



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
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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 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 *Pheolalioides 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

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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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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 Bailey 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 x 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 x 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 m ²	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 \approx 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 Bailey 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 Bailey 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, *Acyrtosiphon 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 effect 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 m². 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 Bailey 1993), 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 Kruskal-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

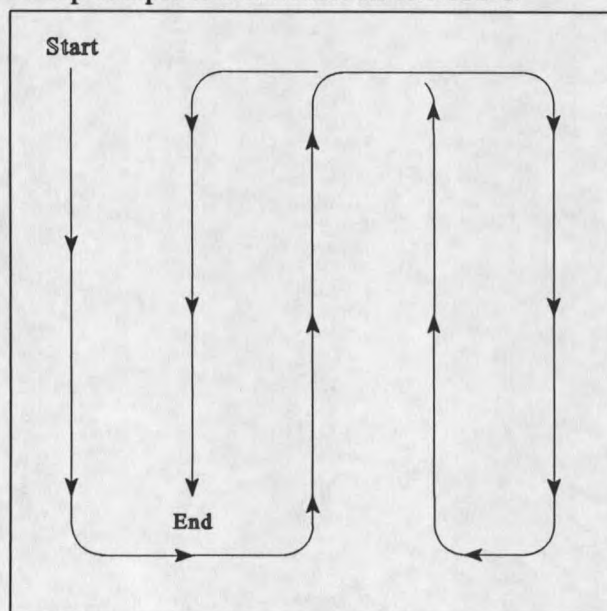
I collected data for this study during the summer of 1994 at three sites. The area most frequently sampled, "Red Barn" (RB), is located 10 km south of Three Forks, MT (latitude 45° 45'N, longitude 111° 35'W). The second site, "Check Schoolhouse" (CSH), is located 14 km south of Three Forks, MT and the 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, 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

Figure 2. Pattern in which one person alternated taking samples of different sweeping styles using sweep height as an example. Numbers refer to the order in which samples were taken.

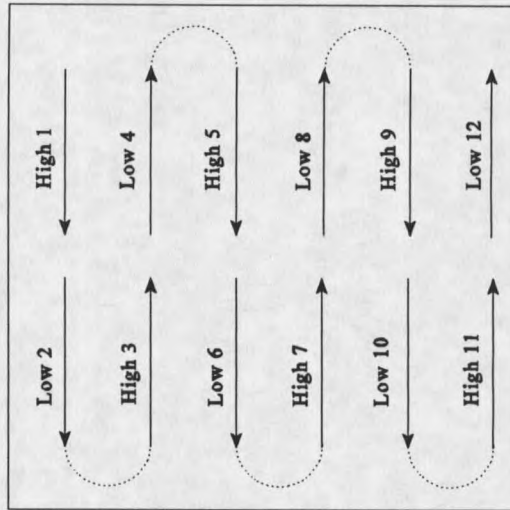
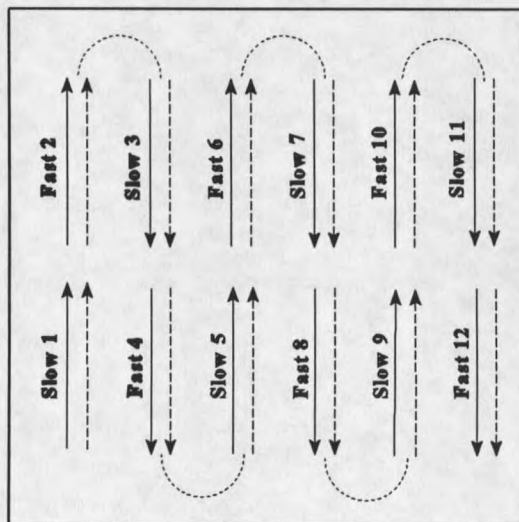


Figure 3. Pattern in which sweep samples were taken by two people sweeping simultaneously in the same style 5 m apart using sweep speed as an example. Numbers refer to the order in which samples were taken.



samples were taken by one sampler on three dates at the RB site (18 June, 12 July, and 12 August) and by two samplers at the Logan site (27 June).

3) Arc length. The radius of the sweep arc and consequently the distance traversed by the net were changed between long and short arc sweep samples. Long arc sweep samples were taken, by both samplers, with a radius of approximately 1 m and an arc length of about 3.0 m, while short arc sweep samples were taken with a radius of 0.5 m and an arc length of 1.6 m. Long and short arc sweep samples were taken by one sampler on three dates (8 and 11 July and 9 August) at the RB site and by two samplers at the Logan site (13 July).

4) Stride length. For short and long stride sweep samples, one sampler alternated taking samples with a long stride length of 1 m and a short stride length of 0.6 m. Long and short stride sweep samples were taken by one sampler at RB site on 27 July and 9 August.

5) Net Size. For small and large net sweep samples one sampler alternated taking samples with a 30 cm diameter net and a 38 cm diameter net. Small and large net sweep samples were taken by one sampler at the RB site on 30 June.

Simultaneous Sweep Samples

In another set of comparisons, I compared sweep samples taken by people sweeping simultaneously in their own style to determine if sweep sampling gives consistent results regardless of sampler. These samples were taken in sets of four 200-

sweeps by two people sweeping approximately 5 m apart on 6 June at RB, 6 June at CSH, and 27 June at Logan.

To determine if sampler training affects sweep sample estimates, on 16 August at RB, five samplers took two sets of five 100-sweep samples simultaneously. For the first set, two of the five samplers were untrained in the sweep sampling technique and took sweeps in the shape of a vertical pendulum while the three previously trained individuals took sweeps in a horizontal 180° arc. Before taking a second set of five samples, I trained all samplers to sweep in a horizontal 180° arc.

Statistical Analyses

Using chi-square contingency table analyses, I tested sweep sampling accuracy by comparing the frequency distributions of species, stages, and sexes in sweep samples taken adjacent to enclosures, as this technique is typically employed, to those collected by exhaustively sweeping enclosures. For the dates on which samples adjacent to enclosures were taken in different sweeping styles, I used chi-square contingency table analyses to compare samples of each style to enclosure samples and to each other.

For the dates on which sweeping style was alternated in sets of twelve consecutive 100-sweep samples, I combined samples of each style and used chi-square contingency table analyses to test for differences between styles in the overall frequency distributions of species, instars, and sexes. I also used factorial analysis of variance on the square root transformation of grasshopper counts to determine the effect that style had on total catch and to determine the affect of sweep style on individual species by testing for interactions

between species and sweeping style. For the three most abundant species, I tested for interactions between instar and sweeping style.

For each date that samples were taken by two or more people sweeping simultaneously, I combined samples taken by each sampler and tested for differences in the overall frequency distributions using chi-square contingency table analyses and factorial analysis of variance in the same manner described above.

When comparing the frequency distributions of species with chi-square contingency table analyses, the nine or ten most abundant species were separated in analyses, while less common species were combined into one category. If tests were significant, further 2×2 analyses were performed for each abundant species to determine which species were responsible for differences. The overall stage-frequency distributions were compared in chi-square contingency table analyses by combining developmental stages with counts of five or less with an adjacent category. Stage categories were combined such that younger instars were included with the next older stage category and older instars were included in the next younger category. If tests were significant, further 2×2 contingency table analyses were conducted for each developmental stage. The results of the 2×2 contingency table analyses for species and instars should be viewed with some caution since the probability of incorrectly obtaining at least one significant result due to chance increases when many comparisons are made. I also used chi-square contingency table analyses to test for differences in sex ratios of adult grasshoppers for the three most abundant species when adult grasshoppers were present in sufficient numbers.

For the factorial analysis of variance, I used the same species as in the contingency table analyses except that the less common species or instars were excluded from the analyses. Prior to analyses, I transformed the data by taking the square root of all grasshopper counts to stabilize variances.

RESULTS

Sweep Samples vs Enclosures

Standard Sweep Samples. I evaluated the accuracy of sweep net sampling by comparing abundances of species, stages, and sexes captured in sweep samples to those collected within enclosures under the assumption that samples from enclosures represented absolute estimates of community composition. The overall frequency distributions of species significantly differed between enclosures and sweep samples in chi-square contingency table analyses on the four dates on which sweep samples adjacent to enclosures were taken by samplers sweeping in their usual sweeping style (Table 2). For all dates, sweep samples overestimated *P. nebrascensis* by 13.0-15.5% and underestimated *S. equale* by 2.7-4.3%. On three dates, *A. pseudonietana* was underestimated and on two of the four dates, *M. packardii* was underestimated in sweeps by 7.1% and 4.7%.

The stage frequency distributions of *P. nebrascensis* captured by sweeps differed significantly from those collected within enclosures on all four dates (Table 3). However, the stage frequency distributions of *M. sanguinipes* differed significantly between an enclosure and sweep sample on only one of the four dates (Table 4). Whereas, the stage frequency distributions of *A. deorum* did not differ between sweeps and enclosures on 28 June ($\chi^2=4.0$, $df=3$, $P>0.05$), 30 June ($\chi^2=1.8$, $df=4$, $P>0.05$), 8 July ($\chi^2=4.3$, $df=3$, $P>0.05$) and 10 July ($\chi^2=1.1$, $df=3$, $P=0.05$). For the cases that showed significant

Table 2. Relative abundances of species in sweep samples adjacent to enclosures and within enclosures on 28 and 30 June and 8 and 10 July in 1994 at the RB site and results of chi-square contingency table analysis. (Enc=Enclosure)

Species	28 June		30 June		8 July		10 July	
	Within Enc	Adjacent to Enc	Within Enc	Adjacent to Enc	Within Enc	Adjacent to Enc	Within Enc	Adjacent to Enc
<i>A. deorum</i>	0.143	0.121	0.132**	0.087	0.133	0.093	0.150	0.121
<i>A. pseudonietana</i>	0.024**	0.003	0.024**	0.004	-	-	0.016*	0.003
<i>A. ellioti</i>	0.046	0.064	0.074	0.069	0.024	0.032	0.026	0.031
<i>E. costalis</i>	0.073	0.031	0.058**	0.022	0.032	0.032	0.021	0.031
<i>M. infantilis</i>	0.027	0.039	0.016	0.013	0.017	0.028	0.037	0.021
<i>M. packardii</i>	0.065	0.062	0.063	0.063	0.131**	0.060	0.094**	0.047
<i>M. sanguinipes</i>	0.225*	0.175	0.196	0.206	0.209	0.185	0.238	0.238
<i>P. nebrascensis</i>	0.327***	0.482	0.384***	0.517	0.350***	0.496	0.348***	0.478
<i>S. equale</i>	0.046**	0.003	0.036**	0.009	0.032*	0.004	0.039**	0.010
<i>T. kiowa</i>	-	-	-	-	0.034	0.024	-	-
Other	0.024	0.021	0.017	0.011	0.039	0.044	0.032	0.021
N	875	388	1303	462	594	248	1068	387
Contingency table analysis	$\chi^2=55.0$ P<0.0001		$\chi^2=46.3$ P<0.0001		$\chi^2=28.3$ P=0.001		$\chi^2=39.3$ P<0.0001	

*, P<0.05; **, P<0.01; ***, P<0.0001 in 2x2 contingency table analyses for each species.

differences, sweeps tended to collect older stages in larger proportions, however, differences were not always consistent

Long and Short Arc Sweep Samples. On four dates, I evaluated the accuracy in which sweeps of different arc lengths capture species, stages, and sexes by sweeping adjacent to enclosures with an arc length of 3.1 m or 1.6 m. The frequency distributions of species in short and long arc samples differed significantly from those within enclosures on 17 and 18 July, while on 21 July significant differences were found between only long arc sweeps and enclosures (Tables 5 and 6). Regardless of arc length, sweep samples consistently overestimated the proportions of *P. nebrascensis*. These differences were

Table 3. Stage frequency distributions of *P. nebrascensis* in sweep samples adjacent to enclosures and within enclosures on 28 and 30 June and 8 and 10 July 1994 at the RB site and results of chi-square contingency table analysis. Proportions within parentheses were combined with adjacent category in analyses. (Enc=Enclosure)

Instar	28 June		30 June		8 July		10 July	
	Within Enc	Adjacent to Enc	Within Enc	Adjacent to Enc	Within Enc	Adjacent to Enc	Within Enc	Adjacent to Enc
I	0.122	0.070	0.084	0.071	-	-	(0.003)	-
II	0.441	0.369	0.474***	0.310	0.058	0.089	0.212**	0.097
III	0.413**	0.545	0.400***	0.598	0.543	0.512	0.446	0.400
IV	0.025	0.016	0.042	0.021	0.394	0.333	0.341**	0.503
V	-	-	-	-	0.005**	0.065	(0.003)	-
Adults	-	-	-	-	-	-	-	-
N	286	187	500	239	208	123	372	185
Contingency table analysis	$\chi^2=9.2$ P=0.027		$\chi^2=26.5$ P<0.0001		$\chi^2=12.4$ P=0.006		$\chi^2=18.2$ P=0.0001	

*, P<0.05; **, P<0.01; ***, P<0.0001 in 2x2 contingency table analyses for each species.

Table 4. Stage frequency distributions of *M. sanguinipes* in sweep samples adjacent to enclosures and within enclosures on 28 and 30 June and 8 and 10 July 1994 at the RB site and results of chi-square contingency table analysis. Proportions within parentheses were combined with adjacent category in analyses. (Enc=Enclosure)

Instar	28 June		30 June		8 July		10 July	
	Within Enc	Adjacent to Enc	Within Enc	Adjacent to Enc	Within Enc	Adjacent to Enc	Within Enc	Adjacent to Enc
I	0.228	0.132	0.094	0.053	(0.032)	(0.022)	-	-
II	0.269**	0.044	0.153	0.116	0.113	0.109	0.063	0.120
III	0.218	0.250	0.337	0.316	0.242	0.261	0.236	0.261
IV	0.178	0.205	0.212	0.242	0.202	0.304	0.228	0.293
V	0.107***	0.368	0.204	0.274	0.323	0.304	0.339	0.272
Adults	(0.015)	(0.029)	(0.031)	(0.011)	0.121	0.022	0.134	0.054
N	197	68	255	95	124	46	254	-
Contingency table analysis	$\chi^2=34.7$ P<0.0001		$\chi^2=4.0$ NS		$\chi^2=5.1$ NS		$\chi^2=8.8$ NS	

*, P<0.05; **, P<0.01; ***, P<0.0001 in 2x2 contingency table analyses for each species.

Table 5. Relative abundances of species captured by short and long arc sweep samples and collected within enclosures on 17 and 18 July 1994 at the RB site and results of chi-square contingency table analyses. (Enc=Enclosure)

Species	17 July			18 July		
	Within Enc	Adjacent to Enc		Within Enc	Adjacent to Enc	
		Short Arc	Long Arc		Short Arc	Long Arc
<i>A. deorum</i>	0.188	0.140	0.148	0.132	0.106	0.134
<i>A. ellioti</i>	0.061	0.034	0.045	0.096	0.037***	0.060**
<i>E. costalis</i>	-	-	-	0.014	0.022	0.008
<i>M. infantilis</i>	0.023	0.036	0.032	0.037	0.020	0.028
<i>M. packardii</i>	0.127	0.048**	0.067**	0.109	0.054**	0.038***
<i>M. sanguinipes</i>	0.193	0.165	0.234	0.241	0.180**	0.193*
<i>P. nebrascensis</i>	0.215	0.487***	0.424***	0.259	0.500***	0.499***
<i>P. delicatula</i>	0.073	0.031**	0.017***	0.030	0.032	0.017
<i>S. equale</i>	0.023	0.008	0.007*	0.033	0.011**	0.005***
<i>T. kiowa</i>	0.037	0.011*	0.007**	-	-	-
Other	0.061	0.039	0.019	0.049	0.037	0.018
N	521	357	594	935	538	1103
Contingency table analysis ^a		$\chi^2=88.4$ P<0.0001	$\chi^2=99.2$ P<0.0001		$\chi^2=102.5$ P<0.0001	$\chi^2=168.6$ P<0.0001

^a, contingency table analyses separately comparing long arc samples and short arc samples to enclosures.

*, P<0.05; **, P<0.01; ***, P<0.0001 in 2x2 contingency table analyses for each species.

greatest on 17 and 18 July when long and short arc sweeps overestimated *P. nebrascensis* by 21-27%. Sweeps of both arc lengths also underestimated *S. equale* and *M. packardii* on 17 and 18 July.

I also compared sweeps of different arc lengths to each other and found that short arc sweeps captured significantly different proportions of species than long arc sweeps on 18 July ($\chi^2=25.9$, P=0.0022) and 21 July ($\chi^2=17.1$, P=0.0476) but not on 17 July ($\chi^2=10.9$, P>0.05) or 26 July ($\chi^2=3.6$, P>0.05) (Tables 5 and 6). Sweeping with either a long or short arc did not give closer estimates of the frequency distributions of species

Table 6. Relative abundances of species captured by short and long arc sweep samples and collected within enclosures on 21 and 26 July 1994 at the RB site and results of chi-square contingency table analyses. (Enc=Enclosure)

Species	21 July			26 July		
	Within Enc	Adjacent to Enc		Within Enc	Adjacent to Enc	
		Short Arc	Long Arc		Short Arc	Long Arc
<i>A. deorum</i>	0.080	0.102	0.131**	0.111	0.102	0.137
<i>A. elliotti</i>	0.055	0.042	0.044	0.067	0.056	0.059
<i>M. infantilis</i>	0.019	0.014	0.026	0.019	0.035	0.036
<i>M. packardii</i>	0.149	0.085	0.072	0.031	0.029	0.032
<i>M. sanguinipes</i>	0.063	0.148	0.156	0.202	0.190	0.196
<i>P. nebrascensis</i>	0.338	0.391	0.445**	0.365	0.433	0.398
<i>P. delicatula</i>	0.094	0.088	0.046**	0.044	0.038	0.036
<i>T. kiowa</i>	0.025	0.014	0.015	0.023	0.009	0.008
<i>X. corallipes</i>	0.119	0.067	0.033***	0.086	0.073	0.060
Other	0.058	0.049	0.033	0.054	0.039	0.039
N	523	284	609	685	342	663
Contingency table analysis ^a		$\chi^2=10.7$ NS	$\chi^2=60.5$ P<0.0001		$\chi^2=10.20$ NS	$\chi^2=15.7$ NS

^a; contingency table analyses separately comparing short arc and long arc samples to enclosures.
*, P<0.05; **, P<0.01; ***, P<0.0001 in 2x2 contingency table analyses comparing each species.

found within enclosures on three of the four dates. On 21 July, however, sweeping with a short arc provided somewhat better estimates.

