

FLORIDA INTERNATIONAL UNIVERSITY

Miami, Florida

THE INFLUENCE OF HABITAT ON THE DISTRIBUTION AND ABUNDANCE OF
SMALL MAMMALS IN THE SOUTHWEST EVERGLADES

A thesis submitted in partial fulfillment of the

requirements for the degree of

MASTER OF SCIENCE

in

BIOLOGY

by

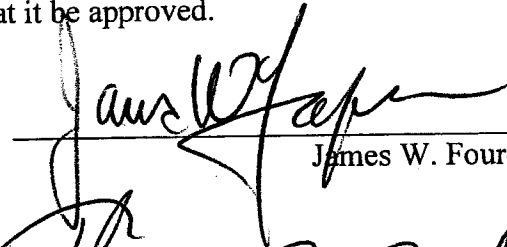
Diane Marie Riggs

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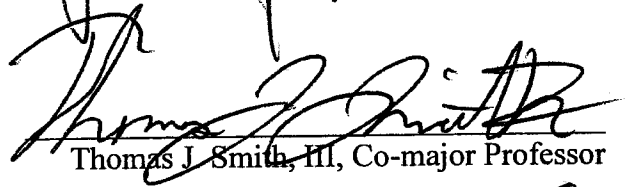
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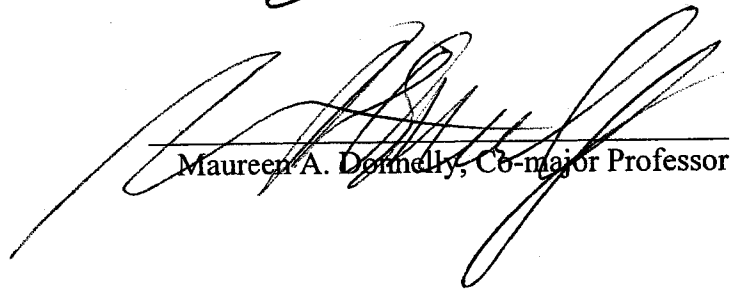
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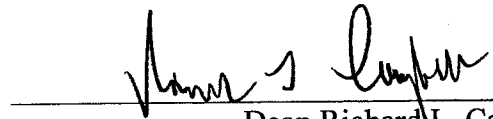
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DEDICATION

It is with pleasure that I dedicate this thesis to Brian R. Lockwood. Brian was my most dedicated field technician, photographer, research assistant, critic and friend.

Without his loving support and encouragement, this work would not have been possible.

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ABSTRACT OF THE THESIS

THE INFLUENCE OF HABITAT ON THE DISTRIBUTION AND ABUNDANCE OF SMALL MAMMALS IN THE SOUTHWEST EVERGLADES

by

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Florida International University, 2000

Miami, Florida

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The goals of this study were to describe the distribution and abundance of small mammals of the southwest Everglades, and to determine the influence of habitat on small mammal distribution and abundance. Since the small mammal communities of the mangrove, marsh and mangrove-marsh ecotones within the southwest Everglades had not yet been described, it was important to gather baseline data on mammals using a mark-recapture technique. Three native and one introduced species were captured during a one-year study period: *Oryzomys palustris*, *Sigmodon hispidus*, *Peromyscus gossypinus* and *Rattus rattus*. Habitat variables were measured and compared to species richness and abundance with correlation, regression and multivariate analyses. Habitat variables that influenced small mammal distribution and abundance were water levels, salinity, elevation and vegetative structure (e.g., tree height and density). Most small mammal species in the southwest Everglades demonstrated a macrohabitat (e.g, mangrove) preference and a microhabitat (e.g, tree height) selection.

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INTRODUCTION

Biodiversity and Habitat Heterogeneity

The concept of biodiversity, a central topic of community ecology (MacArthur 1957; Hutchinson 1959) has assumed a new vitality and an expanded perspective, perhaps reflecting heightened concern for and awareness of threats to biodiversity on a global scale (Wilson 1992; Huston 1994; Schulze and Mooney 1994; Rosenzweig 1995).

