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Evaluating Shade Bias in Insect Trap Catch and Assessing the Short- and Long-term Impacts of Herbicide Application in Regenerating Clearcuts on Flowering Plant Communities

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EVALUATING SHADE BIAS IN INSECT TRAP CATCH AND ASSESSING THE SHORT- AND LONG-TERM IMPACTS OF HERBICIDE APPLICATION IN REGENERATING CLEARCUTS ON FLOWERING PLANT COMMUNITIES

By

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B.S. University of North Carolina at Chapel Hill, 1996

A THESIS

Submitted in Partial Fulfillment of the

Requirements for the Degree of

Master of Science

(in Ecology and Environmental Science)

The Graduate School

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December, 2001

Advisory Committee:

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Thesis Advisor: Dr. Stephen Woods

An Abstract of the Thesis Presented
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Regenerating clearcuts are commonly sprayed with a broad-spectrum herbicide, Glyphosate, to suppress regenerating hardwoods that outcompete the more desirable softwood species. Although the direct effects of herbicide application are minimal, the resulting changes in vegetation have raised concern over its indirect effects on wildlife. On the other hand, clearcuts are high in plant diversity, which may provide beneficial resources for Hymenoptera in the clearcut area and the adjacent forest stands.

To assess the short- and long-term impacts of herbicide application on insect communities, comparisons between stands of various ages and treatments are necessary. Insect traps provide one efficient method for assessing differences in insect communities with minimal effort. However, legitimate comparisons can only be obtained if traps are not biased by the environmental conditions within the stand. One condition that differs between stands with and without herbicide application, as well as between stands of different ages, is the amount of sunlight. Thus, an insect trap that collects equivalent

amounts of insects regardless of differing light conditions would be a benefit to researchers.

The first study examined the potential influence of shade on insect catch in malaise and flight-intercept traps. Six malaise trap types were investigated over a five-year period. The traps differed in the color and type of material used in the lower and upper panels. Trap catch was compared between traps in artificial shade and full sunlight. Also, the trap efficiency of various malaise traps was reported where comparisons were appropriate. Overall there was a consistent shade bias detected in the malaise and flight-intercept traps. Thus, researchers should use caution when using these traps to make comparisons of insect communities from forest stands with differing light levels.

The second study investigated the short- and long-term impacts of herbicide application in regenerating clearcuts on flowering plant communities. Many of the Hymenopteran insect groups require floral resources in order to persist in an environment. Thus, an evaluation of habitat suitability for the beneficial Hymenoptera must contain some measure of available floral resources. The flowering plant communities in twenty forest stands located in western Maine were sampled with the line intercept method. Six treatment groups were investigated: recent clearcuts that were sprayed with herbicide or un-sprayed, older clearcuts that were sprayed with herbicide or un-sprayed, plantations, and mature stands.

Overall there were few differences in flowering plant richness, abundance, and floral density between sprayed and non-sprayed sites within the recent and older age groups. However, there was a general trend of sites sprayed with herbicide having greater numbers of flowering plants. The age of the stand influenced the flowering plant abundance and floral density. The younger sites consistently had more compared to the older sites. The plantations had a greater abundance of flowering plants than did the older sites, possibly related to the uniform spacing between trees. However, the flowering species within the clearcuts and plantations were primarily non-native species or plants found in disturbed areas. Thus, their suitability as floral resources for native pollinators and parasitoids should be investigated.

ACKNOWLEDGEMENTS

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EVALUATING SHADING BIAS IN MALAISE AND INTERCEPT TRAPS

Introduction

Foresters have begun to take into account the importance of managing forests to maintain biodiversity in conjunction with tree production and yield. One important component of biological diversity is the Class Insecta, which contains over half of all described species on the planet. Because insects respond to microclimatic conditions they are sensitive to subtle changes in the ecosystem (Kim 1993). Studies that focus on the impact of silvicultural practices on insect communities are needed in order to develop strategies to maintain insect diversity and abundance within the industrial forest.

Unbiased sampling methods are required to assess the effects of different silvicultural practices on insect communities. Insect traps provide one method for assessing differences in insect communities. Flight-intercept traps are an effective way to sample insect communities along a vertical gradient in forest stands (Jaros-Su 1999). A malaise trap, which is positioned on the forest floor, is an efficient method to collect large quantities of aerial insects with minimal effort. However, legitimate comparisons can only be obtained if these traps are not biased by the environmental conditions within a forest stand.

One environmental condition that differs among stands of different ages, as well as with different management regimes, is sunlight. For example, recent clearcuts (<5 years post-harvest) have less overstory vegetation leading to higher levels of sunlight compared to older clearcuts (>10 years post-harvest). Thus, a malaise trap and/or flight-intercept trap that minimizes the bias associated with different light levels would be an asset to researchers interested in comparing insect communities from forest stands of different ages and/or management regimes.

Most studies have focused on parameters that increase catch efficiency in malaise traps, such as color and placement, without investigating trap bias. Townes (1972) stressed the importance of the color of the bottom mesh screens and collecting hood in his published design for a lightweight malaise trap. Subsequent studies found bicolor traps collected greater numbers of insects compared to mono-colored traps (Matthews and Matthews 1983, Darling and Packer 1988). Although these studies suggest the importance of trap color, neither of these studies was designed to investigate solely the effect of trap color on trap efficiency because the trap designs differed in color as well as other structural components.

Certain insect groups could be attracted to a particular trap due to its color. Traps designed to attract Diptera should maximally contrast the wavelengths of the surrounding environment (Roberts 1970, Pickens 1990). Pan traps are typically yellow in color because certain insects are attracted to particular wavelengths of light (Kennedy *et al* 1961). Sticky traps painted blue, violet, or yellow (420-470 nanometers (nm)) collected the most thrips of the species *Frankliniella occidentalis* (Vernon and Gillespie 1990). Tthe wasp *Campoletis perdistinctus* was more responsive to wavelengths in the green region (~ 560) and in the near ultraviolet region (~365 nm) (Hollingsworth *et al* 1970), suggesting a trap reflecting in the UV wavelengths would collect more of the Hymenoptera. Thus, insect trap catch could increase depending on the trap's degree of contrast with the background or light reflectance.

Also, the placement or location of the malaise trap influences the quantity of insects sampled. Townes (1972) suggests placing the traps in insect "flyways" such as along paths, openings, or around and between bushes. Darling and Packer (1988) reported that the location of the trap affected the number of Hymenoptera recovered, although this study only compared two different locations without trap replication. Another important aspect of trap placement is the vegetation structure surrounding the malaise trap, which has been found to influence the number of insects recovered (Hutcheson 1990). Because trap placement significantly affects trap catch, researchers should be cautious if comparisons based on only one trap per habitat are used to detect differences in insect assemblages.

The flight-intercept traps used in our studies were designed to sample insect communities at varying heights above the ground (Jaros-Su 1999). The Coleoptera constituted the largest percentage of the total trap catch from forest stands. This was attributed to the flight behavior of the Beetles. They are relatively poor fliers which when intercepted by the plexiglass panels have a tendency to fall into the lower collecting cup. Although an efficient way to sample insect communities in forest stands, which vary in vertical structure, the potential shade bias associated with this trap type was not addressed.

Matthews and Matthews (1983) caution against the use of malaise trap samples to compare different habitats. "Habitat" is an ambiguous term, but can be inferred to mean locations with differing vegetational structures and diversities. Although a study encompassing all of the variables that might affect malaise or flight-intercept trap catch is beyond the scope of this study one parameter that is correlated to vegetation structure is sunlight. A series of experiments were conducted from 1996 through 2000 to evaluate the effect of differing light conditions on insect trap catch in malaise and flight-intercept traps. Also, the collecting efficiency of different malaise trap designs was investigated. Six malaise trap designs were investigated over the course of 5 years; the traps differed in the color and material of the upper and lower panels.

Project Methodology

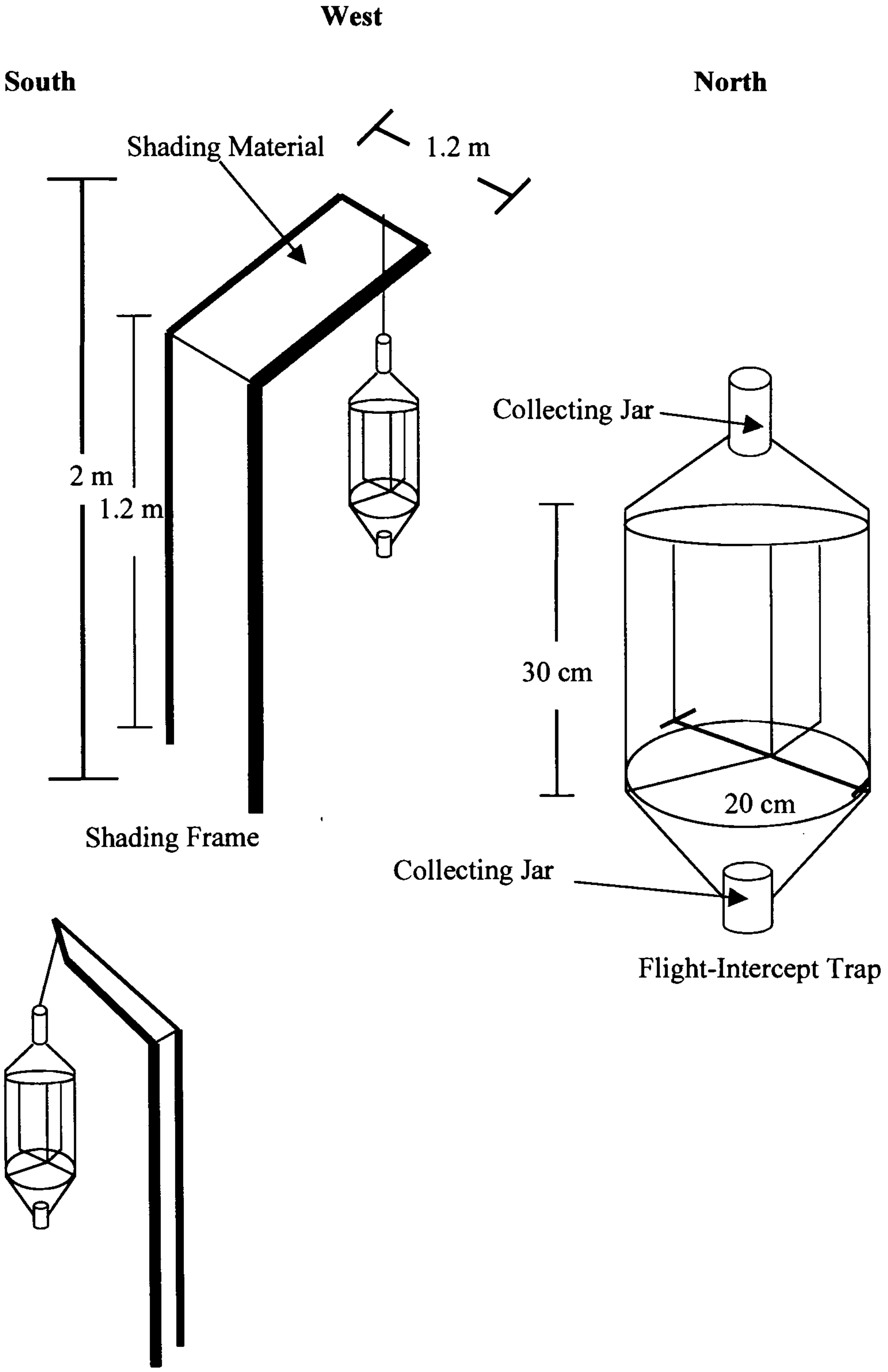
Study Site

Experiments were conducted over a five-year period from 1996 through 2000. During the summers of 1996, 1997, 1998, and 1999, experiments were set-up in a 33.8-hectare clearcut located in the Penobscot Experimental Forest in Bradley, ME. The stand had been harvested in December 1988 and was composed of a mixture of understory vegetation and regenerating balsam fir (*Abies balsamea*), red maple (*Acer rubrum*), and gray birch (*Betula populifolia*) 3-5 m tall. During the summer of 2000, the experiment was conducted in a clearcut that was harvested in the winter of 1994 –1995 and received a herbicide application in the summer of 1997 by ground application. The regeneration was composed of hardwoods, planted spruces, and herbaceous plants, less than 2-3 meters tall.

Materials and Methods

To create artificial shade, a frame was constructed of EMT conduit that was ca. 2 m high and 1.2 m across with the top portion bent at 45° (Figure 1.1). A fabric panel was stretched across the frame, so that the bottom was 1.2 m from the base and was stretched

Figure 1.1 Schematic diagram of shading frame and flight-intercept trap. Diagram is not to scale. Top diagram denotes shading frame in the "shade" position, facing to the north. Bottom diagram depicts shading frame in the "sun" position, facing to the south.



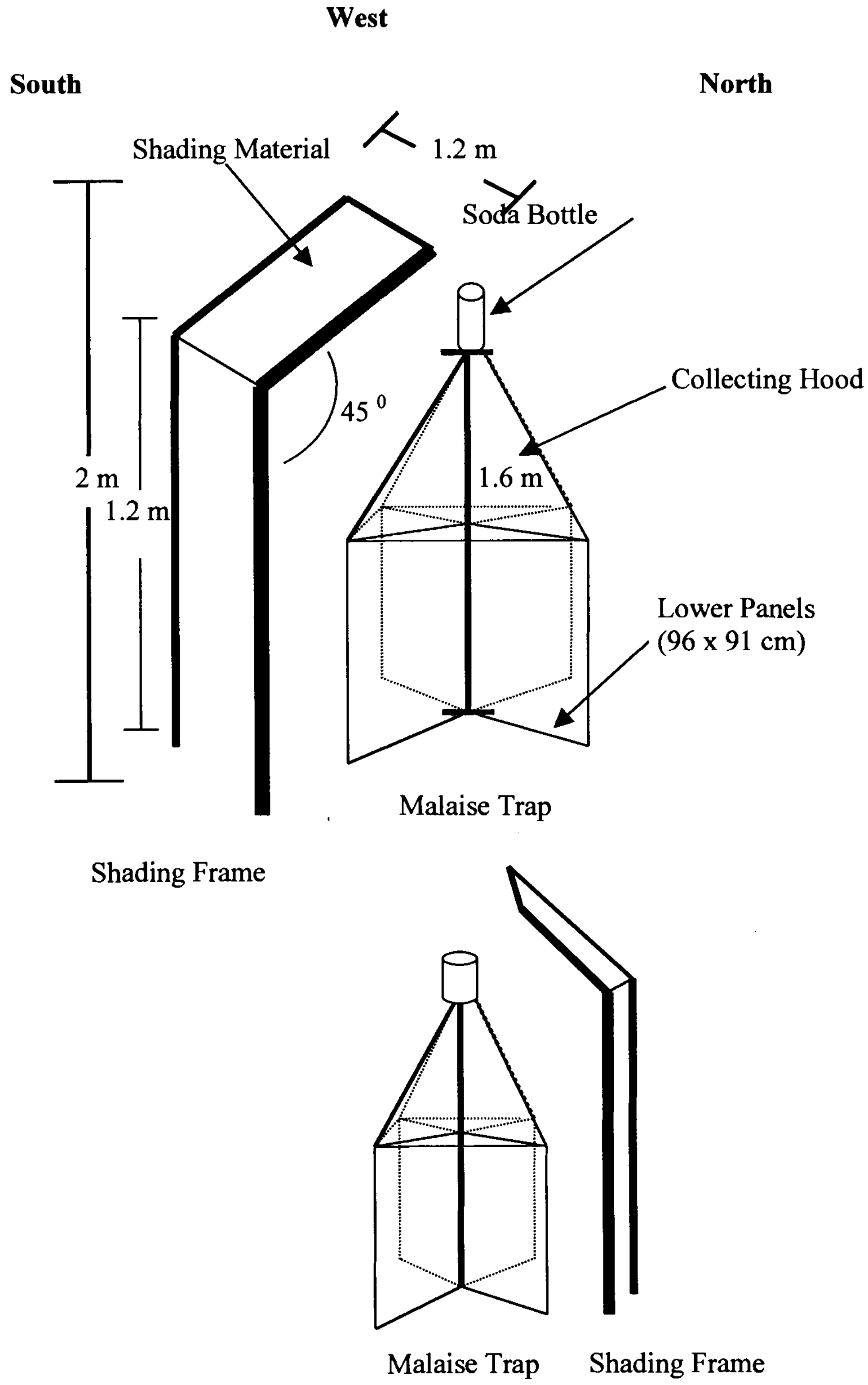
across the angled portion of the frame. Initially, the fabric panel was composed of a white muslin cloth but was changed to a green nursery cloth in 1997. The frames slid over metal bars that were sunk into the ground 15-20 cm. The frame was secured with three lines staked into the ground.

Flight-intercept traps were constructed by intersecting two 23 cm x 30 cm plexiglass panels so they created an “X” when viewed from above (Figure 1.1). A 20-cm diameter translucent funnel was attached at the bottom and top of the panels. A clear plastic specimen cup was affixed to the narrow part of the funnel. Insects that flew into the panels either dropped or continued upwards. They were collected in the cups and were killed with Vapona (2,2-Dichlorovinyl dimethyl phosphate).

Six malaise trap designs were used in the experiments. Within each experiment, all malaise trap designs had the same structural components (Figure 1.2). The only differences were the color and material of the collecting heads and lower panels. The lower panels were 96 cm by 91 cm. Two horizontal dowel rods threaded through the top of the panels were crossed in the middle for support. A collecting hood was placed over the panels and secured to the dowel rods with thumbtacks. A 1.6-m EMT center pole was sunk into the ground 5-10 cm and guy lines from the four corners secured the trap in place. An inverted large-mouth soda bottle was used to collect insects that flew upwards. A small piece of Vapona was placed in the soda bottle to kill the specimens. In 1999 and 2000, the malaise trap design with clear plastic lower and upper panels was modified such that the collecting head contained a propylene glycol solution that killed the insects.

In 1996, three malaise trap designs were monitored from August 1 to September 23. Two were either uniformly white or black, while the third had black mesh lower

Figure 1.2 Schematic diagram of shading frame and malaise trap. Diagram is not to scale. Top diagram denotes shading frame in the "shade" position, facing to the north. Bottom diagram depicts shading frame in the "sun" position, facing to the south.



panels and a collecting hood of white mesh. From August 1 to August 26, a white muslin cloth was used in the shading frame. Then all frames were changed to a green nursery shading material, which allowed 40% of total sunlight penetration. Four traps of each design were situated in a regenerating clearcut for a total of 12 traps. Each trap had a shading frame and half of the traps were shaded each week. The traps were in the shade position when the frames were facing to the North such that the white muslin or green nursery cloth shaded the trap. The shades were reversed to face towards the South for the sun position. The shades were switched to the alternate position every other week. This shading technique was used throughout the five-year study.

In 1997, malaise and flight-intercept traps were sampled from August 7 to October 9. The same three malaise trap designs were used as in 1996, black/black, black/white, and white/white. Three of each malaise trap design were established for a total of 9 malaise traps. One flight-intercept trap was suspended from each of three shading frames. The flight-intercept traps were sampled in 1995, as well (Jaros-Su unpublished). All 12 traps had a shading frame with green nursery cloth.

In 1998, two malaise trap designs were deployed from August 28 through October 17. The clear/white design had lower panels of clear plastic and a white mesh top. The green/white design had green mesh lower panels and a collecting hood of white mesh. Eight clear/white and four green/white malaise traps were established. Each trap had a shading frame with green nursery cloth used for the shading material.

In 1999, two experiments were conducted. The first experiment used the same experimental design as was used in 1998. Eight clear bottom/white top and four green bottom/white top traps were deployed from July 13 through August 10. For the second experiment, the eight traps were replaced with an all clear plastic design from August 10 through September 9. The all clear plastic design (clear/clear) was constructed with clear plastic panels and a clear plastic hood.