I also tested for differences in capture of development stages between sweeps and enclosures and found that the stage-frequency distributions of *P. nebrascensis* collected within enclosures differed significantly from short arc sweeps on 18 and 21 July and from long arc sweeps on 21 July (Tables 7 and 8). I also found that the stage-frequency distributions of *M. sanguinipes* differed significantly between sweeps of both arc lengths and the enclosures on the 17 and 18 July while on 26 July significant differences were found only between enclosures and short arc sweep samples (Tables 9 and 10). For *A.*

Table 7. Stage frequency distributions of *P. nebrascensis* captured by short and long arc sweep samples and collected within enclosures on 17 and 18 July 1994 at the RB site and results of chi-square contingency table analyses. Proportions within parentheses were combined with adjacent category in analyses. (Enc=Enclosure)

Instar	17 July			18 July		
	Within Enc	Adjacent to Enc		Enc	Adjacent to Enc	
		Short Arc	Long Arc		Short Arc	Long Arc
I	-	-	-	-	-	-
II	(0.009)	(0.006)	-	-	-	-
III	0.152	0.126	0.159	0.091	0.115	0.096
IV	0.455	0.448	0.397	0.605	0.758**	0.669
V	0.393	0.425	0.444	0.305	0.126***	0.235
Adults	-	(0.006)	(0.008)	(0.021)	(0.007)	(0.004)
N	112	174	252	243	269	550
Contingency table analysis ^a		$\chi^2=0.5$ NS	$\chi^2=1.9$ NS		$\chi^2=24.4$ P<0.0001	$\chi^2=3.0$ NS

^a; contingency table analyses separately comparing long arc samples and short arc samples to enclosures.
*, P<0.05; **, P<0.01; ***, P<0.0001 in 2x2 contingency table analyses comparing each species.

deorum, the stage frequency distributions within enclosures did not differ from sweeps on 17 July (long arc: $\chi^2=2.2$, df=2, P>0.05, short arc: $\chi^2=1.8$, df=2, P>0.05) and 18 July (long arc: $\chi^2=6.1$, df=2, P>0.05, short arc: $\chi^2=0.0$, df=2, P>0.05). Tests were not performed for this species on the 21 and 26 July because most grasshoppers of this species were adults. Differences between sweeps and enclosures were not consistent among dates and no trends were evident.

I also compared sweeps of different arc lengths to each other using chi-square contingency table analyses and found that the stage-frequency distributions of *P. nebrascensis* differed significantly between arc lengths on 18 July ($\chi^2=14.9$, df=2, P=0.002), but not on the 17 July ($\chi^2=1.5$, df=2, P>0.05), 21 July ($\chi^2=0.3$, df=3, P>0.05),

Table 8. Stage frequency distributions of *P. nebrascensis* captured by short and long arc sweep samples and collected within enclosures on 21 and 26 July 1994 at the RB site and results of chi-square contingency table analyses. Proportions within parentheses were combined with adjacent category in analyses. (Enc=Enclosure)

Instar	21 July			26 July		
	Within Enc	Adjacent to Enc		Enc	Adjacent to Enc	
		Short Arc	Long Arc		Short Arc	Long Arc
I	-	-	-	-	-	-
II	-	-	-	-	-	-
III	0.062	0.054	0.056	(0.008)	(0.020)	(0.008)
IV	0.497	0.324**	0.310**	0.196	0.203	0.170
V	0.367	0.559**	0.583***	0.584	0.635	0.625
Adults	0.073	0.063	0.052	0.220	0.162	0.205
N	177	111	271	250	148	264
Contingency table analysis ^a		$\chi^2=10.6$ P=0.014	$\chi^2=20.7$ P=0.0001		$\chi^2=3.1$ NS	$\chi^2=1.0$ NS

^a, contingency table analyses separately comparing long arc samples and short arc samples to enclosures. *, P \leq 0.05; **, P \leq 0.01; ***, P \leq 0.0001 in 2x2 contingency table analyses comparing each species.

or 26 July ($\chi^2=2.4$, df=2, P>0.05). In addition, the stage frequency distributions of *M. sanguinipes* significantly differed between short arc samples and long arc samples on the 18 July ($\chi^2=13.7$, df=4, P=0.018) and 26 July ($\chi^2=12.2$, df=3, P=0.007) but not on 17 July ($\chi^2=1.5$, df=3, P>0.05) and 21 July ($\chi^2=2.8$, df=3, P>0.05). For *A. deorum*, I found no significant differences between the stage-frequency distributions captured by short arc and long arc sweeps on 17 July ($\chi^2=2.2$, df=2, P>0.05), and 18 July ($\chi^2=3.1$, df=1, P>0.05). Tests were not performed for this species on 21 and 26 July because most grasshoppers of this species were adults. For the cases that showed significant differences, further 2x2 contingency table analyses indicated that on 18 July long arc sweeps captured a smaller proportion of fourth instars of *P. nebrascensis* ($\chi^2=6.8$, df=1, P=0.009) while capturing a

Table 9. Stage frequency distributions of *M. sanguinipes* captured by short and long arc sweep samples and collected within enclosures on 17 and 18 July 1994 at the RB site and results of chi-square contingency table analyses. Proportions within parentheses were combined with adjacent category in analyses. (Enc=Enclosure)

Instar	17 July			18 July		
	Within Enc	Adjacent to Enc		Within Enc	Adjacent to Enc	
		Short Arc	Long Arc		Short Arc	Long Arc
I	-	-	-	(0.004)	-	-
II	-	(0.017)	(0.022)	0.040	0.072	-
III	0.188	0.119	0.187	0.174	0.186	0.108*
IV	0.129	0.220	0.187	0.121	0.165	0.155
V	0.218	0.390*	0.360*	0.277	0.351	0.272
Adults	0.465	0.271*	0.266**	0.388	0.227**	0.465
N	101	59	139	224	97	213
Contingency table analysis ^a		$\chi^2=10.5$ P=0.015	$\chi^2=14.1$ P=0.007		$\chi^2=30.2$ P<0.0001	$\chi^2=19.6$ P=0.002

^a; contingency table analyses separately comparing long arc samples and short arc samples to enclosures. *, P≤0.05; **, P≤0.01; ***, P≤0.0001 in 2×2 contingency table analyses comparing each species.

larger proportion of fifth instars ($\chi^2=14.5$, df=1, P<0.0001) (Table 7). Long arc sweeps captured adult *M. sanguinipes* in larger proportions than short arc sweeps on 18 July ($\chi^2=15.9$, df=1, P<0.0001) and on 26 July ($\chi^2=7.6$, df=1, P=0.005) while capturing a smaller proportion of second instars on 18 July ($\chi^2=15.7$, P<0.0001) and a smaller proportion of third instars on 26 July ($\chi^2=5.3$, df=1, P=0.021) (Table 9 and 10).

Sex ratios of grasshoppers collected within enclosures did not differ significantly from those captured by sweeps for *P. nebrascensis* on 21 July (short arc: $\chi^2=1.6$, P>0.05, long arc: $\chi^2=0.3$, P>0.05) and between enclosures and short arc sweeps on 26 July ($\chi^2=1.6$, P>0.05). For *M. sanguinipes*, sex ratios also did not differ significantly between sweeps and enclosures on 17 July (short arc: $\chi^2=0.0$, P>0.05, long arc: $\chi^2=0.2$, P>0.05),

Table 10. Stage frequency distributions of *M. sanguinipes* captured by short and long arc sweep samples and collected within enclosures 21 and 26 July 1994 at the RB site and results of chi-square contingency table analyses. Proportions within parentheses were combined with adjacent category in analyses. (Enc=Enclosure)

Instar	21 July			26 July		
	Within Enc	Adjacent to Enc		Enc	Adjacent to Enc	
		Short Arc	Long Arc		Short Arc	Long Arc
I	-	-	-	-	-	-
II	-	-	-	-	(0.015)	-
III	0.154	0.190	0.168	0.029	0.215***	0.085
IV	0.230	0.190	0.147	0.174	0.154	0.185
V	0.256	0.405	0.326	0.297	0.338	0.231
Adults	0.359	0.214	0.358	0.500	0.292**	0.500
N	78	42	95	138	65	130
Contingency table analysis ^a		$\chi^2=4.2$ NS	$\chi^2=2.4$ NS		$\chi^2=22.1$ P=0.0001	$\chi^2=4.9$ NS

^a; contingency table analyses separately comparing long arc samples and short arc samples to enclosures.
*, P \leq 0.05; **, P \leq 0.01; ***, P \leq 0.0001 in 2 \times 2 contingency table analyses comparing each species.

21 July (short arc: $\chi^2=2.7$, P $>$ 0.05, long arc: $\chi^2=1.8$, P $>$ 0.05), and on 26 July between the enclosure and long arc sweeps ($\chi^2=4.9$, P $>$ 0.05). Sex ratios of *A. deorum* did not differ between sweeps and enclosures on 17 July (short arc: $\chi^2=0.2$, P $>$ 0.05, long arc: $\chi^2=1.4$, P $>$ 0.05), 18 July (short arc: $\chi^2=0.0$, P $>$ 0.05, long arc: $\chi^2=6.1$, P $>$ 0.05), 21 July (short arc: $\chi^2=1.7$, P $>$ 0.05, long arc: $\chi^2=1.4$, P $>$ 0.05) and 26 July (short arc: $\chi^2=2.5$, P $>$ 0.05, long arc: $\chi^2=0.0$, P $>$ 0.05). However, for *M. sanguinipes*, sex ratios differed significantly from enclosures for sweep samples on 18 July (short arc: $\chi^2=5.7$, P=0.017, long arc: $\chi^2=4.7$, P=0.030) and on 26 July for short arc sweep samples ($\chi^2=12.2$, P=0.007). In addition, sex ratios of *P. nebrascensis* differed significantly between long arc sweeps and enclosures on 26 July ($\chi^2=5.0$, P=0.0257). Sweeps of both arc lengths underestimated the proportion of

Table 11. Relative abundances of species captured by short and long stride sweeps and collected within enclosures on 28 July and 3 August 1994 at the RB site and results of chi-square contingency table analysis. (Enc=Enclosure)

Species	28 July			3 August		
	Within Enc	Adjacent to Enc		Enc	Adjacent to Enc	
		Short Stride	Long Stride		Short Stride	Long Stride
<i>A. deorum</i>	0.068	0.103	0.135**	0.199	0.216	0.191
<i>A. elliotti</i>	0.085	0.063	0.051*	0.090	0.080	0.079
<i>E. costalis</i>	0.019	0.040	0.016	0.018	0.038	0.027
<i>M. infantilis</i>	0.041	0.016	0.025	0.019	0.005	0.018
<i>M. packardii</i>	0.074	0.016**	0.035**	0.029	0.024	0.047
<i>M. sanguinipes</i>	0.194	0.127*	0.137*	0.144	0.099	0.115
<i>P. nebrascensis</i>	0.275	0.401**	0.406***	0.361	0.343	0.388
<i>P. delicatula</i>	0.066	0.048	0.055	0.063	0.089	0.056
<i>X. corallipes</i>	0.105	0.115	0.084	0.038	0.047	0.050
Other	0.072	0.071	0.057	0.039	0.061	0.029
N	484	252	512	667	213	340
Contingency		$\chi^2=33.8$	$\chi^2=44.4$		$\chi^2=11.9$	$\chi^2=6.9$
Table analyses ^a		P=0.0001	P<0.0001		P: NS	P: NS

^a, contingency table analyses separately comparing short stride samples and long stride samples to enclosures. *, $P \leq 0.05$; **, $P \leq 0.01$; ***, $P \leq 0.0001$ in 2×2 contingency table analyses comparing each species.

male *M. sanguinipes* on 18 July by 28.0% for short arc sweeps and by 15.9% for long arc sweeps. In contrast, long arc sweeps captured larger proportions of male *P. nebrascensis* (19.6%) than collected within the enclosure on 26 July.

Long and Short Stride Sweep Samples. On two dates, I evaluated the accuracy in which sweeps of different sampler stride lengths capture species, stages, and sexes by sweeping adjacent to enclosures with stride lengths of 1 m and 0.6 m. On one of these two dates, the frequency distributions of species captured by long stride samples and short stride samples significantly differed from those collected within enclosures (Table 11).

Table 12. Stage frequency distributions of *M. sanguinipes* captured in long and short stride sweeps and collected within enclosures on 28 July and 3 August 1994 and results of chi-square contingency table analyses. Proportions within parentheses were combined with adjacent category in analyses. (Enc=Enclosure)

Instar	28 July			3 August		
	Within Enc	Adjacent to Enc		Within Enc	Adjacent to Enc	
		Short Stride	Long Stride		Short Stride	Long Stride
I	-	-	-	-	-	-
II	-	-	-	-	-	-
III	(0.021)	(0.094)	(0.029)	-	(0.047)	(0.077)
IV	0.160	0.344	0.271	0.094	0.238	0.205
V	0.234	0.313	0.357	0.135	0.190	0.256
Adults	0.606	0.344**	0.371**	0.771	0.571	0.538**
N	94	32	70	96	21	39
Contingency		$\chi^2=7.5$	$\chi^2=8.9$		$\chi^2=4.2$	$\chi^2=7.2$
Table analyses ^a		P=0.0296	P=0.0116		P: NS	P=0.0268

^a; contingency table analyses separately comparing long stride samples and short stride samples to enclosures. *, $P \leq 0.05$; **, $P \leq 0.01$; ***, $P \leq 0.0001$ in 2×2 contingency table analyses comparing each species.

On this date, sweeps of both stride lengths overestimated *P. nebrascensis* and underestimated *M. sanguinipes* and *M. packardii*.

I also compared sweeps taken with different stride lengths to each other and found that long stride sweeps did not capture species in significantly different proportions than short stride sweeps on 28 July ($\chi^2=11.5$, $P > 0.05$) and on 3 August ($\chi^2=10.9$, $P > 0.05$).

The stage frequency distributions of *M. sanguinipes* and *P. nebrascensis* differed significantly between sweeps and enclosures on 28 July and 3 August (Tables 12 and 13). On both dates, regardless of stride length sweeps captured fewer adults of *M. sanguinipes* and *P. nebrascensis* and in most cases these differences were significant. Sweeps also tended to overestimate fifth instars of *P. nebrascensis*.

Figure 13. Stage frequency distributions of *P. nebrascensis* captured in long and short stride sweeps and collected within enclosures on 28 July and 3 August 1994 and results of chi-square contingency table analyses. Proportions within parentheses were combined with adjacent category in analyses. (Enc=Enclosure)

Instar	28 July			3 August		
	Within Enc	Adjacent to Enc		Within Enc	Adjacent to Enc	
		Short Stride	Long Stride		Short Stride	Long Stride
I	-	-	-	-	-	-
II	-	-	-	-	-	-
III	(0.008)	-	-	-	-	-
IV	0.128	0.099	0.139	0.033	0.055	0.053
V	0.496	0.594	0.620*	0.266	0.452**	0.371*
Adults	0.376	0.307	0.240**	0.701	0.493**	0.576*
N	133	101	208	241	73	132
Contingency		$\chi^2=2.2$	$\chi^2=7.3$		$\chi^2=10.7$	$\chi^2=6.0$
Table analyses ^a		P: NS	P=0.0225		P=0.0048	P=0.0494

^a; contingency table analyses separately comparing long stride samples and short stride samples to enclosures. *, $P \leq 0.05$; **, $P \leq 0.01$; ***, $P \leq 0.0001$ in 2×2 contingency table analyses comparing each species.

When testing for differences between short and long stride samples, I found that the stage frequency distributions did not differ between short and long stride sweeps for *M. sanguinipes* on 28 July ($\chi^2=2.1$, $df=2$, $P>0.05$) and 3 August ($\chi^2=0.8$, $df=2$, $P>0.05$) and for *P. nebrascensis* on 28 July ($\chi^2=2.1$, $df=2$, $P>0.05$) and 3 August ($\chi^2=1.4$, $df=2$, $P>0.05$).

For *P. nebrascensis*, sex ratios did not differ significantly between sweeps of both stride lengths and the enclosure on 28 July (short stride: $\chi^2=0.3$, $P>0.05$, long stride: $\chi^2=0.2$, $P>0.05$) and between long stride sweeps and the enclosure on 3 August ($\chi^2=2.6$, $P>0.05$). Sex ratios of *M. sanguinipes* also did not differ between sweeps and enclosures on 28 July (short stride: $\chi^2=1.0$, $P>0.05$, long stride $\chi^2=0.3$, $P>0.05$) and 3 August (short

stride: $\chi^2=0.6$, $P>0.05$, long stride: $\chi^2=0.9$, $P>0.05$). For *A. deorum*, sex ratios did not differ significantly between enclosures and long stride sweeps on 28 July ($\chi^2=0.9$, $P>0.05$) and between enclosures and sweeps of both stride lengths on 3 August (short stride: $\chi^2=0.0$, $P>0.05$, long stride: $\chi^2=0.6$, $P>0.05$). Sex ratios, however, significantly differed between short stride sweeps and enclosures for *A. deorum* on 28 July ($\chi^2=5.0$, $P>0.05$) and *P. nebrascensis* on the 3 August ($\chi^2=6.8$, $P>0.05$). Short stride sweeps captured 30.9% more male *A. deorum* on 28 of July than collected within enclosures and 22.9% more male *P. nebrascensis* on 3 August.

I also tested for differences in sex ratios between short and long stride sweeps and found no significant differences in all cases tested. I tested for differences for *A. deorum* on 28 July ($\chi^2=2.8$, $P>0.05$) and 3 August ($\chi^2=0.4$, $P>0.05$), for *M. sanguinipes* on 28 July ($\chi^2=2.1$, $P>0.05$) and 3 August ($\chi^2=0.4$, $P>0.05$), and for *P. nebrascensis* on 28 July ($\chi^2=2.1$, $P>0.05$) and 3 August ($\chi^2=2.0$, $P>0.05$).

Repeated samples within enclosures

I also evaluated sweep sampling accuracy by examining trends in the cumulative proportions of species captured as enclosures were repeatedly sampled (Figures 4 through 13). I found that *P. nebrascensis* was consistently overrepresented, by a wide margin, during the initial sampling of enclosures on nine of ten dates. On the 3 August, however, this species initially was underrepresented, but then overrepresented during later sampling. For other species, differences were not consistent among dates and often the direction bias (i.e overrepresentation or underrepresentation) was not consistent during sampling. For

example, *M. sanguinipes* was overrepresented in sweeps on 28 June but underrepresented on 8, 10, 17, 18, and 28 July and 3 August. On 29 June and 26 July, the cumulative proportions of *M. sanguinipes* captured during sampling were initially greater than the final abundances but then fell below the final abundances during later sampling. The opposite occurred for this species on the 21 July. For *A. deorum*, the cumulative proportions captured by during sampling usually differed little from the final abundances and the cumulative proportions captured often fluctuated above and below the actual abundances.

