

EFFECTS OF FOREST MANAGEMENT ON  
NEST MICROHABITAT AND MICROCLIMATE OF NONGAME BIRDS

A Final Report to Arizona Game and Fish Department  
for Heritage Grant I95008

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## INTRODUCTION

Many studies addressing habitat selection have focused on birds due to their wide distributions in a variety of habitats (Cody 1985). Yet, studies of habitat selection in birds have focused on the importance of foraging sites despite the importance of nest site availability for reproductive success, distribution, and demography (Martin 1993). Availability of suitable breeding sites is an important factor in habitat selection for many animals including fish (Sih et al. 1985, Werner and Hall 1988), small mammals (Geier and Best 1980), lizards (Kiestler et al. 1975), crayfish (Magnuson and Stein 1976), as well as birds (Martin 1988, Bilke 1984, Petit 1988, Steele 1993). Most open-nesting birds have specific microhabitat requirements that directly affect reproductive success, distribution, and demography (Martin and Roper 1988, Martin 1988, 1992, 1993, 1998, Petit 1988, Steele 1993).

Selection of nest sites has evolved in relation to several factors such as predation (Martin 1988, 1992, 1993, 1998, Marzluff et al. 1988), food resource availability (Steele 1993, Crockett et al. 1975, Bekoff et al. 1987), and vegetation and microclimate (Walsberg 1981, Calder 1973, McGillivray 1981, With and Webb 1995, Martin 1998). Some studies have emphasized the importance of nest microclimate and weather in relation to nest placement (Reynolds et al. 1984, Holway 1991, Best et al. 1980, Ricklefs 1969, Page et al. 1985, McGillivray 1981, With and Webb 1993), but only a few studies have shown the importance of microclimate in relation to vegetation cover (see With and Webb 1995, Walsberg 1981, Page et al. 1985). Yet, bird species are known to partition microclimate gradients, using different parts of the gradient (Smith 1977, Karr and Freemark 1983, Martin 1993, 1998). Such differential distributions along microclimate gradients may reflect differences in evolutionary histories and physiological tolerances (e.g,

Hayworth and Weathers 1984) such that differences in distributions of species or habitat choices reflect underlying climate conditions (Root 1988, 1989). If human-induced changes in vegetation cover affect microclimate of nest sites, then we can expect availability of nest sites to be affected by changes in vegetation. We examined the potential for human-induced changes in vegetation structure to influence nest site availability.

In forest landscapes, logging practices can alter the vegetation structure of the forest. The loss of vegetation through logging may influence abundances of microhabitats and create entirely different microclimates than in unlogged areas (Fritschen et al. 1970, Chen 1991). For example, logged areas can have increased exposure to solar radiation and wind in the understory, and create sunnier, warmer, and drier microclimates while unlogged areas can sustain a much cooler and wetter microclimate (Chen et al. 1993). Changes in the amount of vegetation and microclimate of logged areas ultimately might change the number of possible nest sites. In assessing the availability of nest sites following management practices such as logging, we can aid land management decisions for sustainable non-game bird populations. Recently and intensively logged areas in two snow melt drainages offer a perfect system to compare changes in microhabitat and microclimate due to loss of overstory and understory vegetation. Here we quantified microhabitat and microclimate characteristics of nest sites to compare the change in potential nest sites of ground- and shrub-nesting passerines within logged and unlogged areas.

## METHODS

Study sites were high elevation (2600 m) snow melt drainages on the Mogollon Rim, Arizona consisting of an overstory of Douglas-fir (*Pseudotsuga menziesii*), white fir (*Abies*

*concolor*), ponderosa pine (*Pinus ponderosa*), and quaking aspen (*Populus tremuloides*), and an understory of canyon maple (*Acer grandidentatum*), and New Mexican locust (*Robinia neomexicana*) (see Martin 1998 for a more detailed description of the study sites). Microhabitats of nests and general characterization of the microhabitat of these drainages were studied in 20 drainages for the past 10 years (Martin 1998). Two additional snow melt drainages were used for studies of logging, where each had a portion of the drainage that was selectively-logged and a separate portion that was unlogged; logging occurred one year prior to the first year of our measurements. We sought drainages that had both logged and unlogged portions to allow sampling sites of both treatments to be paired within a drainage and thereby minimize spatial influences on vegetation or microclimate. The sites that we sampled were more extensively logged than is typical of selectively-logged sites in the forest, but this more intensive logging allowed clearest tests of whether any effects were evident.

We sampled microclimate conditions at 10 sites within each treatment (i.e., unlogged versus logged) in both drainages; a total of 20 sites per treatment. Microclimate can vary from the bottom to the top of drainages (T. E. Martin, unpubl. data) and so we sampled each treatment at 5 locations from the bottom to top of the sides of the drainage at each of two sampling sites in each study plot. The first 2 sampling sites were located by walking along the bottom of the drainage 25 m from the edge of the cut into the logged area, and 25 m from the edge of the cut into the unlogged area. Four sampling points were placed up the side of the drainage in both the logged and unlogged areas, perpendicular to the drainage axis, yielding 2 sampling points each at the bottom, lower 1/3, middle 1/3, upper 1/3, and top of the slope. A second topographic suite of sampling points was located 75m from the first in each study plot and treatment. At each

sampling point, temperature and relative humidity were recorded using probes attached to Campbell Scientific, Inc. CR10 dataloggers. Temperature and relative humidity were recorded simultaneously in the logged and unlogged areas every five minutes for 48 hours.

After sampling microclimate of the general landscape of the drainage, the probes were moved to record the microclimate at sites typical of nest sites of three ground-nesting passerines: Orange-crowned Warbler, Red-faced Warbler, and Virginia's Warbler. Each species has a preferred microhabitat type (plant species) and topolocation along the slope where it usually nests; Orange-crowned Warbler usually nest in patches dominated by small maple stems at the bottom 1/3 of the slope, Red-faced Warbler in patches dominated by small firs in lower or middle 1/3 of the slope, and Virginia's Warbler in patches dominated by small locust at the top 1/3 of the slope (Martin 1998). The probe that had been at the bottom 1/3 of the slope was moved underneath the nearest small maple to represent Orange-crowned Warbler nest sites, the probe placed at the middle 1/3 of the slope was moved underneath the nearest small fir to represent Red-faced Warbler nest sites, and the probe placed at the top 1/3 of the slope was moved underneath the nearest locust to represent Virginia's Warbler nest sites. These microhabitat types also typify shrub-nesters examined here: Green-tailed Towhees nest in patches dominated by locust (like Virginia's Warblers), Hermit Thrushes nest in patches dominated by fir (like Red-faced Warblers), and MacGillivray's Warblers nest in patches dominated by maple (like Orange-crowned Warblers). Thus, although microclimate is sampled at ground sites, we sample microclimate of microhabitat types that typify both ground and shrub-nesting species. Microclimate of these "nest site" sampling points was simultaneously recorded in the logged and unlogged areas every 5 minutes for 48 hours.

We measured vegetation, including shrub and sapling stem counts, within a 5 m radius circle of sampling points (for details of sampling methods see Martin 1998 and methods described at <http://pica.wru.umt.edu/bbird/> for the general BBIRD sampling protocol). Sampling points were placed perpendicular to the drainage contour of all drainages being sampled for bird nest sites to describe the general vegetation gradient of drainages. These sampling points were placed every 50 m down the the drainage to provide a systematic random sample. This same systematic random sampling scheme was used in the 20 drainages where we studied nests to characterize the general vegetation of drainages. In addition, vegetation was sampled at the sites that typified preferred nest sites for three ground-nesting warblers where microclimate was also sampled (see above). All trees and snags were also counted within a 50 m transect that ran perpendicular to the drainage contour and included all the topographical sampling points for each microclimate sampling point. In sum, vegetation was sampled at systematic random samples (random samples hereafter) on nest study plots and the 2 drainages where logging was studied, and vegetation was sampled at topolocations and vegetation patches that were typical of nest sites of Orange-crowned, Red-faced, and Virginia's Warblers (hereafter nest samples).

Discriminant function and correlation analyses of the systematic samples among strata (bottom, lower, middle, and upper 1/3, and ridge) were used to reduce the number of variables based on multicollinearity of variables. Densities of different size classes of the same plant species showed strong positive correlations and demonstrated the same patterns along the gradient sampled by the random samples. Hence, size classes of plant species were pooled.

Multivariate analysis of variance was used initially to test for differences in the habitat variables among bird species. For all species, the multivariate analysis of variance was

significant and univariate analysis of variance was used to examine variation in habitat among the three sampling sites (only these univariate analyses are reported in Results because all multivariate analyses were highly significant).

For comparisons of microclimate between logged and unlogged treatments, paired t-tests were used.