Spatial variation in abundance largely reflects the extent to which local sites satisfy the ecological requirements of a species (Brown et al. 1995). Landscapes composed of spatially heterogeneous habitats should provide a greater diversity of potential niches for animals than do homogeneous landscapes. Burnett et al. (1998) showed that sites with high geomorphological heterogeneity were higher in species richness and diversity of woody plant species, than were sites that exhibited little change in terrain or soil conditions.

In Australia, Williams and Marsh (1998) found that habitat heterogeneity was significantly higher in a mixed open forest-ecotone area than in the adjacent rain forest. There was a large change in the structure of the small mammal assemblage coincident with the vegetation discontinuity. Although the species richness of small mammals was relatively constant across the gradient, evenness and diversity of the assemblage declined from open forest to rain forest. The decline in evenness was associated with an increase in biomass, largely due to the high abundance of *Rattus fuscipes* in the rain forest. Williams and Marsh (1998) suggested that species evenness, but not species richness was strongly affected by habitat heterogeneity.

The landscapes in the southwest Everglades that are composed of heterogeneous habitat are primarily mangrove-marsh ecotonal areas. I predict that these ecotonal areas will support a higher animal species richness and relative abundance than the more homogeneous areas of the mangrove and marsh. The landscapes in ecotonal areas support many plant species and have a high geomorphologic heterogeneity (varying elevation and water depths). It is likely that this combination of vegetative and geomorphologic heterogeneity will support a higher animal species richness and relative abundance of small mammals than the more homogeneous areas of the mangrove and marsh.

Habitat Variables and Species Distributions

Although many "community" studies have focused on the influence of habitat variables on small mammals in arid and temperate zones, (Rosenzweig and Winaker 1969; Brown and Munger 1985; Burnett et al. 1998) few studies have examined the affect of habitat on tropical and subtropical rodents. Since the ecology of small mammals in the subtropical southwest Everglades had not been described, it was important to quantify their distribution and abundance and relate this distribution and abundance to habitat variables within their community.

Rosenzweig and Winakur (1969) observed that several habitat variables, including foliage height diversity, vegetation density and soil structure significantly influenced small mammal species distributions among and within habitats. Harris (1984) lists three characteristics that influence individual species occurrences and species richness in a community. These factors are (1) surface water and moisture levels, (2) elevation and (3)

structural variation in the community (i.e., plant spacing, percent cover, and presence of felled trees). My study examined the influence of surface water, salinity, elevation, and vegetation structure on the distribution and abundance of small mammals in the southwest Everglades.

Habitat Utilization Patterns

Habitat associations and utilization patterns of small mammals can be measured on two different scales. The first scale, the macrohabitat scale, measures habitat usage on a broad level. Examples of macrohabitat variables include the size of an area, percent vegetative cover or type of vegetation (e.g., mangrove, marsh or ecotone). The second scale of habitat usage is considered the microhabitat scale. Microhabitat variables are measured at a finer spatial scale and include variables such as tree height, elevation and litter depth (Anderson and Gutzwiller 1994).

The realization that species respond to specific components of their environment on a scale of resolution much finer than gross habitat differences provided impetus to studies of resource partitioning and interspecific competition (Rosenzweig and Winaker 1969). This understanding, combined with multivariate statistical procedures, resulted in detailed ecological studies on microhabitat selection of small mammals (M'Closkey 1976; Dueser and Shugart 1978; Seagle 1985; Haering and Fox 1995).

My study focused on the effect of macrohabitat (mangrove, marsh and ecotone), hydrology (water level and salinity) and microhabitat (structural variables) on the distribution and abundance of small mammals in the southwest Everglades. If overlap in

macrohabitat use is observed, it implies that species partition one or more resources to coexist. Overlap in macrohabitat use is greatly reduced when trap stations are considered individually, so that multivariate analysis followed by multiple regression can demonstrate marked microhabitat selection (Haering and Fox 1995).

