Small Mammal Demography and Habitat Association in 4 Forest Cover Types on Quantico Marine Corps Base, VA

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SMALL MAMMAL DEMOGRAPHY AND HABITAT ASSOCIATIONS IN 4 FOREST COVER TYPES ON QUANTICO MARINE CORPS BASE, VA

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(ABSTRACT)

I examined small mammal demography and habitat associations in 4 forest cover types on Quantico Marine Corps Base, VA. Study sites included clearcut, shelterwood, mature-riparian, and mature-upland habitats. My primary objective was to determine whether the abundance, species composition and demographic characteristics (density, survival, reproductive effort) of small mammals varied with respect to forest cover type. Secondarily, I was interested in identifying patterns of small mammal habitat selection and the factors that influence those patterns at micro- and macroscales.

Small mammals were captured from May 1997-January 1999 on 10 sites (2 clearcut, 4 shelterwood, 2 riparian, and 2 mature) using a combination of Sherman live-traps and pitfall traps. Small mammal abundance and demographic characteristics were examined across forest cover types using a combination of statistical analyses, including Chi-square tests, Kruskal-Wallis tests and repeated measures ANOVA. I surveyed microhabitat features at individual trap stations (n=1000) using variable sized plots and the point quarter method and used these data to determine macrohabitat characteristics for sites (n=10). I examined species-habitat relationships at micro- and macro-spatial scales using Kruskal-Wallis tests, Wilcoxon Rank Sum tests, simple linear regression, stepwise multiple regression and stepwise logistic regression.

Fourteen species of small mammals were captured over 7 trapping occasions. Five species including white-footed mice (*Peromyscus leucopus*), northern short-tailed shrews (*Blarina brevicauda*), eastern chipmunks (*Tamias striatus*), meadow voles (*Microtus pennsylvanicus*), and woodland voles (*Microtus pinetorum*), accounted for approximately 95% of the total number of individuals captured. Overall relative abundance and species composition of small mammals differed significantly across forest cover types. Catch per unit effort was greatest in shelterwoods followed by riparian, clearcut and mature forest cover types. I found significant differences in the abundances of white-footed mice and eastern chipmunks across forest cover types but not in those of northern short-tailed shrews, meadow voles or woodland voles. Shelterwood stands provided the highest quality habitat for white-footed mice and eastern chipmunks while clearcut stands provided high quality habitat for northern short-tailed shrews. Assessments of habitat quality for other species were based on weak evidence or inconclusive.

Microhabitat preferences for the 5 small mammal species with > 100 captures were generally consistent with those previously reported in the literature. White-footed mice, eastern chipmunks and northern short-tailed shrews were associated with woody debris and brushy microsites, while meadow voles were associated with grassy vegetation and woodland voles with the presence of soft mast and woody stem densities. For each of these species, microhabitat was able to predict presence at individual trapping stations at a level better than expected by chance. For white-footed mice and woodland voles, however, habitat selection was found to be dependent upon macrohabitat, suggesting that habitat selection for these species is dynamic.

Macrohabitat features were related to the abundance of several small mammal species. In general, the habitat characteristics important to individual species at microscales tended to be important at macroscales as well.

The results of this study suggest that current even-aged forest management practices on Quantico Marine Corps Base are compatible with the maintenance of native populations of small mammals. Disturbances created by harvesting, at least temporarily, resulted in favorable microhabitat conditions for a variety of small mammal species. Species such as southern flying squirrels, however, were sensitive to disturbance, although it is likely that successional changes allow rapid recolonization of disturbed sites.

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INTRODUCTION

Patterns of habitat selection reflect the ecological constraints imposed on an organism by a complex array of interacting biotic and abiotic factors. These factors, operating through natural selection, constrain an organism's use of space to some multidimensional suite of environmental features, or niche hypervolume (Hutchinson 1957). In dispersive organisms, habitat use is in part determined by innate and/or learned response to stimuli that direct individuals to select certain habitats over others (Wecker 1964, Fretwell 1972). Individual animals inhabiting heterogeneous environments will seek to occupy the most suitable habitats, i.e., those providing the greatest fitness rewards (Fretwell and Lucas 1970). As a result, habitat selection reflects the biological response of organisms to the spatial composition of environmental resources.

Differential microhabitat selection among sympatric species of temperate North American small mammals has been well documented (M'Closkey and Fieldwick 1975, Dueser and Shugart 1978, Morris 1979, Kitchings and Levy 1981, Seagle 1985, Yahner 1986, Drickamer 1990). The distribution of species within these rodent communities is largely thought to be a consequence of each species' ecological requirements and/or partitioning of resources as a means of reducing interspecific competition (Crowell and Pimm 1976, Porter and Dueser 1982, Gore 1988). On a population level, intraspecific competition, risk of predation, infection by parasites, weather-related phenomena, and the dispersion of potential mates are known to affect habitat use patterns for particular species (Getz 1961, Metzgar 1971, Kotler 1984, Xia and Miller 1989, Longland and Price 1991, Cranford and Tomblin 1993, Longland 1994).

Evaluations of niche partitioning and patterns of habitat selection among rodent communities often have yielded inconsistent results (Thompson 1982, 1987, Gore 1988, Jorgensen et al. 1995). In addition, the few researchers who have tested the accuracy of their

models of microhabitat use have found them to perform poorly when applied at independent locations or times (Parren and Capen 1985, Gore 1988). Parren and Capen (1985) were unable to accurately predict capture stations for deer mice based on discriminant functions of microhabitat use developed in comparble habitats for a previous year. Gore (1998), using logistic regression equations based on microhabitat, was only able to classify capture stations for 3 of 8 small mammal species better than expected by chance and for all species the regression models failed to accurately predict presence at capture stations at an independent grid.

Inconsistencies in microhabitat selection have been explained in several ways, including 1) the failure of trapping methods and the habitat variables measured to accurately reflect microhabitat selection (Thompson 1987, Gore 1988, Taylor 1988, Block et al. 1998), 2) site-specific historical influences acting upon the individuals occupying an area (Brown 1973), and 3) the inability of microhabitat-based models to account for relationships between species and habitat at multiple spatial scales (Morris 1984, 1987, Bowers 1995, Jorgensen and Demarais 1999).

Thompson's studies of desert rodents found that determination of microhabitat selection based on trapping yielded different results from those based on seed use or direct observation (Thompson 1982, 1987). Similarly, Taylor et al. (1988) and Block et al. (1998) found little agreement between models of microhabitat selection based on live-, pitfall- or snap-trapping. The authors explained these discrepancies as likely to be a function of the trap methodology and/or differential trap response by species. Inconsistent microhabitat selection may also arise when unique historical influences act upon sites. This phenomenon has been documented for desert rodents (Brown 1973, Bowers 1988) where slight differences in environmental features

such as temperature, rainfall, and sand particle size have profound impacts on rodent community organization and structure.

A third alternative explanation is that microhabitat selection is driven by some interaction between a species and macrohabitat. Morris (1984) compared microhabitat use of white-footed mice and meadow voles across 6 macrohabitats in Ontario and found that habitat selection was dependent upon macrohabitat. Structural variables that discriminated microhabitat selection were inconsistent across macrohabitats and even changed in the direction of separation. He concluded that patterns of microhabitat selection exhibited by species are flexible and influenced by the degree of environmental variability encountered in a given macrohabitat. Following the recommendations of Morris (1987), Jorgensen and Demarais (1999) compared the ability of microhabitat and macrohabitat to predict use of individual trap stations among desert rodent communities using discriminant function analysis and random null models. For 9 of the 13 species examined, classification rates for species presence based on dummy variables coding for macrohabitat structure outperformed those for microhabitat.

While these findings suggest that studies of habitat selection should incorporate multiple spatial scales, they have also resulted in a debate over whether microhabitat or macrohabitat most influences the density of small mammals (Morris 1987, Jorgensen and Demarais 1999). Adler (1988) suggested that the affinity of small mammals for particular microhabitats results in density-dependent relationships when averaged over larger sampling areas (grids, plots), thus, the availability of suitable microhabitats drives density. Morris (1987) suggested that because small mammal density is dependent upon overall resource abundance, social variables and selective pressures, which are unlikely related to microhabitat structure, density is driven by macrohabitat. Additionally, Jorgensen and Demarais (1999) argue that suitable microhabitat is

likely to be found even within macrohabitats unoccupied by a species, therefore, density (at least among desert rodents) is not determined by microhabitat availability but by macrohabitat.

There is less philosophical disagreement over the role of macrohabitat in influencing demographic parameters other than density. Adler (1988) suggested that macrohabitat primarily affects population stability and the demographic structure of small mammal communities. Several studies have demonstrated that the demographic characteristics of small mammal populations (usually *Peromyscus*) may vary with respect to habitat type (Sullivan 1979, Van Horne 1982, Martell 1983, Adler and Wilson 1987, Linzey 1989, Morris 1989, 1991, McMurry et al. 1996). Linzey (1989) demonstrated that disturbed habitats occupied by *P. leucopus* acted as dispersal sinks for behaviorally subordinate individuals. Van Horne (1982), Martell (1983), and Adler and Wilson (1987) found similar results for *Peromyscus* in other geographic areas. These studies suggest that the demographic characteristics of small mammal populations may be strongly influenced by environmental conditions (Levin 1976, Adler and Wilson 1987). Changes in environmental conditions would be predicted to have profound impacts on rodent communities.

On a landscape-level scale, silvicultural practices and other forms of disturbance create a mosaic of macrohabitats with varying capabilities to support small mammal populations. Within each cover type, disturbance creates new microhabitats of varying quality. Species response varies depending upon whether the physical or biological changes in the environment move away or toward some set of optimal conditions (Kirkland 1990). If the scale of disturbance is sufficiently large, the abundance and composition of species in small mammal communities will change in response to the altered habitat conditions.

Even-aged management of forests is common in the southeastern United States. Regeneration techniques such as clearcut and shelterwood cutting dramatically alter the biotic and abiotic characteristics of habitats. Numerous studies have examined the impacts of silvicultural practices, principally clearcutting, on small mammal communities (Lovejoy 1975, Kirkland 1977, Martell and Radvanyi 1977, Sullivan 1979, Swan et al. 1984, Monthey and Soutiere 1985, Healy and Brooks 1988, Root et al. 1990, see Kirkland 1990 for review). These studies report, in general, increased relative abundances of small mammals following harvesting (Lovejoy 1975, Kirkland 1977, Monthey and Soutiere 1985, Root et al. 1990, Kirkland 1990) or changes in species composition and little to no change in abundance (Martell and Radvanyi 1977, Sullivan 1979).

The response of small mammals to clearcutting often varies with respect to habitat type. In a review of 21 published studies, Kirkland (1990) found that in coniferous and deciduous habitats clearcutting is generally followed by increases in the abundance of microtine rodents while no apparent patterns exist for the response of soricids, sciurids, zapodids and *Peromyscus* spp. However, when only studies conducted in deciduous forests were examined, clearcutting generally resulted in decreased abundances in *Peromyscus* spp. and increased abundances in microtines and zapodids. Other studies indicate a more inconsistent response to harvesting in *Peromyscus*. Hahn and Michael (1980) and Root et al. (1990) found little difference between numbers captured in clearcuts and mature stands and Kirkland et al. (1985) and Buckner and Shure (1985) demonstrated a positive response to harvesting. Seven of 10 studies that included soricids indicated no (2) or a positive response (5) to clearcutting. The response of sciurids to clearcutting remained variable. Sciurids such as eastern chipmunks are known to exploit the

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edges of clearcuts while others including *Glaucomys* spp. are excluded from clearcuts due to a loss of nest sites and suitable shelter (Kirkland et al. 1985).

Quantitative changes in small mammal abundances and species composition have not been well documented with respect to other forms of even-aged timber harvesting. As a result managers are currently forced to evaluate the potential impacts of harvesting regimens on small mammal communities based on relatively little information. Several studies have addressed this knowledge gap. Swan et al. (1984) found no significant difference in the overall relative abundance of small mammals within clearcut, strip-cut, shelterwood cut and uncut stands in northern hardwood forests in Nova Scotia. However, they did detect changes in the abundances of certain species with respect to forest treatment class. Meadow voles were more abundant in clearcuts and *Peromyscus* spp. were captured more frequently within shelterwood sites. Tomblin (1994) examined the ecological niche response of small mammals to gypsy moth disturbance in Virginia (gypsy moth disturbance, by opening the canopy, may create habitat structurally similar to shelterwoods) and found several species to have greater abundances at disturbed sites relative to an undisturbed reference site. In addition, Tomblin found that disturbance (at least temporarily) created higher quality habitat, through enhanced understory structure, for several species.

Although definitions of even-aged silvicultural treatments such as clearcutting are fairly standard, implementation of these treatments often varies considerably depending upon management directives. For example, clearcutting may include the complete removal of the tree canopy or the retention of several snags/and or large diameter trees for wildlife purposes, aesthetics, etc. Similarly, shelterwood harvests may result in removal of between 50-90% of the tree canopy depending upon a variety of considerations. In addition, in intensively managed

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silvicultural systems, stands may or may not be subject to extensive site preparation, fertilizer applications, and other interventions. These factors and local conditions (slope, aspect, elevation, geographic location, stand history, etc.) will affect the micro- and macrohabitat conditions encountered by small mammals. Because of the variation in habitat conditions created by even-aged silvicultural practices, identifying the relevant habitat features to which species respond, either at micro- and macro-scales, would improve management techniques for small mammals in forested habitats. In addition, most studies evaluating the impacts of even-aged timber harvesting on small mammal communities assess the impacts in terms of changes in abundance or density. However, measures of abundance may not reflect habitat quality (Van Horne 1983). Van Horne (1982) and others (Krohne and Baccus 1985, Adler and Wilson 1987) identified populations with high densities yet poor demographic performance (low survivorship, high juvenile: adult ratios, low reproductive rates). Therefore, assessments of timber harvesting related impacts on small mammals should include measures of reproductive output and survival (Van Horne 1983, Adler 1988).

OBJECTIVES

The primary goal of this study was to determine whether the abundance of small mammals differed across 4 forest cover types. Selected forest cover types included stands that were previously clearcut and shelterwood harvested, as well as riparian and mature-upland stands. A secondary goal was to identify patterns of small mammal habitat selection and factors affecting those patterns at micro- and macroscales and evaluate the role of macrohabitat in influencing microhabitat selection. A third goal was to evaluate habitat quality among the forest

cover types by examining the demographic performance of populations and a fourth goal was to develop microhabitat-based models to predict species presence.

Specifically, my objectives and research hypotheses were:

Objective 1: To evaluate small mammal abundance in relation to forest cover type

HO_1: There is no difference in overall small mammal abundance across forest cover types

HO_2: There is no difference in the abundances of individual species across forest cover types

Objective 2: To identify patterns of small mammal habitat selection and factors which influence those patterns at micro- and macroscales

HO_3: There is no difference in microhabitat features between no-use and use trapping stations

HO_4: There are no observed effects on microhabitat selection due to population density or season (summer/winter)

HO_5: There are no relationships between abundance and macrohabitat

HO_6: Patterns of microhabitat selection are consistent across macrohabitat

Objective 3: Determine the relative suitabilities of different forest cover types to small mammal species

HO_7: There is no difference in demographic parameters (density, survival, reproduction, age structure) across forest cover types

Objective 4: Develop models to predict species presence/absence at microsites

HO_8: There is no difference in no-use, use sites, therefore, no model possible

STUDY AREA

I conducted fieldwork on Quantico Marine Corps Base (QMCB), which is located along the west bank of the Potomac River approximately 56 km south of Washington D.C. QMCB is

situated on the eastern edge of the Piedmont plateau physiographic region in Stafford, Prince William, and Fauquier counties, Virginia.   The base comprises an area of approximately 24,300 ha; of which 21,600 ha are forested (Natural Resources Conservation Report 1993). Forested lands consist of hardwood (60%), mixed (19%), and pine (21%) stands dominated by yellow poplar (*Liriodendron tulipifera*), white oak (*Quercus alba*), northern red oak (*Q. rubra*), red maple (*Acer rubrum*), shortleaf pine (*Pinus echinata*) and virginia pine (*P. virginiana*). Landforms generally consist of rolling hills and low ridges with average elevations of 120 meters while the majority of soils on QMCB are classified as acid clay loams and are characterized by low organic content and poor fertility (Banker 1994).

Forested stands on QMCB are extensively managed through silvicultural practices to maintain conditions that meet military training requirements. These management practices, frequent fires, and past agricultural land uses have resulted in a mosaic of cover types on the base (Penhollow 1996). Forest stands are classified according to SAF cover type codes based on the dominant vegetative cover and grouped into forest compartments for management (Appendix A).

STUDY SITE SELECTION

I chose 2 clearcut, 2 riparian and 2 mature sites for study. I sampled 4 shelterwood sites since few studies have examined small mammal assemblages within this forest cover type and because shelterwood cuts are an important component of the gypsy moth control program on QMCB. Riparian study sites were located along first-order streams and paired with study sites in adjacent mature stands. Each riparian-mature pair was separated by > 50 meters when possible to minimize the chances of animals moving between study sites.

I selected study sites based on 3 criteria: 1) time and resource constraints, 2) assurance of access, and 3) similarity of stand characteristics. I limited potential study sites to forest cover types dominated by white, black or northern red oak and/or oak-yellow poplar (based on pre-harvest data). These cover types represent the majority (53%) of forested lands on QMCB (Appendix A). Site selection was additionally restricted to forest compartments where access would be less likely to conflict with military training activities. A GIS database was used to screen potential study sites for similarity of stand characteristics. Study sites were selected based on pre-harvest condition, harvest history and current stand features (Table 1) and were located in 2 areas of the base (Figure 1).

Clearcut sites consisted of mature-oak forests (SAF cover type 52, Table 1) that were harvested 4 years prior to the start of fieldwork in 1997. Canopy cover removal was 100% and both sites were replanted with loblolly pine using 2.74m x 2.74m spacing. Site preparation prior to planting consisted of broadcast burning. Once planted, sites were allowed to regenerate without fertilization or other intervention. Woody vegetation on both clearcuts consisted mainly of a mix of loblolly pine, regenerating hardwoods and blackberry while the understory vegetation consisted of a mix of broomsedge (*Andropogon* spp.), honeysuckle (*Lonicera*), and other grasses.

Shelterwood sites were harvested between 2-4 years prior to the start of fieldwork. Residual basal areas on these sites ranged from $9.2m^2$/ha to $16.1m^2$/ha and averaged 59.7% (range 86.5%-34.5%) of the initial stand basal areas (Table 1). Prior to harvest these sites were dominated by mature oak or oak-poplar forest (SAF cover types 52 and 59). Understory characteristics varied slightly among shelterwood sites. SW1, in particular, contained a greater density of woody stems (Table 24) than other shelterwoods while SW3 and SW4 contained

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Table 1. Stand characteristics of small mammal trapping grid locations on Quantico Marine Corps Base, VA. Trapping was conducted from May 1997-January 1999.

Treatment	Clearcut[a]		Shelterwood				Riparian		Mature	
Site	CC1	CC2	SW1	SW2	SW3	SW4	RI1	RI2	MA1	MA2
SAF Cover Type	81[b]	81	52[c]	59[d]	52	52	59	59	52	59
Stand Area (ha)	12.2	11.1	19.6	16.2	101.4	26.1	28.1	15.5	53.9	20
Stand Age in 1997	4	4	3	4	2	2	77	82	95	94
Year Harvested	1993	1993	1994	1993	1995	1995	1920	1915	1902	1903
Pre-harvest Age	87	80	105	96	84	84	73[e]	78[e]	91[e]	90[e]
Pre-harvest Basal Area[f] (m^2/ha)	24.77	24.54	23.63	18.58	19.03	26.61	-	-	-	-
Basal Area (m^2/ha)	1.53	1.53	14.16	16.07	11.02	9.18	22.58	27.09	21.81	37.65
Tree Density (trees/ha)	121	114	88	254	154	135	404	315	527	528
% Tree Canopy Cover	18	20	60	73	62	57	97	94	95	99

[a]Prior to harvest these stands were classified as SAF cover type 52.
[b]Loblolly Pine
[c]White-Black-Northern Red Oak
[d]Yellow Poplar-White-Northern Red Oak
[e]Stand age in 1993 for unharvested sites
[f]Based on GIS database provided by the Natural Resources and Environmental Affairs Branch of Quantico Marine Corps Base
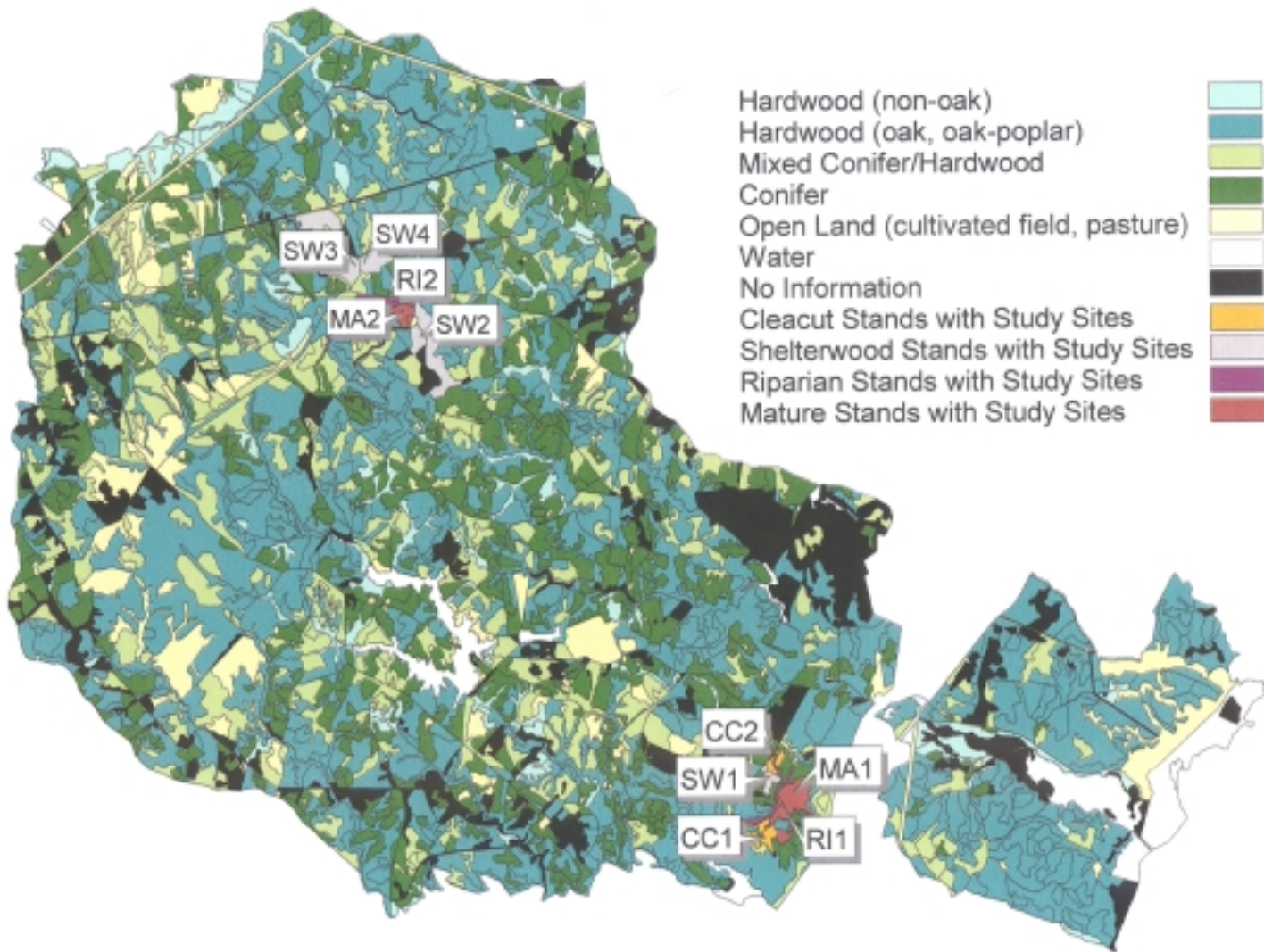
Figure 1. Location of small mammal trapping sites on Quantico Marine Corps Base.

proportionally greater densities of mountain laurel (*Kalmia latifolia*) and blueberry (*Vaccinium* spp.) stems.

Riparian sites were located in 77-82 year old mature forests dominated by a mix of red maple, yellow poplar and oak species (Table 1, 24). Shrub species common on both sites included dogwood (*Cornus florida*), sweetgum (*Liquidambar styraciflua*) and ironwood (*Carpinus virginiana*) while the understory vegetation consisted chiefly of ferns (*Polystichum,*) and grasses. In comparison to RI2, RI1 had a narrower riparian corridor (i.e., a more rapid transition to mature-upland forest) and a smaller area of associated bottomland-riparian forest.

Mature-upland sites were located in 90-91 year old forests dominated by red maple and oak species (Table 1, 24). Both sites contained a fairly open understory with high shrub densities. Dominant shrub species included dogwood and ironwood while understory vegetation consisted chiefly of running pine (*Lycopodium* sp.).

TRAPPING METHODS

I chose grid size based on time constraints and the number of traps available. Mature, clearcut and shelterwood study sites were laid out as 10x10 arrays while riparian study sites consisted of a series of transects placed parallel to stream banks. Transects on riparian sites were of varying lengths and widths, however, as with the other study sites, each riparian site contained a total of 100 trapping stations. Trapping stations on all grids were separated by 15-meter intervals. I attempted to keep trapping stations > 50 meters from edges between forest cover types or paved roads, however, several sites (CC1, CC2, SW2, RI1 and RI2) were located within 50 meters of forest cover type edeges (in all cases these edges consisted of site: mature forest edge).

Small mammals were captured using Sherman live traps (7.6 x 8.9 x 22.9cm) baited with sunflower seeds. During winter trapping, cotton was provided for nesting material and a tablespoon of lard wrapped in wax paper added to the bait. I placed half a sheet of paper towel folded into thirds on the floor of each trap to reduce trap mortality of meadow voles during winter. To improve capture success, 2 traps were assigned randomly to half of the trapping stations during each trapping occasion. In habitats with high small mammal density this could potentially reduce competition for traps and also improve capture rates of nocturnal animals when many diurnal or crepuscular animals were on site. I randomized the allotment of 1 or 2 traps at a station by tossing a coin at the first station on a grid to determine whether it had 1 or 2 traps. I then alternated placing 1 or 2 traps at subsequent stations.

I placed traps within half a meter of the station centers and positioned them to avoid direct sunlight. During each sampling period grids were checked once or twice (for sites where eastern chipmunk mortality occurred in response to heat stress) daily for 3 or 4 consecutive days. Traps were opened for 4 nights in the summer and only 3 during the winter due to time constraints. A maximum of 4 study sites was run concurrently. I collected environmental data from the Natural Resources and Environmental Affairs Branch office weather station.

A pitfall grid was overlaid on each live-trapping grid since capture probabilities of small insectivorous mammals are relatively low in live-traps (Rose et al. 1990, Pagels et al. 1992). I constructed 9 pitfall arrays in an X configuration on 8 grids. Pitfall traps were not installed on 2 sites due to time constraints. Pitfalls installed on RI1 were placed parallel to the stream bank at > 30 meter intervals. Each array consisted of 3, 3-meter sections of landscape fencing (0.4m high) set at 120 degrees from each other and connected in the center by a 3½ gallon bucket set flush with the ground. Researchers have shown that pitfall traps with fences are more effective

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than those without (Bury and Corn 1987, Raphael 1988). The outermost end of each 3-meter section of fencing was equipped with 2, 2-liter bottle pitfall traps. Soda bottles included funnels to reduce the probability of animals climbing out the top (Figure 2).

Captured animals were individually marked with ear tags (size 1005-1 from National Band and Tag, Newport, KY) or toe-clipped, weighed and aged. White-footed mice were aged based on pelage and grouped into 5 categories: juvenile (entirely gray), side-molt (sides showing rufus coloration), back-molt, head-tail molt and adult (entirely rufus). This aging criteria is similar to that established by Linzey and Linzey (1967) for golden mice (*Ochrotomys nuttalli*). Eastern chipmunks were aged according to weight (< 80 g juvenile), as were woodland voles (< 20 g juvenile), meadow (< 30 g juvenile) and northern short-tailed shrews (< 12 g juvenile). I assessed reproductive condition of males by position of the testes (scrotal or nonscrotal) and testes size (mm), and for females by condition of the nipples (small/medium – not easily seen through fur, large/lactating – easily seen through fur, presence of milk), condition of the vagina (perforate or imperforate) and obvious signs of pregnancy (distended abdomen and increased weight). In addition, body length and tail length were measured before release. Torpid animals were removed from the field and released within 24 hours following recovery at the point of capture.

All animals were handled according to Virginia guidelines and regulations as outlined in the Scientific Collection Permit (§ 29.1-412, § 29.1-417, & § 29.1-418 of the code of Virginia). Trapping was conducted from May – August 1997, January-March 1998, May-August 1998 and from December 1998-January 1999.

A.

B.
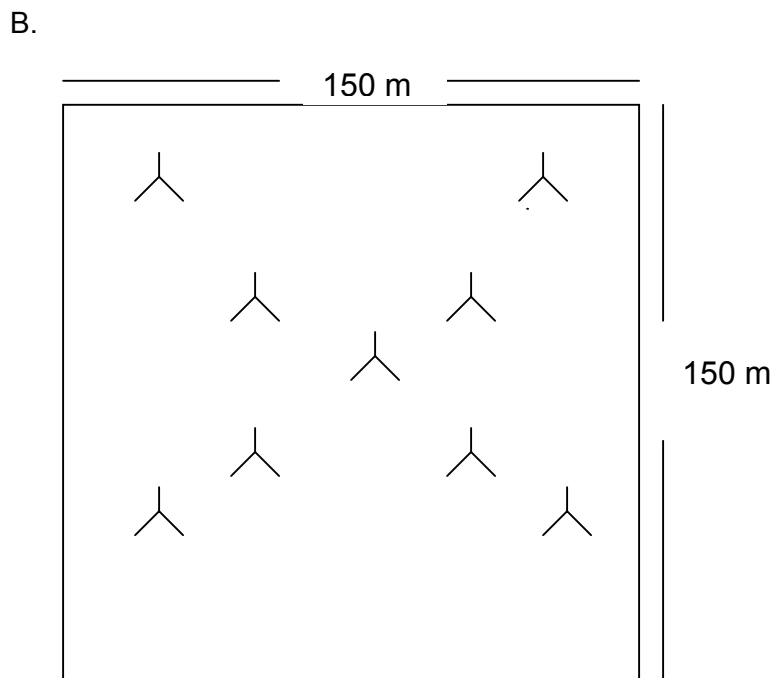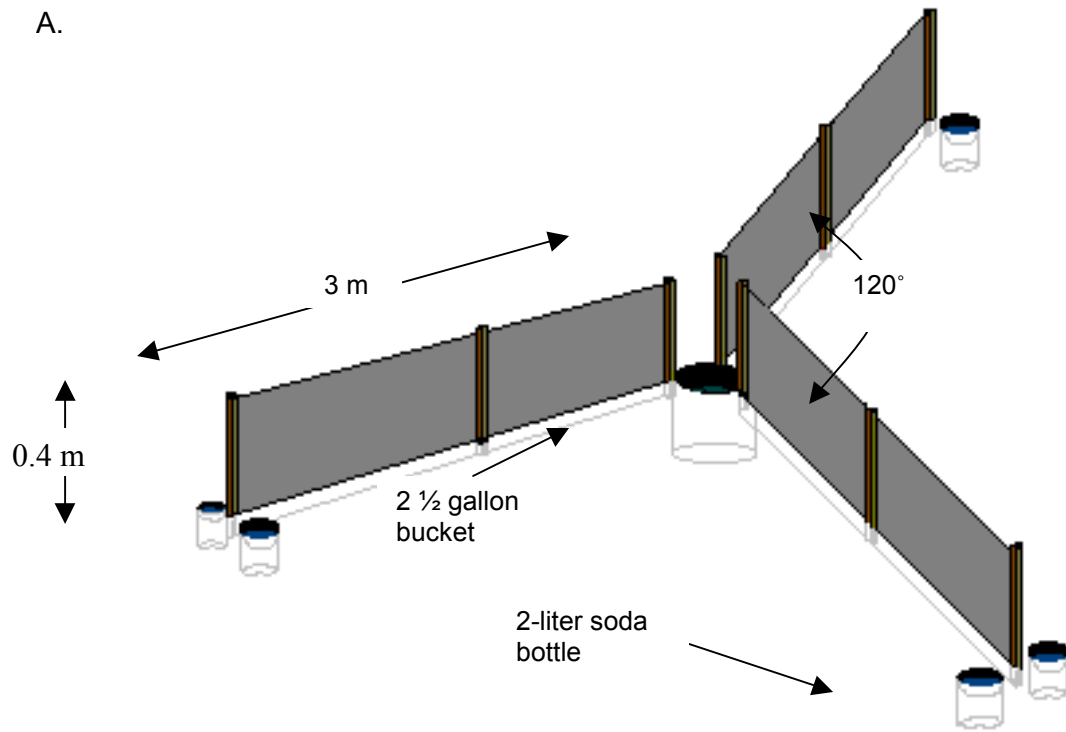
Figure 2. A.) Schematic of a pitfall station. B.) Pitfall locations for mature, shelterwood and clearcut sites. Pitfall stations in riparian stand were located between stations along transects.

HABITAT DATA COLLECTION

A 1.4 x 0.7 meter rectangular plot was centered on each trapping station for microhabitat measurement. Within this plot I estimated the percentages of forbs, ferns, grasses, mosses, sedges, litter, rock, woody debris, and bare ground. Estimates were made of the number of herbaceous stems at ground level and at 0.5-meter height intervals. The dominant herbaceous form (grass, forb, fern or *Lycopodium*) and number of herbaceous species also were determined. I measured litter depth at 4 random locations within the $1m^2$ plot and used the average of these values for subsequent analyses.

A modified point quarter plot (Cherry Keller, USFWS, personal comm.) with a 7.5 meter maximum radius was used to determine the distances to the nearest trees (> 7.5 cm diameter), tree species present, DBH of the nearest trees, distances to the nearest logs (> 2 meters in length and > 7.5 cm diameter), nearest stumps and stump diameters at each grid point. I obtained density estimates for mast trees (oak/hickory) by summing the total area searched in each quarter for all point quarter plots, dividing this number by the total number of mast trees sampled per site and then scaling to trees/ha (multiplying by 10,000). An overall density of trees was obtained in a similar manner.

I used a variable sized circular plot with either a 1, 2 or 3 meter radius to determine: 1) number of blueberry (*Vaccinium* spp), blackberry (*Rubus* spp), mountain laurel (*Kalmia latifolia*) and other woody stems (< 7.5cm DBH) at ground level, 0.5 meters, and 1 meter height intervals; 2) number of woody species; and 3) number of lianas, predominantly honeysuckle and greenbriar (*Similax*). I chose plot diameters based on vegetative density: if the density of woody stems was < $10/m^2$ I used a 3m plot, for woody stem densities between $10-30/m^2$ a 2m plot was used and a

1m radius plot for woody stem densities $> 30/m^2$. For the analyses, all estimates obtained from 1 or 2-meter radius plots were scaled to 3- meter radius plots.

A $10x10m^2$ plot was used to determine the number of shrubs at each station and the dominant shrub species. Tree basal areas of study sites were based on readings from a prism (10 baf) taken at 5 random locations (Figure 3).

Microhabitat measurements were conducted in summer 1997, winter 1998 and summer 98. No microhabitat data were collected for winter 1999 since it was assumed that habitat structure and composition would be similar to that of 1998.

ANALYTICAL METHODS

RELATIVE ABUNDANCE / DENSITY

Relative abundance was defined as the number of new individuals/100 trapnights (TN). I examined differences in relative abundances by forest cover type using repeated measures ANOVA. Density estimates for white-footed mice and chipmunks were obtained through program CAPTURE (White et al. 1982) for each trapping occasion to avoid violating closed Following recommendations of White et al. (1982): 1) if number of deaths < 5% of captured animals, I removed those animals from the analysis, added that number to the density estimate and then multiplied the density estimate by (1+proportion dead). On the SW1 site, > 5% of chipmunks died in traps over several trapping occasions. When this occurred these animals were removed completely from the analysis. Animals that escaped before tagging were excluded.

I let the CAPTURE program select the best model (see White et al. 1982 for explanation of this process). This program includes models that account for 3 types of bias 1) null model of
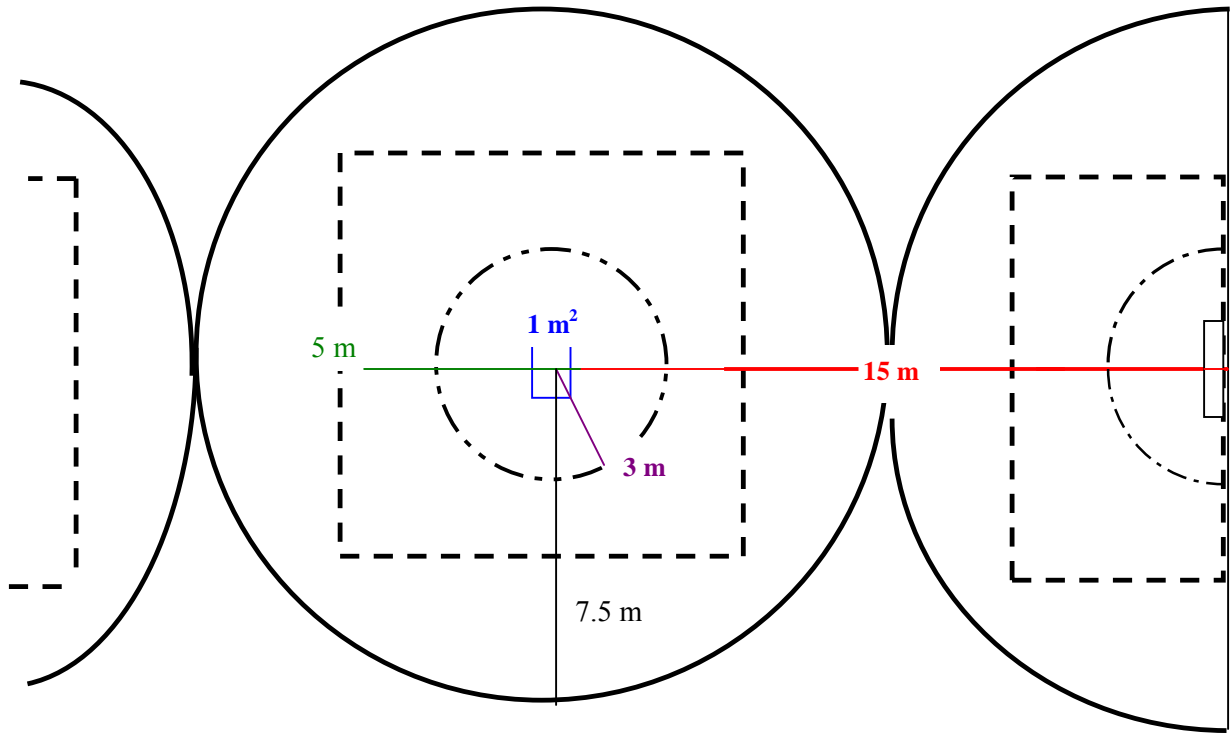
Figure 3. Microhabitat sampling scheme used on Quantico Marine Corps Base, May 1997-January 1999. Habitat plots were centered on each trapping station.

Table 2. Microhabitat variables measured within 1m^2 plots, 3m radius plots, 10m diameter and 7.5 m point quater plots.

Plot Dimensions	Area Sampled	Microhabitat variables measured
1.4 m x 0.7 m	1 m^2	% Bare ground; % Ground cover; % of ground cover composed of Litter, Grass, Moss, Woody debris, Rock; Mean litter depth; Dominant herbaceous cover; Number of herbecaeous stems at ground level and 0.5 meters; Number of herbaceous species; % Canopy cover
3m radius	28.3 m^2	Number of lianas; Number of woody species; Number of blackberry, blueberry, mountain laurel or other stems at ground level, 0.5 meters, and 1 meter height increments
10 m x 10 m	100 m^2	Number of shrubs; Dominant shrub species
7.5 m constrained point quarter plot	≤ 176 m^2	For each quarter: Distance to nearest tree; Tree species; Tree dbh; Distance to nearest log; Height class of log; Distance to nearest stump; Stump diameter

constant capture probabilities, 2) capture probabilities vary with time or trapping occasions (M_T), 3) capture probabilities vary with behavioral response to capture (M_B), 4) and capture probabilities vary with respect to individual animals (M_H) and 5) any combination of 2, 3 and 4 (M_{BT}, M_{BH}, M_{TH}, M_{TBH}). White et al. (1982) recommended that density estimates be based on sample sizes of > 20. This recommendation was met only in 37% of the analyses of white-footed mice densities and 8% for eastern chipmunks. However, because capture probabilities were relatively high (> 50% for white-footed mice, > 60% for eastern chipmunks), I ran CAPTURE with sample sizes > 10. For sites where sample sizes were less than this, I used minimum number known alive as a surrogate abundance measure.

SURVIVAL

Survival estimates were obtained using program MARK (White and Burnham 1999). I constrained survival comparisons to the trapping period from May-August 1998. Selection of appropriate models was based on Akaike's Information Criterion (AIC) values. I used several subsets of data to determine survival. I first included all individuals (adults and juveniles/subadults). Because juveniles/subadult have lower survival rates than adults and because they are likely to disperse as they approach sexual maturity, I separated these two groups. I also compared survival between sexes separated by age class. When possible I tested for differences in survival by forest cover type. Model fit was examined through goodness of fit tests (GOF) from Program Release, Version 3.0 (Burnham et al. 1987).

I also examined differences in the percentage of resident white-footed mice and eastern chipmunks across forest cover type (residents were defined as those individuals present on a site on ≥ 2 trapping occasions). New individuals captured during the last trapping occasion were

excluded from this analysis because residency could not be determined. Sample sizes were too small for other species to be included in this analysis.   I also examined differences in the minimum length of time individuals were observed on sites across forest cover types (individuals not captured during a particular trapping occasion but subsequently recaptured were assumed to have remained on site while those not subsequently recaptured were assumed to have emigrated or died). Differences in the percentage of residents across forest cover types were evaluated using Chi-square Homogeneity Tests while differences in lengths of residency were examined using Kruskal-Wallis tests. Because of unequal trapping intervals (intervals ranged from 14 days-240 days) I constrained these estimates to include mice only caught from summer 1998-winter 1998-1999.

REPRODUCTION AND PHYSICAL CHARACTERISTICS

For white-footed mice I used repeated measures ANOVA to test for differences by forest cover type in the % of females in reproductive condition based on nipple size and/or vaginal condition, % of males in reproductive condition based on testes size and position, % of reproductive adults (males and females), and the ratio of juveniles to adult females. In addition, I backdated the dates of births of juvenile white-footed mice (Citation) to examine timing of birth pulses. Dates of birth were estimated from pelage coloration at initial capture: juveniles (35 days), side-molts (50 days), back-molts (60 days) and head-tail molts (70 days). Low sample sizes excluded other species from these analyses. I tested for differences in the size of the 5 species with >100 captures between forest cover types using repeated measures ANOVA. Analyses were based on mass (g) and body length (mm). All individuals were separated into appropriate age categories for these analyses and mean values were used when individuals were

captured repeatedly. Prior to these analyses, I tested for differences in the size based on sex at all

age levels for each species. When significant differences ($\underline{P} < 0.10$) were detected, individuals

were separated into the appropriate sex class.

I tested the hypothesis of an overall 50:50 sex ratio for white-footed mice, eastern chipmunks,

meadow voles and woodland voles using a goodness of fit chi-square test. Northern short-tailed

shrews were not sexed in the field. For white-footed mice and eastern chipmunks, I tested the

overall 50:50 sex ratio hypothesis by study site as well.

MACROHABITAT SELECTION

      Catch per unit effort (total new individuals captured/100 trapnights) and relative

abundances of small mammal species with > 100 captures were regressed on 30 stand-level

characteristics for all 10 study sites. For southern flying squirrels regressions were based on the

binomial (poisson) distribution because count data were used as the response variable (Noble,

pers. comm.). Predictor variables for regression analyses are listed in Table 3. Because of the

small sample sizes used in these regression analyses (n=10), only 1- and 2-variable models were

fit. SAS PROC REG with the BEST option was used to identify subsets of predictors for

inclusion in the two-variable equations. Only the top 3 models that accounted for the greatest

amount of variation and had the lowest AIC values were included in the results. Prior to

inclusion into the 2-variable models, all predictor variables were screened for multicollinearity

using Pearson's correlations (Appendix B). For variables with correlation values of $\underline{r} > 0.50$, the

predictor variable that explained the least amount of variation or which required more extensive

habitat sampling were discarded.

Table 3. Habitat variables included in analyses of habitat relationships of small mammals captured on Quantico Marine Corps Base, VA. 1997-1999. Coefficients of variation (CV) of selected variables were also included in analyses.