Mowed enclosures

I did not test the hypothesis that capture varies with vegetation height because the total number of grasshoppers captured for each species was small. Thus making it unrealistic to compare a species' rate of capture in mowed and unmowed areas. The species assemblages, however, differed between mowed and unmowed enclosures. Whereas *P. nebrascensis* was the most abundant species found within unmowed enclosures, *A. elliotti* was the most abundant species within the mowed enclosures on all three dates (Figures 14-16).

I also observed consistent trends in the repeated sampling of mowed enclosures. On 27 July and 1 August, *A. elliotti* was underrepresented by sweep sampling while *X. corallipes* was overrepresented by sweep sampling on all three dates. This suggests that sweep sampling may be problematic in other species assemblages.

Figure 4. Cumulative proportions of the nine most abundant species captured during the repeated sampling of an enclosure on 28 June, 1994. Dotted lines represent the total proportions captured within the enclosure.

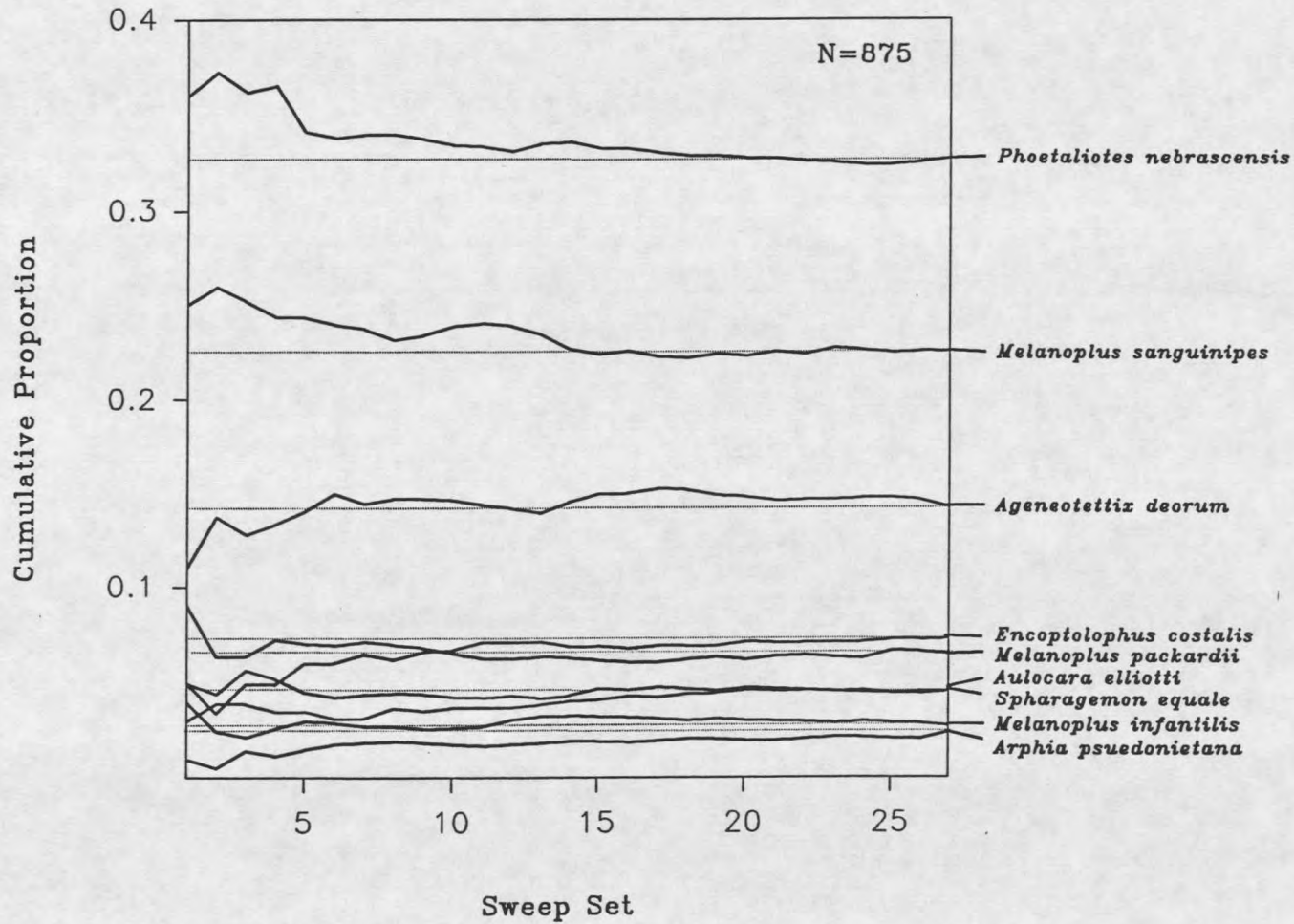


Figure 5. Cumulative proportions of the eight most abundant species captured during the repeated sampling of an enclosure on 29 June, 1994. Dotted lines represent the final or absolute proportions captured.

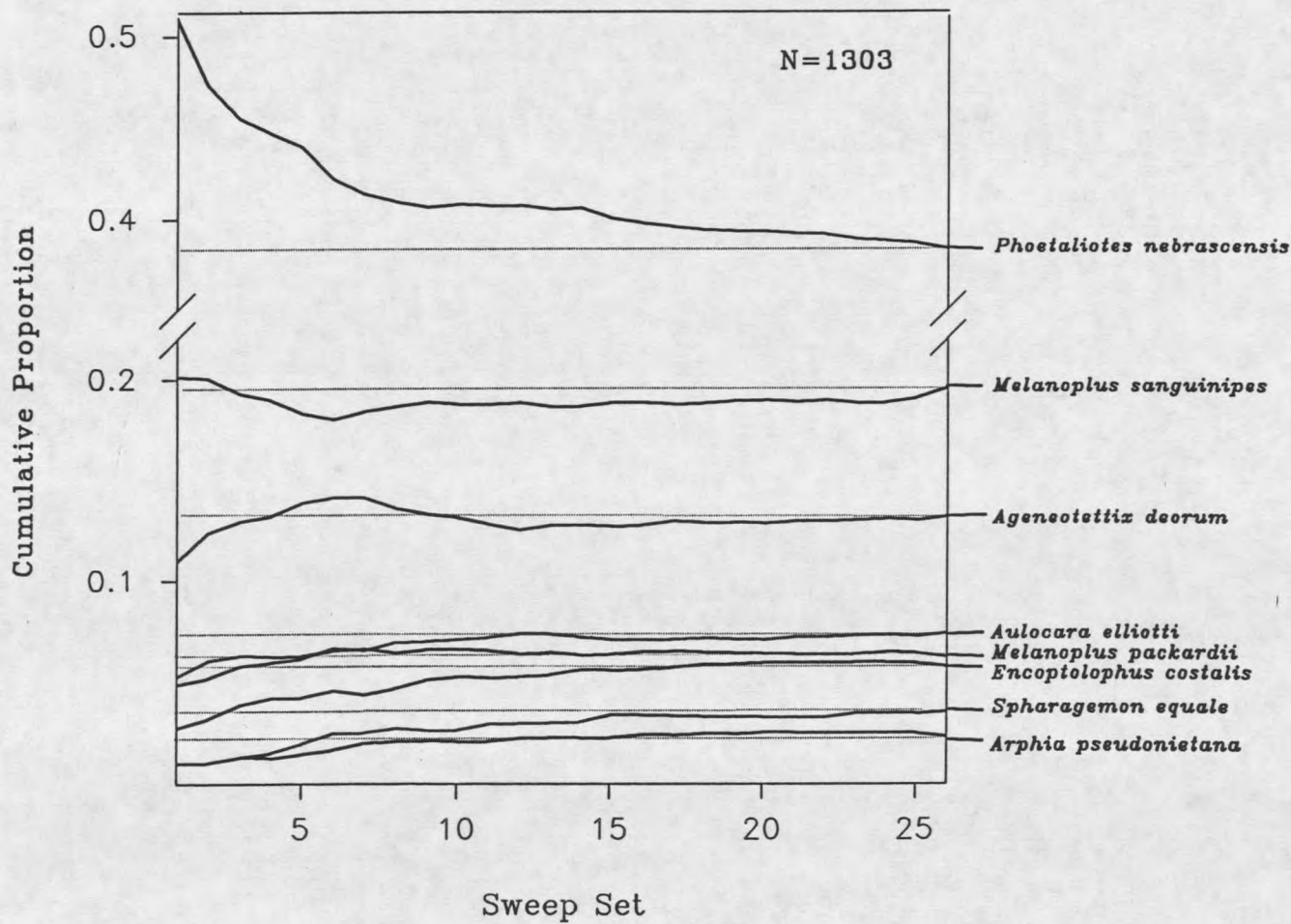


Figure 6. Cumulative proportions of the eight most abundant species captured during the repeated sampling of an enclosure on 8 July, 1994. Dotted lines represent the final or absolute proportions captured.

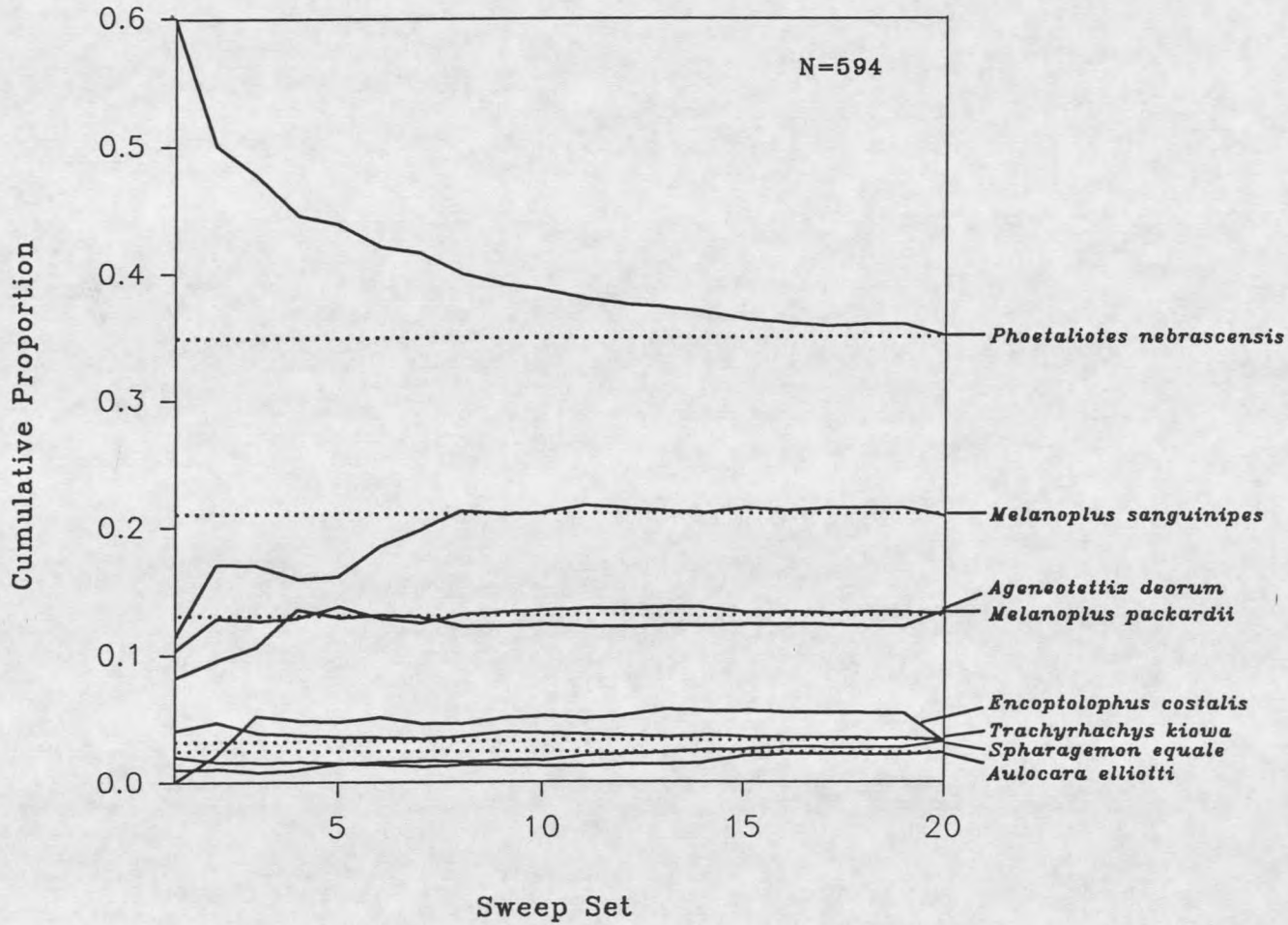


Figure 7. Cumulative proportions of the seven most abundant species captured during the repeated sampling of an enclosure on 10 July, 1994. Dotted lines represent the final or absolute proportions captured.

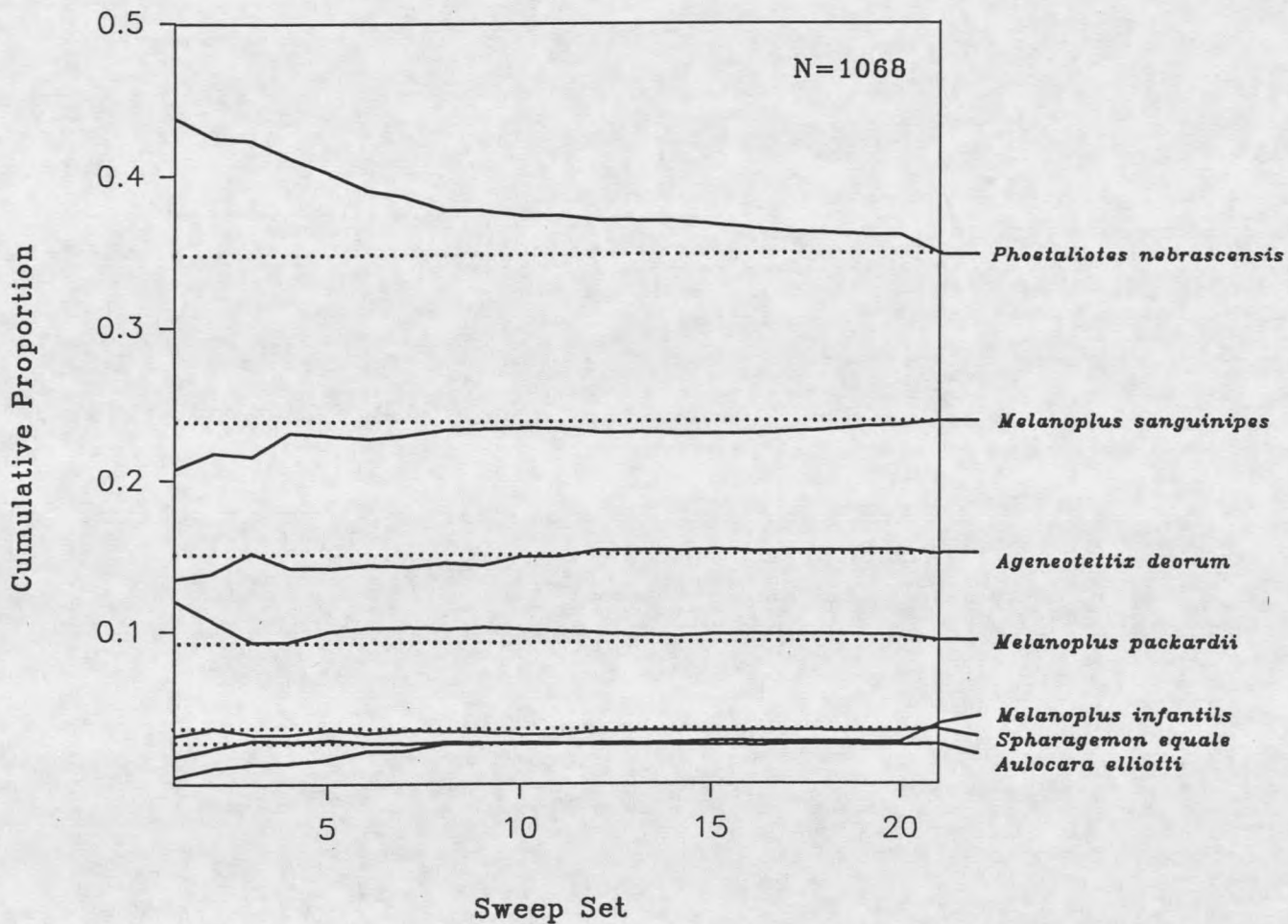


Figure 8. Cumulative proportions of seven most abundant species captured during the repeated sampling of an enclosure on 17 July, 1994. Dotted lines represent the final or absolute proportions captured.

