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Habitat Use By The Southeastern Beach Mouse (peromyscus Polionotus Niveiventris) At Cape Canaveral Air Force Station, Florida

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HABITAT USE BY THE SOUTHEASTERN BEACH MOUSE
(*PEROMYSCUS POLIONOTUS NIVEIVENTRIS*) AT CAPE CANAVERAL AIR FORCE
STATION, FLORIDA

by

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B.S. University of Central Florida, 2004

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ABSTRACT

Successful recovery of the federally threatened southeastern beach mouse (*Peromyscus polionotus niveiventris*) depends in part on an understanding of their habitat requirements. I studied habitat use by beach mice at Cape Canaveral Air Force Station, Florida from March 2005 until March 2006. I livetrapped six grids, three on coastal dunes and three within scrub located inland from the coast. On each grid and trap station, I quantified the extent of bare ground, woody vegetation, non-woody vegetation, height of vegetation, and percentage of coarse sand in the surface soil. I assessed trap success relative to these habitat variables using linear and multiple regression, correlation, and ordination. Significantly higher numbers of mice were captured in the scrub habitat relative to the coastal habitat. Linear regression of trap success against the habitat variables did not reveal any significant relationships at the level of grids. A non-metric multidimensional scaling model was designed to capture the vegetation heterogeneity at the trapping sites and clarify the results. This methodology identified a predominantly dune and predominately scrub cluster of trap sites. A bubble plot showed higher densities of beach mice using the scrub habitat types. These results suggest beach mice are selecting for those habitat variables defined by the ordination: higher vegetation height, more woody vegetation types, less bare ground, and less heterogeneity.

ACKNOWLEDGMENTS

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INTRODUCTION

Habitat loss or degradation is consistently cited as a primary explanation for the decline of many threatened or endangered species (Wilcove et al. 1998), although other factors may be identified across diverse taxonomic groups (Pimm 1996, Logiudice 2006). Changes in habitat may occur naturally, as shifts in climate and vegetation have caused the mammals of North America to expand and contract their distributions over the Holocene period (Blair 1958). For example, a shifting sea level has altered the coast lines in the southeastern United States, causing the isolation and local adaptation of populations of old field mice (*Peromyscus polionotus*) to coastal dune habitats (Bowen 1968, Avise et al. 1983, Hoekstra et al. 2006, Van Zant and Wooten 2007). At least eight subspecies of these oldfield mice (collectively known as beach mice) are recognized in addition to the eight inland subspecies (Hall 1981). However, recent habitat loss due to increased beach development has resulted in the apparent extinction of one beach subspecies and in the listing of six others under the Endangered Species Act (United States Fish and Wildlife Service 1989). Efforts to protect these subspecies from further declines and ultimately to recover them depend in large measure on understanding how features of the remaining habitat influence local distributions and fluctuations in abundance.

Habitat includes all the biotic and abiotic factors that may influence an organism, especially food resources and shelter. Habitat structure, the physical template underlying ecological patterns and processes, may also play an important role in determining species co-occurrence, species richness, and species abundance (Keim 1979). Selection of habitats can be viewed as a behavioral decision of individuals translated into patterns of distribution and abundance (Stapp 1997). Habitat selection by small mammals may be related to microhabitat

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quality represented by density of animals (Price 1978; Jorgensen 2004; Rosenzweig and Abransky 1985). Mouse fitness is positively correlated with population growth, which infers favorable habitat (Halama and Duesser 1994; Van Horne 1982; Morris and Diffendorfer 2004), and may be reflected in fecundity, residence time, or juvenile growth rates (Halama and Duesser 1994).

The purpose of my project was to investigate habitat use by southeastern beach mice at Cape Canaveral Air Force Station. My objectives were to:

1) determine patterns of habitat use by southeastern beach mice in coastal dunes and scrub;

2) identify structural and vegetational features that may be correlated with patterns of habitat use;

3) examine patterns of microhabitat use relative to trap success; and

4) evaluate conservation and management implications of differences in habitat use by southeastern beach mice.

METHODS

Beach Mice

Old field mice are small nocturnal rodents found throughout the southeastern United States on sandy, well-drained soils (Whitaker and Hamilton 1998). Beach mouse subspecies occupy areas closer to the shore line and are typically lighter in color than their inland conspecifics (Bowen 1968; Kaufman 1974; Hoekstra et al. 2006; Mullen and Hoekstra 2008). In 1989, the southeastern beach mouse (*Peromyscus polionotus niveiventris*) was listed as threatened under the Endangered Species Act (United States Fish and Wildlife Service 1989). Currently, the subspecies occupies only portions of its historic range along Florida's east coast.

Beach mice typically inhabit the primary and secondary dunes in association with sea oats (*Uniola paniculata*) (Ivey 1949; Blair 1946; Bowen 1968; United States Fish and Wildlife Service 1993). These dunes, which are comprised of a mosaic of low grassy vegetation and open sandy substrate in close proximity to the ocean, provide opportunities for burrowing (Wolfe and Esher 1977) and access to seed producing plants (Hill 1989). However, populations have also been found farther inland on Cape Canaveral, FL, >1-3 km from the dunes in coastal scrub, which is composed of dense vegetation with few patchy open areas (Keim 1979; Extine and Stout 1987). Population densities were thought to be higher on the dunes along the coast then in the coastal scrub, which was considered secondary habitat (Keim 1979; Extine 1980). The unequal proportion of captures within each habitat suggests beach mice exhibit habitat selection (Extine and Stout 1987).

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Field data were collected from March 2005-March 2006 on Cape Canaveral Air Force Station (CCAFS), Brevard County, FL (Figure 1). Cape Canaveral is part of the Merritt Island complex with an area of 6,396 ha and a 21.7 km coastline on the east coast of Florida (Oddy 2000). CCAFS is contiguous with Kennedy Space Center and Merritt Island National Wildlife Refuge. Merritt Island is separated from the mainland by the Indian River and Mosquito Lagoon. Cape Canaveral is bounded on the west by the Banana River and the Atlantic Ocean to the east. CCAFS supports many endangered and threatened species, including the southeastern beach mouse, Florida scrub-jay (*Aphelocoma coerulescens*), eastern indigo snake (*Drymarchon corais couperi*), loggerhead turtle (*Caretta caretta*), gopher tortoise (*Gopherus polyphemus*), and other species of concern (Breininger et al. 1998).

Cape Canaveral is one of the few locations along the Atlantic coast where resident populations of beach mice regularly occur both on coastal dunes and further inland in the coastal strand and coastal scrub (Stout 1992). The dunes are dominated by sea oats (*Unioloa paniculata*), railroad vine (*Ipomoea pescaprae*), beach morning-glory (*Ipomoea imperati*), beach grass (*Panicum amarum*), and a variety of herbs and grasses (Kurz 1942). Inland from the coastal dunes is a transitional zone called coastal strand that is dominated by saw palmetto (*Serenoa repens*), wax myrtle (*Myrica cerifera*), buckthorn (*Sideroxylon tenax*), and muhly grass (*Muhlenbergia capillaris*) (Johnson and Barbour 1990). Coastal strand has characteristic openings of grasses and sandy areas with patchy shrub areas. Further inland on Cape Canaveral and Merritt Island, coastal scrub is found to be dominated by oak (*Quercus geminata, Q. chapmanii, and Q. mytrifolia*) species. Other species found in coastal scrub include saw

palmetto, wax myrtle, and buckthorn. The scrub soils remain alkaline similar to sand dunes, unlike inland scrub (Schmalzer et al. 2001).

