applied economic threshold for rangeland grasshoppers is a discrete-choice measure (Plant). When grasshopper densities exceed eight per square yard, steps to implement control practices begin, often regardless of rangeland productivity, forage and livestock prices, and characteristics of the insect population. An economic threshold or the entomologists' concept of an economic injury level (EIL) is the level of pest population at which the damage from pests becomes equal to the cost of control (Stern et al.; Headley 1972a; Hall and Norgaard; Hall and Moffitt; Mann, Pfadt, and Jacobs). Conceptually, the economic threshold is a variable dependent on benefits and costs. Although some have argued that a discrete-choice threshold is adequate for control of grasshoppers on rangeland (Torell and Huddleston), an important goal of the GHIPM is to improve upon the discrete-choice threshold as presently practiced. Rather, the economic threshold should vary with the amount and value of forage saved and the cost of saving that forage from destruction by grasshoppers. Economic justification for treatment may depend on rangeland productivity, livestock prices, the accessibility and cost of alternative sources of forage, and the cost, effectiveness, and timing of treatments to control grasshopper populations.

Analytical Framework

The simulation model (HOPRAN) developed to evaluate the benefits and costs of controlling grasshopper populations on public rangelands involves three major components. The first component simulates range forage production on the Northern Great Plains. For a given soil and range type, the RangeMod model is driven primarily by daily precipitation (Berry and Hanson). Temperature determines when spring forage growth is initiated and when plant maturity occurs.

The second component simulates the effects of grasshopper infestations on range forage availability. The grasshopper population dynamics model, HopMod, is based on the observed response of grasshoppers in rangeland and laboratory environments (Kemp and Berry). As a specific species mix of grasshoppers (species vary as to feeding habits and the type and amount of forage destroyed) is given, levels of forage destruction are determined. Grasshopper populations also are affected by temperature (Kemp and Onsager). HopMod estimates the forage destruction by grasshoppers as they move through various nymphal stages to adult, given the temperature and natural mortality (Hewitt; Hewitt and Onsager 1982; Onsager; Parker). As grasshopper densities increase, an annual forage loss occurs for each unit increase in grasshopper population per square yard (Hewitt and Onsager 1983).

In addition to the dynamics of grasshopper populations and their associated feeding habits, HopMod also simulates the efficacy (mortality rates) of available treatment options. Grasshopper mortality and residual densities depend on the treatment applied, the time and method of application, and the efficacy of the application. Grasshopper mortality resulting from a treatment is based on the expected efficacy observed from large numbers of treatments. As grasshopper densities are reduced, forage is saved for use by the ranch operation. HopMod and RangeMod interact to determine the treatment appropriate for conditions encountered with respect to grasshopper species, life stage of grasshoppers, canopy cover, proximity to water, and other factors which help to determine the choice of treatments.

The third component of HOPRAN is a ranch decision model. RanchMod is a linear programming model of a typical ranch utilizing the Little Missouri National Grasslands (LMNG) in western North Dakota. The model is used to determine the impacts on ranch income resulting from destruction of forage by grasshoppers. RanchMod is based on the amounts, types, and productivity of land available to ranchers in the area and also depicts the livestock herd management practices common to the area.

The typical ranch includes 1,505 acres of private land contiguous to the LMNG allotments utilized (Carson). Over one-half of the ranch's animal unit months (AUMs) come from public rangeland; the remainder are derived from hay produced on the ranch, from private rangeland, and a very small amount from crop residue. Native hay production (265 acres) provides for winter feed requirements, while the LMNG are utilized for summer and fall grazing. Crop residue from harvested hay land provides a small number of AUMs of forage for late fall grazing.

All LMNG land is leased by a grazing association; the current lease rate is \$2.86/AUM. The typical ranch's lease includes 3,120 acres of Forest Service land and 150 acres of state land. The average forage production is 924 pounds per acre. Typically, allotments on the LMNG provide forage for livestock for eight months of the year (Carson). Cattle are placed on the lease beginning 1 May and remain until 31 December, when they are returned to private land. The length of the grazing season varies depending on the condition of the range, soil moisture content, grasshopper densities, etc. A preliminary estimate of the carrying capacity of the range is generated annually, as is the AUM price charged to the permittee (Obermiller and Lambert). Based on assumed range condition classifications, carrying capacity on the LMNG ranges from 3.3 acres per AUM for poor and fair classes to 2.2 acres per AUM on good and excellent classes of rangeland (Shaver; Carson). Proper use factor adjustments are made so that overgrazing of total forage produced on the rangeland does not occur.

