Evaluation of sweep sampling as a method for determining grasshopper community composition on rangeland
by Deanne Passaro Larson

A thesis submitted in partial fulfillment of the requirements of the degree of Master of Science in Entomology
Montana State University

Abstract:
Sweep, net sampling is the most commonly used technique to obtain estimates of grasshopper community composition. Therefore, I attempted to determine if this technique provides accurate estimates. I evaluated sweep sampling accuracy by 1) comparing the frequency distributions of species, stages, and sexes collected by the repeated sampling of 10 x 10 m enclosures (absolute estimate) to those captured by sweeps taken within 20 m of the erected enclosure (relative estimate) and 2) examining trends in the cumulative proportions of species captured during the repeated sampling of enclosures. For this species assemblage, I found that sweep samples did not accurately portray the relative abundances of species and that Pheolalioles nebrascensis was responsible for most of the bias. This species was consistently overrepresented in sweep samples, by as much as 27% on some dates.

This study also revealed that sweep sampling does not always accurately portray stage-frequency distributions; when most grasshoppers were nymphs sweeps tended to overestimate older nymphs, but tended to underrepresent adults when adults made up a large proportion of the population. In most cases, sex ratios of grasshoppers captured by sweep samples adjacent to enclosures did not differ from those within enclosures.

I also ,evaluated the precision of sweep sampling regarding sweep height, sweep speed, arc length, stride length, and net size by alternating samples of different sweeping styles (eg., high and low) in sets of twelve 100-sweep samples. The total grasshoppers captured per sample was found to vary with sweep height, sweep speed, sweep arc, and sampler stride length. Relative abundances of species also varied with sweep height, sweep speed, arc length, and stride length. However, differences between sweeping styles were smaller than those observed between relative and absolute samples. I found that stage-frequency distributions differed with sweep height and arc length. Relative to the range of instars present, low sweeps and short arc sweeps tended to capture younger grasshoppers in larger proportions. In all cases except one, sweeping style did not affect the sex ratios captured by sweep sampling. In some cases, samplers captured different numbers of grasshoppers per samples, species proportions, and instar proportions as indicated by comparisons of samples taken by two or more samplers sweeping simultaneously 5 m apart.

When analyzing data for differences among sweeping styles and samplers using chi-square contingency table analyses to test for differences in relative abundance and factorial analysis of variance to test for differences in grasshoppers counts, I found that these tests did not always give similar results and that results conflicted most when I tested for differences among samplers.

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by

Deanna Passaro Larson

A thesis submitted in partial fulfillment
of the requirements of the degree

of

Master of Science

in

Entomology

MONTANA STATE UNIVERSITY
Bozeman, Montana

April 1996

APPROVAL

of a thesis sumitted by

Deanna Passaro Larson

This thesis has been read by each member of the thesis committee and has been found to be satisfactory regarding content, English usage, format, citations, bibliographic style and consistency, and is ready for submission to the College of Graduate Studies.

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ACKNOWLEDGEMENTS

I thank Kevin O'Neill and William Kemp for their help developing and carrying out this project and John Borkowski and William Kemp for their assistance with statistical analyses. Thanks goes to all my committee members, including Bret Olson and Jim Fisher, for proofreading this work. I also thank Jeffrey Holmes and Ruth O'Neill for help with grasshopper identification and Cathy Seibert for help sorting samples. I also greatly appreciate the support and encouragement from Phyllis Mazik and Steve Larson.

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ABSTRACT

Sweep net sampling is the most commonly used technique to obtain estimates of grasshopper community composition. Therefore, I attempted to determine if this technique provides accurate estimates. I evaluated sweep sampling accuracy by 1) comparing the frequency distributions of species, stages, and sexes collected by the repeated sampling of 10 × 10 m enclosures (absolute estimate) to those captured by sweeps taken within 20 m of the erected enclosure (relative estimate) and 2) examining trends in the cumulative proportions of species captured during the repeated sampling of enclosures. For this species assemblage, I found that sweep samples did not accurately portray the relative abundances of species and that *Pheotaliotes nebrascensis* was responsible for most of the bias. This species was consistently overrepresented in sweep samples, by as much as 27% on some dates.

This study also revealed that sweep sampling does not always accurately portray stage-frequency distributions; when most grasshoppers were nymphs sweeps tended to overestimate older nymphs, but tended to underrepresent adults when adults made up a large proportion of the population. In most cases, sex ratios of grasshoppers captured by sweep samples adjacent to enclosures did not differ from those within enclosures.