Trapping Data

I used six trapping grids located on CCAFS to study habitat use by southeastern beach mice (Figure 1). Two of the three scrub grids were located in coastal scrub (Scrub 1 and 2), and the third in coastal strand (Scrub 3) (Schmalzer et al. 1999). The remaining grids were located on dunes adjacent to the high tide line (Dune 1, 2, and 3) (Figure 1).

I trapped at biweekly intervals from March 2005 - March 2006. Trap stations within the 3 scrub grids and Dune 1 were arranged in 8 rows and 8 columns with 15 m between traps. Dune 2 and Dune 3 were constrained by inland vegetation and set in a 4 x 16 pattern. Each trap station was individually recorded with a row letter, column number, and GPS point.

Single Sherman live traps were placed within 2 m of each trap station. Traps were placed inside a wire mesh cage adopted from Layne (1987) to exclude spotted skunks (*Spilogale putorius*) and raccoons (*Procyon lotor*).. Traps were opened in the afternoon, baited with sunflower seeds, and checked for captures the following morning. When temperatures dropped below 13˚C cotton was placed inside traps to allow a nest to be made. However, if temperatures dropped below 10˚C trapping did not occur. My biweekly trapping schedule was planned to include 27 nights; however, cold weather conditions limited the effort to 25 nights for each trapping grid.

Each new capture was tagged with a uniquely numbered monel ear tag, mass determined with a Pesola spring scale, sexed, reproductive status recorded, and classified as adult, sub-adult, or juvenile based on pelage characteristics and body mass. Male reproductive status was

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determined by the position of the testes (descended or non-descended). Female reproductive status was determined by the condition of the vagina (perforate or imperforate), mammary development, and evidence of pregnancy.

My trapping was carried out in accordance with a permit issued by the Institutional Animal Care and Use Committee, University of Central Florida. Trapping was conducted with permits issued to I. Jack Stout by the Florida Fish and Wildlife Conservation Commission and the U. S. Fish & Wildlife Service.

<u>Habitat Data</u>

Vegetation composition and structure were measured on randomly oriented 10-m line transects centered on each trap station in summer and fall 2005. All 6 grids were measured as line intercept coverage (cm) for woody, non-woody, and bare ground (Kaiser 1983). Woody vegetation included woody stems (e.g., buckthorn, *Sideroxylon tenax* and oaks, *Quercus spp.*). Non-woody vegetation included grasses, sedges, herbs, and vines (e.g., railroad vine, *Impomoea pes-caprae* and saw palmetto, *Serenoa repens*). The coverage of each category was measured (cm) independently and overlapping could occur. Leaf litter was nearly continuous at most trap stations on the scrub grids whereas bare ground was rare. Large patches of sea grapes (*Coccoloba uvifera*) were sparsely located throughout the dune grids and less commonly on the scrub grids. To capture them in the analysis, the distance to the nearest sea grape was recorded as greater or less than 5 m from the midpoint of the transects on all 6 grids.

Two random height measurements (cm) were taken on each transect with the average recorded for each trap station. Vegetation at each trap station was categorized as patchy if there were any open areas greater than 30 square centimeters within 5 m of the trap; otherwise the

vegetation at that station was considered continuous. Longitude and latitude of each trap station was recorded using a hand held Garmin GPS unit.

Soil samples were collected at three random locations around each trap station (within 1 m). The three samples were pooled, cleaned of vegetative material, dried, and sieved through 2mm and 0.25mm mesh in the lab. The mass of the sieved samples was expressed as percentages for three categories: shell (> 2mm), coarse sand (2-0.25mm), and fine sand (< 0.25mm; Chapman 1976). I calculated the geometric mean sand grain size and sand sorting (standard deviation) using program GRADISTAT (Blott and Pye 2001; Microsoft Excel 2007).

Data Analysis

Statistics were performed using JMP In statistical software (JMP In 2003) and SPSS (SPSS for Windows 2007). Several measures were used to quantify trapping success on each grid. The total number of captures by grid was divided by the number of trap nights to reflect the overall success of each grid. I used four measures of trapping success by trap station: total captures, only first time captures (individual mice), total captures of males, and total captures of females. These categories were summarized and examined relative to dune and scrub grids.

The mean amount of bare ground in each grid was nested into habitat type, dune or scrub. ANOVA was performed to determine if there was a significant difference between the two habitat types. The test was repeated for these habitat variables: woody vegetation, non-woody vegetation, mean vegetation height, mean sand grain size, and sand sorting.

The relationship between the habitat variables and the number of captures of beach mice at a trap station was explored with simple linear regression. Total captures were regressed against the habitat variables for each grid. These regressions were done using untransformed and

transformed (square root, log, natural log, arcsine, and inverse) values for total captures. The fit of the arcsin transformed data, based on the distribution of the residuals matrix, provided an increase in normality. Therefore, arcsine measures of capture success were used in the analysis.

Independence of the 10 original variables (bare ground, woody, non-woody, sand grain size, sand sorting, sea grape, patchy/continuous, latitude, longitude, and average height) was screened using a Spearman's correlation matrix. Patchy vs continuous was found to be highly correlated ($r > 0.6$) with vegetation height ($r = -0.64$).

Ordination of the habitat, spatial, and trap success variables was done by combining all the grids. Habitat data were standardized by dividing each value by the highest value in its category. Patchy/continuous variable was omitted because of its correlation with other variables. These standardized values were pooled into one data set and imported into PCORD (McCune and Mefford 1999). An initial Monte Carlo ordination analysis was run using all possible dimensions. Preliminary analysis of the first ordination attempt indicated it was best to use 3 dimensional axes and I repeated the analysis using only 3 dimensions. Once the matrix of data points was created, I extracted the Axis 1, Axis 2 and Axis 3 data scores and designed the ordination matrix (McCune and Grace 2002). All 9 variables are included as points in the matrix.

A second correlation table was produced to examine the relationship between the 9 habitat variables (see methods section) with the 3 dimensional non-metric multidimensional scaling ordination (NMS) outputs. This table was used to observe the weight each variable has on the ordination axes. All 6 grids were included in the analysis. The pair-wise correlations (r values) based on one independent variable have critical values of 0.159 ($p = 0.05$) and 0.208 ($p = 0.01$) (Rohlf and Sokal 1969). Spearman's rank correlation coefficient was used as a measure of correlation between ranks.

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A third correlation table was constructed to look at the association between the axes and trapping success. This table included the ordination outputs and the 4 measures of trapping success: all captures, new mice only, number of male captures, and number of female captures. The critical values remained the same.

A bubble plot graph was created to show the ordination matrix clusters relationship with the distribution of beach mice captures. The ordination output scores and total mouse capture data were imported into SPSS (SPSS for Windows 2007). A bubble plot was created using the 3 scores as the axes and the size of the bubble to represent the trapping data.

Multiple logistic regression was used to further examine the relationship between total mice captures and the 3 axes. All possible models were evaluated using Akaike's information criterion (3 axes, 7 models; SPSS 2007; Burnham and Anderson 2002). AIC values were examined to determine the importance of each axis in the seven models used to predict trapping success.