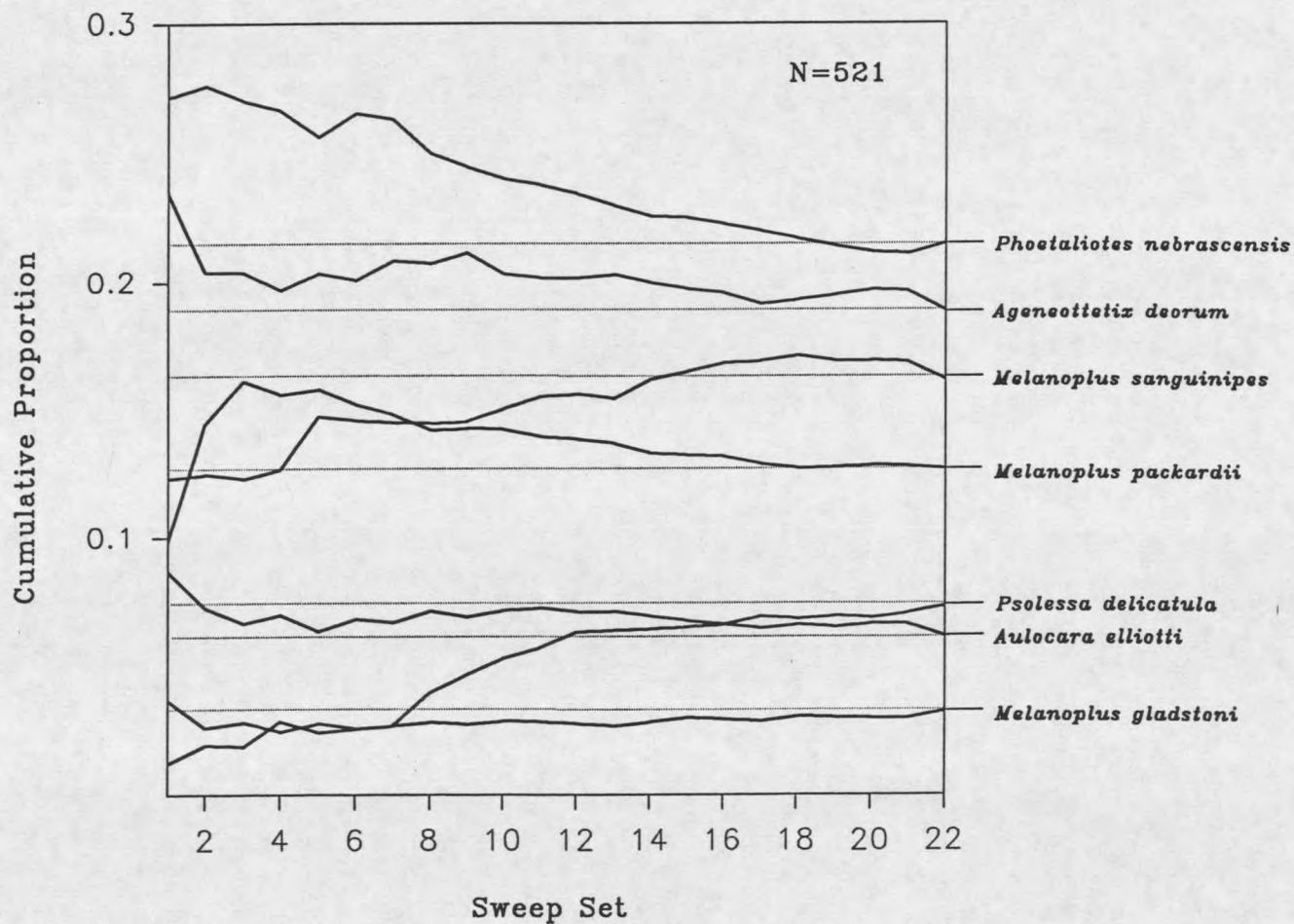


Figure 9. Cumulative proportions of the seven most abundant species captured during the repeated sampling of an enclosure on 18 July, 1994. Dotted lines represent the final or absolute proportions captured.

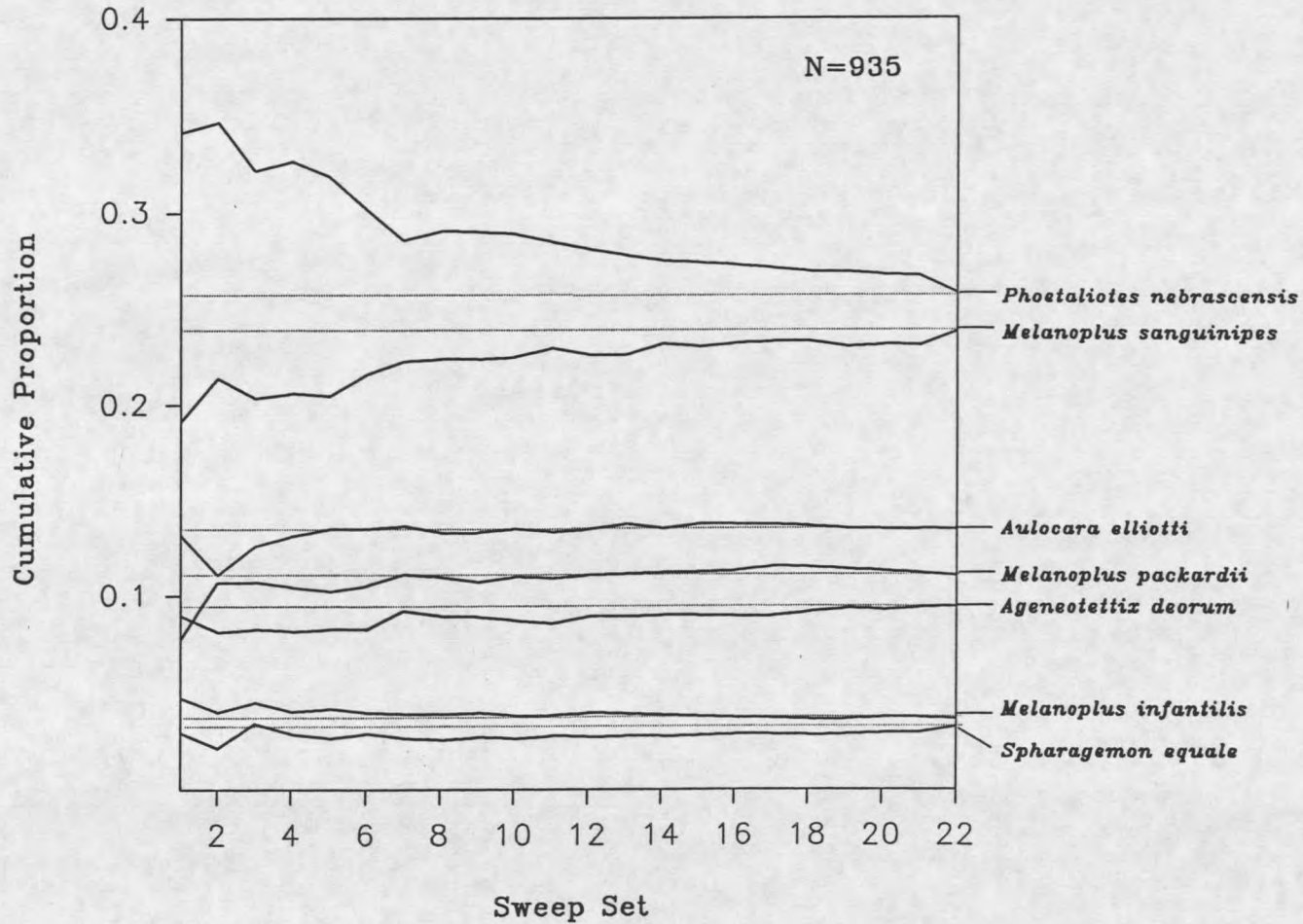


Figure 10. Cumulative proportions of the seven most abundant species captured during the repeated sampling of an enclosure on 21 July, 1994. Dotted lines represent the final or absolute proportions captured.

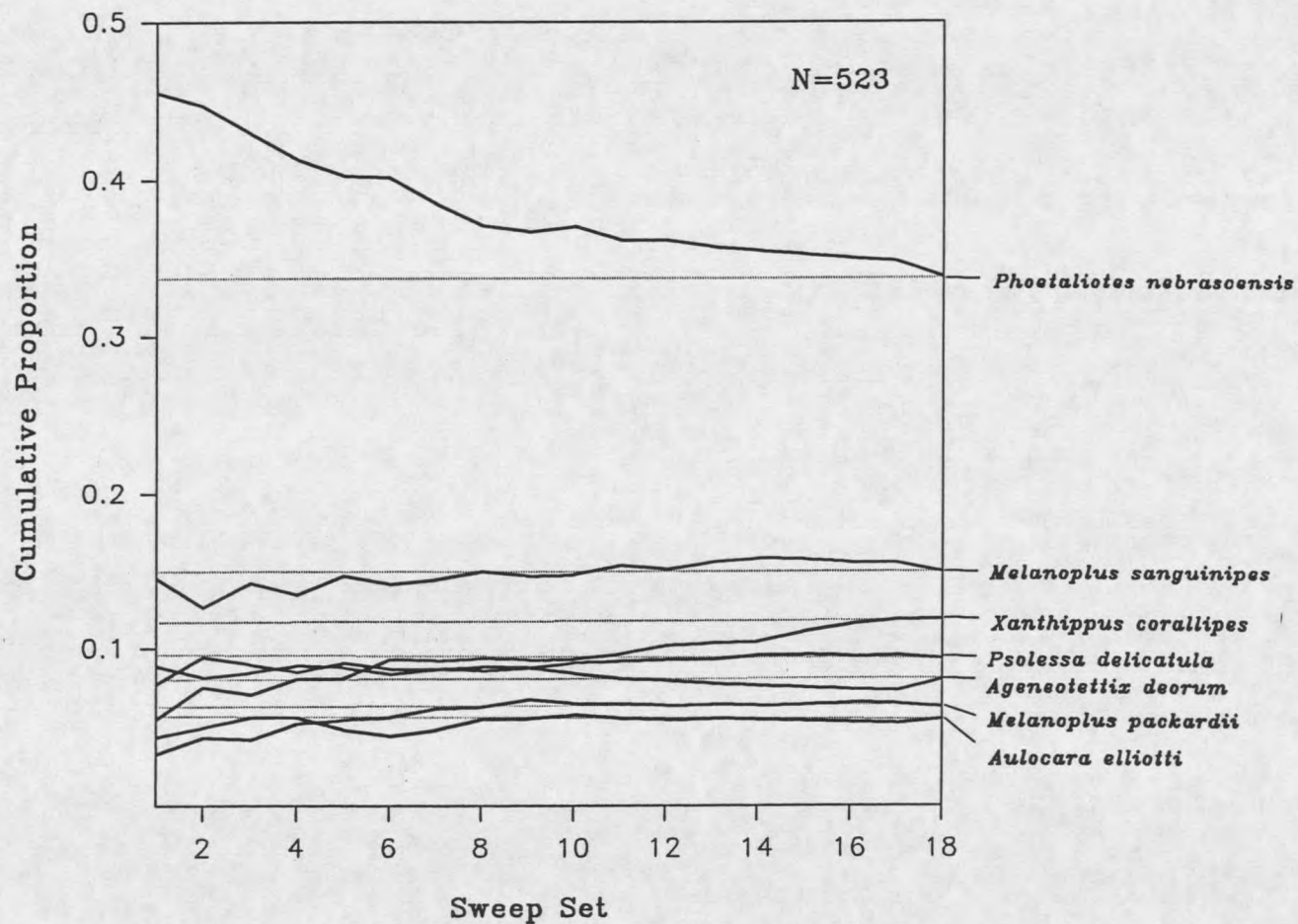


Figure 11. Cumulative proportions of the six most abundant species captured during the repeated sampling of an enclosure on 26 July, 1994. Dotted lines represent final or absolute proportions captured.

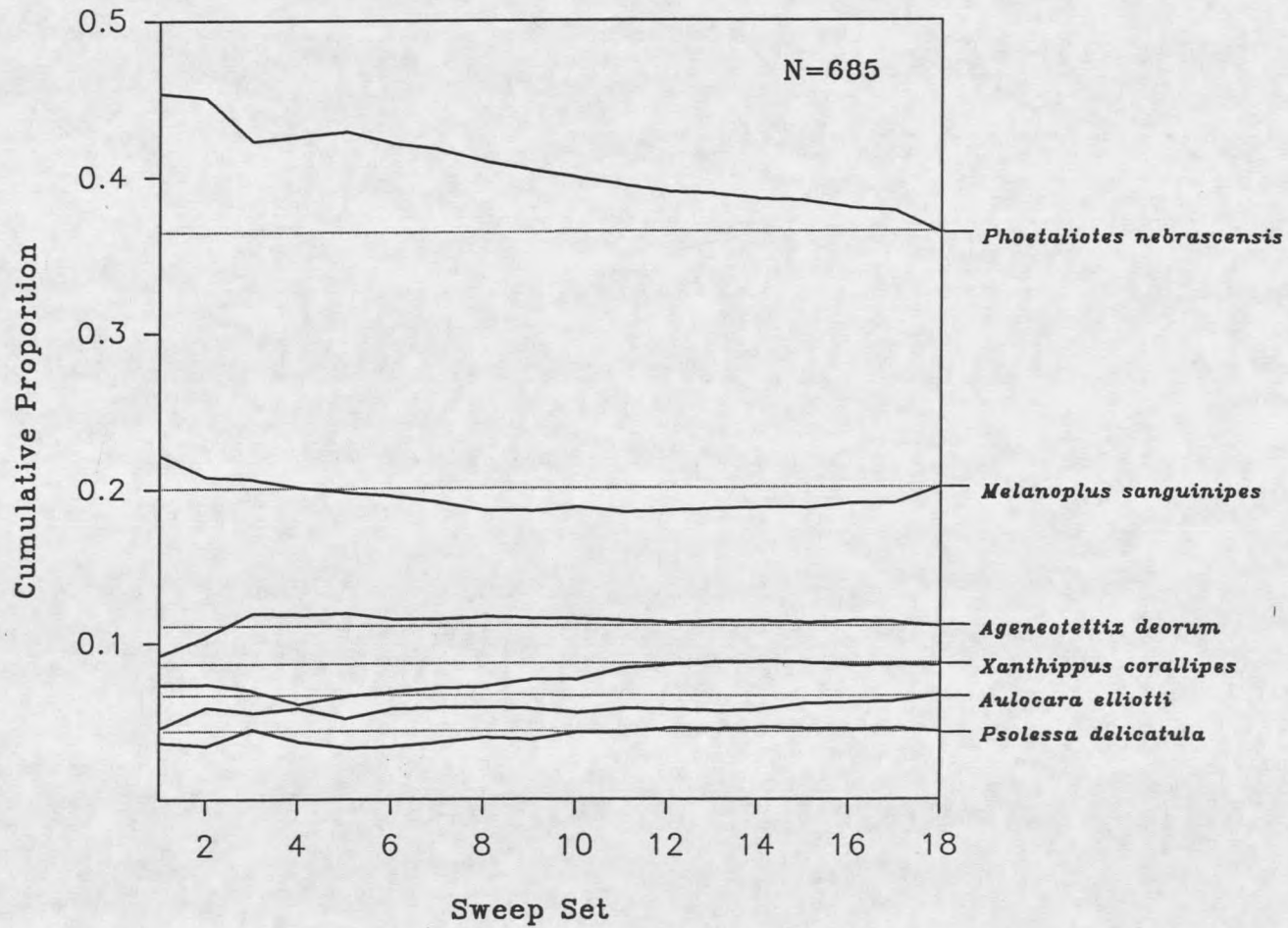


Figure 12. Cumulative proportions of the eight most abundant species captured during the repeated sampling of an enclosure on 28 July, 1994. Dotted lines represent the final or absolute proportions captured.

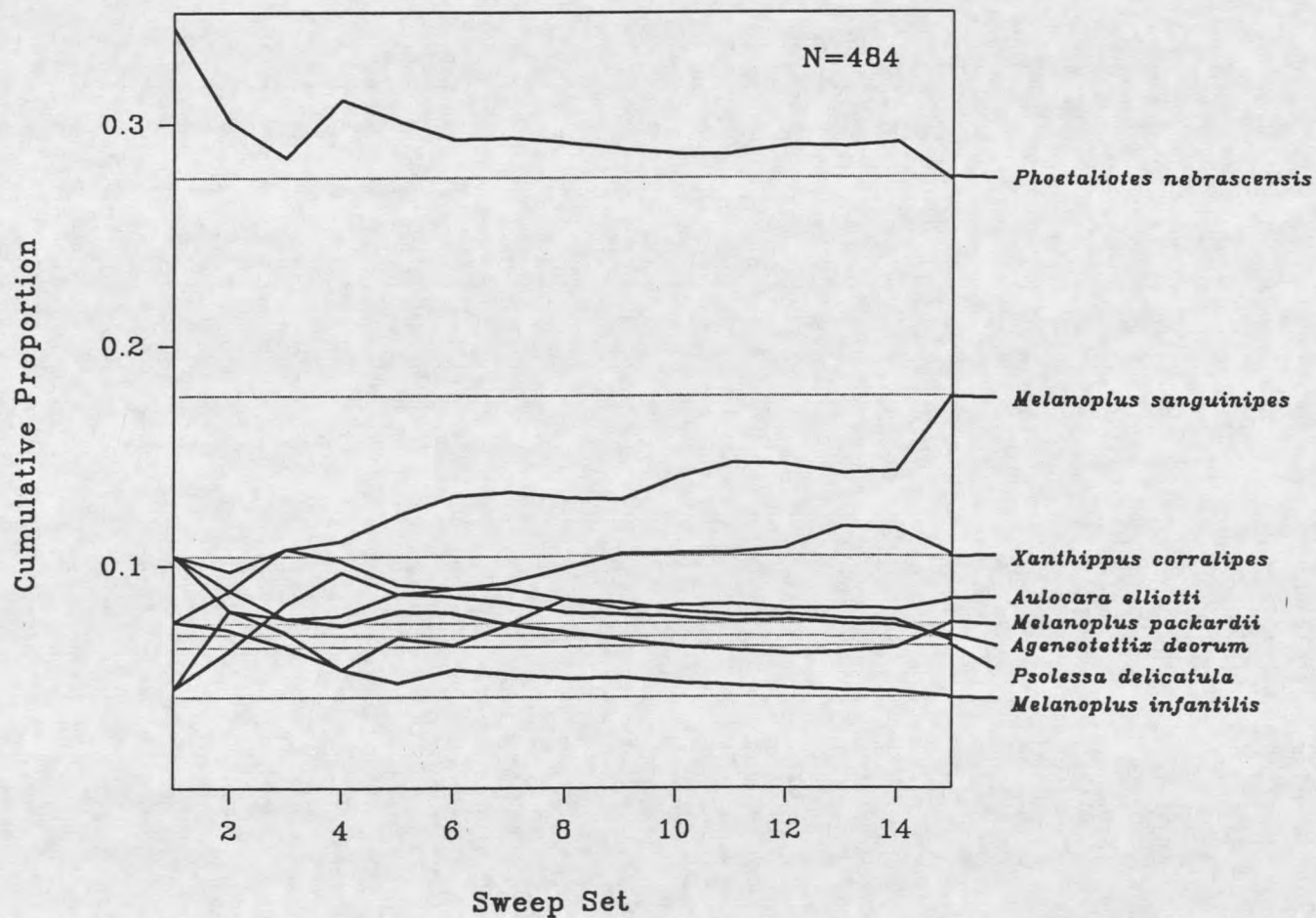


Figure 13. Cumulative proportions of the seven most abundant species captured during the repeated sampling of an enclosure on 3 August, 1994. Dotted lines represent final or absolute proportions captured.