Livestock are fed during December, January, February, and March from the stocks of native hay produced on the ranch. One ton of native hay provides the equivalent of 3.3 AUMs of forage and a yield of one ton per acre is assumed to arrive at 874.5 AUMs. Crop aftermath grazing provides 13.25 AUMs and is based on 20 acres of aftermath per one AUM (Burns et al.).

The typical ranch is a cow/calf operation with a base herd size of 200 cows. Retention of replacement heifers allows the maintenance of a constant herd size. The assumptions for the base cow herd are for a 90% conception rate and a 95% birth rate from those females which conceive, giving an 85.5% calf crop equally divided between steers and heifers. There is a 3% death loss for cows. Weaned steer calves are sold (\$95/cwt); heifer calves not retained for herd replacement are also sold (\$90/cwt). A 35% culling rate is assumed for replacement heifers (Ensminger); thus, of the 40 retained, only 26 will enter the base herd as brood cows. Cull replacement heifers, cull cows, and bulls also are sold at representative market prices.

As grasshopper densities increase and destroy available forage, alternative sources of forage for the livestock must be found. RanchMod considers two alternative sources of forage: purchased hay and leased private rangeland. Hay may be purchased for \$100 per ton. Alternatively, as on-ranch grazed forage becomes limited, ranchers using the LMNG often move their livestock to other leased rangeland. While the location and availability of such forage may vary from year to year, this range-leasing practice is included in the model. It is assumed that up to 25% of the ranch's base monthly grazing capacity can be leased by the month within 50 miles of the ranch. Another 25% of grazing capacity can be leased within 150 miles, and an unlimited amount of grazing land is assumed to be available beyond 150 miles.[2] The private lease rate reflects the base lease rate of \$8.50 per AUM (Joyce) plus a distance-dependent transportation charge to the leased pasture and an additional veterinary expense for the livestock on off-ranch leased rangeland. Ranch labor requirements also increase with the herd more distant from the ranch headquarters.

The RanchMod model assumes that the rancher will consider only adjustments which hold the cow herd size constant. Adjustments are limited to buying hay or leasing private rangeland. While herd-size adjustments might occur, it is expected that they would result only from prolonged forage deficits associated with drought and/or range pests.

Analyses Conducted

Simulation of the range forage–grasshopper–ranch system begins with the range forage model, RangeMod. Two levels of annual precipitation, below normal and normal, are considered and the resulting forage supplies are determined. RangeMod considers precipitation as a function of two parameters: (*a*) the percentage of days during a period of time in which measurable precipitation is received, and (*b*) the average amount of precipitation per event. The below normal precipitation level represents a level for which 21% less precipitation is received than the normal amount (long-term average). Associated with each of the two precipitation levels, four levels of grasshopper infestations are imposed through HopMod: 8, 16, 32, and 40 grasshoppers/square yard (GH/YD²). Six grasshopper treatment options, including no treatment, are evaluated under each rangeland productivity, precipitation level, and density condition. Treatments are assumed to be applied on 15 June; at that time most grasshoppers are in the fourth instar (development stage). Treatments vary as to the immediacy and extent of mortality to the grasshopper population. Consequently, variation exists among treatment options as to how much forage is saved.

Several options are available for grasshopper control. One option is to do nothing; the base simulation assumes that no treatment is applied. If chemical treatments are used, four alternatives are approved: acephate spray, carbaryl bait, carbaryl spray, and malathion spray. A final treatment choice is to use an approved biological control agent, *Nosema locustae. Nosema locustae* is a pathogen which results in morbidity and death to grasshoppers and Mormon crickets. In practice, the choice of treatments is decided by the time of year, age and species of the grasshopper population encountered, the nature of the area to be treated, and the cost of the chemical and its application.