In 2000, two experiments were conducted in a younger clearcut due to the increase in vegetation height in the previous study site. The first experiment was conducted from June 14 to July 24. The clear plexiglass flight-intercept traps were examined again to complement the experiment in 1997. Two different shading materials were used because we suspected that the shade effect observed in previous years might depend on the type of shading material. Six shading frames had a piece of green nursery shading cloth stretched over the bent portion of the frame. Six shading frames had a piece of white muslin cloth stretched over the bent portion of the frame. One flight-intercept trap was suspended from each shading frame for a total of 12 positions. The second experiment was sampled from August 3 to September 13. Eight clear/clear and four green/white malaise traps, which had the same design as the traps used in 1999, were deployed.

For all years, insect samples were returned to the lab and identified to the order level. With the exception of 1996 and 1997 samples, the Hymenoptera were further divided into Ants, Wasps, and Bees (Suborder Apocrita).

Analysis

For all years, insect counts were log transformed to meet the model assumptions of normality and constant variance. For each year, an overall General Linear Model (Proc GLM, SAS Institute 1996) was run with pooled data across all taxa (total insect abundance) (Table 1.1). A similar model was used to detect if there were treatment and

Table 1.1 General Linear Model (Proc GLM, SAS Institute 1996) used for total insect abundance. A similar model was used, minus the treatment*taxa and trap type*taxa factors, to analyze treatment and trap type differences within each taxonomic group.

Factor	**Error Term**
Trap Type	Position (Trap Type)
Treatment (sun vs. shade)	Treatment * Position (Trap Type)
Treatment * Trap Type	Treatment * Position (Trap Type)
Treatment * Taxa	Treatment * Taxa * Position (Trap Type)
Trap Type * Taxa	Taxa * Position (Trap Type)

trap effects within each taxonomic group (number of individuals per order). Those groups that did not meet the model assumptions of normality or constant variance were not analyzed with statistical tests. Analyzing the data by taxonomic groups was justified because of the known behavioral differences between groups and the researcher's interest in specific taxa, particularly the Coleoptera and Hymenoptera.

If there was significant treatment by trap type interaction, linear contrasts were used to evaluate the shading effect for each trap separately. This was not possible in 1996 because only three sample dates were available when the analysis was separated by shade material. Pairwise comparisons were used when three malaise trap designs (1996 and 1997) were investigated simultaneously, to elucidate which trap design collected higher numbers of insects. In 2000, linear contrasts were also used to evaluate shading effects in the flight-intercept traps independently for each cover type.

Results

Over the five-year study each trap design was tested at least twice. There were some instances where a trap design displayed detectable differences between the full sunlight and shade one year but not the following or vice versa. However, in these cases some of the taxonomic groups displayed patterns consistent with a shade bias even when the overall model had non-significant treatment effects. We present the results for the overall model and the taxonomic groups to illustrate, although there was not statistically significant differences in the overall model, the patterns are consistent with a shade bias on insect trap catch at the order level.

1996

In 1996, three malaise trap designs were investigated, an all white trap, a bicolor trap with a black bottom and white top, and an all black trap. A white muslin cloth was used for the shading material during the first three weeks and then all traps had green nursery shading material for the last three weeks. The data were analyzed separately for the two different shading materials.

White Muslin Shading Material. Overall the traps (black/black, black/white, and white/white) in full sunlight collected comparable numbers of insects compared to those in artificial shade created by the white muslin cloth (Figure 1.3) and there was not a shade by taxa interaction (shade*taxa interaction $F_{6,59} = 1.59$, $P=0.16$). Consistent with the overall model, when analyzed separately for each taxonomic group, the traps in full sunlight collected comparable numbers of most taxa, except the Hymenoptera, compared to those in the shade (Figure 1.4). Only the Hymenoptera displayed a significant treatment effect with more individuals recovered from those traps in the full sunlight. In the overall analysis and within the majority of the taxonomic groups there was not a detectable shading bias when the white muslin material was utilized.

The three malaise trap designs (black/black, black/white, and white/white) collected similar quantities of insects, when the white muslin cloth was used as a shading material (Figure 1.3), and there was no taxa by trap interaction ($F_{12,53} = 0.69$, $P=0.75$).

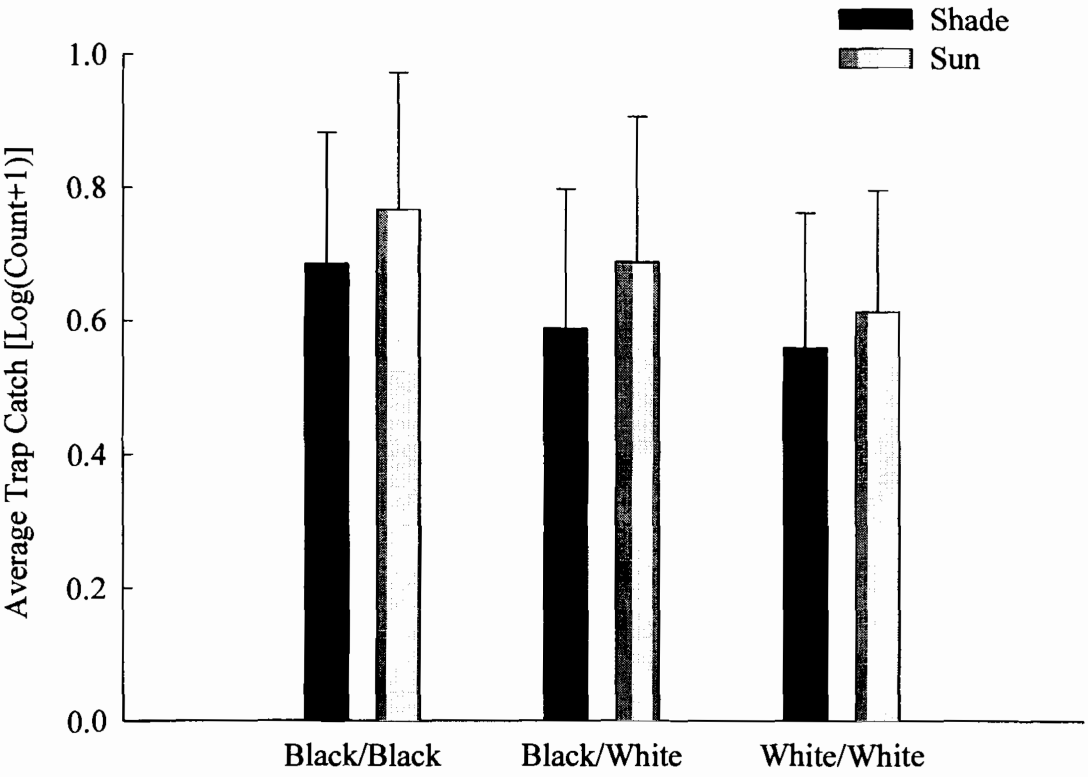


Figure 1.3 Mean number of total insects collected from three malaise trap designs (Black/Black, Black/White, and White/White) with and without white muslin cloth shade in 1996. Error bars represent one standard error of the mean. There was not a significant difference in the total number of insects collected from traps in the sun compared to those in the shade position ($F_{1,9}$=2.55, P=0.14).There was not a significant difference between the total number of insects collected from the three trap designs ($F_{2,9}$=1.27, P=0.33). Also, there was not a significant shade by trap design interaction ($F_{1,9}$=0.07, P=0.93).

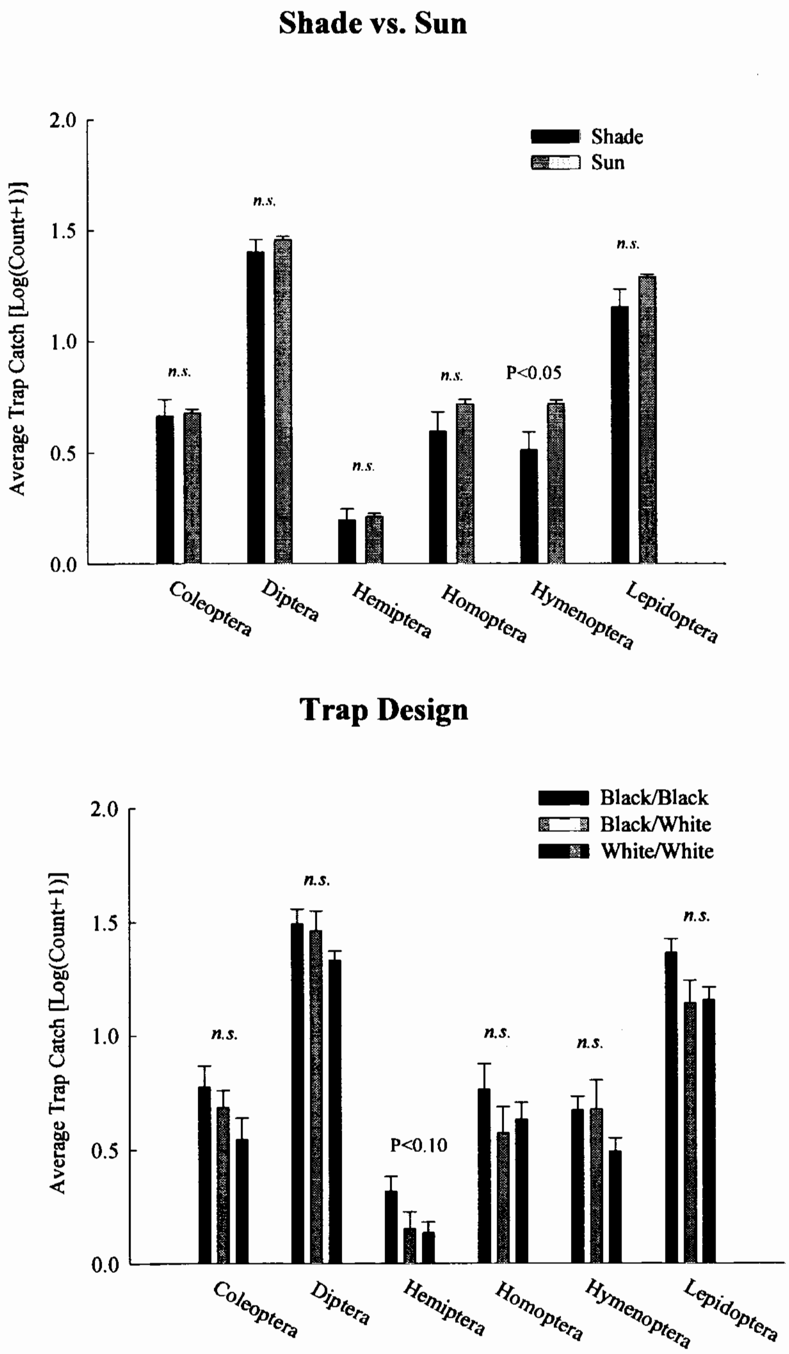


Figure 1.4 The shade and trap effects for each taxa collected from malaise traps (Black/Black, Black/White, and White/White) in 1996. White muslin cloth was used as artificial shading material. P-values reported for taxa with significant differences in catch between sun and shade ($F_{1,9}$) top panel and trap designs ($F_{2,9}$) bottom panel. Non-significant differences are indicated by *n.s.* (P>0.10). Error bars represent one standard error of the mean.

Consistent with this finding when analyzed individually; trap catch was comparable between trap types for the majority of taxa, except the Hemiptera (Figure 1.4). Only the Hemiptera showed weak evidence for a difference in trap catch with the all black design collecting more individuals than the bicolor and all white design (black/black vs. black/white P=0.046; black/black vs. white/white P=0.066) (Figure 1.4).

Green Nursery Shading Material. When the shading material was switched to the green nursery shading cloth, there was an overall significant treatment (sun vs. shade) effect (Figure 1.5). The traps in the full sunlight collected more insects than those in the shade. In general, the effect appears more pronounced in the all black and absent in the uniform white design.

Across the taxonomic groups the effect of shade on trap catch was similar (treatment*taxa $F_{6,56} = 1.03$, P=0.41). Consistent with the overall model, the Coleoptera displayed a strong shading bias with greater numbers recovered from the traps in the full sunlight and within the Hymenoptera a weaker response was detected (Figure 1.6). Although at the order level the remaining taxa did not display significant treatment effects (Figure 1.6), the same pattern emerges of traps in the full sun collecting more insects. This pattern was similar to the results using the white muslin shading cloth although more pronounced.

Consistent with the results using the white muslin shading material, the three malaise trap designs (black/black, black/white, and white/white) collected equivalent numbers of insects when the green nursery cloth was used (Figure 1.5). Similarly, there was not a significant trap by taxa interaction ($F_{12,53} = 1.03$, P=0.44) suggesting across the taxonomic groups the pattern of trap catch was the same between the different trap

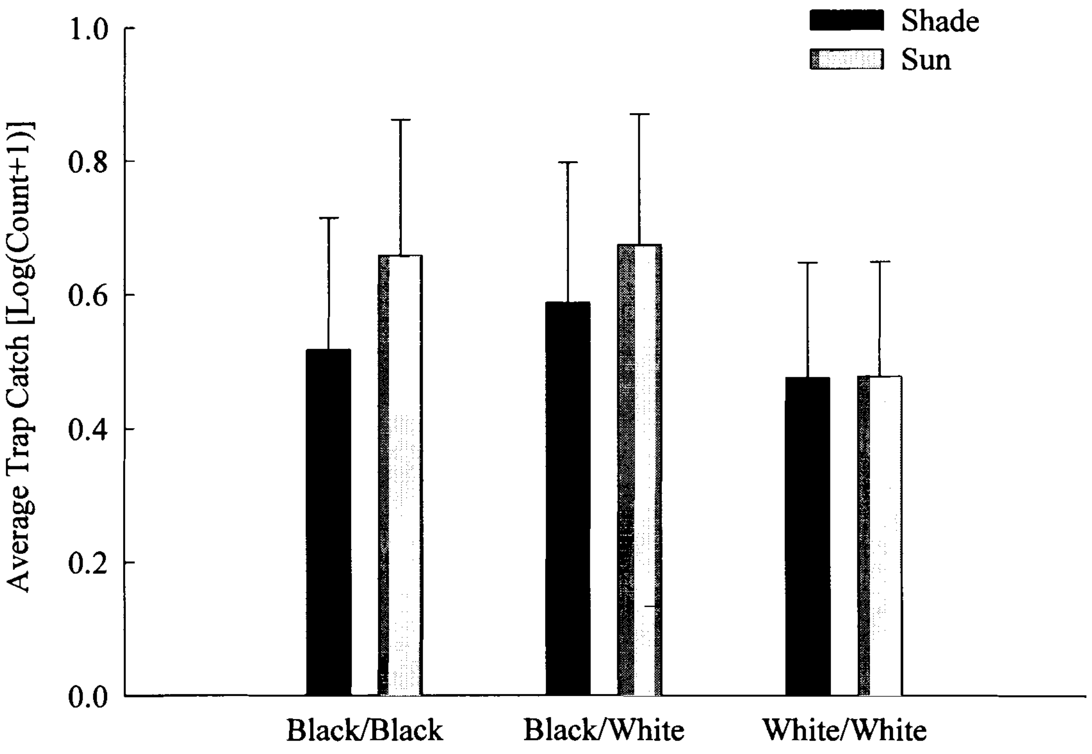


Figure 1.5 Mean number of total insects collected from three malaise trap designs (Black/Black, Black/White, and White/White) with and without green nursery cloth shade in 1996. Error bars represent one standard error of the mean. There was a significant difference in the number of insects collected from traps in the sun compared to in the shade position ($F_{1,9}$=10.79, P=0.009). There was not a significant difference between the number of insects collected from the three trap designs ($F_{2,9}$=0.94, P=0.43). There was not a significant shade by trap design interaction ($F_{1,9}$=1.19, P=0.35).

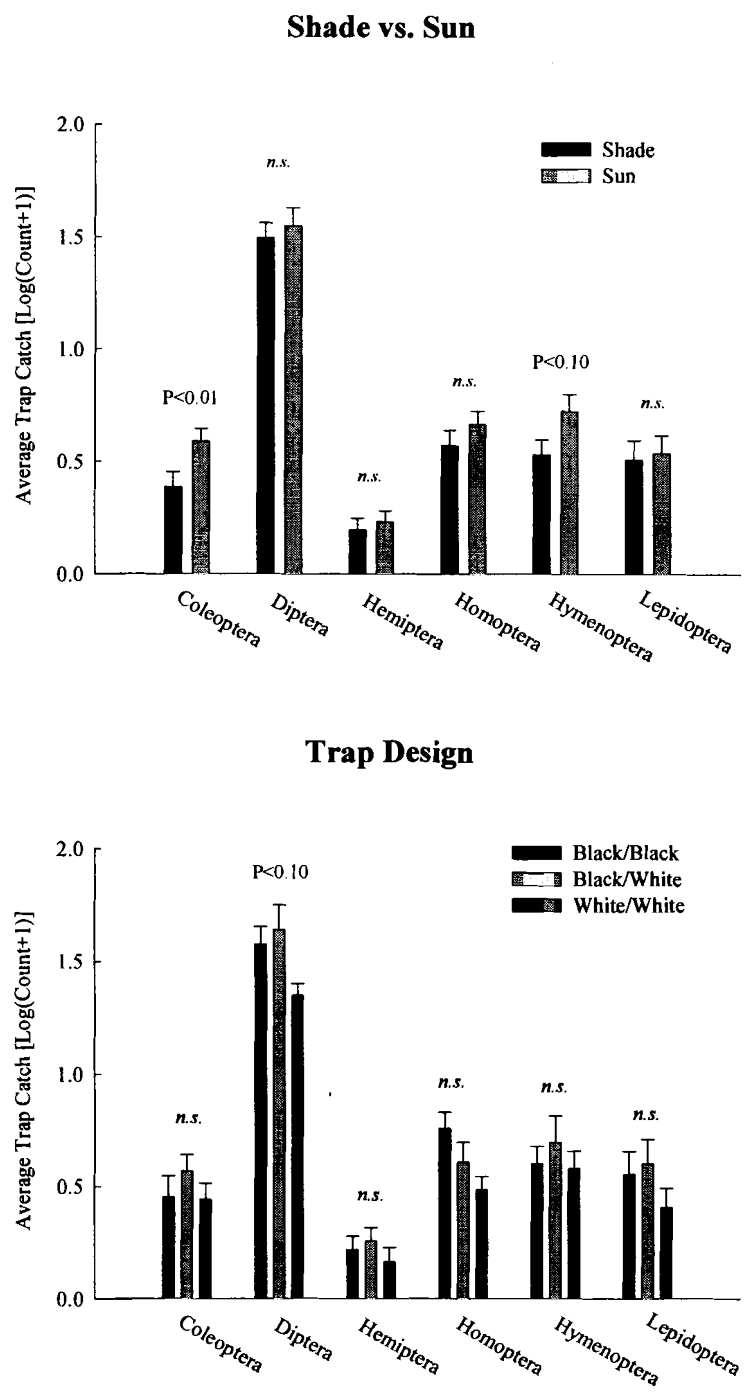


Figure 1.6 The effect of shade and trap design on the mean number of each taxa collected from malaise traps (Black/Black, Black/White, and White/White) in 1996. Green nursery shading material was used as the artificial shading material. P-values reported for taxa with significant differences between shade and sun ($F_{1,9}$) top panel and trap designs ($F_{2,9}$) bottom panel. Non-significant differences are indicated by *n.s.* (P>0.10). Error bars represent one standard error of the mean.

designs. Consistent with the overall model, when analyzed at the order level, the three trap designs collected similar numbers of Coleoptera, Homoptera, Hemiptera, Hymenoptera, and Lepidoptera (Figure 1.6).

Although the overall pattern suggested the all black, all white, and the bicolor traps collected equivalent numbers of insects. There was one exception within the Diptera. The black/black and black/white malaise trap designs captured more Diptera (black/black vs. white/white $t_{2,9}$ = -2.096, P=0.065; black/white vs. white/white $t_{2,9}$ = -2.37, P=0.042) compared to the all white design (Figure 1.6). But the overall trend suggested the traps had equivalent means collected in the three designs for the majority of taxa. All three designs had the same dimensions, thus sampled the same air space, which could explain the similarity in catch.