Habitat variable	Abbreviation	Definition
% Canopy cover	CC	% of stations with overstory vegetation directly above trapping station
Basal area	Ba	Mean basal area measured in m^2/ha, based on 5 random samples taken within each site with an angle gauge
Distance to nearest tree	Ntree	Mean distance to nearest tree (m) based on samples from point quarter plot
Tree density	Tree/ha	Total number of trees/ha
Trees density index	Treesrch	Index based on the total number of trees/area searched in each point quarter plot
Mean dbh of trees	Dbh	Mean dbh of trees (cm) from point quarter sample
Density of mast trees/ha	Dmast	Density of oak and hickory trees/ha, estimated from point quarter sample
Density of soft mast stems	Smast	Estimated density of soft mast stems (*Rubus* + *Vaccinium*)/ha from 3m radius plots
Density of shrubs	Shrub/ha Nshrub	Estimated shrub density/ha from $100m^2$ plots (macroscale) Number of shrubs/$100m^2$ plot (microscale)
Log density	Logden	Estimated density of logs (logs/ha) based on point quarter sample
Distance to nearest log	Nlog	Distance to nearest log (m)
Log density index	Logsrch	Index based on the total number of logs/area searched in each point quarter plot
Stump density	Stmpden	Estimated density of stumps (stumps/ha) based on point quarter sample
Distance to nearest stump	Nstump	Distance to nearest stump (m)
Stump density index	Stmpsrch	Index based on the total number of stumps/area searched in each point quarter plot
Woody stem density at 1 meter height	Woody1	Estimated number of woody stems at 1 m height based on 3m radius plots. Also individually for the number of *Rubus* (crub1), *Vaccinium* (cblue1), *Kalmia latifolia* (cmtnlr1), and other woody stems (cother1).
Woody stem density at 0.5 meter height	Woody5	Estimated number of woody stems at 0.5 m height based on 3m radius plots. Also individually for the number of *Rubus* (crub5), *Vaccinium* (cblue5), *Kalmia latifolia* (cmtnlr5), and other woody stems (cother5)
Woody stem density at ground level	Woody0	Estimated total number of woody stems at ground level based on 3m radius plots. Also individually for the number of *Rubus* (crub0), *Vaccinium* (cblue0), *Kalmia latifolia* (cmtnlr0), and other woody stems (cother0)
Vertical woody stem density	Vwsd	Index of the woody stem height density ([woody5/woody0] + [woody1/woody0])
Number of *Vaccinium* stems/ha	Blue/ha	Estimated number of *Vaccinium* stems/ha based on 3m radius plots

Table 3. Continued

Habitat variable	Abbreviation	Definition
Number of *Rubus* stems/ha	Blkbry	Estimated number of *Rubus* stems/ha based on 3m radius plots
Woody species density	Wdysp	Number of woody species/ 3 m radius plot
Presence of herbaceous ground cover	Hcvr	Presence of herbaceous ground cover within $1m^2$ plot at an individual trapping station; on macroscale, number of stations per site with herbaceous cover within $1m^2$ of the station center
Herbaceous stem density	Hstem	Mean number of herbaceous stems/m^2
Grass stem density	Grass	Mean number of grass stems/m^2
Herbaceous stem density at 0.5 meter height	Herb5	Estimated number of herbaceous stems > 0.5 meters height/m^2
Herbaceous species density	Herbsp	Mean number of herbaceous species/m^2
Dominant herbaceous form consisting of grass or sedges	Domveg1	Dominant herbaceous form of vegetation with $1m^2$ plot consisting of grass or sedges
Dominant herbaceous form consisting of forbs	Domveg2	Dominant herbaceous form of vegetation with $1m^2$ plot consisting of forbs
Dominant herbaceous form consisting of ferns	Domveg3	Dominant herbaceous form of vegetation within $1m^2$ plot consisting of ferns
Dominant herbaceous form consisting of *Lycopodium*	Domveg4	Dominant herbaceous form of vegetation within $1m^2$ plot consisting of *Lycopodium*
Woody debris	Cdwnwood	Amount of woody debris (> 2cm dbh, < 7.5cm dbh; > 0.5 m in length) per 3m radius plot
Liana density	Dliana	Estimated density of lianas (honeysuckle, smilax) per 3m radius plot
Ground Cover	Grndcvr	Mean % of ground cover per 1 m^2 plot
Woody ground cover	Wdycvr	Mean % of ground cover composed of woody debris per 1 m^2 plot
Grass ground cover	Grscvr	Mean % of ground cover composed of grass per 1 m^2 plot
Fern ground cover	Ferncvr	Mean % of ground cover composed of fern per 1m^2 plot
Mean litter depth	Ldepth	Mean litter depth estimated from 4 samples taken/m^2 plot
Number of stations without herbaceous vegetation	Noveg	Number of stations without herbaceous vegetation per study site

I used Canonical Correspondence Analysis (ter Braak 1986, 1994) to examine species macrohabitat selection in relation to environmental gradients among sites. This analysis was undertaken in a descriptive context using PC-ORD, Version 3.18 (McCune and Medford 1997). Canonical correspondence analysis ordinates a main matrix (species relative abundances) that is constrained by a multiple regression on variables included in a second matrix (macrohabitat variables). For the analysis, row and column scores were standardized using the centering and normalizing default. This default rescales site scores such that the mean = 0 and variance = 1. Ordination scores were scaled to optimize columns (species relative abundances), allowing for the direct spatial interpretation of the relationship between habitat and species points. For graphing, scores for species relative abundances represented linear combinations of the habitat variables.

MICROHABITAT SELECTION

I examined selection at the microsite scale for 30 individual habitat variables (Table 3) across all sites and by treatment using Kruskal-Wallis tests or Wilcoxon Rank Sum tests. Sample sizes of white-footed mice, eastern chipmunks and meadow voles based on all sites were sufficiently large to describe 3 levels of use: no-use, low-use (1-2 individuals captured) and high-use (> 2 individuals captured). For northern short-tailed shrews and woodland voles, I employed a use, no-use classification. For white-footed mice, I examined seasonal differences in microhabitat use based on summer and winter captures. In addition, I examined differences in variables based on density in shelterwoods. High-densities of mice (26.3 individuals/ha, SE = 2.9) were recorded in shelterwoods during the winter trapping (Dec 1998-Jan 1999). Differences

in habitat selection were compared to winter 1998 (Feb-March) when densities of white-footed

mice averaged < half those recorded in Dec-Jan 1999 (11.2 individuals/ha, SE = 1.4).

I used forward stepwise logistic regression (SAS PROC LOGISTIC; Stokes et al. 1995)

to identify variables that collectively influenced habitat selection at the microsite scale (n=1000)

for 5 small mammal species. I defined habitat selection based on the presence/absence of a

particular species at a trapping station. I only included species with > 100 captures for these

analyses. Significance of logistic models was determined by -2 log likelihood values, which test

the null hypothesis that all $\beta = 0$. Variables included in the final models had to have $\underline{P} \leq 0.15$.

To verify the association between predicted probabilities and observed responses, I examined

concordant and discordant pairs of observations (See Clark et al. 1999 for explanation). I

assessed model goodness of fit by examining the Hosmer-Lemeshow statistic. Significant values

($\underline{P} \leq 0.05$) indicate the selected model is a poor fit for the data. Models failing this test were

discarded. I developed models, grouped by treatment, to assess variation in habitat use in

different cover types. I included only species where captures occurred at > 10% of stations. For

white-footed mice, I examined seasonal and density-dependent habitat selection as well.

Because individual animals were captured at > 1 trapping station, these analyses violated the

independence assumption of logistic regression. I assumed that this had little effect on my

results, however, verification of this assumption would require further analysis.

WEATHER EFFECTS

I examined weather related influences on small mammal capture probabilities by

regressing the percent of animals captured each night (out of the total number captured on a grid

during each trapping occasion) on a set of 10 weather variables. Predictor variables for

regression analyses are listed in Table 4. SAS PROC REG with the BEST option was used to identify subsets of predictors for inclusion in the multiple variable equations (SAS PROC REG). Prior to inclusion into multiple variable models, all predictor variables were screened for multicollinearity using Pearson's correlations. For variables with correlation values of $r > 0.5$, the predictor variables that explained the least amount of variation or which required more extensive habitat sampling were discarded.

RESULTS

PITFALLS

Nine species of small mammals were captured in pitfalls, including 2, the southeastern shrew (23 captures), and pygmy shrew (1 capture), not captured in live-traps (Table 5). Twelve species of reptiles and amphibians were recorded as incidental captures (Table 5). The northern short-tailed shrew was the most common small mammal species captured in pitfalls (29 captures), and the only mammal species captured on all study sites. This species was captured more frequently in riparian and clearcut stands than in mature or shelterwood. The second most common species, southeastern shrews, were found in all forest cover types but not all sites. Greater numbers of this species were captured in clearcuts (13) followed by RI1 (5), MA1 (3) and shelterwood (4) stands. Captures of other small mammals in pitfalls included white-footed mice (11 captures), meadow jumping mice (8 captures), meadow voles (7 captures), woodland voles (5 captures), eastern chipmunk (1 capture), and house mouse (1 capture).

LIVE-TRAPS

A total of 39,000 trapnights resulted in 4,070 captures of 12 small mammal species (Table 6). Southern flying squirrels (*Glaucomys volans*), eastern cottontails (*Sylvilagus floridanus*),

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Table 4. Weather variables used for analysis of environmental impacts on capture probabilities for small mammal species captured on Quantico Marine Corps Base, VA, 1997-1999.

Weather Variable	Abbreviation	Definition
Temperature	Temp	Mean daily temperature based on 24 hourly measurements (F˚)
High Temperature	Htemp	Highest daily temperature recorded (F˚)
Low Temperature	Ltemp	Lowest daily temperature recorded (F˚)
Humidity	Hmdy	Mean daily percent humidity
Dew Point	Dwpt	Dew point
Wind Chill	Wndchl	Mean daily wind chill factor
Wind Speed	Wndspd	Mean daily wind speed (miles/hour)
High Wind Speed	Hwndsp	Highest recorded winds peed (miles/hour)
Barometric Pressure	Barom	Mean daily barometric pressure (millibars)
Rain	Rain	Total daily accumulation (inches)

Table 5. Number of animals captured in pitfall traps in 4 forest cover types on Quantico Marine Corps Base, VA. Trapping was conducted from May-August 1998 for a total of 936 trapnights.

	Clearcut		Shelterwood				Riparian	Mature
	CC1	CC2	SW1	SW2	SW3	SW4	RI1	MA1
Trapnights sampled	144	108	144	108	108	108	108	108
Eastern chipmunk *Tamias striatus*				1				
Meadow vole *Microtus pennsylvanicus*	1	1			3	2		
White-footed mouse *Peromyscus leucopus*	3	1					3	4
Woodland vole *Microtus pinetorum*	2	1				2		
Meadow jumping mouse *Zapus hudsonius*		4					4	
House mouse *Mus musculus*								1
Northern short-tailed shrew *Blarina brevicauda*	4	7	2	3	2	1	7	3
Southeastern shrew *Sorex longirostris*	4	9			2	2	5	3
Pygmy shrew *Sorex hoyi*	1							
Marbled salamander *Ambystoma opacum*				1			5	6
Spotted salamander *Ambystoma maculatum*							1	
Red-backed salamander *Plethodon cinereus*							1	
Northern red salamander *Pseudotriton ruber*	1							
Eastern spotted newt *Notophthalamus viridescens*							1	
Green frog *Rana clamitans*		1	1				2	
Fowlers toad *Bufo woodhousii fowleri*		2	6				23	26
American toad *Bufo americanus*	5	3	9	5	1	2	34	53
Eastern box turtle *Terrapene carolina*	2	1						1
Worm snake *Carphophis amoenus*			2				1	
Eastern fence lizard *Sceloporus undulatus*			2		3	3	1	
Eumeces sp.	1		2	3	5	2	1	3

Table 6. Total number of small mammal captures (based on live-trap results, includes recaptures) within 4 forest cover types on Quantico Marine Corps Base. Trapping was conducted May-August 1998, January-March 1998, May-August 1998 and December-January 1999. Each site was trapped for a total of 26 days or 3,900 trapnights.

Species	Clearcut (n=2)		Shelterwood (n=4)				Riparian (n=2)		Mature (n=2)		Total Captures
	CC1	CC2	SW1	SW2	SW3	SW4	RI1	RI2	MA1	MA2	
White-footed mouse	109	143	193	353	458	487	251	288	103	109	2494
Eastern chipmunk	18	7	126	235	86	76	0	79	1	29	657
Northern short-taile shrew	66	84	36	39	56	35	18	46	32	71	483
Meadow vole	85	29	0	0	99	31	1	2	0	0	247
Woodland vole	9	5	3	22	14	35	7	12	2	13	122
Southern flying squirrel	0	0	4	1	2	0	0	6	0	16	25
Meadow jumping mouse	2	3	3	0	2	0	5	3	0	0	18
Eastern cottontail	3	1	0	3	1	0	0	0	0	0	8
Eastern harvest mouse	0	0	0	0	1	3	0	0	0	0	4
American opossum	4	0	0	0	0	0	0	0	0	0	4
Gray squirrel	0	0	0	0	0	0	2	0	0	2	4
House mouse	0	1	0	0	0	2	0	0	0	0	3
Least shrew	0	0	0	0	1	0	0	0	0	0	1

Table 7. Number of individuals of small mammals captured in live-traps within 4 forest cover types on Quantico Marine Corps Base. Trapping was conducted May-August 1998, January-March 1998, May-August 1998 and December-January 1999. Each site was trapped for a total of 26 days or 3,900 trapnights.

Species	Clearcut (n=2)		Shelterwood (n=4)				Riparian (n=2)		Mature (n=2)		Total Captures
	CC1	CC2	SW1	SW2	SW3	SW4	RI1	RI2	MA1	MA2	
White-footed mouse	36	49	96	116	150	154	82	90	39	34	846
Northern short-tailed shrew	59	84	35	39	55	34	18	45	31	70	470
Meadow vole	65	27	0	0	90	30	1	2	0	0	215
Eastern chipmunk	10	4	40	42	31	18	0	18	1	7	171
Woodland vole	9	5	3	18	11	30	7	10	2	11	106
Southern flying squirrel	0	0	4	1	2	0	0	5	0	10	22
Meadow jumping mouse	2	3	3	0	2	0	5	3	0	0	18
Eastern cottontail	3	1	0	3	1	0	0	0	0	0	8
Gray squirrel	0	0	0	0	0	0	2	0	0	2	4
American opossum	4	0	0	0	0	0	0	0	0	0	4
Eastern harvest mouse	0	0	0	0	1	3	0	0	0	0	4
House mouse	0	1	0	0	0	2	0	0	0	0	3
Least shrew	0	0	0	0	1	0	0	0	0	0	1

eastern harvest mice (*Reithrodontomys humulis*), least shrews (*Cryptotis parva*), and gray squirrels (*Sciurus carolinensis*) were recorded in live-traps and not pitfalls. The overall capture rate of live-traps was 9.6% (total captures/total trapnights). White-footed mice were the most abundant species, representing 61% of the overall captures, followed by eastern chipmunks (16%), northern short-tailed shrews (12%), meadow voles (6%) and woodland voles (3%). All other species accounted for approximately 2% of the total captures. A total of 1825 individual animals was captured (Table 7). White-footed mice represented the most individuals captured (45%), followed by northern short-tailed shrews (26%), meadow voles (12%), eastern chipmunks (9%) and woodland voles (6%). All other species made up approximately 3% of individual captures. Of the rarely captured species, eastern harvest mice occurred on 2 shelterwood sites (SW3 and SW4) and meadow jumping mice were captured in every forest cover type except mature-upland. The only capture of a least shrew occurred on a shelterwood site, SW3.

RELATIVE ABUNDANCES

There was a difference in the overall relative abundance (new individuals/100 TN) of small mammals among forest cover types (Table 8, P=0.05, 3, 6 df). Mean total small mammal catch per unit effort (CPUE) was highest in shelterwood (8.98 new individuals/100 TN, SE = 1.55) followed by riparian (5.71/100 TN, SE = 0.91), clearcut (5.25/100 TN, SE =0.53) and mature (3.25/100 TN, SE=0.46) stands (Figure 4). There was a significant time (P=0.0001, 6, 36 df) and time*treatment (forest cover type) interaction (P=0.003, 18, 36 df), primarily a result of high capture rates of white-footed mice in shelterwoods during December 1998-January 1999.

There was a difference among forest cover types in the abundance of white-footed mice (P=0.03, 3, 6 df) and eastern chipmunks (P=0.065, 3, 6 df)(Table 9, Figure 5). Mean capture

Table 8. ANOVA results of tests for treatment effects, time effects and treatment by time interaction for relative abundances of small mammals (new individuals/100 TN) captured within 4 forest cover types on Quantico Marine Corps Base, VA. May 1997-January 1999.

Trapping Occasions	Source	df	SS	MS	F	P
1-7	Between Sites					
	Treatment	3	351.56	117.19	4.62	0.05
	Residual between	6	152.11	25.35		
	Within Sites					
	Time	6	187.79	31.30	8.60	0.0001
	Treatment x Time Interaction	18	196.50	10.92	3.00	0.003
	Residual within	36	130.99	3.64		
	Total	69				
1-6	Between Sites					
	Treatment	3	177.10	59.03	3.53	0.09
	Residual between	6	100.41	16.75		
	Within Sites					
	Time	5	34.61	6.92	2.38	0.06
	Treatment x Time Interaction	15	74.04	4.94	1.70	0.11
	Residual within	30	87.30	2.91		
	Total	59				
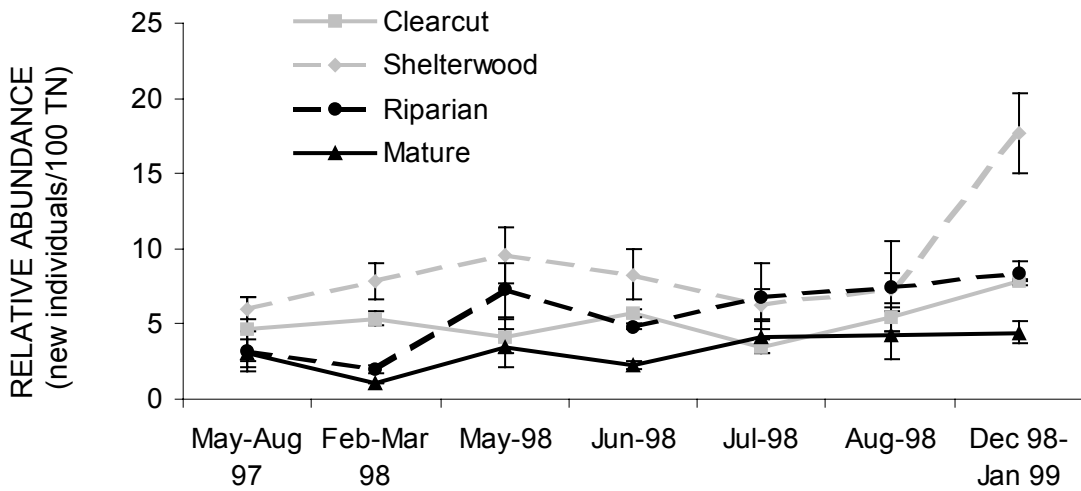
Figure 4. Relative abundances (new individuals/100 TN) of small mammals captured on Quantico Marine Corps Base, VA by forest cover type and standard errors. Trapping was conducted from May 1997 through January 1999.

Table 9. ANOVA results of tests for treatment effects, time effects and treatment by time interaction for relative abundances (new individuals/100 TN) of 5 small mammal species captured on Quantico Marine Corps Base. Relative abundances were based on average number of new individuals captured per 100 trapnights. Trapping was conducted on 7 occasions from May 1997-January 1999 in 4 forest cover types.

Species	Source	df	SS	MS	F	P
White-footed mouse[a]	Between Sites					
	Treatment	3	85.76	28.59	5.87	0.03
	Residual between	6	29.24	4.87		
	Within Sites					
	Time	5	13.41	2.68	2.28	0.07
	Treatment * Time Interaction	15	33.56	2.24	1.91	0.06
	Residual within	30	35.23	1.17		
	Total	59	197.2			
Eastern chipmunk[b]						
	Between Sites					
	Treatment	3	28.56	9.52	4.16	0.07
	Residual between	6	13.73	2.29		
	Within Sites					
	Time	4	2.51	0.63	4.25	0.01
	Treatment * Time Interaction	12	2.56	0.21	1.44	0.21
	Residual within	24	3.55	0.15		
	Total	49	50.91			
Northern short-tailed shrew						
	Between Sites					
	Treatment	3	9.04	3.01	2.34	0.17
	Residual between	6	7.72	1.29		
	Within Sites					
	Time	6	10.45	1.74	4.5	0.002
	Treatment * Time Interaction	18	12.68	0.7	1.82	0.062
	Residual within	36	13.93	0.39		
	Total	69	53.82			

[a]The seventh trapping occasion was removed from this analysis because of high levels of juvenile recruitment into the population on all study sites.
[b]Trapping occasions 2 and 7 were removed from this analysis because of winter torpor.

Table 9. Continued

Species	Source	df	SS	MS	F	P
Woodland vole[c]	Between Sites					
	Treatment	3	29.14	9.71	0.79	0.54
	Residual between	6	73.71	12.29		
	Within Sites					
	Time	6	23.86	3.98	0.75	0.62
	Treatment * Time Interaction	18	52.06	2.89	0.55	0.91
	Residual within	36	190.29	5.29		
	Total	69	369.06			
Meadow vole[d]	Between Sites					
	Treatment	2	270.29	135.14	0.76	0.51
	Residual between	5	884.00	176.80		
	Within Sites					
	Time	6	97.14	16.19	1.32	0.28
	Treatment * Time Interaction	12	67.71	13.98	1.14	0.39
	Residual within	30	368.00	12.27		
	Total	55	1687.14			

[c]Data distributions were non-normal, ANOVA results should be viewed in this light and were included only because they allow examinations of time and time*treatment interactions. Kruskal-Wallis tests on the overall relative abundance of woodland voles by forest cover type also revealed no significant differences (P=0.63, df=3).

[d]Mature sites were excluded from ANOVA analysis. Data distributions were non-normal. Wilcoxon Rank Sum tests on the overall relative abundance of meadow voles by forest cover type also revealed no significant differences (P=0.31, df=3) between clearcuts and shelterwoods. Mature and Riparian sites were not included in the analysis.
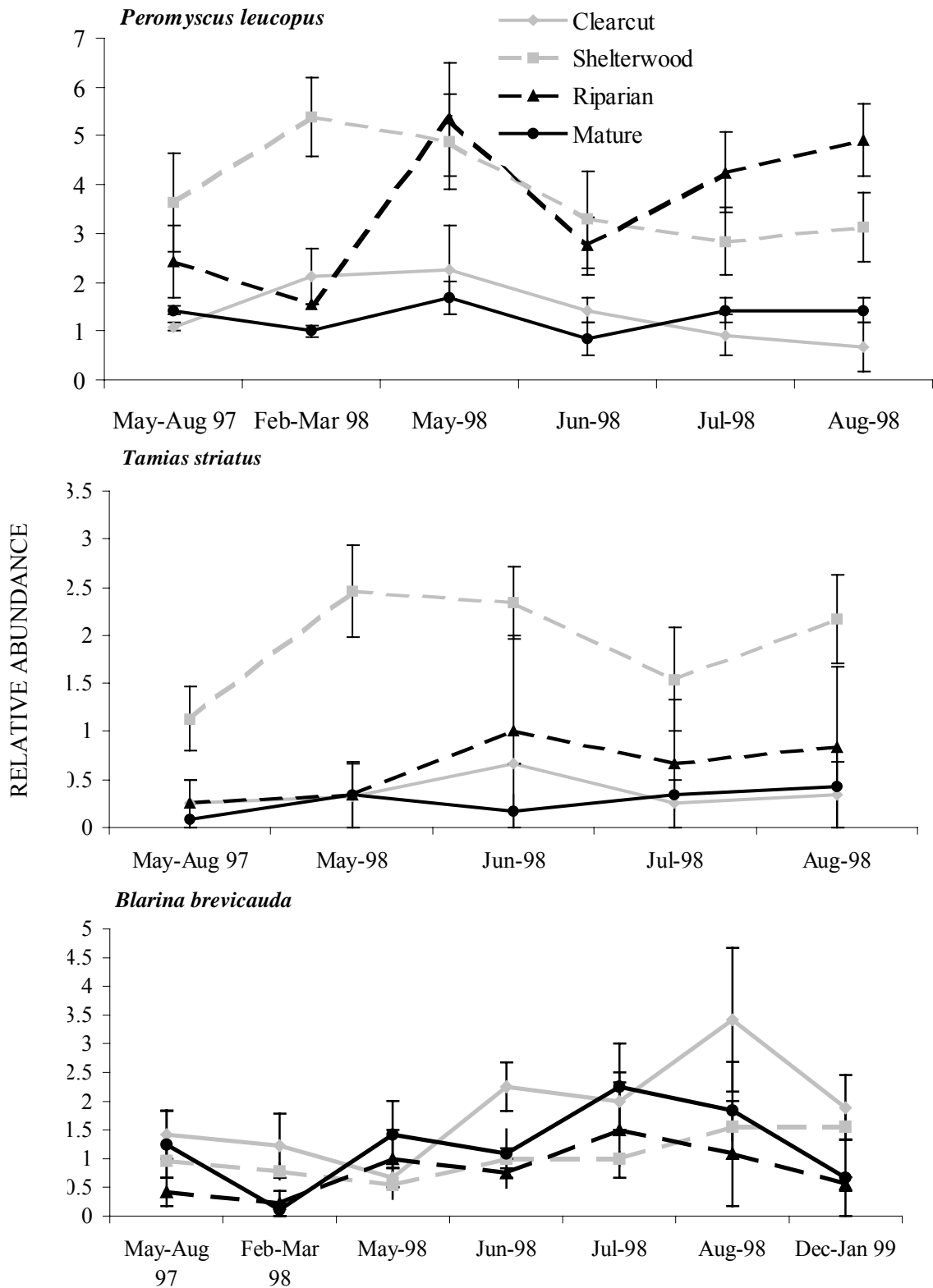
Figure 5. Relative abundances (new individuals/100 TNs) of 5 small mammal species captured on Quantico Marine Corps Base. Trapping occasion 7 was excluded from analysis for *Peromyscus leucopus* because of high numbers of juveniles present in the population. Trapping occasions 2 and 7 were excluded from analysis for *Tamias striatus* because of winter inactivity.

Microtus pennsylvanicus

Microtus pinetorum
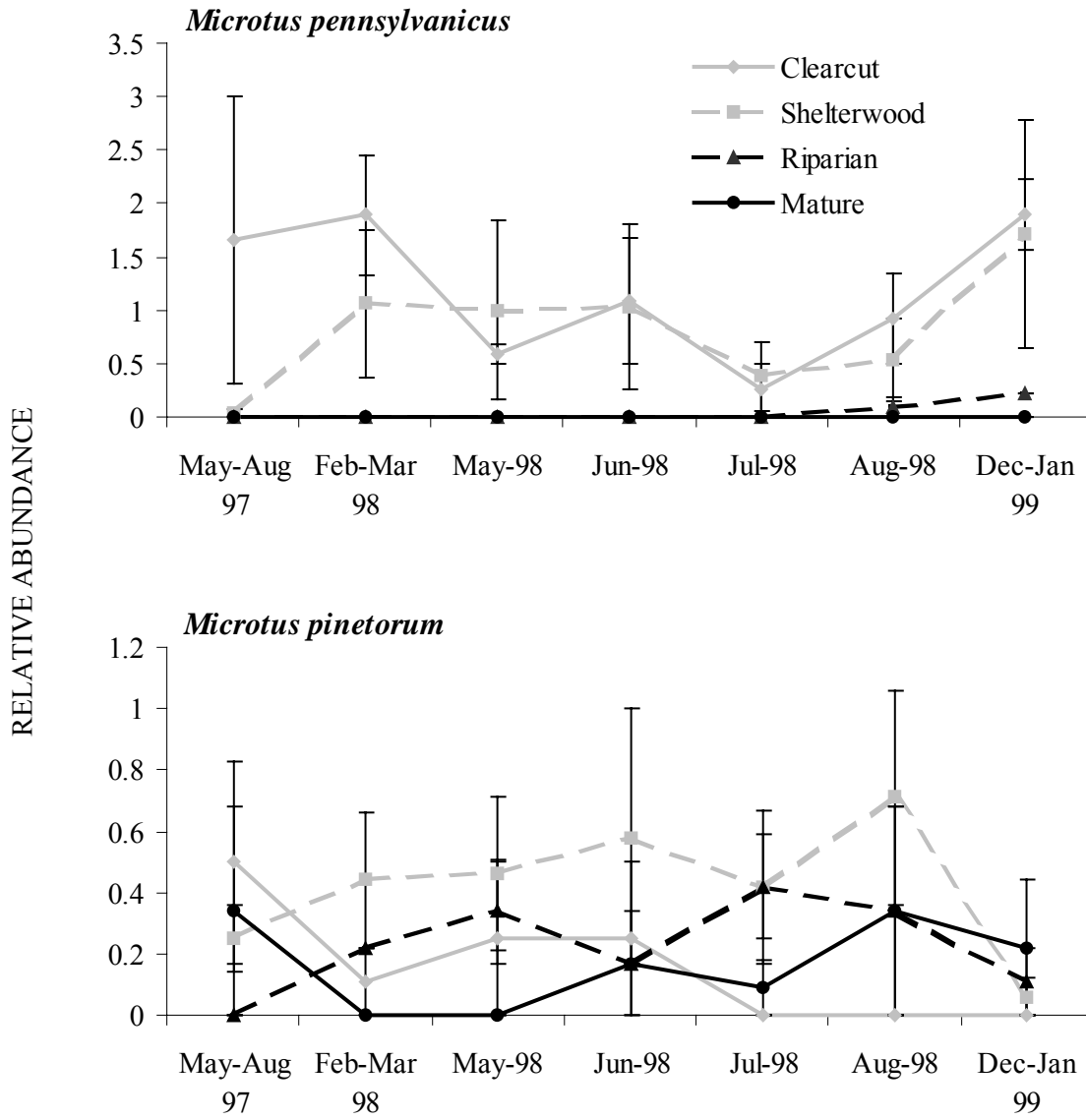
Figure 5. Continued

rates for white-footed mice were similar in shelterwood (3.86/100 TN, SE = 0.29) and riparian stands (3.54/100 TN, SE = 0.68), and were lowest in clearcut (1.41/100 TN, SE = 0.29) and mature stands (1.30/100 TN, SE = 0.14). A marginally significant time ($\underline{P}$=0.07, 5, 30 df) and time*treatment interaction ($\underline{P}$=0.06, 14, 30 df) was detected. Mean capture rates for eastern chipmunks were highest in shelterwood stands (1.93/100 TN, SE = 0.28), followed by riparian (0.62/100 TN, SE = 0.16), clearcut (0.37/100 TN, SE = 0.09) and mature (0.27/100 TN, SE = 0.07) stands. A highly significant time effect was detected ($\underline{P}$=0.009 4, 24 df) for chipmunks. No significant differences were found among forest cover types for the relative abundances of northern short-tailed shrews ($\underline{P}$=0.17, 3, 6 df), woodland voles ($\underline{P}$=0.54, 3, 6 df) or meadow voles ($\underline{P}$=0.46, 3, 6 df). For northern short-tailed shrews, a significant time ($\underline{P}$=0.001, 6, 36 df) and marginally significant time*treatment interaction ($\underline{P}$=0.06, 28, 36 df) was detected.

DENSITIES

White-footed mice. —Densities of white-footed mice ranged from a low of 0.9/ha to a high of 29.8/ha (Table 10). Mean overall densities (± SE) were highest in shelterwood (12.2/ha ± 1.42) and riparian (10.2/ha ± 1.19) cover types and lowest in clearcut (4.7/ha ± 0.95) and mature (3.8/ha ± 0.37) stands. Peak densities of white-footed mice were recorded in all shelterwoods, CC1 and RI1 during the Dec-98, Jan-99 trapping period. Densities were highest in CC2, RI2, and MA2 during the May-98 trapping period and for MA1 during August-98. There was a high correlation between density estimates calculated using program CAPTURE and relative abundances (Pearson's correlation $\underline{r}$ = 0.94, n = 70).

Eastern chipmunks. —Densities of eastern chipmunks ranged from 0/ha to a high of 10.7/ha (Table 11). Mean overall densities were highest in shelterwoods (5.3/ha ± 0.67) and similar in riparian (2.1/ha ± 1.00), clearcut (0.98/ha ± 0.24) and mature (0.8/ha ± 0.29) stands.

Table10. Density estimates (individuals/ha) obtained using program CAPTURE (White et al. 1982) by site and trapping occasion for white-footed mice captured within 4 forest cover types on Quantico Marine Corps Base, VA. May 1997-January 1999.

Treatment	Site	Trap Occasion	Density (SE)	95% CI	Model[a]	Estimator[a]
Clearcut	CC1	June 97	1.8[b]	-	-	-
		February 98	2.7	-	-	-
		May 98	3.6	-	-	-
		June 98	3.6	-	-	-
		July 98	1.3	-	-	-
		August 98	0.9	-	-	-
		January 99	14.7 (6.09)	9.8, 39.6	M(th)	Chao's M(th)
	CC2	June 97	2.2	-	-	-
		February 98	5.8 (0.62)	5.3, 7.6	M(o)	Null
		May 98	8.9 (2.02)	7.6, 18.2	M(th)	Chao's M(th)
		June 98	4.4 (0.37)	4.4, 4.4	M(o)	Null
		July 98	3.6	-	-	-
		August 98	2.7	-	-	-
		January 99	4.9 (1.84)	4.4, 16.4	M(th)	Chao's M(th)
Shelterwood	SW1	June 97	4.9 (0.79)	4.9, 9.8	M(th)	Chao's M(th)
		February 98	13.8 (0.61)	13.3, 15.1	M(o)	Null
		May 98	5.8 (0.90)	4.9, 9.3	M(h)	Jacknife
		June 98	3.6	-	-	-
		July 98	2.7	-	-	-
		August 98	2.7	-	-	-
		January 99[c]	17.8	-	-	-
	SW2	June 97	5.8 (0.10)	5.8, 5.8	M(o)	Null
		February 98	8.0 (3.50)	6.2, 25.8	M(th)	Chao's M(th)
		May 98	19.6 (3.00)	16, 28.4	M(h)	Jacknife
		June 98	5.8 (1.88)	4.9, 16	M(th)	Chao's M(th)
		July 98	12.0 (0.87)	11.1, 15.1	M(o)	Jacknife
		August 98	9.3 (0.51)	9.3, 12.4	M(b)	Zippin
		January 99	28.4 (1.23)	27.1, 32.4	M(o)	Jacknife
	SW3	June 97	16.9 (4.60)	15.6, 45.8	M(tb)	Burnham's M(tb)
		February 98	13.3 (0.37)	13.3, 13.3	M(o)	Null
		May 98	15.6 (0.71)	15.1, 17.3	M(o)	Jacknife
		June 98	11.1 (0.54)	10.7, 13.3	M(o)	Null
		July 98	6.7 (1.36)	5.8, 12.4	M(th)	Chao's M(th)
		August 98	9.3 (0.37)	9.3, 9.3	M(bh)	Generalized
		January 99	29.8 (0.44)	29.8, 29.8	M(tb)	Burnham's M(tb)
	SW4	June 97	14.7 (1.84)	12.9, 21.9	M(h)	Jacknife
		February 98	9.8 (0.24)	9.8, 9.8	M(bh)	Generalized
		May 98	15.6 (1.48)	14.2, 21.3	M(h)	Jacknife
		June 98	10.7 (0.29)	10.7, 10.7	M(o)	Null
		July 98	8.9 (0.49)	8.9, 8.9	M(o)	Null
		August 98	10.2 (0.48)	10.2, 10.2	M(o)	Null
		January 99	29.3 (2.17)	29.3, 29.3	M(tb)	Burnham's M(tb)

[a]See White et al. 1982 for explanation
[b]Low sample sizes prevented analyses, therefore these represent minimum known alive.
[c]Density estimates were based on two days of trapping due to inclement weather and were not considered accurate,
 therefore minimum known alive was used as a substitute.

Table10. Continued

Treatment	Site	Trap Occasion	Density (SE)		95% CI	Model[a]	Estimator[a]
Riparian	RI1	June 97	4.4	(0.64)	4.0, 7.6	M(o)	Null
		February 98	5.8	(2.66)	3.6, 17.3	M(o)	Null
		May 98	11.1	(0.30)	11.1, 11.1	M(bh)	Generalized
		June 98	8.9	(0.28)	8.9, 8.9	M(bh)	Generalized
		July 98	11.1	(1.03)	9.8, 19.1	M(th)	Chao's M(th)
		August 98	12.9	(1.03)	11.6, 16.4	M(o)	Null
		January 99	13.3	(0.86)	12.4, 16.4	M(t)	Darroch
	RI2	August 97	9.3	(1.03)	8.4, 13.3	M(h)	Jacknife
		March 98	3.6		-	-	-
		May 98	18.2	(1.52)	16.0, 23.6	M(o)	Null
		June 98	4.4	(0.67)	4.4, 8.9	M(bh)	Generalized
		July 98	14.7	(2.99)	12.0, 26.2	M(th)	Chao's M(th)
		August 98	14.2	(0.51)	13.8, 16.0	M(t)	Darroch
		December 98	10.7	(1.08)	10.2, 16.0	M(bh)	Generalized
Mature	MA1	June 97	4.0	(0.41)	4.0, 4.0	M(o)	Null
		February 98	2.2[b]	(2.22)	-	-	-
		May 98	3.6		-	-	-
		June 98	3.6		-	-	-
		July 98	4.0		-	-	-
		August 98	6.2	(1.92)	4.4, 14.2	M(o)	Null
		January 99	4.9	(0.01)	4.9, 4.9	M(t)	Darroch
	MA2	August 97	3.1		-	-	-
		March 98	1.8		-	-	-
		May 98	5.3	(0.27)	5.3, 5.3	M(o)	Null
		June 98	1.3		-	-	-
		July 98	4.4	(0.30)	4.4, 4.4	M(o)	Null
		August 98	2.7		-	-	-
		December 98	4.0		-	-	-

[a]See White et al. 1982 for explanation
[b]Low sample sizes prevented analyses, therefore these represent minimum known alive.

Table 11. Density estimates (individuals/ha) obtained using program CAPTURE (White et al. 1982) by site and trapping occasion for eastern chipmunks captured within 4 forest cover types on Quantico Marine Corps Base, VA. May 1997-January 1999.

Treatment	Site	Trap Occasion	Density (SE)		95% CI	Model[a]	Estimator[a]
Clearcut	CC1	June 97	1.3[b]		-	-	-
		May 98	0.9		-	-	-
		June 98	1.8		-	-	-
		July 98	1.3		-	-	-
		August 98	1.8		-	-	-
	CC2	June 97	0.0		-	-	-
		May 98	0.9		-	-	-
		June 98	1.8		-	-	-
		July 98	0.0		-	-	-
		August 98	0.0		-	-	-
Shelterwood	SW1	June 97	2.7		-	-	-
		May 98	5.3	(0.48)	5.3, 5.3	M(o)	Null
		June 98	6.2	(0.58)	6.2, 10.2	M(b)	Zippin
		July 98	5.3	(0.83)	4.9, 9.8	M(o)	Null
		August 98	9.8	(2.49)	7.1, 18.7	M(th)	Chao's M(th)
	SW2	June 97	8.0	(3.22)	4.9, 20.4	M(th)	Chao's M(th)
		May 98	10.7	(0.80)	9.8, 13.8	M(o)	Null
		June 98	8.4	(0.67)	8.4, 9.8	M(o)	Null
		July 98	7.6	(0.05)	7.6, 7.6	M(o)	Null
		August 98	8.4	(0.63)	8.4, 9.7	M(o)	Null
	SW3	June 97	2.2		-	-	-
		May 98	7.6	(1.00)	6.7, 11.6	M(o)	Null
		June 98	3.1		-	-	-
		July 98	3.0		-	-	-
		August 98	3.6		-	-	-
	SW4	June 97	0.4		-	-	-
		May 98	4.4	(0.28)	4.4, 4.4	M(o)	Null
		June 98	5.3	(0.68)	5.3, 8.4	M(o)	Null
		July 98	2.2	(0.61)	2.2, 2.2	M(o)	Null
		August 98	3.1	(0.92)	3.1, 3.6	M(o)	Null
Riparian	RI1	June 97	0		-	-	-
		May 98	0		-	-	-
		June 98	0		-	-	-
		July 98	0		-	-	-
		August 98	0		-	-	-
	RI2	August 97	1.3		-	-	-
		May 98	1.8		-	-	-
		June 98	9.8	(5.03)	5.8, 31.1	M(th)	Chao's M(th)
		July 98	3.6		-	-	-
		August 98	4.4	(0.74)	4.4, 7.6	M(h)	Jackknife

[a]See White et al. 1982 for explanation
[b]Low sample sizes prevented analyses, therefore these represent minimum known alive.

Table 11. Continued

Treatment	Site	Trap Occasion	Density (SE)	95% CI	Model[a]	Estimator[a]
Mature	MA1	June 97	0	-	-	-
		May 98	0	-	-	-
		June 98	0	-	-	-
		July 98	0.4[b]	-	-	-
		August 98	0	-	-	-
	MA2	August 97	0.4	-	-	-
		May 98	1.8	-	-	-
		June 98	0.9	-	-	-
		July 98	1.3	-	-	-
		August 98	2.2	-	-	-

[a]See White et al. 1982 for explanation
[b]Low sample sizes inhibited analyses, therefore these represent minimum known alive.

There was no consistent trend in peak densities for all study sites. There was a high correlation between density estimates and relative abundance (Pearson's correlation $\underline{r} = 0.95$, n = 50).

PHYSICAL CHARACTERISTICS

Prior to analyses of physical characteristics, I tested whether significant ($\underline{P} \leq 0.05$) differences in body measures (body length, tail length and mass) existed between sexes for each species at all age classifications. White-footed mice and meadow voles were the only species in which body characteristics were significantly different between sexes for adults and therefore were separated for analysis. For all other species, sexes were pooled within the appropriate age class.

White-footed Mice – Sex ratios differed significantly for all individuals captured ($\underline{P}<0.01$, Table 12). Overall, 1.33 males were captured for every female captured. Sex ratios differed from the hypothesized 1:1 ratio only on one site, RI1 ($\underline{P} = 0.01$) and were marginally different on two sites, MA1 ($\underline{P} = 0.07$) and MA2 ($\underline{P} = 0.08$)(Table 13).

No significant differences in mass were detected among forest cover types for all age classes: 1 ($\underline{P}=0.25$), 2.3 ($\underline{P}=0.91$), 2.6 ($\underline{P}=0.65$), 2.9 ($\underline{P}=0.15$) and adult male ($\underline{P}=0.31$) and female ($\underline{P}=0.20$) white-footed mice (Tables 14, 15).

Significant differences across forest cover types in body length were detected for age class 1 ($\underline{P}=0.05$) and adult females ($\underline{P}=0.02$)(Tables 14, 15). Pairwise comparisons ($\underline{P}<0.05$ considered significant) for age class 1 showed juvenile mice captured in mature stands to be smaller than those from shelterwoods. Adult females captured in clearcuts had significantly smaller body sizes than those from shelterwoods, and were marginally smaller than adult females from riparian stands.

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Table 12. Captures of small mammals on Quantico Marine Corps Base by sex. The hypothesis of a 50:50 sex ratio was tested with a goodness-of-fit chi-square (1 df). Data represent individual animals captured from May-August 1997, January-March 1998, May-August 1998 and December-January 1999 for a total of 39,000 trapnights.

	Individual Captures				
Species	Males	Females	Sex Ratio	Chi-square	P
White-footed mouse	500	375	1.33 : 1	17.86	<0.01
Eastern chipmunk	79	71	1.11 : 1	0.42	0.52
Woodland vole	44	54	0.81 : 1	1.02	0.31
Meadow vole	102	96	1.06 : 1	0.18	0.67

Table 13. Captures of White-footed mice and Eastern chipmunks by study site and sex. The hypothesis of a 50:50 sex ratio was tested with a goodness-of-fit chi-square (1 df). Data represent animals captured from May-August 1997, January-March 1998, May-August 1998, and December-January 1999 over a period of 39,000 trapnights.

	Individual Captures for White-footed mice						Individual Captures for Eastern chipmunks				
Site	Male	Female	Sex Ratio	Chi-square	P		Male	Female	Sex Ratio	Chi-square	P
CC1	22	14	1.57 : 1	1.78	0.18		5	3	1.67 : 1	0.50	0.48
CC2	25	19	1.32 : 1	1.08	0.37		2	1	2 : 1	1.00	0.32
SW1	54	39	1.38 : 1	2.42	0.12		21	15	1.4 : 1	1.00	0.32
SW2	60	54	1.11 : 1	0.32	0.57		16	20	0.8 : 1	0.44	0.51
SW3	75	67	1.12 : 1	0.46	0.50		8	7	1.14 : 1	0.06	0.81
SW4	82	64	1.28 : 1	2.22	0.14		13	12	1.08 : 1	0.04	0.83
RI1	47	25	1.88 : 1	6.72	0.01		0	0	-	-	-
RI2	41	40	1.03 : 1	0.02	0.89		8	9	0.89 : 1	0.58	0.45
MA1	24	13	1.85 : 1	3.28	0.07		0	1	0 : 1	1.00	0.32
MA2	21	11	1.91 : 1	3.12	0.08		4	3	1.33 : 1	0.14	0.71

Table 14. Mean weights, body lengths and tail lengths by forest cover type and age class for white-footed mice captured on Quantico Marine Corps Base from May 1997-January 1999. Age classification was based on pelage coloration (Linzey and Linzey 1967). Standard errors are noted in parentheses.

Age Class	Clearcut	Shelterwood	Riparian	Mature
1.0 (juvenile)	-	(n=36)	(n=7)	(n=4)
Weight	-	12.5 (0.34)	12.8 (1.05)	11.4 (0.69)
Body length	-	71.9 (1.06)	71.1 (2.84)	62.3 (3.79)
Tail length	-	56.9 (1.04)	59.7 (1.95)	55.3 (2.50)
2.3 (side-molt)	(n=7)	(n=28)	(n=11)	(n=6)
Weight	14.4 (0.87)	14.8 (0.40)	15.4 (0.78)	14.5 (0.47)
Body length	72.9 (3.11)	74.4 (1.14)	71.8 (2.89)	80.2 (1.77)
Tail length	56.8 (2.57)	60.4 (0.70)	59.5 (2.19)	60.0 (2.10)
2.6 (back-molt)	(n=2)	(n=28)	(n=7)	(n=2)
Weight	15.4 (0.38)	16.6 (0.47)	16.2 (0.95)	14.7 (0.33)
Body length	75.3 (2.25)	80.3 (1.43)	80.1 (1.96)	81.0 (3.00)
Tail length	59.8 (3.25)	62.8 (1.38)	63.4 (1.95)	63.0 (6.00)
2.9 (head-tail molt)	(n=20)	(n=73)	(n=24)	(n=15)
Weight	16.2 (0.47)	17.1 (0.27)	17.8 (0.54)	16.9 (0.67)
Body length	82.1 (1.30)	82.0 (0.55)	80.5 (0.86)	80.5 (1.70)
Tail length	62.2 (0.94)	64.6 (0.73)	64.1 (0.78)	63.8 (1.01)
3 (adult females)	(n=23)	(n=154)	(n=49)	(n=17)
Weight	18.5 (0.80)	19.8 (0.27)	20.00 (0.48)	18.6 (0.56)
Body length	83.3 (1.47)	87.7 (0.47)	86.2 (0.78)	85.1 (1.68)
Tail length	65.1 (1.52)	68.1 (0.52)	69.0 (0.78)	64.8 (1.77)
3 (adult males)	(n=39)	(n=197)	(n=84)	(n=35)
Weight	20.5 (0.48)	20.8 (0.21)	20.7 (0.33)	19.9 (0.46)
Body length	86.5 (1.01)	87.9 (0.44)	86.5 (0.73)	86.4 (1.17)
Tail length	66.3 (0.76)	68.6 (0.43)	69.2 (0.66)	69.7 (1.19)

Table15. Results of Kruskal-Wallis tests for differences in mass, body length and tail length by age class and/or sex for 5 small mammal species captured on Quantico Marine Corps Base, VA. May 1997-January 1999. Species were separated by sex when Wilcoxon Rank Sum tests indicated significant differences ($P<0.05$) in physical characteristics between males and females.