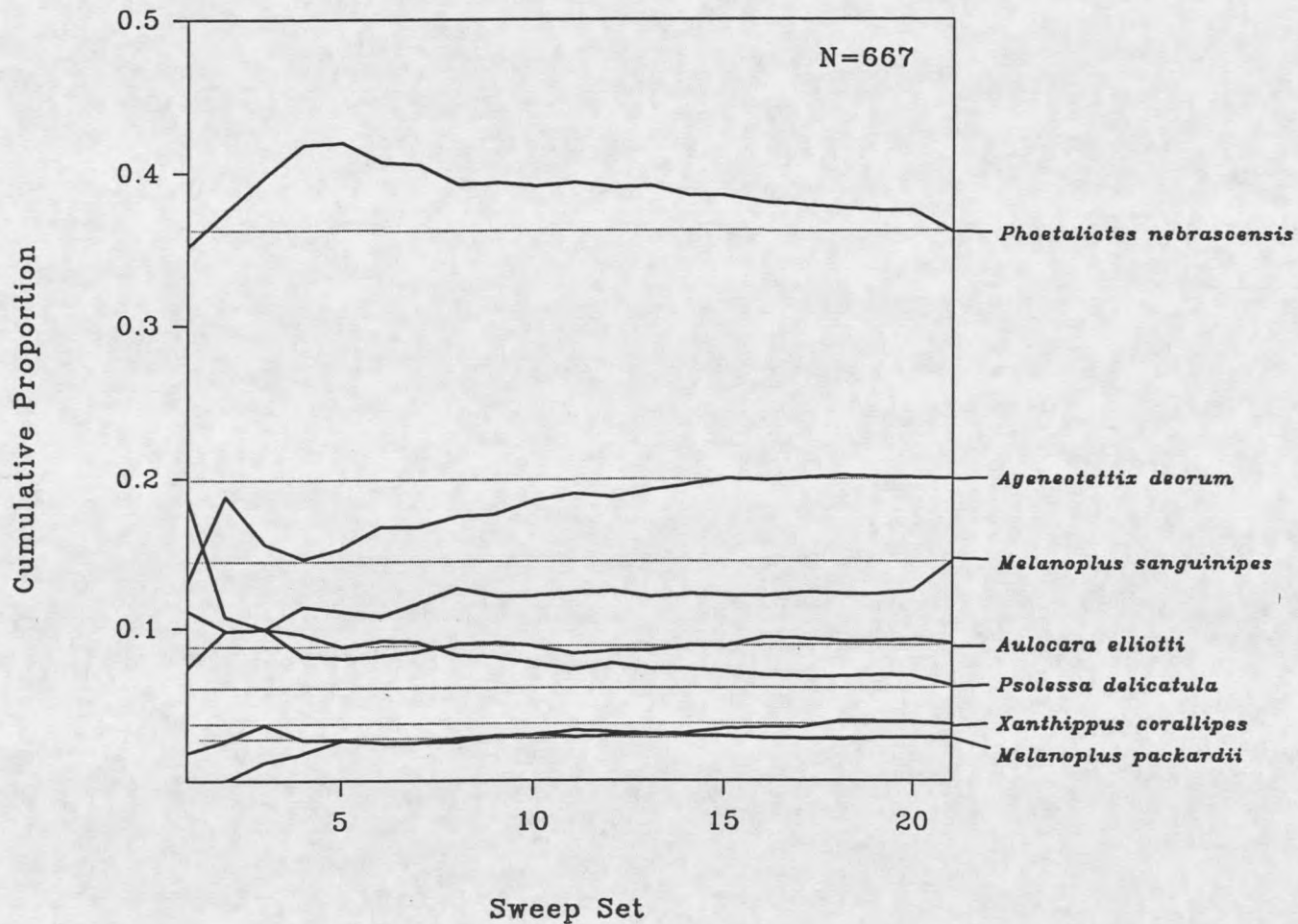


Figure 14. Cumulative proportions of the seven most abundant species captured during the repeated sampling of a mowed enclosure on 27 July, 1994. Dotted lines represent the final or absolute proportions captured.

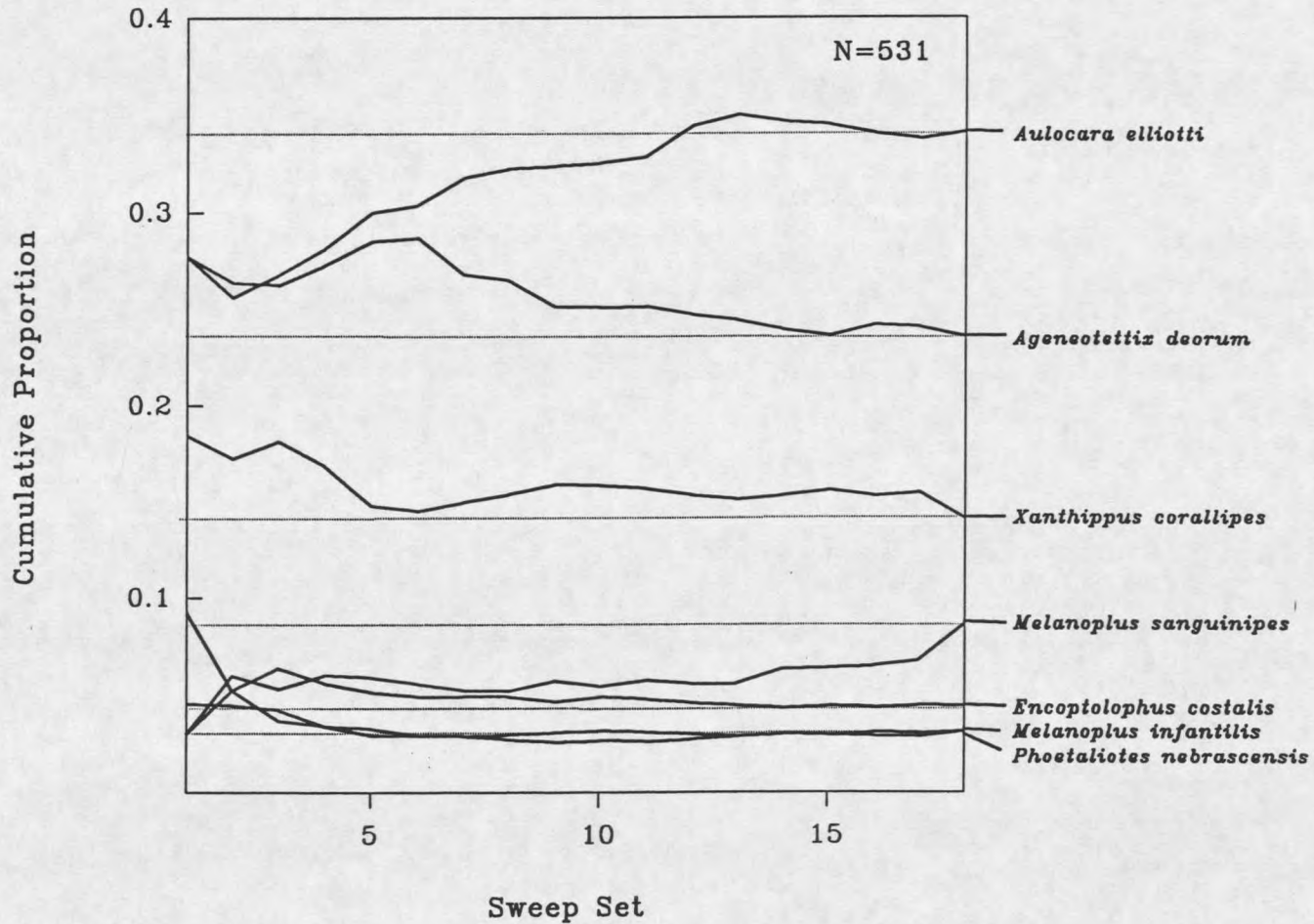


Figure 15. Cumulative proportions of the ten most abundant species captured during the repeated sampling of a mowed enclosure on 1 August, 1994. Dotted lines represent the final or absolute proportions captured.

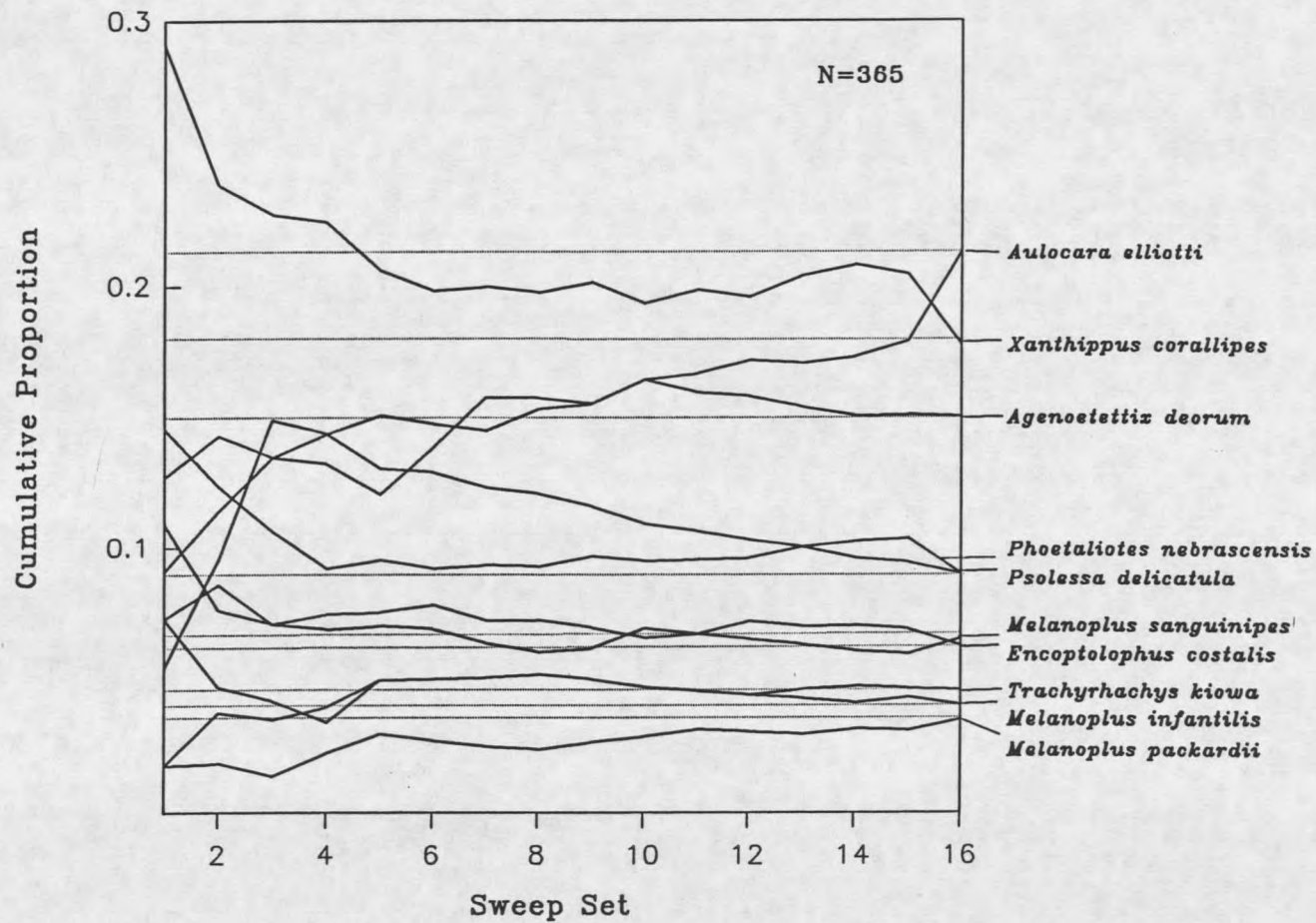
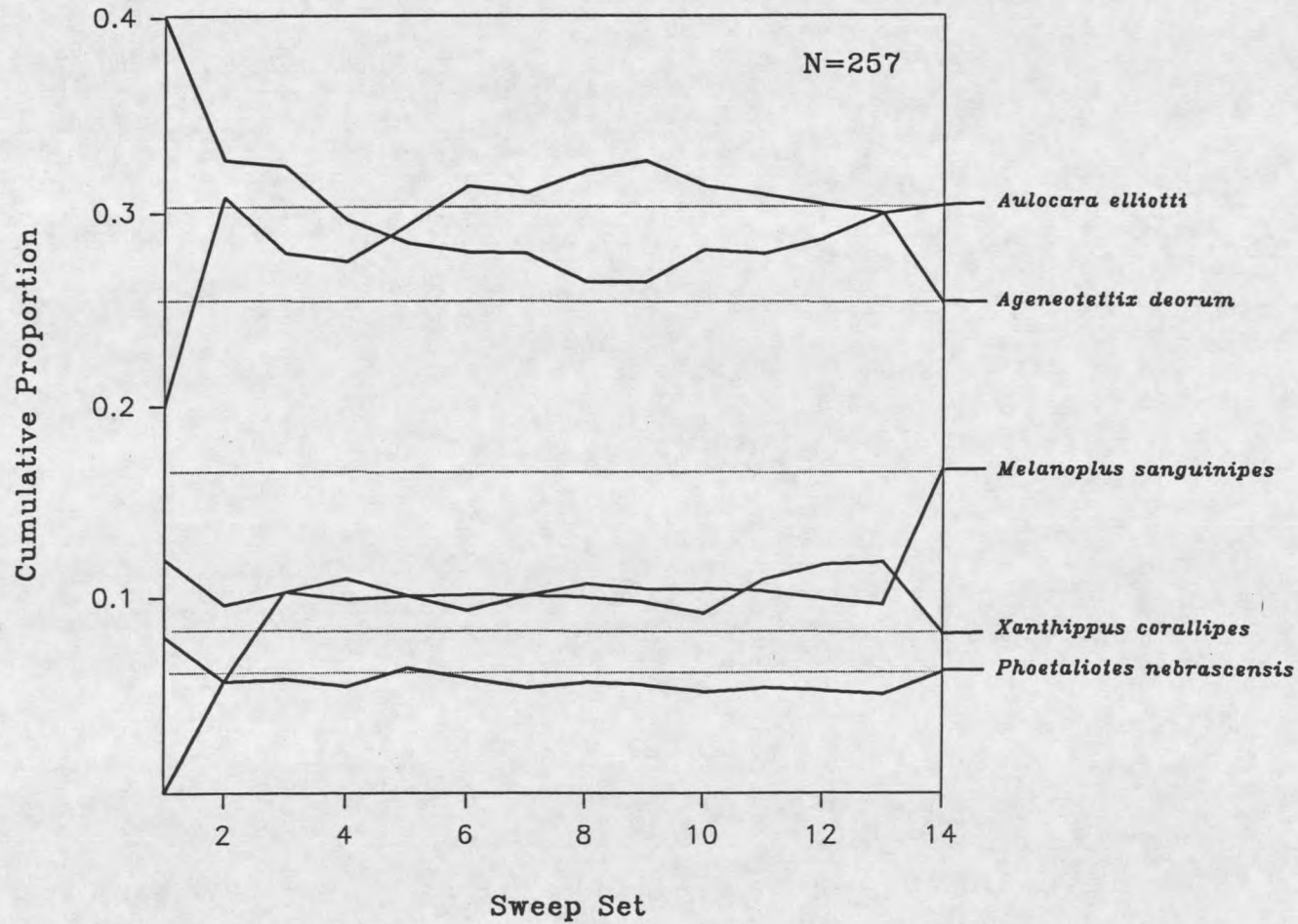


Figure 16. Cumulative proportions of the five most abundant species captured during the repeated sampling of a mowed enclosure on 5 August, 1994. Dotted lines represent final or absolute proportions captured.



Sweep Height

Grasshoppers often attempt to escape an oncoming sweep net by jumping. Because different species, developmental stages, and sexes jump to different heights (e.g. Gabriel 1985, Bennet-Clark 1975), I hypothesized that the height of the sweep net above the ground affects the number of grasshoppers of each species/stage/sex category that are captured. For the dates on which we alternated sweeping with the net 20 cm (high) or 5 cm (low) above the ground, low sweep samples captured 1.7 to 4.0 times more grasshoppers than high sweep samples (Table 14).

Table 14. Mean number of grasshoppers captured in high and low sweep samples taken during 1994 and results of factorial analysis of variance comparing the mean number of grasshoppers captured per species in high and low sweep samples.

Date	High		Low		F-value	P-value
	Mean	SE	Mean	SE		
6/28	69.2	(10.2)	275.3	(22.6)	169.7	P < 0.0001
6/30	77.3	(21.2)	175.5	(15.1)	76.3	P < 0.0001
7/12	81.8	(31.1)	156.8	(5.8)	46.1	P < 0.0001
8/10	33.3	(4.5)	57.5	(4.8)	16.8	P < 0.0001

On 28, and 30 June, I found significant height×species interactions in the factorial ANOVA performed on the square root of grasshopper counts (Table 15). In addition, the overall frequency distributions of species significantly differed between high and low sweep samples on three of the four dates (Table 16). Proportions differed between heights by as much as 7.8% for *E. costalis* and 8.3% for *P. nebrascensis* on 28 June.

Table 15. F-value, DF, and significance of height×species interactions and height×instar interactions from factorial analysis of variance; some analyses were not performed because all grasshoppers were adults.

Date	Height×Species		Height×Instar					
	F	DF	<i>A. deorum</i>		<i>M. sanguinipes</i>		<i>P. nebrascensis</i>	
			F	DF	F	DF	F	DF
6/28	6.7***	7, 80	0.9	2, 30	3.3*	4, 50	11.5***	3, 40
6/30	3.3**	7, 80	1.8	2, 30	1.0	4, 50	4.6**	3, 40
7/12	2.1	7, 80	1.2	2, 30	1.1	4, 50	0.4	2, 30
8/10	0.3	7, 80	-	-	0.7	2, 30	5.7*	1, 20

*, $P \leq 0.05$; **, $P \leq 0.01$; ***, $P \leq 0.0001$ in the factorial analysis of variance.

Table 16. Frequency distributions of species captured by high and low sweep samples on four collection dates during 1994 at the RB site and results of chi-square contingency table analyses.

Species	28 June Sampler #2		30 June Sampler #1		12 July Sampler #3		10 August Sampler #1	
	Low	High	Low	High	Low	High	Low	High
<i>A. deorum</i>	0.157	0.171	0.144	0.177	0.155	0.189	0.243	0.265
<i>A. ellioti</i>	0.082**	0.125	0.051	0.067	0.040	0.043	0.075	0.085
<i>E. costalis</i>	0.085***	0.007	0.090	0.078	0.103**	0.053	0.136	0.125
<i>M. infantilis</i>	0.031***	0.080	0.018	0.030	0.015	0.016	0.046	0.035
<i>M. packardii</i>	0.090**	0.140	0.088	0.086	0.083	0.108	0.023	0.005
<i>M. sanguinipes</i>	0.275	0.299	0.167	0.185	0.180	0.161	0.116	0.100
<i>P. nebrascensis</i>	0.247**	0.164	0.384	0.332	0.361	0.381	0.197	0.180
<i>P. delicatula</i>	-	-	-	-	-	-	0.081	0.115
<i>S. equale</i>	0.010*	0.000	0.031*	0.011	0.031**	0.006	-	-
<i>T. kiowa</i>	-	-	-	-	0.013	0.012	-	-
<i>X. corallipes</i>	-	-	-	-	-	-	0.032	0.045
Other	0.024	0.014	0.026	0.034	0.019	0.031	0.049	0.045
N	1652	415	1053	464	942	491	345	200
Contingency table analysis	$\chi^2=78.9$ $P < 0.0001$		$\chi^2=15.7$ $P=0.048$		$\chi^2=25.7$ $P=0.002$		$\chi^2=6.1$ NS	

*, $P \leq 0.05$; **, $P \leq 0.01$; ***, $P \leq 0.0001$ in 2×2 contingency table analyses for each species.