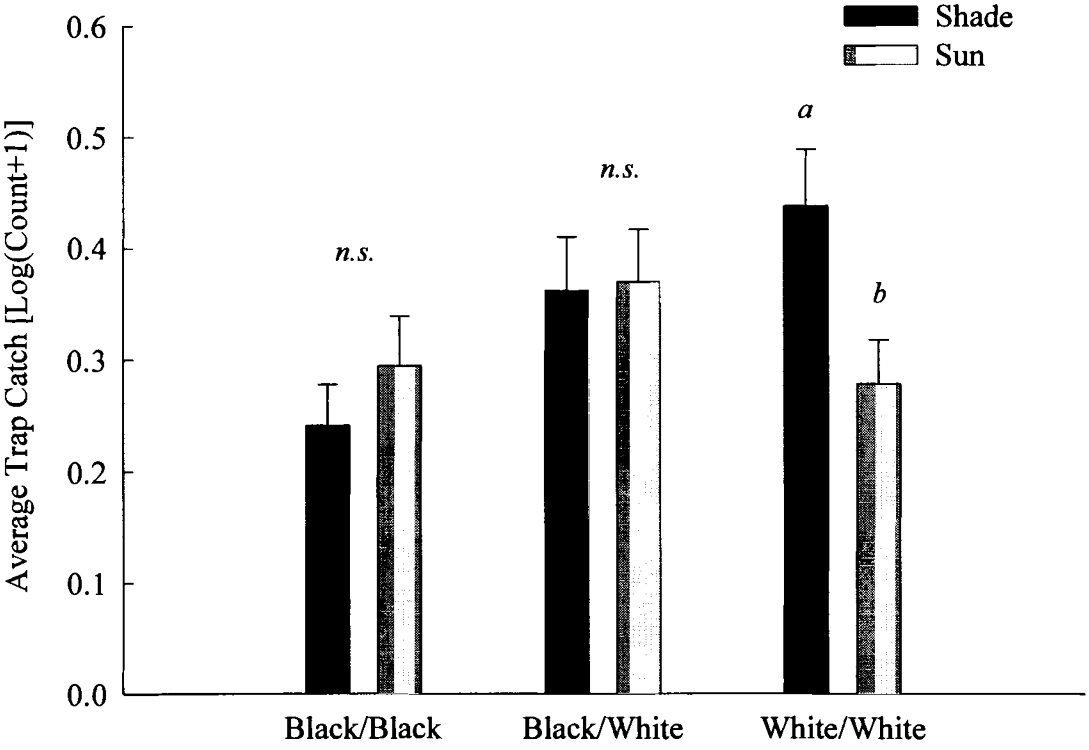
In 1996, the overall pattern was consistent with traps in the sun collecting more insects for both types of shading materials. When the white muslin cloth created artificial shade, the three trap designs showed a similar pattern with more insects recovered from traps in full sunlight (Figure 1.3), although there was not a detectable shade bias. Similarly, when the green nursery shading material was used, the black/black design displayed a stronger trend and the black/white design showed a weaker trend with more insects recovered from traps in full sunlight (Figure 1.5). The only exception was the all white design that had equivalent means in the sun and artificial shade created by the green nursery material. Thus, although the three traps showed a similar pattern regardless of shading material (minus the white design), a shade bias was only detectable when the green nursery material was used.

1997

In 1997, flight-intercept traps were deployed in addition to the same three malaise trap designs (black/black, black/white, and white/white) from 1996. Because the two trap types have known differences in the insect groups collected, the analysis was conducted on the malaise and flight-intercept traps separately. Malaise traps were better suited for sampling aerial insects (Hymenoptera and Diptera), whereas intercept traps tended to collect insects that were relatively "poor" flyers (Coleoptera).

Malaise Traps. The malaise traps in full sunlight collected similar numbers of insects compared to those in the shade (Figure 1.7). In the overall model, while the effect of shade was similar across the taxonomic groups (treament*taxa interaction $F_{9,72} = 1.52$, P=0.15), the Hymenoptera were more abundant in the traps in the shade (Figure 1.8). The remaining groups were not significantly different, although the means were consistently lower in the sun (Figure 1.8).

However, in the overall model, there was a significant trap design by treatment (shade vs. sun) interaction (Figure 1.7), suggesting the effect of shade was not the same across the three trap types. Although not statistically meaningful, the black/black design collected more insects in the sun ($t_{2,6}=1.65$, P=0.15), which is consistent with the findings from 1996. In 1996, the black/black malaise trap design collected more individuals in the sun by a ratio of 1.6 to 1. The black/white trap did not display a shading bias ($t_{2,6}=0.51$, P=0.62), but in 1996 there was a weak trend of traps in full sunlight collecting more insects. Conversely, the white/white design collected more insects when the trap was artificially shaded ($t_{2,6}=4.83$, P=0.003) by a ratio of 2:1, this pattern was driven by the group Hymenoptera, whereas in 1996 a shading bias was not apparent.



Figures 1.7 Mean number of insects recovered from three malaise trap designs (Black/Black, Black/White, and White/White) with and without green nursery material shade in 1997. Overall there was not a significant difference between traps in the shade compared to in the sun ($F_{1,6}$= 1.98, P=0.21) and there was not a significant difference between the three malaise trap designs ($F_{2,6}$= 1.49, P=0.29). However, there was a significant trap by shade interaction ($F_{2,6}$= 11.89, P=0.009). Only the all white trap displayed a significant shade bias ($t_{2,6}$=4.83, P=0.003).

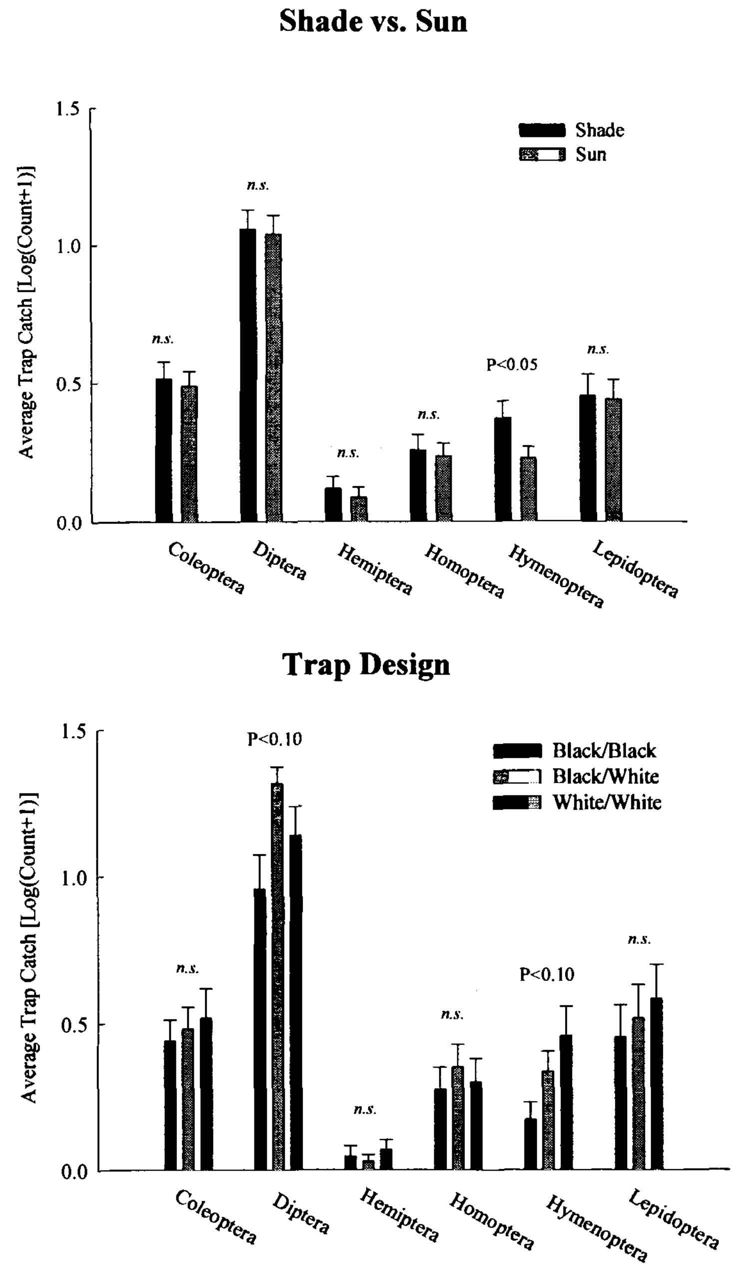


Figure 1.8 The effect of shade and trap design on the mean number of each taxa collected from malaise traps (Black/Black, Black/White, and White/White) in 1997. Artificial shade was created from a green nursery shading material. P-values reported for taxa with significant differences between sun and shade ($F_{1,6}$) top panel and trap design ($F_{2,6}$) bottom panel. Non-significant differences indicated by *n.s.* ($P>0.10$). Error bars represent one standard error of the mean.

In 1997, the three different malaise trap designs (black/black, black/white, and white/white) recovered equivalent numbers of insects (Figure 1.7), but there was a significant trap by taxa interaction ($F_{18,54} = 1.72$, $P=0.06$). The majority of the taxa did not display differences in trap catch between the three designs, but two of the groups (Diptera and Hymenoptera) did have detectable differences (Figure 1.8). As in 1996, the number of Diptera was not the same between the different malaise traps (Figure 1.8). The black/white design collected more compared to the all black design ($t_{2,6}= 2.97$, $P=0.025$), but not more than the all white design ($t_{2,6}= 1.31$, $P=0.237$). Within the order Hymenoptera the all white design collected more compared to the all black design ($t_{2,6}=2.72$, $P=0.034$), but the black/white was not different than the all white or all black designs (Figure 1.8). However, the three designs collected the comparable numbers of Coleoptera, Hemiptera, Homoptera, and Lepidoptera (Figure 1.8).

Flight-Intercept Traps. In 1997, the artificial shade treatment did not affect the total number of insects collected in flight-intercept and there was not a significant taxa by treatment interaction in the overall model. When the groups were analyzed separately, it confirmed the flight-intercept traps in the sun and shade recovered similar numbers of each taxa ($P>0.40$) (Figure 1.9). The flight-intercept traps were first tested for a shade bias in 1995 and a bias was not detected (Jaros-Su unpublished), similar to the result in 1997.

1998

In 1998, the clear/white and green/white malaise trap designs were deployed. A malaise trap design was developed with similar components to the flight-intercept traps because the flight-intercept traps did not display a shade bias in both 1995 (Jaros-Su

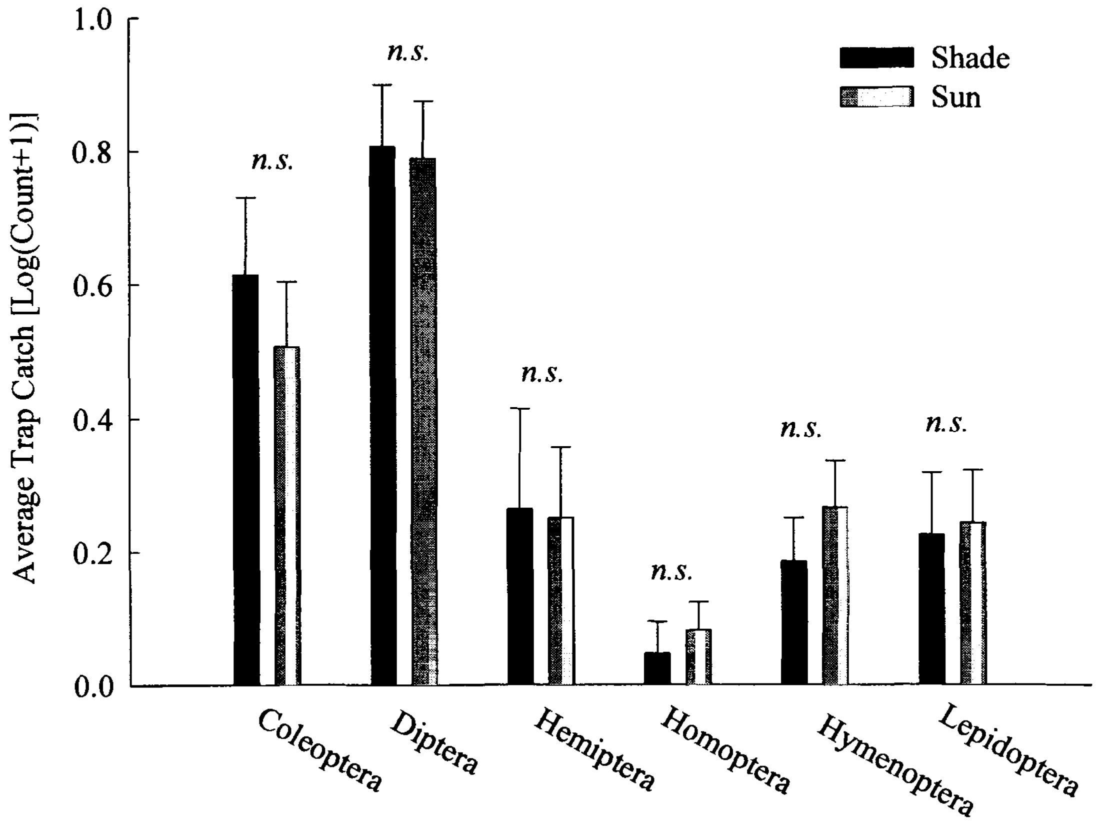


Figure 1.9 Mean number of each taxa collected from flight-intercept traps with and without artificial shade in 1997. P-values reported for taxa with significant differences between traps in the sun and shade position ($F_{1,19}$). Non-significant differences are indicated by *n.s.* ($P>0.10$). Error bars represent one standard error of the mean. There was not a significant treatment effect in the overall model ($F_{1,191}=0.01$, $P=0.132$). Similarly, there was not a significant taxa by shade interaction in the overall model ($F_{9,191}= 0.23$, $P=0.99$).

unpublished) and 1997. Thus, a malaise trap with similar clear panels and white top might also be unbiased.

Malaise traps in the full sunlight collected similar numbers of insects compared to those in the shade (Figure 1.10). The effect of shade on trap catch was similar in both the clear/white and green/white design (Figure 1.10). Although there was not a significant shade bias detected in either trap design (clear/white $t_{1,10} = 0.582$, $P=0.57$; green/white $t_{1,10} = 1.52$, $P=0.16$), both malaise trap designs displayed a similar pattern, more insects were collected in the shade.

However, there was a significant taxa by shade interaction in the overall model ($F_{9,99} = 2.70$, $P=0.007$), suggesting the effect of shade on trap catch was not the same across the taxonomic groups. When analyzed individually, traps in the shade captured more Ants, Lepidoptera, Spiders, and Wasps compared to those exposed to full sunlight, whereas the remaining taxa did not display significant treatment differences (Figure 1.11). Thus, in 1998, a shade bias was only detectable at the order level and was not displayed when the analysis was conducted on total insect abundance.

The majority of taxa displayed similar trends in both trap designs (treatment*trap interaction $P>0.10$). But within the Bees the effect of shade on trap catch was different between the trap types (treatment *trap $F_{1,10} = 6.81$, $P<0.05$). Within the clear/white design more bees were recovered from traps in full sunlight ($t_{1,10}= 2.41$, $P=0.036$); however, within the green/white design the numbers recovered from the traps in the shade and sun were similar, or possibly reversed ($t_{1,10}=1.50$, $P=0.16$).

In 1998, the clear/white and green/white trap designs collected similar numbers of total insects (Figure 1.10) and there was not a trap by taxa interaction ($F_{9,90} = 0.47$,

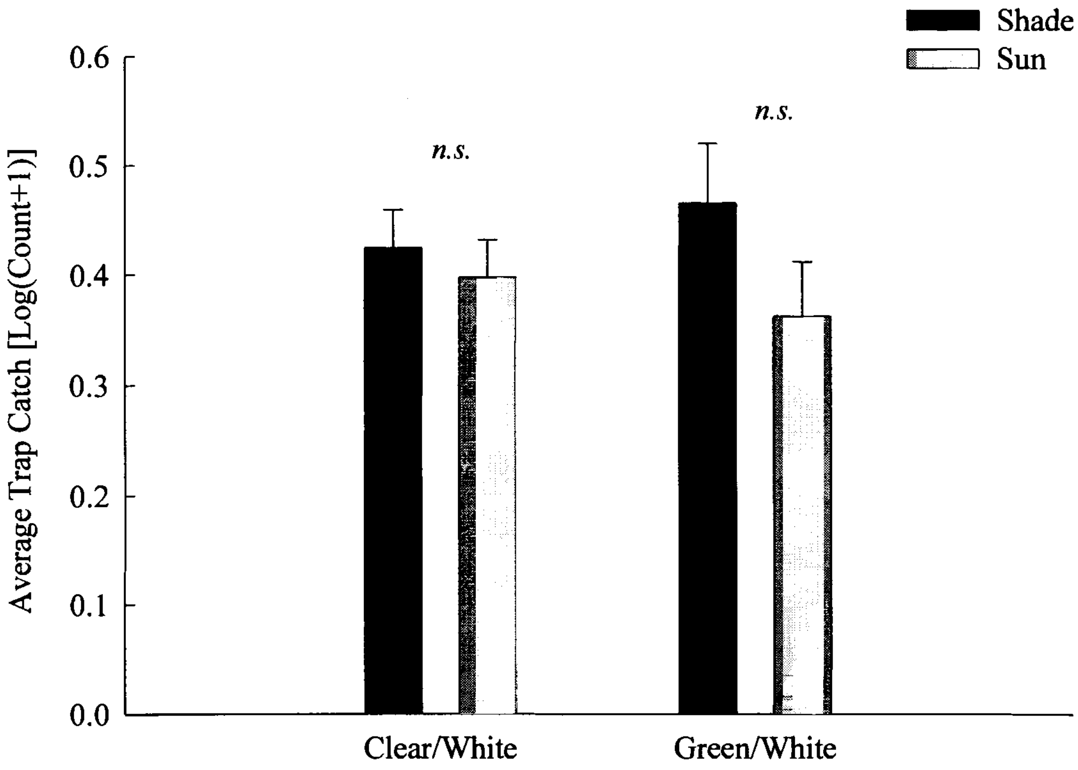


Figure 1.10 Mean number of total insects collected in 1998 from two malaise trap designs (Clear/White and Green/White) with and without artificial shade. Error bars show one standard error of the mean. There was no significant shade (F1,10=2.42, P=0.15) or trap type (F1,10=0.04, P=0.83) main effects and no significant shade by trap type interaction (F1,10=0.84, P=0.38).

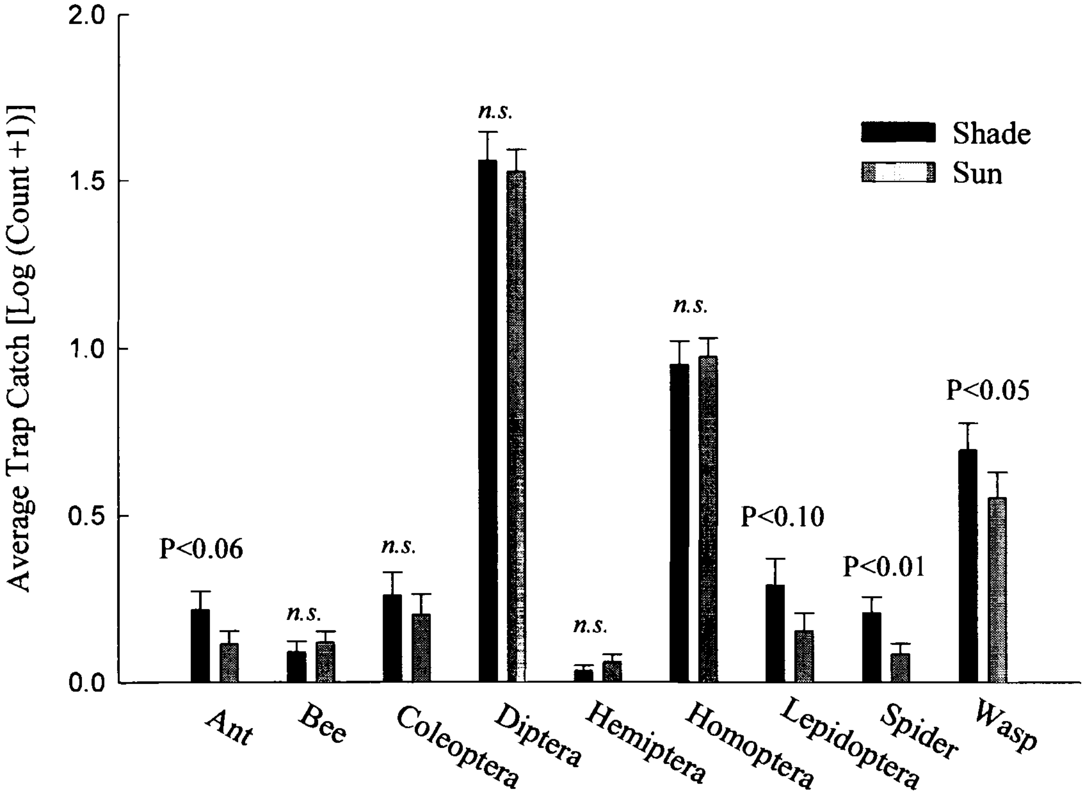


Figure 1.11 Mean number of each taxa recovered from malaise traps (Clear/White and Green/White) with and without artificial shade in 1998. P-values reported for taxa with significant differences between traps in the sun compared to those in the shade ($F_{1,10}$). Non-significant differences are indicated by *n.s.* ($P>0.10$). Error bars show one standard error of the mean.