Species	Age Class	Sex	Sample Sizes CC, SW, RI, MA	Weight P-Value[a]	Body Length P-Value	Body Length Site Comparisons[b]	Tail Length P-Value	Tail Length Site Comparisons
White-footed mouse[c]	1	M, F	0, 36, 7, 4	0.25	0.05	SW^A, RI^{AB}, MA^B	0.33	-
	2.3	M, F	7, 28, 18, 6	0.91	0.16	-	0.60	-
	2.6	M, F	2, 28, 7, 2	0.65	0.53	-	0.78	-
	2.9	M, F	20, 73, 24, 15	0.15	0.36	-	0.24	-
	3	M	41, 198, 84, 35	0.31	0.39	-	0.03	CC^A, SW^A, RI^A, MA^B
	3	F	25, 157, 50, 17	0.20	0.01	CC^A, SW^B, RI^{AB}, MA^{AB}	0.01	CC^{AB}, SW^{BC}, RI^C, MA^A
Eastern chipmunk[d]	1	M, F	5, 64, 12, 2	0.62	0.32	-	0.97	-
	3	M, F	7, 70, 8, 8	0.29	0.68	-	0.87	-
Northern short-tailed shrew[e]	1	M, F	47, 64, 23, 43	0.42	0.35	-	0.05	CC^A, SW^A, RI^A, MA^B
	3	M, F	82, 65, 25, 31	0.20	0.49	-	0.02	CC^A, SW^B, RI^{AB}, MA^{AB}
Meadow voles[f]	1	M, F	27, 37	0.27	1.00	-	0.79	-
	3	M	39, 33, 2	0.46	0.15	-	0.06	-
	3	F	20, 35	0.23	0.96	-	0.12	-
Woodland vole[g]	1	M, F	4, 10, 3, 8	0.65	0.58	-	0.16	-
	3	M, F	8, 48, 10, 7	0.49	0.14	-	0.49	-

[a]All Kruskal-Wallis tests had 3 df
[b]Between forest cover type comparisons were made using Wilcoxon Rank Sum tests. Same letter group indicates no significant difference between levels of use based on $\alpha=0.05$.
[c]Age classification was based on pelage (1=entirely gray, 2.3=side molt, 2.6=back molt, 2.9=head-tail molt, 3=adult)
[d]Age classification was based on weight, juveniles (age class 1) had weights < 80g
[e]Age classification was based on weight, < 12g=juveniles
[f]Age classification was based on weight, < 30g=juveniles
[g]Age classification was based on weight, < 20g=juveniles

Tail sizes were significantly different among forest cover types for both adult males (P=0.03) and females (P=0.01). Pairwise tests showed adult females in riparian and shelterwood stands have longer tails than those in clearcuts and mature stands. Adult males from mature stands had significantly smaller tails than those captured in the other forest cover types. Captured individuals were examined for the presence of bot fly larvae (*Cuterebra* spp.) during the summer 1998 trapping season (Figure 6). No significant difference was detected for rates of parasitism by forest cover type (Table 16, P=0.67). The overall rate of infestation was 24%. Parasitism rates exceeded 35% in CC2, SW3 and RI2 and were lowest (< 6% individuals parasitized) in MA1 and RI1. The high rates of botfly parasitism on CC2, SW3 and RI2 may be related to the proximity of these sites to riparian corridors, although RI1 is the exception.

Eastern Chipmunks – There was no significant difference among forest cover types (P=0.52)(Table 11) and individual sites (Table 12) in the overall sex ratio of eastern chipmunks. No significant differences were detected in all body measurements among forest cover types for juveniles and adults (Table 15).

Northern Short-tailed Shrews— No significant differences were detected in weight and body length measurements among forest cover types for both age classes of short-tailed shrews. Significant differences in tail lengths were detected for juveniles (P=0.05) and adults (P=0.02, Table 15). For adults, shrews captured in shelterwoods had significantly shorter tails than those from clearcuts. For juveniles, shrews from mature stands had significantly longer tails than those from other forest cover types.

Meadow Voles—Overall sex ratios did not differ significantly from a 1:1 ratio (P=0.67, Table 11). No significant differences were detected in all body measurements among forest cover types for juveniles and adult males and females (Table 15).
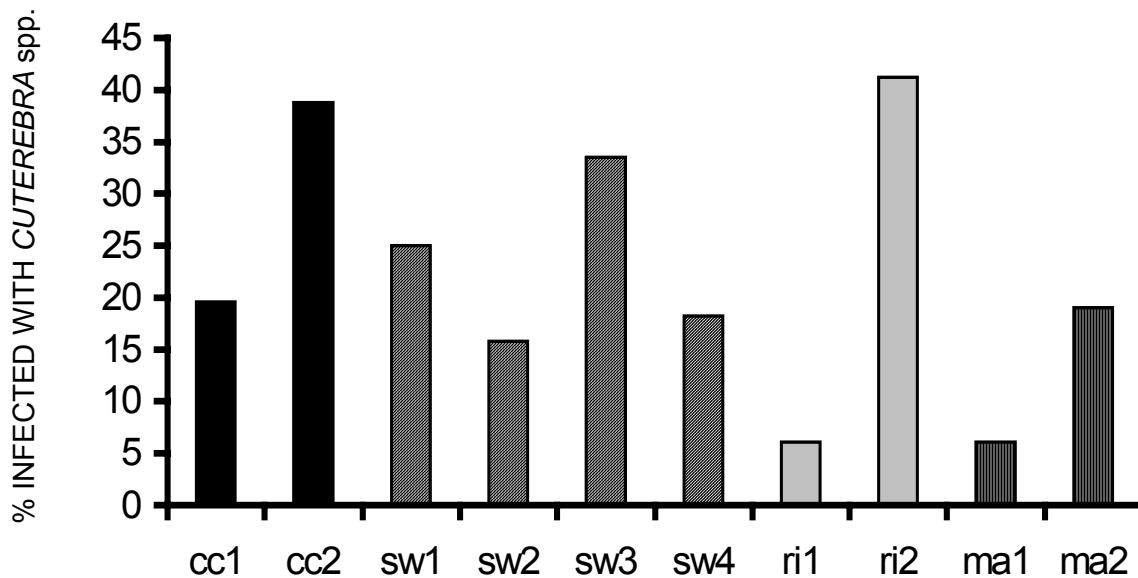
Figure 6. Percentages of white-footed mice infected with bot fly (*Cuterebra* spp.) larvae during June-August 1998 on Quantico Marine Corps Base, VA.

Table 16. ANOVA results of tests for differences in bot fly infestation rates by treatment for white-footed mice captured on Quantico Marine Corps Base from June-August 1998.

Source	df	SS	MS	F	P
Treatment	3	292	97	0.54	0.67
Error	6	1073	179		
Total	9	1364			

Table 17. Mean weights, body length and tail length by treatment and age class for four small mammal species captured on Quantico Marine Corps Base from May 1997-January 1999. Standard errors are in parentheses.

Species Age Class		Clearcut	Shelterwood	Riparian	Mature
Eastern chipmunk[a]					
Juvenile		(n=5)	(n=67)	(n=12)	(n=2)
	Weight	71.4 (3.40)	68.3 (1.33)	71.8 (1.94)	71.8 (5.88)
	Body length	137.3 (1.87)	130.1 (1.54)	134.3 (3.41)	133.8 (1.25)
	Tail length	80.4 (2.24)	81.1 (0.87)	80.2 (1.77)	79.6 (3.38)
Adult		(n=7)	(n=71)	(n=8)	(n=8)
	Weight	89.1 (1.68)	91.2 (0.97)	88.8 (1.91)	90.7 (2.14)
	Body length	141.6 (4.22)	143.4 (1.10)	142.1 (4.66)	146.5 (3.41)
	Tail length	80.3 (2.80)	81.4 (0.84)	82.9 (5.91)	79.9 (1.89)
Northern short-tailed shrew[b]					
Juvenile		(n=46)	(n=64)	(n=23)	(n=43)
	Weight	10.5 (0.11)	10.5 (0.09)	10.2 (0.18)	10.3 (0.14)
	Body length	80.0 (1.18)	78.4 (0.98)	77.9 (1.43)	76.7 (1.62)
	Tail length	17.6 (0.47)	17.0 (0.45)	17.0 (0.76)	19.0 (0.47)
Adult		(n=82)	(n=65)	(n=25)	(n=31)
	Weight	13.5 (0.15)	13.9 (0.27)	14.5 (0.52)	13.5 (0.43)
	Body length	80.9 (0.81)	82.2 (1.10)	79.6 (1.31)	81.1 (1.59)
	Tail length	18.5 (0.32)	16.9 (0.37)	17.8 (0.66)	17.8 (0.58)
Meadow vole[c]					
Juvenile		(n=27)	(n=37)		
	Weight	23.7 (0.77)	24.9 (0.55)	-	-
	Body length	99.5 (2.71)	99.4 (1.79)	-	-
	Tail length	31.8 (1.07)	32.1 (0.72)	-	-
Adult females		(n=18)	(n=34)		
	Weight	36.1 (0.97)	37.5 (1.05)	-	-
	Body length	107.6 (3.08)	109.2 (1.80)	-	-
	Tail length	36.7 (1.06)	35.0 (0.87)	-	-
Adult males		(n=30)	(n=39)	(n=2)	
	Weight	41.0 (1.19)	40.2 (1.08)	34.8 (3.25)	-
	Body length	116.5 (2.25)	113.9 (1.45)	102.0 (8.00)	-
	Tail length	40.0 (1.20)	36.1 (0.83)	37.5 (2.50)	-

[a]Individuals weighing < 80 grams at first capture were classified as juveniles (Cranford, personal comm.).
[b]Individuals weighing < 12 grams were classified as juveniles (Cranford, personal comm.).
[c]Individuals weighing < 30 grams were classified as juveniles (Cranford, personal comm..).

Table 17. Continued

Species Age Class		Clearcut	Shelterwood	Riparian	Mature
Woodland vole[d]					
Juvenile		(n=5)	(n=13)	(n=6)	(n=8)
	Weight	14.9 (1.91)	17.3 (0.41)	15.7 (1.20)	16.6 (1.12)
	Body length	80.8 (5.07)	85.8 (1.56)	86.8 (4.71)	90.9 (4.31)
	Tail length	18.0 (1.64)	17.5 (0.83)	18.2 (2.68)	14.6 (1.05)
Adult		(n=8)	(n=44)	(n=10)	(n=7)
	Weight	24.8 (1.25)	23.7 (0.50)	23.0 (0.89)	25.1 (1.36)
	Body length	93.8 (3.89)	90.4 (1.01)	99.2 (8.26)	99.7 (3.81)
	Tail length	16.8 (0.73)	16.7 (0.94)	16.1 (0.63)	17.6 (1.07)

[d]Individuals weighing < 20 grams were classified as juveniles (Cranford, personal comm.)

Woodland Voles—Overall sex ratio did not differ significantly from a 1:1 ratio (P=0.31, Table 11). No significant differences were detected in all body measurements among forest cover types for juveniles and adults (Table 15).

AGE STRUCTURE

White-footed mice.—Age structures of white-footed mice were similar across forest cover types from May-98 to Dec-98, Jan-99 (Figure 7). Trapping occasions 1 (May, Aug-97) and 2 (Feb, Mar-98) were excluded because the time interval between trapping on all sites was > 3 weeks. The greatest percentages of juveniles in the population were recorded for Dec-98, Jan-99 and May-98. This also corresponds to the time period when the most juveniles were captured (Figure 8B.). During these trapping occasions, the percentage of juveniles within the population averaged between 32-35%. Over the summer 1998 trapping period, the percent of juveniles present declined steadily from May (32%) until August (2%).

No significant difference was detected in the ratio of juvenile: adult females across cover types (Table 18, P=0.27)(Figures 7, 8A), although clearcut and mature forest cover types tended to have greater juvenile: adult female ratios.

Eastern chipmunks.—There were no consistent trends in age distributions over time among forest cover types (Figure 9) for chipmunks. Over the 1998 summer trapping period the overall percentage of juveniles within the population was highest in clearcut stands (73%, SE=16.6), followed by riparian (62%, SE=5.6), shelterwood (54%, SE=6.4) and mature (34%, SE=11.0) stands. The largest number of juveniles was captured in clearcuts during May and June, in shelterwoods during May, and in riparian stands during June (Figure 10B). New juveniles were captured within mature stands in low numbers across May, June and July.
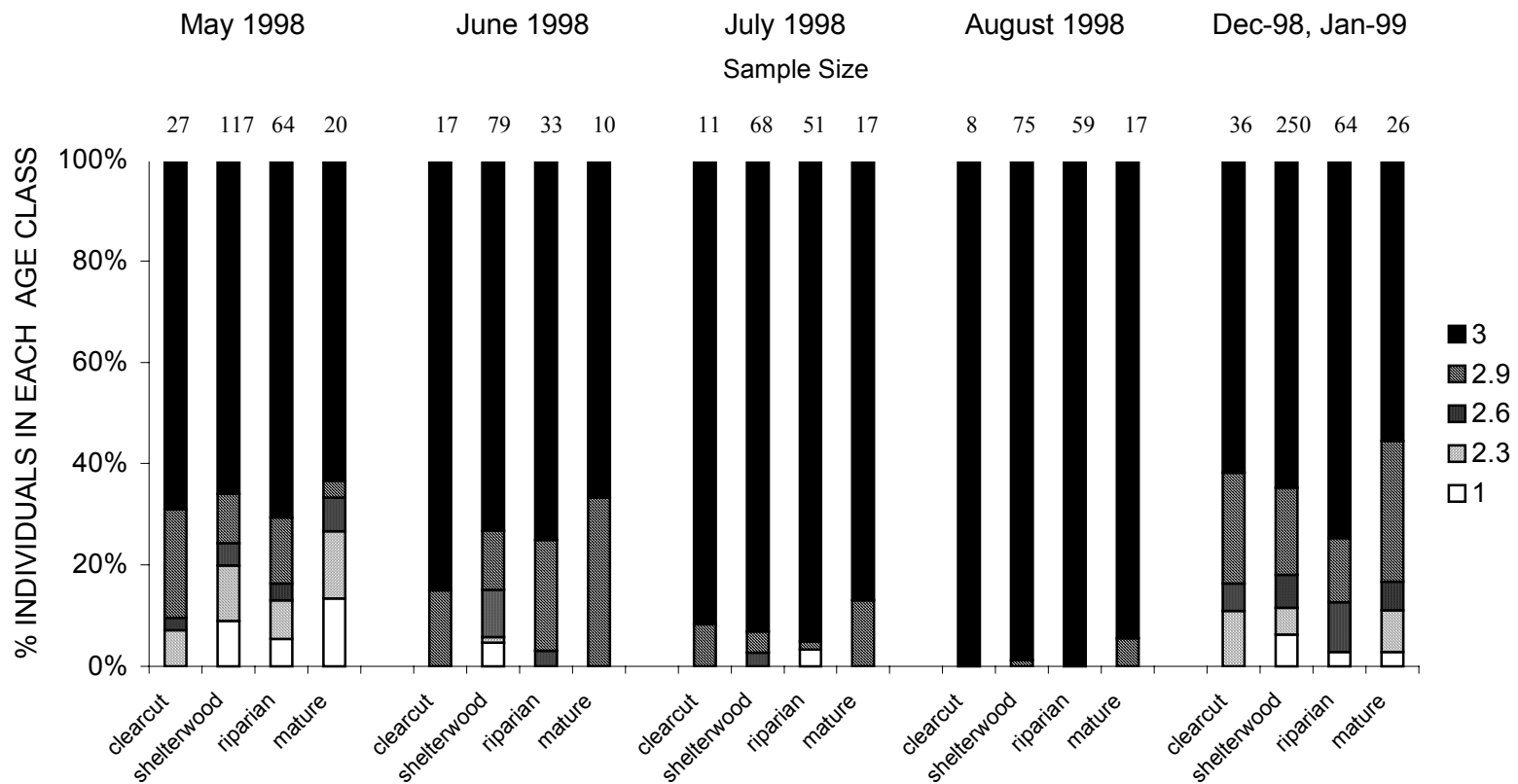
Figure 7. Age distributions by forest cover type for white-footed mice captured on Quantico Marine Corps Base, VA. May 1998-January 1999. Age classification was based on pelage coloration at the time of capture (Linzey and Linzey 1967)

A.

B.
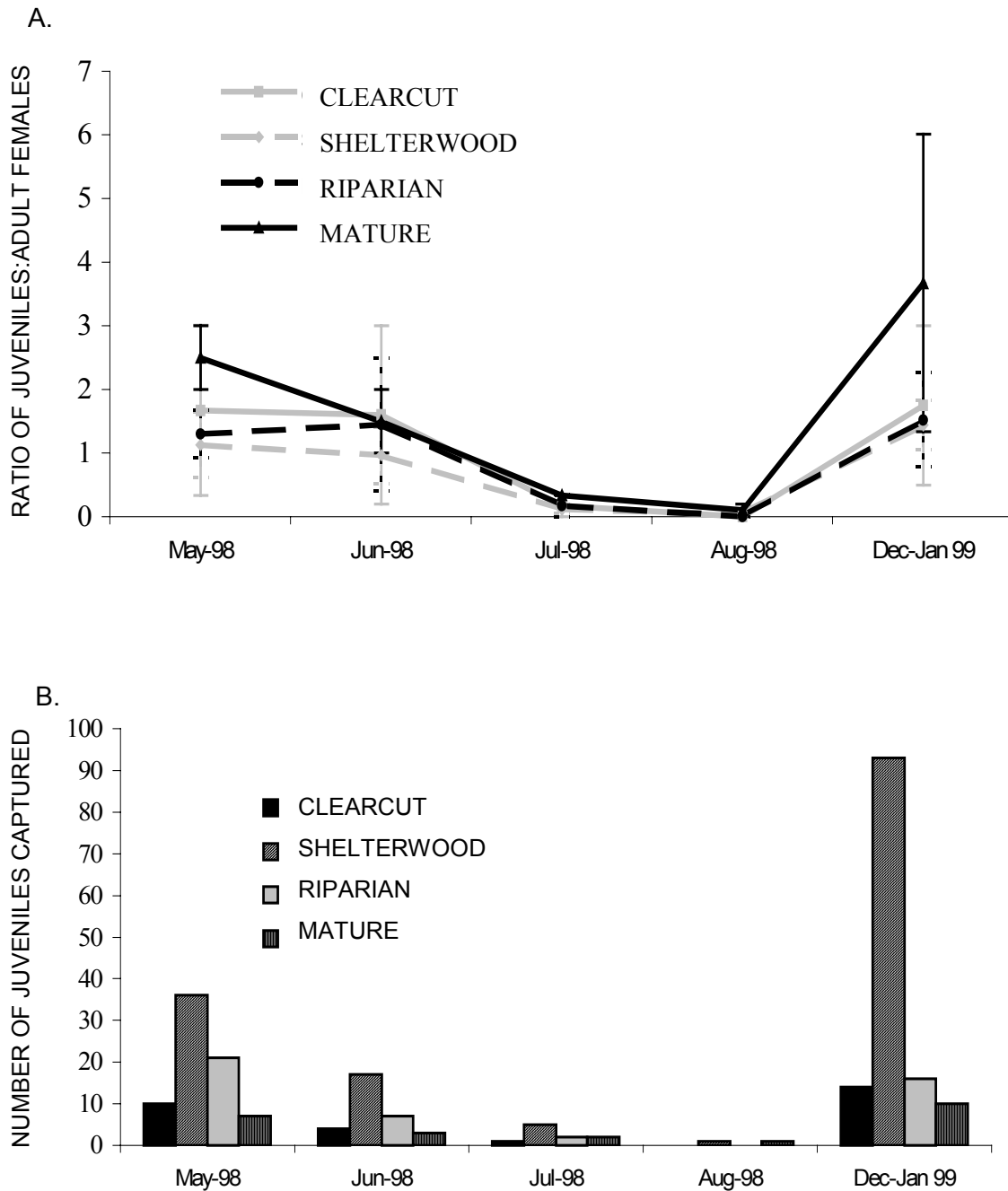
Figure 8. A) Mean ratio of juvenile: adult female white-footed mice by forest cover type with standard errors. B) Total captures of new juvenile white-footed mice by forest cover type. Trapping was conducted on Quantico Marine Corps Base, VA, from May 1997 through January 1999. Trapping occasions 1 and 2 were excluded because the time intervals between trapping rotations for all grids > 3 weeks.

Table 18. ANOVA results for treatment effects, time effects and treatment by time interaction for the ratio of juvenile:adult female white-footed mice captured on Quantico Marine Corps Base. Trapping data were collected for 4 forest cover types from May, June, July, August and December 1998-January 1999. Trapping occasions 1 and 2 were excluded from analysis because the time intervals between trapping rotations for all grids were > 3 weeks.

Source		df	SS	MS	F	P
Between Sites						
	Treatment	3	5.35	1.78	1.68	0.269
	Residual Between	6	6.38	1.06		
Within Sites						
	Time	4	30.18	7.54	6.64	0.001
	Treatment*Time Interaction	12	5.58	0.46	0.41	0.95
	Residual Between	24	27.27	1.14		
Total		49				
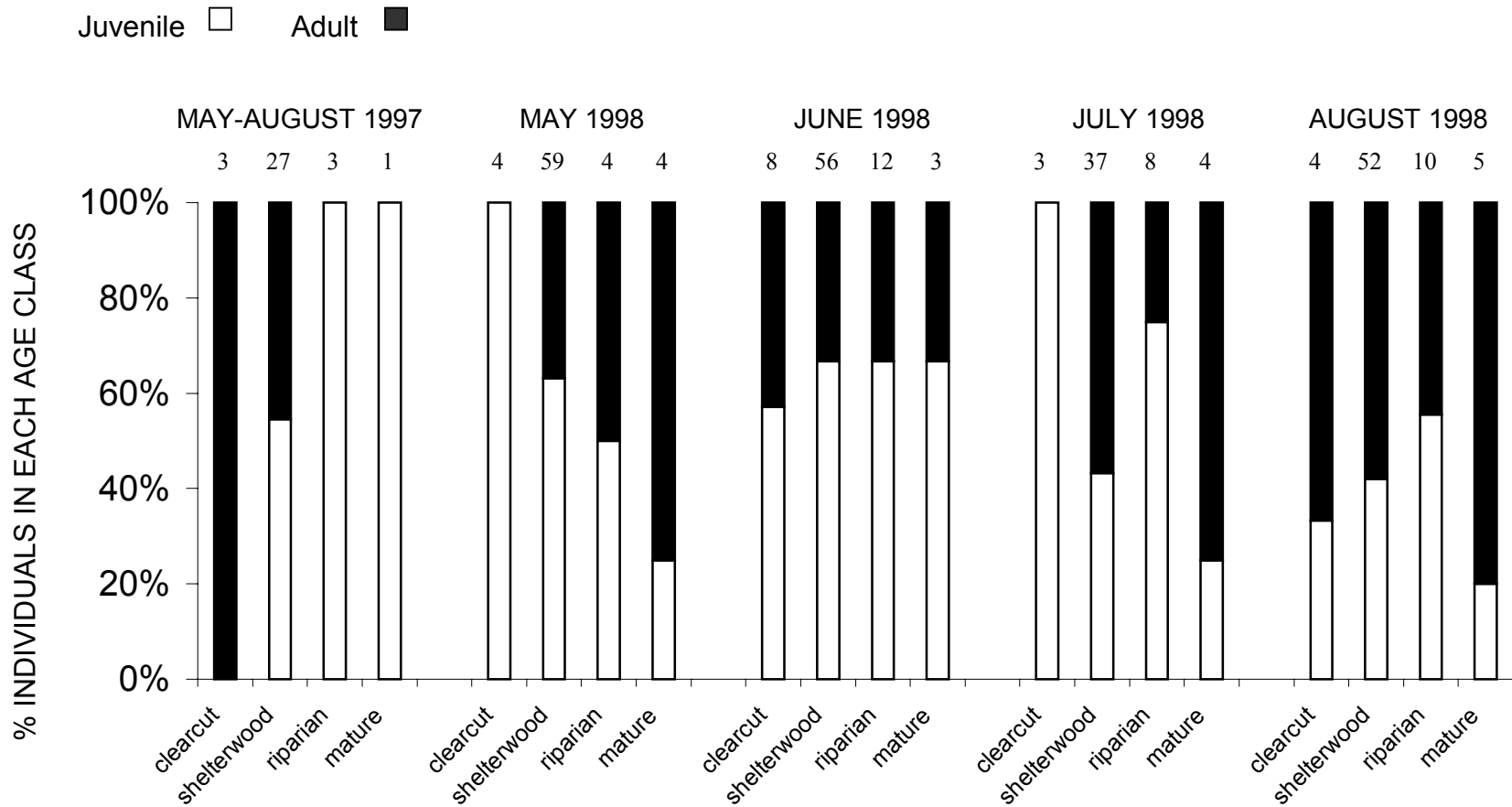
Figure 9. Age distributions by forest cover type for eastern chipmunks captured on Quantico Marine Corps Base, VA. May 1997-August 1998. Age classification was based on weight at time of capture (Cranford, personal comm.) Individuals < 80 grams were considered juveniles (age class 1).
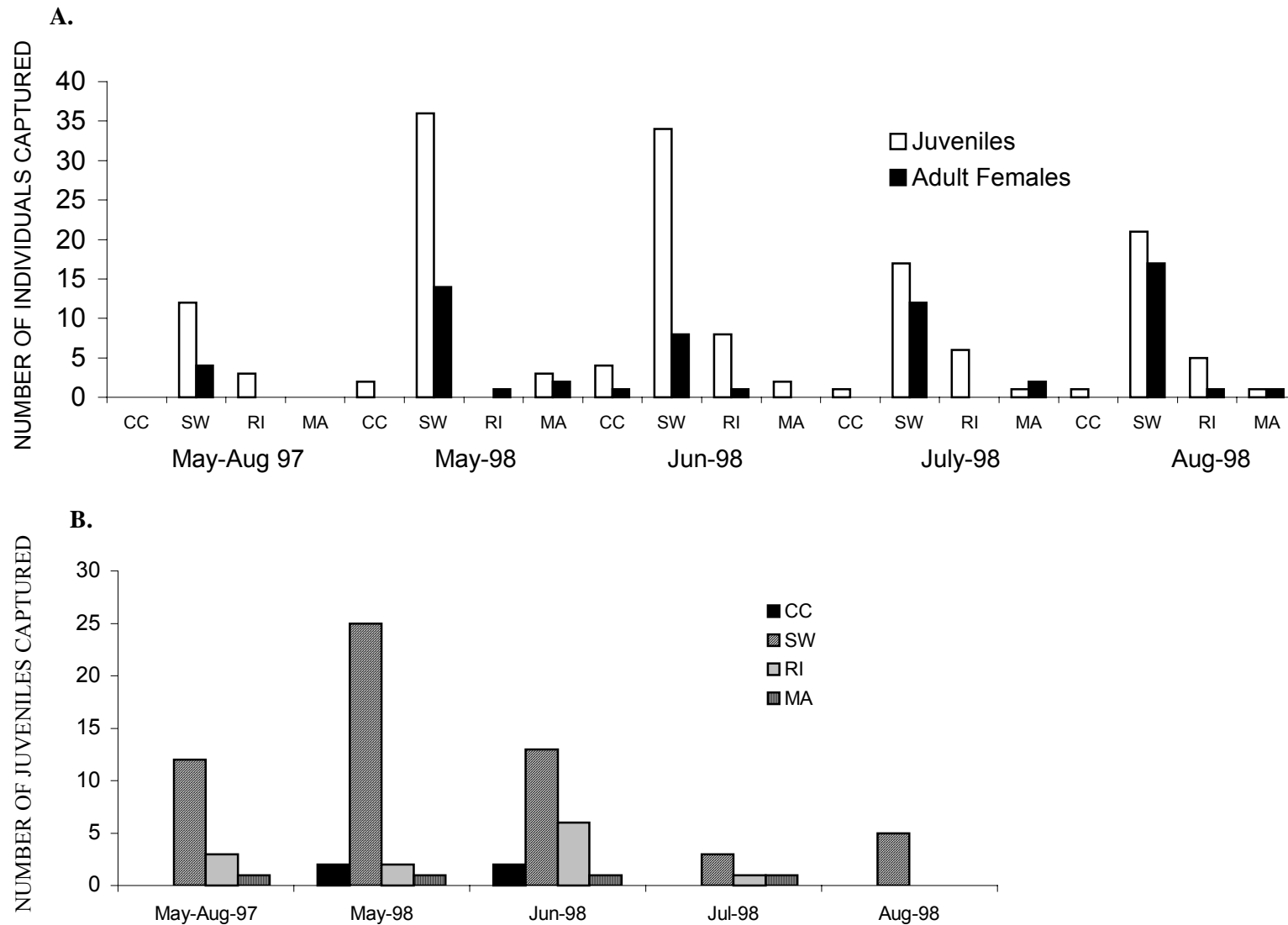
Figure 10. A) Number of juvenile and adult female eastern chipmunks captured on Quantico Marine Corps Base, VA by forest cover type and trapping occasion. Trapping occasions 2 and 7 were excluded due to winter torpor. B) Total captures of new juvenile eastern chipmunks by forest cover type.

The ratio of juvenile: adult female eastern chipmunks could not be compared among forest cover types because of the number of trapping occasions when no juveniles and/or adult females were captured (Figure 10A). No other species were included in these analyses because small sample sizes were likely to bias results.

REPRODUCTION

Because of limited sample sizes, only white-footed mice were used in analyses of reproductive activity. No difference among forest cover types was detected in the proportion of reproductively active adult female white-footed mice based on both vaginal perforation and nipple size (P=0.36, 3, 6 df, Table 19). However, there was a trend for reproductive rates within mature stands to be the lowest among all forest cover types (Figure 11A.). A moderately significant time effect was detected (P=0.09, 4, 24 df, Table 19). During the 1998 summer trapping period the percentage of reproductively active female white-footed mice dropped from a high during May of 28.9% to a low of 1.3% during June and subsequently recovered during July (17.4%) and August (27.2%). The highest percentages of reproductively active females were recorded during the Dec-1998, Jan-1999 trapping period, (31.5%).

When the criteria for assessing female reproductive condition (nipples size, vaginal perforation) were examined separately, no differences among forest cover types were detected (nipple size: P=0.40, 3, 6 df; vaginal perforation: P=0.14, 3, 6 df, Table 19). A significant time effect was detected for measures based on nipple size (P=0.02, 4, 24 df). More females were classified as being reproductive based on nipple size during May 1998 (23.3%) and Dec-1998, Jan-1999 (27.8%) than for June (0%), July (2.1%) and August 1998 (4.6%)(Figure 11B.).

Table 19. ANOVA results for treatment effects, time effects and treatment by time interaction for the proportion of reproductively active adult female and male white-footed mice. Data were collected for 4 forest cover types from May-August and December-January 1999. Reproductive of condition of females was assessed on basis of nipple size and/or perforation and for males on the size and position of the testes.

Females: based on all measures

Source	df	SS	MS	F	P
Between Sites					
Treatment	3	0.17	0.06	1.28	0.36
Residual Between	6	0.27	0.05		
Within Sites					
Time	4	0.56	0.14	2.28	0.09
Treatment*Time Interaction	12	0.54	0.04	0.73	0.71
Residual Between	24	1.47	0.06		
Total	49				

Females: based on nipple size only

Source	df	SS	MS	F	P
Between Sites					
Treatment	3	0.05	0.02	1.17	0.40
Residual Between	6	0.09	0.01		
Within Sites					
Time	4	0.61	0.15	3.48	0.02
Treatment*Time Interaction	12	0.20	0.02	0.37	0.96
Residual Between	24	1.05	0.04		
Total	49				

Females: based on vaginal perforation only

Source	df	SS	MS	F	P
Between Sites					
Treatment	3	0.22	0.07	2.72	0.14
Residual Between	6	0.16	0.03		
Within Sites					
Time	4	0.52	0.13	1.78	0.17
Treatment*Time Interaction	12	0.91	0.08	1.04	0.45
Residual Between	24	1.74	0.07		
Total	49				

Table 19. Continued

Adult males

Source	df	SS	MS	F	P
Between Sites					
Treatment	3	0.22	0.07	1.15	0.40
Residual Between	6	0.39	0.06		
Within Sites					
Time	4	0.54	0.14	4.71	0.006
Treatment*Time Interaction	12	0.46	0.04	1.33	0.26
Residual Between	24	0.69	0.03		
Total	49				

Adult males and females

Source	df	SS	MS	F	P
Between Sites					
Treatment	3	0.17	0.06	2.44	0.16
Residual Between	6	0.14	0.02		
Within Sites					
Time	4	0.41	0.10	3.93	0.01
Treatment*Time Interaction	12	0.30	0.03	0.96	0.51
Residual Between	24	0.63	0.03		
Total	49				

A.   All Measures

B.   Nipple Size

C.   Vaginal Perforation
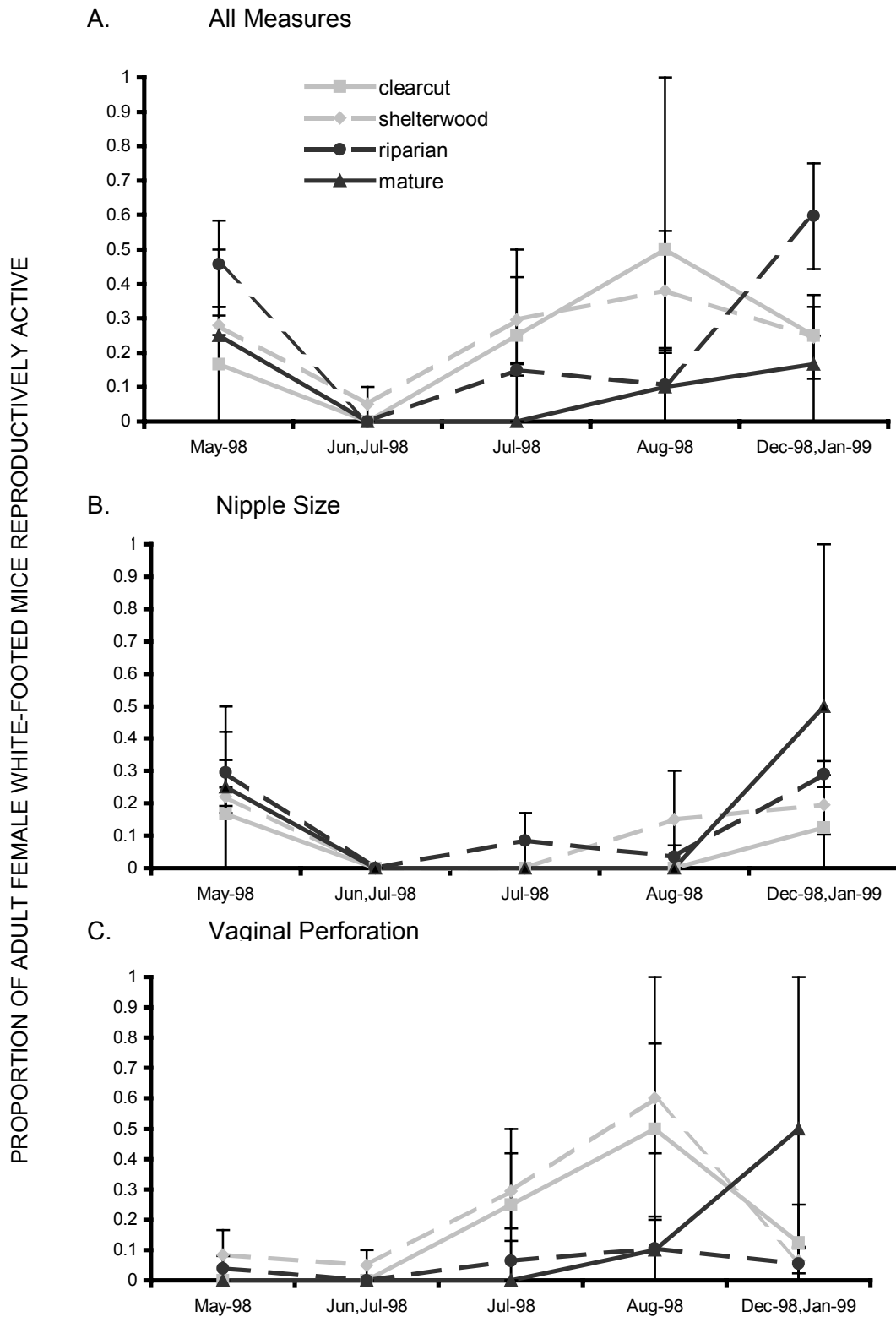
Figure 11. A) Proportion of reproductively active adult female white-footed mice by forest cover type based on vaginal perforation and nipple size. B) Proportion of reproductively active adult females based on nipple size only. C) Proportion of reproductively active adult females based on vaginal perforation only.

D.

E.
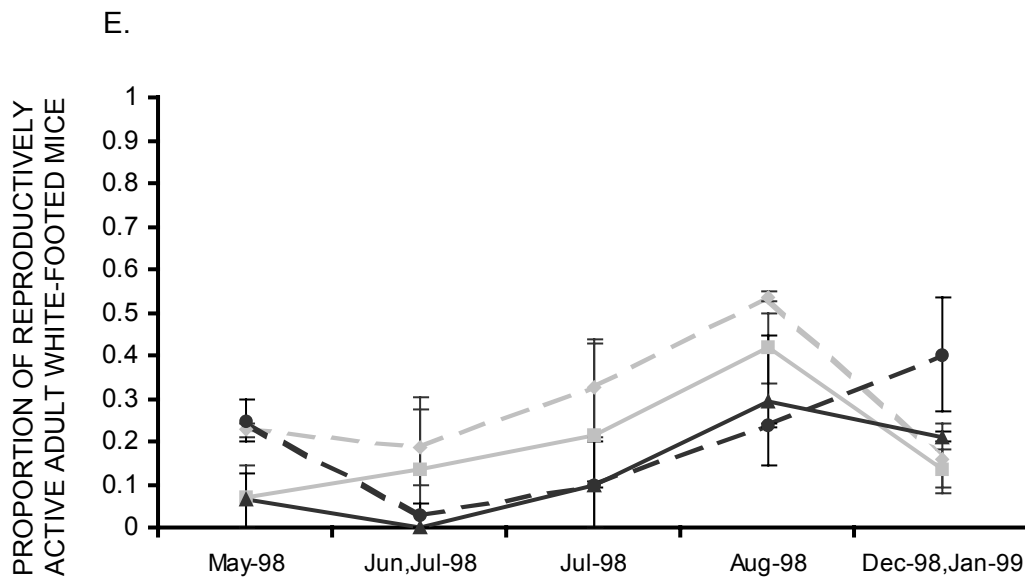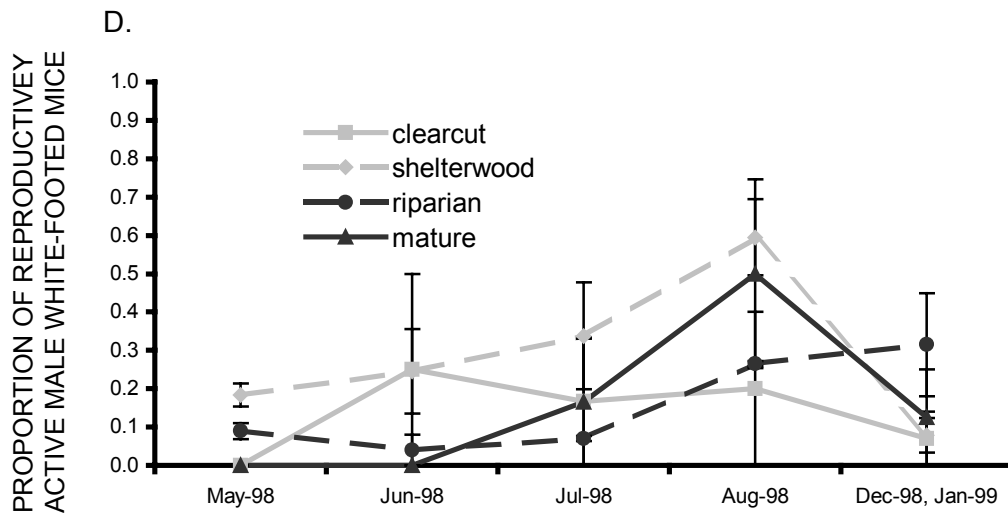
Figure 11. Continued. D) Proportion of reproductively active adult male white-footed mice by forest cover type. E) Proportion of reproductively active adult male and female white-footed mice by forest cover type. Reproductive activity was assessed in males by testes size and position, and for females by vaginal perforation and nipple size.

The percentage of perforate females was low within all forest cover types during May 1998 (3%) and June 1998 (1%)(Figure 11C.). By July the percentage of perforate females within clearcuts and shelterwoods increased (27.3%) but remained low in mature and riparian cover types (3.3%). Peak percentages of perforate females over the summer 1998 trapping period were recorded during August (55% clearcuts/shelterwoods, 10.3% mature/riparian stands). However, differences among forest cover types were masked by considerable amounts of variation within cover types.

No differences among treatments were detected in the percentages of reproductively active adult male white-footed mice based on testes size/position ($\underline{P}$=0.40, 3, 6 df, Table 19). There was a tendency for reproductive rates to be greatest among males within shelterwoods (Figure 11D.). A significant time effect was detected ($\underline{P}$=0.006, 4, 24 df). Over the summer 1998 trapping period the percentage of reproductively active males was lowest in May (18.4%) and June (15.6%) and increased steadily through July (21.5%) to peak in August (43.1%)(Figure 11D.). When males and females were combined for analyses, no differences in the percentages of reproductively active individuals were detected among forest cover types ($\underline{P}$=0.16, 3, 6 df, Table 19). There was a tendency for greater numbers of reproductively active individuals to be captured within the clearcut and shelterwood forest cover types. Following the trends seen in females and males, there was a significant time effect ($\underline{P}$=0.01, 4, 24 df) with an increasing number of reproductively active individuals captured from May to August.

Birth Pulses for White-footed Mice.--Most juveniles captured during the summer '98 trapping season were born at the end of March to mid-late April, based on backdating ages from pelage (Figure 12). Very few white-footed mice were born in May and no mice were captured that were born in June, July or August. Of the juveniles captured during the Dec-98, Jan-99
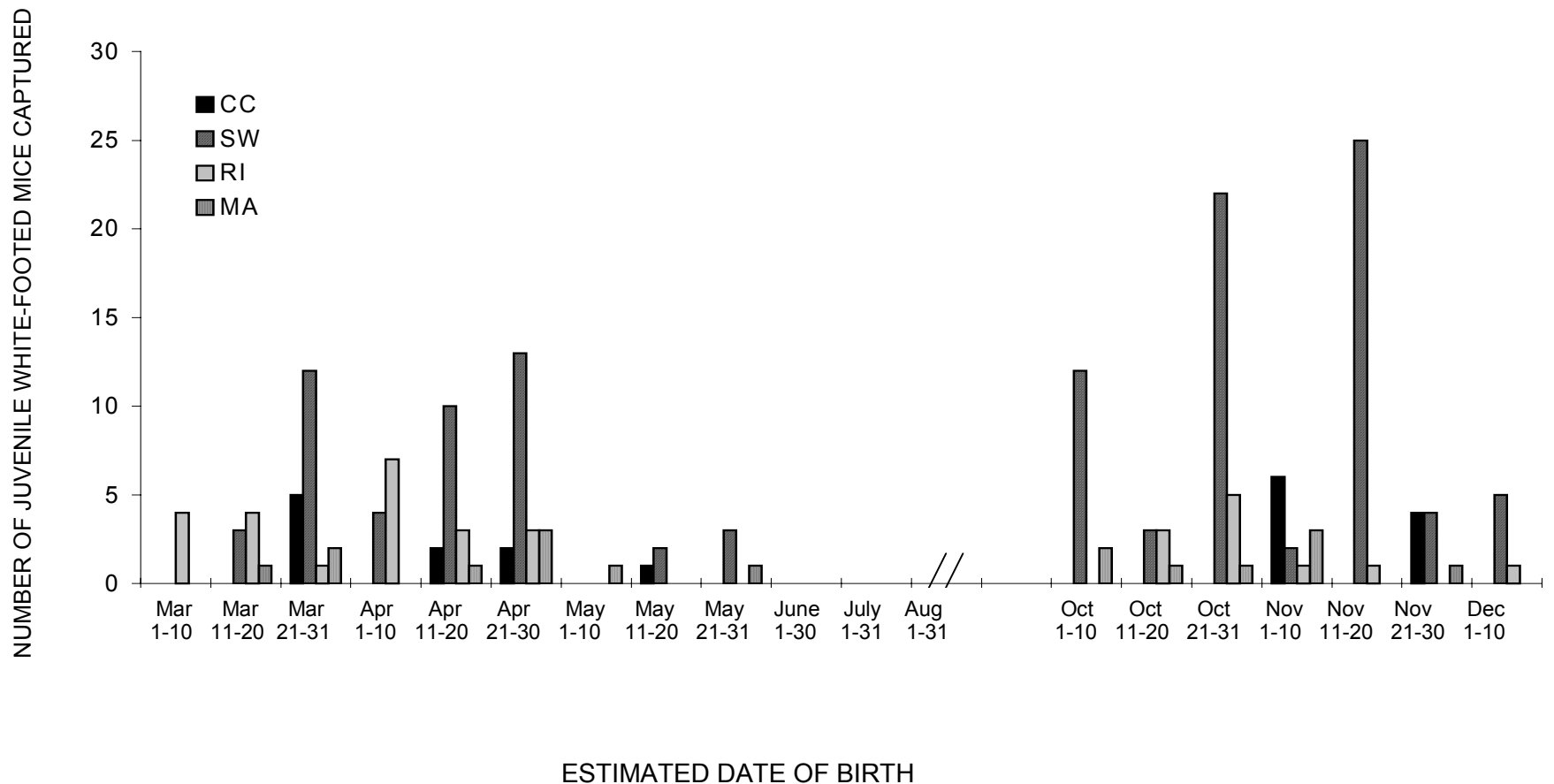
Figure 12. Estimated date of birth frequencies for juvenile white-footed mice captured on Quantico Marine Corps Base, VA during May-August 1998 and December 1998-January 1999 by forest cover type. Trapping was not conducted from mid-August-November 1998, therefore no information is available on dates of birth frequencies for this time period. Dates of birth were back-dated based on pelage characteristics recorded at initial capture (Cranford, personal comm.). Juvenile birthdays were back-dated 35 days, side-molts 50 days, back-molts 60 days, and head-tail molts 70 days.

trapping period, most were born during late October to mid-November. Based on the

frequencies of juveniles captured, the October-November birth pulse was larger than the March-

April birth pulse for shelterwoods and smaller for riparian stands. Mature and clearcut stands

had comparably sized birth pulses during spring and winter.