I also evaluated the precision of sweep sampling regarding sweep height, sweep speed, arc length, stride length, and net size by alternating samples of different sweeping styles (e.g., high and low) in sets of twelve 100-sweep samples. The total grasshoppers captured per sample was found to vary with sweep height, sweep speed, sweep arc, and sampler stride length. Relative abundances of species also varied with sweep height, sweep speed, arc length, and stride length. However, differences between sweeping styles were smaller than those observed between relative and absolute samples. I found that stage-frequency distributions differed with sweep height and arc length. Relative to the range of instars present, low sweeps and short arc sweeps tended to capture younger grasshoppers in larger proportions. In all cases except one, sweeping style did not affect the sex ratios captured by sweep sampling. In some cases, samplers captured different numbers of grasshoppers per samples, species proportions, and instar proportions as indicated by comparisons of samples taken by two or more samplers sweeping simultaneously 5 m apart.

When analyzing data for differences among sweeping styles and samplers using chi-square contingency table analyses to test for differences in relative abundance and factorial analysis of variance to test for differences in grasshoppers counts, I found that these tests did not always give similar results and that results conflicted most when I tested for differences among samplers.

INTRODUCTION

Importance of grasshopper studies

Grasshoppers are major pests on rangeland because they compete with cattle for forage. In order to establish good management practices, it is important to understand how grasshopper communities are influenced by factors such as plant community composition, precipitation and drought, insecticide applications, and grazing. Research in these areas needs accurate estimates of the relative abundance of grasshopper species, instars, and sexes. The most commonly used technique to obtain these estimates is sweep-net sampling because it is quick, easy to use, and relatively inexpensive.

Uses of sweep net sampling

A variety of characteristics of grasshopper populations are estimated by sweep net sampling (Table 1). Sweep net samples are most frequently used to obtain estimates of the frequency distributions of species, developmental stages, and sexes but occasionally are used to estimate relative abundance, species richness, and species diversity. Sweep samples are often combined with absolute density estimates to determine species and instar densities.

Estimates obtained from sweep sampling have been used to compare grasshopper communities at different places and times (Table 1). Temporal and spatial differences in grasshopper communities have been evaluated with sweep samples to determine how

Table 1. A review of the characteristics estimated, the number of sweeps per sample, size of the area to which estimates are extrapolated, and comparisons made with sweep net samples.

Citation	Characteristics Estimated	Sweeps per Sample	Size of Sampling Areas	Comparisons Made
Evans and Bailley 1993	Species Frequencies Instar Frequencies Sex Ratios	700, 500, 400, 300 & 200	areas adjacent to pan traps	Pan traps estimates were compared to sweep sample estimates
Evans 1988a	Species Frequencies Species Richness	400 & 200 180	38 sites on four watersheds 14-134 ha areas of vegetation transects plots 50 ×50 m	Grasshopper communities were compared on sites of different burning treatments and grasshopper communities were compared to plant communities and soil type
Evans 1988b	Species Frequencies Species Richness Species Diversity	400 & 200	three watersheds 16-55 ha	Grasshopper communities were compared on sites of different burning histories
Evans 1984	Species Frequencies Instar Frequencies Species Richness Species Diversity Survivorship	440	four watersheds 20-50 ha	Grasshopper communities were compared on sites of different burning histories
Evans et al. 1983	Species Frequencies Instar Frequencies	400	30 m × 200 m	Sweep sample estimates were compared to estimates from night traps
Fielding and Brusven 1992	Species Frequencies	50-100 grasshoppers	44 sites each within 16 km of each other	Grasshopper communities were compared to vegetation characteristics

Table 1. (Continued)

Citation	Characteristics Estimated	Sweeps per Sample	Size of Sampling Areas	Comparisons Made
Gillespie and Kemp 1994	Instar Frequencies Species Frequencies	10	adjacent to drop net samples areas 50 m × 150 m	Sweep samples estimates were compared to drop net sample estimates in rangeland and winter wheat
Hewitt and Onsager 1988	Species Frequencies Species Densities	20 min	four pastures each 75 ha	Grasshopper communities were compared among control plots and plots interseeded with legumes and with sagebrush removed
Holmes et al. 1979	Species Abundance	50 & 100	four fields	Grasshopper communities were compared among fields with different grazing intensities and were compared to plant communities
Jech et al. 1993	Species Frequencies Instar Frequencies Species Mortalities	50 to 200	24 plots each 16.1 ha	Grasshopper communities were compared among plots with different insecticide applications
Joern and Pruess 1986	Species Frequencies Species Rank	50	26 sites within 33 ha	Grasshopper communities were compared among years
Kemp et al. 1990	Species Frequencies Species Richness Distribution	200	same areas as vegetation transects in 39 sites within 7 habitat types	Grasshopper communities were compared to plant communities and environmental factors
Kemp and Dennis 1991	Instar Frequencies	100 sweeps or ≥100 grasshoppers	12 sites throughout Montana	Model phenology