Principal Components Analysis in Habitat Studies

Principal Components Analysis (PCA) is a multivariate technique that linearly transforms an original set of variables into a substantially smaller set of uncorrelated variables (Duntelman 1989). Small mammal studies have used PCA to take a large set of microhabitat variables and reduce them to a smaller set of uncorrelated variables (August 1981, 1983; Haering and Fox 1995). The uncorrelated variables can be defined on multifactorial axes on which species distributions can be diagrammed and compared.

In order to describe the microhabitat configuration for each rodent species captured, it was first necessary to ordinate the structural microhabitat variables. The linear composites or Principal Components that resulted from this ordination were then compared against species distribution and abundance in a regression analysis. In this way, multivariate analysis in combination with linear regression should help to reduce macrohabitat overlap and determine microhabitat selection.

BACKGROUND

Mangrove, Marsh and Mangrove-Marsh Ecotones

Wetlands come in many varieties, but the two main types are swamps and marshes. Although the definitions are not universal, swamps are usually considered to be wetlands in which the dominant plants are trees (Lodge 1994). Examples of swamps in the Everglades include mangrove swamps found in fresh, brackish and saltwater areas. If trees are so scattered that their shade is insignificant, the area is called a marsh. Marshes are dominated by much lower, herbaceous vegetation and often look like prairies (Lodge 1994).

Mangrove swamps in Florida are important habitats for a wide variety of vertebrates such as fishes, reptiles, amphibians, birds and mammals (Odum et al. 1982). Thirty-six native and nine introduced species of land mammals occur in the South Florida region (Layne 1974b; Hamilton and Whittaker 1979) and almost 50% of these species are found in the mangrove zone (Layne 1974b). Part of my research entailed a quantification of small mammals within the mangroves of the southwest Everglades.

Mangrove-marsh ecotones within Everglades National Park can be characterized as mangroves adjacent to marsh. Examples of these transition zones are found in the southwestern areas of the park between the Ten Thousand Islands and Florida Bay. These areas have an enhanced biological diversity that can serve as potential "early-warning" systems that may reflect environmental change (Holland et al. 1991). At the biome scale, water balance and climatic temperature are usually the dominant controls of ecotone

position (Neilson 1993). Because these controls are components of global climate patterns, ecotones would be expected to respond to patterns of global climate change (Risser 1995; Ross et. al. 2000).

The flows of water, nutrients, and other materials, as well as the movement of organisms, across the landscape are determined by a variety of conditions. Although all of these processes occur within relatively homogeneous habitat types, they tend to be concentrated or intensified in ecotones (Risser 1995). For example, Peterjohn and Correll (1984) studied a landscape in the eastern United States consisting mostly of agricultural fields but having riparian forests along streams. The ecotonal riparian forests captured 60 - 75% of the nitrogen and phosphorous as it moved from the agricultural fields across the landscape and into the streams. Ecotones in the southwest Everglades are an important component of the landscape for managing fluxes of nutrients that will ultimately impact adjacent mangrove and aquatic ecosystems.

In terms of wildlife, land managers have traditionally considered ecotones beneficial because species diversity generally increases near habitat edges (Yahner 1988). Stevens and Husband (1998) found that species diversity of small mammals decreased as the distance from the edge to the forest increased. In comparison, Sekgororoane and Dilworth (1995) found that small mammal species richness increased in "older" edges (6-10 years old) but not in "younger" edges (0-5 years old). It is likely that all edges or ecotones are not the same, and so should be analyzed and interpreted on an individual basis.

Ecotones as Indicators of Change

Historic aerial photographs (1927 to present) indicate that the position of the Everglades mangrove-marsh ecotone has moved considerably over the past 50 years in some areas, and not at all in other areas (T.J. Smith III, pers. comm.). Ross et al. (2000) found that the mangrove-marsh ecotone in the southeast Everglades has shifted inland 3.3 km.

If environmental conditions or management decisions change in ways that are beneficial for one of the adjacent ecosystems, patch size is likely to increase in this system. For example, if conditions change in a way that favors mangrove over marsh communities, the ecotone could move toward the marsh and the mangrove patch size would be increased.