## RESULTS

### *Vegetation on Sides of Drainages*

Vegetation varied up the sides of drainages. New Mexican locust is shade-intolerant and xeric-tolerant (Peattie 1953, Isely and Peabody 1984) and Gambel's Oak also is xeric-tolerant; both were more abundant in the upper than in the middle or lower strata of the sides of the drainage (Fig. 1). Canyon maple is associated with mesic conditions (Peattie 1953, Barker 1977, Barker et al. 1982) and maple, total stems, and ground cover were greater in the lower than in the middle and upper strata (Fig. 1). Maple made up most (63%) of the total stems, so variation in total stems was largely driven by maple ( $r=0.81$ ,  $p<0.0001$ ). Small (<3m tall) firs were abundant while pines were not, but neither conifer type varied among strata. Thus, vegetation defined a moisture gradient with mesic-adapted plants (maple, total woody stems, green ground cover) being greater in the lower reaches of the drainage, xeric-adapted plants (locust, oak) being more abundant at higher reaches and conifers (firs and pines) showing no clear pattern.

Discriminant function analysis yielded a single highly significant axis ( $\chi^2=169.0$ ,  $p<0.0001$ ) that strongly discriminated strata from each other (Mahalanobis distances -  $p<0.0001$

for all pair-wise comparisons of strata). A stepwise procedure included all variables except total stems and pine. Total stems was excluded because of its collinearity with maple stems. Pine simply did not show any tendencies to discriminate among strata and it was never used for nesting by any of the species studied here. The structure coefficients showed high positive correlations for maple stems (0.51) and green ground cover (0.52), negative correlations for locust (-0.31) and oak (-0.18) stems, and low loading for small firs (0.07). This canonical axis classified 61.4% of the sites in their correct strata. Lower and upper strata showed the greatest classification accuracy with 68.3% and 76.2% correct classifications, respectively. In each of these two cases, the strata were most often incorrectly classified as the middle strata (22.8% and 16.8%, respectively). The middle strata showed the weakest discrimination with only 39.6% of the sites being correctly classified. In short, the middle of the gradient overlapped the two ends of the gradient, while the two ends were highly differentiated from each other. Moreover, this differentiation was obtained with a relatively small set of five variables (numbers of stems of maple, locust, small firs, oak, and green ground cover).

#### *Nest patch differences among species*

*Ground-nesting Species.*--Discriminant function analysis was used to examine whether ground-nesting bird species differed in their habitat use. Habitat variables (ground cover, maple, locust, small firs, and oak) were included in the analysis along with four dummy variables representing the plant species or site under which nests were placed (maple, locust, fir, or open). Three highly significant ( $\chi^2 > 130$ ,  $p < 0.0001$  in all cases) discriminant function axes strongly differentiated nest sites of all species from each other ( $F > 19.0$ ,  $p < 0.0001$ ,  $df = 8, 1036$  for all

pairwise comparisons). Nest sites of each species were correctly classified more often than not (Table 1). Nest sites of Orange-crowned and Virginia's Warblers were most often misclassified as each other, while Red-faced Warblers and Dark-eyed Juncos were most frequently misclassified as each other, with Red-faced Warblers also being misclassified as Orange-crowned Warblers often (Table 1).

The correct and incorrect classifications reflected general differences and similarities in nest sites of the four ground-nesting bird species (Fig. 2). In particular, Virginia's Warblers chose nest sites with more locust and oak than the other species (Fig. 2), but they also chose sites with an abundance of maple causing their misclassifications as Orange-crowned Warblers (see Fig. 2 vs Table 1). Dark-eyed Juncos chose nest sites with more ground cover and fewer maple stems (indicating choice of open areas with less woody vegetation). Red-faced Warblers chose nest sites with more small firs and fewer locust stems (Fig. 2). Finally, Orange-crowned Warblers chose nest sites with more maple than the other species (Fig. 2). Note that these differences in vegetation preferences among ground-nesting species reflect variation in the distribution of the vegetation along the topographical gradient.

*Shrub-nesting Species.*--Discriminant function analysis yielded two ( $\chi^2 > 106$ ,  $p < 0.0001$  in both cases) canonical axes that strongly differentiated nest sites of shrub-nesting species ( $F > 64.0$ ,  $p < 0.0001$ ,  $df = 2, 497$  for all pairwise comparisons). Nest sites of all three shrub-nesters were correctly classified most of the time (Table 2), reflecting strong differences among species (Fig. 3). MacGillivray's Warblers chose nest sites with more maple than the other species (Fig. 3). Green-tailed Towhees chose nest sites with more locust and oak and Hermit Thrushes chose nest sites with more small firs than other species (Fig. 3). Both Green-tailed Towhees and

MacGillivray's Warblers were most often misclassified as Hermit Thrushes, because they both use firs for nest sites and choose patches dominated by fir, similar to Hermit Thrush.

Given that all three shrub-nesters most frequently placed their nests in small firs, if analyses are restricted to nests placed in small firs, the same results are found: Discriminant function analysis of nest patches for nests placed in small firs yielded two ( $\chi^2 > 39$ ,  $p < 0.0001$  in both cases) discriminant function axes that strongly differentiated species from each other ( $F > 21.0$ ,  $p < 0.0001$ ,  $df = 2, 411$  for all pairwise comparisons). Thus, species chose differing nest microhabitats even when they chose the same nest substrate. In both cases (i.e., all nest sites or fir only nest sites), the vegetation in the nest patches differed among species in a way that reflected differences in placement along the topographical gradient (see Fig. 4).

#### *Comparisons of Vegetation Between Treatments*

Logged sites differed from unlogged sites at randomly sampled locations; logged sites had less canopy cover ( $F = 24.9$ ,  $p = 0.000$ ), less maple ( $F = 6.4$ ,  $p = 0.013$ ), less locust ( $F = 3.0$ ,  $p = 0.086$ ), less small firs ( $F = 4.9$ ,  $p = 0.029$ ) and more grass ( $F = 3.0$ ,  $p = 0.087$ ) based on the 5 m sampling scheme (Fig 5). It is interesting to note that the biggest impacts seem to be in the bottom and lower portions of drainages (see Fig. 5), but this may reflect the fact that stem density is highest in the lower reaches, thereby allowing detection of greater impact.

Vegetation was sampled at vegetation patches (maple, locust, small firs) that typified preferences of bird species existing on the sites (see above). When vegetation was sampled at these "nest" sampling sites, vegetation density did not differ between logged and unlogged treatments for any of the vegetation types ( $F < 1.8$ ,  $p > 0.15$  for all vegetation characteristics).

The transect sampling scheme for trees showed that white firs ( $t=4.6$ ,  $p=0.01$ ), maple ( $t=3.2$ ,  $p=0.025$ ), locust ( $t=2.8$ ,  $p=0.035$ ), and oak ( $t=2.5$ ,  $p=0.045$ ) trees were less abundant in logged than unlogged sites (Fig. 6), but other tree species did not differ in abundance between treatments. However, most other trees showed a trend towards being less abundant in logged sites such that summing across all trees, the total abundance of trees was less in logged than unlogged ( $t=5.0$ ,  $p=0.008$ ).

### *Microclimate Variation*

Microclimate tended to vary with topographical position; for example, mean minimum temperatures tended to increase up the slope with some leveling off at the top (Fig. 7). However, differences among topographic positions generally were not significant (3-factor ANOVA using topographic position, logging treatment and random vs nest sampling;  $p>0.05$ ) due to relatively small samples per topographic position and replicates being sampled across the season, yielding temporal differences in microclimate (more intensive sampling of the gradient that does not pool different seasonal periods shows clear differences among topographic locations - Martin unpubl. Data). For this paper, we subsequently test for differences between logged and unlogged treatments across topographic positions.

Mean minimum ( $t=-3.058$ ,  $p=0.003$ ) and maximum ( $t=3.626$ ,  $p=0.001$ ) temperatures differed between logged and unlogged sites for random samples (Fig. 8). Most interestingly, the minimum temperatures were coldest and maximum temperatures hottest on logged sites (Fig. 8); in other words, temperature trends crossed in mid-day causing the greatest daily temperature extremes, both hot and cold, in logged sites compared with unlogged sites. As a result, range of

temperature was markedly greater ( $t=4.37$ ,  $p=0.000$ ) in logged sites than unlogged sites for random samples (Fig. 8c). In contrast to random samples, temperature samples at nest sites showed no difference between logged versus unlogged for minimum ( $t=-1.19$ ,  $p=.126$ ), maximum ( $t=0.073$ ,  $p=0.47$ ), or range ( $t=0.46$ ,  $p=0.33$ ) of temperatures (Fig. 8).

Minimum ( $t=-1.59$ ,  $p=0.065$ ), maximum ( $t=1.81$ ,  $p=0.044$ ), and range ( $t=2.09$ ,  $p=0.025$ ) of relative humidity at random samples (Fig. 9) also tended to differ between logged and unlogged sites, but differences were less marked than for temperature (Fig. 8). Nest site samples (Fig. 9) did not differ between logged and unlogged sites for minimum ( $t=-0.48$ ,  $p=0.32$ ), maximum ( $t=-0.07$ ,  $p=0.48$ ), or range ( $t=0.16$ ,  $p=0.44$ ) of relative humidity.