Table 1. (Continued)

Citation	Characteristics Estimated	Sweeps per Sample	Size of Sampling Areas	Comparisons Made
Kemp et al. 1991	Species Frequencies Instar Frequencies	not given	9 sites throughout Montana	Grasshopper development was compared to plant development
Kemp and Sanchez 1987	Species Frequencies Instar Frequencies Distribution Date of hatch	not given	not given	Emergence and development of two species were compared
Kemp 1992a	Species Frequencies Species Richness Distribution	200	not given	Grasshopper communities were compared to habitat type
Kemp 1992b	Species Frequencies Species Richness Distributions	100 sweeps or ≥100 grasshoppers	10-12 sites across Montana	Grasshopper communities were compared in outbreak and non-outbreak years
Kemp and Cigliano 1994	Species Frequencies Instar Frequencies Species Richness Distribution	100 sweeps or ≥100 grasshoppers	10 sites throughout Montana	Grasshopper communities were compared in years of drought and post-drought and among regions of different drought intensity
Lockwood and Bomar 1992	Species Frequencies Instar Frequencies Sex Ratios	100	not given	Grasshopper communities in grassland and cactus patches were compared to grasshoppers observed feeding on cactus flowers

Table 1. (Continued)

Citation	Characteristics Estimated	Sweeps per Sample	Size of Sampling Areas	Comparisons Made
Miller and Onsager 1991	Species Frequencies Peak Density of Species Peak Density of Instars	≥40	260 ha	Grasshopper communities were compared among areas of different grazing intensity
Mulkern 1983	Sex Ratios	not given	not given	Sex ratios were compared to an expected 50/50
Mulkern et al. 1978	Species Frequencies Instar Frequencies Sex Ratios Species Abundance Survivorship	250	4 plots of 4 ha 6 sites in 1745 ha 1700 m²	Grasshopper communities were compared among plots of different insecticide treatment and sweep sweep estimates were compared to cage-vacuum estimates in alfalfa and grassland
Nerney 1961	Species Frequencies	100-300 grasshoppers	not given	Grasshopper communities were compared to plant communities, soil types, and precipitation
Nerney and Hamilton 1969	Species Frequencies Date of Hatch	100-300 grasshoppers	not given	Grasshopper communities were compared to plant communities, soil type, and precipitation
O'Neill et al. 1993	Species Frequencies Instar Frequencies Sex ratios	200	adjacent to grasshopper cadaver transects	Grasshopper communities were compared to grasshoppers feeding upon grasshopper cadavers
O'Neill et al. 1994	Species Frequencies Instar Frequencies	200	adjacent to grasshopper cadaver transects	Grasshopper communities were compared to those first finding and those first feeding upon grasshopper cadavers

Table 1. (Continued)

Citation	Characteristics Estimated	Sweeps per Sample	Size of Sampling Areas	Comparisons Made
O'Neill 1994	Species Frequencies	not given	areas adjacent to grasshoppers feeding upon cattle dung	Grasshopper communities were compared to grasshoppers feeding upon cattle dung
Quinn et al. 1991	Species Frequencies Species Richness Species Densities	200	29 sites each 0.75 ha	Grasshopper communities were compared to vegetation and soil characteristics and were compared before and after insecticide application and between control sites and sites with different insecticide applications
Quinn et al. 1989	Species Frequencies Instar Frequencies	200	30 sites each 0.75 ha	Characteristics of grasshopper populations were compared before and after insecticide application and were compared between control sites and sites with different insecticide applications
Quinn and Walgenbach 1990	Species Abundance Species Richness Incidence	250	29 sites within three locations	Grasshopper communities were compared to plant communities and compared among sites with different grazing histories
Quinn et al. 1993	Species Frequencies Instar Frequencies	200	29 plots each ≈75ha	Grasshopper development was compared to the presence of non-target arthropods
Welch et al. 1991	Species Frequencies	200 grasshoppers	not given	Grasshopper communities were compared among pastures with different grazing regimes

grasshoppers are affected by grazing and burning of vegetation, vegetation characteristics, habitat type, precipitation, topography, soil type, or insecticide applications. Sweep samples have also been used to determine how grasshopper communities change between outbreak and non-outbreak years. In addition, estimates of grasshopper communities that feed on grasshopper cadavers, cattle dung, and prickly pear cactus flowers have been compared with grasshopper communities (at large) using sweep net sampling.