In south Florida, it is possible that an increase in development and a decrease in natural land areas have caused many mammal species to live at the margin of their environmental tolerance. This marginal tolerance would cause environmental changes such as ecotonal shifts to have a significant impact on species' distributions (Gosz and Sharpe 1989).

In order to refine biodiversity predictions for ecotones, demographic features and environmental requirements of individual species or functional groups of species are needed. Biodiversity studies of ecotones should be based upon species' life histories in relation to properties of the landscape as a whole and the ecotone in particular (Johnson 1994). Since small mammal communities of the ecotones within the southwest Everglades had not been described, part of my investigation of habitat use was to first

gather descriptive data on rodent assemblages of the ecotone.

Environmental Fluctuations

In the southwest Everglades, seasonal changes in rainfall and tidal fluctuations affect the primary production of mangoves, marsh and ecotones. It is reasonable to assume that hydrologic changes will also affect the species richness and relative abundance of small omnivorous mammals.

The response of a species to environmental fluctuations depends on a variety of factors including the predictability and intensity of the fluctuations, the population biology of the species, its degree of resource specialization, and the presence or absence of competitors (Leigh 1982). Consequently, different species within a community may respond differently to the same environmental fluctuations. Comparing the responses of different species to these fluctuations provides insight into the role of variable environments in shaping life-history strategies (O'Connell 1989).

Karr et al. (1982) used mist nets to sample forest understory birds in central Panama between August, 1968 and July, 1969 and then again from May, 1977 to January, 1978. When comparing the results of the two samples, they found a similar numbers of species, however the species composition of the two samples was very different. In some cases it seemed that the difference in species composition was due to habitat changes (increase in treefall gaps) and in others, seasonal movement of temperate-tropical migrants was associated with changes in species composition. Samples taken in successive months differed significantly between wet and dry seasons. Some species were captured most

often in the dry season, while others seemed more abundant in the wet season. For example, the insectivore-nectarivore guild was more common in the dry season, while the species that followed army ants were more common in the wet season. Since wet and dry seasons are pronounced in the southwest Everglades, I would expect rodent species to respond differently to seasonal changes.

Seasonality affects tropical frogs in that some breed year-round (Berry 1964; Inger 1969) and some reproduce only during the wet season (Heyer 1973; Aichinger 1987). Donnelly and Guyer (1994) censused pond-breeding hylid frogs in northeastern Costa Rica and showed that reproduction in the Costa Rican assemblage was seasonal (only during the wet months).

Lewellen and Vessey (1998) modeled the effect of density-dependent and density-independent factors on the rate of population change in *Peromyscus leucopus* (white-footed mouse). Their study took place in a 2-ha wood lot in Ohio. Principal Components Analysis identified twelve highly collinear weather variables. Their results suggested that precipitation affected juveniles by influencing food resources that in turn influenced breeding. The rate of population change in the white-footed mouse was positively correlated in autumn with contemporaneous precipitation, and was negatively correlated in the summer when the weather was 'extreme'.

In Kansas, Doonan and Slade (1995) found that the strongly seasonal climatic conditions under which northern *Sigmodon hispidus* (cotton rat) populations exist, produce contrasting selective pressures which might favor season-specific foraging strategies. Their data support a scenario of territorial females and wandering males

during the reproductive season, with females maximizing resource acquisition for production of offspring. During winter, both sexes may restrict foraging time (and exposure to predators and weather) to the minimum required for maintenance.

Rodents exist principally on a diet of seeds and herbaceous plant parts. In arid regions, primary plant production, and ultimately rodent abundance is strongly influenced by annual rainfall quantities and patterns (Beatly 1969; Brown and Munger 1985). In these systems, vegetation responds rapidly to altered precipitation regimes. Rodent populations however may take up to a year to exhibit a significant numerical response to variable rainfall. For example, to maximize persistence during periods of drought, many rodent species exhibit behaviors that promote adult survival in lieu of fecundity (Brown and Harney 1993). As a result, these populations do not typically explode immediately after the onset of more favorable environmental conditions.