RESULTS

Capture Success of Southeastern Beach Mice

A total of 298 individual southeastern beach mice was captured and marked from March 19, 2005 through March 18, 2006. In total, 1,216 captures of southeastern beach mice were recorded. Cotton mice (*Peromyscus gossypinus*) and cotton rats (*Sigmodon hispidus*) were seldom captured on either the dune or scrub grids (Table 1).

The indices of trap success were significantly greater on the scrub grids than the dune grids: all captures ($F_{1,4} = 144.12$, $p < 0.0001$), individuals ($F_{1,4} = 27.37$, $p < 0.0001$), and female ($F_{1,4} = 98.45$, $p < 0.0001$), and male ($F_{1,4} = 52.77$, $p < 0.0001$) (Figure 2a-d).

Comparison of Habitat Variables between Scrub and Dune Grids

I compared the two habitat settings on the basis of six continuous variables: extent of bare ground, woody vegetation, non-woody vegetation, height of vegetation, mean sand grain size, and sand sorting. Each habitat variables was statistically different between the scrub and dune habitats (Figures 3a-f). Dune habitat had significantly more bare ground than the scrub areas ($F_{1,4} = 36.35$, $p < 0.0001$). Woody vegetation accounted for significantly more canopy coverage in the scrub habitat than the dunes ($F_{1,4} = 84.46$, $p < 0.0001$). The non-woody vegetation was significantly more of the canopy coverage on the dune areas relative to the upland habitat ($F_{1,4} = 198.85$, $p < 0.0001$). Average height of the vegetation was significantly greater in the scrub than on the beach dunes ($F_{1,4} = 130.98$, $p < 0.0001$). The mean sand grain size was significantly larger in the beach habitats than the scrub areas ($F_{1,4} = 28.12$, $p < 0.0001$).

Variability of sand grain size (sand sorting) was significantly greater in the dune grids relative to the inland scrub ($F_{1,4} = 6.25$, $p < 0.01$).

<center>Do Individual Habitat Variables Predict Trapping Success?</center>

Trap success was analyzed by grid within habitat type. Trap success at each trap station (number of southeastern beach mice captured divided by 25 trap nights) was regressed against each habitat variable by trap station. Significant linear relationships were not discovered between trap success and habitat variables on any of the grids.

I employed the Spearman's rank correlation coefficient (r) to examine for redundancy among the variables used to characterize the habitats (Table 2). The patchy/continuous variable was highly correlated (above 0.6) with average height (-0.68) and deleted from further analysis.

<center>Ordination</center>

The linear regression of trapping succession on the habitat variables indicated no single variable was predictive of habitat use by southeastern beach mice. Further resolution of the relationships among habitat variables, the two habitats, and captures of southeastern beach mice was sought by an ordination of the habitat data from all trap stations using non-metric multidimensional scaling (NMS). This method yielded a 3 dimensional graph with a pattern of two well-defined clusters that could be associated with dune and scrub clusters (Figure 4). Correlation among the axis scores and habitat variables was explored to understand the factors contributing to the formation of the clusters.

Spearman's rank correlation coefficients are presented for the 9 habitat variables and 3 axes in Table 3. The correlation table represents the weight each variable had on calculating the 3 axes. Seven variables contributed significantly ($p < 0.01$) to Axis 1 with sea grape ($r_s = -0.77$)

<center>11</center>

the most correlated. Of the nine variables, only longitude and latitude did not contribute

significantly to the Axis 1 (p >0.05). Axis 2 was correlated with six of the habitat variables,

longitude, and Axis 1 (Table 3). Non-woody vegetation explained much of the variation (r_s= -

0.80, p < 0.01); only latitude and mean sand grain size were not significant. All 9 variables were

correlated with Axis 3. Most of the variation was attributed to vegetation height (r_s= -0.77, p <

0.01) and sea grape (r_s= 0.84, p < 0.01).

The relationship between NMS scores of trap stations within grids and measures of trap

success (all captures, individuals, male, and female) were examined for correlations with the

axes using Spearman's rank correlation coefficient (Table 4). Axis 1 and axis 3 were correlated

(p < 0.01) with all 4 measures of trapping success. There was no significance correlation (p

>0.05) between axis 2 and any of the measures for trapping success.

Comparison of the Ordination Clusters

Ordination clusters represent a direct measure of use of habitat by southeastern beach

mice (Figure 4 a-c). The ordination of axis 1 and axis 2 does not show a clear separation of the

two habitats based on locations of trap stations in ordination space; however, the centroids for

woody vegetation and sea grape suggest the trend in the scatter of points (Figure 4a). Ordination

of axis 3 on axis 2 reveals a clustering of trap stations from the dune grids in upper portion of the

panel with trap stations from the scrub grids in the lower right (Figure 4b). The relative

position of centroid centers for the habitat variables, e.g., sea grape and woody, support the

relationships between these variables and the likelihood of captures in the habitats. Ordination

of axis 1 on axis 3 reveals the clearest separation of the dune and scrub habitats with sea grape

and woody centroids strongly associated with the clusters (Figure 4c)

A bubble plot of the probability of capture at trap sites with axis 1 plotted against axis 3 reveals the sharpest contrast in habitat use by southeastern beach mice (Figure 5). The larger circles in the scrub cluster represent the higher number of captures in that habitat relative to the dune areas.

I used multiple logistic regression for all possible models (n = 3 axes; 7 possible models) to select the best model to explain trapping success measured as total mice captures. The models were evaluated based on the AIC scores. The strongest model included axis 1 and axis 2 (AIC= -1190.55). All 3 axes are represented in the second model (AIC=-1188.63; Δ AIC=-1.927; Table 5). Any model with a ΔAIC within 2 of the top selected model is considered to be reasonable given the data (Burnham and Anderson 2002). These results suggest all 3 axes are important in predicting trapping success. The variables that have a weight in determining at least one of the 3 axes include all 9 habitat and spatial variables (bare ground, woody, non-woody, vegetation height, mean grain size, sand sorting, sea grape, latitude, and longitude; Table 5).

DISCUSSION

Distribution of Southeastern Beach Mice on Cape Canaveral

Southeastern beach mice were captured in greater numbers on scrub grids than on dune grids from March 2005 to March 2006. Grid trapping in the 1970's indicated reduced numbers inland relative to the dune habitat (Stout 1979). This earlier study was free of major storm activity, whereas hurricane activity during August and September of 2004 occurred five months prior to the beginning of this work. Population trends of the beach mice on scrub grids did not show clear evidence of changes that could be identified with the hurricanes (Stout et al. 2007). In contrast, the dune grids did show declines in populations most likely related to the hurricanes (Stout et al. 2007). Swilling et al. (1998) and Oddy (2000) reported delayed impacts of hurricanes on local abundance of beach mice. In the present example, these effects were no longer important by March 2005 (Stout et al. 2007).

Local distributions of small mammals may be influenced by interspecific competition (Brown 1988). In my study, other species were rarely captured and represented 23 individual cotton mice and 27 cotton rats. The lack of other small mammals on the grids suggests interspecific interactions did not limit population growth of southeastern beach mice and may have resulted in habitat release, whereby they expanded into areas not normally occupied. Blair (1951) found no evidence of other small rodents interacting with Santa Rosa Island beach mice; in fact, no other rodent species was trapped in the same habitat settings. Gore and Schaefer (1993) confirmed the observations of Blair (1951) in a restudy of Santa Rosa Island beach mice.