Developmental stages were also captured in different proportions by high and low sweep samples. In the factorial analysis of variance, I found significant interactions between height and instar for *P. nebrascensis* on 28 June, 30 June, and 10 August but not on 12 July. Height \times instar interactions were significant for *M. sanguinipes* on 28 June but not on the other three dates and I found no interactions between height and instar for *A. deorum* (Table 15). The stage frequency distributions differed significantly between high and low sweep samples in chi-square contingency table analyses for *P. nebrascensis* on 28 June, 30 June, and 10 August, for *M. sanguinipes* on 28 and 30 June, and for *A. deorum* on 12 July (Tables 17-19).

Table 17. Stage-frequency distributions of *Phoetaliotes nebrascensis* captured by high and low sweep samples on four collection dates during 1994 at the RB site and results of chi-square contingency table analyses. Proportions in parentheses were combined with adjacent category in analyses.

Instar	28 June Sampler #2		30 June Sampler #1		12 July Sampler #3		10 August Sampler #1	
	Low	High	Low	High	Low	High	Low	High
I	0.127**	-	0.050**	0.006	-	-	-	-
II	0.505**	0.324	0.381	0.305	(0.006)	(0.005)	-	-
III	0.353**	0.603	0.535	0.552	0.388	0.374	-	-
IV	0.015**	0.074	0.035**	0.136	0.547	0.578	-	(0.030)
V	-	-	-	(0.013)	0.065	0.048	0.118**	0.324
Adults	-	-	-	-	-	-	0.882**	0.676
N	408	68	404	154	340	187	68	34
Contingency	$\chi^2=30.8$		$\chi^2=25.7$		$\chi^2=0.8$		$\chi^2=8.2$	
Table analysis	P<0.0001		P<0.0001		NS		P=0.012	

*, P \leq 0.05; **, P \leq 0.01; ***, P \leq 0.0001 in 2 \times 2 contingency table analyses for each instar.

Table 18. Stage-frequency distributions of *Melanoplus sanguinipes* captured by high and low sweep samples on four collection dates during 1994 at the RB site and results of chi-square contingency table analyses. Proportions within parentheses were combined with adjacent group in analyses.

Instar	28 June Sampler #2		30 June Sampler #1		12 July Sampler #3		10 August Sampler #1	
	Low	High	Low	High	Low	High	Low	High
I	0.121**	0.008	0.074	0.047	(0.006)	-	-	-
II	0.176**	0.073	0.239	0.140	0.212	0.114	-	-
III	0.253	0.250	0.278	0.244	0.371	0.405	(0.025)	-
IV	0.246**	0.379	0.222	0.209	0.188	0.203	0.150	0.150
V	0.203**	0.290	0.188**	0.360	0.229	0.279	0.375	0.500
Adults	(0.007)	-	(0.006)	(0.058)	(0.029)	(0.038)	0.475	0.350
N	454	124	176	86	170	79	40	20
Contingency	$\chi^2=29.2$		$\chi^2=11.0$		$\chi^2=3.4$		$\chi^2=1.0$	
Table analysis	P<0.0001		P=0.029		NS		NS	

*, $P \leq 0.05$; **, $P \leq 0.01$; ***, $P \leq 0.0001$ in 2×2 contingency table analyses for each instar.

Table 19. Stage-frequency distributions of *Ageneotettix deorum* captured by high and low sweep samples on four collection dates during 1994 at the RB site and results of chi-square contingency table analyses. Proportions within parentheses were combined with adjacent group in analyses.

Instar	28 June Sampler #2		30 June Sampler #1		12 July Sampler #3		10 August Sampler #1	
	Low	High	Low	High	Low	High	Low	High
I	-	-	-	-	-	-	-	-
II	(0.023)	-	(0.020)	-	-	-	-	-
III	0.127	0.056	0.099	0.122	(0.014)	-	-	-
IV	0.421	0.465	0.414	0.427	0.130	0.054	-	-
V	0.425	0.437	0.447	0.390	0.480	0.387	-	-
Adults	0.027	0.042	0.040	0.061	0.390**	0.560	1.000	1.000
N	136	52	152	82	146	93	85	53
Contingency	$\chi^2=3.2$		$\chi^2=1.2$		$\chi^2=7.9$			
Table analysis	NS		NS		P=0.019			

*, $P \leq 0.05$; **, $P \leq 0.01$; ***, $P \leq 0.0001$ in 2×2 contingency table analyses for each instar.

Sex ratios of adult grasshoppers did not differ significantly between heights. Chi-square contingency table analyses were performed when adult grasshoppers were present in sufficient numbers for *P. nebrascensis* on the 10 August ($\chi^2=2.0$, $P>0.05$), for *M. sanguinipes* on the 10 August ($\chi^2=2.1$, $P>0.05$), and for *A. deorum* on 12 July ($\chi^2=0.1$, $P>0.05$) and 10 August ($\chi^2=0.2$, $P>0.05$).

Sweep Arc

Because different species, stages, and sexes of grasshoppers may jump at different distances from the sampler, I hypothesized that the distance between the sampler and sweep net (i.e. radius of sweep arc) affects the number of grasshoppers of each category that are captured. Sweep samples with an long arc radius of 1.0 m captured 1.8 to 2.0 times more grasshoppers than samples taken with a short arc radius of 0.5 m (Table 20).

Table 20. Mean number of grasshoppers captured in short and long arc sweep samples on four collection dates in 1994 and results of factorial analysis of variance comparing the mean number of grasshoppers captured per species per sample.

Date	Short Arc		Long Arc		F-value	P-value
	Mean	SE	Mean	SE		
7/8	170.0	(15.7)	337.2	(12.4)	103.9	P<0.0001
7/11	129.7	(11.5)	261.0	(15.5)	87.3	P<0.0001
7/13	134.0	(7.3)	242.6	(17.3)	34.2	P<0.0001
8/9	59.2	(4.3)	108.7	(15.0)	28.9	P<0.0001

Table 21. F-value, DF, and significance of arc length×species interactions and arc length×instar interactions from factorial analysis of variance; some analyses were not performed due to low species abundance or because all grasshoppers were adults.

Date	Arc length×Species		Arc length×Instar							
			<i>A. deorum</i>		<i>M. sanguinipes</i>		<i>P. nebrascensis</i>		<i>M. infantilis</i>	
	F	DF	F	DF	F	DF	F	DF	F	DF
7/8	4.5**	7, 80	1.6	3, 40	1.9	4, 50	5.5**	3, 40	-	-
7/11	3.9**	6, 70	2.5	2, 30	2.6*	4, 50	2.6	3, 40	-	-
7/13 ^a	4.1**	7, 160	15.0***	3, 80	-	-	-	-	3.2*	3, 80
8/9	2.0	8, 90	-	-	8.3**	1, 20	7.4*	1, 20	-	-

*, $P \leq 0.05$; **, $P \leq 0.01$; ***, $P \leq 0.0001$ in the factorial analysis of variance.

^a, samples were taken at Logan site. All other samples were taken at RB site.

Table 22. Frequency distributions of species captured by short and long arc sweep samples on three collection dates during 1994 at the RB site and results of chi-square contingency table analyses.

Species	8 July Sampler #1		11 July Sampler #2		9 August Sampler #1	
	Short Arc	Long Arc	Short Arc	Long Arc	Short Arc	Long Arc
<i>A. deorum</i>	0.128	0.145	0.122	0.134	0.149**	0.238
<i>A. ellioti</i>	0.064	0.075	0.028**	0.064	0.079	0.086
<i>E. costalis</i>	0.076	0.062	0.090**	0.049	0.085	0.097
<i>M. infantilis</i>	0.020	0.026	0.036	0.038	0.034	0.038
<i>M. packardii</i>	0.076	0.075	0.071	0.083	0.062*	0.034
<i>M. sanguinipes</i>	0.204	0.213	0.219**	0.283	0.183**	0.115
<i>M. gladstoni</i>	-	-	-	-	0.048	0.046
<i>P. nebrascensis</i>	0.381	0.374	0.388**	0.328	0.239	0.230
<i>P. delicatula</i>	-	-	-	-	0.054	0.043
<i>S. equale</i>	0.014	0.007	0.009	0.003	-	-
<i>T. kiowa</i>	0.017*	0.008	0.010	0.006	-	-
Other	0.023	0.015	0.027	0.012	0.068	0.074
N	1020	2023	778	1566	355	652
Contingency table analysis	$\chi^2=17.83$ P=0.037		$\chi^2=52.95$ P<0.0001		$\chi^2=21.96$ P=0.009	

*, $P \leq 0.05$; **, $P \leq 0.01$; ***, $P \leq 0.0001$ in 2×2 contingency table analyses for each species.

For some dates, the proportions of species varied between short and long arc sweep samples. I found significant arc length×species interactions in the factorial analysis of variance on 8, 11, and 13 July (Table 21), as well as significant differences in the frequency distributions of species on 8, 11, and 13 July and 9 August in chi-square contingency table analysis (Tables 22 and 23). The species responsible for these differences, however, were not consistent among dates.

Table 23. Frequency distributions of species captured by short and long arc sweep samples taken by two samplers sweeping simultaneously on 13 July 1994 at the Logan site and results of chi-square contingency table analyses.

Species	13 July Sampler #1		13 July Sampler #2	
	Short Arc	Long Arc	Short Arc	Long Arc
<i>A. coloradus</i>	0.071**	0.119	0.096	0.103
<i>A. deorum</i>	0.435	0.444	0.423	0.442
<i>A. ellioti</i>	0.030**	0.056	0.028	0.041
<i>M. infantilis</i>	0.245**	0.236	0.248*	0.288
<i>M. sanguinipes</i>	0.036	0.042	0.048	0.037
<i>M. gladstoni</i>	0.076***	0.021	0.094***	0.027
<i>P. quadrimaculatum</i>	0.035**	0.017	0.017	0.013
<i>P. delicatula</i>	0.011	0.010	0.006	0.010
<i>T. kiowa</i>	0.042	0.034	0.021	0.026
Other	0.019	0.021	0.021	0.012
N	830	1547	778	1364
Contingency table analysis	$\chi^2=70.5$ P<0.0001		$\chi^2=51.3$ P<0.0001	

*, P≤0.05; **, P≤0.01; ***, P≤0.0001 in 2×2 contingency table analyses for each species.

The proportions of grasshoppers of each instar captured also varied between short and long arc sweep samples. I found significant arc length×instar interactions in the factorial analysis of variance for *P. nebrascensis* on 8 July and 9 August, but not on 11

Table 24. Stage frequency distributions of *Phoetaliotes nebrascensis* captured by long and short arc sweeps on three collection dates during 1994 at the RB site and results of chi-square contingency table analyses. Proportions within parentheses were combined with adjacent category in analyses.

Instar	8 July Sampler #1		11 July Sampler #2		9 August Sampler #1	
	Short Arc	Long Arc	Short Arc	Long Arc	Short Arc	Long Arc
I	(0.021)	(0.001)	-	-	-	-
II	0.211***	0.053	0.010	0.023	-	-
III	0.481	0.527	0.434*	0.355	-	(0.013)
IV	0.298**	0.399	0.523*	0.604	-	-
V	0.010	0.020	0.033	0.018	0.212*	0.100
Adults	-	-	-	-	0.788*	0.900
N	389	757	302	513	85	150
Contingency table analysis	$\chi^2=68.4$ P<0.0001		$\chi^2=9.11$ P=0.028		$\chi^2=5.61$ P=0.018	

*, P≤0.05; **, P≤0.01; ***, P≤0.0001 for 2×2 contingency table analyses for each instar.

July (Table 21). In chi-square contingency table analyses, the overall stage frequency distributions of *P. nebrascensis* differed significantly between arc lengths on all three dates (Table 24). I found significant arc length×instar interactions for *M. sanguinipes* on 11 July and 9 August, but not on 8 July (Table 21); stage frequency distributions differed on all three dates (Table 25). At the RB site, I found no interactions between arc length and instar for *A. deorum* and the stage frequency distributions did not differ between short and long arc sweep samples on 8 July ($\chi^2=2.2$, df=3, P>0.05) and 11 July ($\chi^2=2.4$, df=2, P>0.05). However, at the Logan site where long and short arc sweep samples were taken simultaneously, interactions between height and instar were significant for *A. deorum* and the stage frequency distributions significantly differed between short and long sweeps for both samplers (Table 26). For *M. infantilis* on 13 July, I found a significant instar×arc

Table 25. Stage frequency distributions of *Melanoplus sanguinipes* captured in short and long arc sweeps taken on three dates during 1994 at the RB site and results of chi-square contingency table analyses. Proportions within parentheses were combined with adjacent category in analyses.

Instar	8 July Sampler #1		11 July Sampler #2		9 August Sampler #1	
	Short Arc	Long Arc	Short Arc	Long Arc	Short Arc	Long Arc
I	(0.019)	(0.002)	-	-	-	-
II	0.173	0.144	0.118	0.075	-	-
III	0.260	0.262	0.247	0.178	-	-
IV	0.284*	0.200	0.224	0.208	(0.031)	-
V	0.212*	0.304	0.306	0.348	0.262**	0.040
Adults	0.072	0.091	0.106*	0.192	0.738**	0.960
N	208	431	170	443	65	75
Contingency table analysis	$\chi^2=10.1$ P=0.039		$\chi^2=11.8$ P=0.019		$\chi^2=14.0$ P=0.0002	

*, $P < 0.05$; **, $P < 0.01$; ***, $P < 0.0001$ for 2×2 contingency table analyses for each instar.

length interaction (Table 21) and stage frequency distributions differed between arc lengths for one of the two samplers sweeping simultaneously (Table 26). For each case where differences were significant, younger stages were captured in larger proportions by short arc sweeps, relative to the range of instars present

The proportions of male and female adult grasshoppers did not differ between short and long arc sweep samples in contingency table analyses for all cases where adults were present in sufficient numbers to test this hypothesis. At the RB site, differences in sex ratios were tested for *A. deorum* on 8 July ($\chi^2=1.4$, $P > 0.05$), 11 July ($\chi^2=2.7$, $P > 0.05$), and 9 August ($\chi^2=0.6$, $P > 0.05$), for *M. sanguinipes* on 8 July ($\chi^2=0.0$, $P > 0.05$), 11 July ($\chi^2=0.1$, $P > 0.05$) and 9 August ($\chi^2=0.3$, $P > 0.05$), and for *P. nebrascensis* on 9 August ($\chi^2=2.1$, $P > 0.05$). At the Logan site, the affect of sweep arc on sex ratios was tested on

Table 26. Stage frequency distributions of *M. infantilis* and *A. deorum* captured in long and short arc sweeps taken by two people sweeping simultaneously on 13 July 1994 at the Logan site and results of chi-square contingency table analyses. Proportions within parentheses were combined with adjacent category in analyses.

Instar	<i>A. deorum</i>				<i>M. infantilis</i>			
	Sampler #1		Sampler #2		Sampler #1		Sampler #2	
	Short Arc	Long Arc	Short Arc	Long Arc	Short Arc	Long Arc	Short Arc	Long Arc
I	-	-	-	-	-	-	-	-
II	-	-	(0.003)	-	(0.005)	-	(0.005)	-
III	(0.006)	-	(0.027)	(0.002)	0.054	0.027	0.036	0.035
IV	0.036	0.022	0.079***	0.017	0.113	0.104	0.124	0.088
V	0.305**	0.195	0.356***	0.202	0.448**	0.318	0.285	0.305
Adults	0.659***	0.783	0.565***	0.781	0.384**	0.551	0.554	0.572
N	361	687	329	603	203	365	193	341
Contingency	$\chi^2=18.9$		$\chi^2=55.1$		$\chi^2=16.1$		$\chi^2=1.9$	
Table analysis	P=0.0001		P<0.0001		P=0.001		NS	

*, $P \leq 0.05$; **, $P \leq 0.01$; ***, $P \leq 0.0001$ for 2×2 contingency table analyses for each instar.

13 July for *A. deorum* (sampler #1: $\chi^2=0.0$, $P > 0.05$, sampler #2: $\chi^2=0.0$, $P > 0.05$), for *A. coloradus* (sampler #1: $\chi^2=0.8$, $P > 0.05$, sampler #2: $\chi^2=0.8$, $P > 0.05$), and *M. infantilis* (sampler #1: $\chi^2=0.6$, $P > 0.05$, sampler #2: $\chi^2=1.5$, $P > 0.05$).

Sampler Stride Length

Because grasshoppers species, stages, and sexes may jump at different distances from the on-coming sweep net, I hypothesized that the distance between successive sweeps (i.e. stride length of the sampler) affects the number of grasshoppers in each category that are captured. For the two dates on which one sampler alternated sweeping

Table 27. Mean number of grasshoppers captured in short and long stride sweep samples on two collection dates in 1994 and results of factorial analysis of variance comparing the mean number of grasshoppers captured per species per sample.

Date	Short Stride		Long Stride		F-value	P-value
	Mean	SE	Mean	SE		
7/27	75.3	(5.7)	143.2	(8.9)	45.8	P<0.0001
8/9	40.5	(2.2)	59.5	(7.0)	6.83	P=0.0113

with long stride of 1 m and a short stride of 0.6 m, long stride sweep samples captured 1.5 to 1.9 times more grasshoppers (Table 27).

On 27 July, the proportions of species captured varied with stride length. This was reflected by significant stride length \times species interaction in the factorial analysis of variance on 27 July (F=3.32, df=7, 80, P=0.0037) and significant differences in chi-square contingency table analysis between the frequency distributions of species captured by short and long stride sweep samples on 27 July (Table 28). In the analysis of variance, I found no interaction between stride length and species on 9 August (F=0.4, df=5, 60, P>0.05).