Rodent Ecology

The order Rodentia is the largest order of mammals, comprising 28 living families and more than 2,000 species (Wilson and Reeder 1993). All rodents share a distinctive cranial feature in that the upper and lower jaws each bear a single pair of persistently growing incisors. This feature developed early in the evolution of rodents, and committed them to a basically herbivorous mode of feeding, but permitted the exploitation of such often abundant foods as insects (Vaughan 1986).

Although there is a fair amount of knowledge available on the impact rodents can have on agricultural crops such as sugarcane and rice, not much is known about their diet in the

wild. There is however, evidence to suggest that south Florida rodents are omnivores.

Goodyear (1992) conducted a laboratory experiment in which she presented ten different food items to *Oryzomys palustris argentatus* (silver rice rat) and *Rattus rattus* (black rat).

Of the ten food items offered, three were animal and seven were plant. The boat roach (*Ligia* sp.) was the animal eaten most frequently and among plant material offered, *Rhizophora mangle* (red mangrove) propagules and *Avicennia germinans* (black mangrove) seedlings were most often consumed. From this experiment and from my own field observations, it is evident that red mangrove propagules are eaten by many rodents.

It is possible therefore, that rodents in the southwest Everglades play a role in the recruitment and mortality of mangroves and other plants.

Most rodents exhibit a high reproductive potential, and many species produce large litters of offspring several times a year (Svihla 1931; Meyer and Meyer 1944; Worth 1950; Pournelle 1952). Rodents have a number of reproductive specializations that are advanced and unusual. These include induced ovulation and induced estrus, as well as postpartum pregnancies (Svihla 1931; Meyer and Meyer 1944; Worth 1950; Pournelle 1952). In induced ovulation, the act of copulation with a male stimulates the release of eggs from the female's ovary. The presence of males also induces estrus in some female rodents. Most rodent species are capable of breeding throughout the year however usually have a peak breeding season(s). These reproductive specializations and other adaptive features make rodents one of the most successful of all mammal groups (Brown 1997).

Sigmodon hispidus (cotton rat) is the most ubiquitous mammal in Florida (Layne 1974b) and has a three to five year population cycle, reaching peak numbers as high as 10 - 28 individuals per 0.4 ha. (Odum 1955). This high point is followed by a die-off of most of the population to very low densities of less than one cotton rat per 0.4 ha. Cotton rats slowly increase in numbers after crashes over several years to peak once again (Odum 1955).

Rodents are an important prey species for many predators including hawks, owls, bobcats, foxes, minks and snakes (Brown 1997). In addition, rodents have limited movement (Burt and Grossenheider 1980) so it is possible that they are susceptible to environmental changes.

The Non-Indigenous Rattus Rattus

Except for feral pigs, *Rattus rattus* (the black rat) was probably the first non-indigenous mammal to reach Florida (Layne 1997). It is likely that black rats were on the ships of the earliest Spanish explorers (Silver 1927) and may have become established during that period. The first documented record was in the late 1800's (Rhoads 1894). This species is widely distributed in Florida, including the Florida Keys and the more isolated Dry Tortugas (Layne 1974b). It is more common than its congener, *Rattus norvegicus* (the norway rat) and typically inhabits more natural habitats than this species (Layne 1997).

Salinity Tolerance

Results of experiments on water balance and salt tolerance in the order Rodentia demonstrate that some species can survive on sea water, its equivalent in salt solution, and occasionally, higher concentrations of either (Chew 1951; Schmidt-Nielsen and Schmidt-Nielsen 1951; Getz 1963). Most rodents that survive on saline solutions equal to or higher than that of sea water have been from an arid environment, but a few have been taken from a salt water region (Schmidt-Nielsen et al. 1964).