The RangeMod–HopMod interaction results in varied levels of forage available for livestock on the typical ranch. The amount of forage available becomes input to the ranch decision model, RanchMod. Solution of RanchMod provides ranch net returns and alternative sources and values for range forage, given the productivity and cost characteristics specified for the range–livestock economy. Benefits are evaluated as damages abated (Headley 1972b). Damages abated is calculated as the difference in ranch net returns with a given treatment and the no treatment case. The benefits from control are then evaluated relative to the cost of the approved treatment alternative and financial benefit-cost ratios are estimated.

Competition from Grasshoppers

As grasshopper densities increase, they become increasingly competitive with livestock for available forage. Each one-unit increase in grasshopper density per square yard results in the destruction of an average of about 18.2 pounds of forage per acre. Forage destruction varies by species and age. There is some density-dependent mortality among grasshoppers (Onsager) which is not presently recognized by HopMod. HopMod utilizes an assumed mix of grasshoppers which includes 25% grass feeders (*Aulocara elliotti*) and 75% mixed feeders (such as *Melanoplus sanguinipes*). Such a species mixture may be present on the Northern Plains. Given precipitation-dependent forage production from RangeMod and forage destruction associated with a representative grasshopper population in HopMod, the amount of forage available to the ranch becomes input into RanchMod.

Results

Damages Abated

As increasing densities of grasshoppers compete with livestock for available forage, ranch net returns are adversely affected. Damages abated are taken as the difference between net returns on a typical ranch for a given treatment case and net returns when no treatment occurs. Thus, damages abated are calculated as:

$$DA_{t,d,c} = NR_{t,d,c} - NR_{0,d,c}, \tag{1}$$

where $DA_{t,d,c}$ = damage abated for treatment t ($t = 1, 2, \ldots, 5$), grasshopper density d ($d = 0, 8, 16, 32, 40$), and precipitation level c (c = normal, below normal); $NR_{t,d,c}$ = typical ranch net returns with a specified treatment; and $NR_{0,d,c}$ = typical ranch net returns with no treatment and specific grasshopper density and precipitation condition. The calculated damages abated for each treatment, DA_t, reflect the unique characteristics of each treatment and the immediacy and extent of mortality it causes to the grasshopper population. Treatments which act fast and result in high rates of grasshopper mortality provide larger damage abatement estimates than do treatments which provide a slower and lower mortality response.

As grasshopper densities increase, ranchers are forced to obtain alternative, more costly forage to replace that destroyed by grasshoppers. Paying more for forage increases their costs and, as a result, net returns decrease. For this typical ranch, options are present to lease grazed forage at varied distances from the ranch or to purchase hay. However, leasing even the most distant grazing forage is preferable to purchasing hay as a replacement for grasshopper destroyed forage. Cost-ranging analysis indicates that hay would have to be purchased at less than $45 per ton before it would become competitive with leased grazed forage.

Treatment Costs

Treatment costs also vary. Recent per-acre costs experienced are: acephate spray, $2.47; carbaryl spray, $3.50; carbaryl bait, $4.50; malathion spray, $2.25; and *Nosema locustae,* $4.75 (APHIS 1990). Total costs of treatment change in direct proportion to the area which must be covered to protect a specified amount of forage from destruction by grasshoppers. For example, on the LMNG some of the more highly productive rangeland requires only 2.2 acres per AUM. Other, less productive rangeland requires 3.3 acres per AUM. Consequently, treatment costs depend on the treatment selected and the area which must be treated to protect one AUM of forage from destruction. So,

$$TC_{t,p} = \$/AC_t{*}AC/AUM_p{*}AUM, \tag{2}$$

where $TC_{t,p}$ = treatment cost for the rangeland on a typical ranch for treatment t, and rangeland productivity level p (p = highly productive, less productive); $\$/AC_t$ = per-acre treatment cost for treatment t; AC/AUM_p = rangeland productivity level p; and AUM = total AUMs of treated rangeland forage on the typical ranch.