P=0.89). Consistent with this finding, when the taxa were analyzed separately, the two malaise trap designs collected similar numbers of all taxonomic groups.

Overall in 1998 the two trap designs (clear/white and green/white) displayed a trend of collecting more insects when artificially shaded, which was similar to the one detected in 1997 in the all white trap design. However, this pattern was the opposite of the one detected in the black/black design in 1996 and the black/white during the summer of 1996 and 1997, which collected more insects in full sunlight.

1999

The major objective for 1999 was to repeat the previous experiment in 1998 and to evaluate a clear/clear trap design. In the first experiment the clear/white traps were deployed with the green/white malaise design again. In a second experiment, clear/clear and green/white malaise trap designs were tested for shading bias. The two experiments were analyzed separately.

Clear/White and Green/White Malaise Traps. In 1999, the clear/white and green/white malaise traps in the full sunlight collected more insects compared to those in the shade (Figure 1.12). The green/white design collected more insects by a ratio of 1.8 to 1 in the sun. However, there was a significant treatment by taxa interaction ($F_{9,99} = 2.42$, P=0.02). Consistent with the overall model, the exposed malaise traps collected higher numbers of Coleoptera, Diptera, Hemiptera, Homoptera, Lepidoptera, and Wasps than shaded traps (Figure 1.13). The Spiders were the only group without a significant shade bias (Figure 1.13). The same pattern emerges across the taxa with traps in the sun collecting more compared to those in the shade (treatment*trap interaction P>0.10).

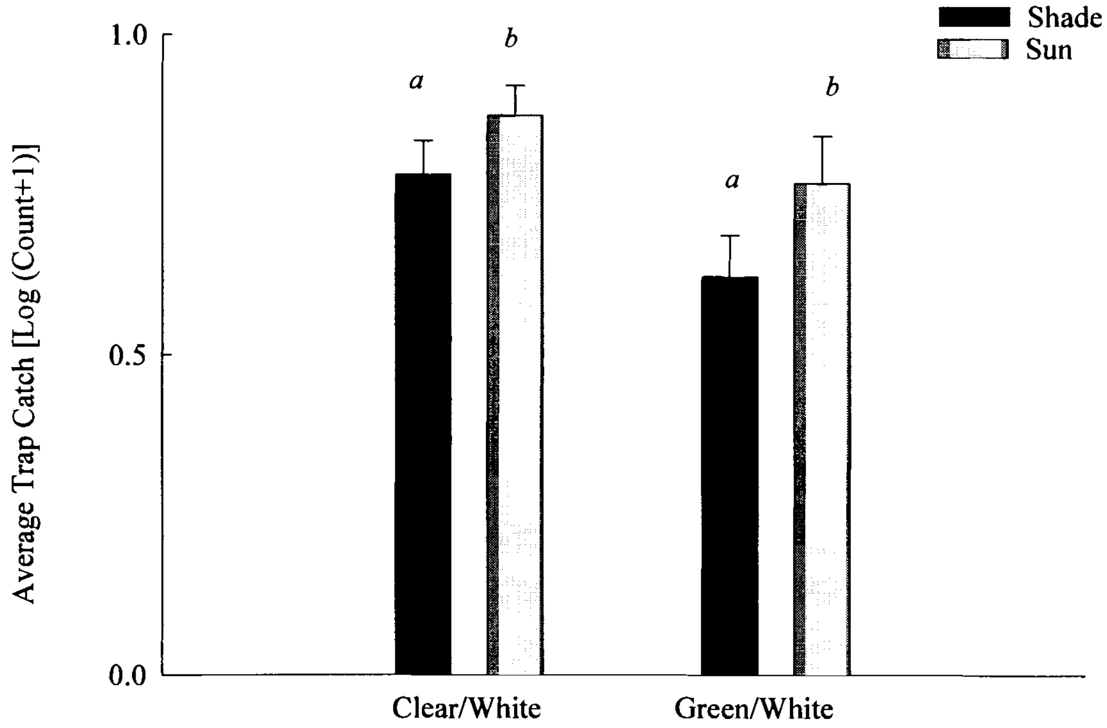


Figure 1.12 Mean number of total insects collected in 1999 from two malaise trap designs (Clear/White and Green/White) with and without artificial shade. Error bars show one standard error of the mean. There was a significant shading effect ($F_{1,10}$ = 7.64, P=0.02) and a significant trap type effect ($F_{1,10}$ = 7.82, P=0.02). There was not a significant interaction between shade and trap type ($F_{1,10}$ = 0.16, P>0.50). There was a significant shade bias in the Clear/White design ($t_{1,10}$=2.068, P=0.065) and the Green/White design ($t_{1,10}$=2.73, P=0.02).

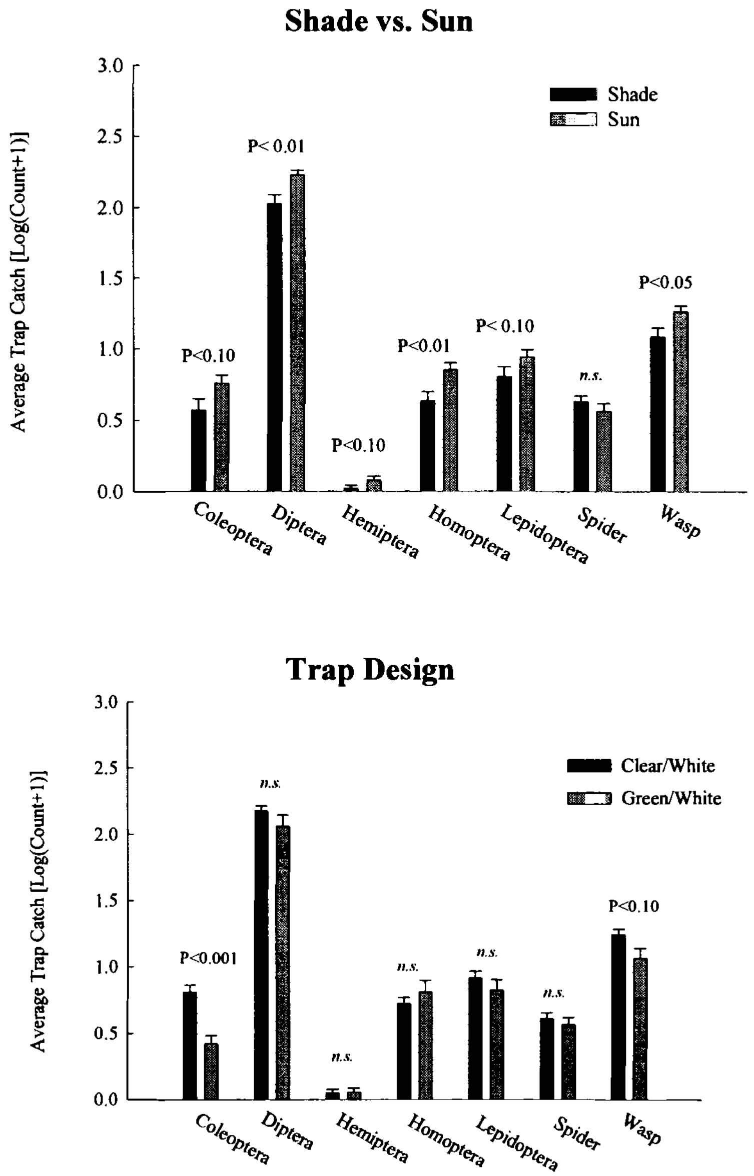


Figure 1.13 The effect of shade and trap design (Clear/White and Green/White) on the mean number of each taxa collected from malaise traps in 1999. P-values reported for taxa with significant differences between shade and sun ($F_{1,10}$) top panel and trap design ($F_{1,10}$) lower panel. Non-significant differences are indicated by *n.s.* ($P>0.10$). Error bars represent one standard error of the mean.

In 1999, the clear/white design collected more total insects than the green/white trap design (Figure 1.12). The pattern of trap catch was not the same for the two designs at the order level (trap*taxa $F_{9,90}$=3.56, P=0.0008). However, when analyzed individually, most taxa were collected in comparable abundance in the clear/white and green/white malaise traps (Figure 1.13). However, the clear/white design collected more Coleoptera compared to the green/white traps (Figure 1.13). Similarly, a weaker trend was displayed within the Wasps with the clear/white traps collecting more than the green/white traps (Figure 1.13). This was in contrast with 1998, when there were no detectable differences in trap catch within the Coleoptera or Wasps. The only structural difference between the clear/white design and green/white design was the lower panel. In the clear/white design it was a solid clear plastic, whereas in the green/white design it was constructed from a green mesh fabric.

The green/white trap design displayed the opposite pattern in 1998, shaded traps collecting more than exposed, compared to the trend in 1999, although this was not significantly different. Within the Lepidoptera and Wasps, a similar pattern was detected with shaded traps collecting more in 1998, whereas in 1999 the traps in full sunlight had higher mean numbers of individuals. The experiment in 1998 was conducted later in the summer (August –October) than in 1999 (July –August); thus, there were many seasonal differences confounding comparisons between the two years.

Clear/Clear and Green/White Malaise Traps. In 1999, both the clear/clear and green/white traps displayed a weak trend of traps in full sunlight capturing the most insects (Figure 1.14), although not highly statistically significant (P<0.10). There was no significant treatment by taxa interaction ($F_{9,99}$ = 1.35, P=0.22) in the overall model.

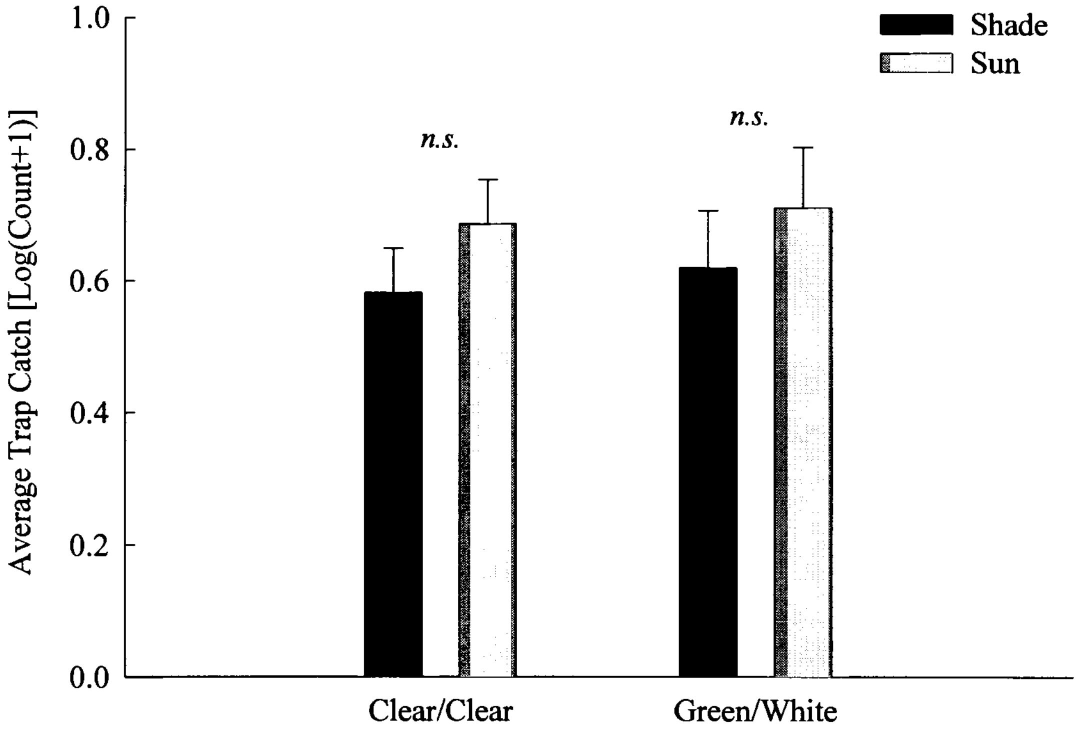


Figure 1.14 Mean number of total insects recovered in 1999 from two malaise trap designs (Clear/Clear and Green/White) with and without artificial shade. Error bars indicate one standard error of the mean. The traps in the sun position collected more total insects than the traps in the shade, although not statistically different ($F_{1,10}$ =3.52, P=0.09). There was no significant difference in the total numbers of insects collected in the two designs ($F_{1,10}$ =2.02, P=0.18). There was not a significant interaction between shade position and trap type ($F_{1,10}$ =0.15, P=0.22).

Consistent with this finding when analyzed by groups, the traps in full sunlight and artificial shade collected equivalent numbers for each taxa (treatment effect $P>0.10$) (Figure 1.15). Also, there was not a significant interaction between treatment and trap design for any taxa ($P>0.10$). Although there were not detectable treatment effects, it is interesting to note that all taxa had means that were higher for traps in the sun. Furthermore, this pattern was consistent with previous years with exposed malaise traps collecting more insects than shaded traps.

In 1999, the total number of insects collected in the clear/clear and green/white malaise traps were similar (Figure 1.14), but there was a significant trap type by taxa interaction ($F_{9,90}=6.11$, $P<0.0001$). Consistent with this finding, some taxa were collected in greater numbers in the clear/clear design, whereas others displayed the converse with more individuals in the green/white design (Figure 1.15). The clear/clear malaise traps collected more Wasps (Figure 1.15). Conversely, the green/white traps collected more Homoptera, Lepidoptera, and Spiders (Figure 1.15). There was not a significant difference in the numbers of Diptera or Coleoptera collected in either trap design (Figure 1.15). Thus, the pattern of trap catch was not consistent at the order level.

2000

In 2000, the clear/clear and green/white malaise trap designs were tested for the second time. The second experiment examined the flight-intercept traps again to complement the experiment in 1997. In the second experiment, the two different shading materials were used on the shading frames with the flight-intercept traps. We suspected that the type of shading material might influence the effect of shade on trap catch because

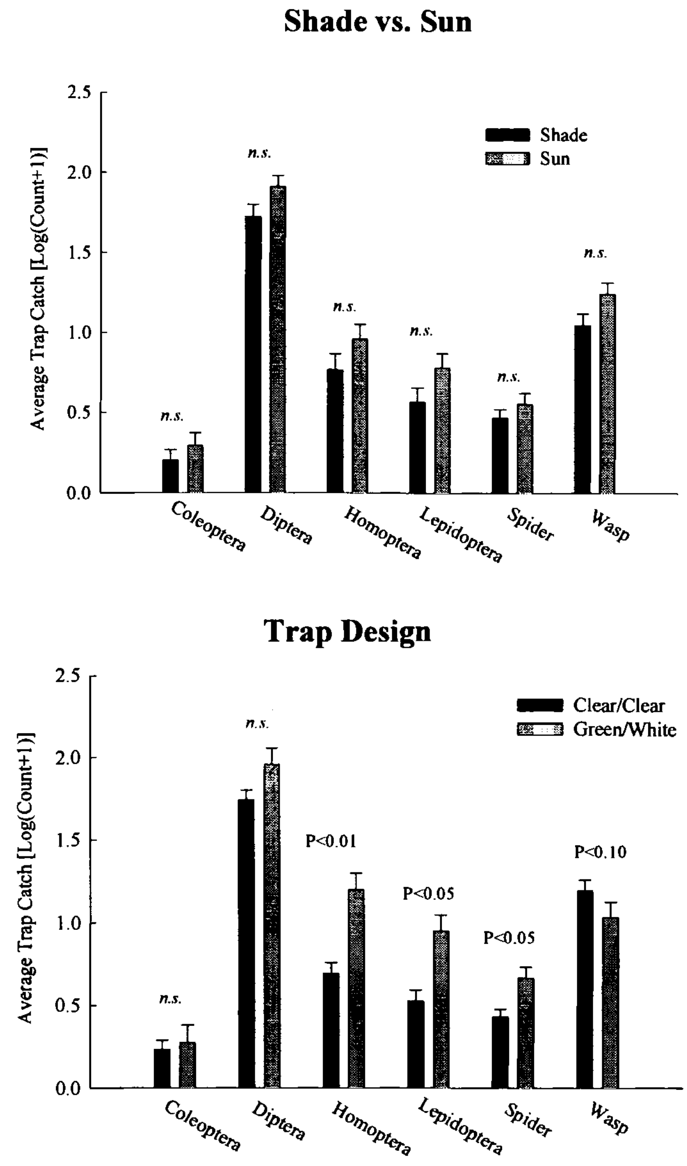


Figure 1.15 The effect of shade and trap design on the number of taxa collected from malaise traps (Clear/Clear and Green/White) in 1999. P-values reported for taxa with significant differences between shade and sun ($F_{1,10}$) top panel and trap design ($F_{1,10}$) lower panel. Non-significant differences are indicated by *n.s.* ($P>0.10$). Error bars represent one standard error of the mean.

in 1996, with the malaise traps, the shade effect was less pronounced when the white muslin cloth created artificial shade compared to when the green nursery cloth was used.

Clear/Clear and Green/White Malaise Traps. In 2000, the clear/clear and green/white traps displayed a similar pattern of collecting more insects in the sun compared to those in artificial shade (Figure 1.16). The clear/clear design displayed an overall significant shade bias ($t_{1,10} = 2.146$, $P=0.06$), collecting insects by a factor of 1.4 to 1 in the full sunlight. Even though the means were consistent with the overall pattern, the shade bias for the green/white design was not significant ($t_{1,10} = 0.69$, $P=0.50$). As in 1999, the effect of shade on trap catch was consistent between the clear/clear and green/white trap designs in overall insect abundance.