RESIDENCY

White-footed mice.—No difference was detected between residency rates and lengths of

residency for juvenile and adult white-footed mice, therefore, these groups were pooled for

analyses (Residency rate: P=0.41, df; Residency length: P=0.32, df)

No difference was detected across cover types in the ratio of resident (individuals caught

on $\geq$ 2 trapping occasions) to transient white-footed mice over the 1998 summer trapping period

(P=0.68, 2 df, Table 20). The overall residency rate among white-footed mice was 65%.

Residency rates were greatest within riparian stands (74.6% ± 3.2) followed by shelterwoods

(68.8% ± 7.4), clearcuts (65.9% ± 2.3) and mature (50.7% ± 10.7)(Figure 13).

A marginal difference was detected in the number of days residents were observed on site

among forest cover types (P=0.09, 3df, Table 20). Minimum length of residency was greatest in

shelterwoods (129 days ± 10.0), followed by riparian (120 ± 11.0), clearcut (106 ± 24.7), and

mature (86 ± 23.6) stands (Figure 13).

Eastern chipmunks.— A difference was detected in the ratio of resident to transient

eastern chipmunks over the 1998 summer trapping period (P<0.01, 2 df, Table 20). The overall

residency rate among eastern chipmunks was 51%. Residency rates were greatest within RI2

(76.9%) followed by shelterwood (53.2% ± 5.0), mature (50.0% ± 30.0) and clearcut (25.0% ±

25.0) stands (Figure 14). There was considerable variation in residency rates within mature and

Table 20. Percent of the population (captured from May-August 1998) classified as residents and mean lengths of residency (in days) by forest cover type for white-footed mice and eastern chipmunks captured on Quantico Marine Corps Base, VA from May-Aug 1998. Residents were classified as those individuals present on a site ≥ 2 trapping occasions. Standard errors are noted in parentheses. The mean length of time between trapping occasions over the summer trapping period was 22 days, SE = 2.6.

Forest Cover Type	White-footed Mice			Eastern Chipmunks		
	Total white-footed mice	% Residents	Mean length of residency	Total eastern chipmunks	% Resident	Mean Length of residency
CC	33	65.9 (2.3)	105.5 (24.7)	8	25.0 (25.0)	46 (20.0)
SW	148	68.8 (7.4)	129.1 (10.0)	76	53.2 (5.0)	82.1 (15.0)
RI	94	74.6 (3.2)	120.2 (11.0)	13	76.9 -	43.0 (3.24)
MA	34	50.7 (10.7)	86.1 (23.6)	6	50.0 (30.0)	57.3 (8.7)
P-Value[a]		0.68	0.09		<0.01	0.56
Cover Type Comparisons		-	-		CC[A]SW[A]RI[B]MA[AB]	-

[a]Significance tests for numbers of residents consisted of Chi-Square Goodness of Fit Tests (2 df). Significance tests for lengths of residency were Kruskal-Wallis tests (3df). Forest cover type comparisons were made using Wilcoxon Rank Sum tests.

A.

B.

N = 33   N = 148   N = 94   N = 34
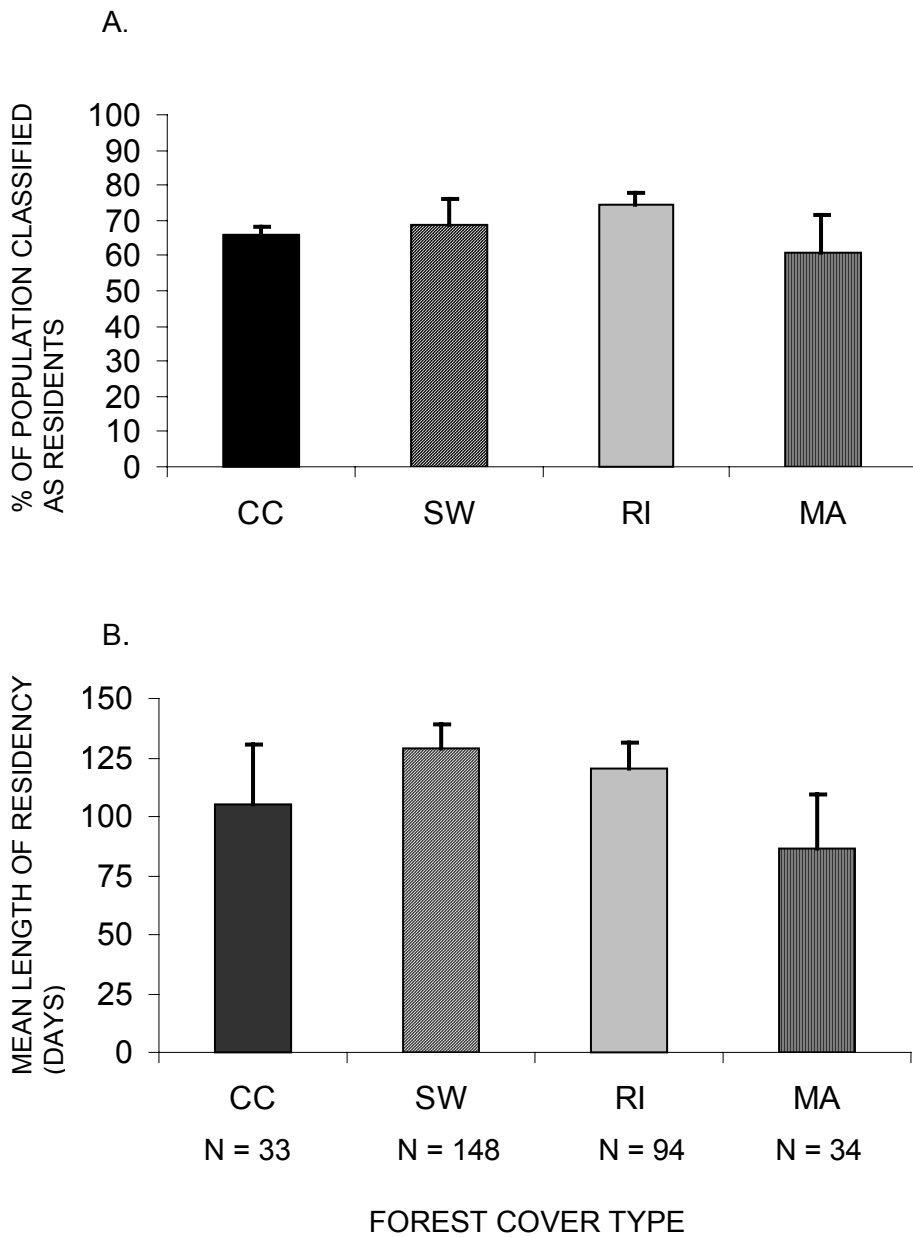
FOREST COVER TYPE

Figure 13. A) Percentage of individual white-footed mice captured on Quantico Marine Corps Base from May 1998-August 1998 classified as residents by forest cover type (excludes animals captured as new individuals from August 1998 since a determination of residency could not be made). B) Mean length of time (days) residents were observed by forest cover types. Bars represent standard errors.
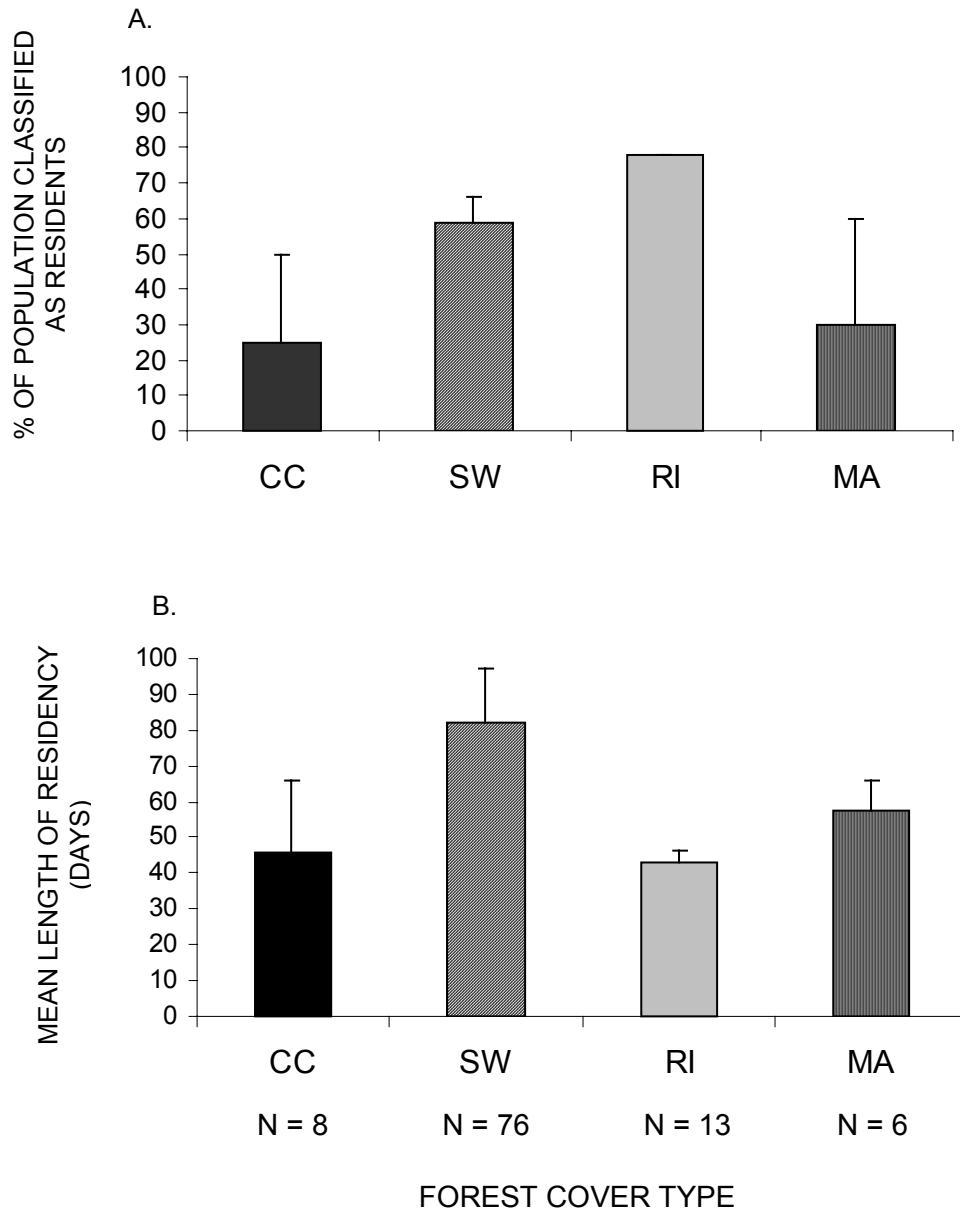
Figure 14. A) Percentage of individual eastern chipmunks captured on Quantico Marine Corps Base from May 1998-August 1998 classified as residents by forest cover type (excludes animals captured as new individuals from August 1998 since a determination of residency could not be made). B) Mean length of time (days) residents were observed by forest cover type. Bars represents standard errors.

clearcut cover types and residency rates for riparian stands reflect only those from one site since no eastern chipmunks were captured on RI1. No difference was detected in the number of days residents were observed on site among forest cover types (P=0.56, 3 df, Table 20). Length of residency was greatest in shelterwoods (82 days ± 15.0), followed by mature (57 ± 8.7), clearcut (46 ± 20.0), and riparian (43 ± 3.24) stands (Figure 14).

SURVIVAL

<u>White-footed mice</u>.—Overall survival rates were standardized to 26-day intervals and could only be estimated for trapping occasions 1-6. Survival rates (from when individuals entered the trappable population) ranged from 100% ± 0.00 (trapping interval 5-6) to 73% ± 5.0 (3-4)(Table 21). Average 26-day survival rates were 82.6% ± 5.0. Once individuals entered the trappable population, 7.4% could expect to survive their first year. Capture probabilities ranged from 49.0% ± 5.0 (3-4) to 84.0% ± 6.0 (2-3) with an average value of 62.8 % ± 6.0.

Comparisons of survival and capture probabilities among juvenile and adult white-footed mice were constrained to the 1998 summer trapping season. No difference was detected in survival and capture probabilities among adults and juveniles (Program Release GOF, <u>P</u>=0.40, 7 df). Summer survival estimates of adults (59%) were not significantly different from juveniles (49%). Among juveniles, no significant differences were found in survival rates or capture probabilities between the sexes (Program Release GOF, <u>P</u>=0.86, 7 df). There was a tendency for summer survival estimates of juvenile females (59%) to be greater than for juvenile males (41%).

A difference was detected in survival rates but not capture probabilities among forest cover types (Program Release GOF, <u>P</u>=0.01, df). However this difference was an artifact of the

standard error estimates for shelterwood and riparian stands during the interval between trapping occasions 5 to 6 (during this interval, standard error estimates for both cover types were 0.00)(Table 22). Mean survival rates were generally greater in riparian stands (84.8% ± 5.0) and shelterwoods (82.0 ± 5.2) than for mature (78.2 ± 4.2) or clearcut (75.4 ± 7.0).

Eastern chipmunks.— Overall survival rates were standardized to 26-day intervals and could only be estimated for trapping occasions 1-3, 3-4 and 4-5. Survival rates (from when individuals entered the trappable population) ranged from 89% ± 9.0 (trapping interval 1-3) to 62% ± 7.0 (3-4)(Table 23). Average 26-day survival rates were 76.7% ± 7.9. Capture probabilities ranged from 100.0% ± 0.0 (1-3) to 77.0% ± 7.0 (4-5) with an average value of 88.7% ± 6.6.

No difference was detected in survival rates and capture probabilities of adults and juveniles (Program Release GOF, $\underline{P}$=0.49, 6 df). Summer survival of adults (43%) was not significantly different from juveniles (19%) while capture probabilities of juveniles (89.1% ± 5.9) was non-significantly greater than for adults (71.4% ± 8.9)(Table 23). Because of low sample sizes, no examination of survival rates among forest cover types was possible.

HABITAT RELATIONSHIPS

CANONICAL CORRESPONDANCE ANALYSIS

Three canonical axes collectively explained a significant amount of the variation in species' relative abundances based on macrohabitat features (Monte Carlo test, $\underline{P}$=0.03). Axes 1 and 2 accounted for the greatest amount of the variation (76%) in species data and results are restricted to their interpretation (Table 25). In CCA, ordination of species is constrained by the multiple regression of species on habitat characteristics for sites (ter Braak 1987). The canonical coefficients from the multiple regression report the effectiveness of the environmental variables

Table 21. Survival estimates and capture probabilities for white-footed mice (including residents and transients) captured on Quantico Marine Corps Base, May 1997 - August 1998. Survival estimates were obtained through MARK (Cooch and White 1998) and are standardized for 26-day intervals.

Classification	Sample Size	Model	Trap Interval[a]	Survival (26 day)	SE	95% CI	Capture Probability	SE	95% CI
All Individuals	516	Phi(t)p(t)	1-2	0.87	0.02	0.83-0.91	0.53	0.11	0.32-0.73
			2-3	0.78	0.02	0.72-0.82	0.84	0.06	0.69-0.92
			3-4	0.73	0.05	0.62-0.82	0.49	0.05	0.40-0.59
			4-5	0.75	0.05	0.64-0.82	0.64	0.04	0.56-0.71
			5-6	1.00	0.00	0.99-1.00	0.64	0.04	0.56-0.71
Adults	175	Phi(g*t)p(t)	3-4	0.86	0.08	0.64-0.95	0.48	0.06	0.38-0.59
			4-5	0.74	0.06	0.60-0.84	0.64	0.05	0.53-0.74
			5-6	0.93	0.06	0.67-0.99	0.72	0.07	0.56-0.83
			Summer98	0.59		0.26-0.79			
Juveniles	88		3-4	0.74	0.09	0.52-0.88			
			4-5	0.67	0.08	0.51-0.81			
			5-6	0.98	0.07	0.01-0.99			
			Summer98	0.49		0.01-0.71			
Juveniles									
Males	48	Phi(g*t)p(.)	3-4	0.59	0.11	0.37-0.78	0.63	0.05	0.52-0.72
			4-5	0.69	0.10	0.46-0.85			
			5-6	1.00	0.00	0.99-1.00			
			Summer98	0.41	-	0.17-0.66			
Females	40		3-4	0.77	0.10	0.52-0.91			
			4-5	0.77	0.10	0.54-0.91			
			5-6	1.00	0.00	0.99-1.00			
			Summer98	0.59	-	0.28-0.83			

[a]Mean time between trapping intervals: 1-2 = 228 days, 2-3 = 93 days, 3-4 = 26 days, 4-5 = 23 days, 5-6 = 17 days

Table 22. Survival estimates and capture probabilities by forest cover type for white-footed mice (including residents and transients) captured on Quantico Marine Corps Base, May 1998 - August 1998. Survival estimates were obtained through MARK (Cooch and White 1998) and are standardized for 26-day intervals.

Model	Forest Cover Type	Trap Interval[a]	Survival (26 day)	SE	95% CI	Capture Probability	SE	95% CI
Phi(g*t)p(t)	Clearcut[b]	1-2	0.97	0.04	0.57-0.99	0.52	0.11	0.31-0.73
	Shelterwood[c]		0.86	0.02	0.81-0.90			
	Riparian[d]		0.84	0.05	0.73-0.91			
	Mature[e]		0.88	0.06	0.73-0.96			
	Clearcut	2-3	0.67	0.08	0.51-0.80	0.84	0.06	0.68-0.92
	Shelterwood		0.79	0.03	0.73-0.84			
	Riparian		0.83	0.06	0.67-0.92			
	Mature		0.68	0.12	0.41-0.86			
	Clearcut	3-4	0.86	0.16	0.29-0.99	0.49	0.05	0.39-0.58
	Shelterwood		0.72	0.07	0.58-0.83			
	Riparian		0.69	0.08	0.51-0.83			
	Mature		0.76	0.18	0.32-0.95			
	Clearcut	4-5	0.59	0.14	0.31-0.82	0.65	0.05	0.55-0.73
	Shelterwood		0.73	0.06	0.60-0.83			
	Riparian		0.88	0.07	0.65-0.97			
	Mature		0.71	0.16	0.34-0.92			
	Clearcut	5-6	0.68	0.13	0.39-0.88	0.68	0.04	0.59-0.75
	Shelterwood		1.00	0.00	0.99-1.00			
	Riparian		1.00	0.00	0.99-1.00			
	Mature		0.88	0.12	0.43-0.98			

[a] Mean time between trapping intervals: 1-2 = 228 days, 2-3 = 93 days, 3-4 = 26 days, 4-5 = 23 days, 5-6 = 17 days.
[b] N=80
[c] N=460
[d] N=149
[e] N=63

Table 23. Survival estimates and capture probabilities for eastern chipmunks (including residents and transients) captured on Quantico Marine Corps Base, May 1997 - July 1998. Survival estimates were obtained through MARK (Cooch and White 1998) and are standardized for 26-day intervals.

Classification	Sample Size	Model	Trap Interval[a]	Survival (26 day)	SE	95% CI	Capture Probability	SE	95% CI
All Individuals	142	Phi(t)p(t)	1-3	0.89	0.09	0.11-0.44	1.00	0.00	0.99-1.00
			3-4	0.62	0.07	0.48-0.74	0.89	0.06	0.70-0.96
			4-5	0.79	0.06	0.65-0.89	0.77	0.07	0.60-0.88
			Summer98[b]	0.35	-	0.16-0.46			
Adults	73	Phi(g*t)p(g)	1-3	0.86	0.05	0.75-0.93	0.71	0.09	0.51-0.85
			3-4	0.71	0.11	0.45-0.88			
			4-5	0.80	0.11	0.52-0.93			
			Summer98	0.43		0.11-0.74			
Juveniles	93		1-3	0.83	0.06	0.67-0.92	0.89	0.06	0.71-0.96
			3-4	0.59	0.09	0.41-0.75			
			4-5	0.55	0.08	0.40-0.69			
			Summer98	0.19		0.07-0.37			

[a]Mean time between trapping intervals: 1-3 = 321 days, 3-4 = 26 days, 4-5 = 23 days
[b]Summer survival estimates represent an average based on trapping occasions 3-4 and 4-5 (May-July). The average was then cubed to get the value across the entire summer since MARK does not compute survival for the last trapping occasion.

Table 24. Habitat characteristics for 10 small mammal study sites located on Quantico Marine Corps Base, VA. Habitat data were collected from May 1997-Febuary 1999. When appropriate, SE presented in parentheses.

| | Treatment and Site | | | | | | | | | |
| | Clearcut | | Shelterwood | | | | Riparian | | Mature | |
Variable	CC1	CC2	SW1	SW2	SW3	SW4	RI1	RI2	MA1	MA2
% Canopy cover	18	20	60	73	62	57	97	91	95	99
CV canopy cover	215	201	82	61	79	99	18	32	15	10
Basal area (m^2/ha)	1.53	1.53	14.16	16.07	11.02	9.18	22.58	27.09	21.81	37.65
Distance to nearest tree from station center (m)	4.17 (0.25)	4.47 (0.26)	4.95 (0.23)	3.13 (0.18)	3.98 (0.20)	3.92 (0.22)	2.17 (0.15)	2.83 (0.18)	2.01 (0.09)	2.11 (0.11)
Tree density (trees/ha)	121	114	88	254	154	135	404	315	527	528
CV tree density index	35	40	20	39	26	27	48	44	42	39
Dominant tree species	Loblolly	Loblolly	Tulip poplar	Chestnut oak	Blackgum	Blackgum	Tulip poplar	Red Maple	Red Maple	Red Maple
Density of mast trees (trees/ha)	0	3	53	99	55	48	63	50	127	212
Mean tree DBH (cm)	8.8 (0.12)	12.3 (1.05)	40.8 (1.45)	26.6 (1.12)	24.2 (1.08)	24.6 (1.27)	25.2 (0.92)	28.5 (1.32)	21.1 (1.01)	27.5 (0.84)
Shrub density (shrubs/ha)	2479	1473	1265	997	1052	1269	1262	948	1935	1480
CV shrub density	57	63	80	88	80	83	118	77	68	53
Dominant shrub species	Loblolly	Loblolly	Maple	Oak spp.	Sweetgum	Maple	Dogwood	Sweetgum	Dogwood	Dogwood
Vertical woody stem density	1.75 (0.09)	1.54 (0.06)	0.93 (0.05)	0.80 (0.05)	1.00 (0.08)	0.88 (0.06)	0.52 (0.06)	0.84 (0.09)	0.30 (0.08)	0.99 (0.06)
CV vertical woody stem density	53	42	54	59	80	73	112	106	102	57
Soft mast stem density (stems/ha)	54,890	37,733	43,807	51,632	32,862	70,649	5,196	2,858	8,709	4,637

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Table 24. Continued.

	Clearcut		Shelterwood				Riparian		Mature	
Variable	CC1	CC2	SW1	SW2	SW3	SW4	RI1	RI2	MA1	MA2
Blueberry stem density (stems/ha)	1,956	300	6,476	32,122	25,394	57,622	4,527	1,963	7,456	4,637
Blackberry stem density (stems/ha)	52,930	37,429	37,327	19,505	4,248	13,024	648	895	1249	0
Woody stem density at ground level (stems/ha)	242 (16.70)	198 (16.23)	797 (50.01)	344 (25.28)	385 (49.01)	512 (40.16)	170 (15.42)	82 (8.51)	234 (14.04)	52 (3.43)
CV woody stem density at ground level	69	82	93	74	127	73	89	104	60	66
Woody stem density at 0.5 meters (stems/ha)	260 (21.67)	214 (20.30)	543 (45.64)	212 (17.70)	244 (37.18)	312 (31.85)	58 (8.14)	39 (5.77)	59 (7.96)	37 (4.34)
CV woody stem density at 0.5 meters	83	95	84	83	152	102	137	145	133	116
Woody stem density at 1 meter (stems/ha)	260 (14.63)	215 (9.57)	223 (26.93)	73 (8.06)	67 (7.27)	105 (17.85)	23 (4.18)	20 (3.05)	22 (3.94)	21 (2.31)
CV woody stem density at 1 meter	98	100	121	110	108	170	177	154	180	12
Dominant low shrub species	Blackberry	Blackberry	Oak spp.	Oak spp.	Mountain laurel	Mountain laurel	Dogwood	Sweetgum	Oak spp.	Dogwood
Log density (logs/ha)	130	637	547	478	516	923	273	205	255	201
Log density index	122.9	49.3	52.4	66.3	39.9	59.5	89.4	104.3	90.0	105.4
CV log density index	39	91	363	228	377	83	45	315	51	38
Stump density (stumps/ha)	175	78	181	56	86	231	55	41	48	26
Stump density index	113.6	137.6	116.5	153.0	109.2	138.5	156.0	157.4	154.7	164.0

Table 24. Continued.

Variable	Clearcut		Shelterwood				Riparian		Mature	
	CC1	CC2	SW1	SW2	SW3	SW4	RI1	RI2	MA1	MA2
CV stump density index	37	27	28	17	20	28	48	16	21	13
Herbaceous stems (stems/m^2)	290 (16.67)	293 (14.85)	177 (16.48)	146 (17.45)	272 (20.89)	162 (19.32)	222 (15.81)	221 (12.39)	32 (3.73)	101 (4.62)
CV mean herbaceous stems/m^2	58	50	93	119	77	119	71	56	117	46
Mean number of herbaceous stems > 0.5m/m^2	9.7 (1 .70)	9.7 (2.23)	3.2 (0.83)	32.4 (6.40)	90.5 (11.44)	44.0 (8.79)	2.0 (1.02)	29.9 (4.41)	0.0 (0.01)	0.0 (0.03)
Mean number of grass stems/m^2	256	288	161	136	255	156	100	119	8	1
Dominant herbaceous type	Grass	Grass	Grass	Grass	Grass	Grass	Grass	Fern	*Lycopodium*	*Lycopodium*
Number of stations with no herbaceous vegetation within 1m^2 plot	1	1	2	31	23	46	0	0	16	1
Density of lianas (lianas/m^2)	42 (8.10)	43 (4.42)	1.4 (0.57)	1.3 (0.46)	3.6 (0.76)	6.2 (1.02)	15.2 (1.78)	2 (0.33)	1.7 (0.20)	0.7 (0.08)
% Ground cover	93.6 (1.23)	96.7 (0.69)	97.7 (0.44)	92.9 (1.15)	95.1 (0.84)	91.7 (1.46)	94.1 (1.00)	95 (0.90)	94.7 (0.69)	97.2 (0.48)
% Woody ground cover	5.9 (0.89)	14.5 (1.47)	7.8 (0.92)	8.8 (0.85)	10.3 (0.96)	9.2 (0.91)	4.6 (0.85)	4.8 (0.77)	4.7 (0.77)	4.2 (0.57)
% Grass ground cover	34.4	33.7	15.7	12.9	19.0	5.8	3.8	6.2	0	0
Mean litter depth (cm)	2.6 (0.93)	2.7 (0.91)	2.9 (0.83)	1.7 (0.64)	2.2 (0.87)	1.6 (0.72)	1.6 (0.47)	1.6 (0.50)	2.3 (0.60)	2.1 (0.62)

Table 25. Summary statistics derived from Canonical Correspondence Analysis for species/habitat data collected on Quantico Marine Corps Base, VA 1997-1999. Habitat variable definitions are listed in Table 3.

Habitat Variables	Standardized canonical coefficients	
	Axis1	Axis2
Nshrub	0.990	-0.587
Vwsd	1.984	-5.304
Grass	1.914	-2.318
Herb5	-1.507	4.131
Blue/ha	-0.364	1.755
Woody0	0.421	-1.833
CC	0.780	-0.982
Blkbry	-2.891	7.143
CVhstem	0.942	-3.109
Eigenvalue[a]	0.145	0.074
% Variance explained	50.3	25.7

[a]Total variance in species data = 0.289

in structuring the ordination and describe the relationships. Because the number of habitat variables included in the regression (n=9) of this dataset is large relative to sample sizes (n=10), results of CCA are only used as a descriptive tool.

Ordination diagrams (biplots) of CCA display sites, species and environmental variables (habitat characteristics). Environmental variables (displayed as lines radiating from the centroid of the ordination) indicate the direction of maximum variation for that variable. The length of each line is proportional to the rate of change in that direction. Thus, variables with longer lines are more strongly related to the pattern of community variation shown in the biplot (ter Braak 1987). The position of species and site points relative to the environmental lines are used to interpret relationships.   Approximate rankings of species' response to environmental variables can be ascertained by imagining perpendicular lines running from each species point to the environmental line.

Meadow voles (Mpe) were positively associated with increased densities of shrubs (Nshrub), tall herbaceous vegetation (Herb5), grass stems (Grass) and vertical woody stem densities (Vwsd) and negatively associated with canopy cover (CC), variation in herbaceous stem densities (CVhstem) and low woody stem densities (Woody0). These features were associated with sites SW3 and CC1.

Northern short-tailed shrews (Bb) were associated with increasing vertical woody stem density (Vwsd) and shrub (Nshrub) densities and negatively associated with Herb5, Grass, Woody0, CVhstem and CC. These environmental gradients were associated with sites MA1, MA2 and CC2.

No other species showed strong relationships to environmental gradients, as indicated by their positions near the centroid. All 3 of these species were associated with increased canopy
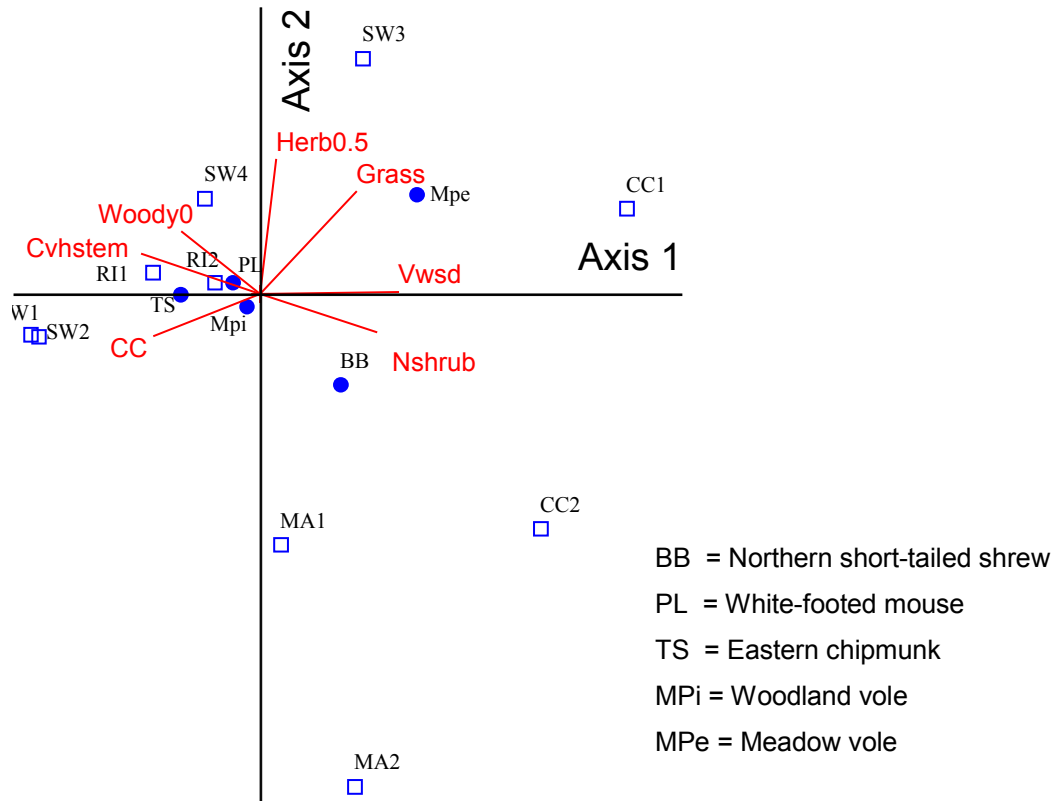
Figure 15. Ordination biplot from Canonical Correspondence Analysis of site and species scores for small mammal species captured on Quantico Marine Corps Base, VA, in 4 forest cover types (clearcut, shelterwood, riparian and mature-upland). Habitat variables include; CC = canopy cover, Vwsd = vertical woody stem density index, Nshrub = density of shrubs, CVhstem = coefficient of variation in herbaceous stem densities, Grass = density of grass stems, Herb0.5 = density of tall herbaceous vegetation, Woody0 = density of woody stems measured at ground level. Sites are denoted by boxes, species by circles.

cover (CC), low woody stems (Woody0) and variation in herbaceous stem densities (CVhstem) and negatively associated with Herb5, Grass and Nshrub. These environmental gradients were associated with SW1, SW2, SW4, RI1 and RI2.

MACROHABITAT ANALYSES

Six species' relative abundances and the overall small mammal catch per unit effort (CPUE) were included as response variables for regressions. Thirty-nine habitat characteristics were included as potential predictor variables (Table 3). All but 3 variables (Blkbry, Woody5, Woody1) explained significant amounts of variation ($P \leq 0.10$) in at least 1 simple linear regression model. Canopy cover was a significant predictor for 5 of 6 species and the percent of ground cover composed of grass was a significant predictor for 4 of 6 species. All other habitat variables were significant for ≤ 3 models.

Nineteen habitat variables were included as significant predictors in at least 1 multiple linear regression model. The mean density of tall herbaceous vegetation (Herb5) was selected most often as a significant predictor of relative abundance, appearing in 7 of 21 species models (the top 3 models are reported for each species). In 6 of those 7 models, CPUE or species relative abundance was positively related to the density of tall herbaceous vegetation. All other variables appeared in ≤ 5 models.

Total Small Mammal Captures.—Sixteen habitat variables individually accounted for a significant amount ($P<0.10$) of variation in the relative abundances of total small mammal captures across forest cover types (Table 26). Three variables (CC, Herb5, and Grass) individually explained > 50% of the variation in CPUE among sites. The 3 best 2-variable multiple linear regression models included 4 variables: Herb5, Treesrch, CVtreesrch and Smast

Table 26. Regression results testing for linear and quadratic relationships between the catch per unit effort of all small mammals in 4 forest cover types and macrohabitat characteristics. Small mammal trapping was conducted on Quantico Marine Corps Base from May 1997-January 1999 (seven 3-4 day trapping periods). For all regressions, n=10.

	Beta Coefficients					
	Linear	*P*	Quadratic	*P*	Overall *P*	R^2
% Overstory canopy cover	0.20	0.24	.002	0.009	0.01	0.64
Coefficient of variation in % canopy cover	0.06	0.07	-	-	0.07	0.29
Distance to nearest tree (m)	41.80	0.08	-	-	0.08	0.25
Tree density						
Coefficient of variation in tree density index	-0.15	0.05	-	-	0.05	0.34
Density of soft mast stems (stems/ha)	0.007	0.07	-	-	0.07	0.29
Blueberry stem density (stems/ha)	.003	0.05	-	-	0.05	0.34
Log density	0.18	0.08	-	-	0.08	0.24
Coefficient of variation in log density index	0.008	0.10	-	-	0.10	0.21
Number of stations without herbaceous cover	2.73	0.08	-	-	0.08	0.25
Number of herbaceous stems > 0.5 m (stems/m^2)	0.63	<0.001	-	-	<0.001	0.89
Number of grass stems (stems/m^2)	0.49	0.05	-	-	0.05	0.31
% Ground cover composed of woody material	12.90	0.10	-	-	0.10	0.22
% Ground cover composed of grass	16.31	0.34	0.41	0.37	0.06	0.54

Table 27. Multiple linear regression models developed for relative abundances of small mammals captured on Quantico Marine Corps Base and macrohabitat characteristics. For all regressions, n=10. Variable codes are listed in Table 3.   The 3 best 2-variable models are presented.

Species	Variable	Parameter Estimate	P	AIC	F	Model P	R^2adj
All	Intercept	0.844	0.231	2.26	68.29	<0.001	0.94
	Herb5	0.054	<0.001				
	Treesrch	-0.026	0.004				
	Intercept	2.66	<0.001	2.28	58.95	<0.001	0.93
	Herb5	0.056	<0.001				
	Smast	0.0001	0.007				
	Intercept	6.24	<0.001	0.397	38.09	<0.001	0.89
	Herb5	0.054	<0.001				
	CVtreesrch	-0.073	0.032				
White-footed mouse	Intercept	-2.23	0.024	-9.66	53.86	<0.001	0.92
	CVwoody0	0.0562	<0.001				
	Blue/ha	0.00008	<0.001				
	Intercept	-4.55	0.005	-4.67	31.33	<0.001	0.87
	CVwoody0	0.062	<0.001				
	CVherbsp	0.0492	<0.001				
	Intercept	-2.55	0.041	-4.50	30.73	<0.001	0.87
	CVwoody0	0.0609	<0.001				
	Noveg	0.0883	<0.001				
Eastern chipmunk	Intercept	0.491	0.408	-16.17	23.38	0.001	0.83
	Shrub/ha	-0.000667	0.054				
	CVdliana	0.00787	<0.001				
	Intercept	-0.860	0.030	-15.36	21.26	0.001	0.82
	Herb5	0.0208	0.075				
	CVdliana	0.00866	<0.001				
	Intercept	-0.669	0.063	-14.94	20.25	0.001	0.81
	Woody1	-0.000016	0.089				
	CVdliana	0.0115	<0.001				
Northern short-tailed shrew	Intercept	2.74	<0.001	-24.46	13.58	0.004	0.74
	CVwoody1	-0.00686	0.005				
	DBH	-0.0304	0.018				
	Intercept	2.34	<0.001	-24.35	13.38	0.004	0.73
	CVrubus0	-0.00246	0.005				
	DBH	-0.0255	0.039				
	Intercept	2.27	<0.001	-23.14	12.94	0.004	0.73
	CVwoody1	-0.003	<0.001				
	CVdliana	0.002	0.044				

Table 27. Continued

Species	Variable	Parameter Estimate	P	AIC	F	Model P	R^2adj
Meadow vole	Intercept	-0.236	0.332	-11.37	12.85	0.005	0.73
	Grscvr	0.032	0.006				
	Herb5	0.02	0.029				
	Intercept	3.13	0.041	-11.24	10.99	0.007	0.69
	Stmpsrch	-0.02	0.047				
	Herb5	0.016	0.036				
	Intercept	-0.441	0.58	-11.18	8.73	0.013	0.63
	DBH	-0.0628	0.016				
	CVwoody0	0.0308	0.009				
Woodland vole	Intercept	0.185	0.007	-46.21	26.25	0.001	0.85
	Woody0	-0.000001	0.093				
	Blue/ha	0.000012	<0.001				
	Intercept	0.399	0.045	-45.51	24.26	0.001	0.84
	Blue/ha	0.000009	<0.001				
	Litter	-0.121	0.124				
	Intercept	0.819	<0.001	-43.61	19.43	0.001	0.80
	Smast	0.000023	<0.001				
	Litter	-0.349	<0.001				
Southern flying squirrel	Intercept	3.60	0.055	-13.52	19.25	0.001	0.80
	BA	0.186	0.004				
	CVwoody1	-0.036	0.008				
	Intercept	3.00	0.242	-32.54	9.66	0.01	0.66
	DBH	0.200	0.029				
	CVwoody1	-0.046	0.009				
	Intercept	10.20	<0.001	-36.98	8.07	0.015	0.61
	Herb5	-0.017	0.047				
	CVwoody1	-0.045	0.012				

(Table 27). Of these, the best model indicated that 94% of the variability in total small mammal relative abundance was explained by the combined effects of the density of tall herbaceous vegetation and an index of tree density. Total catch per unit effort of small mammals was positively related to the density of tall herbaceous vegetation and negatively related to tree density.

White-footed Mice.--Fourteen individual predictor values accounted for a significant amount of variation in the relative abundance of white-footed mice among study sites (Table28). Of these, 6 variables (CC, CVCC, Blue/ha, Herbsp, Herb5, and Grscvr) individually accounted for > 50% of the variation. The 3 best 2-variable multiple linear regression models included 4 variables: CVwoody0, Blue/ha, CVherbsp, and Noveg (Table 27). Of these, the best model indicated that 92% of the variability in the relative abundance of white-footed mice was explained by the combined effects of the amount of variability in the density of low woody stems and the density of blueberry stems. The relative abundance of white-footed mice was positively related to both of these variables.

Eastern Chipmunks.--Nine variables explained a significant amount of the variation in chipmunk relative abundances among sites (Table 29). Four of these variables (CC, CVCC, CVdliana, and Grscvr) individually accounted for > 50% of the variation.
The 3 best 2-variable multiple linear regression models included 4 variables: Shrub/ha, CVdliana, Herb5, and Woody1 (Table 27). Of these, the best model indicated that 83% of the variability in the relative abundance of eastern chipmunks was explained by the combined effects of the shrub density and the coefficient of variation in the density of lianas. The relative

Table 28. Regression results testing for linear or quadratic relationships between the mean relative abundance of white-footed mice in 4 forest cover types and macrohabitat characteristics. Small mammal trapping was conducted on Quantico Marine Corps Base, VA, from May 1997-January 1999 (seven 3-4 day trapping periods). For all regressions, n=10.

	Beta Coefficients					
	Linear	P	Quadratic	P	Overall P	R^2
% Overstory canopy cover	0.27	0.85	-0.002	0.002	0.007	0.71
Coefficient of variation for canopy cover	0.08	0.68	0.0004	0.001	0.005	0.78
Density of shrubs (shrubs/ha)	-0.01	0.02	0.000003	0.24	0.04	0.50
Coefficient of variation for shrub density	0.06	0.08	-	-	0.08	0.24
Coefficient of variation for woody stem density at 0 meters	0.06	0.07	-	-	0.07	0.27
Blueberry stem density (stems/ha)	0.00008	0.01	-	-	0.01	0.54
Log density index	-0.04	0.07	-	-	0.07	0.26
Coefficient of variation in log density index	0.008	0.08	-	-	0.08	0.24
Number of stations without herbaceous cover	0.08	0.02	-	-	0.02	0.43
Number of herbaceous species (species/m^2)	-7.39	0.19	0.09	0.02	0.02	0.66
Coefficient of variation of herbaceous species	0.05	0.03	-	-	0.03	0.42

Table 29. Regression results testing for linear or quadratic relationships between the mean relative abundance of eastern chipmunks in 4 forest cover types and macrohabitat characteristics. Small mammal trapping was conducted on Quantico Marine Corps Base, VA, from May 1997-January 1999 (7, 3-4 day trapping periods). For all regressions, n=10.

	Beta Coefficients					
	Linear	P	Quadratic	P	Overall P	R^2
% Overstory canopy cover	0.12	0.90	-0.001	0.007	0.02	0.59
Coefficient of variation for % canopy cover	0.035	0.907	-0.0002	0.014	0.04	0.60
Mean dbh of trees (cm)	0.060	0.104	-	-	0.10	0.21
Density of shrubs (shrubs/ha)	0.008	0.108	-0.000002	0.141	0.09	0.35
Woody stem density at 0 meters	0.000007	0.083	-	-	0.08	0.24
Coefficient of variation of log density index	0.005	0.02	-	-	0.02	0.45
Coefficient of variation for liana stem density	0.009	<0.001	-	-	<0.001	0.74
% Ground cover composed of woody material	1.232	0.547	-0.066	0.015	0.04	0.50
% Ground cover composed of grass	0.231	0.91	-0.007	0.004	0.01	0.64

abundance of eastern chipmunks was negatively related to shrub density and positively related to the amount of variability in the density of lianas.

Northern Short-tailed Shrews.--Twelve predictor variables explained a significant amount of the variation in the relative abundance of northern short-tailed shrews (Table 30). Four of these variables (BA, Vwsd, CVblkberry, and Dliana) explained > 50% of the variation. The 3 best 2-variable multiple linear regression models included 4 variables: CVwoody1, Dbh, CVrubus0, and CVdliana (Table 27). Of these, the best model indicated that 74% of the variability in the relative abundance of northern short-tailed shrew was explained by the combined effects of the variability in tall woody stem densities and tree size. The relative abundance of shrews was negatively related to both variables.

Meadow Voles.— Eight predictor variables explained a significant amount of the variation in the relative abundances of meadow voles among study sites (Table 31). No individual predictors explained > 50% of the variability. The 3 best 2-variable multiple linear regression models included 5 variables: Grscvr, Herb5, Stmpsrch, Dbh, and Cvwoody0 (Table 27). Of these, the best model indicated that 73% of the variability in the relative abundance of meadow voles was explained by the combined effects of the percent of grass cover and the density of tall herbaceous vegetation. The relative abundance of meadow voles was positively related to both variables.

Woodland Voles.— Eight predictor variables explained a significant amount of the variation in woodland vole relative abundances among sites (Table 32). Of these, 4 predictors (Blue/ha, Noveg, Herbsp, and % ground cover) individually explained > 50% of the variability. The 3 best 2-variable multiple linear regression models included 4 variables: Woody0, Blue/ha,

Table 30. Regression results testing for linear or quadratic relationships between the mean relative abundance of northern short-tailed shrews in 4 forest cover types and macrohabitat characteristics. Small mammal trapping was conducted on Quantico Marine Corps Base, VA, from May 1997-January 1999 (7, 3-4 day trapping periods). For all regressions, n=10.