Objectives of this study

Conclusions from grasshopper studies may be incorrect if sweep sampling does not accurately estimate community composition. Therefore, I attempted to determine 1) if sweep sampling provides accurate estimates of the relative abundances of species, developmental stages, and sexes, 2) if total catch and community composition of sweep samples varies among samplers or with variation in sweeping technique such sweep height, sweep speed, sweep arc length, sampler stride length, and net size, and 3) if sweep samples estimates are affected by vegetation height.

Sweep sampling technique

Sweep sampling technique can vary with respect to sweep form, number of sweeps per sample, and the equipment used to take samples. Sweep samples are often taken under different weather conditions and the method of sweep sample implementation can vary.

Sweep-net samples on shortgrass and tallgrass prairie are typically taken by traversing a sweep net in a horizontal 180° arc (e.g. Evans and Bailley 1993, Evans 1988a, 1984, Evans et al. 1983, Jech et al. 1993, Kemp and Cigliano 1994, Kemp 1992, Kemp and Dennis 1991, Kemp et al. 1990, O'Neill et al. 1993). For other insect groups in other habitats, sweep-net samples are often taken by sweeping in a vertical arc or "pendulum" (e.g. Fleisher et al. 1982). Pendular sweeps may penetrate the vegetation better than horizontal 180° arc sweeps, especially in dense vegetation. For example, Evans (1988a, 1988b, 1984) noted that he took horizontal 180° arc sweeps through the top layer of vegetation when sampling grasshoppers on tallgrass prairie and Browde et al. (1992) and Ellington et al. (1984) took horizontal 180° arc sweeps through the uppermost 15 cm of the cotton foliage.

Researchers have also used different sweep heights and speeds. For example, Jech et al. (1993) took equal numbers of low-slow and high-fast sweeps because he considered low-slow sweeps to capture early stages and slow moving species more effectively and high-fast sweeps to capture more active instars and species. Sweep height also varied among habitat types in a study by Lockwood and Bomar (1992) which included sites with prickly pear cacti. Sweeps in this study were taken at a greater height above the ground in cactus patches to avoid destroying the nets.

Equipment used to take sweep samples is also somewhat variable. Nets with 38 cm diameter are typically used to sample grasshoppers (e.g. Evans and Bailley 1993, Evans 1988a, 1988b, 1984, Evans et al. 1983, Quinn and Walgenbach 1990). However, 30 cm and 40 cm diameter nets have also been used (e.g. Lockwood and Bomar 1992, Jech et al. 1993). Net handle length is not usually noted in publications except by Jech et al. (1993).

The number of sweeps taken per sample is quite variable both among studies and within studies (Table 1). Samples of grasshoppers on short and tall grass prairie usually taken in sets of 100 to 200 sweeps, however, larger samples of 400 to 700 sweeps are also used. Sweep samples have also been regulated by sweeping for a certain amount of time or by collecting a certain number of grasshoppers.

Some researchers have considered that abiotic factors may influence sweep sample estimates and have noted the time of day, the amount of cloud cover, and the wind speed when samples were taken (e.g. Evans 1988a, 1988b, 1984, Evans and Bailey 1993, Evans et al. 1983, Kemp and Cigliano 1994). To avoid potential biases, Jech et al. (1993) took sweep samples in a circular pattern so that the sampler would approach grasshoppers at a variety of angles to the sun and wind.

Samples are also taken by sweeping along transects. Evans (1988b, 1984, 1983) took sweep samples along two parallel transects separated by 10 m while Quinn and Walgenbach (1990) took sweep samples along five transects separated by 50 m.

Sweep samples typically are not taken according to a random sampling plan. Sweep samples are often taken in close proximity to other sample methods (e.g. vegetation transects, pan traps, and drop net samples) with which they are being compared (Table 1). However, sweep net samples are also used on much larger areas ranging from 14 ha to 1745 ha without the use of a random sampling plan. Frequently, researchers fail to note the size of the area to which extrapolations from sweep samples are being made.