Random samples were more extreme than nest samples in logged sites for all variables (see Figs. 8, 9): minimum temperature ( $F=6.62$ ,  $p=0.008$ ), maximum temperature ( $F=2.95$ ,  $p=0.048$ ), range in temperatures ( $F=13.3$ ,  $p<0.001$ ), minimum relative humidity ( $F=1.97$ ,  $p=0.085$ ), maximum relative humidity ( $F=3.8$ ,  $p=0.03$ ), range in relative humidity ( $F=5.3$ ,  $p=0.014$ ). In contrast, random samples did not differ from nest samples in unlogged sites for most variables (see Figs. 8, 9): minimum temperature ( $F=1.67$ ,  $p=0.11$ ), maximum temperature ( $F=0.0$ ,  $p=0.50$ ), range in temperatures ( $F=0.4$ ,  $p=0.28$ ), minimum relative humidity ( $F=1.3$ ,  $p=0.14$ ), maximum relative humidity ( $F=3.0$ ,  $p=0.047$ ), range in relative humidity ( $F=4.24$ ,  $p=0.024$ ). In short, the increased vegetation at nest sites and unlogged sites was associated with more ameliorated microclimate.

## DISCUSSION

Vegetation varied up the sides of drainages in an obvious gradient and bird species

showed very specific vegetation preferences that differed along this vegetation gradient (summarized in Fig. 4). Use of different microhabitat can be critical for successful coexistence of species because overlap in nesting microhabitat can cause increased predation rates on coexisting species due to predators responding to the increased cumulative density of nests in a given microhabitat (Martin 1993, 1996). Vegetation differences along this gradient appear to reflect microclimate variation and can be explained based on known physiological tolerances of the common plant species (i.e., xeric adapted plants like locust and oak occur most frequently at the top where it is warmest and driest, while mesic adapted plants like maple occur most abundantly at the bottom or lower portions of slopes where it is coolest and moistest). Maintenance of the vegetation gradient, and hence continued local coexistence of nongame birds, may depend on maintaining the microclimatic gradient because of its potential influence on plant distribution, but the microclimate gradient may be strongly affected by logging.

Logging of drainages led to a reduction in overhead canopy cover and reduction in the number of maple, locust, and fir stems. These are plants that typify the nest sites of the differing ground- and shrub-nesting bird species that occupy these drainages and logging generally led to a reduction in stem densities below the average level typically used as nesting sites by birds. For example, Virginia's Warblers generally chose nest patches dominated by locust that averaged more than 40 stems in the 5 m radius sampling plot (see Fig. 2); logged sites had a much lower abundance of locust in the sampling plot, averaging only about 15 stems in the 5 m radius sampling plot on the ridge, where locust is most abundant (see Fig. 5c). Green-tailed Towhees choose nest patches with an even greater abundance of locust (see Fig. 3), such that logged sites may create an even greater problem for them to find suitable nest patches. The same patterns are

true for all of the remaining species, except Dark-eyed Junco, which chooses nest patches in the open with an abundance of grass and few woody stems (see Fig. 2); logging led to an increase in grass cover (see Fig. 5b), probably due to the decrease in canopy cover (Fig. 5a) allowing greater sunlight to the forest floor, and a reduction in woody stems (see Fig. 5c, 5d, and 5e), thereby potentially benefitting Dark-eyed Juncos. However, the remaining 6 species are all potentially negatively impacted by intensive logging due to the reduced availability of nest patches with stem densities typical of their preferred nest patches. Negative impacts may arise in three ways. First, a reduced availability of appropriate patches may cause a reduction in densities of the birds. Second, birds may use patches with lower stem densities and other work shows that birds using patches with lower stem densities generally suffer higher predation rates (Martin and Roper 1988, Martin 1992, 1993). Third, reduction in vegetation may reduce nesting options and cause an increase in use of nesting microhabitats that overlap among coexisting species, which also can cause increased predation rates (Martin 1992, 1993, 1996). Thus, reduction in vegetation can have direct impacts on both population sizes and nesting success of bird species.

Besides directly affecting vegetation and nesting microhabitats, modification of vegetation also potentially influenced the availability of suitable nesting microclimates for birds. Fluctuations in egg temperature even as small as 1°C can have large impacts on hatching success of eggs (White and Kinney 1974). In addition, fluctuations in temperatures can affect activity patterns of parents, requiring greater incubation attentiveness or greater brooding of young and such influences on parental activity can subsequently influence physiological condition of the parents and, thus, their subsequent survival (see Martin 1995).

Logging reduced stem density and foliage cover. Birds commonly choose sites with

extensive foliage cover because of potential influences on predation risk (see Martin 1992), or potential influences on microclimate (see Walsberg 1981, Calder 1973, With and Webb 1993). Logged sites typically had more extreme temperatures (colder and hotter) that led to greater daily temperature fluctuation than unlogged sites at random but not nest sampling sites. The lack of differences at nest sites emphasize the importance of vegetation for ameliorating extremes in microclimate. Nest sampling sites were patches of vegetation that typified bird species preferences (maple, fir, locust) and these sampling sites were similar in vegetation between logged and unlogged. Consequently, nest sampling sites were also similar in microclimate between logged and unlogged areas. However, random samples of logged sites showed less of these vegetation types indicating that potential nesting patches were simply a lot less frequent in logged sites. Hence, logged sites had greater local fluctuation in microclimate and significantly greater daily extremes in microclimate compared to unlogged sites. In contrast, unlogged random sites did not differ from logged or unlogged nest sites in microclimate (see Figs. 8, 9). Thus, random sampling of logged sites shows an average reduction in vegetation that causes an average increase in extreme (hot and cold, wet and dry) microclimates and greater daily fluctuation in microclimate, whereas sites with more vegetation (i.e., nest vegetation patches in logged sites or unlogged sites) had more ameliorated microclimates.

In summary, logging has direct impacts on availability of nest patches in terms of vegetation density typical of nest patches chosen by birds, but logging also has indirect impacts by affecting microclimate conditions and potentially affecting the hatching success of eggs and necessary activity patterns of parents. Preventing logging from lower slopes and bottoms of maple drainages on the Mogollon Rim undoubtedly helps ameliorate the negative effects of

logging by maintaining at least some of the vegetation and microclimatic gradient necessary for successful coexistence of local understory nongame birds. The logging sites sampled here were intensively logged and the impacts of less intensively logged are as yet unknown. Nonetheless, these results show that logging can have negative impacts, suggesting caution is needed in considering logging prescriptions. The longterm ramifications of such logging are unknown, but the changes in microclimate, opening of the canopy and reduction of understory plants may lead to greater abundance of xeric-tolerant species such as locust in the future causing a possible shift from maple-dominated to locust-dominated understory in these drainages if logged extensively. Fortunately, the Coconino National Forest has designated such drainages as important wildlife use areas and do not allow logging below the upper portions of the drainages where xeric tolerant plants already exist anyway. Yet, it is worthwhile noting that even these upper portions are important to some bird species (i.e., Virginia's Warblers, Green-tailed Towhees) that seem to prefer xeric conditions, but also prefer stem densities of plants such as locust that are greater than found in logged sites, at least in the short term.

#### ACKNOWLEDGEMENTS

We thank Blue Ridge Ranger Station of the Coconino National Forest, and Cheylon Ranger Station of the Apache-Sitgreaves National Forest for their support of this work. We thank Arizona Game and Fish Department for providing Heritage Grant funds for conducting this work on logging and are grateful for support from the National Science Foundation (BSR-8614598, BSR-9006320, DEB-9407587, DEB-9527318) and the BBIRD (Breeding Biology Research and Monitoring Database) program under the Global Change Research Program of the Biological Resources Division for funding support of the nesting work.

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Table 1. Classification results (percent of cases classified as each species) from discriminant function analysis of nest sites of the four ground-nesting bird species based on separate covariance matrices.

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	PREDICTED GROUP MEMBERSHIP			
	Orange-crowned Warbler	Red-faced Warbler	Dark-eyed Junco	Virginia's Warbler
Orange-crowned Warbler	60.7	7.4	12.1	19.8
Red-faced Warbler	23.6	36.6	26.9	13.0
Dark-eyed Junco	13.2	13.2	60.6	12.9
Virginia's Warbler	25.3	9.0	16.9	48.8

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Table 2. Classification results (percent of cases classified as each species) from discriminant function analysis of nest sites of the three shrub-nesting bird species based on separate covariance matrices.