Benefit/Cost Ratios

Costs are incurred in the current year and only current year damages abated are considered. Consequently, when the results are presented as benefit/cost (B/C) ratios, financial justification for treatment is identical to presenting the results in the economist's preferred net benefit criterion. The B/C framework criterion is applied for purposes of communication with a broader readership, many of whom use B/C ratios to evaluate resource use decisions. From the damages abated in (1) and the treatment costs in (2), B/C ratios can be estimated. The ratios in table 1 are derived by:

$$B/C_{t,d,c,p} = DA_{t,d,c}/TC_{t,p}. \tag{3}$$

The analysis does not distinguish who receives the benefits, which are private, or who bears the costs, which are public. Rather, the resulting benefits from treatments are compared to the costs incurred. Consequently, the analysis can apply to any land ownership circumstance, whether federal, state, or private land. The economic B/C analysis evaluates the economic threshold—the level of pest population at which the benefits from control accruing to the ranchers are equal to the cost borne by the USDA, i.e., B/C = 1.0.

The B/C ratios from table 1 are plotted against grasshopper densities in figures 1–4. Figures 1 and 2 relate to the below normal precipitation condition for the two rangeland productivity levels; figures 3 and 4 correspond to figures 1 and 2, but for normal precipitation. It is instructive to make comparisons on the basis of rangeland productivity, precipitation condition, and between treatments.

If below normal precipitation conditions are present, the highly productive rangeland can be economically justified for treatment with grasshopper densities of 13–14 GH/YD^2. The treatments with the highest B/C ratios at these relatively low densities are the chemical sprays malathion, acephate, and carbaryl, in order. The economic threshold for less productive rangelands is not achieved until grasshopper densities of 17–18 GH/YD^2 occur (figure 2). Similarly, differences in the economic threshold for treatment can be observed between the rangeland productivity levels under normal precipitation. The B/C = 1.0 at about 23–24 GH/YD^2 on the highly productive rangeland, but not until densities of 28–29 GH/YD^2 are reached on the less productive rangeland (figures 3 and 4, respectively).

When the availability of forage is already limited by below normal precipitation, economic justification for grasshopper treatments occurs at lower grasshopper densities than under normal precipitation conditions. In table 1, the differences between B/C ratio columns one and three or columns two and four reflect the effects of precipitation on the rationale for treatment intervention. Either acephate or malathion sprays can be economically justified on the highly productive rangeland at 16 GH/YD^2 when precipitation is below normal, but neither can be justified at that grasshopper density when precipitation is normal.

As grasshopper densities increase, the B/C ratios tend to increase. However, a departure from this pattern occurs when precipitation is below normal, and carbaryl bait or *Nosema locustae* is applied to grasshopper densities beyond 32 GH/YD^2. Apparently, as grasshopper densities increase, the damage abated does not increase proportionately. With no treatment and below normal precipitation, typical ranch net returns fall only a relatively small amount as grasshopper densities increase from 32 to 40 GH/YD^2. With 32 GH/YD^2 and below normal precipitation, ranchers are forced to secure nearly all of the

Table 1. Benefit/Cost Ratios for Grasshopper Controls by Range Productivity, Precipitation Condition, Treatment, and Grasshopper Density

Treatment/ Grasshopper Population	Benefit/Cost Ratio When: Below Normal Precip. 2.2 ac./AUM	Below Normal Precip. 3.3 ac./AUM	Normal Precip. 2.2 ac./AUM	Normal Precip. 3.3 ac./AUM
Acephate:				
8 GH/YD^2	.36	.24	0	0
16 GH/YD^2	1.34	.89	.09	.06
32 GH/YD^2	3.79	2.53	1.90	1.27
40 GH/YD^2	3.87	2.58	2.79	1.86
Carbaryl Bait:				
8 GH/YD^2	.20	.13	0	0
16 GH/YD^2	.69	.46	.05	.03
32 GH/YD^2	1.78	1.18	1.05	.70
40 GH/YD^2	1.67	1.12	1.53	1.02
Carbaryl Spray:				
8 GH/YD^2	.25	.17	0	0
16 GH/YD^2	.95	.63	.06	.04
32 GH/YD^2	2.67	1.78	1.34	.90
40 GH/YD^2	2.68	1.79	1.97	1.31
Malathion:				
8 GH/YD^2	.39	.26	0	0
16 GH/YD^2	1.47	.98	.10	.07
32 GH/YD^2	4.16	2.77	2.09	1.39
40 GH/YD^2	4.27	2.85	3.06	2.04
Nosema locustae:				
8 GH/YD^2	.19	.12	0	0
16 GH/YD^2	.54	.36	.05	.03
32 GH/YD^2	1.34	.90	.99	.66
40 GH/YD^2	1.07	.71	1.37	.91