Potential reasons for biases in sweep net samples

The distance jumped by grasshoppers varies among species, instars, and sexes. For example, mature male desert locusts, *Schistocerca gregaria*, can jump twice as far as fifth instar males (Gabriel 1985) and male locusts jump farther than female locusts (Bennet-Clark 1975). Distance jumped could affect susceptibility to capture among stages if older grasshoppers are flushed and captured by subsequent sweeps more often than younger grasshoppers which may not jump far enough to be captured by later sweeps. This effect could also occur among species or sexes.

The height that grasshoppers jump could affect the proportion of species, instars, and sexes captured by sweep net sampling. For example, sweeps could be less effective at capturing early developmental stages than later stages if sweep height is greater than that jumped by younger stages.

Grasshopper species, instars, and sexes may employ different escape tactics in response to sweep sampling and these behaviors could lead to differences in capture among species, instars and sexes. For example, grasshoppers that fail to jump as the sampler approaches may consistently avoid capture by sweep nets. Certain species, such as *Arphia pseudonietana* and *Dissosteira carolina*, may avoid capture by flushing readily at long distances from oncoming samplers. Quinn and Walgenbach (1990) noted that *Arphia* spp. are particularly difficult to capture. Capture may also vary among species, instars, or sexes that choose different landing spots after flushing by the sweep net or sampler. Grasshoppers that jump and land upon vegetation may be captured more frequently by subsequent sweeps than grasshoppers that jump and land on the ground.

Grasshoppers choose microhabitats based on feeding, mating, and thermoregulatory needs and these requirements have been found to vary among species and sexes (e.g. Joern et al. 1986). Although grasshoppers may differ in their choice of microhabitats, they often change their position in the environment as a sampler approaches and as a result, grasshoppers often are not in their usual microhabitats at the time of sampling. Microhabitat choice, however, could influence sweep sample estimates if grasshoppers choose different microhabitats to avoid predation (Kevan et al. 1983) or employ different escape tactics relative to their position in the environment. For example, grasshoppers within vegetation may jump less frequently in response to potential predators (e.g. sweep net) than grasshoppers on bare ground. Belovsky et al. (1990) suggested that male grasshoppers which spend more time on bare ground jump and are captured more frequently by sweeps than females which spend more time within vegetation.

Vegetation structure could also affect sweep sample estimates. Dense vegetation may affect sweeping height. Vegetation height could also affect estimates if, for example, grasshoppers that jump onto vegetation are captured more frequently in tall vegetation than on grazed or burned areas.

Abiotic factors (e.g. temperature, wind) that affect the behaviors described above could influence the number of grasshoppers of each species, stage, and sex captured by sweeps. Temperature affects the height and distance that grasshoppers can jump and choice of microhabitat is influenced by temperature and wind.

Studies assessing the accuracy of grasshopper sweep sampling

The greatest problem in evaluating the accuracy of sweep sampling is the difficulty of determining the actual community composition which usually occurs by collecting all grasshoppers within a given area. For practical reasons, absolute samples, used in comparisons to sweep samples, are taken on very small plots. The result is that the total number of grasshoppers captured by absolute sampling techniques is relatively small, thus making it difficult to evaluate sweep sampling accuracy. For example, night traps captured total of 45 to 140 grasshoppers (Evans et al. 1983). Despite such problems, several studies have investigated whether sweep samples accurately estimate relative abundance of species, developmental stages, and sexes; others have evaluated the variability of total catch due to factors such as temperature and vegetation structure.

Evans et al. (1983) found that sweep net samples captured species in different proportions than those collected by night traps, the differences being as great as 16% for *Orphulella speciosa* (Scudder). However, results were not consistent between samples taken early and late in the summer and this inconsistency caused Evans et al. (1983) to conclude that sweep samples are not biased. Similarly, Mulkern et al. (1978) compared sweep samples to cage-vacuum samples and concluded that sweep samples were not biased in grassland or alfalfa. Species proportions captured by the two techniques, however, differed by up to 9% for *Melanoplus sanguinipes.* Because the total number of grasshoppers captured by each technique was not given and because statistical analyses were not used, it is not possible to further evaluate their results. Browde et al. (1992)

found that two species, *Melanoplus femurrubrum* and *M. differentialis,* were captured with similar efficiencies by sweep samples and cage bag samples in soybean.

Judgements have also varied on how well sweep samples assess stage-frequency distributions. Stage frequency distributions of *Melanoplus femurrubrum* and *M. differentialis* in sweep samples differed significantly from those collected by cage bag samples in soybean (Browde et al. 1992). In contrast, Gillespie and Kemp (1994) found that developmental stages were collected in similar proportions by sweep samples and drop cages on rangeland and winter wheat. Mulkern et al. (1978) concluded that the stage frequency distributions captured by sweep samples were similar to those collected in cage-vacuum samples even though sweeps captured 7.6% more adults and 8.6% fewer fourth instars.