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	PREDICTED GROUP MEMBERSHIP		
	MacGillivray's	Hermit	Green-tailed
	Warbler	Thrush	Towhee
MacGillivray's Warbler	67.9	24.7	7.4
Hermit Thrush	11.8	79.4	8.8
Green-tailed Towhee	9.4	36.2	54.3

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Fig. 1. Mean ( $\pm 1$  SE) abundance of plant species in the lower, middle, and upper one-third of the sides of drainages. Twenty drainages were studied and stem densities of plants were measured in 5 m-radius plots in the lower, middle, and upper one-third of the sides of the drainages ( $n = 101$  plots per strata = 303 plots total). Differences among strata for each plant type were tested with ANOVA and numbers above each group of bars are F-values and letters above individual bars indicate differences ( $p < 0.05$ ) between strata based on Least Significant Difference test. Significance of F-values is: \* $p < 0.05$ , \*\* $p < 0.01$ , \*\*\* $p < 0.001$ , \*\*\*\* $p < 0.0001$ , with  $df = 2,301$  in all cases. Vegetation included New Mexican locust (*Robinia neomexicana*), Gambel's oak (*Quercus gambelii*), canyon maple (*Acer grandidentatum*), small (<3m tall) firs (*Abies concolor*, *Pseudotsuga menziesii*), small (< 3 m tall) pines (*Pinus ponderosa*, *Pinus strobiformes*), total woody stems of all plant species, and percentage ground cover.

Fig. 2. Mean ( $\pm 1$  SE) abundance of plants at nest patches (numbers of stems in a 5m-radius circle) of ground-nesting birds. Differences among bird species for each plant type were tested with ANOVA and numbers above each group of bars is the F-value, where significance is: \* $p < 0.05$ , \*\* $p < 0.01$ , \*\*\* $p < 0.001$ , \*\*\*\* $p < 0.0001$ , with  $df = 3, 1048$ . Numbers next to birds represent sample sizes in terms of numbers of nests and vegetation measured.

Fig. 3. Mean ( $\pm 1$  SE) abundance of plants at nest patches (numbers of stems in a 5m-radius circle) of shrub-nesting birds. Differences among bird species for each plant type were tested with ANOVA and numbers above each group of bars is the F-value, where significance is:

\* $p < 0.05$ , \*\* $p < 0.01$ , \*\*\* $p < 0.001$ , \*\*\*\* $p < 0.0001$ , with  $df = 2, 503$ . Numbers next to birds represent sample sizes in terms of numbers of nests and vegetation measured.

Fig. 4. Schematic drawing of vegetation and understory bird distribution along a moisture gradient in snow-melt drainages in Arizona. The 4 ground-nesting bird species (listed underneath the gradient) nest at the base of plant species that occur at different points along the gradients (Martin 1996a, 1998).

Fig. 5. Mean a) percent canopy cover and b) percent grass cover, plus number of stems in a 5 m sampling circle for c) maple, d) locust, and e) small white firs in logged versus unlogged sites for the five topographic locations.

Fig. 6. Numbers of stems of trees in logged versus unlogged sites based on sampling of 50 m wide transects.

Fig. 7. Mean minimum temperature (in °C) for logged and unlogged sites along topographical locations. Temperature (and humidity) were sampled at 5 min intervals for 48 hours at each of two replicate locations in each of two sampling drainages that contained each treatment (logged and unlogged).

Fig. 8. Temperature (in °C) extremes (maximum and minimum temperatures) and range in temperature for logged and unlogged sites. Temperature was sampled at 5 min intervals for 48

hours at each of two replicate locations in each of two sampling drainages that contained each treatment (logged and unlogged).

Fig. 9. Relative humidity extremes (maximum is wet and minimum is dry) and range in relative humidity for logged and unlogged sites. Relative humidity was sampled at 5 min intervals for 48 hours at each of two replicate locations in each of two sampling drainages that contained each treatment (logged and unlogged).

Fig. 1.