Also, in the overall model the effect of shade on trap catch was consistent across the taxonomic groups (treatment*taxa interaction $F_{9,99} = 1.51$, $P=0.15$). As in 1999, there were more Diptera ($F_{1,10} = 4.34$, $P=0.06$) collected from the traps in full sunlight compared to in artificial shade (Figure 1.17). The Wasps displayed a weak trend of traps in full sunlight collecting more individuals than in shade ($F_{1,10} = 3.00$, $P=0.11$), although not significant (Figure 1.17). However, the traps in the sun and shade collected comparable numbers of Homoptera, Lepidoptera, and Spiders (Figure 1.17). But within the Lepidoptera (treatment*trap interaction $F_{1,10} = 5.13$, $P=0.047$) the clear/clear traps had a detectable shade bias ($t_{1,10}=2.65$, $P=0.024$), whereas the green/white trap did not ($t_{1,10}=1.11$, $P=0.29$) (Figure 1.17). Similarly, there was a weaker trend within the Spiders (treatment*trap interaction $F_{1,10} = 3.98$, $P=0.074$), the green/white traps had higher means

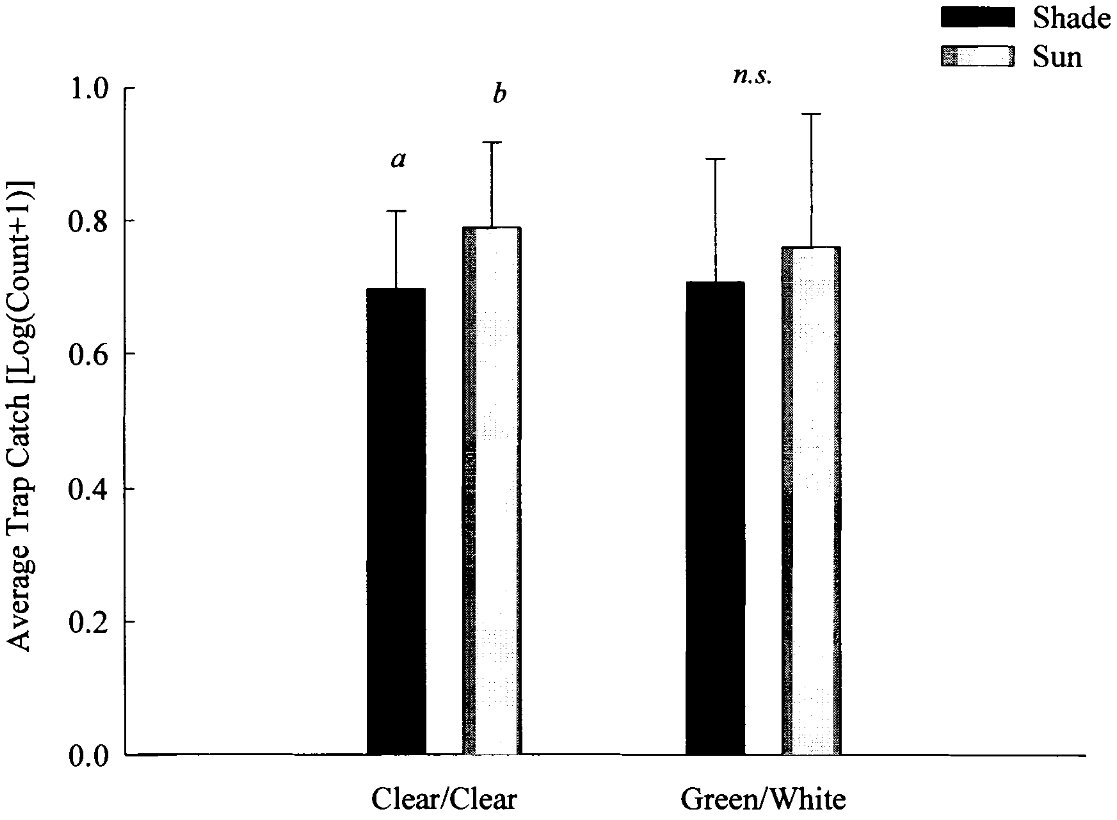


Figure 1.16 Mean number of total insects collected from two malaise trap designs (Clear/Clear and Green/White) with and without artificial shade in 2000. Error bars represent one standard error of the mean. There was a significant difference between the total number of insects collected from traps in the sun and in the shade ($F_{1,10}$=11.22, P=0.007). Only the Clear/Clear design had a significant shade bias ($t_{1,10}$=2.146, P=0.06). There was not a significant difference between the numbers of insects collected in the Clear/Clear trap compared to the Green/White trap ($F_{1,10}$=0.94, P=0.35). Also, there was not a significant shade by trap type interaction ($F_{1,10}$=1.01, P=0.34).

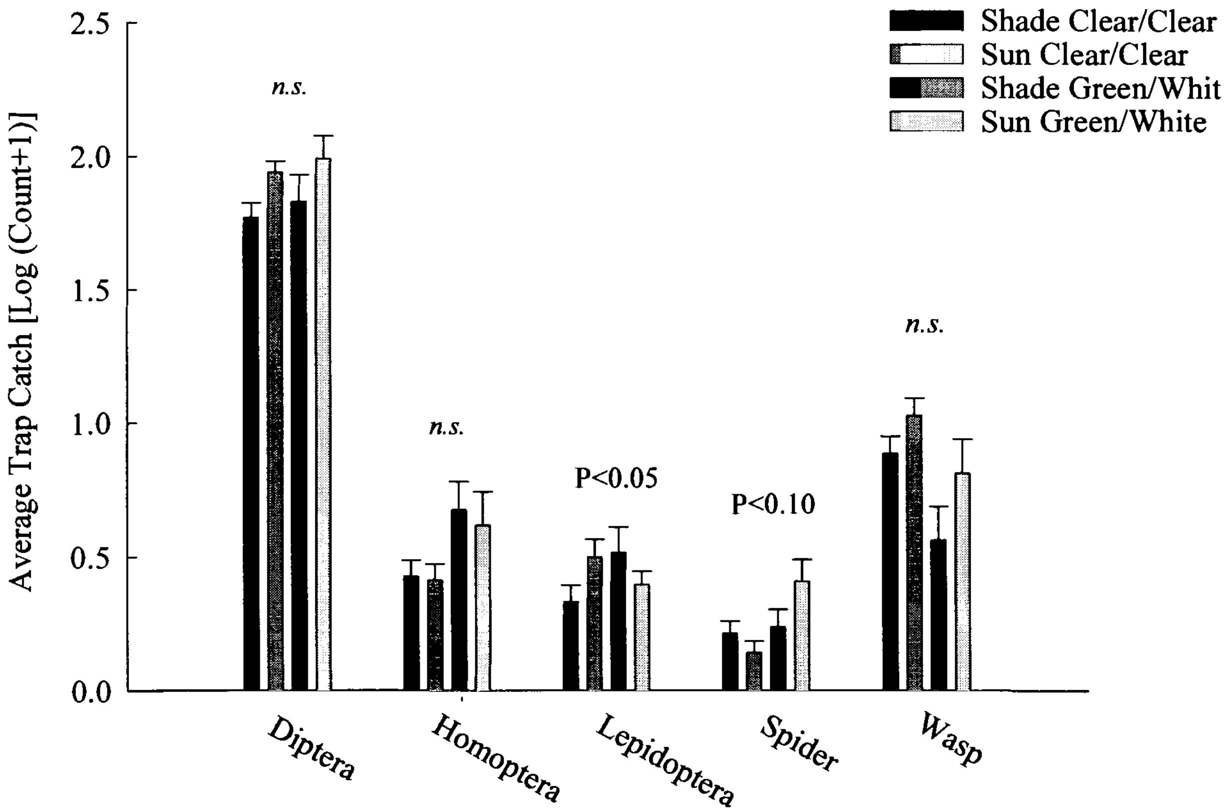
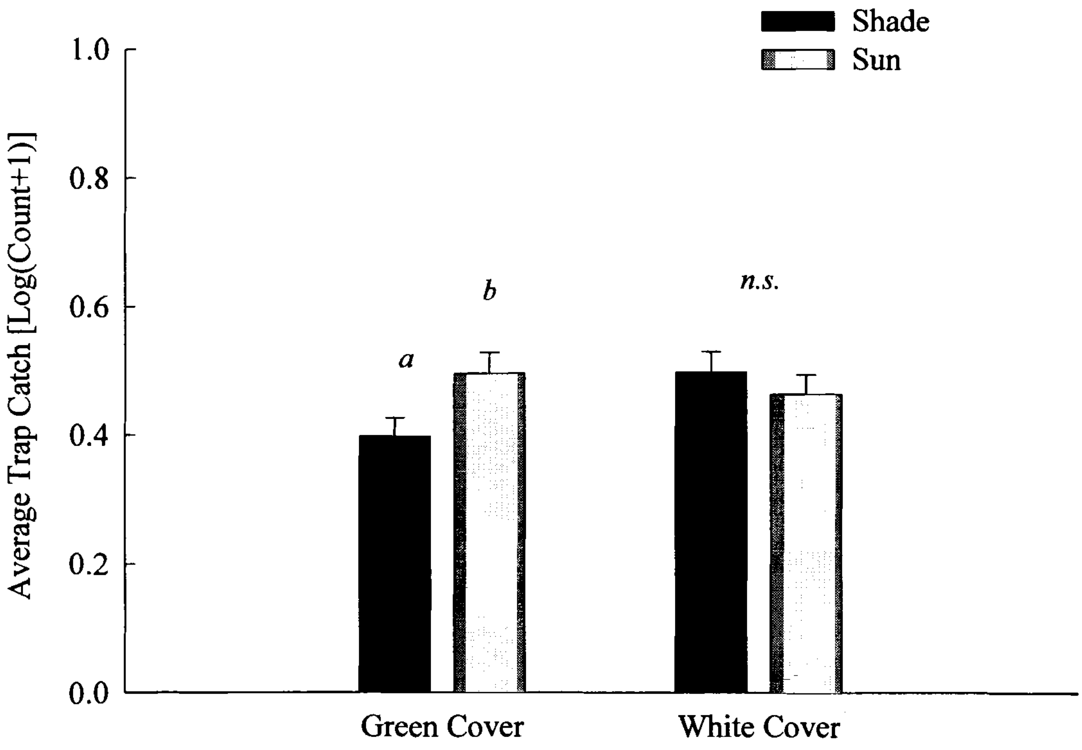


Figure 1.17 Mean number of individuals collected for each taxa by trap design (Clear/Clear and Green/White) and treatment (shade and sun) in 2000. P-values reported for taxa with significant shade by trap type interactions ($F_{1,10}$). Non-significant interactions are indicated by *n.s.* ($P>0.10$). Error bars are one standard error of the mean.

in the sun ($t_{1,10}$=1.63, P=0.13), although not statistically significant. However, the clear/clear traps had equivalent means in the sun and shade ($t_{1,10}$=1.16, P=0.27). Thus, although some taxa had a detectable shade bias in only one trap design, the patterns were consistent with traps in full sunlight collecting higher numbers compared to in the shade.

In 2000, the clear/clear and green/white malaise trap designs collected similar numbers of total insects (Figure 1.16), but there was a significant trap design by taxa interaction ($F_{9,90}$=5.51, P<0.0001). Thus, the pattern of trap catch was not consistent across the taxonomic groups. The green/white trap design collected more Spiders (trap effect $F_{1,10}$=5.56, P=0.04) (Figure 1.17). Conversely, the clear/clear trap design collected slightly more Wasps (trap effect $F_{1,10}$ =3.63, P=0.09) (Figure 1.17). However, there were no significant differences in the numbers of Diptera, Homoptera, or Lepidoptera collected in either trap design (Figure 1.17).

Flight-Intercept Traps. Overall intercept traps in the sun and shade collected equivalent numbers of total insects (Figure 1.18) in 2000. The type of shading cover did not influence the total number of insects collected in the flight-intercept traps (Figure 1.18). However, there was a significant interaction between the type of shading cover and treatment (sun vs. shade) (Figure 1.18). A shade bias was detectable in the flight-intercept traps using the green nursery shading material ($t_{1,10}$=3.61, P=0.005), but a shade bias was not detectable with the white muslin cloth ($t_{1,10}$=1.45, P=0.18). Therefore, the effect of shade on trap catch depends on the type of shading material used; thus, shading effects were evaluated separately for each shading material (white and green).



Figures 1.18 Mean number of all taxa collected from flight-intercept traps by cover type (Green and White) and treatment (shade and sun) in 2000. There was no difference in the total number of insects collected from intercept traps with the green or white shading material ($F_{1,10}$ = 1.64, P=0.23). There was also not a significant difference between intercept traps in the shade or sun position ($F_{1,10}$ = 2.48, P=0.15). There was a significant interaction between cover type and shade position ($F_{1,10}$ = 11.58, P=0.007). There was a significant shade bias using the green cover ($t_{1,10}$ = 3.61, P=0.005). A shade bias was not detectable with the white muslin cloth ($t_{1,10}$ = 1.45, P=0.18).

When the white muslin shading material was used, flight-intercept traps in the sun and shade collected similar numbers of Diptera, Homoptera, Lepidoptera, Spiders, and Wasps (Figure 1.19). However, more Coleoptera were collected from the flight-intercept traps in the shade (Figure 1.19).

When the green nursery shading material was used, there were more individuals of Diptera, Homoptera, Spiders, and Wasps collected from flight-intercept traps in the full sunlight than in the shade (Figure 1.19). There were not significant differences in the numbers of Coleoptera or Lepidoptera recovered from flight-intercept traps in the shade or sun (Figure 1.19). The overall pattern suggests the green shading material created a larger difference in the number of individuals collected within each group between the sun and shade position. This pattern was consistent with the trend in 1996 with the two cover types influencing the effect of shade on trap catch in malaise traps.

Discussion

Over the five-year period and seven experiments five of the six malaise traps collected higher numbers of insects in full sunlight compared to in the shade. Thus, the results of the five-year study suggest researchers should use caution if malaise traps are utilized to compare insect communities from forest stands with and without overstory vegetation. The black/white bicolor trap was the only design that consistently displayed minimal bias during the two years it was deployed. Perhaps, this design, which was the color scheme suggested in the original design by Townes (1972), is the best choice to minimize shade bias on insect trap catch. However, Townes also found the bicolor design collected higher numbers of insects in the sunlight. Another solution might be to use a

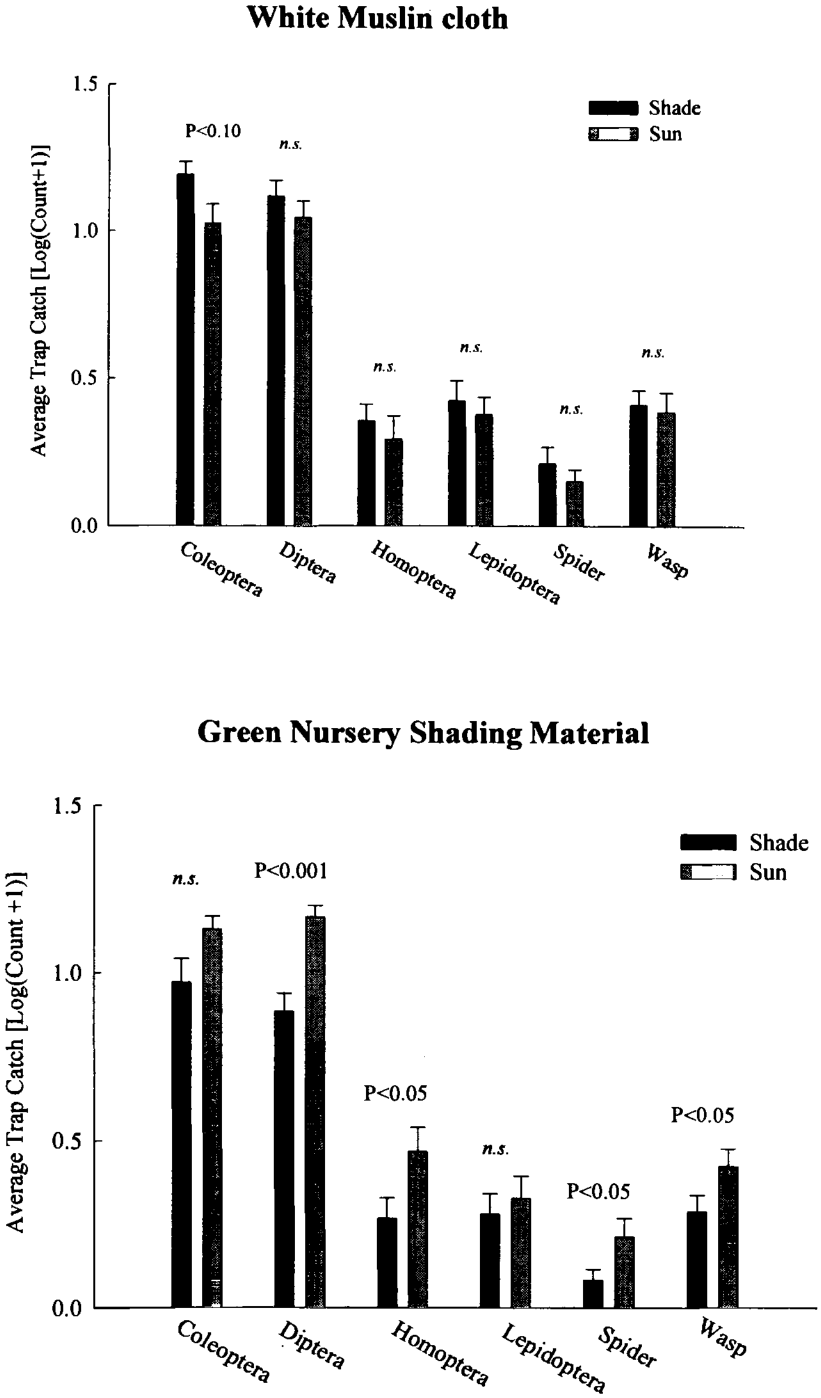


Figure 1.19 The effect of shade and shading material on the number of each taxa collected from flight-intercept traps in 2000. P-values reported for taxa with significant differences in catch between intercept traps in the sun compared to in the shade. Artificial shade created by white muslin cloth (top) and green nursery shading material (bottom). Non-significant differences are indicated by *n.s.* ($P>0.10$). Error bars represent one standard error of the mean.

combination of trap designs to minimize shade bias on trap catch depending on the taxa of interest.

The one exception to the general trend was the all white design that displayed an opposite pattern with shaded traps collecting more than the exposed, the result was driven by the Hymenoptera during that year. Similarly, although the results were not significant, the clear/white and green/white designs displayed this same pattern during one year. A possible explanation for this inconsistency was the time of year these experiments were conducted, the traps were deployed later in the summer (August –October) compared to the other years (July –August) and (June-September). Insect trap catch has been found to be affected by weather factors, such as air temperature, wind speed, vapor pressure, precipitation, and solar radiation (Nasr *et al* 1984, Vogt 1986, Pitcairn *et al* 1990, Horton *et al* 1997). All of these factors can vary significantly from year to year and season to season, unfortunately we do not have weather data for the corresponding years to confirm if they differed significantly from the other years.

In this study, Hymenoptera in particular appeared to be affected by shade. Interestingly, the all white trap appeared to possibly attract more of the Hymenoptera in the shade. The trap designs with clear panels and a white or clear top were more efficient in comparison to the green/white design in collecting the wasps. A study of the spectral response of one species of wasp found wavelengths in the green region (~ 560 nanometers (nm)) and in the near ultraviolet region (~365 nm) elicited the most activity (Hollingsworth *et al* 1970). The Hymenoptera might have been attracted to the malaise designs with clear and white components in the full sunlight because of their light reflectance.

Another difference between the clear and green lower panels was the airflow through the traps. The clear panels were made from a solid plastic, whereas the green panels were constructed from a mesh screen. One study found the type of mesh influenced the number of Hymenoptera collected (Darling and Packer 1988). Interestingly, in this study the Aculeata were collected in greater abundance in the coarser mesh traps, whereas the smaller microhymenoptera were in greater abundance in the smaller mesh size traps. One hypothesis for the difference was smaller insects were unable to crawl through the openings of the fine mesh to escape once they alighted on the trap. Perhaps in our trap designs a similar phenomenon was occurring, the wasps were unable to fly or crawl through the clear solid panels, which would account for their greater abundance in the clear/white or clear/clear compared to the green/white trap design.

Diptera, Coleoptera, and Homoptera also seemed to be affected by shade conditions, although the magnitude of the difference between full sunlight and shade differed between the sample years. The Lepidoptera, Hemiptera, and Spiders also displayed evidence of a shade bias; however, these groups were typically a minor component of the total catch. Most orders displayed a consistent pattern across years with traps in full sunlight collecting more individuals than those in the shade. However, this study cannot address the potential bias associated with sampling for specific families with malaise or flight-intercept traps. Furthermore, due to the taxonomic breadth within many families, some studies concentrate on the more abundant species or morph species. Thus, although the traps in our study displayed a potential shade bias, the difference in the number of individuals collected in the sun compared to in the shade was minimal.

The shading effect in the flight-intercept traps was dependent on the type of shading material employed. It appears as though there was no detectable shading bias in the flight-intercept traps, when the green nursery shading cloth was used in 1997, but the number of traps was quite limited (n=3). In 2000 there was not a noticeable shade effect if the white muslin cloth created artificial shade, but if the green nursery shading material was utilized, the flight-intercept traps in the sun collected the most insects. Undoubtedly, the green nursery shading material is more comparable to sampling conditions in the forest than the white muslin. Thus, similar to with the malaise traps researchers should be cautious if flight-intercept traps are employed to sample insect communities from different forest stands.