Mulkern et al. (1978) compared sweep samples to cage-vacuum samples and found that sex ratios were not biased by sweep sampling. In a later study, Mulkern (1983) found that the sex ratios of some species significantly differed from an expected 50/50 in sweep net samples but not in cage-vacuum samples. However, sweep samples were taken in different locations and dates than the cage-vacuum samples.

Differences in vegetation structure affected the number of grasshoppers captured per sweep sample. Sweeps taken in alfalfa captured fewer of the grasshoppers present than sweeps in grassland (Mulkern 1978) and Evans et al. (1983) found that grasshoppers were captured more effectively on burned areas than on unburned areas. Both studies suggest that sweeps in dense vegetation capture smaller proportions of the grasshoppers present than in sparse vegetation.

The number of grasshoppers captured per sweep sample on rangeland has been correlated with temperature (Mulkern 1978). Time of day also affected total catch; sweeps taken during the day in soybean captured fewer grasshoppers than sweeps taken at night (Browde et al. 1992).

The use of sweep samples for other insect taxa

Sweep samples are commonly used for other insect groups to estimate insect density and to determine spatial and temporal variation in population size. A few studies have attempted to determine the accuracy of density estimates obtained from sweep sampling and if total catch varies with factors such as vegetation structure, temperature, and time of day.

Studebaker et al. (1991) found that sweeps taken in artificial infestations of larval corn earworm and soybean looper (Lepidoptera: Noctuidae) in soybean did not accurately estimate population size. Snodgrass (1993) found that nymphs of *Lygus lineolaris* (Heteroptera: Miridae) placed on cotton plants were collected more efficiently by drop cloths than sweep-net samples. In contrast, Nilakhe and Chalfant (1982) found no difference in the capture of Lepidopterans by ground cloth samples and sweep-net samples in cowpeas.

Marston et al. (1982) found that the efficiency in which insects are captured by sweeps varies among insect groups. Nilakhe and Chalfant (1982) found that the size of larval velvetbean caterpillars, corn earworm, and soybean loopers did not affect capture by sweep sampling and Snodgrass (1993) found that developmental stage did not affect capture of tarnished plant bug nymphs.

Vegetation structure affected total catch by sweep samples for many insect groups. Plant height affected the efficiency in which nymphs of *Lygus lineolaris* (Palisot de Beauvois) were captured by sweeps in cotton (Snodgrass 1993). Saugstad et al. (1967) found that height of alfalfa plants can affect capture of pea aphids, *Acyrthosiphon pisum* (Harris), potato leafhopper, *Empoasca fabae* (Harris), and meadow spittlebug, *Philaenus spumarius* (L.). Studebaker et al. (1991) found that the efficiency in which sweep samples captured larval *Pseudoplusia includens* (Lepidoptera: Noctuidae) differed between conventional-row and narrow-row plantings for one soybean growth stage. The growth stage of soybean plants also affected the efficiency in which nymphs and adults of *Orius insidiosus* (Hemiptera), adult Chloropidae, and adult Aleyrodidae were captured (Marston et al. 1982). Studebaker et al. (1991) found that sweep sampling captured smaller proportions of *Helicoverpa zea* (Lepidoptera: Noctuidae) in larger vegetative stages of alfalfa plants.

Position on the plant did not affect capture of tarnished plant bugs by sweep nets. Bugs placed on the inside and outside of cotton bracts were captured with similar efficiencies by sweeps (Snodgrass 1993).

The total number of insects captured by sweeps can vary with time of day. Time of day was found to affect total capture of pea aphids, nabids, lady beetles, and lacewings by sweeps in lentils (Schotzko and O'Keeffe 1989) and capture of *Lygus hesperus* nymphs (Heteroptera: Miridae) in lentils (Schotzko and O'Keeffe 1986). However, time of day did not have an affect on capture of larval corn earworm or soybean looper (Lepidoptera: Noctuidae) in soybean (Studebaker et al. 1991).

Other factors have affected total insect catch. Schotzko and O'Keeffe (1989) found that the number of pea aphids, nabids, lady bird beetles, and lacewings captured by sweeps can be affected by relative humidity, wind, temperature, and light intensity. Saugstad et al. (1967) found that the number of pea aphids, potato leafhoppers, and meadow spittle bugs captured by sweep samples in alfalfa varied with identity of sampler, net type (nylon mesh or muslin), week, temperature, relative humidity and cloud cover.