	Beta Coefficients					
	Linear	P	Quadratic	P	Overall P	R²
% Overstory canopy cover	-0.01	0.09	-	-	0.09	0.23
Coefficient of variation for % canopy cover	0.004	0.066	-	-	0.07	0.28
Basal area	-0.127	0.481	0.003	0.001	0.00	0.74
Mean dbh of trees (cm)	-0.033	0.086	-	-	0.09	0.24
Density of mast trees (trees/ha)	-0.221	0.367	0.011	0.004	0.06	0.43
Coefficient of variation for shrub density	-0.020	.014	-	-	0.01	0.50
Vertical woody stem density	2.410	0.007	-	-	0.01	0.57
Coefficient of variation in vertical woody stem density	-0.013	0.038	-	-	0.04	0.37
Coefficient of variation in woody stem density at 1 meter	-0.007	0.019	-	-	0.02	0.46
Coefficient of variation in blackberry stem densities	-0.003	0.008	-	-	0.008	0.55
Number of woody species (species/3m²)	-0.555	0.073	-	-	0.07	0.27
Density of lianas	-0.083	0.079	0.002	0.039	0.02	0.56

Table 31. Regression results testing for linear or quadratic relationships between the mean relative abundance of meadow voles in 4 forest cover types and macrohabitat characteristics. Small mammal trapping was conducted on Quantico Marine Corps Base, VA, from May 1997-January 1999 (7, 3-4 day trapping periods). For all regressions, n=10.

	Beta Coefficients					
	Linear	P	Quadratic	P	Overall P	R^2
% Overstory canopy cover	0.015	0.10	-	-	0.10	0.21
Basal area	-0.041	0.095	-	-	0.10	0.22
Coefficient of variation for woody stem density at 0 meters	0.023	0.094	-	-	0.09	0.23
Stump density index	-0.03	0.02	-	-	0.02	0.47
Number of herbaceous stems (stems/m^2)	-0.005	0.036	0.00003	0.313	0.08	0.39
Number of herbaceous stems > 0.5 m (stems/m^2)	0.02	0.01	-	-	0.01	0.50
Number of grass stems (stems/m^2)	0.006	0.019	-	-	0.02	0.46
% Ground cover composed of grass	0.037	0.090	-	-	0.09	0.23

Table 32. Regression results testing for linear or quadratic relationships between the mean relative abundance of woodland voles in 4 forest cover types and macrohabitat characteristics. Small mammal trapping was conducted on Quantico Marine Corps Base, VA, from May 1997-January 1999 (7, 3-4 day trapping periods). For all regressions, n=10.

	Beta Coefficients					
	Linear	P	Quadratic	P	Overall P	R^2
Density of soft mast stems (stems/ha)	0.00002	0.099	-	-	0.10	0.22
Blueberry stem density (stems/ha)	0.00001	0.000	-	-	0.00	0.80
Log density	0.0005	0.068	-	-	0.07	0.28
Stump density	-0.009	0.255	0.0004	0.061	0.08	0.37
Number of stations without herbaceous cover	0.011	0.004	-	-	0.00	0.62
Number of herbaceous species (species/m^2)	0.02	0.15	-1.73×10^{-4}	0.03	0.03	0.52
Coefficient of variation in herbaceous species	0.006	0.015	-	-	0.02	0.49
% Ground cover	-0.082	0.026	-	-	0.03	0.69
Mean litter depth (cm)	-0.288	0.050	-	-	0.05	0.32

litter, and Smast (Table 27). Of these, the best model indicated that 85% of the variability in the relative abundance of woodland voles was explained by the combined effects of the density of low woody stems and the density of blueberry stems. The relative abundance of woodland voles was negatively related to low woody stem density and positively related to the density of blueberry stems.

Southern Flying Squirrels.—Twenty-one predictor variables explained a significant amount of the variation in the relative abundance of southern flying squirrels (Table 33). Five predictors (BA, Dmast, Woody0, CVwoody1, and Dliana) individually accounted for > 50% of the variation. The 3 best 2-variable multiple linear regression models included 4 variables: BA, CVwoody1, Dbh, and Herb5, (Table 27). Of these, the best model indicated that 80% of the variability in the relative abundance of southern flying squirrels was explained by the combined effects of basal area and the coefficient of variation in woody stem densities at 1 meter. The relative abundance of southern flying squirrels was positively related to basal area and negatively related to the variation in tall woody stem density.

MICROHABITAT ANALYSES

LEVELS OF USE ANALYSIS

White-footed Mice.—Twenty-four habitat variables differed significantly among levels of use for white-footed mice (Table 34). White-footed mice used microsites characterized by greater tree diameter, overall woody stem densities, mountain laurel and blueberry stem densities, woody species, logs, woody debris and % woody ground cover while avoiding microhabitats containing more shrubs, stumps, lianas, herbaceous stems, herbaceous species, % grass ground cover and deeper litter depth.

Table 33. Regression results testing for linear or quadratic relationships between the number of individual southern flying squirrels captured in 4 forest cover types and macrohabitat characteristics. Small mammal trapping was conducted on Quantico Marine Corps Base, VA, from May 1997-January 1999 (7, 3-4 day trapping periods). For all regressions, n=10.

| | Beta Coefficients | | | | | |
	Linear	P	Quadratic	P	Overall P	R^2
% Canopy cover	0.0341	0.004	-	-	0.004	0.25
CV % canopy cover	-0.0170	0.006	-	-	0.006	0.26
Basal area	0.0961	<0.0001	-	-	<0.0001	0.75
Distance to nearest tree	-0.41	0.065	-	-	0.07	0.08
Tree density	0.0033	0.010	-	-	0.01	0.17
Density of mast trees	0.0121	<0.0001	-	-	<0.0001	0.54
Mean tree dbh	0.0844	0.0008	-	-	0.0008	0.32
CV shrub density	-0.0377	0.018	-	-	0.02	0.15
Density of soft mast stems	-0.0306	0.0064	-	-	0.006	0.20
Woody stem density at ground level	-0.0213	<0.0001	0.0003	<0.0001	<0.0001	0.74
Woody stem density at 1 meter	-0.0244	0.0012	0.0002	0.0014	0.001	0.37
CV woody stem density at 1 meter	-0.0155	<0.0001	-	-	<0.0001	0.54
Log density	-0.0026	0.0302	-	-	0.03	0.12
Stump density	-0.0598	0.002	0.0002	0.0074	0.005	0.38
Herbaceous stem density	-0.0054	0.0315	-	-	0.03	0.11
CV herbaceous stem density	-0.0248	0.0125	-	-	0.01	0.17
Grass stem density	-0.0082	0.0013	-	-	0.001	0.29
Liana density	-0.9093	0.008	-	-	0.008	0.614
% Ground cover	0.4928	0.0005	-	-	0.0005	0.36
% Woody ground cover	-0.2748	0.0112	-	-	0.01	0.18
% Grass ground cover	-0.068	0.0122	-	-	0.01	0.18

Table 34. Results of Kruskal-Wallis tests of differences in microhabitat characteristics among levels of use for white-footed mice captured on Quantico Marine Corps Base, VA, from May 1997-January 1999.

Habitat characteristic	Mean (SE)			Significance[b]
	No-use[a] (n=286)	Low-use (n=386)	High-use (n=317)	
Mean tree diameter (cm)	19.94 (0.87)	21.30 (0.70)	22.40 (0.79)	0.06
Number of shrubs (shrubs/10m^2)	15.63 (0.71)	13.78 (0.11)	13.17 (0.61)	0.04
Number of woody stems at ground level (stems/28.3m^2)	210A[c] (15.39)	282B (17.41)	407C (23.05)	0.0001
Number of woody stems at 0.5 meters (stems/28.3m^2)	140A (13.76)	189B (14.59)	262C (17.33)	0.0001
Number of woody stems at 1 meter (stems/28.3m^2)	64A (8.59)	79B (7.08)	95C (7.15)	0.0001
Number of blackberry stems at ground level (stems/28.3m^2)	51 (6.12)	42 (4.47)	50 (7.46)	0.04
Number of blackberry stems at 0.5 meters (stems/28.3m^2)	44 (5.96)	32 (3.66)	41 (6.94)	0.04
Number of blackberry stems at 1 meter (stems/28.3m^2)	16 (3.63)	13 (1.89)	14 (2.82)	0.03
Number of mountain laurel stems at ground level (stems/28.3m^2)	2A (1.15)	7A (1.53)	45B (1.39)	0.0001
Number of mountain laurel stems at 0.5 meters (stems/28.3m^2)	2A (1.24)	8A (2.94)	49B (1.37)	0.0001
Number of mountain laurel stems at 1 meter (stems/28.3m^2)	0A (0.007)	0.22A (2.42)	9B (0.28)	0.0001
Number of blueberry stems at ground level (stems/28.3m^2)	13A (2.93)	29A (5.51)	77B (10.89)	0.0001
Number of blueberry stems at 0.5 meters (stems/28.3m^2)	6A (1.85)	9AB (1.78)	22B (4.57)	0.001
Woody species (species/28.3m^2)	5.72A[c] (0.12)	6.13AB (0.10)	6.38B (0.11)	0.0007
Distance to nearest log (m)	2.39A (0.14)	1.85A (0.09)	1.44B (0.09)	0.0001
Log density index	1.05A (0.27)	1.24B (0.16)	2.61C (0.44)	0.0001

[a]No-use corresponds to stations with no white-footed mouse captures, low-use to stations with 1-2 captures, and high-use to stations with >2 captures.
[b]All Kruskal-Wallis tests had 2 df.
[c]Between use comparisons were made using Wilcoxon Rank Sum tests. Same letter group indicates no significant difference between levels of use based on α=0.01.

Table 34. Continued

Habitat Characteristic	No-use[a] (n=286)	Low-use (n=386)	High-use (n=317)	Significance[b]
	Mean (SE)			
Distance to nearest stump (m)	4.67 (0.15)	4.45 (0.13)	4.17 (0.14)	0.08
Woody debris (debris/28.3m^2)	6.11A[c] (0.99)	8.59B (0.66)	13.36C (1.23)	0.0001
Number of lianas (lianas/m^2)	159A (26.44)	102AB (13.85)	63B (7.38)	0.02
Herbaceous stems (stems/m^2)	227A (10.33)	185B (8.37)	169C (9.62)	0.0001
Herbaceous species (species/m^2)	4.03A (0.12)	3.68A (0.11)	2.71B (0.12)	0.0001
% Woody ground cover	5.36A (0.47)	7.55B (0.47)	9.35C (0.61)	0.0001
% Grass ground cover	17.85A (1.45)	12.58AB (1.06)	9.71B (1.45)	0.005
Mean litter depth (mm)	20.4A (0.49)	19.6B (0.44)	18.0C (0.46)	0.0001

[a]No-use corresponds to stations with no white-footed mouse captures, low-use to stations with 1-2 individuals captured, and high-use to stations with >2 individuals captured.
[b]All Kruskal-Wallis tests had 2 df.
[c]Between use comparisons were made using Wilcoxon Rank Sum tests. Same letter group indicates no significant difference between levels of use based on $\alpha=0.01$.

High-use stations differed significantly from low-use stations for 15 of 24 habitat variables. More favorable microhabitats (assuming high-use indicates higher habitat quality) were associated with greater overall woody, mountain laurel, and blueberry stem densities, log densities, woody debris, and woody ground cover. Fewer herbaceous stems and herbaceous species and shallower litter depth also characterized higher use microhabitats. Results of analyses within treatment types are in Appendices D, F, H, and I.

Eastern Chipmunks.--Nineteen habitat variables differed significantly among levels of use for eastern chipmunks (Table 35). Eastern chipmunks selected microhabitats with greater tree diameters, woody, mountain laurel and blueberry stem densities, woody species, logs, woody debris and % woody ground cover. Fewer lianas, herbaceous stems and herbaceous species, and % grass ground cover also characterized more favorable microhabitats. Only 3 of 19 habitat characteristics differed between high-use and low-use. Highly used microhabitats were associated with fewer herbaceous stems, herbaceous species, and % grass ground cover. Results of analyses within treatment types are in Appendices L, M, N, and O.

Northern Short-tailed shrews.—Fourteen habitat variables differed between use and no-use stations for northern short-tailed shrews (Table 36). Shrews were captured at stations closer to trees, with smaller tree diameters, greater densities of shrubs, intermediate to tall woody stems, blackberry stems, logs, and lianas as well as greater ground cover, more woody ground cover, and greater litter depth. Results of analyses within treatment types are in Appendices P, Q, R, and S.

Meadow Voles.—Twenty-one habitat variables differed significantly among levels of use for meadow voles (Table 37). Meadow voles used microhabitats characterized by greater distances to trees, smaller tree diameters, greater blackberry, mountain laurel, liana, herbaceous

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stem and tall herbaceous stem densities, as well as more herbaceous species, % grass ground

cover and litter depth. Fewer blueberry stems, woody species, stumps, and woody debris also

characterized meadow vole microhabitats. High-use stations differed significantly from low-use

stations for 4 of 21 habitat variables. More favorable microhabitats were associated with smaller

tree diameters, fewer woody species, more herbaceous stems, and less ground cover. Results of

analyses within treatment types are in Appendices T and U.

       Woodland Voles.—Thirteen habitat variables differed among no-use and use stations for

woodland voles (Table 38). Microhabitats associated with woodland vole captures were

characterized by lower tree density, fewer shrubs and herbaceous stems, greater densities of

woody, blueberry and mountain laurel stems, greater vertical woody stem densities and distances

to stumps and more shallow litter depths. Results of analyses within treatment types are in

Appendices V, W, X, and Y.

LOGISTIC REGRESSIONS

Six species were successfully modeled using logistic regression to predict presences/absence. Of

the 32 habitat variables included in these analyses (Table 39) all were incorporated in at least 1

logistic regression model. The estimated predictability (concordance values) of models ranged

from 59.3% (northern short-tailed shrews) to 90.3% (meadow voles).

Analysis results of microhabitat selection in summer and winter for white-footed mice by

treatment type are in Appendices E, G, J, and K. Analyses of microhabitat selection between

resident and transient white-footed mice are found in Appendix AA and the analysis of micro-

site selection at different densities for this species in shelterwoods is in Appendix AB.

Table 35. Results of Kruskal-Wallis tests for differences in microhabitat characteristics among levels of use for eastern chipmunks captured on Quantico Marine Corps Base, VA, from May 1997-January 1999.

Habitat characteristic	Mean (SE)			Significance[b]
	No-use[a] (n=696)	Low-use (n=234)	High-use (n=59)	
Mean tree diameter (cm)	22.75A[c] (0.50)	28.13B (0.93)	26.39B (1.36)	0.0001
Distance to nearest tree (m)	3.31A (0.08)	3.66B (0.13)	2.92AB (0.08)	0.007
Number of woody stems at ground level (stems/28.3m^2)	232A (13.53)	455B (20.31)	509B (10.26)	0.0001
Number of woody stems at 0.5 meters (stems/28.3m^2)	147A (10.32)	312B (17.68)	348B (8.21)	0.0001
Number of woody stems at 1 meter (stems/28.3m^2)	61A (4.09)	124B (10.46)	116B (4.49)	0.0001
Number of mountain laurel stems at ground level (stems/28.3m^2)	10A (3.20)	37B (2.58)	30B (1.81)	0.0001
Number of mountain laurel stems at 0.5 meters (stems/28.3m^2)	10A (3.96)	38B (4.40)	59AB (2.26)	0.0001
Number of mountain laurel stems at 1 meter (stems/28.3m^2)	1A (0.63)	6B (1.40)	12B (0.51)	0.0001
Number of blueberry stems at ground level (stems/28.3m^2)	25A (5.10)	72B (7.83)	81B (4.07)	0.0001
Number of blueberry stems at 0.5 meters (stems/28.3m^2)	8A (1.97)	20B (3.40)	27B (1.50)	0.0003
Woody species (stems/28.3m^2)	5.94A (0.08)	6.36AB (0.11)	6.86B (0.08)	0.002
Log density index	1.40A (0.16)	1.92B (0.41)	3.12B (1.57)	0.0001
Distance to nearest stump (m)	4.62A (0.10)	3.72B (0.15)	4.93A (0.10)	0.0001
Woody debris (debris/28.3m^2)	7.82A (0.66)	13.85B (1.05)	10.38AB (0.50)	0.01
Number of lianas (lianas/m^2)	129A (12.47)	60B (14.59)	17B (12.26)	0.0001
Herbaceous stems (stems/m^2)	205A (6.62)	184A (9.57)	71B (6.50)	0.0001
Herbaceous species (species/m^2)	3.79A (0.09)	2.96B (0.11)	1.78C (0.08)	0.0001

[a]No-use corresponds to stations with no eastern chipmunk captures, low-use to stations with 1-2 individuals captured, and high-use to stations with >2 individuals captured.
[b]All Kruskal-Wallis tests had 2 df.
[c]Between use comparisons were made using Wilcoxon Rank Sum tests. Same letter group indicates no significant difference between levels of use based on α=0.01.

Table 35. Continued

Habitat characteristic	Mean (SE)						Significance[b]
	No-use[a]	(n=696)	Low-use	(n=234)	High-use	(n=59)	
% Woody ground cover	7.11A[c]	(0.35)	7.86B	(0.59)	10.25B	(0.37)	0.0003
% Grass ground cover	14.03A	(0.82)	12.57A	(1.20)	5.55B	(0.84)	0.004

[a]No-use corresponds to stations with no eastern chipmunk captures, low-use to stations with 1-2 individuals captured, and high-use to stations with >2 individuals captured.
[b]All Kruskal Wallis tests had 2 df.
[c]Between use comparisons were made using Wilcoxon Rank Sum tests. Same letter group indicates no significant difference between levels of use based on α=0.01.

Table 36. Results of Wilcoxon Rank Sum tests for differences in microhabitat characteristics between capture and no-capture stations for northern short-tailed shrews captured on Quantico Marine Corps Base, VA, May 1997-January 1999.

Habitat characteristic	Mean (SE)		Significance[b]
	No-use[a] (n=675)	Use (n=314)	
Mean tree diameter (cm)	25.34 (0.51)	21.67 (0.75)	0.0001
Distance to nearest tree (m)	3.26 (0.08)	3.62 (0.13)	0.04
Number of shrubs (shrubs/100m^2)	13.21 (0.41)	16.08 (0.73)	0.003
Number of woody stems at 0.5 meters (stems/28.3m^2)	184 (10.32)	229 (17.68)	0.01
Number of woody stems at 1 meter (stems/28.3m^2)	65 (4.09)	110 (10.46)	0.0001
Number of blackberry stems at ground level (stems/28.3m^2)	43 (4.09)	55 (6.36)	0.02
Number of blackberry stems at 0.5 meters (stems/28.3m^2)	34 (3.57)	47 (6.32)	0.02
Number of blackberry stems at 1 meter (stems/28.3m^2)	11 (1.52)	21 (3.68)	0.0009
Distance to nearest log (m)	1.97 (0.07)	1.68 (0.11)	0.0001
Log density index	1.38 (0.20)	2.20 (0.36)	0.0007
Number of lianas (lianas/m^2)	97 (12.47)	126 (14.59)	0.02
% Ground cover	94.10 (0.39)	96.59 (0.44)	0.0001
% Woody ground cover	6.77 (0.35)	8.99 (0.59)	0.0001
Mean litter depth (mm)	20.18 (0.32)	23.51 (0.48)	0.0001

[a]No-use corresponds to stations with no northern short-tailed shrews captures and Use to stations with one or more individuals captured.
[b]All Wilcoxon Rank Sum tests had 1 df.

Table 37. Results of Kruskal-Wallis tests for differences in microhabitat characteristics among stations with varying levels of use for meadow voles captured on Quantico Marine Corps Base, VA, from May 1997-January 1999.

Habitat characteristic	Mean (SE)			Significance[b]
	No-use[a] (n=871)	Low-use (n=91)	High-use (n=27)	
Mean tree diameter (cm)	24.93A[c] (0.44)	16.95B (1.57)	20.24C (2.45)	0.0001
Distance to nearest tree (m)	3.18A (0.07)	4.77B (0.25)	4.83B (0.37)	0.0002
Number of woody stems at 0.5 meters (stems/28.3m^2)	195A (9.44)	249B (36.24)	137AB (33.36)	0.006
Number of woody stems at 1 meter (stems/28.3m^2)	78A (4.58)	107B (17.93)	45AB (10.02)	0.003
Number of blackberry stems at ground level (stems/28.3m^2)	41A (3.54)	101B (14.60)	50B (10.87)	0.0001
Number of blackberry stems at 0.5 meters (stems/28.3m^2)	34A (3.18)	80B (15.00)	38B (9.00)	0.0001
Number of blackberry stems at 1 meter (stems/28.3m^2)	12A (1.36)	34B (10.76)	9AB (2.65)	0.0001
Number of mountain laurel stems at ground level (stems/28.3m^2)	16A (2.35)	26B (11.06)	30B (13.86)	0.0001
Number of mountain laurel stems at 0.5 meters (stems/28.3m^2)	19A (3.32)	17B (5.80)	41AB (24.49)	0.003
Number of blueberry stems at ground level (stems/28.3m^2)	43A (4.80)	15B (6.24)	11B (6.78)	0.0001
Number of blueberry stems at 0.5 meters (stems/28.3m^2)	13A (1.93)	6B (2.76)	3AB (2.04)	0.003
Woody species (species/28.3m^2)	6.20A (0.07)	5.56B (0.21)	4.33C (0.39)	0.0001
Distance to nearest stump (m)	4.55A (0.09)	3.40B (0.25)	3.76AB (0.46)	0.0001
Woody debris (debris/28.3m^2)	9.92A (0.62)	6.64B (1.23)	2.19B (0.55)	0.0001
Number of lianas (lianas/m^2)	83A (8.23)	296B (62.42)	201AB (81.23)	0.0001
Herbaceous stems (stems/m^2)	169A (5.45)	337B (16.75)	434C (18.97)	0.0001
Herbaceous stems at 0.5m (stems/m^2)	8A (1.37)	41B (9.86)	44B (16.28)	0.0001

[a]No-use corresponds to stations with no meadow vole captures, low-use to stations with 1-2 individuals captured, and high-use to stations with > 2 individuals captured.
[b]All Kruskal-Wallis tests had 2 df.
[c]Between use comparisons were made using Wilcoxon Rank Sum tests. Same letter group indicates no significant difference between levels of use based on α=0.01.

Table 37. Continued

Habitat Characteristic	Mean (SE)			
	No-use[a] (n=871)	Low-use (n=91)	High-use (n=27)	Significance[b]
Herbaceous species (species/m^2)	3.38A[c] (0.08)	4.03B (0.21)	4.50B (0.40)	0.0009
% Ground cover	94.8AB (0.33)	96.5B (0.62)	91.98A (1.66)	0.02
% Grass ground cover	10.50A (0.65)	33.20B (2.71)	32.13B (4.21)	0.0001
Mean litter depth (mm)	20.86A (0.28)	24.44B (0.95)	22.63AB (1.37)	0.0002

[a]No-use corresponds to stations with no meadow vole captures, low-use to stations with 1-2 individuals captured, and high-use to stations with > 2 individuals captured.
[b]All Kruskal-Wallis tests had 2 df.
[c]Between use comparisons were made using Wilcoxon Rank Sum tests. Same letter group indicates no significant difference between levels of use based on α=0.01.

Table 38. Results of Wilcoxon Rank Sum tests for differences in microhabitat characteristics between capture and no-capture stations for woodland voles captured on Quantico Marine Corps Base, VA, May 1997-January 1999.

Habitat characteristic	Mean (SE)		Significance[b]
	No-use[a] (n=911)	Use (n=88)	
Tree density index	105.62 (1.54)	115.80 (4.45)	0.02
Distance to nearest tree (m)	3.36 (0.07)	3.57 (0.21)	0.08
Number of shrubs (shrubs/100m^2)	14.34 (0.39)	12.39 (1.19)	0.02
Number of blueberry stems at ground level (stems/28.3m^2)	37 (4.29)	75 (19.41)	0.03
Number of mountain laurel stems at ground level (stems/28.3m^2)	16 (2.31)	36 (11.34)	0.002
Number of woody stems at 0.5 meters (stems/28.3m^2)	197 (9.60)	214 (25.10)	0.01
Number of blueberry stems at 0.5 meters (stems/28.3m^2)	12 (1.83)	19 (4.62)	0.01
Number of mountain laurel stems at 0.5 meters (stems/28.3m^2)	19 (3.15)	34 (11.29)	0.003
Number of mountain laurel stems at 1 meter (stems/28.3m^2)	3 (0.62)	7 (2.75)	0.008
Vertical woody stem density	0.95 (0.03)	1.02 (0.07)	0.07
Distance to nearest stump (m)	4.47 (0.08)	4.05 (0.28)	0.05
Number of herbaceous species (species/m^2)	3.51 (0.07)	3.14 (0.27)	0.04
Mean litter depth (mm)	21.3 (0.28)	19.8 (0.88)	0.03

[a]No-use corresponds to stations with no woodland vole captures and Use to stations with one or more individuals captured.
[b]All Wilcoxon Rank Sum tests had 1 df.

White-footed Mice

Overall Model.—Six microhabitat variables were included as predictors in the logistic regression model for white-footed mice (Table 39). Based on these predictors, 71.8% of stations were correctly classified as use/no-use. White-footed mouse presence was negatively associated with liana density, litter depth and presence of herbaceous cover and associated positively with the density of woody stems measured at ground level, log density and the % of woody ground cover.

Undisturbed Habitats (Riparian/Mature).—Five microhabitat variables were included as predictors in the logistic regression model for all undisturbed habitats (Table 39). Based on these predictors, 75.1% of stations were correctly classified as use or no-use. White-footed mice presence was negatively associated with litter depth, presence of *Lycopodium*, and associated positively with the density of woody stems measured at 1 meter, the % of woody ground cover, and the presence of ferns in riparian and mature sites.

Disturbed Habitats (Clearcuts/Shelterwoods).—Five microhabitat variables were included as predictors in the logistic regression model for disturbed sites (Table 39). Based on these predictors, 79.2% of stations were correctly classified as use or no-use. White-footed mice presence in clearcuts and shelterwoods was negatively associated with liana density, herbaceous species and presence of herbaceous ground cover and positively associated with woody species and log density.

Clearcuts.—Four habitat variables were included as predictors in the logistic regression model for clearcuts (Table 39). Based on these predictors, 76.5% of stations were correctly classified as use or no-use. White-footed mouse presence in clearcuts was negatively associated

with the areas searched for trees and logs and positively associated with woody species and the density of woody stems measured at 1 meter.

Shelterwoods.—Five habitat variables were included as predictors in the logistic regression model (Table 39). Based on these predictors, 75.6% of stations were correctly classified as use or no-use. White-footed mouse presence in shelterwoods was negatively associated with distance to nearest tree, tree diameter, the density of herbaceous stems and litter depth and positively associated with the area searched for trees.

Riparian Stands.—Three habitat variables were included as predictors in the logistic regression model for riparian sites (Table 39). Based on these predictors, 73.3% of stations were correctly classified as use or no-use. White-footed mouse presence in riparian stands was negatively associated with the density of herbaceous stems and lianas and the presence of *Lycopodium*.

Mature Stands.--Three habitat variables were included as predictors in the logistic regression model for mature sites (Table 39). Based on these predictors, 65.8% of stations were correctly classified as use or no-use. White-footed mouse presence in riparian stands was negatively associated with the presence of *Lycopodium*, and positively associated with the density of woody stems measured at 1 meter and the presence of ferns.

Table 39. Results from stepwise logistic regression analyses for predicting the presence or absence of white-footed mice at trapping stations as a function of microhabitat. Small mammals were trapped on Quantico Marine Corps Base, VA, 1997-1999. Habitat variables are detailed in Table 3.

		Model Input					Model Evaluation		Hosmer-Lemeshow GOF Test		
Grouping Level		Variable	β	SE(β)	Wald X^2	P	Somers' D	Concordant Observations	Test Statistic	DF	P
All[a]		Intercept	2.9574	0.4292	47.49	<0.001	0.44	71.8%	6.73	8	0.57
		Dliana	-0.0008	0.0003	8.67	0.003					
		Logsrch	-0.0074	0.0017	18.87	<0.001					
		Ldepth	-0.0479	0.0092	26.95	<0.001					
		Hcvr	-0.9033	0.3293	7.52	0.006					
		Allwdy0	0.0011	0.0003	14.11	<0.001					
		Wgc	0.0314	0.0103	9.31	0.002					
Undisturbed[b]	RI/MA	Intercept	0.0761	0.7321	0.01	0.920	0.51	75.1%	11.01	8	0.20
		Ldepth	-0.0702	0.0200	12.30	<0.001					
		Domveg4	-0.9358	0.2532	13.66	<0.001					
		Allwdy1	0.0148	0.0046	10.14	0.002					
		Wgc	0.0547	0.0210	6.82	0.009					
		Domveg3	1.3349	0.4342	9.45	0.002					
Disturbed[c]	CC/SW	Intercept	3.2405	0.6928	21.88	<0.001	0.59	79.2%	4.68	8	0.79
		Dliana	-0.0008	0.0003	8.20	0.004					
		Logsrch	-0.0114	0.0022	28.30	<0.001					
		Herbsp	-0.2613	0.0624	17.56	<0.001					
		Hcvr	-1.4378	0.6412	5.03	0.025					
		Woodsp	0.1688	0.0537	9.90	0.002					

[a]Sample sizes for analyses: Capture stations (n=703), Noncapture stations (n=286), Model sensitivity = 66.2%, Model specificity = 63.4%
[b]Capture stations (n=263), Noncapture stations (n=137), Sensitivity = 70.4%, Specificity = 65.4%
[c]Capture stations (n=449), Noncapture stations (n=151), Sensitivity = 73.8%, Specificity = 73.5%

Table 39. Continued

Grouping Level		Variable	β	SE(β)	Wald X^2	P	Somers' D	Concordant Observations	Hosmer-Lemeshow GOF Test		
									Test Statistic	DF	P
Treatment	CC	Intercept	0.0087	0.6648	0.0002	0.990	0.53	76.5%	13.24	8	0.10
		Treesrch	-0.0094	0.0037	6.52	0.011					
		Logsrch	-0.0126	0.0030	18.03	<0.001					
		Woodsp	0.3013	0.0938	10.32	0.001					
		Allwdy1	0.0050	0.0015	11.50	<0.001					
	SW	Intercept	4.2065	0.7943	28.05	<0.001	0.52	75.6%	6.88	8	0.55
		Treedis	-0.4492	0.1519	8.75	0.003					
		Xtdbh	-0.0412	0.10	16.94	<0.001					
		Hstem	-0.0032	0.009	12.79	<0.001					
		Ldepth	-0.0432	0.0179	5.84	0.016					
		Treesrch	0.0185	0.0082	5.08	0.024					
	RI	Intercept	3.3878	0.0663	44.78	<0.001	0.47	73.3%	10.20	8	0.25
		Hstem	-0.0052	0.00143	13.41	<0.001					
		Domveg4	-0.9838	0.4763	4.27	0.039					
		Dliana	-0.0027	0.0014	3.73	0.053					
	MA	Intercept	-0.1221	0.2379	0.26	0.608	0.34	65.8%	3.22	8	0.92
		Domveg4	-0.6782	0.3068	4.89	0.027					
		Allwdy1	0.0136	0.0053	6.66	0.010					
		Domveg3	1.4509	0.6789	4.57	0.033					

[a]Sample sizes for analyses: Capture stations (n=102), Noncapture stations (n=98), Sensitivity = 69.6%, Specificity = 67.3%
[b]Capture stations (n=347), Noncapture stations (n=53), Sensitivity = 71.4%, Specificity = 69.8%
[c]Capture stations (n=166), Noncapture stations (n=34), Sensitivity = 70.7%, Specificity = 60.6%
[d]Capture stations (n=97), Noncapture stations (n=103), Sensitivity = 58.8%, Specificity = 51.5%

Eastern Chipmunks

      Overall Model.—Eight variables were included as predictors in the logistic regression model for all forest cover types for chipmunks (Table 40). Based on these predictors, 77.7% of stations were correctly classified as use/no-use. Eastern chipmunk presence was negatively associated with lianas, herbaceous species, litter depth, stumps and presence of *Lycopodium* and positively associated with woody species, the density of woody stems measured at intermediate heights and tree diameter.

      Undisturbed Habitats (Riparian/Mature).—Three variables were included as predictors in the logistic regression model for disturbed habitats (Table 40). Based on these predictors, 73.6% of stations were correctly classified as use or no-use. Eastern chipmunk capture stations in riparian/mature sites were negatively associated with short hardwood stems and positively associated with tall woody stems and tall herbaceous vegetation.

      Disturbed Habitats (Clearcuts/Shelterwoods).—Seven predictor variables resulted in a 78.1% correct classification rate for disturbed habitats (Table 40). Eastern chipmunk captures in disturbed habitats were negatively associated with lianas and herbaceous species and positively associated with woody species, presence of canopy trees, the density of low woody stems, tree diameter, and presence of forbs.

      Clearcuts.—Only 1 predictor variable (Allwdy5), resulting in a 74.5% classification rate, was included in the logistic regression model for clearcuts (Table 40). Eastern chipmunk presence in clearcuts was positively associated with woody vegetation of intermediate heights.

      Shelterwoods.—Three predictor variables resulted in a 69.5% correct classification rate for shelterwoods (Table 40). Eastern chipmunk presence in shelterwoods was negatively

associated with area searched for trees and the density of tall herbaceous vegetation and positively associated with the density of woody stems measured at intermediate heights.

Riparian Stands.—Two predictor variables resulted in a 70.6% correct classification rate for riparian sites (Table 40). Eastern chipmunk presence in riparian stands was negatively associated with liana density and the presence of *Lycopodium.*

Mature Stands.— Only 1 predictor variable, vertical woody stem density, resulting in a 78.5% classification rate, was included in the logistic regression model (Table 40). Eastern chipmunk presence in mature stands was positively associated with vertical woody stem density.

Northern Short-tailed shrews

Overall Model.--Seven variables were included as predictors in the logistic regression model for all habitat types for northern short-tailed shrews (Table 41). Based on these predictors, 69.3% of stations were correctly classified as use or no-use. Northern short-tailed shrew presence was negatively associated the density of woody stems measured at ground level, and mean tree diameter and positively associated with distance to nearest stump, the density of woody stems measured at 1 meter, ground cover, log density and litter depth.

Undisturbed Habitat (Riparian/Mature).—Six variables were included as predictors in the logistic regression model for undisturbed habitats (Table 41). Based on these predictors, 70.0% of stations were correctly classified as use or no-use. Northern short-tailed shrew presence in riparian/mature sites was negatively associated with presence of tree canopy cover, herbaceous species and the density of blackberry stems and positively associated with distance to nearest stump, area searched for logs and the vertical woody stem density.

Disturbed Habitat (Clearcuts/Shelterwoods).—Nine predictor variables resulted in a 72.7% correct classification rate for disturbed habitats (Table 41). Northern short-tailed shrew presence in disturbed habitats was negatively associated with the area searched for logs, the density of low woody stems, and tree diameter and positively associated with shrubs, area searched for stumps, the densities of tall woody stems and tall herbaceous vegetation, ground cover and litter depth.

Clearcuts.—Five predictor variables resulted in a 72.6% correct classification rate for clearcuts (Table 41). Northern short-tailed shrew presence in clearcuts was negatively associated with woody debris and positively associated with area searched for stumps, the presence of soft mast, the density of hardwood stems, and woody ground cover.

Shelterwoods.—Seven predictor variables resulted in a 73.8% correct classification rate for shelterwoods (Table 41). Northern short-tailed shrew presence in shelterwoods was negatively associated with area searched for logs and trees, mean tree diameter, and the density of lianas and positively associated with the densities of woody stems measured at 1 meter and tall herbaceous stems, and litter depth.

Riparian Stands.—Two predictor variables resulted in a 70.0% correct classification rate for riparian sites (Table 41). Northern short-tailed shrew presence in riparian stands was positively associated area searched for logs and litter depth.

Mature Stands.—One predictor variable, density of tall hardwood stems, resulted in a 59.3% correct classification rate for mature sites (Table 41). Northern short-tailed shrew presence in mature stands was positively associated with the density of tall hardwood stems.

Table 40. Results from stepwise logistic regression analyses for predicting the presence or absence of eastern chipmunks at trapping stations as a function of microhabitat. Small mammals were trapped on Quantico Marine Corps Base, VA, 1997-1999. Habitat variables are detailed in Table 3.

Grouping Level		Variable	Model Input				Model Evaluation		Hosmer-Lemeshow GOF Test		
			β	SE(β)	Wald X^2	P	Somers' D	Concordant Observations	Test Statistic	DF	P
All[a]		Intercept	-0.8129	0.4179	3.87	0.049	0.56	77.7%	15.25	8	0.06
		Dliana	-0.0018	0.0006	9.69	0.002					
		Herbsp	-0.1449	0.0373	15.09	<0.001					
		Ldepth	-0.0193	0.0098	3.89	0.049					
		Nstump	-0.0709	0.0312	5.17	0.023					
		Domveg4	-1.2628	0.3211	15.47	<0.001					
		Woodsp	0.0795	0.0379	4.404	0.036					
		Allwdy5	0.0021	0.0003	38.50	<0.001					
		DBH	0.0214	0.0056	14.51	<0.001					
Undisturbed[b]	RI/MA	Intercept	-1.5133	0.2308	42.99	<0.001	0.48	73.6%	4.51	8	0.81
		Cother0	-0.0083	0.0024	12.36	<0.001					
		Allwdy1	0.0126	0.0046	7.53	0.006					
		Herb5	0.0119	0.0039	9.43	0.002					
Disturbed[c]	CC/SW	Intercept	-1.7279	0.4159	17.26	<0.001	0.56	78.1%	29.66	8	<0.01[d]
		Dliana	-0.0011	0.0005	4.01	0.045					
		Herbsp	-0.1663	0.0530	9.83	0.002					
		Woodsp	0.1238	0.0467	7.04	0.008					
		Canopy	0.4855	0.2183	4.95	0.026					
		Allwdy0	0.0011	0.0002	18.85	<0.001					
		DBH	0.0178	0.0069	6.62	0.010					
		Domveg1	0.7833	0.3195	6.01	0.014					

[a]Sample sizes for analyses: Capture stations (n=293), Noncapture stations (n=696), Sensitivity = 70.0%, Specificity = 70.3%
[b]Capture stations (n=54), Noncapture stations (n=340), Sensitivity = 59.3%, Specificity = 65.2%
[c]Capture stations (n=239), Noncapture stations (n=356), Sensitivity = 71.3%, Specificity = 72.0%
[d]The validity of this model is questionable according the the Hosmer-Lemeshow Goodness of Fit Test

Table 40. Continued.

Grouping Level		Variable	β	SE(β)	Wald X^2	P	Somers' D	Concordant Observations	Hosmer-Lemeshow GOF Test		
									Test Statistic	DF	P
Forest Cover Type	CC[e]	Intercept	-2.7199	0.3564	58.23	<0.001	0.51	74.5%	14.63	8	0.07
		Allwdy5	0.0025	0.0009	7.93	0.005					
	SW[f]	Intercept	1.6900	0.3954	18.27	<0.001	0.39	69.5%	6.17	8	0.63
		Treesrch	-0.0143	0.0031	20.89	<0.001					
		Herb5	-0.0058	0.0025	5.51	0.019					
		Allwdy5	0.0012	0.0003	12.71	0.004					
	RI[g]	Intercept	-0.5564	0.2343	5.64	0.018	0.43	70.6%	6.37	8	0.61
		Dliana	-0.0147	0.0053	7.63	0.006					
		Domveg4	-1.2678	0.6446	3.87	0.049					
	MA[h]	Intercept	-4.0122	0.5673	50.02	<0.001	0.58	78.5%	5.85	8	0.66
		Vwsd	1.5112	0.4248	12.65	<0.001					

[e]Sample sizes for analyses: Capture stations (n=23), Noncapture stations (n=176), Sensitivity = 56.5%, Specificity = 68.9%
[f]Capture stations (n=216), Noncapture stations (n=180), Sensitivity = 62.1%, Specificity = 61.7%
[g]Capture stations (n=41), Noncapture stations (n=153), Sensitivity = 63.4%, Specificity = 66.0%
[h]Capture stations (n=13), Noncapture stations (n=187), Sensitivity = 56.1%, Specificity = 53.5%

Table 41. Results from stepwise logistic regression analyses for predicting the presence or absence of northern short-tailed shrews at trapping stations as a function of microhabitat. Small mammals were trapped on Quantico Marine Corps Base, VA, 1997-1999. Habitat variables are detailed in Table 3.

Grouping Level		Variable	β	SE(β)	Wald X^2	P	Somers' D	Concordant Observations	Hosmer-Lemeshow GOF Test Test Statistic	DF	P
All[a]		Intercept	-3.4759	0.9603	13.10	<0.001	0.39	69.3%	7.17	8	0.52
		Logsrch	-0.0053	0.0015	12.32	<0.001					
		Allwdy0	-0.0011	0.0003	14.46	<0.001					
		DBH	-0.0204	0.0055	13.83	<0.001					
		Nstump	0.0780	0.0293	7.12	0.008					
		Allwdy1	0.0034	0.0007	1.04	<0.001					
		Grndcvr	0.0272	0.0101	7.21	0.007					
		Ldepth	0.0293	0.029	7.12	<0.008					
Undisturbed[b]	RI/MA	Intercept	-4.8012	0.2229	4.76	0.029	0.40	70.0%	5.74	8	0.68
		Canopy	-1.4709	0.7703	3.64	0.056					
		Nstump	0.0992	0.0506	3.85	0.050					
		Herbsp	-0.1830	0.0611	8.98	0.003					
		Crub5	-0.1353	0.0722	3.15	0.061					
		Logsrch	0.3683	0.1286	8.21	0.004					
		Vwsd	0.4032	0.1809	4.96	0.026					

[a]Sample sizes for analyses: Capture stations (n=314), Noncapture stations (n=675), Sensitivity = 65.0%, Specificity = 63.3%
[b]Capture stations (n=111), Noncapture stations (n=283), Sensitivity = 58.0%, Specificity = 59.9%

Table 41. Continued.

Grouping Level		Variable	β	SE(β)	Wald X^2	P	Somers' D	Concordant Observations	Hosmer-Lemeshow GOF Test		
									Test Statistic	DF	P
Disturbed[c]	CC/SW	Intercept	-3.7457	1.1937	9.85	0.002	0.46	72.7%	4.24	8	0.83
		Logsrch	-0.0061	0.0020	9.61	0.002					
		Allwdy0	-0.0008	0.0003	6.33	0.012					
		DBH	-0.0254	0.0068	14.15	<0.001					
		Nshrub	0.0184	0.0009	4.46	0.035					
		Stmpsrch	0.0056	0.0026	4.76	0.029					
		Allwdy1	0.0025	0.0008	10.96	<0.001					
		Herb5	0.0037	0.0013	7.82	0.005					
		Grndcvr	0.0242	0.0121	3.99	0.046					
		Ldepth	0.0262	0.0109	5.88	0.015					
Forest Cover Type	CC[d]	Intercept	-4.2559	1.3163	10.45	0.001	0.45	72.6%	8.21	8	0.41
		Cdwnwood	-0.0552	0.0243	5.18	0.023					
		Stmpsrch	0.0073	0.0040	3.39	0.065					
		Smast	2.3055	1.11305	4.16	0.041					
		Cother1	0.0099	0.0027	13.54	<0.001					
		Wdycvr	0.0570	0.0163	12.25	<0.001					
	SW[e]	Intercept	-1.5333	0.4189	13.40	<0.001	0.48	73.8%	4.67	8	0.79
		Logsrch	-0.0136	0.0036	11.32	<0.001					
		DBH	-0.0242	0.0088	7.64	0.006					
		Treesrch	-0.0121	0.0036	11.32	<0.001					
		dliana	-0.0360	0.0115	3.31	0.065					
		Allwdy1	0.0020	0.0007	8.07	0.005					
		Herb5	0.0068	0.0016	18.40	<0.001					
		Ldepth	0.0483	0.0137	12.38	<0.001					

[c]Sample sizes for analyses: Capture stations (n=203), Noncapture stations (n=392), Sensitivity = 62.6%, Specificity = 64.7%
[d]Capture stations (n=91), Noncapture stations (n=108), Sensitivity = 62.6%, Specificity = 61.1%
[e]Capture stations (n=112), Noncapture stations (n=284), Sensitivity = 64.3%, Specificity = 63.9%

Table 41. Continued.

Grouping Level		Variable	β	SE(β)	Wald X^2	P	Somers' D	Concordant Observations	Hosmer-Lemeshow GOF Test		
									Test Statistic	DF	P
Forest Cover Type	RI[f]	Intercept	-3.6758	0.7004	27.52	<0.001	0.41	70.0%	1.67	8	0.99
		Logsrch	0.3978	0.2017	3.89	0.049					
		Ldepth	0.1340	0.0391	12.38	<0.001					
	MA[g]	Intercept	-0.9757	0.1865	27.37	<0.001	0.24	59.3%	9.12	7	0.24
		Cother1	0.0137	0.0054	6.45	0.011					

[f]Sample sizes for analyses: Capture stations (n=45), Noncapture stations (n=149), Sensitivity = 63.0%, Specificity = 64.1%
[g]Capture stations (n=66), Noncapture stations (n=134), Sensitivity = 54.5%, Specificity = 57.5%

Meadow Voles

Overall Model.--Nine variables were included as predictors in the logistic regression model for all habitat types for meadow voles (Table 42). Based on these predictors, 88.1% of stations were correctly classified as use or no-use. Meadow vole presence was negatively associated with woody species, presence of canopy, woody debris, and the distance to nearest stump and positively associated with area searched for trees, the densities of lianas, herbaceous stems and tall herbaceous stems and litter depth.

Clearcuts.—Five predictor variables resulted in a 78.7% correct classification rate for clearcuts (Table 42). Meadow vole presence in clearcuts was negatively associated with woody debris and presence of grass and positively associated with the densities of lianas and grass stems and herbaceous species.

Shelterwoods.—Three predictor variables resulted in a 90.3% correct classification rate for shelterwoods (Table 42). Meadow vole presence in shelterwoods was positively related to the densities of lianas, herbaceous stems, and tall herbaceous stems.