Although the consistent pattern of a shade bias indicates researchers should be cautious in their use of malaise and flight-intercept traps to compare habitats with different light levels, the shading conditions in our study were artificially created and are not necessarily indicative of natural forest shade conditions. The shading frame was always present to eliminate any potential bias introduced by the frame itself. However, we do not have a measure of the actual degree of difference between the shade and the sun positions in our experiment. Thus, in an actual field study the difference between an "open" habitat and a "shade" habitat could be far different from our artificially created shade.

Although the efficiency of the various trap designs was not the main question of interest, there were no detectable differences in the total abundance of insects captured in the different malaise trap designs for most years except 1999. In 1999, there were more insects collected from the clear/white than the green/white design. All six malaise trap designs sampled the same volume of air, possibly explaining the similarity of overall insect abundance recovered from the different designs.

However, at the order level there were differences in trap catch between the different designs as mentioned earlier for the Hymenoptera. The Spiders and Homoptera were collected in greater abundance in the green/white trap design compared to the clear/clear design. Homoptera are primarily plant feeders, potentially explaining their abundance in the green/white design. They were possibly attracted to the color of the panels. Another structural difference, besides the lower and upper panels, between the two designs was the collecting head. The clear/clear design had an inverted flexible funnel filled with a pink colored propylene glycol solution, whereas the green/white had an inverted plastic soda bottle without any liquid. During collection of the samples it was noted that spiders had a tendency to form webs in the opening of the soda bottles, this was not observed in the other collecting head design. The numerical difference was possibly attributed to the Spiders preference for web building in the soda bottles versus the flexible funnels.

The Diptera and Wasps were the most abundant taxa within all the malaise trap designs, which was consistent with other studies (Matthews and Matthews 1970). Whereas, the flight-intercept traps collected greater numbers of Coleoptera and Diptera compared to the other orders. Because there is not a way to assess the absolute abundance of insects in an environment, we are unable to determine the efficiency of the various traps. However, when the flight-intercepts and malaise traps were deployed simultaneously there were more Coleoptera sampled in the flight-intercepts and more Wasps in the malaise traps.

Researchers should be aware of the limitations in insect sampling techniques. “Open” sunny habitats might lead to higher insect trap catch in malaise and flight-intercept traps. Depending on the trap design employed certain insect orders display a similar shading bias. Depending on the goals and insect group of interest, researchers should use caution when malaise and flight-intercept traps are used to make comparisons of insect communities from habitats with varying light levels.

Chapter 2

SHORT- AND LONG-TERM EFFECTS OF HERBICIDE APPLICATION IN REGENERATING CLEARCUTS ON FLOWERING PLANT COMMUNITIES

Introduction

Regenerating clearcuts are commonly sprayed with a broad-spectrum herbicide, Glyphosate, to suppress regenerating hardwoods that outcompete the more desirable softwood species. Although its direct effects are minimal, the resulting changes in vegetation have raised concern over its indirect effects on wildlife (Freedman 1991). Two review articles compiled research on the effects of forest herbicides and habitat alteration on birds, small mammals, deer, and moose (Morrison and Meslow 1983, Lautenschlager 1993). Both reported the response was dependent on the taxa of interest and their required habitats. None of the reviewed studies investigated the effects of herbicide and habitat alteration on insect communities.

Insects represent over half of all described species on the planet (Kim 1993). Among the insects, the order Hymenoptera is rich in species and biological diversity (Grissell 1999). They are a major component of insect biodiversity and help to maintain the diversity of other plant and animal taxa, through their roles as pollinators, predators, and parasitoids. As pollinators they are a keystone taxa and as natural enemies they can reduce the frequency of insect pest outbreaks. Many of these groups require floral resources in order to persist in an environment (Bugg *et al* 1989, Jervis *et al* 1993). Thus, a measure of habitat suitability for the beneficial Hymenoptera must contain some measure of available floral resources. Therefore, a study focusing on the beneficial Hymenoptera and their response to habitat alteration due to herbicide use in regenerating clearcuts requires an assessment of the effects of herbicide on the flowering plant communities.

Many studies have documented the effects of herbicides on plant communities, although these studies did not focus on the available floral resources for nectar/pollen dependent insects. Several studies recorded an increase in herbaceous cover following herbicide application (Borrecco *et al* 1979, Freedman *et al* 1993, Sullivan and Sullivan 1982, Sullivan 1994, and Sullivan *et al* 1996). Several perennial species survived the herbicide treatment and experienced relatively free-growth. The increase in percent cover of the herb layer following treatment was theorized as a result of the decrease in overstory vegetation. Conversely, other researchers found a decrease in herb cover following treatments with herbicides (Spencer and Barrett 1980, and Santillo *et al* 1989). Although most studies documented an increase in herbaceous cover, several species were eliminated or decreased following herbicide, such as *Vaccinium* species (blueberry), *Oxalis stricta* (yellow wood sorrel), and *Scirpus cyperinus*. Parasitoids have been found to demonstrate selectivity in the types of plants utilized as food sources (Leius 1960). Thus, the absence of a particular or combination of species could effect the diversity, abundance, and distribution of the parasitic Hymenoptera in a forested landscape.

The importance of flowering weeds in terms of increasing parasitoid diversity and abundance has been well documented in agroecosystems, but not in forest ecosystems. Parasitism rates are higher in weedy areas compared to non-weedy areas (Van Emden 1963 and Leius 1967). Food plants are important to maximize the longevity, fecundity, and searching activity of parasitoids (Leius 1961a, Leius 1961b, Syme 1975, Foster and Ruesink 1984, and Idris and Grafius 1995). Plants can provide direct food sources to parasitoids through nectar and pollen or indirectly through honeydew produced from aphids (Bugg *et al* 1989, Jervis *et al* 1993). Therefore, the presence and abundance of flowering plants in industrial forests could provide a valuable tool for pest management.

The long-term impacts of herbicide application have not been investigated as thoroughly compared to the short-term alterations. One study found major differences in height and cover between sprayed and non-sprayed plots remained for up to 16 years (Newton *et al* 1992). The stands not treated with Glyphosate had a plant community simplified in structure compared to the treated areas. Conversely, another study in Maine found the changes in plant community structure and species composition to be short-lived (May *et al* 1982), but the duration of time after treatment was only 3 years. However, neither of these studies documented the long-term effects of herbicide application on floral resources for the beneficial Hymenoptera.

There were four main objectives of this study. First, we determined the effects of clearcut harvesting followed by herbicide application on floral resources potentially utilized by the beneficial insect communities. Second, we investigated whether the impacts of herbicides are still apparent 10 years after application. Third, we assessed whether black spruce (*Picea mariana* (Mill.)B.S.P.) plantations have different flowering plant communities compared to those stands not planted following herbicide application 10 years prior. Finally, mature stands adjacent to clearcuts were hypothesized to be lower in plant species richness and abundance due to the increase in shade from the closed canopy. Therefore, the adjacent clearcut areas could serve as a source of food plants for pollinators and parasitoids in the mature forests, which would lead to fewer pests in the adjacent forests.

Project Methodology

Study Sites

Twenty stands located throughout three adjacent townships (Bald Mountain, Mayfield, and Moscow TWP, Maine) owned and managed by Plum Creek Inc. were sampled during the summer of 2000 (Table 2.1). To assess the short-term impacts of herbicide application six recently clearcut stands were selected; three of the stands had subsequent herbicide applications of Glyphosate. To assess long-term implications of herbicide application four treated and four non-treated stands were identified. This treatment group contains four pairs because of the increased variability between sites.

Additionally, three stands planted with black spruce following clearcut harvesting were used to compare with stands in the older clearcut treatment group. The plantation stands also had a herbicide application of Glyphosate. The remaining three stands were classified as "mature" due to their closed canopies and apparent lack of recent logging activity. Two mature stands (site 18 and site 17) were adjacent to recent clearcuts. One mature stand (site 16) was adjacent to an older clearcut. Two of the mature stands were riparian buffer strips; site 18 bordered the south branch of Austin stream and site 16 was adjacent to Withee Pond.

Vegetation Sampling

Vegetation sampling began on June 14 and was repeated every two weeks until September 1 to capture the abundance and richness of flowering plants in all 20 stands. Only species currently in bloom were included during each sampling period. Species that were considered of little value as floral resources for insects (e.g., grasses, sedges, and trees) and/or were not in bloom during the sample period were not included in this

Table 2.1 Descriptions of the twenty sites used to assess the effects of herbicide application during the summer of 2000. Information in the table was gathered from the Plum Creek Inc. G.I.S. database. Although the harvest year was unknown, site 19 was chosen because of its apparent similarity to site 8. Sites 7, 14, and 20 were pre-commercially thinned during the summer of 2000. Sites 11 and 19 were pre-commercially thinned prior to the summer. Black spruce was the species planted in sites 4, 13, 14, and 15.

Site #	Treatment				
	Age Group	*Clearcut*	*Herbicide Yr*	*Year Planted*	*Thinning*
1	Young	1995	1997		
2	Young	1995	-		
3	Young	1997	-		
4	Young	1996	1998	1998	
5	Young	1996	-		
6	Young	1996	1997		
7	Old	1986	1989		PCT
8	Old	1985	-		
9	Old	1986	-		
10	Old	1986	198?		
11	Old	1985	1987		PCT
12	Old	1985	-		
13	Plantation		1986	1985	
14	Plantation	1986	1989	unknown	PCT
15	Plantation		1990	1988	
16	Mature				
17	Mature				
18	Mature				
19	Old	unknown	-		T 1996
20	Old	1979	1984		PCT

sampling. Four 40-meter lines were sampled per site during each sample period with the line- intercept method (Eberhardt 1978). New transects were sampled each week to eliminate excessive trampling of vegetation. A compass was used to ensure transects were parallel and relatively straight in denser vegetation. A standard tape measure was used for each 40-m line transect.

All plants that were in bloom on the day of sampling and that were intersected by the vertical plane associated with the line were recorded. A plant was considered "touching" if the vertical plane passed through any part of the plant (stem, leaves, or flowers). The data collected for each plant consisted of the date, site number, transect, position along the tape, species, general shape of the plant, dimensions of the shape, the number of stems (for many species this was 1, for some, such as raspberry, this was several to many), and the total number of flowers and/or buds. For flowers that occurred in clusters (e.g. racemes, numbels), an estimate was recorded as the sum of the number of flowers on each cluster. Bunchberry (*Cornus canadensis* L.) flowers were recorded as a single flower. The shape of the plant was determined by visualizing the plant (including leaves, stems, and flowers) as a 2-dimensional object (circle or rectangle) from above. . The dimensions of each shape (diameter for circle, length x width for rectangles) were recorded to determine an area for each recorded plant.

To increase efficiency of vegetation sampling, if the line intercepted an aggregate of many individuals of one species with a discrete decrease in density which could be used to delineate the perimeter of the aggregation (clump), then the total area covered by the clump was recorded. In this case, the number of stems was recorded as the total number of stems for that clump. A stem was defined as a single stalk originating from the soil. The number of flowers was the total number counted within that measured area (i.e. sum of all the flowers within the clump).

The total number of flowering species (species richness), the total number of flowering stems, and the overall density of flowers were calculated for each site per sampling period. This sampling protocol assumes that the probability of inclusion in any sample is proportional to the diameter of the plant or clump. Thus, the diameter recorded for each plant was used to determine the inclusion probability (or the size of the quadrat from which each plant was sampled).

For rectangular shaped plants, an approximate diameter in centimeters was determined by converting the area recorded to that of a circle. For each plant, the diameter was calculated using the formula: diameter (cm) = $2*[(\text{length(cm)}*\text{width(cm)})/3.14]^{1/2}$ for rectangles. Then the density of flowers was calculated using the formula: $y = \Sigma\ (a*100\ /\ (b*c))$, where a = total number of flowers per plant, b = the approximate diameter of each plant in cm, and c = total transect length sampled in m (160 m).

Visualization of the area of a plant or clump provides an estimate of the diameter with additional error that becomes part of the variance and may have inherent bias. Further, the definition of what constitutes a plant (ramet vs. genet) or a "flower" for each species may be different and somewhat arbitrary. Nevertheless, comparisons between treatments should be valid because the same protocol was consistent across the treatments and within each species.

A woody vegetation survey was conducted on September 9-11 and September 24. A clinometer was used to measure the height of five representative trees for each site. Four belt transects 2 by 20 meters were sampled at each site. The date, site, transect, position along transect, species, and height class was recorded for any tree species over 1 meter tall within the "belt." The relative percentage of hardwood and softwood tree species (trees/ha) within each site was subsequently calculated. This was not calculated for the younger sites because the tree regeneration was less than 1 m tall during the summer of 2000.

Data Analysis

Repeated measures ANOVA was performed on the response variables (species richness, stem abundance, and floral density) by sample period to determine if there were shifts in these floral resource measures between treatment groups throughout the summer. There was a significant sample period by treatment group interaction in species richness ($F_{25, 60}$=2.30, P=0.004), stem abundance ($F_{25, 60}$=1.75, P=0.039), and floral density ($F_{25, 60}$=1.60, P=0.071). Therefore, sample periods were analyzed separately to determine treatment effects across the six groups.

For each sample period, a one-way ANOVA (PROC GLM, SAS Institute 1996) was used to detect an overall treatment effect across the six groups (young with herbicide, young without herbicide, old with herbicide, old without herbicide, plantation, and mature). Linear contrasts were used to compare: young with herbicide to young without herbicide, old with herbicide to old without herbicide, old clearcuts to young clearcuts, plantations to old clearcuts, and mature to clearcuts. Response variables were richness, stem abundance, and density of flowers per unit area. Site was considered the unit of replication. For the sample period beginning on July 24, August 8, and August 30, the species richness data were log transformed to meet the assumptions of normality and constant variance. For the sample period beginning on August 8 the relative abundance data were log transformed. The floral density measures were log transformed for all sample dates.

Detrended correspondence analysis (DCA) (McCune and Medford 1999) was used to discern groups of sites with distinct flowering plant communities. The most common plant species were plotted by site to identify sites with distinct plant assemblages. The number of stems per plant species summed across all dates was used. The DCA was used on all sites except site 9 because it was considered an outlier possibly due to soil type and/or stand history. There was visual evidence of a burn within the past 5-10 years.

Canonical correspondence analysis (CCA) (PC-Ord McCune and Medford 1999) was used to evaluate how differences in plant communities might be related to herbicide application and stand age. This analysis was performed on the number of stems per plant species summed across all dates for each site, excluding the mature sites and site 9. CCA was also used to determine if the older age group (excluding mature sites) had differences in plant communities related to the planting of black spruce and herbicide application.

A Kruskal-Wallis one-way analysis of variance was performed to determine significant treatment differences across the six groups (young with herbicide, young without herbicide, old with herbicide, old without herbicide, plantation, and mature) for each of the ten most common flowering species. The non-parametric test was used due to concerns of meeting the assumptions of equal error variance and normality (Conover

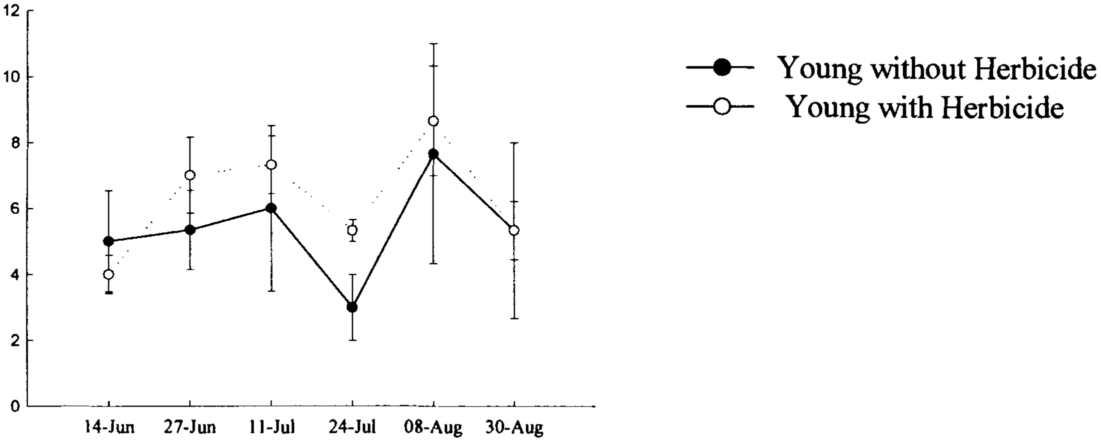
1980). If the species was sampled during more than one period, an average number of flowering stems was found for each of the 20 sites sampled throughout the summer. The response variable was the average number of flowering stems for each species. Only blackberry (*Rubus allegheniensis* T.C. Porter), goldenrod (*Solidago* L.), pearly everlasting (*Anaphalis margaritacea* L.), and field hawkweed (*Heiracium caespitosum* Dumort.) of the ten displayed significant treatment differences (P<0.07). Post-hoc multiple pairwise comparisons were performed for these species to determine if there were significant differences between treatment groups (Conover 1980).

A linear regression analysis was used to determine the relationship between tree height and density and the response variables floral density and abundance. Eighteen sites were used in the analysis. Site 8 and 20 were removed from the analysis because they were outliers (studentized residuals of 3.119 and 3.460, respectively). The response variables were summed across all dates to calculate a total floral density and stem abundance for the summer of 2000.

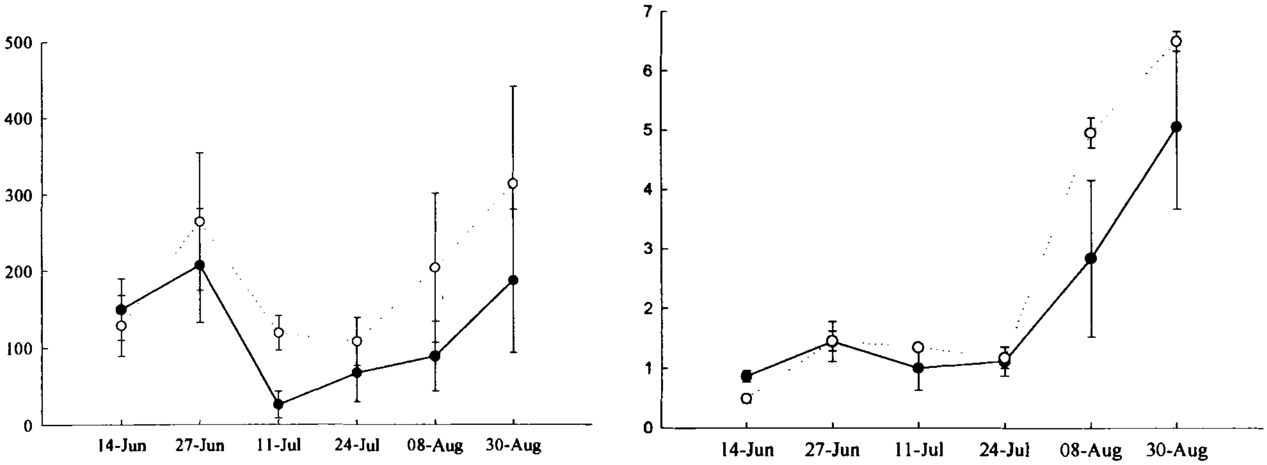
Results

Short-term Effects of Herbicide Application

Throughout the summer, linear contrasts suggested there were no significant differences in the richness of flowering plants (count/160m) in the recent clearcuts with and without herbicide application (P>0.10) (Figure 2.1). During the week of July 24th, the pattern suggests the sites with herbicide application had a greater number of species compared to those not sprayed with herbicide, but this pattern can be explained by sampling variability. In site 5 only bristly sarsaparilla (*Aralia hispida* Vent.) and bunchberry (*Cornus canadensis* L.) were sampled. Similarly, site 3 had only pearly



Average Species Richness



Average Number of Total Stems

Mean Floral Density (log flowers/m^2)

Figure 2.1 The short-term effects of herbicide application in recent regenerating clearcuts on species richness, stem abundance, and floral density. Six recent clearcuts were sampled during six weeks in the summer of 2000. Error bars represent one standard error of the mean.

everlasting and dewdrop (*Dalibarda repens* L.) sampled on the transects. Incorporating those species that were in flower but located off the vegetation transect within sites 5 and 3 would have resulted in similar species richness between the sites with and without herbicide during the week of July 24th.