Other techniques used to sample grasshoppers

Although sweep sampling is the most commonly used technique to estimate characteristics of grasshopper communities, a variety of other techniques have been used on short and tallgrass prairie. Visual surveys have been made by counting and identifying grasshoppers found within metal rings (e.g. Jepson-Innes and Bock 1989, Hewitt and Onsager 1988, Bock and Bock 1991, Joern 1982) or within other areas of estimated size (e.g., Joern and Rudd 1982, Pfadt 1977). Grasshoppers communities have also been characterized by capturing and identifying grasshoppers upon flushing (Bergmann and Chaplin 1992, Capinera and Sechrist 1982, Capinera and Thompson 1987) or by collecting grasshoppers in the order that they were observed (Joern 1986). Trapping devices such as a cage vacuum device (e.g., Mulkern 1983, 1983, Mulkern et al. 1978), drop cages (Gillespie and Kemp 1994, Gandar 1982, Welch et al. 1991), night traps (Evans 1983), and pitfall and barrier traps (Parmenten et al. 1991) have also been used. Van Wingerden et al. (1991) collected all grasshoppers from within fenced plots of 100 or 200 m^2. Some publications fail to mention techniques used to obtain estimates (e.g. Joern 1979, Gage et al. 1976).

Statistical analyses used on sweep sample data

Overall frequency distributions of species, developmental stages, and sexes obtained from sweep samples have been compared using a variety of statistical tests. Frequency distributions have been compared using chi-square contingency table analyses (O'Neill et al. 1994, 1993), Pearson chi-square statistic in chi-square analysis (Evans and Bailley1993), chi-square analysis (Lockwood and Bomar 1992), the G-statistic (Evans et al. 1983, Mulkern 1983, Quinn et al. 1989), log likelihood ratio test (Evans et al. 1983), maximum likelihood estimation (Quinn et al. 1989), Fisher's Exact Test (Gillespie and Kemp 1994, Kemp et al. 1990) and loglinear models (Gillespie and Kemp 1994).

Relative abundances of species captured in sweep samples have been compared using nonparametric tests. Kemp (1992b) compared the relative abundances of species using Wilcoxon two-sample test and Kemp et al. (1990) used Mann-Whitney U-test. Species densities have been compared using Kruskall-Wallis test (Quinn et al. 1989).

Parametric tests have been used to compare the abundance of species captured by sweep samples. Quinn et al. (1993) and Quinn and Walgenbach (1990) used analysis of variance to detect differences among species abundances.

Similarities among grasshopper communities have been evaluated using Detrended Correspondence Analysis (e.g. Kemp et al. 1990, Evans 1988a, 1988b, Quinn and

Walgenbach 1990, Quinn et al. 1991), Principle Components Analysis (Joern and Preuss 1986), and Cluster Analysis (Joern and Preuss 1986).

MATERIALS AND METHODS

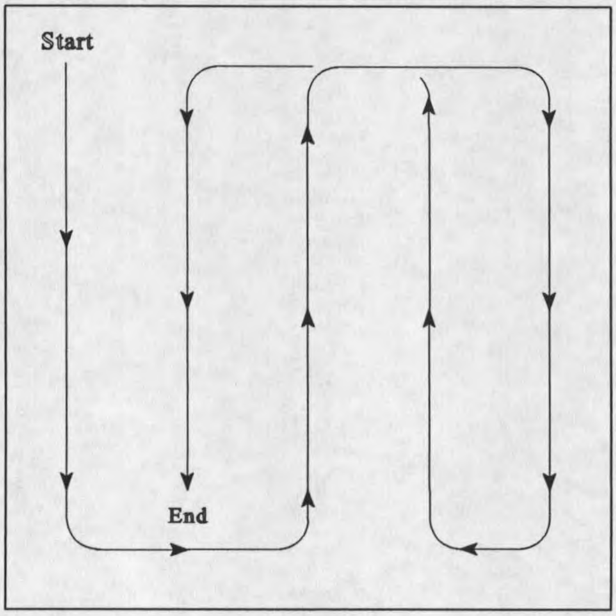
Study Sites

I collected data for this study during the summer of 1994 at three sites. The area most frequently sampled, "Red Barn" (RB), is located 10 km south of Three Forks, MT (latitude 45° 45'N, longitude 111° 35'W). The second site, "Check Schoolhouse" (CSH), is located 14 km south of Three Forks, MT and the third area (Logan) is 5 km north of Logan, MT. The native vegetation at all three sites is dominated by the grasses *Stipa comata* Trin. & Rupr. and *Bouteloua gracilis* (H. B. K.) Lag. ex Steud. However, the two sites near Three Forks had been plowed and reseeded with crested wheatgrass, *Agropyron cristatum* (L.) Gaertn., and alfalfa, *Medicago sativa* L.