I conclude that local distributions of southeastern beach mice during my study were the result of interactions with conspecifics and the habitat setting.

<center>Comparison of Habitat Variables between Scrub and Dune Grids</center>

A focus of management and conservation actions intended to benefit the southeastern beach mouse should be the habitat. Defining the habitat type or mix of habitats that maintain populations over years or decades is central to land management interests. In the absence of such information, efforts to manage, restore, or select suitable habitat for reintroductions risk failure (Morris 2003; Hill 1989). Relocating beach mice to previously occupied habitats has been addressed in recovery plans (U. S. Fish & Wildlife Service 1989).

I used habitat variables to capture what McCoy and Bell (1991) define as habitat structure. Habitat structure refers to physical objects in space and may offer insights into the potential role these objects play in the use of space by organisms. Of the five continuous variables I studied (viz., extent of bare ground, woody vegetation, non-woody vegetation, height of vegetation, and percentage of coarse sand in the surface soil), course sand is perhaps problematic as a physical object. Coarse sand does make sense as a potential predictive variable because southeastern beach mice dig burrows and are restricted to substrates suitable for this activity (Hayne 1936; Layne and Ehrhart 1970; Wolfe and Esher 1977).

The strong contrast in habitat structure and the use of the dune and scrub habitats by southeastern beach mice on Cape Canaveral is in conflict with existing dogma on macrohabitat use by this subspecies. Coastal dunes are generally identified as the primary habitat with almost no record of occurrence in other habitats (Stout 1992).   The context for the variation I found in habitat use is embedded in the last several thousand years of coastal geology. Cape Canaveral is

a unique feature of the east coast of Florida where upland habitats extend inland unbroken by water or other barriers to dispersal of local organisms, e.g., mice (Kurz 1942). The substrate is progressively older to the northwest of the existing shoreline of the cape due to accretion processes with a parallel progression from basic to acidic soils (Schmalzer et al.2003). Vegetation also changes along the edaphic gradient with subtle changes in plant species composition. Therefore the response of a semi-fossorial small mammal to the landscape of the cape should not be unexpected; the old field mouse (*Peromyscus polionotus*) occupies deep, well-drained sandy soils throughout the northern two-thirds of peninsular Florida (Smith 1966; Hall 1981).

Do the Habitat Variables Predict Trapping Success in the Habitats?

I predicted trapping success would be tightly correlated with different habitat variables in the dune and scrub areas. Trap success (number of captures per trap night) was not correlated with woody plant cover, average height of vegetation, or course sand on either the dune or scrub grids. Significant correlations between non-woody vegetation, bare ground, and trap success showed opposing trends and could not be generalized

Individual habitat variables measured in my study did not capture the attributes of the local environment (microhabitat) that might offer a means to predict the occurrence of trappable southeastern beach mice.   Rather, the data suggest the habitat gestalt is variable and combinations of variables and expressions of the variables may provide acceptable space to support southeastern beach mice.

The response of Alabama beach mice (*P. p. ammobates*) to habitat heterogeneity and plant cover was studied by Hill (1989), who found significant associations between the number

of mouse captures and the mean percent cover of sedges (*Cyperus* spp.) and seashore elder (*Iva imbricata*), whereas overall vegetative cover was not correlated with the number of mouse captures. Orrock and Danielson (2005) found *Peromyscus polionotus* in pine plantations in South Carolina to avoid open microhabitats near patch edges whereas open areas were not avoided in the patch interiors.

<div align="center">Ordination</div>

The NMS effort proved effective in identifying the heterogeneity across the landscape of Cape Canaveral associated with trap success and discrete and continuous habitat descriptors used to characterize trap stations. The ordination is based on ranks of the distances among the objects of interest, in my case trap stations and habitat variables, and allows the analysis to clarify dissimilarities (James and McCulloch 1990; Leps and Smilauer 2003). Nonetheless, the interpretation is largely qualitative in nature (James and McCulloch 1990).

The NMS ordination identified two clusters of trap sites based on the heterogeneity of the habitat structure. Scrub grids were strongly clustered with woody plant cover and vegetation height and significantly correlated with axes 1, 2, and 3 of the ordination. In contrast, coastal dune grids were strongly associated with non-woody vegetation, bare ground, and sea grape. Locations of the habitat variables in the ordination matrix suggest the weight of each variable. The higher weight a variable has on the matrix, the more extreme the variable will be placed in ordination space. Average vegetation height, woody coverage, sea grape proximity, and bare ground are close to the extremities of the graph; therefore, they have a greater weight on the grouping of the trap stations. Longitude, latitude, and both sand variables are located towards

the center of the matrix and have a lesser effect on the matrix. These interpretations are supported by the linear correlations and Spearman's rank correlation coefficients.

I found southeastern beach mice to occupy a wide-range of local habitat settings and differences in trap success among the habitats (grids serve as surrogates for habitat) argue for differential use. Differential use is predicted by density-dependent habitat selection theory (Rosenzweig and Adramsky 1985). The unevenness in habitat use was illustrated by a bubble plot that reflects the probability of capture at each trap station. Collectively the probability of capture was much greater in the cluster consisting primarily of scrub trap stations relative to trap stations in the dune cluster.

Bird (2003) studied *P. p. leuocephalu*s on isolated primary dunes vegetated with sea oats on Santa Rosa Island. Her data strongly support the notion that beach mice prefer to forage under vegetative cover and avoid open areas. Further, Bird demonstrated the consumption of seeds in her experiments was significantly greater in landscapes with higher connectivity (> 50% vegetation cover) than in more open areas. Bird's interpretation of these microhabitat and landscape results was mostly informed by numerous published studies that offer predation threats and avoidance behavior as the explanation for the findings (e.g., Bowers and Dooley 1993). Because I did not measure foraging activities or predation threats on Cape Canaveral, I only can suggest interactions between beach mouse abundance and habitat structure. The positive correlation of woody plant cover was important in the formation of the scrub cluster, whereas non-woody plant cover was positively significant in the formation of the dune cluster. I infer that woody cover may have provided some level of security from predation while southeastern beach mice were foraging. Conversely, I infer that the microhabitat of the dune grids would offer

less security from predation with respect to any above-ground activity of southeastern beach mice.

Hill (1989) studied Alabama beach mouse densities and seasonal abundances on frontal and secondary dunes, interdune areas, blowouts, and scrub dunes, which were as far inland as mice were trapped. Landscape and microhabitat features of Cape Canaveral differ from the habitat where Alabama and Santa Rosa Island beach mice were studied. Perhaps the major difference among these areas is the inland reach of scrub habitat on the cape relative to the coastal and barrier island locations of the gulf coast of Alabama and Florida. The disparity in total habitat area between the coastal dune system and the inland scrub clearly favors the scrub on Cape Canaveral. The relative vastness of the scrub (its "area" effect) can sustain larger numbers of southeastern beach mice than the linear, narrow and more dynamic coastal dune system. Another feature of the coastal dunes that may be unfavorable for southeastern beach mice is the extreme heterogeneity as shown by the NMS ordination. However, coastal dune systems on Cape Canaveral may sustain very high densities of southeastern beach mice on occasion (Extine and Stout 1987; Oddy 2000).