Woodland Voles

Overall Model.--Four variables were included as predictors in the logistic regression model for all habitat types (Table 43). Based on these predictors, 63.0% of stations were correctly classified as use or no-use. Woodland vole presence was negatively associated with the presence of herbaceous vegetation and positively associated with area searched for trees, the density of tall herbaceous stems, and the presence of *Lycopodium*.

Undisturbed Habitat (Riparian/Mature).—Two variables were included as predictors in the logistic regression model for undisturbed habitats (Table 43). Based on these predictors,

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71.1% of stations were correctly classified as use or no-use. Woodland vole presence in riparian/mature sites was positively associated with the density of herbaceous stems and the presence of soft mast.

Disturbed Habitat (Clearcut/Shelterwood).—Two predictor variables resulted in a 62.7% correct classification rate (Table 43). Woodland vole presence in disturbed habitats was negatively associated with herbaceous species and positively associated with the density of tall herbaceous vegetation.

Shelterwoods.—Five predictor variables resulted in a 74.8% correct classification rate for shelterwoods (Table 43). Woodland vole presence in shelterwoods was negatively associated with the distance to nearest tree, the density of hardwood stems measured at ground level, and the presence of herbaceous vegetation and positively associated with the area searched for trees and the density of lianas.

Riparian Stands.—Three predictor variables resulted in a 73.0% correct classification rate for riparian sites (Table 43). Woodland vole presence in riparian stands was negatively associated with tree diameter and positively associated the density of blackberry stems and herbaceous species.

ENVIRONMENTAL EFFECTS ON TRAPPING

The proportion of the total population captured each night (based on each minimum number known alive from each sampling occasion) of 5 species was included as response variables for simple and multiple linear regressions. No single predictor variable for any species individually explained > 17% of the variation in the proportion of animals captured each night.

Table 42. Results from stepwise logistic regression analyses for predicting the presence or absence of meadow voles at trapping stations as a function of microhabitat. Small mammals were trapped on Quantico Marine Corps Base, VA, 1997-1999. Habitat variables are detailed in Table 3.

Grouping Level		Variable	β	SE(β)	Wald X^2	P	Somers' D	Concordant Observations	Hosmer-Lemeshow GOF Test		
									Test Statistic	DF	P
All[a]		Intercept	-3.2668	0.8120	16.18	<0.001	0.77	88.1%	13.95	8	0.08
		Woodsp	-0.1361	0.0592	5.29	0.022					
		Canopy	-1.1074	0.2970	13.91	<0.001					
		Cdwnwood	-0.0259	0.0116	5.00	0.025					
		Stumpdis	-0.1069	0.0489	4.78	0.029					
		Treesrch	0.0081	0.0033	6.20	0.013					
		Dliana	0.0008	0.0003	8.49	0.004					
		Herb5	0.0037	0.0016	5.46	0.020					
		Hstem	0.0042	0.0008	28.67	<0.001					
		Ldepth	0.0359	0.0128	7.89	0.005					
Forest Cover Type	CC[b]	Intercept	-2.8581	0.6549	19.05	<0.001	0.53	76.5%	11.01	8	0.20
		Cdwnwood	-0.0841	0.0348	5.83	0.016					
		Dliana	0.0015	0.0004	11.52	<0.001					
		Grass	0.0168	0.0070	5.78	0.016					
		Herbsp	0.2473	0.1074	5.29	0.021					
	SW[c]	Intercept	-5.8869	0.7983	19.05	<0.001	0.81	90.3%	4.22	8	0.84
		Dliana	0.0073	0.0020	13.71	<0.001					
		Hstem	0.0087	0.0021	17.21	<0.001					
		Herb5	0.0064	0.0013	24.18	<0.001					
	RI	No Model	-	-	-	-	-	-	-	-	-
	MA	No Model	-	-	-	-	-	-	-	-	-

[a]Sample sizes for analyses: Capture stations (n=118), Noncapture stations (n=871), LR for disturbed sites yielded same results as overall model, Sensitivity = 78.0%, Specificity = 81.2%
[b]Capture stations (n=56), Noncapture stations (n=143), Sensitivity = 71.4% Specificity = 68.5%
[c]Capture stations (n=60), Noncapture stations (n=336), Sensitivity = 80.9%, Specificity = 82.1%

Table 43. Results from stepwise logistic regression analyses for predicting the presence or absence of woodland voles at trapping stations as a function of microhabitat. Small mammals were trapped on Quantico Marine Corps Base, VA, 1997-1999. Habitat variables are detailed in Table 3.

Grouping Level		Variable	β	SE(β)	Wald X^2	P	Somers' D	Concordant Observations	Hosmer-Lemeshow GOF Test		
									Test Statistic	DF	P
All[a]		Intercept	-2.4268	0.3894	38.85	<0.001	0.28	63.0%	10.71	8	0.22
		Hcvr	-1.1240	0.3006	13.98	<0.001					
		Treesrch	0.0076	0.0029	7.00	0.008					
		Herb5	0.0036	0.0016	5.25	0.022					
		Domveg4	0.8813	0.3527	6.24	0.013					
Undisturbed[b]	RI/MA	Intercept	-4.2164	0.5274	61.22	<0.001	0.44	71.1%	3.68	8	0.89
		Hstem	0.0049	0.0013	13.42	<0.001					
		Smast	1.0681	0.4587	5.42	0.020					
Disturbed[c]	CC/SW	Intercept	-1.5496	0.2183	50.37	<0.001	0.32	62.7%	5.85	8	0.66
		Herbsp	-0.3012	0.0815	13.67	<0.001					
		Herb5	0.0050	0.0017	8.25	0.004					
Forest Cover Type	CC	No Model	-	-	-	-	-	-	-	-	-
	SW[d]	Intercept	-3.1513	0.7620	17.11	<0.001	0.50	74.8%	10.96	8	0.20
		Ntree	-0.3112	0.1214	6.57	0.010					
		Cother0	-0.0020	0.0008	7.39	0.007					
		Treesrch	0.0267	0.0082	10.57	0.001					
		Hcvr	-1.0107	0.3708	7.43	0.007					
		Dliana	0.0049	0.0019	6.57	0.010					

[a]Sample sizes for analyses: Capture stations (n=87), Noncapture stations (n=902), Sensitivity = 52.3%, Specificity = 57.4%
[b]Capture stations (n=28), Noncapture stations (n=366), Sensitivity = 51.7%, Specificity = 65.0%
[c]Capture stations (n=59), Noncapture stations (n=536), Sensitivity = 57.6%, Specificity = 59.6%
[d]Capture stations (n=48), Noncapture stations (n=348), Sensitivity = 60.4%, Specificity = 70.1%

Table 43. Continued

Grouping Level		Variable	β	SE(β)	Wald X^2	P	Somers' D	Concordant Observations	Hosmer-Lemeshow GOF Test		
			Model Input					Model Evaluation			
									Test Statistic	DF	P
	RI[e]	Intercept	-2.2766	0.9753	5.45	0.020	0.47	73.0%	8.15	8	0.42
		DBH	-0.0808	0.0303	7.12	0.008					
		Crub0	0.0407	0.0195	4.37	0.037					
		Herbsp	0.2675	0.1262	4.49	0.034					
	MA	No Model	-	-	-	-	-	-	-	-	-

[e]Sample sizes for analyses: Capture stations (n=16), Noncapture stations (n=178), Sensitivity = 62.5%, Specificity = 60.6%

Significant relationships were only detected for 3 species, white-footed mice, northern short-tailed shrews, and woodland voles.

White-footed mice.—Three predictor variables explained significant amounts of variation; total rainfall (R^2adj=0.09, $\underline{P}$=0.01), % humidity (R^2adj=0.12, $\underline{P}$=0.004), and mean temperature (R^2adj=0.17, $\underline{P}$=0.001). Total rainfall ranged from _ to _ during trapping while % humidity ranged from _ to _ and mean temperature from _ to _. The proportion of white-footed mice captured each night was negatively related to all three environmental variables. The only significant multiple linear regression model indicated that 24% of the variability in capture occurrence was explained by the combined effects of the total rainfall and mean temperature (F=9.99, $\underline{P}$=0.001).

Northern short-tailed shrews.—Only one predictor variable (mean temperature) explained a significant amount of the variation in shrew capture probabilities (R^2adj=0.07, P=0.07). Capture probabilities of northern short-tailed shrews declined with increasing temperature.

Woodland voles.—Only one predictor variable individually accounted for a significant amount of the variation in woodland vole capture probabilities, mean wind speed (R^2adj=0.05, $\underline{P}$=0.06). Wind speed ranged from _ to _ during trapping. The proportion of individuals captured declined with increased wind speed.

DISCUSSION

White-footed mice.—White-footed mice are common in a variety of habitats throughout eastern North America. Densities generally are stable and range from 2-23 individuals/ha (Terman 1968, Batzli 1977, Whitaker and Hamilton 1998), although numbers in excess of 100/ha have been reported (Jacquot and Vessey 1995, Nupp and Swihart 1996). Habitat structure strongly influences the abundance of *Peromyscus* spp. (M'Closkey and Lajoie 1975, Kitchings and Levy 1981, McMurry et al. 1996). Although different habitats may support similar densities, the demographic performance of these populations often varies substantially in response to habitat quality (Van Horne 1982, Morris 1984, Krohne and Baccus 1985, Adler 1987, Linzey 1989).

Significantly greater numbers of white-footed mice were captured in shelterwood and riparian sites than mature or clearcut sites (Table 9, Figure 5.). Low numbers of white-footed mice captured in riparian sites during February-March 1998 resulted in a marginally significant time effect and time*treatment interaction (Table 9). These low densities were likely the result of winter flooding. Other researchers (Blair 1939) have noted similar declines in density following flooding events. On my study sites survival appeared unaffected by flooding, as survival rates from trapping occasion 2-3 in riparian sites were similar to those in other forest cover types during this time interval (Table 22). Weather apparently had little influence on capture probabilities, although capture probabilities tended to decline with increasing rainfall, humidity and temperature.

Densities of white-footed mice were slightly greater in clearcut (mean density = 4.7 individuals/ha, SE = 1.0) than mature forest cover types (3.8 individuals/ha, SE = 0.4). Buckner and Shure (1985) also found higher densities of white-footed mice in recent clearcuts (< 2 years

old) than in uncut forested sites in western North Carolina. Similarly, Root et al. (1990) found greater numbers of white-footed mice in clearcuts than in uncut oak-hickory forests in Missouri and Mitchell et al. (1997) captured more white-footed mice in recent clearcuts than second-growth mature sites in Virginia. In contrast to these results, Kirkland (1990) reviewed studies on clearcutting of deciduous forests and *Peromyscus* spp. and found that most researchers reported a negative response to clearcutting (7 of 11 published studies).   Other studies have indicated no response in *Peromyscus* spp. to clearcutting. Kirkland (1977) found similar numbers of white-footed mice in clearcuts < 6 years old, 16-25 years old stands, and stands > 25 years old in hardwood forests in West Virginia and Healy and Brooks (1988) found a similar outcome for deer mice, *P. maniculatus*, across successional gradients in West Virginia.

Studies that have evaluated the impacts of partial cuts, including shelterwood cuts, generally report a positive response of *Peromyscus* spp. to harvesting. Monthey and Soutiere (1985) captured more *P. maniculatus* in uncut and partially cut stands than clearcuts in northern Maine while Swan et al. (1984) captured significantly greater numbers of *Peromyscus* spp. in shelterwoods than uncut, clearcut or strip-cut treatments in northern hardwood forests in Nova Scotia. Tomblin (1994) found a positive response in *Peromyscus* spp. to disturbance created by gypsy moths in Appalachian hardwood forests in Virginia. Such disturbances often create habitats structurally similar to shelterwoods.

Geier and Best (1980) reported higher abundances of white-footed mice in floodplains than in grazed and ungrazed upland habitats in Iowa. In my study, densities of white-footed mice in riparian stands (10.2 individuals/ha, SE = 1.2) were more than double those of mature-upland sites (3.8 individuals/ha, SE = 0.4).

Differences in habitat quality (based on demographic performance) were evident across and even within forest cover types. In general, the demographic performance of white-footed mouse populations in clearcut and mature sites was poor in comparison to shelterwood and riparian sites. Poor habitat quality was characterized by any combination of the following: low density, high proportions of juveniles, smaller body sizes, lower survival/residency, sex ratios skewed towards males, and lower proportions of reproductively active individuals.

White-footed mice occupying clearcut sites were generally smaller (Table 14), had lower densities (Table 10), survival (Table 22), residency rates (Figure13), and higher proportions of juveniles represented in the population (Figure 8). This combination of demographic characteristics suggests that clearcuts functioned as population sinks for white-footed mice. Smaller body sizes would be associated with younger, subordinate individuals while the lower survival rates I detected may be related to increased rates of predation and/or dispersal. Sullivan (1979), Martell (1983), Linzey (1989), and Linzey and Kesner (1991) also found early successional habitats served as dispersal sinks for *Peromyscus* spp. In a reciprocal removal study, Linzey (1989) demonstrated that white-footed mice inhabiting clearcuts were subordinate to individuals occupying adjacent wooded habitats. She suggested that individuals occupying clearcuts were likely forced into these habitats by the territorial actions of woodland mice. When resident mice were removed from the woodlot, individuals from the clearcut quickly colonized the vacated sites. However, when residents were removed from clearcuts, no woodland mice colonized these habitats. Linzey's results also may explain some of the lower survival/residency rates I found. Once individuals occupying clearcuts achieved higher social status and were able to successfully compete for territories, they may have dispersed back into the wooded habitats surrounding the clearcuts.

Although I detected no significant differences in proportions of reproductively active white-footed mice across forest cover types, there was a tendency for disturbed habitats (clearcuts and shelterwoods) to have greater proportions of reproductively active individuals (Figure 11). Higher rates of reproduction in clearcuts seems unusual for low quality habitat, however, disturbed sites likely had increased food resources such as invertebrates, soft mast, and seed-producing herbaceous plants associated with early successional habitats (Halma and Dueser 1994, Lovejoy 1975). Tomblin (1994) found a similar positive response in reproductive rates of white-footed mice following gypsy moth disturbance in hardwood Appalachian forests in Virginia.

Populations of white-footed mice occupying mature stands were characterized by low reproductive activity (Figures11), survival (Table 22), and residency (Figure 13), had sex ratios strongly skewed towards males (Table 13), and had higher proportions of juveniles (Figure 8). As with clearcut sites, these demographic characteristics are associated with dispersal sinks. The overrepresentation of juvenile males in poor quality habitats also has been reported by Martell (1983). This would be expected since dispersing *Peromyscus* spp. are generally young males Fairbairn (1977, 1978). The low quality of the mature-upland forests is surprising. Sullivan (1979), Martell (1983) Linzey (1989), Linzey and Kesner (1991) all found mature forests to represent high quality habitat. However, mature study sites on Quantico Marine Corps Base were structurally simple habitats, i.e. sparse understory, low densities of logs, rock, and few gaps in the canopy (Table 24). These characteristics may be largely responsible for the poor demographic performance of the white-footed mice occupying mature sites.

Shelterwood and riparian forest cover types generally provided the highest quality habitats. These sites were associated with higher survival (Table 21), longer residency (Figure

13), higher proportions of adults (Figure 8) and females (Table 13) and larger body sizes (Table 14). Previous research suggests that populations oriented towards these K-selected demographic characteristics (Pianka 1970) occupy high quality habitats (Adler and Tamarin 1984, Adler and Wilson 1987, Linzey and Kesner 1991, Tomblin 1994). Of the shelterwood study sites, however, SW1 had a sex ratio strongly skewed towards males (Table 13.), lower residency rates (47% residency) and lower densities than other shelterwood sites (mean density = 7.3 individuals/ha, SE = 2.3 in SW1 compared to 11.5 indiviudals/ha, SE = 1.9 in the other shelterwoods). These characteristics suggest poor quality habitat and may be the result of understory structure. SW1 was characterized by an extremely dense understory of regenerating hardwoods (Table 24). Surprisingly, white-footed mice occupying riparian study sites had poor rates of reproduction in comparison to other forest cover types (Figure 11). The poor rates of reproduction may be attributed to several factors; an overrepresentation of males on RI1 (Table 13), high rates of botfly parasitism on RI2 (from June-August 1998, approximately 40% of the population was infected), and possibly lower availability/quality of forage. Scott and Snead (1942) reported declines in reproduction coinciding with high rates of botfly parasitism.

Density appears to be a reasonably good indicator of habitat quality for white-footed mice on Quantico Marine Corps Base. The overall density of white-footed mice in high quality habitats (shelterwood/riparian) was 11.53/individuals/ha (SE = 1.85) compared to 4.23/individuals/ha (SE =0.60) in low quality habitats (mature/clearcut). Density was highly correlated with the proportion of reproductively active adults (r = 0.84, n = 10) and moderately correlated with the % of residents (r = 0.64) and the overall proportion of males (r = -0.68). I did not detect any high-density populations characterized by poor demographic performance (Van

Horne 1981, 1983, Adler and Wilson 1987) nor did I detect wide-scale fluctuations in density over time (2 years of trapping) often associated with this species (Wolff 1986).

Peak densities were in May 1998 and December 1998-January 1999 and coincided with periods of high juvenile recruitment (Table 10, Figures 8 and 12). Based on back-dating the ages of juveniles captured (Figure 12) and the reproductive condition of adults (Figure 11), 2 major periods of reproduction likely occur, one from March-April and the other from August-November. The success of the late fall and early spring litters may depend heavily on hard-mast production. Wolff (1996) found densities of white-footed mice to be correlated with hardmast production. Adult females were reproductively quiescent from May-early July (Figure 11C). Other researchers have noted a similar decline in *Peromyscus* spp. reproduction over the summer (Terman 1968, Wolff 1986, Goundie and Vessey 1986). The reasons for the decline in reproductive activity remain poorly understood and likely include factors such as botfly parasitism (Scott and Snead 1942), and a physiological recovery period (Wolff 1986b).

Overall summer residency rates (65%) were generally higher than those reported by other researchers, despite the longer time intervals between trapping occasions in this study. Mature forest residency rates (50.7%, SE = 10.7), however, were similar to results from other studies conducted in mature forested habitats. Adler et al. (1987) found residency rates during the breeding season (proportion of mice present on a grid > 2 weeks) to be 0.55 for adult males, 0.44 adult females, 0.37 juvenile males, and 0.53 juvenile females in deciduous forest habitat in Massachusetts while Krohne and Burgin (1987) found residency rates of 59% in hardwood forests in Indiana.

Survival rates for white-footed mice were fairly high. Average 26-day survival rates were 0.83 (SE = 0.05)(Tables 21, 22). Adler reported 14-day survival rates of 0.52 for adult

males, 0.56 for adult females, 0.44 for juvenile males, and 0.59 for juvenile females. I also found summer survival of juvenile males (0.41) to be lower than juvenile females (0.59), although the difference was not significant (Table 22). The lower survival rate of juvenile males is likely a result of male-biased dispersal (Wolf 1986).

Microhabitat affinities of white-footed mice on Quantico Marine Corps Base were similar to those previously reported for this species (Barry and Franq 1980, Cranford and Maly 1986, Graves et al. 1988, Planz and Kirkland 1992, Tomblin 1994). Overall, white-footed mice were associated with microhabitats characterized by greater numbers of woody stems, and logs, larger trees, fewer shrubs, and more evergreen cover (Tables 34, 39). Logs and woody debris serve as navigational landmarks, provide quiet routes of travel, and are associated with greater abundances of invertebrates (Lovejoy 1975, Barry and Franq 1980, Graves et al. 1988, Planz and Kirkland 1992, McMillan and Kaufman 1995). Woody stems and evergreen shrubs (mountain laurel) provide cover from predators. Tomblin (1994) also found these 2 variables to be important to white-footed mice in Appalachian forests disturbed by gypsy moths in Virginia. White-footed mice also avoided microhabitats dominated by grasses.

The importance of specific components of microhabitat structure to white-footed mice, in particular herbaceous vegetation characteristics, varied with respect to macrohabitat. This suggests that habitat selection is driven by a behavioral response to the varying capabilities of different suites of environmental features to meet life requisites. Within undisturbed habitats (riparian and mature sites) white-footed mice were associated with microhabitats dominated by fern cover, tall woody stems and woody ground cover (Table 39) while within disturbed habitats (clearcuts and shelterwoods) white-footed mice selected microsites characterized by greater densities of logs and woody species, fewer lianas and less herbaceous cover (Table 39). In both

habitat types, woody debris and the density of woody stems were important, however, in comparison to disturbed sites, undisturbed sites had relatively sparse, low woody understories. It is likely that white-footed mice compensated for the paucity of woody stem cover in undisturbed habitats by selecting microsites dominated by ferns.

Across forest cover types, microhabitat varied with macrohabitat structure. Woody debris and woody stem density appeared to be important in sites lacking canopy cover (clearcuts) or those with open understories (riparian and mature sites)(Table 39, Appendices H and I). In addition, shrub cover apparently substituted for tree canopy cover in clearcuts (Table 39, Appendix D). In shelterwoods, where there were high densities of woody stems, white-footed mice selected microsites dominated by blueberry or mountain laurel (Table 39, Appendix F.).

Patterns of microhabitat selection during summer and winter trapping occasions were similar within forest cover types (Appendices E, G, J, K). In general, during winter white-footed mice tended to be captured at stations closer to logs and with greater densities of woody stems. This trend was especially apparent in mature sites where concordance values in the logistic regression models increased from summer to winter (73.2%-81.5%). Such shifts in microhabitat use may be a response to increased vulnerability to predators during the winter and changes in food resources. Shrub cover appeared to be more important to white-footed mice during the winter. In shelterwoods, white-footed mice were captured at stations with greater densities of mountain laurel and fewer blueberry stem densities during the winter than in summer. In addition, white-footed mice showed no avoidance of herbaceous vegetation. Mountain laurel and herbaceous vegetation (typically broom sedge) may provide year-round cover from predators. During the summer blueberries may provide an important source of forage for white-footed mice. However, the low-growing woody stems provide unsuitable winter habitat. In

riparian sites, white-footed mice also showed no avoidance of areas with high densities of herbaceous stems during the winter. In addition, capture sites were associated with larger trees during the winter. Larger trees may be associated with greater production of hard-mast, a critical winter food source for white-footed mice (Gashwiler 1979, Wolff 1996).

Density had no apparent affect on patterns of habitat selection for white-footed mice occupying shelterwoods during the winter. Mean density during December 1998-January 1999 was 26.3 individuals/ha compared to 11.2 individuals/ha in February-March 1998. Low-density and high-density logistic models were comparable in performance (Appendix AB). Territoriality in white-footed mice declines and may cease altogether outside of the breeding season (Wolf 1986). The increased tolerance of adults towards juveniles and subadults allowed them to remain within higher quality microsites, whereas they would otherwise haven been excluded during the breeding season.

Transient white-footed mice were generally less selective of microhabitat than residents (Appendix AA). The exception was mature sites, where only transient mice showed selection for microhabitat. Across forest cover types the general trend was for transient mice to occupy microsites with more woody debris than no-use microsites. Since white-footed mice use this substrate for travel, such a pattern is not unexpected. Few other variables distinguished between use and no-use stations for this subset of individuals.

I found significant associations between the relative abundance of white-footed mice and several macrohabitat variables (Table 28), including tree density, canopy cover, herbaceous stem density, grass stem density, shrub density, blueberry stem density, the CV in low growing woody stem densities and log density. Geier and Best (1980) found a positive association between white-footed mouse abundance and mean log length. In contrast to my results, however, they

found a positive association between abundance and grass cover. Healy and Brooks (1988) found correlations between deer mouse abundance and tree density (-), tree DBH (+), vine cover (-), and log cover (-). In my study, there was no relationship between abundance and tree DBH, and more complex quadratic relationships to vine density (lianas) and tree density. The nonlinear relationships were largely caused by the presence of clearcuts in the analyses. When these sites are excluded, I also found negative associations between tree density and vine cover. The abundance of white-footed mice across forest cover types was largely a curvilinear function of the % tree canopy cover (R^2adj = 71%). The strong relationship between tree canopy cover and white-footed mice abundance is not surprising. Tree canopy cover influences the development of the herbaceous and woody understories of sites. White-footed mice reached their highest abundances on sites with moderate canopy closure (57-73%). These sites also had patchy distributions of woody stems, high blueberry stem densities, and larger numbers of stations with no herbaceous cover.

Even-aged silvicultural practices significantly affected the population structure of white-footed mice. Although present in all of the forest cover types examined, clearcuts and mature stands provide only marginal habitat for white-footed mice on Quantico Marine Corps Base. Silvicultural practices that preserve a large portion of the canopy and enhance the woody components of habitats will likely improve habitat quality for white-footed mice. However, as hardwoods regenerate and form a dense shrub layer, habitat quality may decline (as suggested by SW1). This likely occurs as herbaceous species and low-growing blueberries are crowded out and the flush of early successional plant and insect species declines. Periodic burning and/or thinning of these sites may maintain high habitat quality. Riparian stands also provide high quality habitat for white-footed mice. Silvicultural practices that improve habitat quality for

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white-footed mice elsewhere will likely improve habitat quality in riparian sites as well. However, care should be taken to leave the fern cover intact.

       Eastern Chipmunks.—Eastern chipmunks are common inhabitants of deciduous forests and forest edges. Preferred habitats generally consist of oak-hickory or beech-maple forests (Hamilton and Whitaker 1998). Chipmunks are solitary and defend small territories around their burrows. These burrows act as foci of activity and eastern chipmunks will more finely discriminate among microhabitats at increased distances from them (Bowers and Ellis 1993, Bowers 1995). Home ranges often overlap and under optimal conditions, densities as high as 38 individuals/ha have been reported (Hamilton and Whitaker 1998). Demography of chipmunks is strongly influenced by food resources, especially hard-mast production (Mares et al. 1982, Sullivan et al. 1983, Harlow and Doyle 1990).

       I detected a marginal difference in relative abundances of eastern chipmunks across forest cover types (Table 9). Relative abundances were highest in shelterwood and riparian sites and similar in mature and clearcut sites (Figure 5). A significant time interaction that was detected was largely the result of low numbers of eastern chipmunks captured in shelterwoods during May-August 1997. The majority of trapping during 1997 was conducted later in the summer (July-August) and may have coincided with a period of inactivity often observed in chipmunk populations (Dunford 1972, Wrazen 1980). Interestingly, no eastern chipmunks were captured on RI1 and only 1 capture occurred on MA1. These sites were located adjacent to SW1, which supported moderate densities of chipmunks (mean density = 6.0 individuals/ha). It is possible that the higher quality of habitat available in SW1 attracted individuals from surrounding habitats.

Clearcuts had moderately ($P > 0.1$) greater overall abundances (0.98 individuals/ha) of eastern chipmunks than mature sites (0.75 individuals/ha). Kirkland (1990) found mixed results in studies that examined the impacts of clearcutting deciduous forest on eastern chipmunks. Of 5 studies included in Kirkland's review, 3 reported a decrease in abundance of chipmunks and 2 an increase. In contrast to my results, Brooks and Healy (1988) found non-significantly greater relative abundances of eastern chipmunks in sawtimber and mature stands than seedling or sapling stands in deciduous forests in West Virginia. Similarly, Kirkland (1977) captured more eastern chipmunks in stands > 15 years old than those in younger age classes in a deciduous forest in West Virginia. Although eastern chipmunks were captured more frequently in clearcuts than mature forest, most captures (61 %) occurred on the edges of the trapping grid within a mean distance of 9.5 m (SE = 2.9 m) from the study site boundaries. Kirkland et al. (1985) also found eastern chipmunks actively exploited the edges of clearcuts and avoided the interior. Chipmunks captured in clearcuts were probably attracted to these habitats by the increased forage and many likely had home ranges that overlapped with the adjacent mature forested habitat.

Studies that have evaluated the response of eastern chipmunks to shelterwood harvests (Swan et al. 1984) or the creation of shelterwood-like conditions (Tomblin 1994) have reported mixed results. Swan et al. (1984) found similar numbers of eastern chipmunks in uncut northern hardwoods and clearcuts in Nova Scotia but captured moderately more ($P > 0.1$) individuals in strip-cuts and shelterwoods. Tomblin (1994) found similar numbers of eastern chipmunks in sites disturbed by gypsy moths and an undisturbed reference site.

In contrast to my results, Geier and Best (1980) captured fewer chipmunks in wet floodplain habitats than dry floodplain or upland sites subject to various levels of grazing

intensity. In my study, mean density of chipmunks in riparian areas was 2.09 individuals/ha compared to 0.75 individuals/ha in mature sites. Density of chipmunks on RI2 was unusually high (9.8 individuals/ha) in June 1998 (Table 11). Trapping may have coincided with a period of dispersal from surrounding habitats, however, I noted no increase in chipmunk densities on the adjacent site, MA2, suggesting that RI2 may have functioned as a dispersal corridor for eastern chipmunks on Quantico Marine Corps Base.

I detected no significant differences in several demographic characteristics of eastern chipmunks across forest cover types. However, several trends suggest habitat quality is highest in shelterwoods. Adult eastern chipmunks from shelterwoods tended to be larger than those from the other forest cover types (Table 17). In addition, of the 12 adult females captured (44 total) over the course of this study that showed evidence of lactation, 11 came from shelterwoods and 1 from MA2. Eastern chipmunks occupying shelterwood sites also had longer lengths of residency, although RI2 had the largest overall percentage of residents (Figure 14). The large percentage of juveniles captured in RI2 further suggests this site may act as a dispersal site for subordinate individuals (Table 13).

Because of low sample sizes survival rates for eastern chipmunks could not be compared across forest cover type. Yearly survival rates based on mean 26-day intervals suggest that < 5% of eastern chipmunks survive their first year (Table 23). These results are similar to those in other studies. Whitaker and Hamilton (1998) reported average life spans to be about 1 year with few individuals surviving 2-3 years and Tyron and Synder (1973) found mean life expectancy to range from 1.0 to 2.25 years with an average of 1.29 years. Summer survival rates over the 1998 trapping period were low for adults (0.43) and juveniles (0.19, Table 23). In juveniles, lower perceived survival rates were likely the result of dispersal off the study plots. Among adults,

however, this low rate is puzzling. One possibility is that subordinate adults temporarily moved onto study sites in an attempt to establish territories and failing to do so, either through the antagonistic actions of residents or poor habitat quality, subsequently dispersed. Another possibility is that high rates of predation contributed to poor survival.

Overall eastern chipmunks selected microhabitats characterized by larger trees, greater woody stem densities (including mountain laurel and blueberry), greater woody species richness, greater densities of logs, woody debris and woody ground cover, fewer lianas, and lower densities of herbaceous stems than at sites with no captures (Tables 35 and 40). This pattern is consistent with avoidance of open, grass-dominated microsites and a preference for wooded habitats. Dueser and Shugart (1978) found similar patterns of habitat selection in a second-growth mixed forest in Tennessee. In their study, eastern chipmunks occupied sites associated with greater canopy cover, higher tree and evergreen shrub density and lower overall shrub density. Linzey and Linzey (1971) and Tomblin (1994) also found eastern chipmunks associated with evergreen shrub cover. The preference eastern chipmunk showed for microhabitats with greater woody stem densities contradicts Mahan and Yahner (1996) who found that eastern chipmunks relied heavily on sight to monitor the activities of conspecifics and predators and, therefore, avoided microhabitats with high densities of low-growing stems. Eastern chipmunks selected microhabitats with greater log densities and more woody debris. In addition to providing observation posts, these features provide runways for travel (Ryan and Larson 1976, Yahner 1992).

The overall logistic regression model for eastern chipmunks performed fairly well (Concordance was 77.7%, Table 40), however, the techniques I used to assess microhabitat (averaging microhabitat use across a population) may produce biased results. Bowers (1995)

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suggested that individual eastern chipmunks use microhabitats in a manner consistent with central-place foraging, i.e. as individuals move farther from their burrows they more highly discriminate among microhabitats because of increased risks of predation. Consequently, microhabitat studies would tend to overrepresent the role of microhabitat close to burrows and underrepresent it at some distance from them.

Patterns of habitat selection displayed by eastern chipmunks differed in disturbed and undisturbed habitats (Table 40). Within undisturbed sites, eastern chipmunks selected microsites with greater tall woody stem and herbaceous stems densities, and avoided areas with short growing hardwoods. Such a pattern would be consistent with selection for microsites with thick fern cover. Within disturbed areas, chipmunks selected microsites associated with trees and woody stems and avoided more open areas dominated by grasses and lianas. Patterns of habitat selection were similar between clearcuts and shelterwoods (Tables 40, Appendices L and M). Within both forest cover types eastern chipmunks showed a preference for microsites with greater vertical woody structure. This type of microsite would provide cover from potential predators. Within shelterwoods, eastern chipmunks were additionally associated with blueberry, mountain laurel and greater tree densities, features absent in clearcuts, which may provide richer foraging opportunities.

Within riparian sites eastern chipmunks selected microsites with greater densities of shrubs and tall herbaceous stems, fewer woody stems and lianas, and less woody debris. (Table 40 and Appendix N). Tall herbaceous vegetation in riparian areas typically consisted of ferns. The lack of well-developed fern cover in RI1 may have attributed to the absence of eastern chipmunks from this site. The logistic regression model for this forest cover type performed fairly (71% concordance, sensitivity, specificity).

Within mature sites, eastern chipmunks selected microhabitat characterized by greater densities of tall woody stems, greater vertical woody stem density, more stumps and less woody debris. Vertical woody stem density was the sole variable included in the logistic regression model for mature stands. However, this model performed with the highest level of accuracy among all logistic regression models developed for eastern chipmunks (78.5% concordance, sensitivity, specificity). Kitchings and Levy (1981) also found eastern chipmunks associated with high stump densities and higher shrub densities while Gore (1988) found eastern chipmunks selected microsites in mature stands associated with large trees, downed wood and dense vegetation > 2 meters tall.

Brooks and Healy (1988) found no significant relationships between relative abundance of eastern chipmunks and macrohabitat characteristics. However, non-significant negative relationships ($0.20 < \underline{r} < 0.50$ were found between chipmunk relative abundance and tree density, tree seedling cover, shrub cover and positive relationships to mean tree DBH, basal area and forb cover. Geier and Best (1980) reported positive relationships between the abundance of eastern chipmunks and the density of logs, plant species richness, vertical stratification of the understory and shrub density. I also found positive relationships between relative abundance of eastern chipmunks and tree DBH and woody stem density (Table 29). In addition, eastern chipmunk abundance was positively related to the CV in log and liana densities. I found more complex quadratic relationships to variables relating to tree density, tree canopy cover, % grass ground cover, woody ground cover and shrub density (Table 29). The CV in liana density was included in all 3 multiple linear regression models. Other variables included shrub density (-), the density of herbaceous stems > 0.5 meters (+), and the density of tall woody stems (-). The positive association between eastern chipmunks and the coefficient of variation in log density seems

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contradictory. The more patchily distributed logs were, the greater the abundance of chipmunks. However, these conditions were associated with shelterwood sites, where chipmunks reached their greatest abundances. The positive association between chipmunk relative abundance and coefficient of variation in liana density may be associated with chipmunks avoiding habitats with vine cover which would inhibit rapid travel and/or their preference for wooded habitats.

Eastern chipmunks are compatible with even-aged silvicultural practices on Quantico Marine Corps Base. Shelterwood harvesting, in particular, improves eastern chipmunk habitat. Increased production by residual mast trees, the enhanced vertical woody structure, and flush of resources associated with early successional habitats, all likely contribute to the higher habitat quality of this forest cover type. Eastern chipmunks limited their exploitation of clearcuts to the periphery of these habitats, likely in response to increased predation risks. The addition of small clearcuts (< 2 ha) or single-tree harvests in homogenous mature sites, may improve habitat quality for eastern chipmunks by enhancing the woody understory and increasing available forage. Enhancement of the woody understory may improve habitat quality in these habitats.

Northern short-tailed shrews.—The northern short-tailed shrew is one of the most abundant small mammals in eastern North America (Getz 1989). The distribution of short-tailed shrews is largely dependent upon adequate microclimate and prey availability (Pruitt 1959, Getz 1961). The inability of short-tailed shrews to regulate water evaporation through their skin restricts these animals to microhabitats where air humidity approaches 100% (Pruitt 1959). However, provided adequate microclimate conditions, short-tailed shrews can successfully occupy a wide range of habitats (Getz 1961, Linzey and Linzey 1971, Cranford and Maly 1986, Mengak et al. 1987, DeGraaf et al. 1991).

I did not detect a significant difference in capture rates of short-tailed shrews across forest cover types. However, there was a trend for relative abundances to be greater in clearcuts (1.42 individuals/100 TN, SE = 0.33) than mature (0.99 individuals/100 TN, SE = 0.27), shelterwood (0.74 individuals/100 TN, SE = 0.12) or riparian (0.63/100 TN, SE = 0.17) stands (Figure 5). Other researchers have documented similar patterns. Healy and Brooks (1988b) captured more short-tailed shrews in seedling clearcut stands than uncut hardwood forest in West Virginia. Mitchell et al. (1997) captured more short-tailed shrews in a recent clearcut (<3 years old) than in forested stands in an Appalachian forest in Virginia, and Tomblin (1994) found greater densities in habitats disturbed by gypsy moths in the same geographic area. Lovejoy (1975) noted that increases in shrew abundance following clearcutting (and other forms of disturbance) might be associated with increases in invertebrate abundance. In the present study, however, I did not attempt to measure this variable.

Several studies have noted little to no response in short-tailed shrews to clearcuts or other forms of silviculture (DeGraaf et al. 1991, Pagels et al. 1992) while others have found short-tailed shrews to be more abundant in undisturbed or older successional stands. Kirkland (1977) reported higher relative abundances of short-tailed shrews in stands > 25 years old (1.28 individuals/100 TN) than stands < 5 years old (0.61 individuals/100 TN) in West Virginia. Monthey and Soutiere (1985) found short-tailed shrews to be more common in uncut hardwoods than clearcut or partially cut stands in Maine.

Overall relative abundance of short-tailed shrews based on live-trapping was lowest in riparian stands. In contrast to my results, Mengak et al. (1987) reported relative abundances of short-tailed shrews in floodplains along 1st and 2nd order streams to be > 5 times greater than those from hardwood forests in western South Carolina. Geier and Best (1980) captured more

short-tailed shrews in channelized and wet floodplains than upland habitats. In this study, when only pitfall trapping data are examined, greater trap rates of short-tailed shrews were recorded for RI1 than any other site/cover type (Table 5). However, to be effective pitfall traps must be open for extended periods of time, i.e. several months (Corn and Bury 1987). In this study pitfalls were open only for a total period of 12-16 days and captured low numbers (29) of individual short-tailed shrews. Conclusions based solely on pitfall trapping results are therefore questionable. Live-trapping may have resulted in underestimation of short-tailed shrew abundances but should provide a representative estimate provided shrews did not have differential susceptibilities to live-traps among forest cover types.

There was a marked increase in short-tailed shrew captures during June and July with a peak in August 1998 (Figure 5). This increase resulted in a significant time effect when relative abundances were examined across forest cover types (Table 9). Getz (1989) reported similar trends in shrews studied over a 14-year period in Illinois. Getz found populations exhibited a consistent annual population cycle, increasing steadily from lows during late winter (January-March) to peak in late summer-early autumn with a subsequent decline. These trends are most likely caused by increased juvenile recruitment following peaks in reproductive activity. French (1985) found that peaks of breeding occurred in a population of short-tailed shrews in Indiana during late spring (March-June). Similarly, Getz (1989) found reproductive activity peaked during May. I did not examine short-tailed shrews for reproductive status, however, the marked increase in the number of juveniles captured in June suggests reproductive activity peaked in April-May. The ratio of juveniles to adults increased from 0.31 juveniles per 1 adult in May and June to an approximate 1:1 ratio in July and August.

Total numbers of short-tailed shrews captured (including adults and juveniles) doubled from May to June (Appendix B). Shrews may have been exhibiting a behavioral response to environmental conditions, traps or some other factor. Gentry et al. (1971) and Zegers and Ha (1981) suggested that different movement patterns and trap shyness resulted in longer time periods before short-tailed shrews would enter traps. Shrews may have become more acclimated to the presence of traps over time and thus more willing to enter them. Only 1 variable, mean temperature, explained a significant amount of variation (7%) in the daily proportion of individuals captured. As temperature increased, the proportion of shrews captured decreased. The low amount of variability in captures explained by weather conditions in the proportion of animals captured each night suggests that weather did not have a significant influence on shrew activity patterns. However, this analysis did not include measures of luminosity and/or cloud cover. Other researchers (Getz 1961, Smith et al. 1974) have found weather-related factors to influence shrew relative abundance over longer time scales. Getz (1989) found relative abundances of shrews to decline during periods of low rainfall and peak during periods of higher than average rainfall. Smith et al. (1974) also found a significant correlation between summer precipitation and population density. Measurable rainfall occurred on only a few days of trapping at Quantico, thus no discernable patterns could be observed in short-tailed shrew response to precipitation.

I found few differences in the physical characteristics of short-tailed shrews across forest cover types. Adult short-tailed shrews captured in shelterwoods had smaller tails than those from clearcuts, and juveniles occupying mature stands had longer tails than juveniles from other forest cover types (Table 15). Tail size may not correlate well with general condition thus generalizations about habitat quality based on this measurement are questionable. Although no

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significant difference was detected in mass or body length across forest cover types, short-tailed shrew juveniles from clearcuts tended to have larger body sizes and mass than those from other forest cover types (Table 17). No consistent trend was seen among adult shrews.

The larger body sizes of juveniles from clearcuts suggest that this habitat may be of higher relative quality. In addition, there was a lower overall juvenile:adult ratio in clearcuts (0.52 juveniles:1 adult) than other forest cover types; riparian (0.80:1), shelterwood (0.93:1) and mature (1.27:1). Short-tailed shrews are territorial (Platt 1976) and may follow the ideal despotic theory of habitat selection (Fretwell 1972). Thus, adult shrews may preclude juveniles from the best habitats. As a result, populations occupying higher quality habitat may have age ratios skewed towards adults. More research, however, is needed on reproductive effort and survival of short-tailed shrews across forest cover types to effectively evaluate habitat quality.

Overall, short-tailed shrews selected microhabitats characterized by fewer stumps, smaller trees, greater tree, shrub, woody stem, log, and liana densities, as well as greater percentages of ground cover, woody ground cover and greater litter depth (Tables 37, 42). This pattern of habitat selection is consistent with other studies (Hamilton 1943, Morris 1955, Kirkland 1978, Kitchings and Levy 1981, Cranford and Maly 1986, Tomblin 1994). Cranford and Maly (1986) found short-tailed shrews to occupy microsites associated with greater shrub cover than herbaceous cover in an old-field community. Tomblin (1994) found northern short-tailed shrews associated with areas of greater log, rock and shrub density. Others have shown shrews to select moist habitats with abundant leaf litter, logs, rock and woody debris (Hamilton 1943, Morris 1955, Kirkland 1978). In contrast to my results, Kitchings and Levy (1981) found short-tailed shrews associated with areas of greater stump density and less shrub cover in forest habitats. However, they did note a positive relationship between logs and short-tailed shrews.

Habitats with greater numbers of small trees, shrubs, woody stems, and % ground cover may create more favorable microclimate conditions for short-tailed shrews as well as providing protection from potential predators (Kirkland 1978, Kirkland 1990). In addition, greater numbers of logs, woody ground cover, and litter depth may provide more favorable foraging and nesting sites for short-tailed shrews (Lovejoy 1975).

Despite obvious physical differences among forest cover types, microhabitat selection differed only slightly between disturbed (clearcut/shelterwood) and undisturbed (riparian/mature) forest cover types (Table 42). Within both types of habitat, short-tailed shrews avoided areas with higher stump density and selected microsites with higher log density. The logistic regression models developed for disturbed and undisturbed habitats also included several variables correlated to each other ($r > 0.40$) but which appeared in different models. Short-tailed shrews were positively associated with vertical woody stem density in undisturbed habitats. This variable was correlated to 4 variables (shrub density, tall woody stem density, litter depth, mean tree diameter) significant in the logistic regression model developed for disturbed habitats (Appendix B). The remaining habitat variables that differed between disturbed and undisturbed sites may reflect avoidance by short-tailed shrews of open areas in undisturbed sites and drier microhabitats in disturbed sites. Short-tailed shrews in undisturbed habitats avoided microhabitat characterized by tree canopy cover, higher herbaceous species richness, and intermediate height blackberry stems. The avoidance of canopy cover seems contradictory given the other variables included in the undisturbed logistic regression model. In fact, this variable was borderline significant ($P=0.06$, Table 41) and may be biologically irrelevant. The remaining variables suggest that within riparian and mature habitats, short-tailed shrews avoided more open areas. These more open areas may be associated with higher predation risks and drier

conditions. Within disturbed habitats, short-tailed shrews additionally selected microhabitats with greater densities of tall herbaceous stems and greater % ground cover and avoided microhabitats characterized by high low woody stem density. Tall herbaceous stems and greater % of ground cover may create more favorable moist microsites for shrews. The avoidance of areas with high densities of low woody stems may be more related to habitat conditions within shelterwoods than clearcuts. Within shelterwoods, areas of high low-growing woody stem densities were associated with potentially more dry microsites dominated by low growing *Vaccinium* spp.

The logistic regression models developed to predict short-tailed shrew presence or absence at individual trapping stations in disturbed and undisturbed habitats resulted in concordance values of 73% and 70.0% respectively. These values indicate only a fair level of accuracy in predicting capture stations of short-tailed shrews. The low susceptibility of short-tailed shrews to live-traps may account for the performance of the logistic regression models, resulting in errors of omission (lower sensitivity). For disturbed and undisturbed habitats estimated sensitivities (percentage of 'presence' response predicted correctly) were 62.6% and 58.0% respectively. Estimated model specificities (percentage of 'absence' responses predicted correctly) were 64.7% and 63.3% respectively.

Short-tailed shrews occupying clearcuts selected microhabitat characterized by greater shrub and tall-growing woody stem densities, greater woody species richness, more woody ground cover, and fewer herbaceous stems and lianas (Appendix P). LR models indicated avoidance of areas with denser concentrations of downed woody debris and stumps and selection for areas with soft mast, and greater densities of hardwood stems and woody ground cover (Table 42). These suites of environmental conditions are associated with areas of dense

hardwood regeneration in clearcuts and indicate avoidance of more open grass-dominated microsites. LR models demonstrated only a fair level of accuracy (72.6% concordance).