The proportions of instars captured did not vary with stride length. I found no significant interactions between stride length and instar in the factorial analysis of variance on 27 July for *M. sanguinipes* (F=1.0, df=3, 40, P>0.05) and *P. nebrascensis* (F=1.0, df=2, 30, P>0.05) or on 9 August for *E. costalis* (F=0.6, df=1, 20, P>0.05) and *P. nebrascensis* (F=0.1, df=1, 20, P>0.05). In contingency table analyses, I also found no significant differences between stage frequency distributions captured by short and long stride sweeps on 27 July for *M. sanguinipes* ($\chi^2=3.9$, df=3, P>0.05) and *P. nebrascensis*

Table 28. Relative abundances of species captured by short and long stride sweep samples on two collection dates during 1994 at the RB site and results of chi-square contingency table analyses.

	27 July		9 August	
	Short Stride	Long Stride	Short Stride	Long Stride
<i>A. deorum</i>	0.146	0.159	0.189	0.213
<i>A. ellioti</i>	0.055	0.063	0.078	0.048
<i>E. costalis</i>	0.124	0.107	0.235	0.213
<i>M. infantilis</i>	0.011	0.020	0.041	0.017
<i>M. packardii</i>	0.055	0.040	0.016	0.025
<i>M. sanguinipes</i>	0.142	0.139	0.070	0.067
<i>P. nebrascensis</i>	0.228**	0.302	0.185	0.238
<i>P. delicatula</i>	0.108**	0.064	0.058	0.050
<i>X. corallipes</i>	0.097*	0.063	0.045	0.056
Other	0.033	0.044	0.082	0.073
N	452	859	243	357
Contingency table analysis	$\chi^2=23.1$ P=0.0060		$\chi^2=8.9$ NS	

*, $P \leq 0.05$; **, $P \leq 0.01$; ***, $P \leq 0.0001$ in 2×2 contingency table analyses for each species.

($\chi^2=0.4$, $df=2$, $P>0.05$) or on 9 August for *E. costalis* ($\chi^2=3.6$, $df=1$, $P>0.05$) and *P. nebrascensis* ($\chi^2=0.3$, $df=1$, $P>0.05$).

Sex ratios did not vary between stride lengths on all dates on which adults were present in sufficient numbers to test for differences using chi-square contingency table analyses. Analyses were performed on 27 July for *A. deorum* ($\chi^2=1.7$, $P>0.05$), *M. sanguinipes* ($\chi^2=0.0$, $P>0.05$), and *P. nebrascensis* ($\chi^2=0.0$, $P>0.05$) and on 9 August for *A. deorum* ($\chi^2=0.4$, $P>0.05$), *E. costalis* ($\chi^2=0.0$, $P>0.05$), and *P. nebrascensis* ($\chi^2=0.5$, $P>0.05$).

Sweep speed

Because grasshoppers respond quickly to the advance of samplers with sweep nets, I hypothesized that the speed at which a sampler sweeps and walks affects the number of grasshoppers of each species, instar, and sex that are captured. Sweep speed significantly affected the number of grasshoppers captured on two of the four dates on which sets of twelve fast and slow 100-sweep samples were taken (Table 29). For these two dates, fast sweeps captured 1.6 to 1.7 times more grasshoppers than slow sweeps.

Table 29. Mean number of grasshoppers captured in fast and slow sweep samples on four collection dates in 1994 and results of factorial analysis of variance comparing the mean number of grasshoppers captured per species by fast and slow sweep samples.

Date	Fast		Slow		F-value	P-value
	Mean	SE	Slow	SE		
6/18	200.8	(10.0)	204.8	(19.1)	0.3	NS
6/27	182.8	(26.1)	200.9	(20.6)	1.7	NS
7/12	197.7	(6.9)	117.0	(15.8)	44.8	P < 0.0001
8/12	64.3	(3.5)	40.0	(1.3)	41.1	P < 0.0001

On some dates, the proportions of species captured varied with sweeping speed. I found a significant speed×species interaction in the factorial analysis of variance on 12 August, but not on the 18 and 27 June or 12 July (Table 30). In chi-square contingency table analyses, I found significant differences between the frequency distributions of species captured by fast and slow sweep samples on 12 August and on 27 June for samples taken by one of the two samplers sweeping simultaneously (Tables 31 and 32).

Table 30. F-value, DF, and significance of speed×species interactions and speed×instar interactions from factorial analysis of variance; some analyses were not performed due to low species abundance or because all grasshoppers were adults.

Date	Speed×Species		Speed×Instar							
			<i>A. deorum</i>		<i>M. sanguinipes</i>		<i>P. nebrascensis</i>		<i>M. infantilis</i>	
	F	DF	F	DF	F	DF	F	DF	F	DF
6/18	0.3	7, 80	0.2	4, 50	0.4	4, 50	0.0	1, 20	-	-
6/27 ^a	0.5	7, 160	0.2	4, 100	-	-	-	-	0.3	5, 120
7/12	1.8	8, 90	0.3	2, 30	1.3	4, 50	2.4	3, 40	-	-
8/12	4.3**	7, 80	-	-	-	-	-	-	-	-

*, $P \leq 0.05$; **, $P \leq 0.01$; ***, $P \leq 0.0001$ in the factorial analysis of variance.

^a, samples were taken at Logan site. All other samples were taken at RB site.

Table 31. Relative abundances of species captured by fast and slow sweep samples on three collection dates during 1994 at RB site. Average sweep times are given in parentheses.

	18 June Sampler #2		12 July Sampler #1		12 August Sampler #1	
	Slow (135 sec)	Fast (95 sec)	Slow (149 sec)	Fast (107 sec)	Slow (117 sec)	Fast (94 sec)
<i>A. deorum</i>	0.153	0.165	0.138	0.111	0.246	0.246
<i>A. ellioti</i>	0.103	0.107	0.037	0.062	0.067	0.073
<i>E. costalis</i>	0.072	0.060	0.167	0.145	0.142*	0.088
<i>M. gladstoni</i>	-	-	-	-	0.075	0.073
<i>M. infantilis</i>	0.079	0.079	0.021	0.025	0.029	0.042
<i>M. packardii</i>	0.091	0.090	0.043	0.047	0.025	0.049
<i>M. sanguinipes</i>	0.311	0.349	0.182	0.197	0.046**	0.127
<i>P. nebrascensis</i>	0.151	0.121	0.353	0.369	0.154***	0.210
<i>P. delicatula</i>	-	-	0.014	0.001	0.117**	0.049
<i>S. equale</i>	0.014	0.007	0.016	0.013	-	-
Other	0.027	0.023	0.029	0.031	0.100	0.044
N	1229	1205	702	1185	240	386
Contingency table analysis	$\chi^2=12.1$ NS		$\chi^2=13.7$ NS		$\chi^2=35.4$ P=0.0001	

*, $P \leq 0.05$; **, $P \leq 0.1$; ***, $P \leq 0.0001$ in 2×2 contingency table analyses for each species.

Table 32. Relative abundances of species captured in fast and slow sweep samples taken by two samplers sweeping simultaneously on 27 June 1994 at Logan site and results of chi-square contingency table analyses. Average sweep times are given in parentheses.

	Sampler #2		Sampler #1	
	Slow (136 sec)	Fast (94 sec)	Slow (91 sec)	Fast (117 sec)
<i>A. deorum</i>	0.408	0.399	0.401	0.411
<i>A. coloradus</i>	0.113	0.107	0.144	0.132
<i>A. elliotti</i>	0.066*	0.048	0.061	0.050
<i>M. infantilis</i>	0.323	0.351	0.283	0.285
<i>M. packardii</i>	0.005	0.015	0.006	0.003
<i>M. sanguinipes</i>	0.042	0.051	0.028	0.037
<i>P. quadrimaculatum</i>	0.014	0.010	0.031	0.036
<i>T. kiowa</i>	0.020**	0.007	0.031	0.033
Other	0.008	0.013	0.014	0.013
N	1555	1441	639	970
Contingency table analysis	$\chi^2=26.7$ P=0.001		$\chi^2=3.6$ NS	

*, P \leq 0.05; **, P \leq 0.1; ***, P \leq 0.0001 in 2 \times 2 contingency table analyses for each species.

For most dates, the proportions of instars did not differ significantly between fast and slow sweeps. I found no significant interactions between sweep speed and instar in the factorial analysis of variance for all cases tested (Table 30). I also found that stage-frequency distributions did not differ between sweeping speeds in chi-square contingency table analyses for *A. deorum* on 18 June ($\chi^2=5.7$, df=4, P>0.05) and on 12 July ($\chi^2=1.3$, df=1, P>0.05), for *M. sanguinipes* on 18 June ($\chi^2=8.0$, df=4, P>0.05) and 12 July ($\chi^2=6.9$, df=4, P>0.05), and for *P. nebrascensis* on 18 June ($\chi^2=0.2$, df=1, P>0.05). However, the stage frequency distributions differed significantly between fast and slow sweep samples for *P. nebrascensis* on 12 July ($\chi^2=12.5$, df=3, P=0.006).

Sex ratios significantly differed between fast and slow sweeps in chi-square contingency table analyses for *M. sanguinipes* on the 12 August ($\chi^2=5.0$, $P=0.026$), but not for *M. sanguinipes* on 12 July ($\chi^2=0.7$, $P>0.05$), *A. deorum* on 12 July ($\chi^2=1.2$, $P>0.05$) and 12 August ($\chi^2=0.8$, $P>0.05$), for *A. coloradus* on 27 June (sampler #1: $\chi^2=2.0$, $P>0.05$, sampler #2: $\chi^2=0.2$, $P>0.05$), and on 27 June for *M. infantilis* (sampler #1: $\chi^2=0.0$, $P>0.05$, sampler #2: $\chi^2=0.3$, $P>0.05$). On the one date that sex ratios differed, fast sweeps captured male grasshoppers of *M. sanguinipes* in larger proportions (55.8%) than slow sweep samples (18.2%).

Net Size

Because nets of different size intersect different volumes of habitat, I hypothesized that size of the sweep net influences the number of grasshoppers of each species, instar, and sex that are captured. On the one date on which one person alternated sweeping with a large net of 38 cm and a small net of 30 cm diameter, net size did not significantly affect the number of grasshoppers captured per sample in the factorial analysis of variance ($F=0.8$, $df=1$, 70, $P>0.05$).

Net size also did not affect the proportions of species captured. I found no significant interaction between net size and species in the factorial analysis of variance ($F=0.8$, $df=6$, $P>0.05$) and the frequency distributions of species did not differ significantly in chi-square contingency table analysis ($\chi^2=13.0$, $df=9$, $P>0.05$) on 30 June.

Table 33. Stage frequency distributions of *A. deorum*, *M. sanguinipes*, and *P. nebrascensis* captured by small and large net sweep samples on 30 June 1994 at the RB site and results of chi-square contingency table analyses.

Instar	<i>A. deorum</i>		<i>M. sanguinipes</i>		<i>P. nebrascensis</i>	
	Small Net	Large Net	Small Net	Large Net	Small Net	Large Net
I	-	-	0.067*	0.143	0.098	0.071
II	(0.015)	-	0.194*	0.286	0.412	0.414
III	0.092	0.066	0.424**	0.270	0.471	0.491
IV	0.385	0.303	0.182	0.189	0.020	0.023
V	0.523	0.632	0.133	0.112	-	-
Adults	(0.031)	(0.039)	(0.018)	(0.010)	-	-
N	65	76	165	196	255	220
Contingency table analysis	$\chi^2=1.7$ NS		$\chi^2=14.7$ P=0.012		$\chi^2=1.0$ NS	

proportions within parentheses were combined with adjacent instar category in analyses.

*, $P \leq 0.05$; **, $P \leq 0.01$; ***, $P \leq 0.0001$ for 2×2 contingency table analyses for each instar.

Net size usually did not affect the proportions of instars captured. I found no significant interactions between net size and instar in the factorial analysis of variance for *A. deorum* ($F=0.3$, $df=2$, 30 , $P>0.05$), *M. sanguinipes* ($F=1.6$, $df=4$, 50 , $P>0.05$), and *P. nebrascensis* ($F=0.2$, $df=3$, 40 , $P>0.05$). The stage frequency distributions also did not differ significantly between net sizes in chi-square contingency table analyses for *A. deorum* and *P. nebrascensis* (Table 33). However, the stage frequency distributions of *M. sanguinipes* differed significantly between small and large net sweep samples taken on this date. Small net samples captured smaller proportions of first instars and second instars of *M. sanguinipes*, but larger proportions of third instars.

Sampler

People may differ with regards to the manner in which they take sweep samples. For example, people may sweep at different heights above the ground. Therefore, I hypothesized that the number of grasshoppers of each species, instar, and sex captured by sweeps varies among samplers. The average number of grasshoppers captured per sample did not differ significantly between samplers in the factorial analysis of variance on 9 June at RB ($F=0.5$, $df=1$, 42, $P>0.05$), on 9 June at CSH ($F=0.9$, $df=1$, 48, $P>0.05$), and on 27 June at Logan ($F=2.6$, $df=1$, 42, $P>0.05$) when sweeps were taken by two people sweeping simultaneously approximately 5 m apart.

I found no significant interactions between sampler and species at the RB site on 9 June ($F=0.6$, $df=6$, 42, $P>0.05$), at CSH on 9 June ($F=0.7$, $df=7$, 48, $P>0.05$), and at Logan on 27 June ($F=2.2$, $df=6$, 42, $P>0.05$) in the factorial analysis of variance performed on the square root transformation of grasshopper counts. However, the overall frequency distributions of species significantly differed between samplers on two of the three dates (Table 34). On these two dates, one sampler captured *P. nebrascensis* in larger proportions (3.3-6.0%) and *M. infantilis* in smaller proportions (3.3-8.0%).

For the three most abundant species on each date, I tested for interactions between sampler and instar and found no significant interactions for *A. deorum*, *A. elliotti*, and *M. sanguinipes* on 9 June at RB, for *A. elliotti*, *M. packardii*, *M. sanguinipes* on 9 June at CSH, and for *A. deorum* and *M. infantilis* on 27 June at Logan (Table 35).

Table 34. Frequency distributions of species captured by two people sweeping simultaneously approximately 5 m apart on one collection date at each site during 1994 and results of chi-square contingency table analysis.

Species	RB 9 June		CSH 9 June		Logan 27 June	
	Sampler #1	Sampler #2	Sampler #1	Sampler #2	Sampler #1	Sampler #2
<i>A. clavatus</i>	0.032	0.043	0.010	0.003	-	-
<i>A. deorum</i>	0.284	0.263	0.011	0.012	0.343	0.413
<i>A. coloradus</i>	-	-	0.011	0.008	0.055	0.041
<i>A. pseudonietana</i>	-	-	-	-	0.034	0.015
<i>A. elliotti</i>	0.218	0.195	0.062	0.052	0.025	0.009
<i>M. bivittatus</i>	-	-	0.005	0.009	-	-
<i>M. infantilis</i>	0.106*	0.139	0.018	0.019	0.263*	0.343
<i>M. packardii</i>	0.048	0.036	0.077	0.080	-	-
<i>M. sanguinipes</i>	0.206*	0.252	0.794	0.811	0.076	0.067
<i>P. quadrimaculatum</i>	-	-	-	-	0.034	0.041
<i>P. nebrascensis</i>	0.077**	0.044	-	-	0.089**	0.029
<i>S. equale</i>	-	-	-	0.002	-	-
<i>T. kiowa</i>	-	-	-	-	0.051**	0.009
Other	0.027	0.027	0.013	0.005	0.030	0.032
N	770	882	946	1172	236	341
Contingency table analysis	$\chi^2=24.8$ P=0.003		$\chi^2=9.6$ NS		$\chi^2=29.1$ P=0.001	

*, $P \leq 0.05$; **, $P \leq 0.01$; ***, $P \leq 0.0001$ in 2×2 contingency table analyses for each species.

Table 35. F-value, DF, and significance of sampler \times instar interactions from factorial analysis of variance; some analyses were not performed due to low species abundance or because all grasshoppers were adults.

Date	Site	<i>A. deorum</i>		<i>A. elliotti</i>		<i>M. sanguinipes</i>		<i>M. packardii</i>		<i>M. infantilis</i>	
		F	DF	F	DF	F	DF	F	DF	F	DF
6/9	RB	0.4	3, 24	0.0	3, 24	0.2	3, 24	-	-	-	-
6/9	CSH	-	-	1.5	3, 24	0.8	3, 24	0.2	3, 24	-	-
6/27	Logan	0.8	3, 24	-	-	-	-	-	-	0.9	2, 18
6/27 ^a	Logan	1.8	4, 100	-	-	-	-	-	-	0.3	5, 120
7/13 ^a	Logan	1.0	3, 80	-	-	-	-	-	-	0.7	3, 80

*, $P \leq 0.05$; **, $P \leq 0.01$; ***, $P \leq 0.0001$ in the factorial analysis of variance.

^a, samples were taken by two samplers sweeping simultaneously in the same style.

The overall stage frequency distributions did not differ significantly in chi-square contingency table analyses for *A. deorum* ($\chi^2=1.3$, $df=3$, $P>0.05$), *A. elliotti* ($\chi^2=0.7$, $df=3$, $P>0.05$) and *M. sanguinipes* ($\chi^2=0.8$, $df=3$, $P>0.05$) on 9 June at RB, for *A. deorum* ($\chi^2=2.8$, $df=2$, $P>0.05$) and *M. infantilis* ($\chi^2=7.1$, $df=3$, $P>0.05$) on 27 June at Logan, or for *M. packardii* ($\chi^2=2.5$, $df=2$, $P>0.05$) on 9 June at CSH. However, on 9 June at CSH the overall stage frequency distributions of *A. elliotti* and *M. sanguinipes* differed significantly between samplers (Table 36). On this date, one sampler captured first instars of both *A. elliotti* and *M. sanguinipes* in larger proportions.

Simultaneous samples varied in sweeping style

I also tested for differences due to sampler in sweeps taken by two samplers sweeping simultaneously in the same sweeping style. The average number of grasshopper captured per sample did not differ significantly between samplers in short and long arc sweeps combined on 13 July ($F=3.4$, $df=1, 160$, $P>0.05$), but differed significantly for fast and slow sweeps combined on 27 June ($F=49.3$, $df=1, 160$, $P<0.0001$). On 27 June, one sampler captured 1.5 times more grasshoppers in fast sweeps and 2.4 times more grasshoppers in slow sweep samples.

The proportions of species captured also varied with sampler. For the dates on which simultaneous sweep samples were varied in style, I found a significant interaction between sampler and species in the factorial analysis of variance for fast and slow sweep samples on 27 June ($F=6.7$, $df=7, 160$, $P<0.0001$), but not for long and short arc sweep samples on 13 July ($F=0.9$, $df=7, 160$, $P>0.05$).

Table 36. Stage frequency distributions of *A. ellioti* and *M. sanguinipes* captured by two people sweeping simultaneously at the CSH site on 9 June and results of chi-square contingency table analyses.