Strong support for the claim that the southeastern beach mouse is a habitat generalist comes from the modeling results based on predicting capture success from the NMS ordination scores. Models based on single axes of the ordination were rejected based on AIC scores. These results demonstrate one or more heavily weighted habitat or spacial variables were poor predictors of capture success. Models built on two or three dimensions of the NMS ordination were accepted based on AIC scores. These models incorporated seven to nine of the habitat variables, which were significantly correlated with the axes. I predicted more mouse captures at trap stations representing the most favorable conditions for breeding success and survival. The

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habitat conditions that support the highest density of beach mice include greater coverage of woody vegetation, higher vegetation heights, lower amounts of non-woody vegetation, less bare ground, and fewer sea grape clumps, which is typical of inland scrub at Cape Canaveral.

Differential use of habitats by southeastern beach mice within the landscape of Cape Canaveral has not resulted in an underlying genetic structure (Degner et al. 2007). A lack of genetic structure suggests gene flow between and among the various habitats of the cape. These dispersal events, though indirectly inferred, support my inference that southeastern beach mice are habitat generalists and not restricted to a narrowly defined habitat space.

Conclusion

I found the highest abundance of southeastern beach mice on Cape Canaveral to be associated with the woody vegetation of the coastal scrub rather than the coastal dunes. This finding is at odds with my original assumption that southeastern beach mice were most abundant on the coastal dunes. Furthermore, my results suggest southeastern beach mice may be expected to occur wherever well drained sandy soils are found on Cape Canaveral under a variety of habitat conditions.

Cape Canaveral may very well play a more important role in the long-term survival of the southeastern beach mice than any other single portion of the current geographic range. This importance derives from the protection the area and westward extent (depth) of the cape offers relative to the impact of tropical storms and hurricane events at the coastline (Stout et al. 2007). In the case of Hurricane Opal (1995), local movement of Alabama beach mice to an inland scrub/transition habitat allowed survival rates in the post-hurricane setting to remain at pre-hurricane levels (Swillling et al. 1998). Lag effects were suspected in that survival the following

summer did decline. Oddy (2000) documented the response of southeastern beach mice on Cape Canaveral to two hurricanes and a tropical storm in 1995. The physical damage to coastal dune habitat resulted in a severe reduction in the abundance of southeastern beach mice and three of four study sites did not begin to recover until the following season (> 3 month time lag). Recovery was attributed to immigration and reproduction of residents that survived the storms impact (Oddy 2000).

My study during 2005-2006 showed significantly more southeastern beach mice were trapped on the scrub grids relative to the coastal grids. Previous work at Cape Canaveral over a three year period suggested coastal dunes supported more southeastern beach mice than scrub settings (Stout 1979).   I used measures of trap success as surrogates for density. Density is often assumed to reflect habitat quality (Garshelis 2000); however, generally, as in my study, no independent measure of habitat quality is available. Habitat quality of these grids probably varies seasonally and yearly and the duration of my study was insufficient to capture this variation. Furthermore, density may be a misleading indicator of carrying capacity and habitat quality (Van Horne 1983; Garshelis 2000).

I studied habitat structure to infer habitat selection by southeastern beach mice. Habitat structure was assumed to operate as a proximate factor in habitat selection in the life time of individual beach mice. Organisms are assumed to reproduce and survive better in habitats they prefer, which increases fitness (Morris 1991; Garshelis 2000). My study design did not allow me to take a direct measure of fitness across the habitat gradient as identified in the NMS analysis. Garshelis (2000) offers a "Demographic Response Design" that more directly looks at this assumption by measuring fitness.

Long term survival and recovery of the southeastern beach mouse will likely depend on the future protection and management of the remaining suitable habitat on Cape Canaveral. These populations have the most favorable landscape to survive in given the unpredictable nature of hurricanes and tropical storms and their severe impacts on coastal dune habitat. In addition, these populations provide the logical source of individuals for re-introductions elsewhere in the former range where suitable conditions may exist or be restored.

APPENDIX: TABLES AND FIGURES

Table 1: Number of *Peromyscus polionotus niveiventris, Peromyscus gossypinus, Sigmodon hispidus* captured on trapping grids at Cape Canaveral Air Force Station, Florida, March 2005 to March 2006. The column headings reflect the total number of new and recaptured mice (Captures) and first time captured mice (Individuals).

Grids	*P. polionotus niveiventris*		*P. gossypinus*		*S. hispidus*	
	Captures	Individuals	Captures	Individuals	Captures	Individuals
Dune Grids						
1	127	29	1	1	0	0
2	135	40	2	2	12	9
3	56	30	10	7	3	3
Dune Grid Total	318	99	13	10	15	12
Scrub Grids						
1	278	56	36	10	2	2
2	51	10	9	2	15	11
3	569	133	1	1	3	2
Scrub Gird Total	898	199	46	13	20	15
Grand Total	1216	298	59	23	35	27

Table 2: Spearman's rank correlation coefficients of the 10 habitat and spatial variables used in the ordination test. The 6 trapping grids are shown pooled in the analysis. Coefficients are included in the table if significant at p < 0.05.

	Bare Ground	Woody	Non-Woody	Avg Height	Sand Grain Size	Sand Sorting	Patchy / Cont.	Sea grape	Latitude	Longitude
Bare Ground										
Woody	-0.1987[2]									
Non-Woody		-0.1504[2]								
Avg Height	-0.4716[2]	0.3658[2]	-0.2186[2]							
Sand Grain Size		-0.2649[2]	0.1640[2]							
Sand Sorting	0.3562[2]	0.1484[2]	0.2173[2]	-0.2622[2]	-0.2640[2]					
Patchy / Cont.	0.3725[2]	-0.4838[2]	0.3802[2]	-0.6769[2]	0.1195[1]	0.1559[2]				
Sea grape	0.2109[2]	-0.5604[2]	0.4383[2]	-0.4757[2]	0.2160[2]	0.1062[1]	0.5692[2]			
Latitude	-0.2984[2]		-0.1303[1]	0.1862[2]		-0.3792[2]	-0.2722[2]	-0.1453[2]		
Longitude		-0.1051[1]	-0.4067[2]	0.1997[2]		-0.4889[2]		-0.3021[2]	-0.2255[2]	

[1] indicates a significant values p < 0.05

[2] indicates a significant value at p <0.01

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Table 3: Spearman's rank correlation coefficients of the 9 habitat and spatial variables used in the ordination test and the 3 dimensional output axes from the ordination. The 6 trapping grids are pooled in the analysis. Coefficients are included in the table if significant at p < 0.05.

	Bare Ground	Woody	Non-Woody	Vegetation Height	Mean Grain Size	Sand Sorting	Sea Grape	Latitude	Longitude	Axis 1	Axis 2	Axis 3
Axis 1	0.1357^2	0.7186^2	-0.2886^2	0.1942^2	-0.3664^2	0.4048^2	-0.7704^2					
Axis 2	0.4523^2	-0.1060^1	-0.8042^2	-0.1063^1		-0.1832^2	-0.3714^2		0.4631^2	0.2574^2		
Axis 3	0.5548^2	-0.5481^2	0.4596^2	-0.7685^2	0.1758^2	0.3475^2	0.8395^2	-0.2645^2	-0.3259^2	-0.4770^2	-0.1519^2	

[1] indicates a a significant values p < 0.05

[2] indicates a significant value at p < 0.01

Table 4: Spearman's rank correlation coefficients of the 4 trapping success variables and the 3 output axes from the ordination. The 6 trapping grids are pooled in the analysis.   Spearman's correlation coefficients are not included if not significant at p < 0.05.