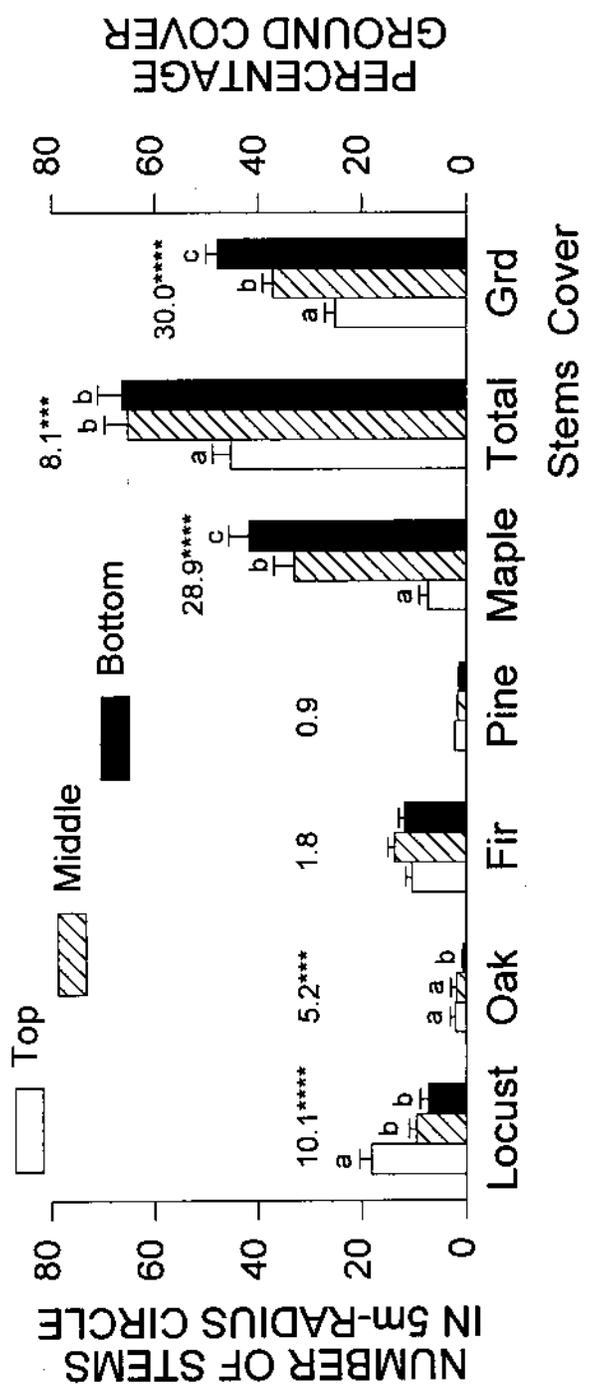


Fig. 2

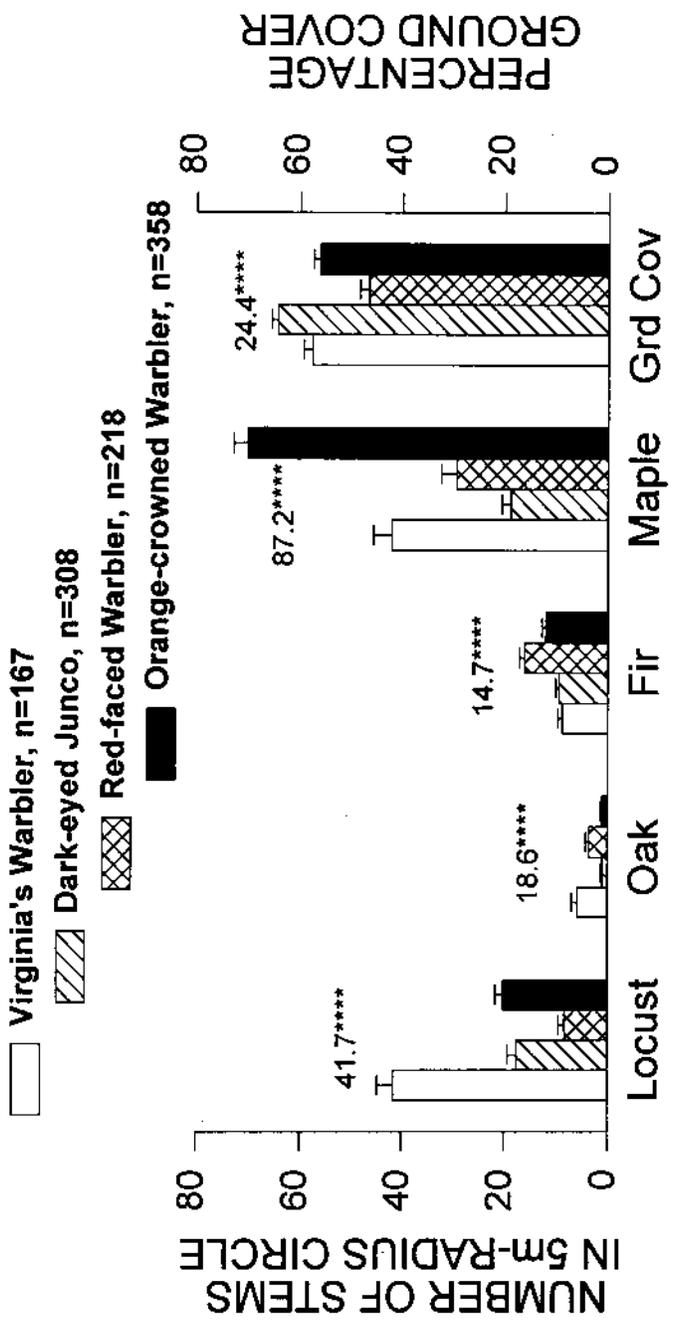
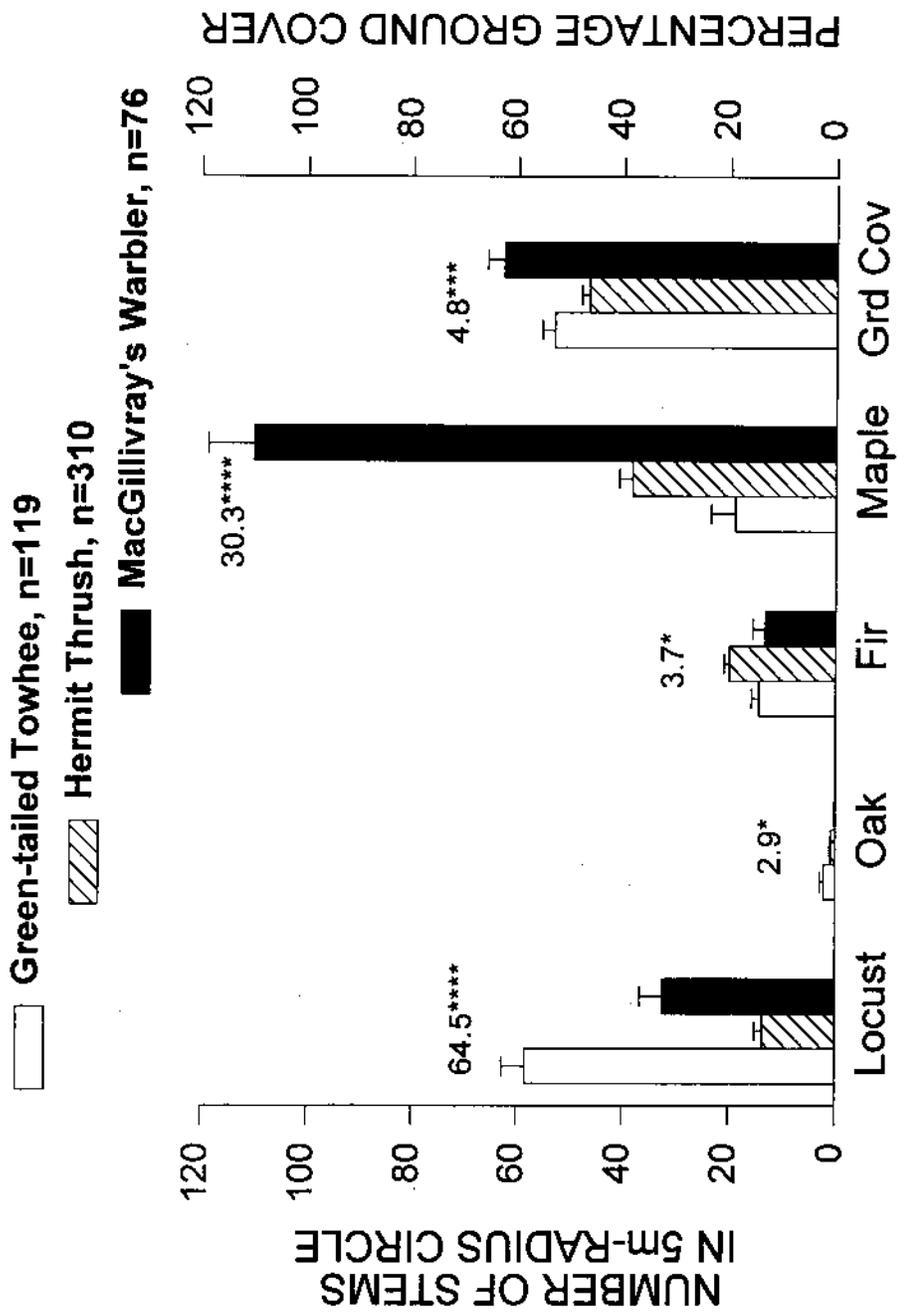


Fig. 3.



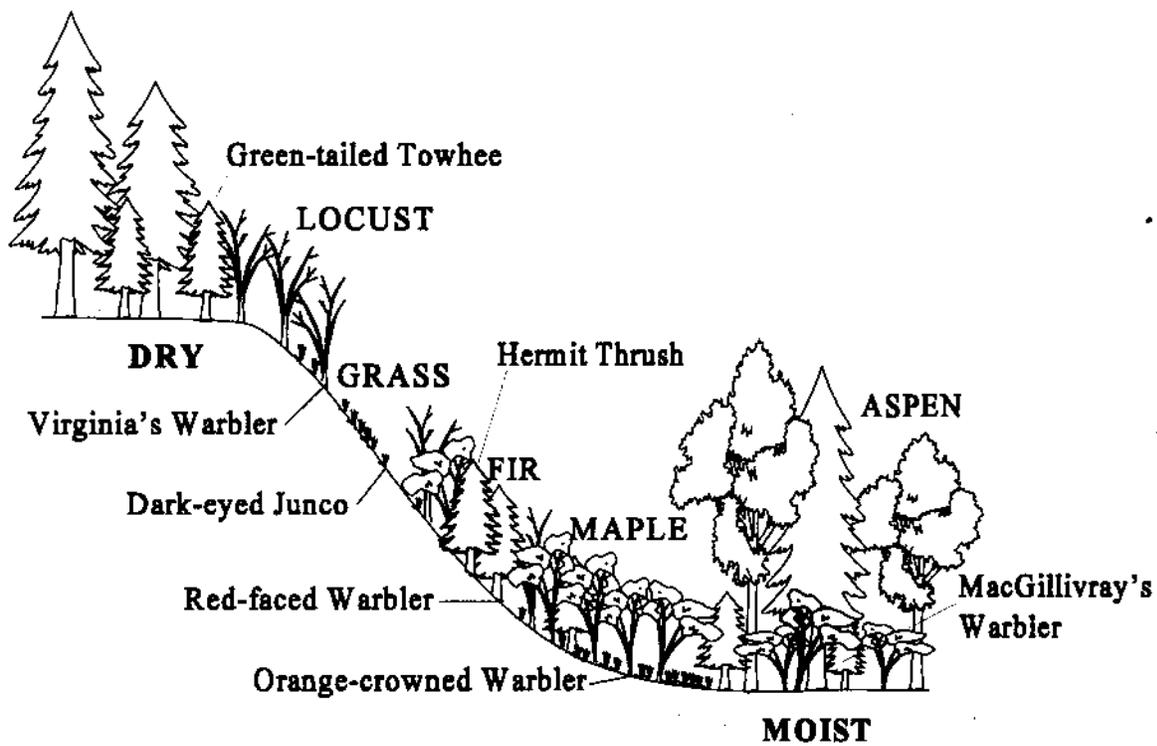


Fig. 4.

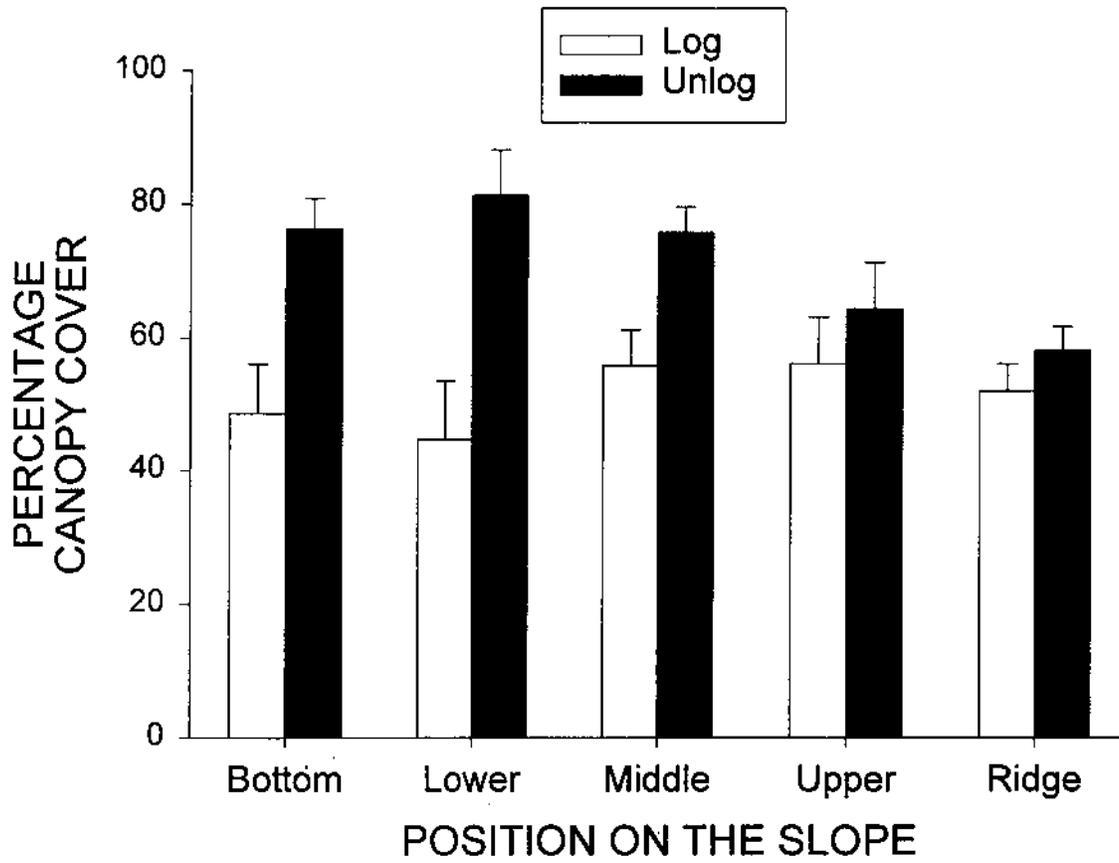


Fig. 5a.