Instar	<i>A. ellioti</i>		<i>M. sanguinipes</i>	
	Sampler #1	Sampler #2	Sampler #1	Sampler #2
I	0.288*	0.115	0.546**	0.469
II	0.407	0.377	0.293*	0.346
III	0.203	0.295	0.161	0.185
IV	0.102	0.213	(0.008)	(0.002)
V	-	-	-	-
Adults	-	-	-	-
N	59	61	751	951
Contingency Table analysis	$\chi^2=7.8$ P=0.0475		$\chi^2=13.9$ P=0.0031	

proportions within parentheses were combined with adjacent group in analyses.

*, $P \leq 0.05$; **, $P \leq 0.01$; ***, $P \leq 0.0001$ in 2x2 contingency table analyses for each instar.

In chi-square contingency table analyses, the frequency distributions of species differed significantly between samplers for fast and slow sweeps (fast: $\chi^2=63.8$, $P < 0.0001$, slow: $\chi^2=19.7$, $P=0.0117$)(Table 32) and long and short arc sweeps (long arc: $\chi^2=18.7$, $P=0.0168$, short arc: $\chi^2=17.4$, $P=0.0266$) (Table 23). Samplers captured significantly different proportions of *P. quadrimaculatum* (fast sweeps: $\chi^2=20.2$, $P < 0.0001$, slow sweeps: $\chi^2=7.1$, $P=0.0077$). Samplers also captured different proportions of *M. infantilis* ($\chi^2=11.5$, $P=0.0007$) and *T. kiowa* ($\chi^2=23.0$, $P < 0.0001$) in fast sweep samples and significantly different proportions of *A. coloradus* in slow sweeps ($\chi^2=4.2$, $P=0.0407$). For short and long arc samples, the two samplers captured significantly different proportions of *M. infantilis* in long arc sweep samples ($\chi^2=10.3$, $P=0.0014$) and significantly different proportions of *P. nebrascensis* and *T. kiowa* in short arc sweep samples ($\chi^2=5.2$, $P=0.0220$; $\chi^2=6.1$, $P=0.0135$).

I found no significant interactions between sampler and instar for *A. deorum*, *M. infantilis*, and *A. coloradus* ($F=2.5$, $df=2$, 60 , $P>0.05$) for the dates on which simultaneous sweep samples were varied in sweeping style (Table 35). In chi-square contingency table analyses, stage frequency distributions did not differ between samplers for *A. deorum* (fast sweeps: $\chi^2=8.3$, $df=4$, $P>0.05$, slow sweeps: $\chi^2=6.3$, $df=4$, $P>0.05$), *M. infantilis* (fast sweeps: $\chi^2=4.3$, $df=5$, $P>0.05$, slow sweeps: $\chi^2=7.5$, $df=4$, $P>0.05$), and *A. coloradus* (fast sweeps: $\chi^2=4.1$, $df=2$, $P>0.05$, slow sweeps: $\chi^2=1.9$, $df=2$, $P>0.05$). The stage frequency distributions also did not differ between samplers for *A. deorum* in long arc sweeps ($\chi^2=0.5$, $df=2$, $P>0.05$) and for *M. infantilis* in long arc sweeps ($\chi^2=1.1$, $df=3$, $P>0.05$). However, the overall stage frequency distributions significantly differed between samplers in short arc sweeps for *A. deorum* ($\chi^2=10.9$, $df=2$, $P=0.0125$) and *M. infantilis* ($\chi^2=14.1$, $df=3$, $P=0.0028$) (Table 26). For *A. deorum*, samplers captured different proportions of adults ($\chi^2=6.4$, $P=0.0113$) and for *M. infantilis*, samplers captured different proportions of fifth instars ($\chi^2=11.3$, $P=0.0008$) and adults ($\chi^2=11.5$, $P=0.0007$).

In testing for differences in sex ratios captured by samplers using chi-square contingency table analyses I found only one instance of apparent sampler bias. Sex ratios did not differ between samplers for *A. deorum* (long arc sweeps: $\chi^2=0.3$, $P>0.05$, short arc sweeps: $\chi^2=0.2$, $P>0.05$), *A. coloradus* (long arc sweeps: $\chi^2=0.0$, $P>0.05$, short arc sweeps: $\chi^2=2.3$, $P>0.05$), and *M. infantilis* (long arc sweeps: $\chi^2=3.0$, $P>0.05$, short arc sweeps: $\chi^2=0.7$, $P>0.05$). Sex ratios also did not differ between samplers for *M. infantilis* (fast sweeps: $\chi^2=0.2$, $P>0.05$, slow sweeps: $\chi^2=0.7$, $P>0.05$) and for *A. coloradus* in fast sweeps ($\chi^2=0.5$, $P>0.05$). However, sex ratios significantly differed between samplers for

A. coloradus in slow sweep samples ($\chi^2=6.5$, $P=0.011$). One sampler captured 37.7% adult males while the other sampler captured 60.6 % males.

Sampler training

Because different samplers may sweep in different manners depending upon their experience, I hypothesized that sampler training affects the number of grasshoppers of each species, instar, and sex that are captured. For the set of five samples in which three trained and two untrained individuals swept simultaneously, the average number of grasshoppers captured per sample significantly differed among samplers in the factorial analysis of variance ($F=11.4$, $df=4$, 140 , $P<0.0001$) (Table 37). For this set of samples, one of the trained individuals, who swept in a horizontal 180° arc, captured almost twice as many grasshoppers as the other two trained individuals and the two untrained individuals, who swept in the form of a vertical pendulum. For the second set of five samples in which all individuals were trained to sweep in a 180° arc, the number of grasshoppers captured per sample again differed significantly among samplers ($F=5.1$, $df=4$, 140 , $P=0.0007$) (Table 37). For this set of samples, one of the previously untrained samplers captured significantly more grasshoppers than the other untrained sampler and the three trained samplers. This sampler captured the least number of grasshoppers when sweeping in the form of a pendulum and the most number of grasshoppers when sweeping in a 180° arc. Hence, training seemed to have affected the number of grasshoppers captured per sample for one of the two untrained samplers.

Table 37. Mean number of grasshoppers captured by samplers sweeping in 180° arc and in the shape of a pendulum for one set of five samples and by same five samplers trained to sweep in a 180° arc for another set of five samples on 16 August, 1994 at the RB site.

Sampler	Sweep form	First Set		Sweep form	Second Set	
		Mean	SE		Mean	SE
#4	180° arc	142.0b	(20.1)	180° arc	67.2bc	(5.1)
#3	180° arc	74.4a	(10.3)	180° arc	57.0ab	(6.8)
#1	180° arc	61.6a	(7.0)	180° arc	51.4a	(3.6)
#5	pendulum	73.2a	(16.9)	180° arc	48.6a	(2.4)
#6	pendulum	59.2a	(10.6)	180° arc	86.0c	(12.2)

Factorial analysis of variance performed on the number of grasshoppers captured per species per sample. Means followed by different letters are significantly different from each other. LSD $P > 0.05$.

Table 38. Frequency distributions of species captured in the first set of five sweep samples taken by trained and untrained samplers sweeping simultaneously on 16 August, 1994 at the RB site. Frequency distributions of species differed among samplers in chi-square contingency table analyses $\chi^2 = 122.8$ and $P < 0.0001$.

	180° arc sweeps			Pendulum sweeps	
	Sampler #1	Sampler #3	Sampler #4	Sampler #5	Sampler #6
<i>A. deorum</i>	0.179	0.175	0.156	0.101	0.139
<i>A. ellioti</i>	0.055	0.078	0.076	0.041	0.068
<i>E. costalis</i>	0.107	0.167	0.149	0.120	0.132
<i>M. infantilis</i>	0.026	0.019	0.023	0.025	0.027
<i>M. packardii</i>	0.088	0.040	0.042	0.109	0.078
<i>M. sanguinipes</i>	0.299	0.199	0.244	0.404	0.213
<i>P. nebrascensis</i>	0.172	0.245	0.249	0.158	0.260
<i>P. delicatula</i>	0.026	0.008	0.006	0.011	0.014
<i>S. equale</i>	0.000	0.019	0.014	0.014	0.020
<i>X. corallipes</i>	0.013	0.024	0.013	0.000	0.010
Other	0.036	0.027	0.028	0.016	0.041
N	308	372	710	366	296

Sampler training did not affect the proportions of species captured in sweep samples. I found no significant interactions between sampler and species in the factorial ANOVA for the first set ($F=1.0$, $df= 24, 140$, $P>0.05$) and the second set of samples ($F=0.7$, $df= 24, 140$, $P>0.05$). However, the overall frequency distributions of species in both sets significantly differed among samplers in chi-square contingency table analyses (Tables 38 and 39). Differences were not consistent among trained and untrained samplers. Hence, differences among samplers were probably due to factors other than sweeping in a horizontal 180° arc or sweeping in the form of a vertical pendulum.

Table 39. Frequency distributions of species captured in the second set of five samples on 16 August, 1994 at the RB site by five samplers trained to sweep in a 180° arc. Frequency distributions of species differed among samplers in chi-square contingency table analysis $\chi^2=68.02$ and $P=0.0010$.

	Sampler #1	Sampler #3	Sampler #4	Sampler #5	Sampler #6
<i>A. deorum</i>	0.222	0.249	0.217	0.305	0.237
<i>A. elliotti</i>	0.058	0.056	0.107	0.070	0.058
<i>E. costalis</i>	0.160	0.175	0.161	0.160	0.163
<i>M. infantilis</i>	0.016	0.063	0.012	0.025	0.009
<i>M. packardii</i>	0.035	0.025	0.021	0.021	0.021
<i>M. sanguinipes</i>	0.140	0.095	0.104	0.099	0.165
<i>P. nebrascensis</i>	0.187	0.204	0.256	0.226	0.230
<i>P. delicatula</i>	0.058	0.021	0.024	0.025	0.035
<i>S. equale</i>	0.023	0.011	0.015	0.016	0.012
<i>X. corallipes</i>	0.058	0.039	0.024	0.021	0.005
Other	0.043	0.063	0.060	0.033	0.065
N	257	285	336	243	430

The proportions of developmental stages did not differ among samplers for *M. sanguinipes* and thus did not differ among sweeping techniques for this species. I found no significant interactions between sampler and instar for *M. sanguinipes* in the factorial

analysis of variance (first set: $F=1.08$, $df=8, 60$, $P>0.05$, second set: $F=0.61$, $df=8, 60$, $P>0.05$) and between the stage frequency distributions in chi-square contingency table analysis (first set: $\chi^2=11.3$, $df=8$, $P>0.05$, second set: $\chi^2=7.1$, $df=8$, $P>0.05$).

I also found that sampler did not affect the sex ratios of grasshoppers captured. Sex ratios of grasshoppers captured by sweeps did not differ among samplers in chi-square contingency table analyses for *A. deorum* (first set: $\chi^2=5.2$, $df=4$, $P>0.05$, second set: $\chi^2=1.5$, $df=4$, $P>0.05$) and *P. nebrascensis* (first set: $\chi^2=2.8$, $df=4$, $P>0.05$, second set: $\chi^2=3.1$, $df=4$, $P>0.05$).

Because a large number of samples were taken, we collected the second set of samples over an area with different vegetation than that over which we took the first set. Therefore, I tested the hypothesis that grasshopper community composition differed between the two areas. I found that the total catch per sample significantly differed between the two areas in the factorial analysis of variance ($F=16.4$, $df=1, 288$, $P=0.0001$) and that the abundance of individual species differed between areas as indicated by a significant interaction between area and species ($F=6.7$, $df=5, 288$, $P<0.0001$). Also, the proportions of *A. deorum* and *M. sanguinipes* consistently differed between the areas (Tables 38 and 39). Although this hypothesis was not developed *a priori*, it seems that grasshopper communities can vary over relatively short distances.

DISCUSSION

Accuracy of sweep sampling

Sweep sampling does not always accurately portray the relative abundances of species. This was demonstrated by 1) comparing sweep samples adjacent to enclosures and from within enclosures on unmowed areas and 2) by examining trends in the cumulative proportions of species captured during the repeated sampling of mowed and unmowed enclosures. Biases were also observed when using sweeps to estimate stage-frequency distributions and sex ratios.

Given the results of this study, however, I do not suggest that other grasshopper sampling techniques be used instead of sweep sampling. Absolute sampling techniques are time consuming and expensive and have low precision due to the small numbers of grasshoppers that these techniques capture. The low precision of these techniques may be more problematic than the biases observed in sweep samples, especially if grasshoppers have clumped distributions. Sweep sampling has the favorable quality of sampling quickly over a variety of microhabitats.

It may be possible to avoid biases in sweep sampling by sweeping many times over the same area similar to the manner that I repeatedly sampled enclosures. After about nine sweep samples taken over the same area within enclosures the cumulative proportions were close to the final abundances. Possibly, future research could further investigate this hypothesis, and determine if repeated sampling on non-enclosed areas would reduce sweep sampling bias.

Biases observed in sweep sampling probably were due to behavioral differences among species. The species *Phoetaliotes nebrascensis*, which was responsible for most of the bias on the unmowed areas, was very susceptible to capture because after flushing this grasshopper lands high on the vegetation and then is captured easily by subsequent sweeps. *Spharagemon equale* tended to be under represented by sweeps. I often observed nymphs of this species fail to jump in response to the sampler and that this resulted in failure of capture by the sweep net.

Accuracy of sweep sampling with regards to implementation

Grasshopper community composition can vary over relatively short distances suggesting that a random sampling plan should be implemented when using sweep sampling in order to account for spatial variation in grasshopper communities. It would be easy to estimate the dimensions of an area as a measure of steps by walking the perimeter of the area in interest and then devising a sampling plan from these dimensions.

Sensitivity of sweep sampling to variation in sweeping technique

Abundance. The total numbers of grasshoppers captured per sample varied dramatically with sweep height, sweep arc length, sampler stride length, sweeping speed, and sampler. Thus, when using sweeps to estimate species or instar abundance it is very important to keep sweeping style as consistent as possible and to have sweeps taken by one sampler.

Sweep height. Samples taken at different heights above the ground captured different proportions of species. In particular, low sweeps gave higher estimates of late hatching species *E. costalis* and *P. nebrascensis* probably because low sweeps are better at capturing younger stages than high sweeps. Low sweeps probably gave more accurate estimates of *E. costalis* which was captured in smaller proportions by sweeps adjacent to the enclosures than within the enclosures. However, low sweeps simultaneously gave more biased estimates of the greatly overrepresented species *P. nebrascensis*. Thus, sweeping with the net low or high above the ground may give more accurate estimates of species proportions depending upon the species of interest. If late hatching species are not of interest, they could be excluded from analyses.

Height of sweeps also affected the proportions of instars captured. Early in the summer, low sweeps tended to give higher estimates and possibly more accurate estimates for early developmental stages. Results, however, were variable when adults were abundant; low sweeps captured adults of *P. nebrascensis* in larger proportions but adults of *A. deorum* in smaller proportions. Thus, early in the summer, it may be best to sweep with the net close to the ground.

Arc length. Sweep arc length affected the proportions of species captured however, the species responsible for differences and direction of change were quite variable even among samples taken on close dates. Long arc sweeps captured larger proportions of older instars, relative to the range of instars present. When adults were abundant, long arc sweeps consistently captured adults in higher proportions for many species. Long arc may give more accurate estimates of proportions of adults; sweeps

taken adjacent to enclosures captured adult *M. sanguinipes* in higher and more accurate proportions than short arc sweeps on three of four dates. Thus, sweeping with longer arc lengths may give better estimates when many of the grasshoppers are adults.

Stride Length. Sampler stride length can affect the proportions of species captured by sweeps. However, results varied even on close dates. Stride length did not affect the proportion of instars captured. Thus, stride length does not seem to be an important variation of sweeping style to consider when sampling grasshoppers. However, the affect of stride length was not tested in early summer.

Sweep Speed. Sampler walking and sweeping speed can affect the proportions of species captured for sweeps taken later in the summer, but in almost all cases did not affect the proportions of instars captured. Sweep speed may an important variation of the sweep sampling technique to consider later in the summer when grasshoppers are adults. The results of my study gave no suggestions for which sampling speed gives better estimates.

Net Size. Net size did not affect the proportions of species captured but did affect the proportion of instars captured for some species. Large net sweeps captured larger proportions of first and second instars of *M. sanguinipes* while capturing smaller proportions of third instars. However, for the same data I found no interaction between net size and instar in factorial analysis of variance.

Sampler. Samplers captured different proportions of species and instars probably due to variation in sweeping style among samplers. To avoid biases due to sampler, sweeps should be taken by the same person.

Sex ratios. For most cases sex ratios captured in sweeps adjacent to enclosures did not differ from those within enclosures and, in all cases except one, sweep style did not affect the sex ratios of grasshoppers captured by sweeps. Thus, sweep sampling tended to accurately portray sex ratios regardless of sweeping style.

Statistical analyses

For comparisons of species, the factorial analysis of variance gave different results than the chi-square contingency table analyses for many of the cases when I tested for differences in capture among species and instars. Results of these two tests were most variable when I tested for differences among samplers. These tests may give different results because they tested different hypotheses. Chi-square contingency analyses tested for differences in the proportions captured while the factorial ANOVA was used to test for differences in the number of grasshoppers captured. These tests also differed because in chi-square contingency table analyses samples were combined prior to analyses, ignoring variability among samples. The assumption that grasshopper community composition was homogeneous across the field in which samples were taken may have been false. Thus, combining samples as I did for the chi-square contingency table analyses may have lost variability due to heterogeneity of grasshopper communities. I observed instances in which contingency table analyses indicated that differences were significant for a species when one sample was responsible for the majority of the differences. Thus, it may be more appropriate to use tests that measure the variability of grasshopper communities.

General Recommendations

1) Be aware that biases may occur and that they can vary with technique, community, season, species, stage, or sex. Those conducting studies that rely heavily on sweep sampling may consider testing for biases before beginning their study.

2) When comparisons are made between sweep samples, attempts should be made to keep sweeping technique as consistent as possible especially when using sweep samples to estimate abundance of species, stages, or sexes. This would increase the precision of sample estimates relative to each other although, not necessarily the accuracy relative to the real community composition.

3) Researchers should also note the manner in which sweep samples were taken (e.g. sweep height), the number of samplers used to collect data, and other variations of the sweep sampling technique that could affect sweep sample estimates.

4) When using sweep samples to estimate community composition over large areas, multiple samples should be taken according to a random sampling plan in order to properly account for spatial variation in grasshopper communities.

5) Researchers might consider using a sampling plan that mixes different sweep styles (e.g. 50% low, 50% high) in order to offset potential biases in sampling species or instars. Repeated sweep sampling of small non-enclosed areas over a short time intervals might reduce sweep sampling bias.

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