Within shelterwoods short-tailed shrews selected microhabitats characterized by smaller trees, more logs, greater percentages of ground cover and greater litter depth (Appendix Q). Additionally, LR models indicated shrews selected areas with smaller trees, fewer lianas, greater densities of tall woody stems and herbaceous stems and greater litter depth (Table 42). These habitat characteristics indicate short-tailed shrews select more shrubby microsites associated with regenerating hardwoods, logs and avoid more open habitats. One variable included in the LR model, the density of herbaceous stems, seems to contradict this conclusion. Short-tailed shrews may use these areas for foraging when they are located proximally to areas of regenerating hardwoods. Among all the LR models developed for short-tailed shrews, the model for shelterwoods performed the best, with 73.8% concordance.

Within riparian sites short-tailed shrews selected microhabitats characterized by greater numbers of woody stems, more logs, fewer herbaceous species, more woody ground cover, less grass and greater litter depth (Appendix R). This suggests that short-tailed shrews avoided areas of open canopy and selected microsites with more complex woody components. Only 2 variables, log density and litter depth, were significant in the LR model (Table 42). Despite the limited number of variables included in the model, concordance values indicated a fair level of accuracy (70.0%).

Within mature stands, northern short-tailed shrews selected microhabitats with greater densities of woody stems at intermediate and tall heights (Appendix S). Only 1 variable, the density of hardwood stems, was included in the LR model (Table 42). This is consistent with the trend seen in other forest cover types for shrews to select microsites with greater woody

components. Within the more homogenous mature sites, however, it is more difficult to detect this trend. The LR model was only able to predict use stations slightly better than by chance (59.3%). The low predictability of this LR model suggests that other factors, such as soil properties, may influence the distribution of short-tailed shrews or that shrews were not as selective in their habitat use within mature stands. Gore (1988) developed a logistic regression model for predicting presence of northern short-tailed shrews based on microhabitat in old-growth northern hardwood forests that resulted in higher classification rates (70%) for short-tailed shrews than my own model. His model included the density of snags (-), % of cover < 0.5 m above the ground (+), rock cover (+), herbaceous cover 0.5-2.0 above ground (+), and depth of litter (+). The greater structural diversity of the mature forests used in Gore's research (especially the presence of rocky cover and gaps in the canopy) likely accounts for the number of variables in the model.

Significant relationships existed between the overall relative abundance of northern short-tailed shrews (n=10) and macrohabitat characteristics related to tree density (canopy cover, basal area, density of mast trees, density of lianas), tree size (mean tree DBH, CV shrub density), and woody stem density (vertical woody stem density, CV tall woody stems, CV blackberry stems)(Table 31). Healy and Brooks (1988) found relative abundances of northern short-tailed shrews captured in northern hardwood stands in West Virginia to be negatively correlated with DBH, basal area, and tree seedling density while positively related to tree density, shrub density and vine cover. There are few consistencies between their study and my own. While I did find the relative abundance of short-tailed shrews to be negatively correlated to mean tree DBH and positively correlated to shrub density ($\underline{r}$ = -0.65 for the 2 variables), I found positive associations with woody stem density, and negative associations between short-tailed shrew abundance and

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tree density. In addition, short-tailed shrews exhibited quadratic relationships to basal area and vine density; abundance declined with increasing basal area and vine density and then subsequently increased. The discrepancies between Healy and Brooks (1988) results and my own may reflect differences in our approaches to collecting and analyzing habitat data. Brooks and Healy calculated tree density using 2.5 cm DBH as a cutoff point for inclusion in their density calculations, I included only trees > 7.5 cm DBH.

Only 74% of the variation in relative abundances of short-tailed shrews was explained by the coefficient of variation in tall woody stem densities and tree DBH. Two other models explained similar amounts of variation included the coefficient of variation in blackberry stem densities and DBH, and the coefficient of variation in tall woody stems densities and the coefficient of variation in the density of vines.

Even-aged silvicultural practices appeared to have little influence on northern short-tailed shrews. Shrews selected microhabitat characterized by higher densities of woody stems, shrubs and logs. Adequate environmental conditions existed in all forest cover types allowing occupation by short-tailed shrews. Variables important to shrews at the micro-scale also tended to be important on a landscape level. Increased prey availability in clearcuts may explain the slightly greater number of shrews captured in this forest cover type. The lower numbers of shrews captured in riparian stands is puzzling. Mengak et al. (1987) and Geier and Best (1980) noted greater abundances in riparian stands than adjacent mature forest. Low numbers of shrews captured may be related to the periodic flooding that occurs on these sites, especially during winter-early spring.

Meadow voles.—Meadow voles are generalist herbivores found in a wide variety of habitats but generally associated with grasslands (Getz 1985, Linzey and Cranford 1984, Cranford and Maly 1990). Densities of meadow voles are variable, as many as 600/ha have been reported (Taitt and Krebs 1985). Populations often display cyclicity (Taitt and Krebs 1985) or erratic annual or multiannual fluctuations (Getz et al. 1987). Researchers have reported that population structure of meadow voles is regulated by plant-community structure, vegetative cover, plant diversity, and food quality (Getz 1960, Tait and Krebs 1981, Jones 1990, Hall et al. 1991). In general, environmental suitability for meadow voles can best be described as being related to a gradient of increasing grass cover (Adler and Wilson 1989) and forage availability (Jones 1990).

I detected no significant difference in meadow vole relative abundances across forest cover types (Table 9), despite the virtual absence of this species from mature and riparian sites. Large standard errors among clearcut and shelterwood sites masked any treatment effect (Figure 5). Overall mean relative abundance of meadow voles was similar in clearcut and shelterwood stands even though meadow voles were not captured in SW1 and SW2 (Appendix B). When meadow voles were present in shelterwoods (SW3 and SW4), mean relative abundance (1.56 individuals/100 TN, SE = 0.80) was non-significantly greater than that of clearcuts (1.13 individuals/100 TN, SE = 0.44). Population levels (based on mean relative abundance) were similar within clearcuts and shelterwoods with the exception of May-August 1997 (Figure 5). In general, abundances appeared to peak in early-late winter and decline to lows during July and August, however, no significant time effect was detected (Table 9). Peaks observed during the winter may represent the greater willingness of meadow voles to enter traps because of the decreased availability and quality of winter forage.

Numerous other studies have documented increases in meadow voles following timber harvesting. Kirkland (1990) reviewed 8 published studies on the effects of clearcutting deciduous forests on small mammals and found the majority (7) reported positive responses in microtine rodents. Swan et al. (1994) found greater numbers of meadow voles in stripcut (2.6 individulas/100 TN) and clearcut (2.8/100 TN) sites than in mature (0.2/100 TN) or shelterwood (0.6/100 TN) cuts. Similarly, Monthey and Soutiere (1985) found greater abundances of meadow voles in *Rubus* dominated clearcuts than uncut or partially cut hardwood stands in northern Maine, while Healy and Brooks (1988) only captured this species in seedling clearcuts in West Virginia. In contrast to these results, Kirkland et al. (1985) reported no response of meadow voles to clearcutting oak forests in Pennsylvania. However, these clearcuts contained only sparse herbaceous vegetation and were dominated by low growing woody plants, features associated with poor quality meadow vole habitat. Similar to my results, Geier and Best (1980) reported low numbers of meadow voles in riparian habitats and the absence of this species in (ungrazed) upland habitats. In this study, the 3 meadow voles captured in riparian sites may have represented dispersing individuals.

The low relative abundances of meadow voles in clearcuts and shelterwoods suggest that these forest cover types only provided marginal habitat. Meadow voles were present only in shelterwood sites that had open, grass-dominated patches. Recapture rates of meadow voles were extremely low (< 13% of individuals were subsequently recaptured and only 3 meadow voles were captured > 1 trapping occasion). This suggests poor survival and/or high transiency rates. Alternatively, trapping methods may have inadequately sampled this species or meadow voles became extremely trap-shy as a result of handling. However, these last 2 explanations are unlikely. The mean length of time between trapping intervals during the summer 1998 field

season was 22 days, substantially shorter than the average lifespan of meadow voles (range = 3.8 – 12.4 weeks, Hall et al. 1991, Bowers et al. 1996). In addition, more meadow voles were captured during the winter when traps were only open 3 days, than during the summer when traps were open for 4 (Appendix B).

Comparisons between clearcuts and the shelterwood sites where meadow voles were present suggest little difference in habitat quality. Despite low residency rates, most individuals captured in both habitat types were adults, the overall juvenile to adult ratio in clearcuts was 0.6: 1.0 and in shelterwoods, 0.5: 1.0. The total number of breeding adults captured in both forest cover types was similar (shelterwoods, 7; clearcuts, 6). (Interestingly, all breeding condition individuals in clearcuts were male and 6 of the 7 in shelterwoods female.) Given the potential reproductive rates of meadow voles, these numbers seem dismally low. Sex ratios among juveniles and adults were similar across both forest cover types, although there was a tendency towards more adult males in clearcuts (Clearcuts: juveniles, 0.79 males: 1 female; adults, 1.71: 1; Shelterwoods: juveniles, 0.73: 1; adults, 1.08: 1). Adler and Wilson (1989) found higher quality meadow vole habitats were not necessarily associated with more females or adults, which complicates interpretation of these results. It is possible that the shelterwood and clearcut sites included in this study acted as dispersal sinks for subordinate individuals. The dominant grass on all sites, broom sedge, provides only poor quality forage (Cranford, personal comm.). Once individuals attained larger sizes (and greater social ranking) they may have dispersed to higher quality habitats.

Logistic regression models predicting species presence/absence performed well for this species (Table 42). Within clearcuts and shelterwoods meadow voles selected similar microhabitats that were characterized by low densities of woody stems, fewer logs and other

woody debris, and a greater density and diversity of herbaceous vegetation (Table 42, Appendices T and U). Other studies have reported similar patterns of microhabitat selection. Adler (1985, 1987) found meadow voles were associated with microhabitats characterized by little vertical woody development, less woody ground cover, and dense grass cover. Similarly, Birney et al. (1976), Cranford and Maly (1986, 1990), and Snyder and Best (1988) found meadow voles associated with grass-dominated microhabitats.

The importance of herbaceous vegetation to meadow voles was also evident in the multiple regression analyses (Tables 27 and 31). Five of 7 macrohabitat characteristics were moderately to strongly correlated ($0.58 < \underline{r} < 0.94$) with tree canopy cover. As canopy cover increased, the development of herbaceous understory vegetation declined. Other studies have noted macro-scale habitat associations for meadow voles. Birney et al. (1976) found as grass cover increased, population density of meadow voles also increased. Adler and Wilson (1989) suggested an average grass cover of 30-40% per 0.4 ha was necessary to permanently support meadow voles. They also found survival rates increased along an increasing gradient of grass cover.

Even-aged silvicultural practices on Quantico will strongly impact this species. Meadow voles require large open areas with dense grasses. The low densities of meadow voles in relation to other studies suggest that clearcuts and shelterwoods only contained marginal habitat. Short-term high quality habitat within clearcuts and shelterwoods could be improved by seeding with a greater diversity of grasses. Alternatively, maintaining openings through prescribed burns may also have a positive impact. Riparian areas may provide dispersal corridors for meadow voles, particularly when beaver activity opens canopy, allowing development of herbaceous vegetation.

Woodland Voles.—Woodland voles are a common pest in fruit orchards of eastern North America, often reaching densities as high as 150/ha (Hamilton 1938, Anthony et al. 1986). In natural habitats, however, this species is relatively scarce (Crain and Packard 1966, Goertz 1971). Among microtine rodents, woodland voles are unusual, being strongly fossorial, producing small litters, having delayed reproductive maturity, and living in small family units (Valentine and Kirkpatrick 1970, Fitzgerald and Madison 1983). Previous research indicates that woodland voles are habitat generalists and forage on a variety of herbaceous and woody plants, in particular the roots and stems. Preferred natural habitats include mixed deciduous woods, woodland edges and overgrown fields (Hamilton 1938, Benton 1955, Goertz 1971).

Due to limited population sizes of woodland voles in natural habitats, little is known about patterns of habitat selection and population dynamics outside of orchards (Anthony et al. 1986). However, researchers have often reported that soil properties influence the distribution of woodland voles. Rhodes and Richmond (1985) found woodland voles avoided soils with gravel and stone while Fisher and Anthony (1985), Haines and Geier (1951), and Goertz (1971) found woodland voles selected light, friable soils in which to dig their burrows. In addition, Goertz (1971) reported woodland voles also prefer moist soils.

I did not detect a significant difference in woodland vole abundances across forest cover types (Table 9). There was a slight trend for relative abundances of woodland voles to be greater in shelterwoods than other forest cover types (Figure 5) but considerable variation in abundances among shelterwoods likely resulted in no significant difference being detected (43% of woodland vole captures occurred on 2 sites, SW3 and SW4, while SW1 and SW2 accounted for only about 13% of captures). The differences in the number of woodland voles captured among the shelterwoods is likely related to the high densities of blueberry stems present on SW3 and SW4.

Another possible explanation is that capture probabilities varied across sites. The absence of a well-developed leaf litter may have increased probabilities of capture in shelterwoods in comparison to other forest cover types. The lack of a well-developed leaf litter on shelterwood sites may have forced woodland voles to spend more time foraging aboveground, where they were more likely to be captured.

Goertz (1971) found woodland voles to be more common in savanna edges followed by upland woods, grasslands and bottomland woods. The savanna-edge habitat described by Goertz is similar to habitat conditions within the shelterwoods of my own study. In contrast to Goertz's results, I found abundances in riparian sites (similar to Goertz's bottomland forest) to be generally greater than those in upland mature sites or clearcuts. Low capture rates of woodland voles (overall relative abundance was 0.26 individuals/100 TN), however, makes these results tenuous at best.

I found no significant differences in the physical characteristics of woodland voles across forest cover types (Table 15). Juveniles from clearcuts tended to have smaller body masses and lengths than those from other forest cover types (Table 17). Adults captured in clearcuts, however, tended to be larger than those from other forest cover types, with the exception of mature sites. Overall more females (57) were captured than males (43, Table 12). Anthony et al. (1986), Goertz (1971) Millar and Getz (1969) similarly reported greater numbers of females captured to males. Across forest cover types, clearcut and mature sites had greater proportions of females to males (2.38 females: 1 male) while riparian and shelterwood sites tended to have equal proportions of males and females (1.09 females: 1 male). Overall juvenile to adult ratios were greatest in mature sites (1.14 juveniles:1 adult) followed by clearcuts (0.50: 1 adult), riparian sites (0.27: 1 adult) and shelterwoods (0.21: 1 adult).

No strong evidence indicates any difference in habitat quality across the 4 forest cover types. The slightly greater numbers of woodland voles captured in shelterwoods would suggest this cover type provides somewhat higher quality habitat. This forest cover type also had the lowest juvenile:adult ratio, which would seem to indicate poor reproduction. However, previous research has shown woodland voles to have low reproductive rates in general (Valentine and Kirkpatrick 1970, Schadler 1977). Anthony et al. (1986) found that in high-quality orchard habitat, the percentages of juveniles in the population over the summer ranged from 0-21.1%. The high % of juveniles in mature and clearcut sites may reflect rates of dispersal and not reproduction. However, these sites had greater proportions of females to males (a trend seen in among adults and juveniles), a characteristic associated with higher quality habitats in other species, such as white-footed mice (Pianka 1970). This could be explained if females were the dispersive sex, however this phenomenon has not been previously documented. Sample sizes in the present study limit the validity of these conclusions and more research would be needed to accurately evaluate habitat quality.

Patterns of microhabitat selection displayed by woodland voles seem strongly influenced by macrohabitat. Within undisturbed habitats (riparian and mature sites) woodland voles selected microsites with greater herbaceous components while within disturbed habitats (clearcuts and shelterwoods) these microsites were avoided (Table 43, Appendices V, W, X and Y). The overall logistic regression model developed for woodland voles reflects this discrepancy in microhabitat selection (several contradictory variables are included in the model, Table 43). Not surprisingly, this model performed poorly (63% concordance, 57.4% specificity, 52.3% sensitivity). Common elements, however, such as selection for microsites with greater vertical woody stem and soft mast densities, were found across forest cover types (Table 43, Appendices

V, W, X and Y). Microsites with greater vertical woody stem profiles may provide better cover

from potential predators (perhaps not as important to a fossorial species) and more moist

microenvironments. These microhabitats also may be associated with more highly developed

root systems. Roots, particularly those of soft mast bearing plants, are known to provide year-

round food sources for woodland voles (Hamilton and Whitaker 1998).

Woodland voles exhibited different patterns of microhabitat selection in clearcuts and

shelterwoods, which is reflected by the poor performance of the disturbed sites' logistic

regression model (Table 43). In clearcuts, woodland voles selected microhabitats with greater

shrub, blackberry, tall hardwood, and greater vertical woody stem densities, greater ground cover

and fewer tall herbaceous stems (Table 43, Appendix V). Based on these results, it appears

woodland voles avoid open areas dominated by grasses and instead occupy microsites dominated

by regenerating hardwoods (similar to northern short-tailed shrews). This type of microhabitat

would provide woodland voles with year-round food resources, a well-developed leaf cover for

foraging, and a moist microenvironment.

Within shelterwoods woodland voles avoided open areas dominated by grasses, as in

clearcuts. However, they did not repeat the pattern of selecting microsites dominated by

regenerating hardwoods. Instead, woodland voles appeared to use microhabitats dominated by

blueberry and mountain laurel (Table 43, Appendix W). While these microsites lack a well-

developed leaf litter and are likely drier, the presence of an important food source, blueberry,

may be an important factor for predicting presence of woodland voles. The logistic regression

model for shelterwoods performed the best among those developed for this species.

Concordance values (74.8%), however, only indicate a fair level of accuracy in predicting

microsite use.

In contrast to the patterns seen in clearcuts and shelterwoods, in riparian sites woodland voles appeared to occupy more open grass-blackberry dominated microsites (Table 43, Appendix X). Smaller trees and fewer shrubs would allow more light to penetrate the forest floor and stimulate herbaceous growth. A well-developed herbaceous understory may provide woodland voles with alternative food sources particularly since densities of soft-mast bearing woody plants were relatively low in this forest cover type (Table 24). These more open habitats would also be associated with greater densities of blackberry stems. Despite the limited number of captures (16) occurring in riparian sites, the logistic regression model performed with a fair level of accuracy (Concordance = 73.0%).

Patterns of habitat selection in riparian and mature stands were similar. While mature sites lacked grass-dominated microsites, woodland voles repeated that pattern of selecting microsites with fewer shrubs and greater development of herbaceous vegetation (Appendix Y).

The importance of soft mast bearing woody plants to woodland voles, as indicated by blueberry stem density, is supported by the regression analyses at a macrohabitat level. Relative abundances of woodland voles were significantly related to 9 individual macrohabitat variables (Table 32). Of these, all were at least moderately correlated ($r > 0.46$) with the density of blueberry stems/ha. Only one multiple linear regression model included 2 significant predictor variables, the density of soft mast stems and litter depth (Table 27). The other 2 multiple regression models included the density of blueberry stems/ha as a predictor and either litter depth (-) or the density of low growing woody stems (-). The negative association between woodland vole relative abundances and litter depth at first seems unusual for a fossorial species. Sites with lower litter depths, however, had greater densities of blueberry and may have had more suitable soil characteristics for subterranean activities.

Even-aged silvicultural practices appeared to have little influence on woodland voles. Of the forest cover types examined in this study, shelterwoods seemed to provide the highest quality habitat and clearcuts the lowest, although supporting evidence is weak. It is likely that the presence of blueberry is an important factor related to the distribution of this species on Quantico Marine Corps Base. On sites with low densities of soft mast stems, a highly developed herbaceous understory may be important.

Southern flying squirrels.—Southern flying squirrels are common throughout the eastern United States, occupying deciduous or mixed woodlands (Dolan and Carter 1977). This species primarily nests in natural cavities or those excavated by woodpeckers in snags or live-trees (Dolan and Carter 1977). Forest structure and floristics strongly influences the population dynamics of southern flying squirrels. Tomblin (1994) suggested that life history traits, including the absence of seasonal torpor, slow rates of growth and maturity, and low annual fecundity, would likely increase the sensitivity of southern flying squirrels to habitat disturbances. In particular, southern flying squirrels require multiple den sites and populations may be limited by the availability of suitable cavities (Muul 1968, Bendel and Gates 1987). Sonenshine and Levy (1981), Gilmore and Gates (1985), and Bendel and Gates (1987) determined that a well-developed understory, which provides cover from predators, is critical to southern flying squirrels. Bendel and Gates (1987) reported this species preferred forested stands with open upper stratums, which would provide open glide paths. In addition, the presence of a variety of mast-producing trees is critical to winter survival due to annual fluctuations in mast production (Muul 1968, Weigl 1978, Harlow and Doyle 1990).

Southern flying squirrels were captured in all forest cover types with the exception of clearcuts (Table 7). When present, however, relative abundances of flying squirrels were low on most sites, over 39,000 trapnights resulted in the capture of just 25 individuals on 5 study sites (mean relative abundance = 0.06 individuals/100 TN). There was considerable variation in the number of flying squirrels captured within a particular forest cover type. While MA2 and RI2 had 10 and 5 captures respectively, MA1 and RI1 had no captures. The absence of flying squirrels from MA1 and RI1 is puzzling and likely related to a variety of factors discussed later (Interestingly, these sites also had only 1 capture of eastern chipmunks as well). Among the shelterwood sites a total of 7 captures was recorded, 4 of which occurred on SW1.

Given the habitat requirements of southern flying squirrels it is not surprising that few were captured in clearcuts or shelterwoods. Healy and Brooks (1988) and Kirkland (1977) also have noted the absence of flying squirrels from clearcuts or seedling stands. Kirkland (1977) suggested that the lack of suitable canopy trees for nesting was the primary reason for this species absence from such habitats. Bendel and Gates (1987) suggested that predation-related risks caused flying squirrels to avoid occupation of clearcuts. Taulman et al. (1998) investigated the response of southern flying squirrels to a range of even-aged and uneven-aged silvicultural practices in Arkansas and found varied responses. Within most treatments, including shelterwoods, densities initially declined following harvesting and then subsequently recovered to pre-harvest levels within 2-3 years. Seed-tree treatments were the exception; densities remained considerably below pre-harvest levels. In my own study, shelterwood stands were sampled 2-4 years post-harvest and residual basal areas (including mast tree basal area) exceeded the shelterwoods examined in Taulman et al. (1998). It seems unlikely that relative abundances post-harvest had recovered to pre-harvest levels. Similarly, Tomblin (1994) captured greater

numbers of flying squirrels at an undisturbed reference site (mean density was 1.3

individuals/ha) in Virginia than at sites disturbed by gypsy moths. Canopy cover at the actively

disturbed site examined by Tomblin was similar to the range examined in my own study. Mean

density of southern flying squirrels at this site was 0.2 individuals/ha.

Twenty-one macrohabitat variables individually explained significant amounts of

variation in southern flying squirrel numbers across sites (Table 33). I found associations

between numbers of flying squirrels captured and variables related to tree density (canopy cover,

basal area, distance to nearest tree, density of mast trees, stump density, herbaceous stem density,

density of lianas, grass stem density, % ground cover, % woody ground cover, % grass cover),

tree size (tree DBH), shrub density (coefficient of variation in shrub densities), and log and

woody stem densities. Basal area (+) and the mean tree DBH (+) together explained 93% of

variation in flying squirrel numbers across sites (Table 27). Basal area was also included as a

predictor variable in the other 2 multiple linear regression models. These models included shrub

density (-) and the density of low growing woody stems (+). Healy and Brooks (1988) also

found relative abundance of southern flying squirrels to be negatively correlated to shrub cover

and positively associated with tree DBH and basal area. In contrast to my results, however,

Healy and Brooks found southern flying squirrels to be negatively associated with tree densities.

Taulman et al. (1998) found lower-midstory hardwood tree density to be positively related to

flying squirrel density. The positive association with low growing woody stem densities may

reflect the importance of cover to southern flying squirrels as they forage on the forest floor

(Sonenshine and Levy 1981, Gilmore and Gates 1988, Bendel and Gates 1987). The positive

association with basal area and mean tree DBH is not unexpected. Southern flying squirrels

require relatively large living trees and snags for den sites. Bendel and Gates (1987) reported

that the average diameter of live-tree den sites was 50.4 cm for southern flying squirrels. Larger

mast producing trees also produce greater amounts of fruit, a critical over-winter food source.

Even-aged silvicultural practices on Quantico Marine Corps Base likely have significant

impacts on southern flying squirrel populations. Clearcut and shelterwood harvesting drastically

reduce nesting sites and the density of mast trees. However, several studies have shown that

southern flying squirrels can quickly recolonize disturbed habitats (Healy and Brooks 1988,

Taulman et al. 1998). Healy and Brooks (1988) captured no southern flying squirrels in seedling

stands in West Virginia (< 10 years old) but found them to be common in sapling stands (12-14

years old) and Taulman et al. (1998) found densities recovered within 2-3 years after

shelterwood and single-tree harvesting. They suggested that increased mast production by

residual overstory oaks and hickories expedited the recovery of southern flying squirrels.

However, they noted immigrants likely face higher predation risks. On Quantico Marine Corps

Base, mature-upland forest seems to provide the best flying squirrel habitat. These habitats are

associated with higher densities of mast trees and larger diameter trees. The few captures of

flying squirrels in riparian habitats may be related to the lower densities of mast trees and the

periodic flooding that occurs on these sites. However, these sites could act as potential corridors

for dispersing individuals.

CONCLUSIONS AND MANAGEMENT IMPLICATIONS

Abundance of small mammals differed across the 4 forest cover types I examined (Table

8). In general, the relative abundance of small mammals was greatest in shelterwoods (8.89 new

individuals/100 TN, SE = 1.55) followed by riparian (5.71/100 TN, SE = 0.91), clearcut

(5.25/100 TN, SE = 0.53) and mature (3.25/100TN, SE = 0.46) stands (Figure 4). I detected a

significant time effect ($\underline{P}$=0.0001, 6, 36 df) and time*treatment interaction ($\underline{P}$=0.003, 18, 36 df)

that were largely the result of greater numbers of white-footed mice captured during December 1998-January 1999 and lower numbers of small mammals captured in riparian stands during February-March 1998 (trapping was conducted while these sites were flooded). The composition of small mammal communities also varied with respect to forest cover type, reflecting the varying capabilities of the different macrohabitats to support individual species (Table 7). Pitfall trapping, however, yielded relatively little information about soricids (Table 5), resulting in an incomplete picture of the response of the overall small mammal community to habitat.

The results of this study are consistent with previous research examining the impacts of clearcutting deciduous forest on small mammal communities (Lovejoy 1975, Kirkland 1977, Monthey and Soutiere 1985, Root et al. 1990, Kirkland 1990). The majority of these studies also reported changes in small mammal abundance and/or species composition following timber harvesting. Kirkland (1990) identified several trends for the response of small mammals to clearcutting deciduous forests including a decrease in the abundance of *Peromyscus* spp. and increases in the abundance of microtines and zapodids. In addition, he found inconsistent responses among soricids and sciurids. With the exception of the responses of woodland voles and white-footed mice, a similar pattern was repeated in my study. Among sciurids, eastern chipmunks showed a positive response to harvesting while southern flying squirrels responded negatively. Clearcutting had little effect on populations of northern short-tailed shrews and an unknown effect on other soricids (pitfall trapping results suggest a slight benefit to southeastern shrews). My results also are consistent with studies that have examined the impacts of other even-aged harvesting techniques on small mammal communities or natural disturbances that create shelterwood-like conditions (Swan et al. 1984, Tomblin 1994, Taulman et al. 1998). In

general, these studies reported a positive response following disturbance, at least temporarily, in microtines, *Peromyscus* spp. and eastern chipmunks. Northern-shorted tailed shrews and southern flying squirrels, however, showed inconsistent responses across these studies. In my study, both responded negatively to shelterwood harvesting.

Because of the short duration of this study, the response of small mammals to succession in disturbed stands (clearcuts and shelterwoods) could not be examined. However, Kirkland (1977) noted small mammal diversity and abundance decreased following clearcutting as stands reached the sapling-young pole stage (6-15 years post-harvest). These declines corresponded to the disappearance of the herbaceous understory. Such a pattern would also likely be repeated in shelterwood harvested stands as regenerating hardwoods begin to crowd out early-successional plant species. The effects of this process are suggested by the lower abundance and diversity of small mammals captured on SW1 (see discussion of white-footed mice). Small mammals such as southern flying squirrels and eastern chipmunks, however, benefit from these successional changes (Healy and Brooks 1988, Taulman et al. 1998) and may offset the loss of early successional specialists such as meadow voles and eastern harvest mice.

Although riparian stands represented unique habitats with distinctive vegetative characteristics, these sites did not contain a greater diversity or abundance of small mammals than clearcuts or shelterwoods (Tables 7 and 8). Riparian stands surpassed mature stands in diversity and abundance of small mammals; however, this difference was principally due to greater numbers of white-footed mice and the presence of meadow jumping mice. Previous research has shown meadow jumping mice are associated with dense herbaceous vegetation (Lovejoy 1970, Vickery 1981, Gore 1988). The poor development of the herbaceous understory and predominance of *Lycopodium* likely contributed to the absence of this species from mature

stands. Overall, the relatively simple stand structure of riparian sites (i.e., low densities of shrubs and woody stems, Table 24), as well as the periodic flooding that occurs on these sites, may have limited the diversity and abundance of small mammals. Flooding may be especially detrimental to fossorial species with naturally low rates of reproduction such as woodland voles. McComb et al. (1993) also found few differences between total capture rates of small mammals in streamside and upland habitats in red alder dominated stands in central Oregon. They suggested that the similarity of stand structure and composition between streamside and upland habitats resulted in no detectable differences in overall small mammal abundance across habitat types.

Changes in species abundance and composition across forest cover types suggests that habitat structure influences the distribution of small mammals on Quantico Marine Corps Base. For the 5 small mammal species that I modeled using logistic regression, microhabitat was able to successfully predict presence at trapping stations better than expected by chance for all species. Concordance values of the overall models for individual species (n=1000 for each species) ranged from a low of 63.0% for pine voles to a high of 88.1% for meadow voles (Tables 39-43). However, model sensitivity (the % of event responses predicted to be an event) only averaged 66.4% for the 5 species (range 52.3-78.0), while model specificity (% of no-event responses predicted to be no-event) averaged 67.1% (range 57.4-81.2).

A variety of factors can affect the performance of microhabitat-based models (Brown 1973, Bowers 1988, Morris 1984, 1987, Gore 1988, Block et al. 1998, Jorgensen and Demarais 1999). These factors include the following: 1) the failure of the trapping method and habitat variables selected to accurately reflect microhabitat selection (Thompson 1987, Gore 1988, Taylor 1988, Block et al. 1998), 2) site-specific historical influences (Brown 1973, Bowers 1988), and 3) the inability of microhabitat-based models to account for relationships between

species and habitat at multiple spatial scales (Morris 1984, 1987, Gore 1988, Jorgensen and Demarais 1999). Additionally, model performance is related to statistical considerations such as sample sizes and violations of method assumption (in this case, the independence assumption).

Thompson (1987), Taylor (1988) and Block et al. (1998) found that the type of trapping method used (i.e. pitfall trapping, live-trapping, direct observation) affected the results of habitat selection studies for small mammals. These differences stemmed from the variable capture probabilities of species associated with each particular trapping technique. Block et al (1988) determined that live-trapping generally resulted in errors of omission because of the short duration traps are open. In my study traps were open at individual trapping stations for a total of 26 days, which likely reduced the impacts of this source of error. Model performance also depends on the relevancy of the habitat variables included as predictors; habitat characteristics measured must reflect the variation in microhabitats as they are perceived by individual small mammal species (Gore 1988, Block et al. 1998). The poor performance of the logistic regression models for woodland voles and northern short-tailed shrews, in particular, may have been a consequence of the lack of variables relating to soil properties.

Brown (1973) and Bowers (1988) documented the effects of unique historical influences on desert rodent communities. They found that slight variations in environmental features such as temperature, rainfall, etc., and the historical distribution of species profoundly impacted rodent community organization and structure. However, given the similarity of the stand histories (before harvest) of the sites I selected and the widespread distributions of the species included in this research, historical influences are not likely to be a significant source of model error.

Microhabitat-based models cannot account for the relationships between species and habitat at multiple spatial scales (Morris 1984, 1987, Gore 1988, Jorgensen and Demarais 1999). Previous research, however, suggests that macrohabitat features may have a greater influence on species distributions than microhabitat features, at least under certain conditions (Morris 1984, 1987, Gore 1988, Jorgensen and Demarais 1999). There are 2 lines of thought that converge on the theme that macrohabitat ultimately determines species distributions. The first holds that small mammals do not partition microhabitats and, therefore, factors that affect population density subsequently determine species distributions (Gore 1988). The second holds that small mammals may potentially be microhabitat selectors, but that habitat use is constrained by macrohabitat (Morris 1984, Jorgensen and Demarais 1999).

In a study of small mammal habitat use in northern hardwoods in New Hampshire, Gore (1988) found little evidence of microhabitat selection (i.e., poor predictive ability of logistic regression models and little overlap between use stations across trapping periods) and suggested that small mammals did not partition microhabitats because of the large degree of temporal variability in microhabitats and because a wide-range of environmental conditions provided equally suitable habitat. Gore (1988) suggested that density and the factors affecting population size determine the distribution of small mammals. Because the factors that determine population size are strongly influenced by macroscale features, macrohabitat indirectly determines habitat selection.

Morris (1987) and Jorgensen and Demarais (1999) compared the ability of microhabitat features versus dummy variables coding for macrohabitat to predict species presence at trapping stations and found macrohabitat outperformed microhabitat variables. Although they reported microhabitat partitioning, they suggested that microhabitat use is constrained by macrohabitat.

Morris (1984) provided support for this in a study of microhabitat use by white-footed mice and meadow voles across 6 macrohabitats. He found that microhabitat use varied across habitat types. I found similar dependency on macrohabitat for white-footed mice and woodland voles. These results suggest that small mammal habitat use is dynamic (at least for some species). Across habitat types, small mammals may respond behaviorally to select different suites of environmental features that best met their life requisites. This could explain some of the contradictory descriptions of habitat often reported in the small mammal literature.

One result of macrohabitat-dependent microhabitat selection is that microhabitat-based models of habitat selection may be only of limited applicability (Jorgensen and Demarais 1999). Jorgensen and Demarais (1999) suggested that for desert rodents, macrohabitat-based models might prove to be more effective management tools. A similar suggestion may be appropriate for temperate rodent communities as well. I found numerous relationships between individual species abundance and macrohabitat features (Tables 26-33) and, in general, habitat variables important to small mammals on microscales tended to be important at the macroscale as well. Overall small mammal abundance was related to the densities of tall herbaceous stems and soft mast and tree canopy cover. Sites with greater tall herbaceous stem and soft mast densities with intermediate canopy cover generally supported the greatest numbers of small mammals (Table 27).

Many researchers have reported small mammal abundances to vary temporally (Hamilton and Cook 1940, Krull 1970, Petticrew and Sadlier 1974, Swan et al. 1984, Root et al. 1990). These fluctuations may be erratic or closely linked to changes in food resources, weather patterns or other factors (Wolff 1986). Such fluctuations may have significant repercussions on the observed relationships between small mammal abundance and macrohabitat. For example, mast

production often varies considerably from stand to stand and year to year. Density of mast-eating rodents (including eastern chipmunks, southern flying squirrels and white-footed mice) may fluctuate with mast production (Wolff 1986). The sampling period of this study was relatively short (< 24 months) and likely does not reflect the temporal variability of the small mammal populations sampled. Thus, macroscale relationships reflect only a snapshot of stand conditions and small mammal abundances.

Small mammals are compatible with even-aged harvesting techniques (clearcuts and shelterwoods) employed on Quantico Marine Corps Base. Disturbance created favorable microhabitats for a variety of species including white-footed mice, eastern chipmunks and northern short-tailed shrews. Many species were associated with woody debris and logs, therefore, slash and residual logging debris should not be removed following timber harvesting if managers are interested in creating favorable microhabitats for these species. Previous research indicates that small mammals can be responsible for the consumption of entire mast crops, particularly during poor mast years, and can have a negative influence on stand regeneration (Bowers 1993, Ostfeld et al. 1997), therefore, if rapid stand regeneration is desired, reductions in small mammal abundances could be achieved by reducing the herbaceous understory and removing residual logging debris. Although certain species such as southern flying squirrels were sensitive to disturbance, successional changes would allow recolonization within a relatively short time period (10-14 years as suggested by Brooks and Healy 1988). Forest managers may also be able to mitigate the impacts of clearcutting on species such as southern flying squirrels and eastern chipmunks by leaving a few large diameter trees and snags. Alternatively, early successional conditions can be maintained by prescribed burning or periodic mowing and thinning to manage for species such as meadow voles and eastern harvest mice.

Habitat quality in these habitats could likely be improved by seeding these areas with native grasses. Increasing the structural diversity of riparian and mature stands, by opening the canopy, may improve habitat quality for several species, however, in riparian stands care should be taken to leave the fern cover intact. Fern cover provided an alternative source of cover to woody stems for species such as white-footed mice and eastern chipmunks. Management options for such sites could include single-tree removal or group tree harvests or those which minimally disturb the understory.

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APPENDICES

Appendix A. Forest cover types found on Quantico Marine Corps Base and corresponding areas (Natural Resources Conservation Report 1998).

Cover Type	Area (Ha)
Aspen	5
Eastern White Pine	5
Eastern Hemlock	10
Chesnut Oak	171
White-Black-Northern Red Oak	3828
White Oak	138
Yellow Poplar	359
Yellow Poplar-Hemlock	14
Yellow Poplar-White Oak-Northern Red Oak	7663
River Birch-Sycamore	21
Pin Oak-Sweetgum	142
Shortleaf Pine	3655
Virginia Pine-Oak	3820
Virginia Pine	898
Loblolly Pine-Hardwood	77
Sweetgum-Yellow Poplar	433
Sweetgum-Willow Oak	33
Green Ash	9
Sycamore-Sweetgum-Elm	28
Red Maple	159
Paulownia	1
Total Area	21,492

Appendix B. Number of individual animals captured within 4 forest cover types on Quantico Marine Corps Base, VA, 1997-1999, for each of the 7 3 and 4 day trapping periods.

Species	Trap Occasion	Clearcut		Shelterwood				Riparian		Mature	
		CC1	CC2	SW1	SW2	SW3	SW4	RI1	RI2	MA1	MA2
White-footed mouse	1	4	5	10	13	34	30	10	19	9	8
	2	7	12	30	15	30	22	7	7	5	4
	3	8	19	12	38	33	34	25	39	8	12
	4	7	10	8	13	23	35	20	13	7	3
	5	3	8	6	25	16	21	23	28	7	10
	6	2	6	6	22	23	24	25	34	10	7
	7	21	15	40	65	75	70	37	27	17	9
Eastern Chipmunk	1	3	0	8	10	8	1	0	3	0	1
	2	0	0	1	1	1	1	0	0	0	0
	3	2	2	12	23	14	10	0	4	0	4
	4	4	4	16	19	9	12	0	12	0	2
	5	3	0	12	17	3	5	0	8	1	3
	6	4	0	16	19	10	7	0	10	0	5
	7	0	0	1	0	0	1	0	0	0	0
Northern short-tailed shrew	1	11	6	9	8	3	3	1	4	4	11
	2	8	3	2	5	3	4	2	0	0	1
	3	3	5	0	3	7	3	3	9	5	12
	4	11	16	4	3	15	2	4	5	7	6
	5	9	15	6	7	7	4	4	14	9	18
	6	13	28	2	7	8	8	1	12	6	16
	7	6	11	5	6	7	10	3	2	0	6
Meadow vole	1	18	2	0	0	0	1	0	0	0	0
	2	11	6	0	0	13	6	0	0	0	0
	3	4	3	0	0	21	3	0	0	0	0
	4	10	3	0	0	20	5	0	0	0	0
	5	3	0	0	0	8	1	0	0	0	0
	6	8	3	0	0	10	3	0	0	0	0
	7	7	10	0	0	20	11	1	1	0	0

Species	Trap Occasion	Clearcut		Shelterwood				Riparian		Mature	
		CC1	CC2	SW1	SW2	SW3	SW4	RI1	RI2	MA1	MA2
Woodland vole	1	5	1	2	0	1	3	0	0	0	4
	2	0	1	1	1	1	5	1	1	0	0
	3	0	3	0	2	2	7	3	1	0	0
	4	3	0	0	2	1	11	2	0	1	1
	5	0	0	0	5	3	2	1	4	1	0
	6	0	0	0	0	4	3	0	4	0	4
	7	1	0	0	0	0	1	0	1	0	2

Appendix C. Correlations among macrohabitat variables used in multiple linear regression analyses. Habitat data were collected in 4 forest cover types on Quantico Marine Corps Base during May 1998-January 1999. For all regressions n=10.

	Canopy	Ba	Ntree	Dbh	Mast	Smast	Shrub/ha	Logden	Stmpden	Woody1	Woody5	Woody0
Ba	0.90	*	*	*	*	*	*	*	*	*	*	*
Ntree	-0.84	-0.79	*	*	*	*	*	*	*	*	*	*
Dbh	0.56	0.52	-0.35	*	*	*	*	*	*	*	*	*
Mast	0.72	0.60	-0.70	0.21	*	*	*	*	*	*	*	*
Smast	-0.69	-0.77	0.74	-0.17	-0.43	*	*	*	*	*	*	*
Shrub/h	-0.40	-0.31	0.02	-0.65	0.10	0.12	*	*	*	*	*	*
Logden	-0.33	-0.48	0.55	0.15	-0.15	0.67	-0.41	*	*	*	*	*
Stmpden	-0.59	-0.63	0.71	0.00	-0.31	0.82	0.24	0.56	*	*	*	*
Woody1	-0.67	-0.63	0.88	0.15	-0.50	0.71	0.20	0.39	0.80	*	*	*
Woody5	-0.57	-0.60	0.88	0.30	-0.43	0.75	-0.02	0.58	0.79	0.95	*	*
Woody0	-0.27	-0.41	0.68	0.51	-0.16	0.62	-0.16	0.60	0.71	0.82	0.93	*
Blue/ha	0.00	-0.21	0.16	0.14	0.12	0.64	-0.35	0.74	0.48	0.09	0.29	0.41
Wdysp	0.28	-0.07	-0.07	0.31	0.41	0.26	-0.20	0.36	0.05	0.09	0.24	0.49
Hstem	-0.72	-0.62	0.60	-0.41	-0.91	0.28	0.00	0.09	0.24	0.31	0.23	-0.01
Grass	-0.89	-0.88	0.83	-0.43	-0.84	0.60	0.06	0.38	0.45	0.54	0.52	0.28
Herb5	-0.14	-0.22	0.27	-0.01	-0.28	0.22	-0.50	0.38	0.12	-0.12	0.05	0.04
Herbsp	0.01	0.21	-0.21	-0.16	-0.34	-0.56	0.14	-0.62	-0.31	-0.20	-0.40	-0.53
Dliana	-0.81	-0.69	0.41	-0.81	-0.59	0.28	0.58	-0.05	0.22	0.27	0.08	-0.22
Grdcvr	0.02	0.27	0.14	0.31	-0.04	-0.45	-0.04	-0.22	-0.31	0.15	0.10	0.04
Wdycvr	-0.67	-0.71	0.70	-0.25	-0.50	0.56	-0.22	0.73	0.26	0.37	0.47	0.32
Grscvr	-0.94	-0.84	0.76	-0.57	-0.79	0.52	0.36	0.12	0.35	0.57	0.46	0.15
Ferncvr	0.45	0.52	-0.41	0.21	0.03	-0.61	-0.32	-0.45	-0.44	-0.48	-0.53	-0.49
Litter	-0.58	-0.44	0.59	-0.15	-0.23	0.19	0.51	-0.03	0.26	0.65	0.54	0.37
Noveg	0.04	-0.23	0.09	0.06	0.24	0.59	-0.27	0.68	0.38	0.01	0.22	0.36
Vwsd	-0.73	-0.40	0.45	-0.54	-0.57	0.31	0.56	-0.17	0.25	0.41	0.19	-0.17

Appendix C. Continued

	Blue/ha	Wdysp	Hstem	Grass	Herb5	Herbsp	Dliana	Grdcvr	Wdycvr	Grscvr	Ferncvr	Litter	Noveg
Wdysp	0.46	*	*	*	*	*	*	*	*	*	*	*	*
Hstem	-0.17	-0.54	*	*	*	*	*	*	*	*	*	*	*
Grass	0.07	-0.24	0.89	*	*	*	*	*	*	*	*	*	*
Herb5	0.49	-0.16	0.41	0.45	*	*	*	*	*	*	*	*	*
Herbsp	-0.76	-0.68	0.42	0.01	-0.23	*	*	*	*	*	*	*	*
Dliana	-0.35	-0.43	0.68	0.66	-0.16	0.40	*	*	*	*	*	*	*
Grdcvr	-0.68	-0.32	0.01	-0.06	-0.32	0.30	-0.01	*	*	*	*	*	*
Wdycvr	0.29	0.11	0.49	0.75	0.38	-0.37	0.41	0.05	*	*	*	*	*
Grscvr	-0.20	-0.29	0.79	0.91	0.12	0.11	0.82	0.09	0.64	*	*	*	*
Ferncvr	-0.34	-0.39	0.00	-0.30	0.25	0.60	-0.25	0.06	-0.46	-0.36	*	*	*
Litter	-0.47	-0.11	0.21	0.39	-0.36	-0.02	0.44	0.63	0.33	0.62	-0.46	*	*
Noveg	0.97	0.59	-0.27	0.46	0.46	-0.85	-0.36	-0.70	0.29	-0.21	-0.37	-0.42	*
Vwsd	-0.36	-0.63	0.50	0.48	-0.19	0.33	0.75	0.27	0.22	0.72	-0.17	0.53	

Appendix D. Results of Kruskal-Wallis tests for differences among levels of use within clearcuts for white-footed mice captured on Quantico Marine Corps Base, VA, from May 1997-January 1999.