During five of the six sample periods, there was not a significant difference in the number of flowering stems in the two recent clearcut groups (herbicide and non-herbicide), as indicated by the linear contrasts ($P>0.14$) (Figure 2.1). The one exception was the week of July 11, the recent clearcuts with herbicide application had a higher number of stems compared to sites without herbicide treatment ($F_{1,13}=8.62$, $P=0.0116$) (Figure 2.1). During this sample period, the most abundant species were raspberry (*Rubus pubescens* Raf.), healall (*Prunella vulgaris* L.), rough cinquefoil (*Potentilla norvehica* L.), field hawkweed, and bristly sarsaparilla in the sites with herbicide. The sites without herbicide had relatively few flowering stems in comparison.

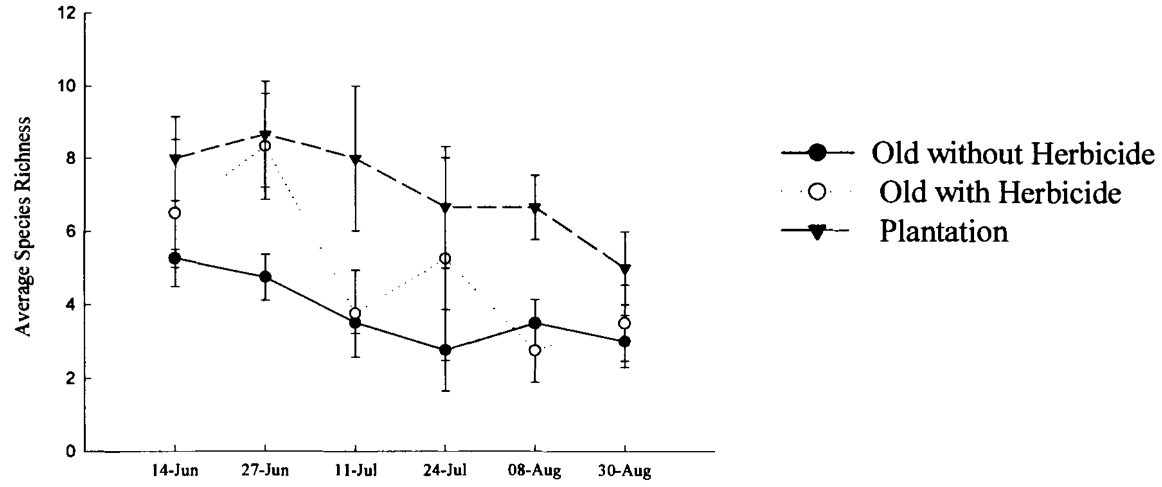
Over the season, there were two peaks in the number of flowering stems in the recent clearcuts with a relatively reduced abundance during the July 11 to July 24 sample periods. Between the first and second sampling periods (June 14 - June 27) there was an increase in the number of flowering stems. During this time, raspberry, blackberry, and field hawkweed began to flower and were the most common species. There also was an increase in the number of flowering stems between the July 24 and August 30 sample periods. During this time interval, goldenrod (*Solidago* L.), pearly everlasting, and aster species (*Aster* L.) were the most common flowering species.

Five of the sample periods did not have significant differences in floral density; the only exception was the week of August 8 (Figure 2.1). During this sample period, the linear contrast suggested that clearcuts sprayed with herbicide had more flowers per site compared to non-sprayed sites ($F_{1,14}$=4.25, P=0.0584). The large variation between sites without herbicide application was because site 5 had only 10 flowers on one flowering plant (bristly sarsaparilla), whereas the others had 80 to 100 flowers per site. When site 5 was eliminated from the analysis, there was not a significant difference between the recent sites with and without herbicide ($F_{1,13}$=0.80, P=0.39). The overall increasing trend in the number of flowers per m^2 towards the end of the summer can be attributed to the abundance of goldenrod, pearly everlasting, and aster species in the recent sites. The goldenrod had typically >100 flowers counted per plant, whereas the other species had only 1-10 flowers per plant.

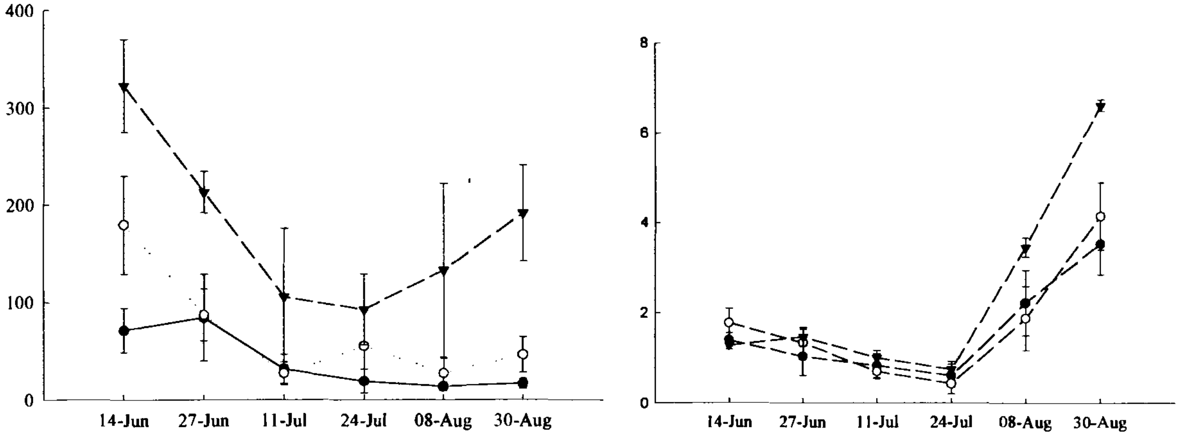
Overall, there were not many statistically significant differences in species richness, stem abundance, or density of flowers between recent treated and non-treated clearcuts. However, the general pattern emerged that sites with herbicide treatments had higher numbers of stems of flowering plants than sites without herbicide treatments. There was little statistical evidence that this was a general phenomenon among the recently harvested stands.

Long-term Effects of Herbicide Application

During five of the six sample periods there were no significant differences in the number of flowering plant species among the older sites with and without herbicide application (P>0.10) (Figure 2.2). There was only one week (June 27) when the older clearcuts that had been treated with Glyphosate had more species of flowering plants than



Average Species Richness



Average Total Number of Flowering Stems

Mean Floral Density (log flowers/m^2)

Figure 2.2 The long-term effects of herbicide application on flowering plant species richness, flowering stem abundance, and floral density throughout the summer of 2000. Error bars represent one standard error of the mean.

the non-sprayed sites ($F_{1,13}$=4.98, P=0.04). During this sample period, raspberry, blackberry, field hawkweed, orange hawkweed (*Hieracium aurantiacum* L.), and bunchberry were the most common species in the older sites with herbicide application.

There was a consistent trend throughout the summer of the black spruce plantations having more species of flowering plants compared to the older clearcut sites (herbicide and non-herbicide), although not statistically significant (P>0.10) (Figure 2.2). During the weeks of July 11 and August 8, linear contrasts indicated the plantation sites had significantly more species of flowering plants compared to the older clearcut sites ($F_{1,13}$= 4.91, P=0.045 and $F_{1,14}$ = 3.74, P=0.07) (Figure 2.2).

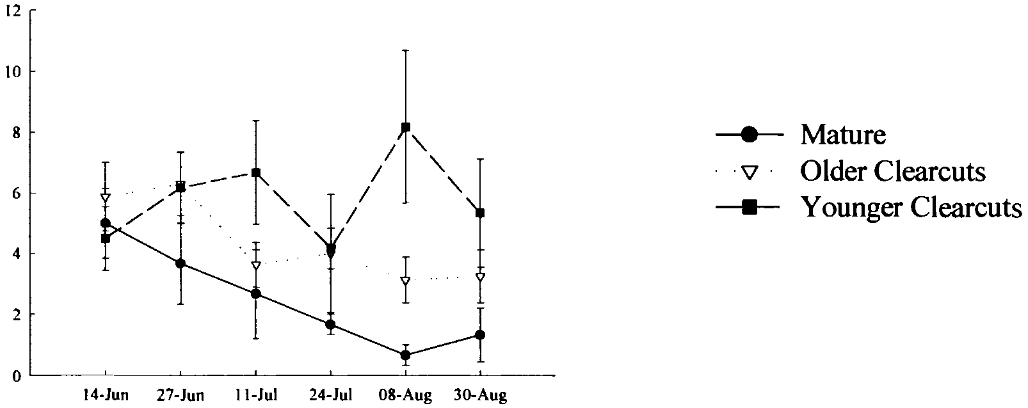
Throughout the majority of the summer, there were not significant differences in the overall number of flowering stems in the two older clearcut treatment groups (P>0.10) (Figure 2.2). However, blackberry had significantly more flowering stems sampled in the older sites without herbicide application (P<0.05). This was the only common species that displayed a long-term effect of herbicide application. The one exception was during the week of June 14, a linear contrast detected the older clearcuts which had a herbicide application had significantly more flowering stems than non-treated clearcuts ($F_{1,14}$=4.64, P=0.049). The most abundant species were bunchberry, Canada mayflower (*Mainthemum canadense* Desf.), and strawberry (*Fragaria* L.) during this sample period. The older sites with and without herbicide showed a steady decline throughout the summer in the number of flowering stems.

The plantation sites showed a decline and then a slight increase in the number of stems unlike the other older sites (Figure 2.2). Throughout the summer, plantation sites had a higher number of flowering stems compared to the older clearcut sites. During the weeks of June 14 ($F_{1,14}$=16.97, P=0.001), June 27 ($F_{1,13}$=3.90, P=0.0698), July 11 ($F_{1,13}$=6.14, P=0.0278), August 8 ($F_{1,14}$= 4.19, P=0.06), and August 30 ($F_{1,14}$=5.62, P=0.0327) there were more flowering stems in the plantations compared to the older clearcuts (Figure 2.2). Only the July 24th sample period did not have a significant difference in stem abundance. Bunchberry, strawberry, raspberry, field hawkweed, and blackberry were the most common flowering species during the beginning of the summer. Later in the summer, pearly everlasting, goldenrod, and aster species were the most common flowering plants in the plantations. The plantation sites had significantly more stems of goldenrod, pearly everlasting, and field hawkweed compared to the older sites without herbicide application (P<0.05).

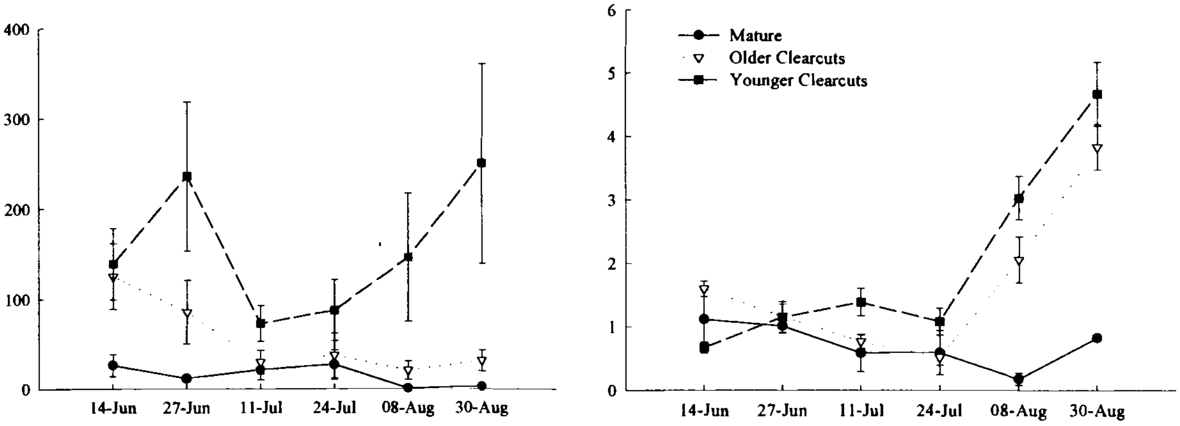
There were also no significant differences in the density of flowers between sprayed and non-sprayed older clearcuts during any of the sample periods (P>0.10) (Figure 2.2). The sharp increase in the density of flowers during the last two sample periods of the summer was due to the abundance of goldenrod, pearly everlasting, and aster species. This trend was similar to that of the younger clearcut group. Interestingly, only during the final sample period was there a significantly higher density of flowers in plantations compared to the other older clearcuts ($F_{1,14}$=10.60, P=0.0059) (Figure 2.2). This was driven by the abundance of goldenrod and pearly everlasting in the plantation sites.

The Effect of Stand Age on Flowering Plant Communities

Only two of the sample periods had significant differences in species richness between the young and old age groups (Figure 2.3). During the weeks of July 11 ($F_{1,13}$= 5.09, P=0.042) and August 8 ($F_{1,14}$=6.64, P=0.02) linear contrasts indicated the younger



Average Species Richness



Number of Flowering Stems

Floral Density (Log flowers/m^2)

Figure 2.3 The effect of stand age on flowering species richness, stem abundance, and floral density. Three mature stands, eight older stands, and six young stands were sampled throughout the summer of 2000. Error bars represent one standard error of the mean.

clearcuts (with and without herbicide) had significantly more flowering plant species compared to the older clearcuts (with and without herbicide).

On the other hand, mature stands tended to have fewer flowering species compared to all the clearcuts (young and old) and plantations (Figure 2.3). Linear contrasts found 3 of the 6 sample periods to have significant differences, while the other sample periods did not display detectable differences. During the weeks of June 27 ($F_{1,13}$=3.97, P=0.068), August 8 ($F_{1,14}$= 14.85, P=0.0018), and August 30 ($F_{1,14}$=4.11, P=0.062), the mature stands had less species of flowering plants compared to the other sites (including all clearcuts and plantations). The first sample date was conducted slightly after the canopy had leafed out in the mature stands. Thus, the species richness in the mature stands steadily declined throughout the summer.

The age of the stand did appear to influence the abundance of flowering stems in the young and old clearcuts (Figure 2.3). During the weeks of June 27 ($F_{1,13}$=8.32, P=0.013), July 11 ($F_{1,13}$=4.23, P=0.06), August 8 ($F_{1,14}$=5.61, P=0.033), and August 30 ($F_{1,14}$= 13.56, P=0.0025) there were significantly more flowering stems in the younger clearcuts compared to the older sites. Only during the weeks of June 14 and July 24 were there not significant differences (P>0.15) in floral abundance between the two age groups. There were significantly more stems of goldenrod in the younger sites with herbicide application compared to the older sites (P<0.05). The younger sites without herbicide had significantly more goldenrod stems compared to the older sites without herbicide, but not more than sites with herbicide. The younger sites with herbicide had significantly more stems of field hawkweed compared to the older sites without herbicide ($P<0.05$).

Throughout the summer, mature stands had very few stems of flowering plants in comparison to the other treatment groups (Figure 2.3). During the sample period weeks beginning with June 14 ($F_{1,14}= 5.52, P=0.034$), June 27 ($F_{1,13}=6.25, P=0.027$), August 8 ($F_{1,14}=12.21, P=0.004$) and August 30 ($F_{1,14}=4.60, P=0.068$) there were significantly less flowering stems in the mature sites compared to the other sites. The mature stands had less stems of blackberry compared to the older and younger sites without herbicide, and plantations ($P<0.05$). Also, there were less stems of goldenrod and pearly everlasting sampled in the mature stands compared to the younger sites and plantations ($P<0.05$). Similarly, the mature stands had less stems of field hawkweed compared to the plantations and younger sites with herbicide ($P<0.05$).

The age of the stand also influenced the floral density. During the week of June 14 ($F_{1,14}=11.63, P=0.004$) the older sites had a higher density of flowers (flowers/m^2) compared to the younger sites (Figure 2.3). Conversely, during the weeks of July 11 ($F_{1,14} = 11.63, P= 0.0042$), July 24 ($F_{1,14}=6.05, P=0.027$), August 8 ($F_{1,14}=5.38, P=0.036$), and August 30 ($F_{1,14}=7.56, P=0.016$) the density of flowers was higher in the recent clearcuts compared to the older clearcuts.

The floral density within mature stands steadily declined throughout the summer. Early spring and summer flowers such as canada mayflower, foamflower (*Tiarella cordifolia* L.), starflower (*Trientalis borealis* Raf.), bunchberry, and common wood sorrell (*Oxalis acetosella* L.) were present in the mature stands during the first four sample periods, but by the end of the summer the floral density in the mature stands dropped to zero (Figure 2.3). During the weeks of August 8 (mature vs. old $F_{1,14}=3.91$, $P=0.0679$, mature vs. young $F_{1,14}= 16.74$, $P=0.0011$) and August 30 (mature vs. young $F_{1,14}=14.72$, $P=0.0018$), there were significantly fewer flowers per m^2 in the mature stands. Goldenrod, pearly everlasting, and aster species were in great abundance in the young and old clearcuts and plantations during the last two weeks, but were not present in the mature stands.

Floral density was found to decease with increasing tree density (trees per hectre) (coefficient of trees per hectare = -0.045, $P=0.048$, $R^2=0.812$). In general the older sites were denser and had taller canopies. Thus, the difference in floral density of younger and older sites was probably related to greater tree density in the older sites.

The recent clearcuts had mainly short (<1.5m) regeneration composed of spruce (*Picea*), balsam fir (*Abies balsamea* (L.) Mill.), stump sprouts of red maple (*Acer rubrum* L.), cherry (*Prunus* spp.) and birch (*Betula* spp.) species. There was more variability among the older clearcuts. The sites sprayed with Glyphosate were composed mainly of softwoods (>90%) or a mixture of softwoods (56%) and hardwoods (46%). The non-sprayed sites were either dominated by hardwoods (>90%) or a mixture of both softwoods (>60%) and hardwoods (<30%).

Flowering Plant Species Composition and Distribution

All flowering plant species sampled throughout the summer of 2000 and the treatment groups where they were found are reported in Appendix 1. A detrended correspondence analysis (DCA) was used to discern groups of sites with distinct flowering plant communities (Figure 2.4). Site 9 was eliminated from the DCA analysis because axis 1 was being driven by the differences between this site and all the others

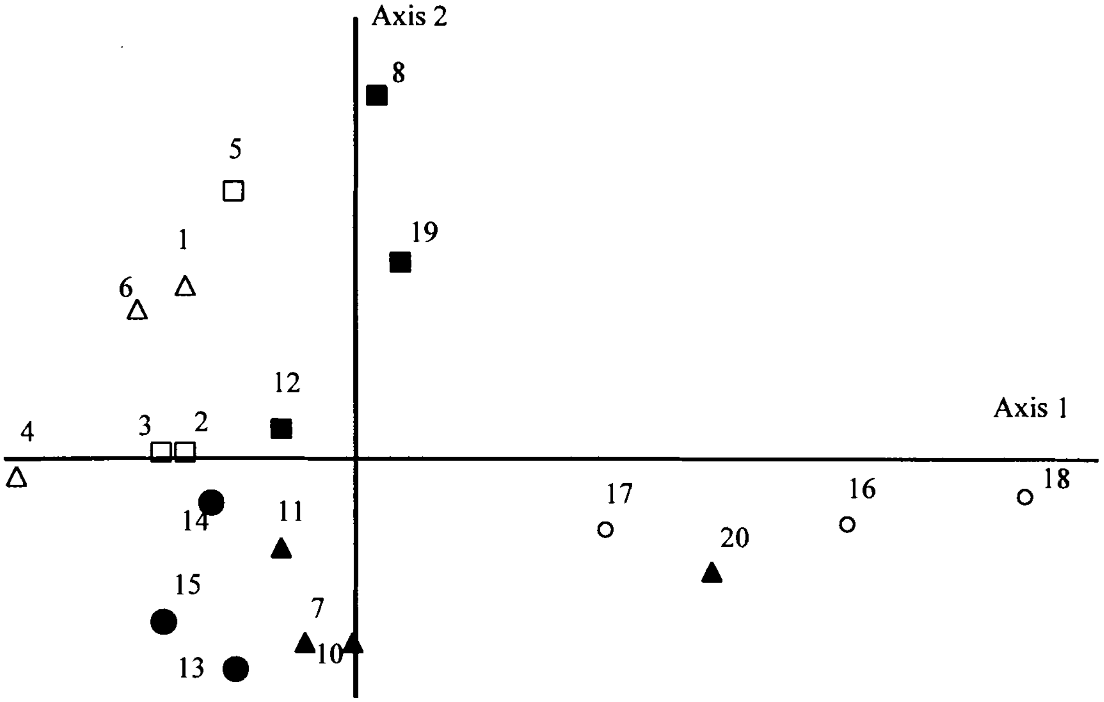


Figure 2.4 Detrended Correspondence Analysis (DCA) of the relative abundance of flowering plant species across 19 forest stands. Site 9 was eliminated from analysis because it was considered an outlier. Symbols denote the six treatment groups: mature stands○ , plantations●, older with herbicide ▲, older without herbicide ■, young with herbicide△ , young without herbicide□ . Relative abundances were summed across dates to generate a total abundance per species. Axis 1 eigenvalue = 0.59, axis 2 eigenvalue = 0.28, and axis 3 eigenvalue = 0.10.

sampled. Site 9 was dominated by blueberry (*Vaccinium angustifolium* Aiton.), sheep laurel (*Kalmia angustifolia* L.), and sheep sorrell (*Rumex acetosella* L.) which are commonly found in nutrient poor habitats or acidic soils. The stand history and soil characteristics were probably a large determinant of the vegetation communities observed in site 9.