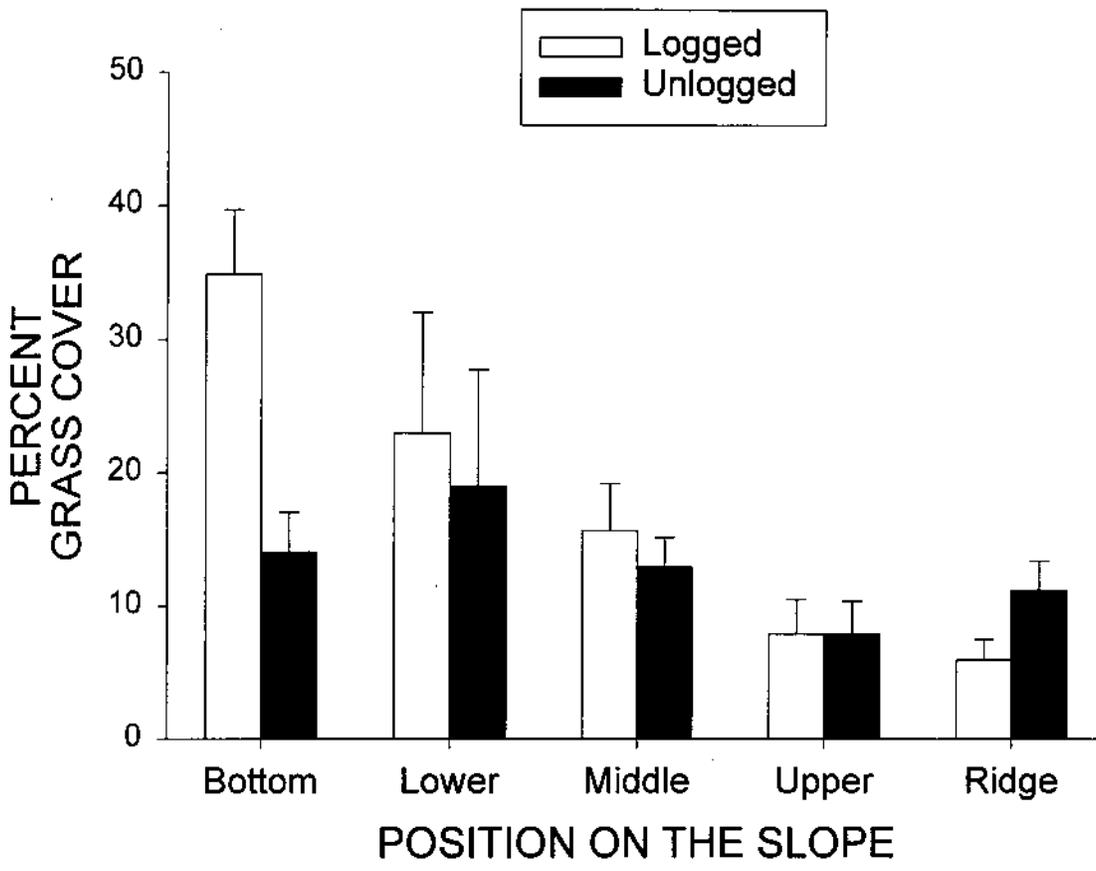


Fig. 0.56.

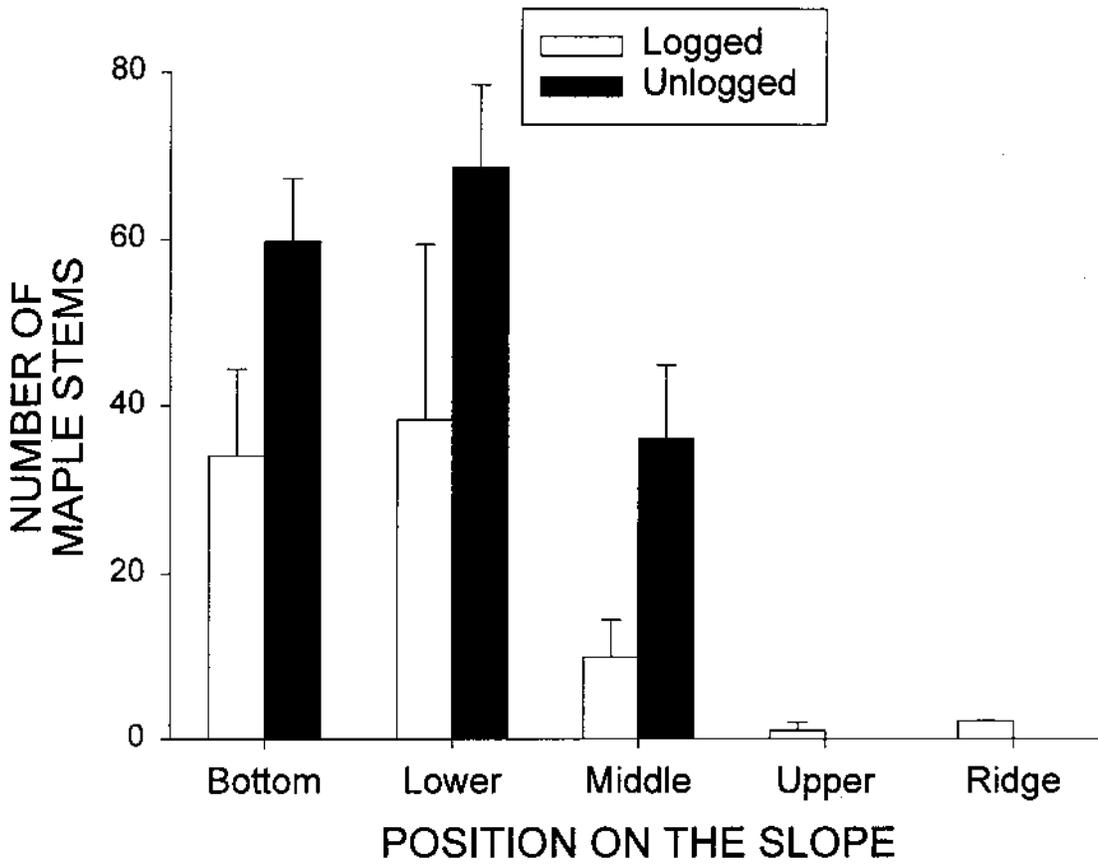
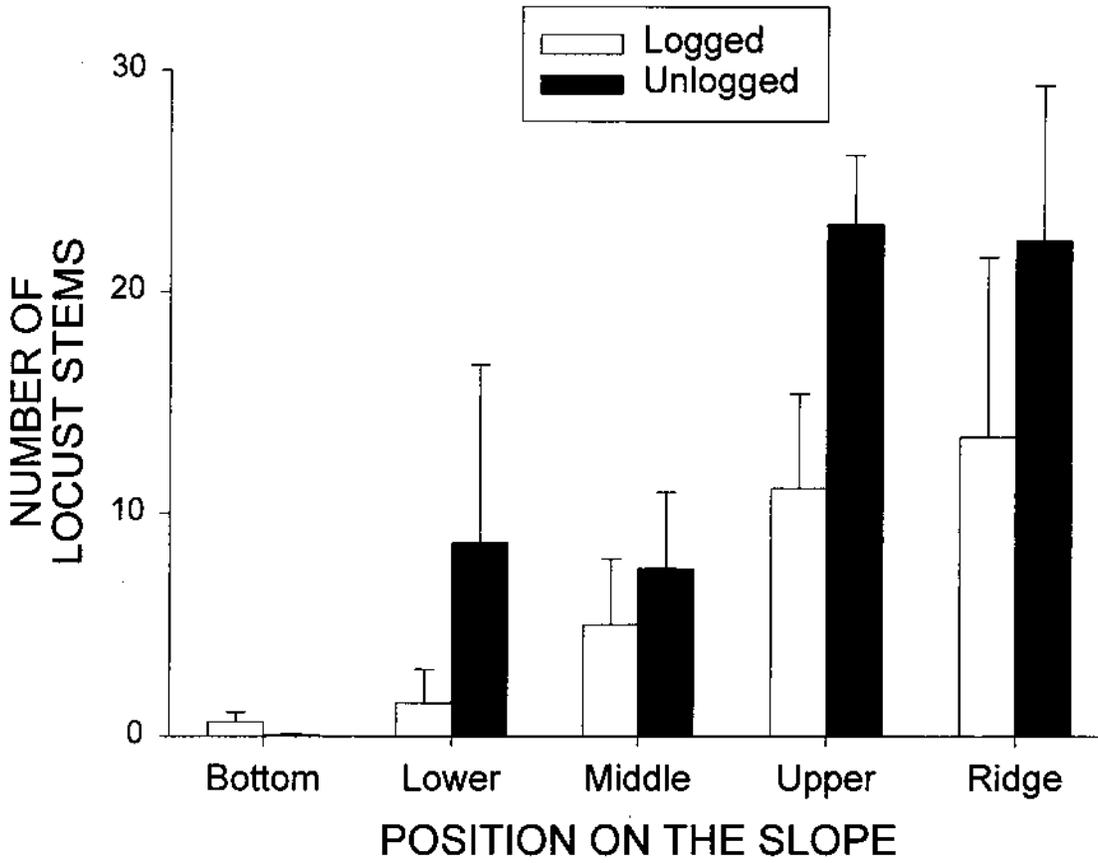