Enclosures

I evaluated the accuracy of sweep net samples by comparing the frequency distributions of species, instars, and sexes in standard sweep net samples to absolute estimates obtained by exhaustively collecting grasshoppers within enclosed areas. Enclosures were set up on four 10 × 10 m areas in a section of the RB site with homogenous vegetation. Early in the morning when grasshoppers were relatively inactive, I erected an enclosure on one of the four areas by attaching four 10 × 1.5 m panels of netting to posts and by securing the bottom of the panels to the ground with stakes and rocks. Over the next few hours, I repeatedly sampled the enclosure with a sweep net until samples captured fewer than five grasshoppers. These samples were taken in a specific pattern, Figure 1, to minimize sweeping an area twice and to ensure that all areas would have approximately equal probability of being swept. As a result of sweeping in this pattern, the total number of sweeps per sample varied between 67 to 95. Prior to taking samples, I often walked around the perimeter of the enclosure and knocked grasshoppers off the sides to prevent their escape and to ensure their potential capture by sweeps. After sweeping, I attempted to capture remaining grasshoppers by visually searching for them and by taking over 400 additional sweeps. I was not able to capture all grasshoppers within enclosures; some grasshoppers escaped by crawling under the bottom of the enclosure or by climbing or flying out the top. However, I consider the number of

Figure 1. Path walked by myself for each sweep sample taken within an enclosure.



grasshoppers that escaped or failed to be collected to be very small in comparison to the total number captured. I later froze each repeated sample until I could identify grasshoppers to species, instar, and sex (adults only). I identified *Melanoplus gladstoni* as *Melanoplus sanguinipes* until some adult *M. gladstoni* were found. For the cases in which *M. gladstoni* was correctly identified, it made up a small portion of the population. After exhaustively collecting grasshoppers within an enclosure, I allowed a period of over two weeks for recolonization before resampling an area.

Data from enclosures were compared to relative estimates obtained by sweeping non-overlapping areas within 20 m of an erected enclosure. These samples were taken in the samplers own sweeping style or were varied in sweeping style. On four dates (28, 30 June and 8, 10 July), a sample of 200 sweeps was taken adjacent to an enclosure by one sampler sweeping in their own style. On four dates (17, 18, 21, and 26 July), one person took a long arc sweep sample and a short arc sweep sample, both of 200 sweeps, before and after an enclosure was exhaustively swept (see descriptions of these techniques below). Long and short stride samples were taken adjacent to enclosures on two dates (28 July and 3 August) in the same manner as short and long arc sweep samples except that these samples were taken in sets of 100 sweeps.

Mowed Enclosures

In addition to the enclosures described above, I erected enclosures on two mowed areas, adjacent to the unmowed areas at the RB site. These areas were mowed with a lawnmower which reduced vegetation height from about 40 cm to 10 cm. Enclosures on mowed areas were erected and repeatedly sampled in the same manner described above on 28 July and 1 and 5 August.

Sweeping Style

To determine if sweep samples gave consistent results with regards to sweeping style, I compared samples taken at different sweep heights, sweep speeds, sweep arc lengths, sampler stride lengths, and net sizes. Usually, either one or two samplers were involved. For example, in sets of 12 consecutive 100-sweep samples across homogenous vegetation, one person alternated taking samples in one of two sweeping styles (e.g. high or low) while keeping all other factors (e.g. arc length) of the sweep sampling technique as constant as possible (Fig. 2). Alternatively, two people collected by sweeping simultaneously in the same style at a distance of approximately 5 m apart from each other (Fig. 3). Specific details of the five comparisons are:

1) Sweep height. We varied sweep net height by taking sweep samples with the bottom of the net at approximately 20 cm above the ground in high sweeps and 5 cm above the ground in low sweeps for the entire 180° sweep arc. Sets of high and low sweep samples were taken by one sampler on four dates at the RB site (28 June, 30 June, 12 July and 10 August).

2) Sweep speed. In these comparisons, samplers varied walking and sweeping speed. Fast sweep samples were taken in an average of 91-95 seconds by both samplers while slow sweep samples were taken in an average of 116-117 seconds by one sampler and in an average of 135-136 seconds by another sampler. Sets of fast and slow sweep