	Axis 1	Axis 2	Axis 3	All Captures	Individuals	Female	Male
Axis 1							
Axis 2	0.2224[2]						
Axis 3	-0.5055[2]	-0.1415[2]					
All Captures	0.5005[2]		-0.2827[2]				
Individual	0.3288[2]		-0.1531[2]	0.6537[2]			
Female	0.4671[2]		-0.2567[2]	0.7802[2]	0.5341[2]		
Male	0.4060[2]		-0.2248[2]	0.8171[2]	0.4787[2]	0.4432[2]	

[1] indicates a a significant values p < 0.05

[2] indicates a significant value at p < 0.01

Table 5: Akaike's information criterion (AIC) scores for data from 3 ordination axis scores based on the captures of southeastern beach mice. Total captures were transformed to arcsin to increase normality. Competing models with ΔAIC<2.0 are shown with an asterisk. The adjusted r^2, Mallow's Cp, and Schwarz Bayesian Information Criterion (BIC) are included for comparison.

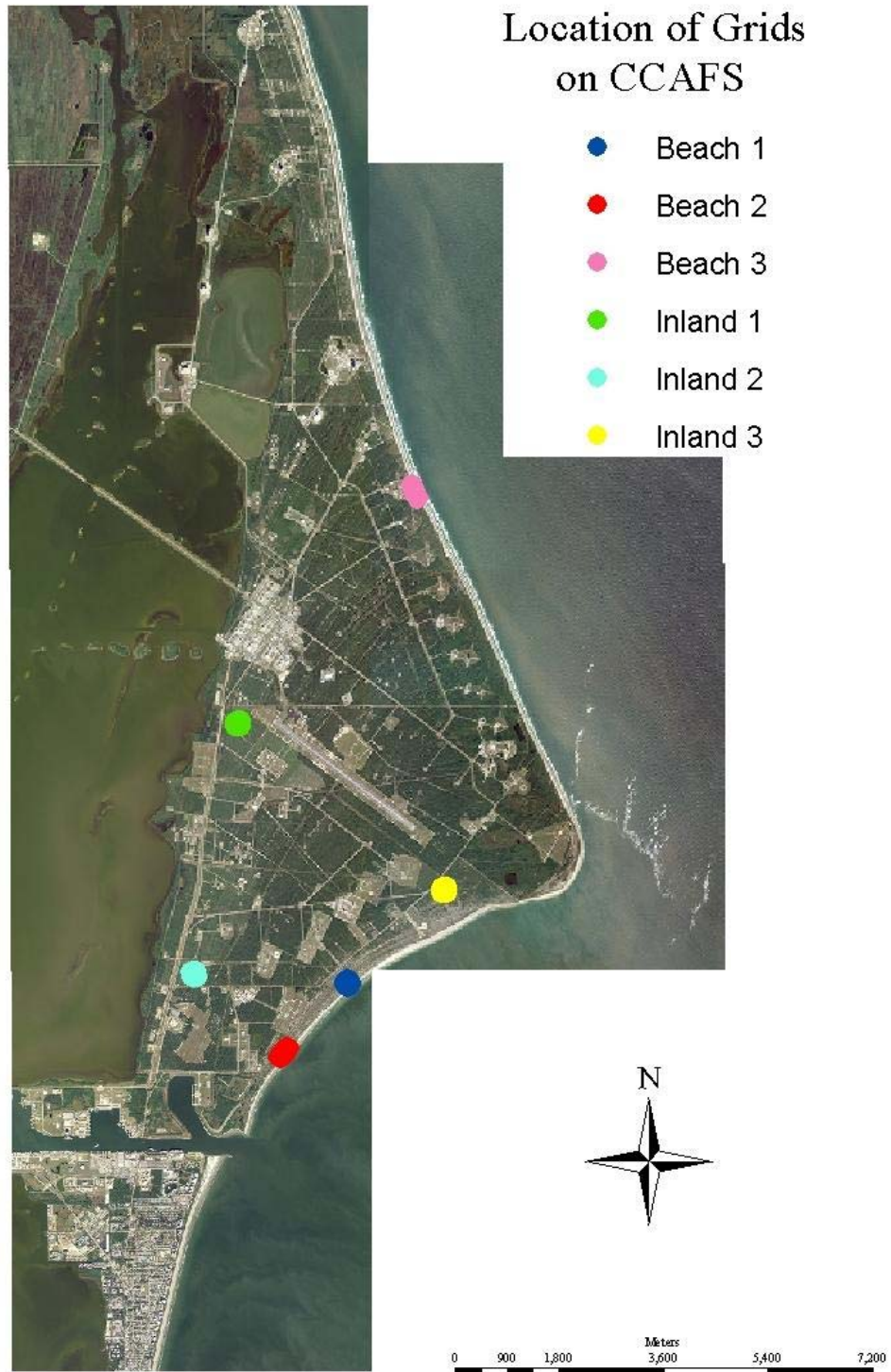| Model	k	Adj r²	AIC	Δ AIC	Cp	BIC
Axis 1, Axis 2	3	.228	-1190.556	0.000*	3.000	-1178.760
Axis 1, Axis 2, Axis 3	4	.226	-1188.629	1.927*	4.000	-1172.900
Axis 1	2	.216	-1185.518	5.038	2.000	-1177.654
Axis 1, Axis 3	3	.214	-1183.549	7.007	3.000	-1171.753
Axis 3	2	.056	-1115.779	74.777	2.000	-1107.915
Axis 2, Axis 3	3	.056	-1114.714	75.842	3.000	-1102.917
Axis 2	2	-.002	-1092.923	97.633	2.000	-1085.059