The DCA analysis produced one obvious division between the mature sites (and site 20) and the remaining clearcut sites (Figure 2.4). The mature stands and site 20 formed a distinct group based on the similarity of their flowering plant species abundance and composition. The younger clearcuts created a "weak" group, and the treated older clearcuts and plantations formed a "weak" grouping of sites. The non-sprayed older clearcuts did not produce an obvious grouping based on plant species composition or abundance.

The similarity between the mature sites and site 20 could be because all of these sites decreased in flowering plant abundance throughout the summer of 2000. During the first sampling period site 20 was a dense thicket of spruce and fir with intermittent small gaps where bunchberry and canada mayflower were abundant. During the week of June 27, the stand was pre-commercially thinned; after this operation very few flowering plants were sampled. By the second week of sampling, the tree canopies in the mature stands were fully enclosed, although some of the mature sites did have small tree fall gaps. Similar to site 20, the overall abundance of flowering plants steadily declined throughout the summer in the mature stands.

Wild cucumber (*Echinocystis lobata* (Michx.) T.&G.) and one-flowered pyrola (*Moneses uniflora* (L.) A. Gray) were only located in the mature stands. However, there were several species that were found across all the treatment types; such as, bunchberry, canada mayflower, dwarf raspberry (*Rubus pubescens* Raf.), foamflower, strawberry, common wood sorrell, twinflower (*Linnaea borealis* L.), sweet scented bedstraw (*Galium triflorum* Michx.) and aster species. Their presence in the clearcut areas could be related to their pre-harvest abundance.

A canonical correspondence analysis (CCA) was used to assess if the old and young clearcuts had different flowering plant communities; this analysis excluded the plantation sites (Table 2.2). The first axis was highly correlated with the age of the site (0.984) and weakly correlated with herbicide application (-0.068). A Monte Carlo test found the older and younger clearcuts had significantly different flowering plant communities (P=0.0040). Several plant species were only associated with the younger sites, for example healall (*Prunella vulgaris* L.), canadian st. johnswort (*Hypericum candense* L.), northern bugleweed (*Lycopus uniflorus* Michx.), narrow leaved willow herb (*Epilobium leptophyllum* Raf.), spotted joe-pye weed (*Eupatorium maculatum* L.), and steeplebush (*Spiraea tomentosa* L.). Only two species were exclusively associated with the older clearcuts, starflower (*Trientalis borealis* Raf.) and Indian pipe (*Monotropa*

Table 2.2 Results from Canonical Correspondence Analysis (CCA) testing for differences in the flowering plant communities. Two linear contrasts that code for the two environmental variables of interest (stand age and herbicide treatment). Contrast 1 compared the young to the old clearcut stands (N=13). Contrast 2 compared the sites sprayed with Glyphosate to the un-sprayed sites (N=13). P= proportion of 999 randomized runs with eignevalue greater than or equal to the observed eigenvalue. Correlations are "intra-set correlations" of ter Braak (1986).

	Eigenvalue	**P**	**Correlation with Age**	**Correlation with Herbicide**
Axis 1	0.336	0.0040	0.984	-0.068
Axis 2	0.143	0.0580	0.180	0.998

uniflora L.). The finding that age was an important factor in determining flowering plant communities was consistent with the finding that the younger sites had significantly more flowering plants compared to the older sites during four of the six sample periods.

CCA was also used to determine if the sites sprayed with herbicide (old and young) had different flowering plant communities compared to the non-sprayed sites (old and young) (Table 2.2). The second axis was highly correlated with herbicide application (0.998) and weakly correlated with age (0.180). A Monte Carlo test found there was some evidence for differences between the flowering plant communities associated with sprayed compared to un-sprayed sites (P=0.058). Fringed bindweed (*Polygonum cilinode* Michx.) was only found in those sites that had not been sprayed with Glyphosate. Healall and rough cinquefoil (*Potentilla norvegica* L.) were only associated with those sites sprayed with herbicide.

A CCA was performed to assess if there were shifts in flowering plant communities among the three treatment groups (plantations, sprayed, and non-sprayed) in the older age group (Table 2.3). The first axis was highly correlated with the

Table 2.3 Results from Canonical Correspondence Analysis (CCA) testing for differences in the flowering plant communities between the plantations and older clearcuts (herbicide and non-herbicide). Two linear contrasts that code for the two environmental variables of interest (herbicide treatment and planting of Black Spruce). Contrast 1 compared the sites sprayed with Glyphosate to the un-sprayed sites (N=9). Contrast 2 compared the plantation sites to the older clearcuts (herbicide and non-herbicide) (N=9). P= proportion of 999 randomized runs with eignevalue greater than or equal to the observed eigenvalue. Correlations are "intra-set correlations" of ter Braak (1986).

	Eigenvalue	**P**	**Correlation with Contrast 1**	**Correlation with Contrast 2**
Axis 1	0.196	0.1560	-0.687	-0.955
Axis 2	0.152	0.0010	0.727	-0.298

plantations (-0.955) and with the herbicide application (-0.687). The second axis was more correlated with the herbicide application (0.727) and weakly correlated with the plantations (-0.298). A Monte Carlo test found axis 1 was not significant (P=0.1560) and axis 2 was significant (P=0.0010). Therefore, the flowering plant communities associated with the older non-sprayed sites were significantly different from the plant communities in the plantations and older sprayed sites. Conversely, the plant communities associated with the black spruce plantations were not significantly different than those found in the other older sites (herbicide and non-herbicide).

The plants that were associated with the non-sprayed older sites from the CCA multivariate analysis were common wood sorrell, Indian cucumber root (*Medeola virginiana* L.), Indian pipe, and hemp nettle (*Galeopsis tetrahit* L.). There were only two species exclusively associated with the plantations, northern bedstraw (*Galium boreale L.*) and spotted joe-pye weed. However, spotted joe-pye weed can not be considered exclusive to the plantations because it was also found in the younger clearcuts, these were not included in this analysis.

Discussion

During the summer of 2000, the general pattern emerged that recently clearcut sites with herbicide application had more species and stems of flowering plants than non-sprayed sites. However, there was little statistical evidence that herbicide application in regenerating clearcuts results in short-term differences in flowering plant communities. The trend was consistent with other studies which found herbaceous cover increased post-spray, possibly linked to a decrease in competition from overstory trees and shrubs (Borrecco *et al* 1979, Freedman *et al* 1993, Sullivan and Sullivan 1982, Sullivan 1994, and Sullivan *et al* 1996). Whether or not these differences are detectable from a beneficial insect's perspective should be investigated in the future.

During the beginning of the summer, the older clearcuts that were sprayed with herbicide had more species and stems of flowering plants than the non-sprayed. This trend was consistent with the trend amongst the younger clearcuts. However, once the spring and early summer species passed there were not differences in the floral parameters measured between the older clearcuts with or without herbicide application.

It should be noted that herbicide application is not independent of site characteristics. Although we attempted to select sites with similar soil classifications, availability of sites within our desired treatment groups and accessibility of the sites limited us. Also, foresters develop management regimes based on a stand's landform, soil type, drainage class, and history, all of which can influence the plant communities found within an area. Therefore, differences in plant communities, although negligible in our study within the older and younger groups, should not be attributed only to herbicide application.

The age of the stand influenced the flowering stem abundance and floral density within regenerating clearcuts. The younger stands ($\leq$5 years) consistently had more flowering plants compared to the older stands ($\geq$15 years). The mature stands showed a decline in flowering plants after the tree canopies were fully closed. A study conducted in Garrett County, Maryland found understory plant species distributions in regenerating clearcuts were highly related to stand age and site moisture (Yorks *et al* 2000). Early successional plants increased after clearcutting and then decreased as stands aged and tree canopies closed, similar to the results in our study.

Interestingly, the plantation sites had consistently a greater abundance of flowering plants compared to the older un-planted sites. The plantations were relatively uniform in tree species, tree height, and spacing. The spacing between trees could have lead to a more even distribution of growing space, which was colonized by flowering plants. Although the plantations in the age group we sampled (>12 years post-planting) were abundant in flowering plants, the management regime leads to a lack of multi-layered canopy, diverse tree sizes, and abundant snags and fallen trees, which exist in natural forests (Hansen *et al* 1991). Wildflowers occurred infrequently under a closed canopy in a mature jack pine plantation in Michigan (Elliott *et al* 1987). In our study the mature stands tended to have less species of flowering plants after canopy closure. However, there were flowering plants present in the later sampling periods in the areas where there was more available sunlight, due to adjacency to the edge or single tree fall gaps. Thus, as plantations mature the uniformity and lack of structural diversity could lead to less wildflowers compared to natural stands.

The presence of flowering plants in plantations would be a benefit in terms of pest management. Plantations are high production, intensively managed stands compared to naturally regenerating stands, which require less monetary input. A study in commercial apple orchards in Belleville, Ontario found parasitism rates of tent caterpillar eggs and pupae, *Malacosoma americamum* (F.) and the larvae of a codling moth, *Carpocapsa pomonella* (L.) were higher by a factor of 18:1 in orchards with rich undergrowth of nectar-producing flowers (Leius 1967). Interestingly, several of the plants recorded in the orchards classified as “rich” were similar to plants we sampled in the recent clearcuts and plantation sites, such as strawberry, *Ranunculus* spp., *Heiracium* spp., *Taraxacum* spp., *Viola* spp., *Erigeron* spp., goldenrod, and aster.

A study investigating the preference of a parasite (Hymenoptera: Ichneumonidae) of the European pine shoot moth (Lepidoptera: Olethreutidae) for various plants found a member of the family Cornaceae and orange hawkweed were ranked as highly attractive (Syme 1975). Some of the more common species in our study were bunchberry, a member of the family Cornaceae, and field and orange hawkweed. Also, the genus *Galium*, *Hypericum*, and *Rubus* were recorded as being visited by Hymenopteran parasitoids (Jervis *et al* 1993), all of which were sampled within our sites. Thus, the presence and abundance of these plant groups within recent clearcuts and plantations could provide benefits in terms of pest management within a stand, as well as in adjacent stands with depauperate floral resources.

Unfortunately, there was not abundant information concerning which insect species were reliant on the flowering plant species that we sampled. However, two characteristics of herbaceous plants could influence their viability as food sources for parasitoids: flowering period and flower morphology. The peak flight period of parasitoids should overlap with the flowering period of potential food sources. Also, the head and mouth dimensions of the insect can regulate their ability to gather nectar sources from flowers with narrow tubular corollas (Compositae and Leguminosae) or small corollas (Compositae) (Jervis *et al* 1993). Umbelliferous species are considered a good alternative to plant in agricultural settings to encourage parasitoids, which help control pest populations (Leius 1960, and Jervis *et al* 1993). An investigation into the floral preferences of the Hymenoptera present in our stands would prove beneficial in terms of forest pest management.

The flowering plant communities could provide a benefit in terms of insect pest outbreaks, but the type of species sampled within the recent and older clearcuts and plantations were 29% exotics. Exotic plants are notorious for causing shifts in native species composition and abundance (Cox 1999). Also, it is unknown whether nectar and pollen sources from exotic plants are available to the native insect communities. However, one study of bumblebees did find non-native plant species were a frequented food plant (Heinrich 1976). Again it would be informative to investigate whether the Hymenoptera present within our sites displayed a preference for the native versus non-native plant species. Thus, although clearcut harvesting leads to increases in flowering plants, it is important to consider the types of colonizers and their potential impact on the plant and insect communities.

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APPENDIX The major families and species of flowering plants sampled during the summer of 2000. The numerical entry for each species is the total number of stems counted in the corresponding stand category(s). Nomenclature follows Gleason and Cronquist (1991).

	Stand Category			
Species	Recent Clearcuts	Older Clearcuts	Plantations	Mature
Family Cornaceae (Dogwood)				
Cornus canadensis L., bunchberry	48	41	56	1
Family Rosaceae (Rose)				
Agrimonia gryposepala Wallr., agrimony			9	
Dalibarda repens L., dewdrop	59	66		9
Fragaria spp. L., strawberry	52	165	174	4
Rubus allegheniensis T.C. Porter, blackberry	96	82	112	
Rubus idaeus L., red raspberry	1748	2707	532	21
Rubus pubescens Raf., dwarf raspberry	24	38	7	3
Potentilla simplex Michx., C. cinquefoil	5	68	25	
Potentilla norvegica L., rough cinquefoil	80	83		
Prunus sp. L., cherry		1		
Spiraea latifolia Aiton Dippel., meadowsweet	1			
Spiraea tomentosa L., steeplebush	11			
Family Asteraceae (Composite)				
Anaphalis margaritacea L., pearly everlasting	341	150	400	
Cirsium Miller., thistle	15	5		
Ambrosia sp. L., ragweed		1		
Aster L. aster	X	X	X	X
A. simplex Willd., pinacled aster			3	
A. dumosus L., bushy aster	9		1	
A. umbellatus Miller., flat topped white aster	23	2	52	
A. vimineus Lam., small white aster	2		2	
A. acuminatus Michx., whorled wood aster		12		
Conyza canadensis (L.) Cronq., horseweed	11			
Erigeron L., fleabane	3	3		
Erigeron annuus (L.) Pers., daisy fleabane	1	2	2	
Eupatorium maculatum L., spotted joe-pye	7		10	1
Hieracium caespitosum Dumort., field hawkweed	556	1823	883	1
H. aurantiacum L., orange hawkweed	26	103	30	
H. gronovii L., hairy hawkweed		1		
H. pilosella L., mouse-ear hawkweed	1	1		
H. scabrum Michx., rough hawkweed	2			
Lactuca canadensis L., wild lettuce	10	5	1	
Lactuca biennis (Moench) Fern., tall blue lettuce	2		8	
Prenanthes boottii (DC.) A. Gray., rattlesnake root	1			
Solidago L., goldenrod	X	X	X	
Taraxacum Wiggers., dandelion		1		
Family Zingiberaceae (Ginseng)				
Aralia nudicauli (L.), wild sarsaparilla		9		6
Aralia hispida (Vent.), bristly sarsaparilla	2		1	
Family Araceae (Arum)				
Arisaema Martius., jack-in-the-pulpit		1		
Family Ranunculaceae (Buttercup)				
Clematis virginiana L., virgin's bower	7			
Thalictrum pubescens Pursh., tall meadow rue	1			
Family Liliaceae (Lily)				
Clintonia borealis (Aiton) Raf., bluebead lily	1			
Maianthemum canadense Desf., Canada mayflower	13	253	3	29
Medeola virginiana L., Indian cucumber root	3	18		1
Trillium undulatum Willd., painted trillium	1	1		

APPENDIX (cont.)

Species	Stand Category Recent Clearcuts	Older Clearcuts	Plantations	Mature
Trillium erectum L., purple trillium		2		
Family Caprifoliaceae (Honeysuckle)				
Diervilla lonicera Miller., N. bush honeysuckle	3	3	3	
Linnaea borealis L., twinflower	39	85	6	32
Virburnum dentatum L., arrowwood		3	3	
Virburnum lentago L., sweet viburnum		5		
Viburnum cassinoides (L.)T. &G., witherod		18		
Family Cucurbitaceae (Gourd)				
Echinocystis lobata (Michx.) T.&G., wild cucumber		1		
Family Onagraceae (Evening Primrose)				
Epilobium angustifolium L., fireweed	5	21	14	
E. leptophyllum Raf., narrow leaved willow herb	10			
Oenothera tetragona Roth., sundrop	15	3		
Family Lamiaceae (Mint)				
Galeopsis tetrahit L., hemp nettle	30	1		
Lycopus americanus Muhl., water horehound	33			
Lycopus uniflorus Michx., northern bugleweed	32	78	64	
Marrubium vulgare L., horehound	2			
Scutellaria lateriflora L., maddog skullcap	4			
Prunella vulgari L., healall	98	68		6
Family Rubiaceae (Madder)				
Galium boreale L., northern bedstraw	X		X	
Galium triflorum Michx., sweet scented bedstraw	11	14	3	1
Galium trifidum L., small bedstraw	11	11		
Hedyotis sp L., bluets			1	
Family Ericaceae (Heath)				
Vaccinium angustifolium Aiton., blueberry	2	98		
Kalmia angustifolia L., sheep laurel		368		
Gaultheria procumbens L., wintergreen	6	41		
Family Clusiaceae (St. John's-wort)				
Hypericum mutilim L., dwarf St. John's-wort	16			
Hypericum canadense L., Canada St. John's-wort	11		2	
Hypericum ellipticum Hook., pale St. John's-wort			2	
Family Balsaminaceae (Touch-Me-Not)				
Impatiens capensis Meerb., jewelweed			1	
Family Campanulaceae (Bellflower)				
Lobelia siphilitica L., great lobelia	4			
Lobelia inflata L., Indian tobacco	91			
Family Scrophulariaceae (Figwort)				
Melampyrum lineare Desr., cowwheat		1		
Veronica officinalis L., common speedwell	47	81	6	
Family Pyrolaceae (Pyrola)				
Moneses uniflora (L.) A. Gray, one-flowered pyrola		3	3	
Pyrola rotundifolia L., round leaf pyrola			4	
Family Monotropaceae (Indian Pipe)				
Monotropa uniflora L. , Indian pipe		10		
Family Orchidaceae (Orchis)				
Orchis sp. L., small woodland orchis		1		

APPENDIX (cont.)

Species	Recent Clearcuts	Stand Category Older Clearcuts	Plantations	Mature
Family Oxalidaceae (Wood Sorrell)				
Oxalis acetosella L., common wood sorrell	1	74	13	87
Oxalis stricta L., yellow wood sorrell	3	3		
Family Polygonaceae (Buckwheat)				
Polygonum cilinode Michx., fringed bindweed	19	55		
Rumex acetosella L., sheep sorrell	5	29	3	
Family Saxifragaceae (Saxifrage)				
Tiarella cordifolia L., foamflower	1	21	7	24
Family Primulaceae (Primrose)				
Trientalis borealis Raf., starflower		8	4	5
Family Violaceae (Violet)				
Viola pallens (Banks) C. L. Hitchc., N. white violet	3			1

BIOGRAPHY OF THE AUTHOR

Kathryn Georgitis was born in Burlington, Vermont on June 11, 1974. She lived in a variety of places including Indiana, New York, California, and finally Winston-Salem, N.C. She graduated from North Forsyth High School located in Winston-Salem, N.C. in 1992. She attended the University of North Carolina at Chapel Hill and graduated in 1996 with a Bachelor's of Science in Biology. During her "breaks" from schooling she hiked the entire Appalachian Trail from Georgia to Maine. Upon walking into the "Vacationland" she decided to enter the Ecology and Environmental Science program at the University of Maine in 1998.

Kathryn will be attending Oregon State University for a masters program in Statistics. She one day hopes to combine her ecological and quantitative skills in a well paying job to pay off her student loans. Kathryn is a candidate for the Master of Science degree in Ecology and Environmental Science from The University of Maine in December, 2001.