forage required for their livestock from off-ranch sources; additional grasshoppers do not cause net returns to fall proportionately. However, when either carbaryl bait or *Nosema locustae* are applied, typical ranch net returns decrease more going from grasshopper densities of 32 to 40 GH/YD^2 than they decrease when no treatment is applied. The lower efficacy of carbaryl bait and *Nosema locustae* results in damages abated not being as great with 40 GH/YD^2 as they are with 32 GH/YD^2. The B/C ratios fall rather than rise.

The pattern of relative cost-effectiveness among the five treatments is consistent. This is partially due to the assumptions used for the analysis. Treatment on 15 June at the fourth instar means that the sprays (acephate, carbaryl, and malathion) are being applied at the time when their effectiveness is the greatest. In general, the contact sprays cause more rapid and more extensive mortality among grasshoppers than do carbaryl bait or *Nosema locustae*. The B/C ratios reflect the relative efficacy of the treatments for the date of treatment, grasshopper development stage, canopy cover, and grasshopper species composition assumed.

The B/C ratios also are greatly influenced by the per-acre cost of treatment—the denominator of the B/C ratios. Malathion has an advantage over acephate and carbaryl spray, not so much due to the higher mortality it inflicts on the grasshopper population, but rather to its lower per-acre treatment cost. Carbaryl bait and *Nosema locustae* suffer from both lower efficacy levels and higher per-acre costs.

Conclusions

Economic justification for grasshopper population control programs has been shown to depend on (*a*) the inherent productivity of the rangeland to be treated, (*b*) the prevailing precipitation conditions, and (*c*) the effectiveness of the treatments imposed. The discrete-choice economic threshold of treating grasshoppers which reach densities of eight GH/YD^2 does not appear to be economically justifiable.

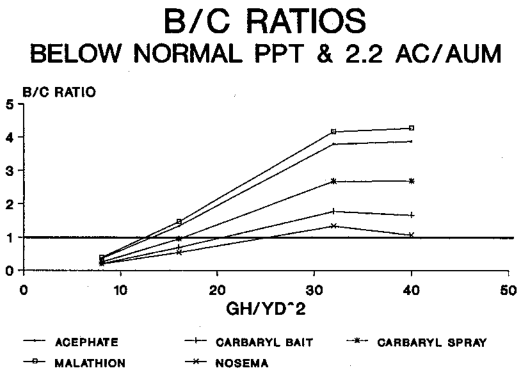

Figure 1. Benefit/cost ratios for below normal precipitation and highly productive rangeland, by treatment

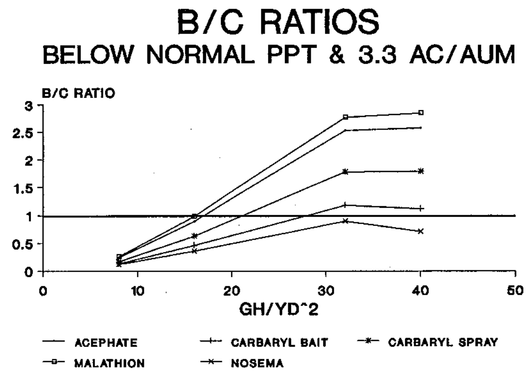

Figure 2. Benefit/cost ratios for below normal precipitation and less productive rangeland, by treatment

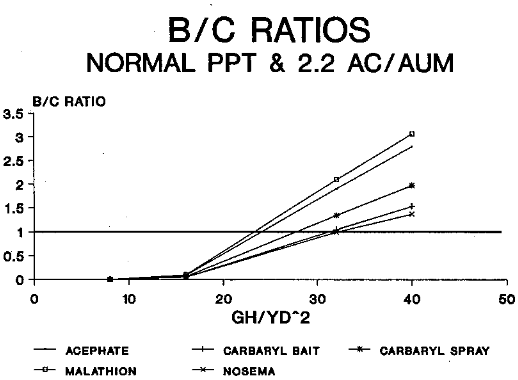

Figure 3. Benefit/cost ratios for normal precipitation and highly productive rangeland, by treatment