Figure 1: Location of trapping grids on Cape Canaveral Air Force Station, Florida.
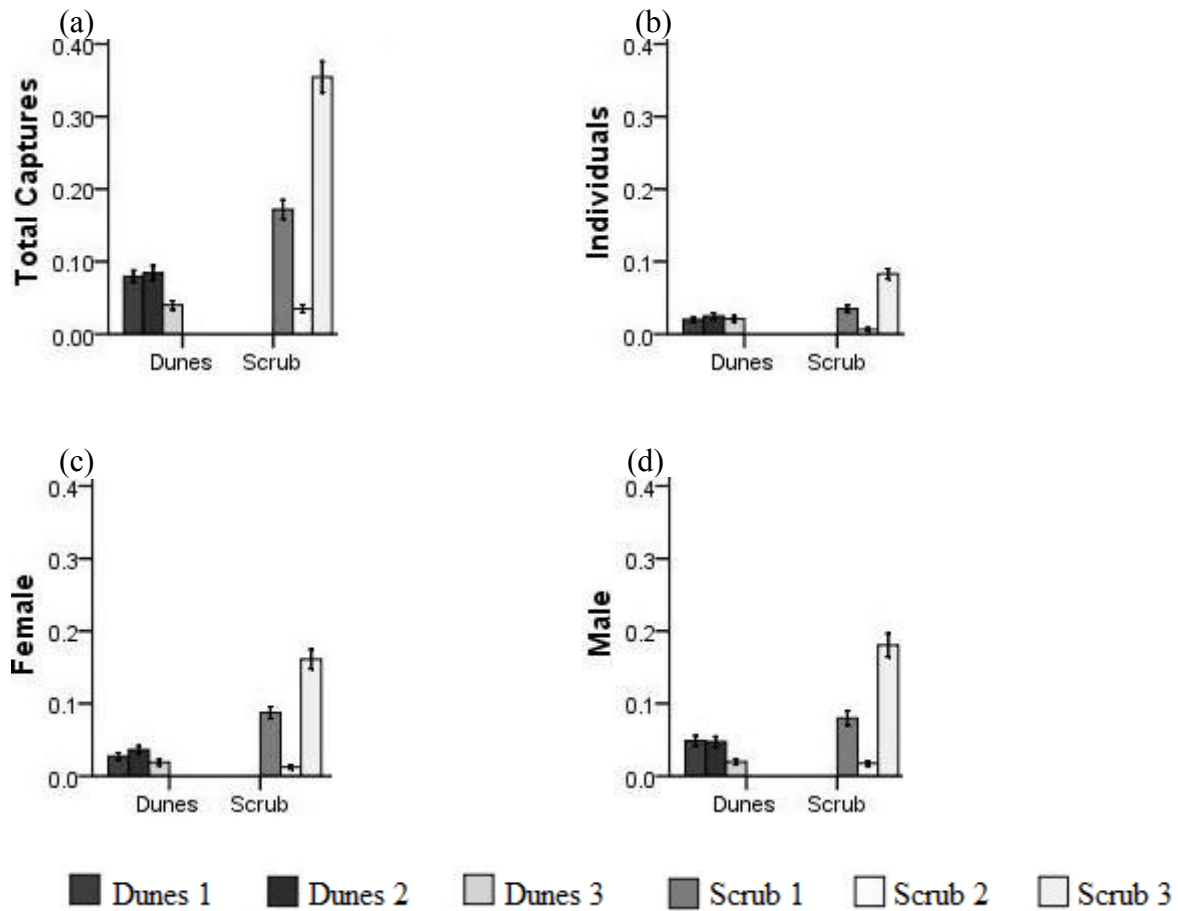
Figure 2: The mean number (+/- 1 SE) of southeastern beach mice trapped on three grids nested within each habitat type. Four measures of trapping success are given: (a) all captures of mice, (b) individual mice only, (c) the total number of females captured, and (d) the total number of males captured. Trapping success is the number of captures divided by 25 trap nights. Grids are located on Cape Canaveral Air Force Station, Florida and the trapping was from March 2005-March 2006.

(a)   (b)

(c)   (d)

(e)   (f)
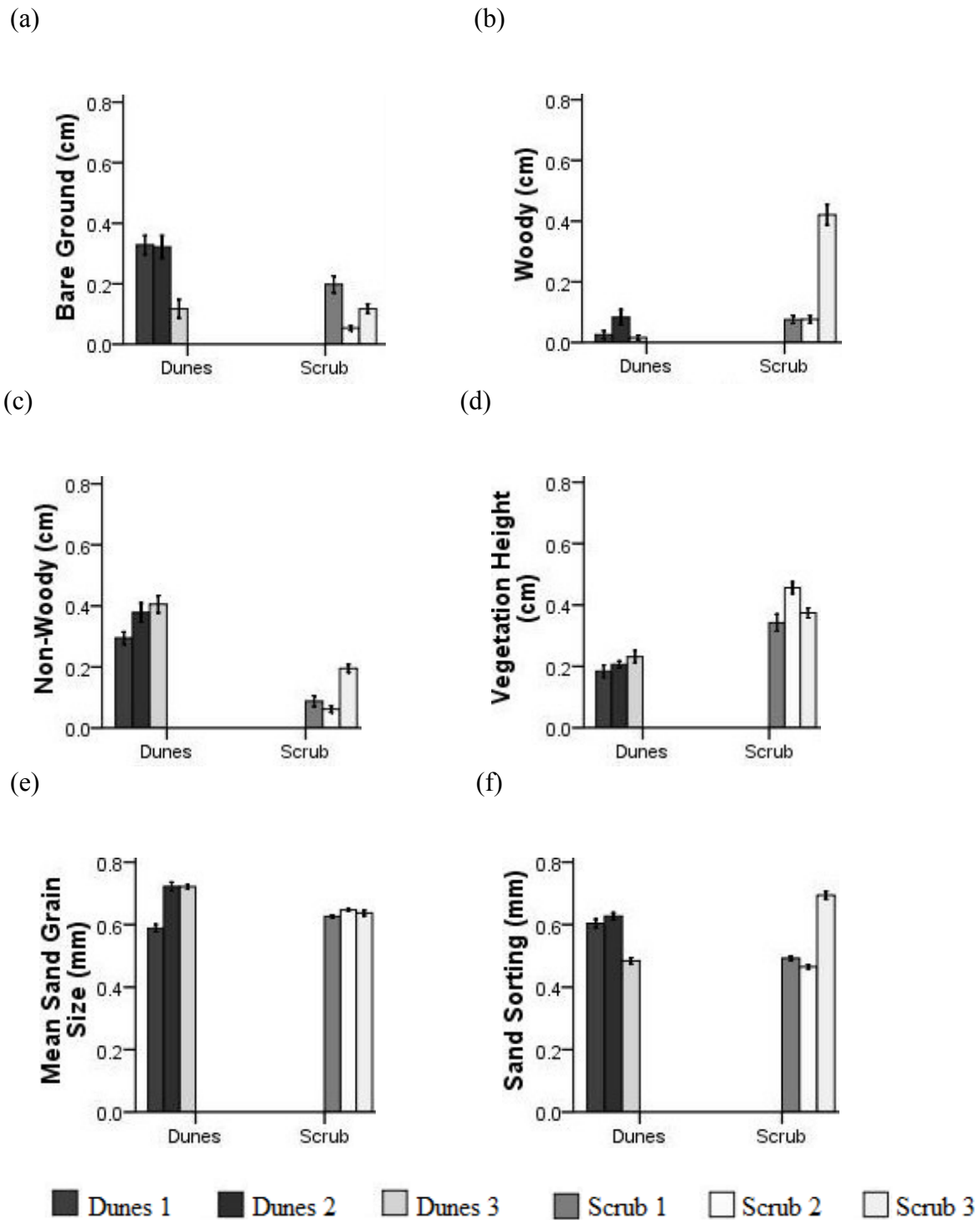
Figure 3: Means (+/- 1 SE) of six habitat variables representing scrub and dune grids. The variables are: (a) bare ground, (b) woody, (c) non-woody, (d) average vegetation height, (e) mean sand grain size, and (f) sand sorting. Grids are located on Cape Canaveral Air Force Station, Florida.