Fig. 5c



5d.  
Fig. 11.100

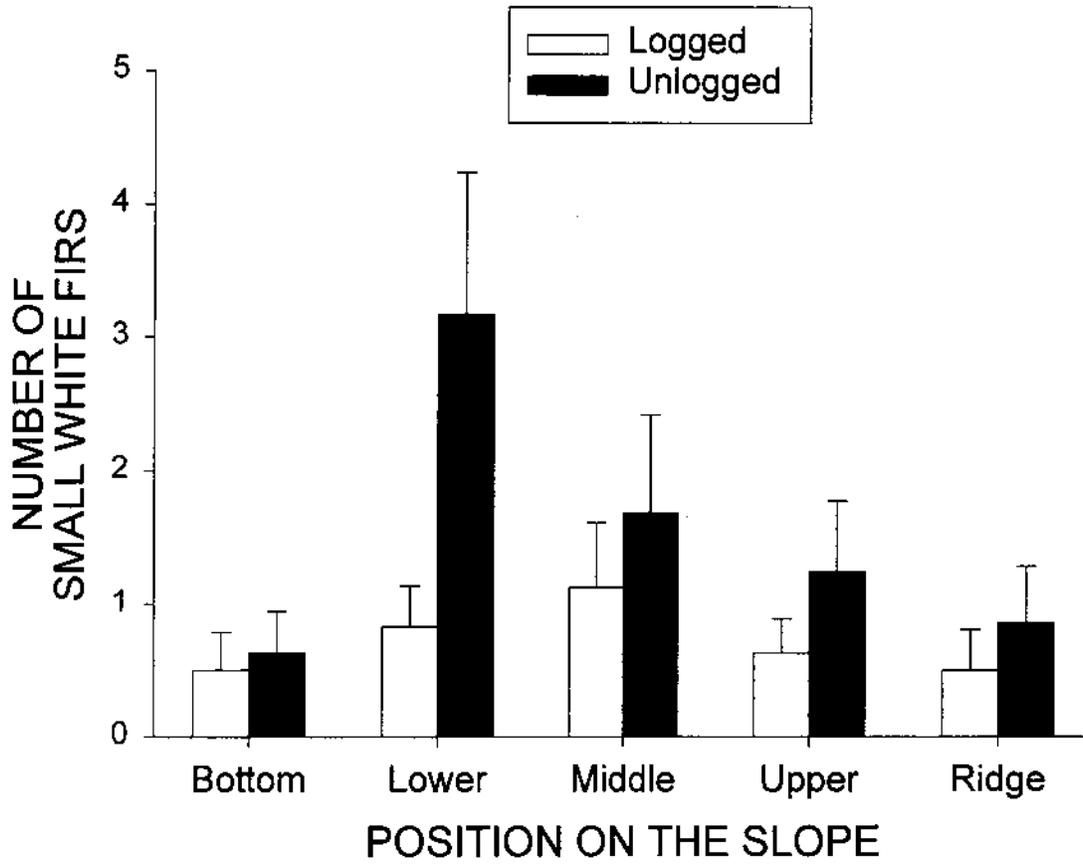


Fig. 5e

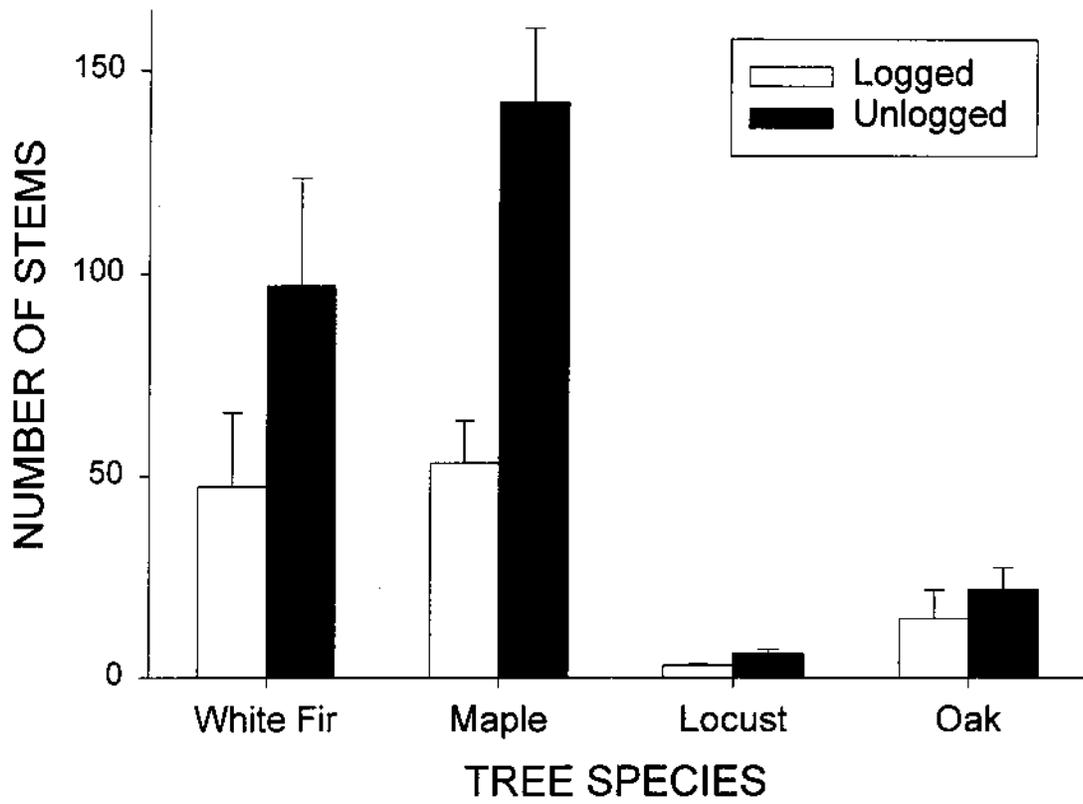


Fig 6  
96