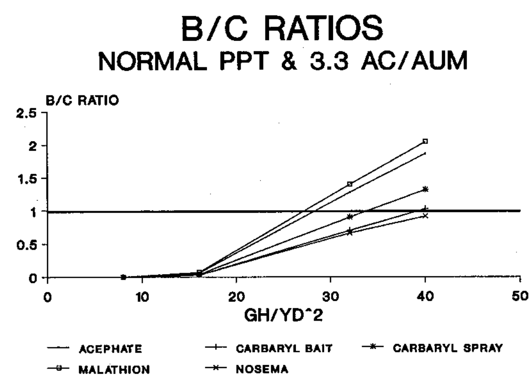

Figure 4. Benefit/cost ratios for normal precipitation and less productive rangeland, by treatment

Rangeland productivity is shown to be an important determinant of the financial justification for treatment of grasshoppers. Under normal precipitation, malathion can be applied to the more productive rangeland when grasshoppers reach densities of about 23 GH/YD^2. Grasshopper densities must reach about 28 GH/YD^2 on the less productive rangeland before malathion can be applied. The LMNG is quite productive relative to most other western range areas. As rangeland productivity falls to the extent that 10, 20, or more acres are required to provide an AUM of grazing, it will be very difficult to attain financial justification for grasshopper control programs.

Precipitation conditions cause a similar shift in the economic threshold. Often grasshopper outbreaks occur when forage supplies already are limited by drought. Treatments can be justified at lower grasshopper densities when below normal precipitation conditions occur than when normal precipitation prevails. Important to the economic threshold is the opportunity cost of forage; as the opportunity cost increases, the economic threshold will occur at lower grasshopper densities.

From figures 1–4 one also can see the relative cost-effectiveness of the treatment alternatives, given the assumed species composition and age of the grasshoppers. For the cases simulated, the sprays (acephate, carbaryl, malathion) are always superior to carbaryl bait and *Nosema locustae*. Because malathion can be applied at a lower per-acre cost, it results in larger B/C ratios than the other chemical sprays.

The economic justification for grasshopper treatments depends on rangeland productivity, precipitation conditions, and the treatment applied. Justification will vary between sites and years. When the area to be treated to protect an AUM of forage from destruction increases, greater grasshopper densities are required to economically justify treatment. The prescribed intervention level of eight GH/YD^2, regardless of rangeland productivity, range condition, or species composition, does not recognize critical differences which are important to a variable economic threshold.

While inclusion of some of the external benefits and costs may change the economic threshold suggested by the B/C = 1.0 criterion, it is not expected that a more complete assessment of costs and benefits will change the basic conclusions of this analysis. The discrete-choice intervention threshold of eight GH/YD^2 has little economic basis. Rather, the economic threshold must consider such things as the value of the crop protected, the opportunity cost of forage destroyed by grasshoppers, and the cost and efficacy of treatment options. The ultimate economic threshold will depend on other factors as well, but this analysis serves to demonstrate how some of those other factors can be evaluated.

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Notes

[1] It is difficult to characterize grasshopper infestations; however, they are often quite localized. When an outbreak occurs, extensive areas may be severely affected while others are free of injurious densities (Pfadt and Hardy). During the most recent major outbreak (1985), contiguous areas of over one million acres were treated. However, during most years of infestation necessary for treatment, treatment of isolated blocks of 10,000 acres is more common.

[2] This feature may be somewhat unique to the Little Missouri Grazing Association which leases the grazing on the Little Missouri National Grassland. For example, during the recent drought (1988–90), ranchers moved their livestock considerable distances to available grazing land. If the grazing option is not available, the alternative source of forage is purchased hay. Because purchased hay is a higher cost source of forage, financial justification for treatment of grasshoppers will occur at lower population densities than when leased grazing land is an option.

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