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(a)

(b)

(c)

Habitat Type
● Scrub
○ Dune
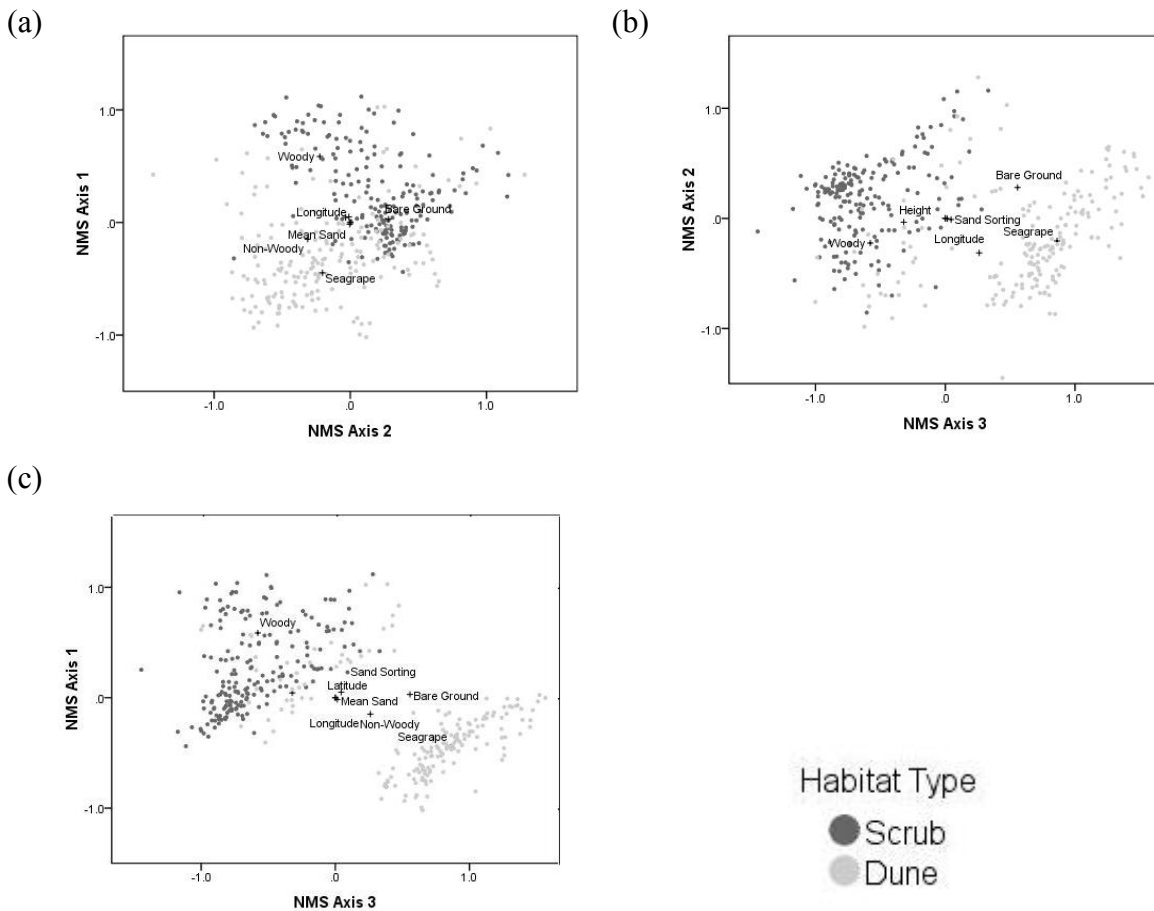
Figure 4: Non-metric multidimensional scaling ordination of trap station across Cape Canaveral Air force Station, Florida. The 3 NMS axes are given: (a) axis 1 and axis 2, (b) axis 2 and axis 3, and (c) axis 1 and axis 3. The 9 environmental variables and trap stations are indicated. Patchy/Continuous was not included because it is highly correlated with average height (-0.68) and sea grape (0.57) The upper left cluster will be referred to as the scrub cluster and the lower right will be called dune cluster.

Figure 5: Bubble plot. Non-metric multidimensional scores represent axis 1 and axis 3. The bubbles are created from the number of captures at the individual trap stations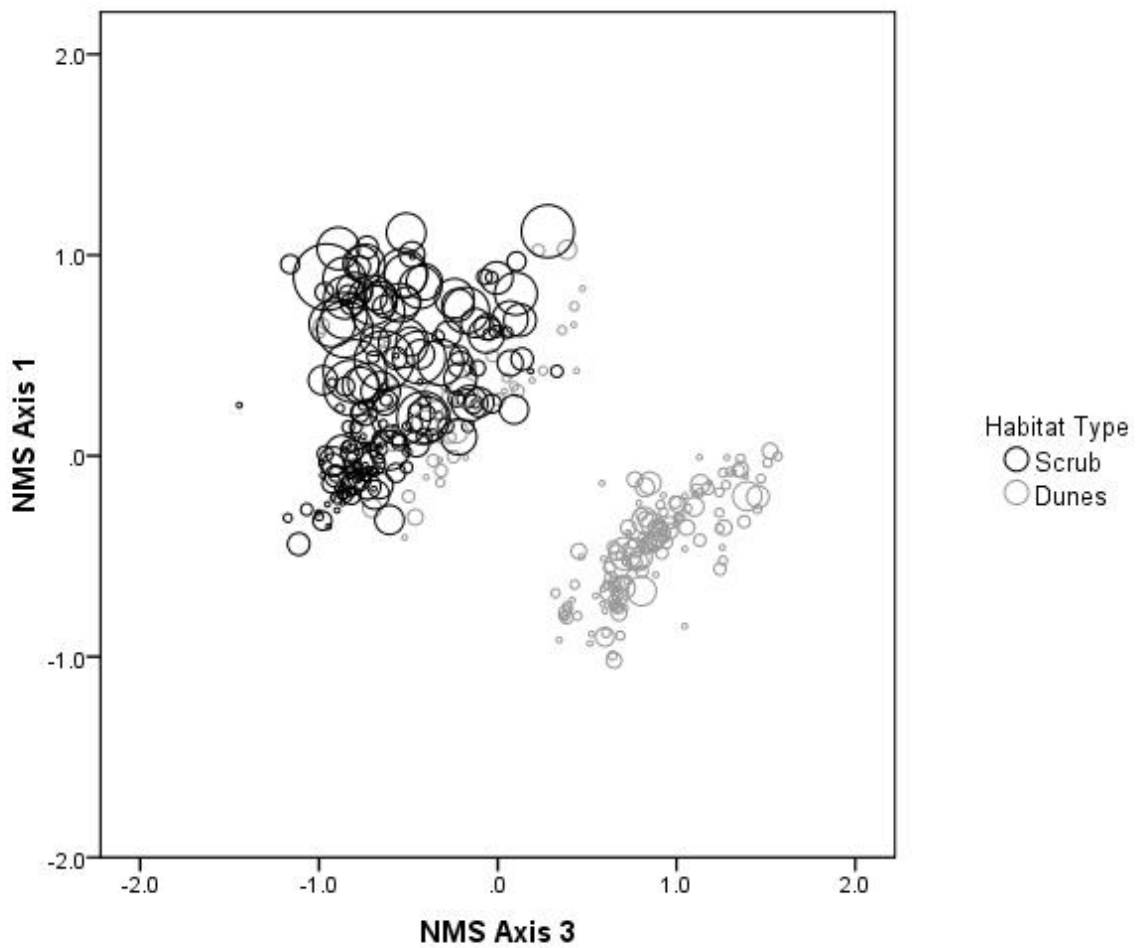. The bubble size represents a relative probability of capture. The upper left cluster will be referred to as the scrub cluster and the lower right will be called dune cluster.

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