Habitat characteristic	Mean (SE)			Significance
	No-use[a] (n=98)	Low-use (n=78)	High-use (n=23)	
Distance to nearest tree (m)	4.31[c] (0.26)	4.01 (0.29)	5.30 (0.47)	0.06
Number of shrubs (shrubs/10m^2)	18.90 (1.39)	18.60 (1.17)	26.91 (3.08)	0.02
Number of woody stems at ground level	191A (15.34)	220AB (16.01)	323B (48.43)	0.002
Number of woody stems at 0.5 meters	195A (17.73)	241AB (20.28)	386B (68.12)	0.002
Number of woody stems at 1 meter	93A (11.39)	127B (12.60)	217C (34.66)	0.0001
Number of blackberry stems at 0.5 meters	105 (12.84)	105 (11.98)	224 (57.63)	0.04
Number of blackberry stems at 1 meter	34A (5.69)	46AB (7.42)	92B (22.57)	0.001
Woody species	5.13A (0.19)	6.13B (0.21	6.00B (0.35)	0.002
Distance to nearest log (m)	2.86A (0.27)	2.01A (0.23)	1.19B (0.45)	.0003
Log density index	1.58A (0.74)	2.69B (0.67)	4.88B (1.30)	0.0001
Woody debris	3.87A (1.03)	7.36B (1.32)	11.28B (2.38)	0.0001
Herbaceous stems (stems/m^2)	331A (14.47)	263B (18.41)	239B (33.46)	0.003
Herbaceous species (species/m^2)	4.69A (0.18)	4.03AB (0.16)	3.39B (0.35)	0.0009
% Woody ground cover	6.87A (1.07)	11.92B (1.47)	17.57B (3.34)	0.0001
% Grass ground cover	40.18A (2.51)	29.09AB (2.78)	26.02B (5.15)	0.002

[a]No-use corresponds to stations with no white-footed mouse captures, low-use to stations with 1-2 individuals captured, and high-use to stations with >2 individuals captured.
[b]All Kruskal-Wallis tests had 2 df.
[c]Between use comparisons were made using Wilcoxon Rank Sum tests. Letter grouping indicates whether significant differences were detected between each pair of groups at α=0.01.

Appendix E. Results of Wilcoxon Rank Sum tests for differences in microhabitat characteristics among capture and no-capture stations within clearcuts for white-footed mice captured on Quantico Marine Corps Base, VA, by season. Summer trapping was conducted from May-August 1997 and 1998. Winter trapping was conducted from February-March 1998, December 1998 and January 1999. Standard errors are presented in parentheses. All tests had 2 df. Dashes indicate variable was non-significant.

| | Mean (SE) | | | Mean (SE) | | |
| | Summer | | | Winter | | |
Habitat Characteristic	No-use (N=125)	Use (N=75)	P-Value	No-use (N=143)	Use (N=57)	P-Value
Number of woody stems at ground level	201 (13.49)	250 (21.35)	0.03	207 (14.34)	250 (19.48)	0.01
Number of woody stems at 0.5 meters	208 (15.78)	286 (29.00)	0.006	228 (18.87)	260 (21.95)	0.02
Number of woody stems at 1 meter	103 (10.54)	154 (15.45)	0.0006	110 (10.27)	153 (17.27)	0.02
Number of blackberry stems at ground level	-	-	-	121 (11.28)	143 (15.72)	0.05
Number of blackberry stems at 0.5 meters	-	-	-	114 (13.27)	136 (17.78)	0.04
Number of blackberry stems at 1 meter	41 (15.86)	56 (9.07)	0.06	38 (5.36)	66 (10.95)	0.01
Number of woody species	5.36 (0.17)	6.11 (0.21)	0.009	-	-	-
Distance to nearest log	2.70 (0.23)	1.71 (0.25)	0.002	3.86 (0.22)	3.03 (0.34)	0.02
Log density index	98.25 (5.08)	65.78 (6.64)	0.0001	92.30 (4.89)	70.45 (7.69)	0.01
Woody debris	4.70 (0.96)	8.40 (1.34)	0.0001	4.99 (0.87)	8.91 (1.67)	0.0002
Number of herbaceous stems at ground level	319 (13.26)	249 (0.003)	0.003	307 (12.89)	257 (21.39)	0.04
Number of herbaceous species	4.56 (0.16)	3.79 (0.17)	0.003	4.45 (0.15)	3.82 (0.20)	0.02
% Woody ground cover	8.04 (1.04)	13.85 (1.62)	0.003	8.8 (1.02)	13.8 (1.85)	0.005
% Grass ground cover	38.0 (2.26)	27.5 (1.12)	0.003	36.4 (2.09)	28.1 (3.41)	0.02

Appendix F. Results of Kruskal-Wallis tests for differences in microhabitat characteristics among levels of use within shelterwoods for white-footed mice captured on Quantico Marine Corps Base, VA, from May 1997-January 1999.

Habitat characteristic	Mean (SE)			Significance
	No-use[a] (n=52)	Low-use (n=141)	High-use (n=203)	
Mean tree dbh (cm)	36.3A[c] (2.04)	29.0AB (1.14)	26.0B (0.92)	0.0001
Distance to nearest tree (m)	4.71A (0.29)	3.99AB (0.18)	3.79B (0.15)	0.01
Number of shrubs (shrubs/10m^2)	12.94 (1.84)	10.09 (0.72)	12.08 (0.62)	0.08
Number of woody stems at ground level	456 (63.65)	489 (39.10)	537 (31.40)	0.10
Number of woody stems at 0.5 meters	301 (57.68)	323 (33.63)	339 (23.07)	0.05
Number of woody stems at 1 meter	134 (38.42)	117 (16.43)	113 (9.27)	0.17
Number of mountain laurel stems at ground level	10A (6.05)	20A (3.98)	70B (10.03)	0.0001
Number of mountain laurel stems at 0.5 meters	9A (6.55)	22A (7.93)	77B (12.82)	0.0001
Number of mountain laurel stems at 1 meter	0A (0)	0A (3.98)	14B (2.86)	0.0001
Number of blueberry stems at ground level (stems/3m^2)	35A[c] (13.49)	64A (14.34)	113B (16.42)	0.0001
Log density index	1.24A (0.27)	1.46AB (0.23)	3.17B (0.66)	0.003
Woody debris	13.72 (4.69)	12.02 (1.20)	16.71 (1.80)	0.06
Herbaceous stems (stems/m^2)	277A (25.55)	192AB (16.09)	164B (13.03)	0.0001
Herbaceous stems at 0.5m (stems/m^2)	29A (8.96)	18B (6.01)	18B (4.88)	0.0003
Herbaceous species (species/m^2)	3.21A (0.24)	2.50B (0.18)	1.88C (0.12)	0.0001
% Woody ground cover	6.39A (0.91)	8.01AB (0.67)	10.50B (0.71)	0.003
% Grass ground cover	16.22A (2.82)	15.61AB (1.83)	11.00B (1.31)	0.003
Mean litter depth (cm)	2.32 (1.28)	2.17 (0.76)	1.99 (0.63)	0.01

[a]No-use corresponds to stations with no white-footed mouse captures, low-use to stations with 1-2 individuals captured, and high-use to stations with >2 individuals captured.
[b]All Kruskal-Wallis tests had 2 df.
[c]Between use comparisons were made using Wilcoxon Rank Sum tests. Same letter group indicates no significant difference between levels of use based on α=0.01.

Appendix G. Results of Kruskal-Wallis tests for differences in microhabitat characteristics among levels of use within shelterwoods for white-footed mice captured on Quantico Marine Corps Base, VA, by season. Summer trapping was conducted from May-August 1997 and 1998. Winter trapping was conducted from February-March 1998, December 1998 and January 1999. Standard errors are presented in parentheses. All tests had 2 df. Dashes indicate variable was non-significant.

Habitat Characteristic	Mean (SE) Summer				Mean (SE) Winter			
	No-use[a] (N=122)	Low-use (N=169)	High-use (N=109)	P-Value	No-use (N=143)	Low-use (N=57)		P-Value
Distance to nearest tree	4.60A[b] (0.19)	3.99B (0.17)	3.32 C (0.20)	0.0001	-	-	-	-
Number of woody stems at ground level	-	-	-	-	415A (34.40)	542B (34.26)	607B (57.75)	0.0008
Number of woody stems at 0.5 meters	-	-	-	-	240A (27.78)	352B (26.52)	438B (49.47)	0.0001
Number of woody stems at 1 meter	-	-	-	-	99A (18.55)	119B (11.41)	147B (18.21)	0.0001
Number of blackberry stems at ground level	68A (12.28)	57AB (10.84)	26B (7.11)	0.0002	-	-	-	-
Number of blackberry stems at 0.5 meters	50A (10.53)	38A (6.94)	16B (5.13)	0.0005	-	-	-	-
Number of blackberry stems at 1 meter	23A (7.70)	12A (2.63)	3B (2.12)	0.0001	-	-	-	-
Number of mountain laurel stems at ground level	15A (4.23)	35A (6.46)	93B (20.45)	0.0001	17A (4.00)	45B (6.84)	100B (23.24)	0.0004
Number of mountain laurel stems at 0.05 meters	22A (9.13)	36A (8.55)	98B (20.45)	0.0001	12A (4.02)	50B (9.00)	121B (31.66)	0.0001
Number of mountain laurel stems at 1 meter	0A (0.30)	7B (2.44)	14B (3.93)	0.0001	1A (0.47)	6A (2.08)	22B (6.15)	0.0001
Number of blueberry stems at ground level	36A (8.23)	104B (19.69)	111B (18.04)	0.0001	-	-	-	-

[a]No-use corresponds to stations with no white-footed mice captures, low-use to stations with 1-2 individuals captured, and high-use to stations with > 2 individuals captured.

[b]Between use comparisons were tested with Wilcoxon Rank Sum tests. Same letter indicates no significant difference between levels of use based on α=0.01.

Habitat Characteristic	Mean (SE) Summer				Mean (SE) Winter			
	No-use[a] (N=122)	Low-use (N=169)	High-use (N=109)	P-Value	No-use (N=143)	Low-use (N=57)	High-use (N=200)	P-Value
Distance to nearest log	-	-	-	-	1.61A (0.12)	1.25B (0.09)	1.00B (0.08)	0.003
Log density index	60.94 (3.50)	50.85 (2.83)	53.08 (4.18)	0.04	63.24A[b] (3.27)	53.83A (2.94)	39.03B (3.99)	0.0001
Woody debris	13.89 (2.39)	14.45 (1.37)	15.39 (2.76)	0.04	-	-	-	-
Number of lianas	-	-	-	-	17 (2.90)	29 (5.06)	48 (12.19)	0.05
Density of herbaceous stems/m^2	253A (17.31)	179B (14.61)	131B (16.76)	0.0001	-	-	-	-
Number of herbaceous species/m^2	3.10A (0.18)	2.20B (0.15)	1.50C (0.15)	0.0001	2.46A (0.15)	2.30A (0.15)	1.85B (0.19)	0.06
% Ground cover	-	-	-	-	92.1 (1.38)	95.1 (0.74)	96.5 (1.03)	0.06
% Woody ground cover	-	-	-	-	7.0A (0.68)	10.1B (0.71)	10.2B (0.05)	0.0001
% Grass ground cover	19.2A (2.13)	13.5B (1.52)	6.6C (1.35)	0.0001	-	-	-	-
Mean litter depth	23.7A (0.80)	20.7B (0.68)	18.2C (0.86)	0.0001	-	-	-	-

[a]No-use corresponds to stations with no white-footed mice captures, low-use to stations with 1-2 individuals captured, and high-use to stations with > 2 individuals captured.
[b]Between use comparisons were tested with Wilcoxon Rank Sum tests. Same letter indicates no significant difference between levels of use based on α=0.01.

Appendix H. Results of Kruskal-Wallis tests for differences in microhabitat characteristics among levels of use within riparian sites for white-footed mice captured on Quantico Marine Corps Base, Va, from May 1997-January 1999.

Habitat characteristic	Mean (SE)			Significance[b]
	No-use[a] (n=33)	Low-use (n=89)	High-use (n=72)	
Number of woody stems at 0.5 meters (stems/3m^2)	37 (9.29)	44 (6.60)	59 (9.74)	0.02
Number of woody stems at 1 meter (stems/3m^2)	15 (4.90)	21 (4.39)	24 (3.66)	0.02
Number of blueberry stems at ground level (stems/3m^2)	3 (2.52)	9 (3.24)	11 (4.06)	0.03
Log density index	0.73 (0.48)	0.33 (0.04)	0.89 (0.30)	0.03
Woody debris	3.39 (1.01)	4.67 (1.03)	6.49 (1.21)	0.01
Herbaceous stems (stems/m^2)	313 (28.29)	213 (13.03)	195 (15.84)	0.002
Herbaceous species (species/m^2)	6.24 (0.44)	5.56 (0.20)	4.87 (0.24)	0.04

[a]No-use corresponds to stations with no white-footed mouse captures, low-use to stations with 1-2 individuals captured, and high-use to stations with >2 individuals captured.
[b]All Kruskal-Wallis tests had 2 df.
[c]Between use comparisons were made using Wilcoxon Rank Sum tests. Same letter group indicates no significant difference between levels of use based on α=0.01.

Appendix I. Results of Kruskal-Wallis tests for differences in microhabitat characteristics among levels of use within mature sites for white-footed mice captured on Quantico Marine Corps Base, VA, from May 1997-January 1999.

Habitat characteristic	Mean (SE)			Significance
	No-use[a] (n=103)	Low-use (n=78)	High-use (n=19)	
Number of woody stems at 1 meter	15 (2.64)	26 (4.14)	28 (8.31)	0.06
Number of blueberry stems at 0.5 meters	3 (1.18)	8 (2.27)	7 (3.59)	0.06
Number of blueberry stems at 1 meter	1 (0.54)	3 (1.80)	4 (2.48)	0.04
Distance to nearest log (m)	2.46 (0.22)	1.98 (0.22)	1.35 (0.35)	0.04
Herbaceous stems (stems/m^2)	74A[c] (5.47)	62AB (5.97)	35B (9.60)	0.006
% Ground cover	96.61 (0.61)	95.72 (0.61)	93.37 (1.71)	0.007
% Woody ground cover	3.47 (0.57)	4.91 (0.68)	7.53 (2.73)	0.04

[a]No-use corresponds to stations with no white-footed mouse captures, low-use to stations with 1-2 individuals captured, and high-use to stations with >2 individuals captured.
[b]All Kruskal-Wallis tests had 2 df.
[c]Between use comparisons were made using Wilcoxon Rank Sum tests. Same letter group indicates no significant difference between levels of use based on α=0.01.

Appendix J. Results of Kruskal-Wallis and Wilcoxon Rank Sum tests for differences in microhabitat characteristics among trapping stations within riparian stands for white-footed mice captured on Quantico Marine Corps Base, VA, by season. Summer trapping was conducted from May-August 1997 and 1998. Winter trapping was conducted from February-March 1998, December 1998 and January 1999. Standard errors are presented in parentheses. All tests had 2 df. Dashes indicate variable was non-significant.

| Habitat Characteristic | Mean (SE) | | | | Mean (SE) | | |
| | Summer | | | | Winter | | |
	No-use[a] (N=47)	Low-use (N=94)	High-use (N=55)	P-Value	No-use (N=134)	Use (N=66)	P-Value
Mean tree dbh (cm)	24.6 (1.86)	29.0 (1.25)	23.2 (1.18)	0.04	-	-	-
Number of woody stems at ground level	-	-	-	-	116 (10.80)	142 (17.34)	0.07
Number of woody stems at 0.5 meter	48 (8.44)	41 (6.51)	61 (11.81)	0.07	43 (6.29)	59 (7.99)	0.004
Number of woody stems at 1 meter	-	-	-	-	18 (2.44)	28 (5.94)	0.01
Distance to nearest log	-	-	-	-	2.58 (0.19)	1.51 (0.17)	0.001
Log density index	-	-	-	-	104.73 (3.64)	80.96 (4.83)	0.0004
Distance to nearest stump	4.71 (0.37)	5.44 (0.25)	4.69 (0.34)	0.07	-	-	-
Stump density index	149.8 (3.91)	165.2 (7.52)	147.9 (4.13)	0.07			
Woody debris	-	-	-	-	4.23 (0.76)	6.98 (1.33)	0.0004
Number of herbaceous stems	294A[b] (22.62)	197B (12.20)	198B (19.25)	0.001	-	-	-
Number of herbaceous species	5.89 (0.33)	5.52 (0.21)	4.75 (0.27)	0.05	5.64 (0.19)	4.89 (0.24)	0.04
% Ground cover	94.9 (1.60)	92.9 (1.05)	97.1 (0.70)	0.04	-	-	-
Mean litter depth (mm)	16.4AB (0.8)	15.1B (0.5)	17.1A (0.6)	0.01	-	-	-

[a]No-use corresponds to stations with no white-footed mice captures, low-use to stations with 1-2 individuals captured, and high-use to stations with > 2 individuals captured.
[b]Between use comparisons were tested with Wilcoxon Rank Sum tests. Same letter indicates no significant difference between levels of use based on α=0.01.

Appendix K. Results of Wilcoxon Rank Sum tests for differences in microhabitat characteristics among capture and no-capture stations within mature for white-footed mice captured on Quantico Marine Corps Base, VA, by season. Summer trapping was conducted from May-August 1997 and 1998. Winter trapping was conducted from February-March 1998, December 1998 and January 1999. Standard errors are presented in parentheses. All tests had 2 df. Dashes indicate variable was non-significant.

Habitat Characteristic	Mean (SE)			Mean (SE)		
	Summer			Winter		
	No-use (N=119)	Use (N=81)	P-Value	No-use (N=163)	Use (N=37)	P-Value
Mean tree dbh (cm)	-	-	-	24.8 (0.76)	21.8 (1.68)	0.06
Number of woody stems at ground level	-	-	-	132 (10.32)	190 (24.35)	0.01
Number of woody stems at 0.5 meters	-	-	-	38 (4.43)	91 (13.31)	0.0001
Number of woody stems at 1 meter	-	-	-	17 (2.37)	36 (5.97)	0.0001
Distance to nearest log	-	-	-	2.43 (0.17)	1.03 (0.15)	0.0002
Log density index	-	-	-	101.57 (3.41)	80.72 (6.20)	0.02
Density of lianas	-	-	-	11.91 (1.18)	6.96 (1.13)	0.08
Number of herbaceous stems at ground level	73 (4.97)	56 (5.91)	0.03	71 (4.31)	46 (7.69)	0.008
Number of herbaceous species	-	-	-	3.28 (0.13)	2.51 (0.29)	0.01
% Woody ground cover	3.66 (0.52)	5.53 (0.88)	0.05	3.97 (0.46)	6.39 (1.54)	0.05

Appendix L. Results of Wilcoxon Rank Sum tests for differences in microhabitat characteristics among capture and no-capture stations for eastern chipmunks captured within clearcuts on Quantico Marine Corps Base, VA, from May 1997-January 1999.

Habitat characteristic	Mean (SE)		Significance[b]
	No-use[a] (n=177)	Use (n=23)	
Number of woody stems at ground level	205 (11.99)	328 (36.54)	0.0001
Number of woody stems at 0.5 meters	220 (15.21)	365 (48.23)	0.0001
Number of woody stems at 1 meter	111 (8.72)	204 (35.06)	0.0001
Number of blackberry stems at ground level	120 (9.84)	181 (24.35)	0.007
Number of blackberry stems at 0.5 meters	114 (11.53)	169 (28.12)	0.01
Number of blackberry stems at 1 meter	43 (5.29)	72 (14.63)	0.003
Number of blueberry stems at ground level	1 (0.49)	17 (10.16)	0.003
Woody species	5.51 (0.14)	6.65 (0.43)	0.01
Distance to nearest log (m)	2.16 (0.18)	3.67 (0.58)	0.005
Log Density Index	83.18 (4.37)	108.33 (13.13)	0.05
% Woody ground cover	11.07 (1.00)	3.70 (0.98)	0.01

[a]No-use corresponds to stations with no eastern chipmunk captures, and Use to stations with ≥ 1 individual eastern chipmunks captured.
[b]All Wilcoxon Rank Sum tests had 2 df.

Appendix M. Results of Kruskal-Wallis tests for differences in microhabitat characteristics among levels of use for eastern chipmunks captured within shelterwoods on Quantico Marine Corps Base, VA, May 1997-January 1999.

Habitat characteristic	Mean (SE)			Significance[b]
	No-use[a] (n=180)	Low-use (n=166)	High-use (n=50)	
distance to nearest tree (m)	4.43A[c] (0.17)	3.79B (0.16)	3.01B (0.25)	0.0001
Number of shrubs (shrubs/10m^2)	10.40A (0.70)	11.52A (0.70)	15.26B (1.50)	0.002
Number of woody stems at ground level	427A (30.75)	574B (36.90)	589B (68.75)	0.0005
Number of woody stems at 0.5 meters	262A (23.27)	378B (30.91)	401B (56.49)	0.0002
Number of woody stems at 1 meter	92A (13.48)	140B (15.10)	131B (13.88)	0.0001
Number of blackberry stems at ground level	48 (8.14)	63 (11.57)	29 (9.95)	0.35
Number of mountain laurel stems at 1 meter	4A (1.96)	8B (1.97)	15B (7.11)	0.08
Number of blueberry stems at ground level	72 (14.87)	98 (16.43)	92 (23.28)	0.08
Distance to nearest stump (m)	3.76A (0.17)	3.49A (0.17)	4.99B (0.36)	0.001
Woody debris	12.41 (1.37)	17.86 (2.27)	12.05 (2.53)	0.11
Number of lianas (lianas/m^2)	30 (5.55)	30 (5.15)	16 (5.87)	0.47
Herbaceous stems (stems/m^2)	239A (14.93)	169B (13.98)	74C (17.15)	0.0001
Herbaceous stems at 0.5m (stems/m^2)	35A (7.18)	7B (2.51)	2B (2.01)	0.001
Herbaceous species (species/m^2)	2.59A (0.15)	2.16A (0.15)	1.56B (0.21)	0.002
% Grass ground cover	16.31A (1.60)	12.17A (1.48)	6.46B (2.40)	0.0001

[a]No-use corresponds to stations with no eastern chipmunk captures, low-use to stations with 1-2 individuals captured, and high-use to stations with >2 individuals captured.
[b]All Kruskal-Wallis tests had 2 df.
[c]Between use comparisons were made using Wilcoxon Rank Sum tests. Same letter indicates no significant difference between levels of use based on α=0.01.

Appendix N. Results of Wilcoxon Rank Sum tests for differences in microhabitat characteristics among capture and no-capture stations for eastern chipmunks captured within riparian stands on Quantico Marine Corps Base, VA, from May 1997-January 1999.

Habitat characteristic	Mean (SE)		Significance[b]
	No-use[a] (n=153)	Use (n=41)	
Number of shrubs (shrubs/10m^2)	10.42 (1.00)	11.90 (1.40)	0.07
Number of woody stems at ground level (stems/3m^2)	138 (11.26)	78 (8.85)	0.01
Woody debris	5.98 (0.84)	1.98 (0.29)	0.09
Number of lianas (lianas/m^2)	92 (11.09)	21 (5.73)	0.0006
Herbaceous stems at 0.5m (stems/m^2)	11 (2.67)	34 (10.82)	0.0001

[a]No-use corresponds to stations with no eastern chipmunk captures and Use to stations with ≥1 individual eastern chipmunk captured.
[b]All Wilcoxon Rank Sum tests had 2 df.

Appendix O. Results of Wilcoxon Rank Sum tests for differences in microhabitat characteristics among capture and no-capture stations for eastern chipmunks captured within mature stands on Quantico Marine Corps Base, VA, from May 1997-January 1999.

Habitat characteristic	Mean (SE)		Significance[b]
	No-use[a] (n=187)	Use (n=13)	
Number of woody stems at 1 meter	20 (2.31)	37 (10.36)	0.04
Distance to nearest stump (m)	5.99 (0.17)	4.34 (0.66)	0.007
Woody Debris	6.73 (0.78)	2.60 (1.31)	0.03

[a]No-use corresponds to stations with no eastern chipmunk captures and Use to stations with ≥1 individual eastern chipmunk captured.
[b]All Wilcoxon Rank Sum tests had 2 df.

Appendix P. Results of Wilcoxon Rank Sum tests for differences in microhabitat characteristics among capture and no-capture stations for northern short-tailed shrews captured within clearcuts on Quantico Marine Corps Base, VA, from May 1997-January 1999.

| Habitat characteristic | Mean (SE) | | Significance[b] |
	No-use[a] (n=108)	Use (n=91)	
Number of shrubs (shrubs/10m^2)	17.41 (1.06)	22.44 (1.52)	0.04
Number of woody stems at 1 meter	94 (8.79)	153 (16.02)	0.007
Woody species	5.34 (0.19)	5.96 (0.19)	0.04
Number of lianas	395 (68.88)	375 (39.04)	0.01
Herbaceous stems	315 (15.36)	269 (18.81)	0.05
% Woody ground cover	7.63 (1.04)	13.01 (1.55)	0.02

[a]No-use corresponds to stations with no northern short-tailed shrews captures, low-use to stations with 1-2 individuals captured, and high-use to stations with >2 individuals captured.
[b]All Wilcoxon Rank Sum tests had 1 df.

Appendix Q. Results of Wilcoxon Rank Sum tests for differences in microhabitat characteristics among capture and no-capture stations for northern short-tailed shrews captured within shelterwoods on Quantico Marine Corps Base, VA, from May 1997-January 1999.

| Habitat characteristic | Mean (SE) | | Significance[b] |
	No-use[a] (n=284)	Use (n=112)	
Mean tree diameter (cm)	29.58 (0.84)	25.16 (1.18)	0.007
Distance to nearest log (m)	1.42 (0.08)	1.08 (0.09)	0.009
Log density index	2.06 (0.37)	3.00 (0.83)	0.0001
% Ground cover	93.38 (0.67)	96.80 (0.77)	0.0004
Mean litter depth (cm)	19.83 (0.51)	23.84 (0.90)	0.0001

[a.]No-use corresponds to stations with no northern short-tailed shrews captures and Use to stations with one or more individuals captured.
[b.]All Wilcoxon Rank Sum tests had 1 df.

Appendix R. Results of Wilcoxon Rank Sum tests for differences in microhabitat characteristics among capture and no-capture stations for northern short-tailed shrews captured within riparian stands on Quantico Marine Corps Base, VA, from May 1997-January 1999.

	Mean (SE)		
Habitat characteristic	No-use[a] (n=108)	Use (n=91)	Significance[b]
Number of woody stems at ground level	133 (11.26)	100 (13.70)	0.05
Distance to nearest log (m)	2.38 (0.16)	1.76 (0.27)	0.03
Log density index	0.37 (0.05)	1.40 (0.57)	0.07
Herbaceous species	5.65 (0.17)	4.66 (0.18)	0.005
% Woody ground cover	4.24 (0.67)	6.10 (1.07)	0.02
% Grass ground cover	5.20 (1.01)	3.91 (1.49)	0.009
Mean litter depth (cm)	15.29 (0.36)	18.10 (0.80)	0.001

[a]No-use corresponds to stations with no northern short-tailed shrews captures and Use to stations with one or more individuals captured.
[b]All Wilcoxon Rank Sum tests had 1 df.

Appendix S. Results of Wilcoxon Rank Sum tests for differences in microhabitat characteristics among capture and no-capture stations for northern short-tailed shrews captured within mature stands on Quantico Marine Corps Base, VA, from May 1997-January 1999.

	Mean (SE)		
Habitat characteristic	No-use[a] (n=134)	Use (n=66)	Significance[b]
number of woody stems at 0.5 meters (stems/3m^2)	43 (5.42)	58 (8.42)	0.08
number of woody stems at 1 meter (stems/3m^2)	17 (2.67)	29 (4.13)	0.006
number of blueberry stems at 0.5 meters (stems/3m^2)	6 (1.58)	5 (1.23)	0.03

[a]No-use corresponds to stations with no northern short-tailed shrews captures and Use to stations with one or more individuals captured.
[b]All Wilcoxon Rank Sum tests had 1 df.

Appendix T. Results of Wilcoxon Rank Sum tests for differences in microhabitat characteristics among capture and no-capture stations for meadow voles captured within clearcuts on Quantico Marine Corps Base, VA, from May 1997-January 1999.

Habitat characteristic	Mean (SE)		Significance[b]
	No-use[a] (n=143)	Use (n=56)	
Number of woody stems at 1 meter	130 (11.12)	97 (13.94)	0.08
Woody species	5.80 (0.16)	5.18 (0.25)	0.06
Log density index	2.62 (0.61)	1.88 (0.68)	0.02
Woody debris	7.15 (1.04)	3.42 (0.84)	0.003
Density of lianas	334 (42.34)	518 (98.05)	0.04
Herbaceous stems at 0.5 m meters	6 (2.44)	15 (4.59)	0.003
Herbaceous species	4.06 (0.13)	4.84 (0.24)	0.01
% Woody ground cover	11.6 (1.15)	6.1 (1.29)	0.007
% Grass ground cover	31.0 (2.08)	42.3 (3.38)	0.01

[a]No-use corresponds to stations with no meadow vole captures and Use to stations with one or more individuals captured.
[b]All Wilcoxon Rank Sum tests had 1 df.

Appendix U. Results of Wilcoxon Rank Sum tests for differences in microhabitat characteristics among capture and no-capture stations for meadow voles captured within shelterwoods on Quantico Marine Corps Base, VA, from May 1997-January 1999.

Habitat characteristic	Mean (SE)		Significance[b]
	No-use[a] (n=336)	Use (n=60)	
Distance to nearest tree (m)	3.80 (0.12)	5.01 (0.27)	0.0001
Number of woody stems at ground level	538 (24.36)	349 (61.02)	0.0001
Number of woody stems at 0.5 meters	343 (19.47)	411 (53.13)	0.0001
Number of woody stems at 1 meter	122 (9.69)	92 (24.96)	0.02
Number of mountain laurel stems at ground level	42 (5.78)	54 (17.39)	0.001
Number of mountain laurel stems at 0.5 meters	49 (8.31)	45 (13.58)	0.03
Number of blueberry stems at ground level	96 (0.56)	27 (9.74)	0.0001
Number of blueberry stems at 0.5 meters	25 (5.78)	10 (4.18)	0.04
Woody species	6.63 (0.11)	5.45 (0.29)	0.0004
Woody debris	15.94 (1.36)	7.42 (1.68)	0.0002
Number of lianas	24 (3.28)	53 (12.58)	0.0001
Herbaceous stems	152 (9.53)	394 (18.69)	0.0001
Herbaceous stems at 0.5 m meters	11 (2.92)	64 (15.21)	0.0001
Herbaceous species	2.07 (0.10)	3.43 (0.24)	0.0001
% Grass ground cover	11.24 (1.04)	25.01 (2.81)	0.0001

[a]No-use corresponds to stations with no meadow vole captures and Use to stations with one or more individuals captured.
[b]All Wilcoxon Rank Sum tests had 1 df.

Appendix V. Results of Wilcoxon Rank Sum tests for differences in microhabitat characteristics among capture and no-capture stations for woodland voles captured within clearcuts on Quantico Marine Corps Base, VA, from May 1997-January 1999.

Habitat characteristic	Mean (SE)		Significance[b]
	No-use[a] (n=189)	Use (n=11)	
Number of shrubs	19.37 (0.93)	26.55 (4.64)	0.06
Number of woody stems at 1 meter	118 (8.91)	95 (51.03)	0.01
Number of blackberry stems at 0.5 meters	116 (10.27)	208 (83.59)	0.06
Number of blackberry stems at 1 meter	45 (5.16)	73 (20.07)	0.04
Number of hardwood woody stems at 1 meter	76 (6.38)	196 (37.22)	0.03
Vertical woody stem density	1.63 (0.06)	1.84 (1.29)	0.09
Number of herbaceous stems at 0.5 meters	10 (1.47)	2 (1.29)	0.07

[a]No-use corresponds to stations with no woodland vole captures and Use to stations with one or more individuals captured.
[b]All Wilcoxon Rank Sum tests had 1 df.

Appendix W. Results of Wilcoxon Rank Sum tests for differences in microhabitat characteristics among capture and no-capture stations for woodland voles captured within shelterwoods on Quantico Marine Corps Base, VA, from May 1997-January 1999.

Habitat characteristic	Mean (SE)		Significance[b]
	No-use[a] (n=325)	Use (n=48)	
Woody species	6.52 (0.12)	6.00 (0.27)	0.05
Number of blueberry stems at ground level	80 (10.50)	133 (33.48)	0.05
Number of mountain laurel stems at ground level	42 (5.70)	66 (19.87)	0.06
Number of hardwood woody stems at ground level	343 (21.32)	201 (28.98)	0.03
Number of blueberry stems at 0.5 meters	22 (4.43)	31 (7.89)	0.03
Number of mountain laurel stems at 0.5 meters	48 (7.90)	61 (19.89)	0.06
Number of mountain laurel stems at 1 meter	7 (1.58)	13 (4.90)	0.05
Vertical woody stem density	0.90 (0.03)	0.96 (0.01)	0.05
Number of herbaceous species	2.36 (0.10)	1.70 (0.26)	0.007
Mean litter depth	21.2 (0.50)	19.0 (1.04)	0.08

[a]No-use corresponds to stations with no woodland vole captures and Use to stations with one or more individuals captured.
[b]All Wilcoxon Rank Sum tests had 1 df.

Appendix X. Results of Wilcoxon Rank Sum tests for differences in microhabitat characteristics among capture and no-capture stations for woodland voles captured within riparian stands on Quantico Marine Corps Base, VA, from May 1997-January 1999.

Habitat characteristic	Mean (SE)		Significance[b]
	No-use[a] (n=182)	Use (n=17)	
Mean tree dbh	26.89 (0.86)	19.55 (2.86)	0.01
Number of shrubs	11.42 (0.90)	6.88 (1.72)	0.03
Number of blackberry stems at ground level	2 (0.61)	7 (3.16)	0.002
Number of blackberry stems at 0.5 meters	1 (0.32)	4 (2.46)	0.04
Log density index	96.09 (3.11)	104.86 (11.75)	0.09
Woody debris	5.46 (0.73)	1.66 (0.66)	0.03
Number of lianas	79 (9.70)	52 (23.00)	0.09
Number of herbaceous stems at ground level	214 (10.34)	296 (34.72)	0.01
Number of herbaceous stems at 0.5 meters	14 (2.32)	35 (34.72)	0.06
Number of herbaceous species	5.31 (0.16)	6.29 (0.58)	0.05
% Grass ground cover	4.7 (0.89)	8.6 (3.02)	0.08
% Woody ground cover	4.8 (0.62)	3.0 (1.33)	0.03
Mean litter depth	16.1 (0.36)	14.4 (1.07)	0.09

[a]No-use corresponds to stations with no woodland captures and Use to stations with one or more individuals captured.
[b]All Wilcoxon Rank Sum tests had 1 df.

Appendix Y. Results of Wilcoxon Rank Sum tests for differences in microhabitat characteristics among capture and no-capture stations for woodland voles captured within mature stands on Quantico Marine Corps Base, VA, from May 1997-January 1999.

| Habitat characteristic | Mean (SE) | | Significance[b] |
	No-use[a] (n=188)	Use (n=12)	
Distance to nearest tree	2.02 (0.07)	2.76 (0.38)	0.04
Number of shrubs	17.27 (0.81)	14.00 (2.56)	0.08
Number of hardwood stems at ground level	128 (9.27)	64 (16.16)	0.09
Number of blueberry stems at 0.5 meters	5 (1.10)	15 (7.43)	0.003
Vertical woody stem density	0.62 (0.04)	1.09 (0.21)	0.01
Woody debris	6.72 (0.78)	2.43 (0.75)	0.04
Number of herbaceous stems at ground level	62 (3.78)	125 (17.59)	0.006
Number of herbaceous species	3.10 (0.12)	3.75 (0.37)	0.08
% Woody ground cover	4.2 (0.49)	7.3 (2.12)	0.02

[a]No-use corresponds to stations with no woodland captures and Use to stations with one or more individuals captured.
[b]All Wilcoxon Rank Sum tests had 1 df.

Appendix Z. Results from stepwise logistic regression analyses for predicting the presence or absence of white-footed mice at trapping stations during summer and winter trapping as a function of microhabitat. White-footed mice were captured on Quantico Marine Corps Base, VA. 1997-1999. Summer trapping was from May-Aug and winter trapping from Dec-Mar. Habitat variables are detailed in Table 3.

Forest Cover Type	Season	Variable	β	SE(β)	Wald X^2	P	Somers' D	Concordant Observations	Hosmer-Lemeshow GOF Test		
									Test Statistic	DF	P
Clearcut	Summer[a]	Intercept	0.4643	0.7563	0.38	0.539	0.52	76.1%	1.35	8	
		Treesrch	-0.0105	0.0037	7.91	0.005					
		Logsrch	-0.0127	0.0031	16.28	<0.001					
		Grass	-0.0119	0.0069	2.96	0.085					
		Woodsp	0.2112	0.0936	5.09	0.024					
		Allwdy1	0.0045	0.0014	11.01	<0.001					
	Winter[b]	Intercept	-0.3143	0.4608	0.47	0.495	0.46	73.0%	3.95	8	
		Logsrch	-0.0105	0.0032	10.85	0.001					
		Allwdy5	-0.0034	0.0016	4.85	0.028					
		Grass	-0.0131	0.0071	3.45	0.063					
		Nshrub	0.0421	0.0143	8.68	0.003					
		Crub1	0.0121	0.0039	9.68	0.002					
Shelterwood	Summer[c]	Intercept	2.5544	0.3635	49.38	<0.001	0.47	73.2%	12.57	8	
		Ldepth	-0.0513	0.0131	15.42	<0.001					
		Herbsp	-0.2889	0.0631	20.99	<0.001					
		Cmntlr1	0.0479	0.0265	3.27	0.071					
	Winter[d]	Intercept	-1.1433	0.9767	1.37	0.24	0.46	72.8%	3.52	8	
		Logsrch	-0.0055	0.0030	3.34	0.068					
		Xtdbh	-0.0240	0.0076	10.06	0.002					
		Cmtnlr5	0.0075	0.0024	9.37	0.002					
		Cother5	0.0009	0.0004	4.51	0.034					
		Grndcvr	0.0218	0.0104	4.23	0.035					
		Wgc	0.0280	0.0143	3.82	0.051					

[a]Sample sizes for analyses: Capture stations (n=75), noncapture stations (n=125)
[b]Capture stations (n=57), noncapture stations (n=143)
[c]Capture stations (n=278), noncapture stations (n=122)
[d]Capture stations (n=260), noncapture stations (n=140)

Appendix Z. Continued.

Forest Cover Type	Season	Variable	β	SE(β)	Wald X^2	P	Somers' D	Concordant Observations	Hosmer-Lemeshow GOF Test Test Statistic	DF	P
Riparian	Summer[e]	Intercept	2.2767	0.4218	29.13	<0.001	0.52	75.7%	12.53	8	
		Crub1	-0.1718	0.1034	2.76	0.096					
		Grass	-0.0260	0.0152	2.91	0.087					
		Hstem	-0.0038	0.0014	7.05	0.008					
		Domveg4	-1.6339	0.4885	11.19	<0.001					
		Smast	1.0820	0.4442	5.93	0.015					
	Winter[f]	Intercept	0.5714	0.6386	0.80	0.371	0.43	71.2%	8.33	8	
		Logsrch	-0.0147	0.0042	12.67	<0.001					
		Herbsp	-0.1680	0.0817	4.23	0.040					
		Xtdbh	0.0268	0.0139	3.71	0.054					
		Wstemd	0.3562	0.2160	2.72	0.099					
Mature	Summer[g]	Intercept	3.9123	1.2254	10.91	0.001	0.47	73.2%	9.19	8	
		Logsrch	-0.0243	0.0096	6.36	0.012					
		Xlarea	-18.3579	7.1063	6.67	0.010					
		Hstem	-0.0076	0.0031	5.95	0.015					
		Ldepth	-0.0769	0.0289	7.08	0.008					
		Wgc	0.0901	0.0306	8.66	0.003					
		Nearlog	0.2174	0.1312	2.75	0.097					
		Domveg3	1.3983	0.6505	4.62	0.032					
	Winter[h]	Intercept	-1.3312	0.3558	13.76	<0.001	0.63	81.5%	2.57	8	
		Crub0	-0.0792	0.0425	3.47	0.062					
		Nearlog	-0.5369	0.1765	9.25	0.002					
		Allwdy5	0.0138	0.0035	15.25	<0.001					

[e]Sample sizes for analyses: Capture stations (n=152), noncapture stations (n=48)
[f]Capture stations (n=66), noncapture stations (n=134)
[g]Capture stations (n=81), noncapture stations (n=119)
[h]Capture stations (n=37), noncapture stations (n=163)

Appendix AA. Results from stepwise logistic regression analyses for predicting the presence or absence of resident or transient white-footed mice at trapping stations as a function of microhabitat. White-footed mice were captured on Quantico Marine Corps Base, VA. 1997-1999. Habitat variables are detailed in Table 3.

Forest Cover Type	Status	Variable	β	SE(β)	Wald X^2	P	Somers' D	Concordant Observations	Hosmer-Lemeshow GOF Test		
									Test Statistic	DF	P
Clearcut[a]	Resident	Intercept	0.3295	0.5748	0.33	0.566	0.42	71.0%	14.21	8	0.08
		Herbsp	-0.2880	0.1159	6.17	0.013					
		Logsrch	-0.0061	0.0029	4.42	0.035					
		Cother0	0.0045	0.0021	4.54	0.033					
	Transient	Intercept	-2.2389	0.3155	50.37	<0.001	0.44	71.4%	4.62	8	0.80
		Cnmlian	-0.0021	0.0008	7.09	0.008					
		Cdwnwood	0.0772	0.0226	11.62	<0.001					
		Crub1	0.0061	0.0028	4.71	0.030					
Shelterwood[b]	Resident	Intercept	3.6365	0.4674	60.52	<0.001	0.52	76.0%	3.55	8	0.90
		Neartree	-0.1582	0.0558	8.03	0.005					
		Logsrch	-0.0078	0.0030	6.89	0.009					
		Herbsp	-0.3547	0.0697	25.88	<0.001					
		Ldepth	-0.0628	0.0132	22.48	<0.001					
	Transient	Intercept	-0.8119	0.1503	29.20	<0.001	0.12	54.6%	23.19	8	<0.01
		Wgc	0.0247	0.0113	4.81	0.028					
Riparian[c]	Resident	Intercept	1.5787	0.3131	25.42	<0.001	0.30	64.2%	13.85	8	0.09
		Hstem	-0.0041	0.0011	13.50	<0.001					
	Transient	No Model	-	-	-	-	-	-	-	-	-

[a]Sample Sizes for analyses: 1) Resident Stations (n=57), No capture stations (n=142), 2) Transient Stations (n=25), No capture stations (n=174)
[b]Resident Stations (n=235), No capture stations (n=161), 2) Transient Stations (n=142), No capture stations (n=254)
[c]Resident Stations (n=126), No capture stations (n=68)

Appendix AA. Continued

Forest Cover Type	Status	Variable	β	SE(β)	Wald X^2	P	Somers' D	Concordant Observations	Hosmer-Lemeshow GOF Test		
									Test Statistic	DF	P
Mature[d]	Resident	No Model	-	-	-	-	-	-	-	-	-
	Transient	Intercept	0.9439	0.8480	1.24	0.266	0.46	72.5%	2.93	8	0.94
		Woodsp	-0.4136	0.1310	9.97	0.002					
		Hstem	-0.0107	0.0049	4.72	0.030					
		Cdwnwood	0.0372	0.0180	4.27	0.039					

[d]Transient stations (n=28), No capture stations (n=172)

Appendix AB. Results from stepwise logistic regression analyses for predicting the presence or absence of white-footed mice at trapping stations as a function of microhabitat and seasonal densities. White-footed mice were captured on Quantico Marine Corps Base, VA. 1997-1999. Habitat variables are detailed in Table 3.

| Model Input | | | | | | Model Evaluation | | Hosmer-Lemeshow GOF Test | | |
Density	Variable	β	SE(β)	Wald X^2	P	Somers' D	Concordant Observations	Test Statistic	DF	P
Low[a] (Winter 1998)	Intercept	-2.1254	0.3194	44.28	<0.001	0.37	68.3%	10.46	8	0.23
	Cmtnlr0	0.0027	0.0011	6.07	0.014					
	Allwdy5	0.0009	0.0003	7.45	0.006					
	Ldepth	0.0316	0.0135	5.44	0.020					
High[b] (Winter 1999)	Intercept	-0.8746	1.0054	0.76	0.38	0.48	73.8%	14.40	8	0.07
	Xtdbh	-0.0211	0.0073	8.48	0.004					
	Ldepth	-0.0544	0.0156	12.21	<0.001					
	Nearlog	-0.2605	0.1037	6.32	0.012					
	Cmtnlr5	0.0033	0.0015	4.82	0.028					
	Allwdy5	0.0010	0.0004	7.56	0.006					
	Xlarea	1.0440	0.5052	4.27	0.039					
	Grndcvr	0.0267	0.0115	5.35	0.021					
Stations with use in Low and Density[c]	Intercept	1.0121	0.3452	8.60	0.003	0.61	80.4%	4.09	8	0.85
	Xtdbh	-0.0337	0.0112	9.00	0.003					
	Cmtnlr0	0.0049	0.0025	3.97	0.046					
	Cmtnlr1	0.0327	0.0181	3.26	0.071					
	Allwdy5	0.0017	0.0004	14.59	<0.001					
	Xlarea	1.5516	0.5879	6.97	0.008					

[a]Sample Sizes for analyses: 1) Captures stations (n=107), No capture stations (n=289)
[b]Capture Stations (n=224), No capture stations (n=172)
[c]Stations with captures during both winter trapping seasons (n=73), No-use capture stations (n=138)

Vitae

Julie Williams was born in Patuxent, MD on August 30, 1974. After graduating from Wake-Forest Rolesville High School in 1992, she attended North Carolina State University (NCSU) at Raleigh. While at NCSU she worked as a technician on a bobwhite quail research project and as a volunteer intern for the U.S. Fish and Wildlife Service, Law Enforcement Division. In May of 1996, she graduated with highest honors (summa cum laude) with a Bachelor of Science degree in Fisheries and Wildlife Science and minors in Botany and Environmental Science. Following graduation, she worked as a summer field technician on a grassland bird survey at Fort Pickett, VA. In the fall of 1996, she was awarded a Graduate Research Assistantship at Virginia Polytechnic Institute and State University, where she pursued a Master of Science degree in Wildlife Science. She received her Master of Science degree in February of 2000. In March of 2000 Julie will begin work for the Georgia Department of Natural Resources as a private lands biologist.