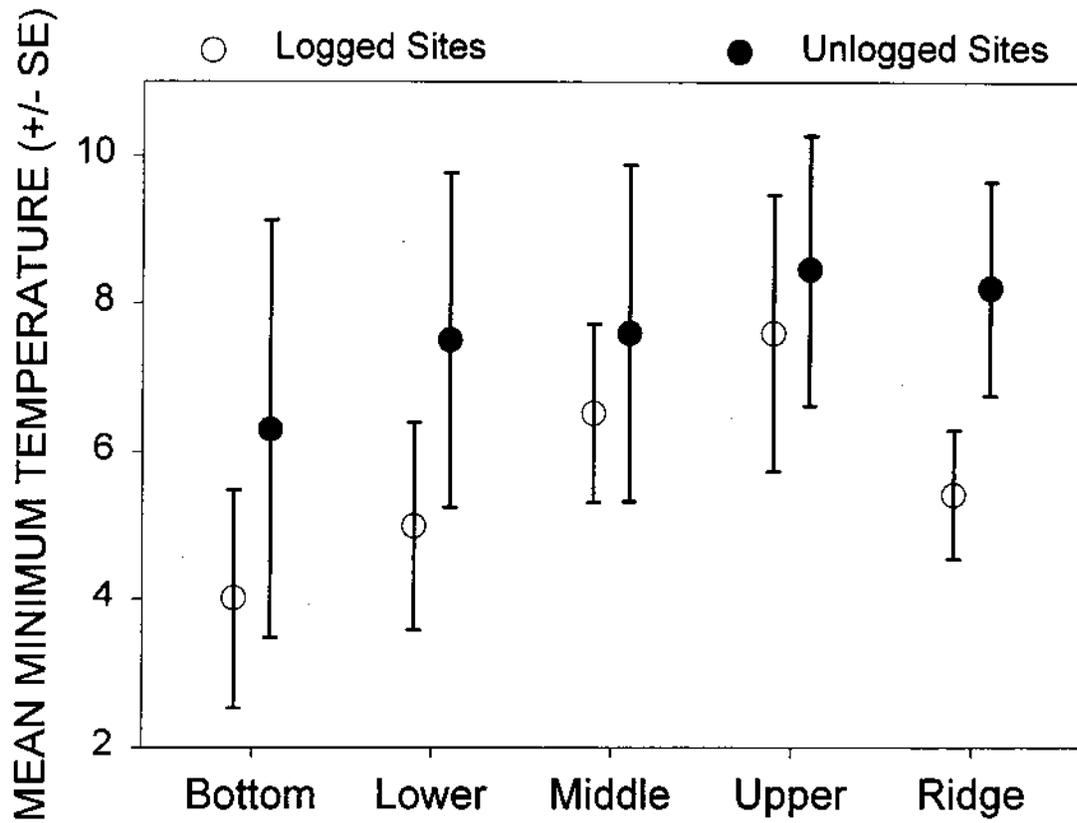


Fig. 7  
1978

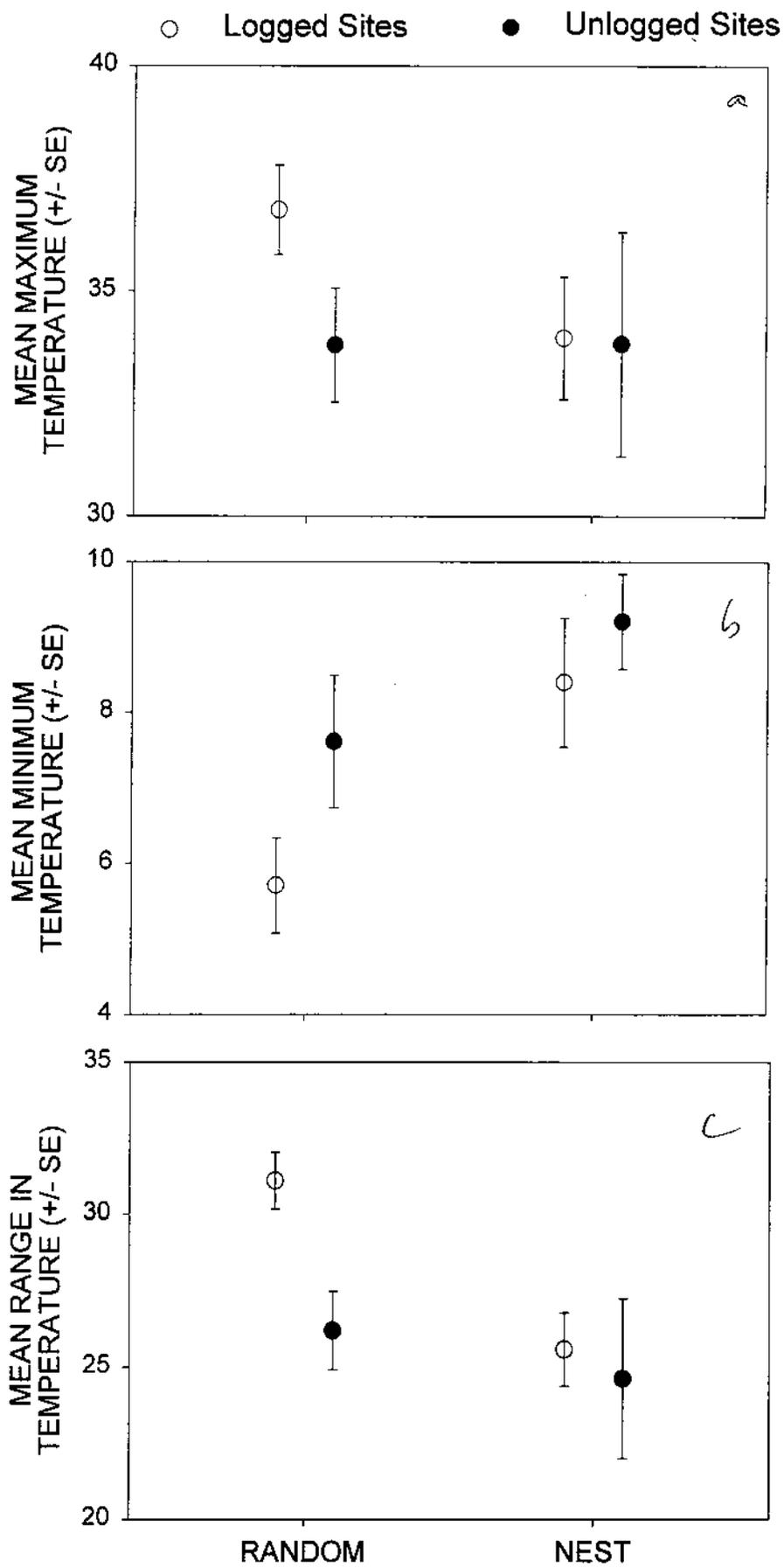


Fig. 8.

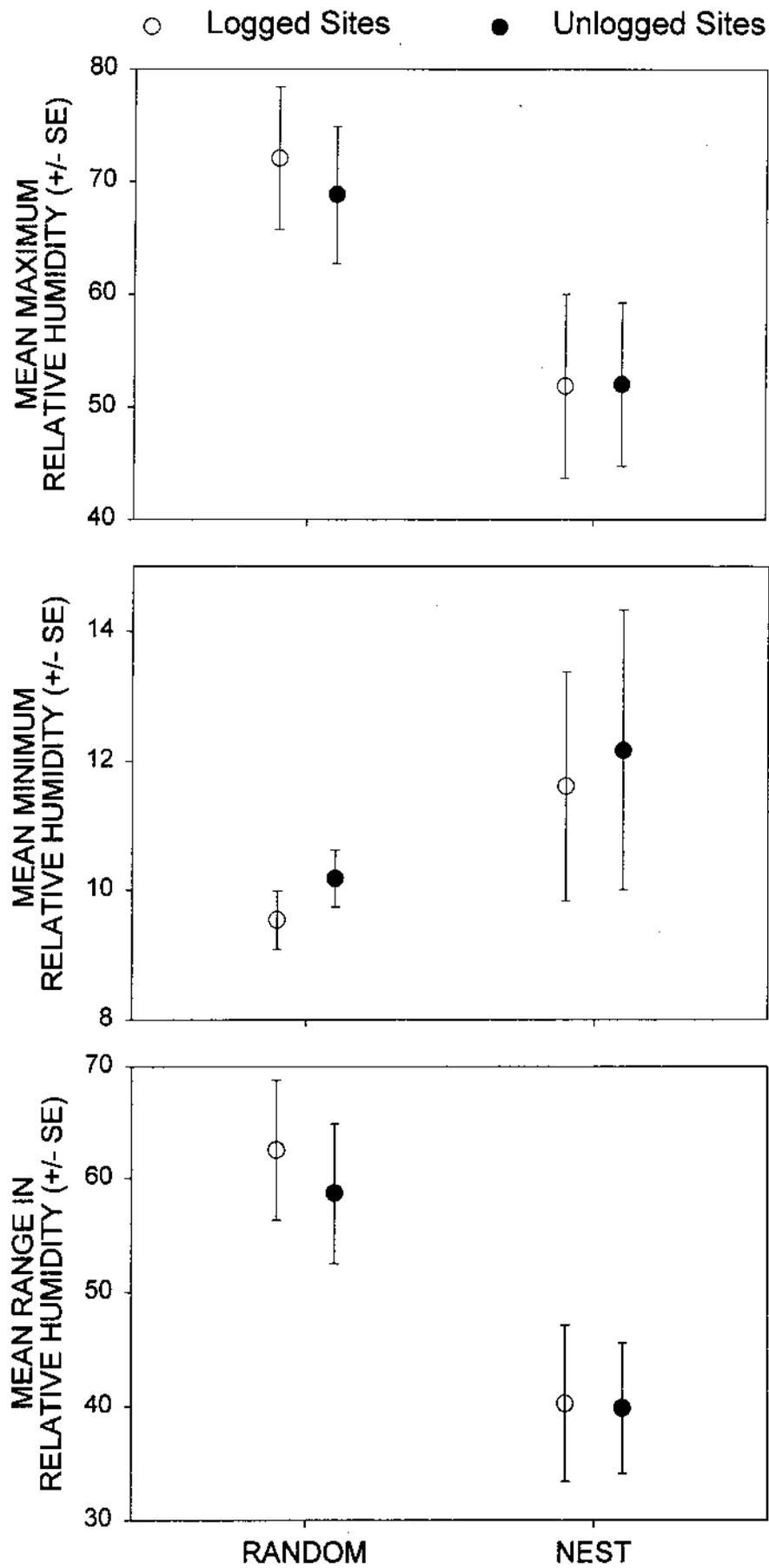


Fig. 9.