Goodyear (1992) suggested that the non-indigenous black rat (*Rattus rattus*) might have a greater tolerance to salinity than the endangered silver rice rat (*Oryzomys palustris argentatus*). Goodyear's research indicated that silver rice rats in the Florida Keys might be jeopardized by the presence of black rats. Oryzomine extinctions in the Galapagos and Antilles islands have been attributed all or in part, to the introduction of black rats to these islands (Jackson 1985; Thornton 1971; Woods 1989).

Dipodomys merriami (kangaroo rat) can exist in a temperature range from 0 - 31°C, on nothing but dried rolled oats or barley, provided the relative humidity is above 20% (Schmidt-Nielsen and Schmidt-Nielsen 1951). This rat can produce concentrated urine and obtain oxidative water from the grain sufficient enough for maintenance. There are two adaptive measures that minimize the loss of water in this rodent; the almost complete absence of cutaneous evaporation, and a mechanism in the nose that condenses water lost to the warm air in the lungs (Schmidt-Nielsen and Schmidt-Nielsen 1951).

The North African rodent *Psammomys obesus* (sand rat) inhabits areas where the vegetation consists of fleshy salt-loving plants such as *Salicornia* sp. The sand rat seems

to eat only succulent plants in which the sap has a salt content often in excess of seawater (Schmidt-Nielsen et al. 1964).

Medlock (1968) took individuals of *Sigmodon hispidus* (cotton rat) from two areas of south Florida. The first area contained only salt water, while the second area had plenty of fresh water available. Medlock took the rats back to the lab, gave them only salt water to drink and monitored their survival time. His results showed that rats taken from freshwater areas died within 12 days of exclusive salt water, while rats taken from saline areas could survive about 50 days. In his discussion, Medlock hypothesized that rats from saline areas of south Florida had developed a tolerance for salt water. This salt-water tolerance is caused by the gradual evaporation of fresh water during the dry season. As fresh water decreases, these rats may be acclimated to living on succulent plants, drinking seawater, or surviving with very little water.

One of the objectives in setting my study up on an environmental gradient was to determine the effects of salinity on species distribution and abundance. Since certain species of rodents may have a greater tolerance to salinity than other species of rodents, changes in salinity could have a direct affect on community structure.

Hypotheses

My research was designed to give a preliminary assessment of the status of rodent populations in the mangrove, marsh and mangrove-marsh ecotones of the southwest Everglades. To test the hypothesis that mangrove, marsh and mangrove-marsh ecotones have a significant effect on small mammal distribution and abundance, I compared frequency distributions of small mammals within these macrohabitat types. To test the hypothesis that habitat variables have a significant influence on small mammal distribution and abundance, I compared the frequency distributions of small mammals over time with habitat variables that fluctuated seasonally. To test the hypothesis that small mammal species in the southwest Everglades have a distinct microhabitat configuration, I first ordinated the habitat structural variables and then compared this ordination result with the capture frequencies of each trap station.

Specifically, my research addressed these questions:

- 1. What is the distribution and abundance of small mammals within the mangrove, marsh and mangrove-marsh ecotonal areas of the southwest Everglades?**
- 2. How do habitat variables influence the distribution and abundance of small mammals in the southwest Everglades?**
- 3. What is the microhabitat configuration of each species found in the southwest Everglades?**

MATERIALS AND METHODS

Study Area

My project was conducted along major tributaries of Shark River Slough, located in southwestern Everglades National Park (Figure 1). Shark River Slough is a freshwater flow that begins south of Lake Okeechobee and ends in the Gulf of Mexico. Slow and rain-driven, the natural flow of water begins fresh, turns brackish in the middle and becomes saline as it empties into the Gulf of Mexico. Shark River Slough in the southwest Everglades provides an environment with a salinity gradient that is influenced by precipitation and tidal fluctuations.

There are several different habitat types located along the flow of the Shark River, including bay heads, cypress stands, tree islands, freshwater marsh and mangrove swamps. Shark Slough supports populations of freshwater fish, reptiles, birds, and mammals. The slough is fed by direct rainfall and water released from a diked water conservation area to the north; historically water flowed from as far north as Lake Okeechobee (Olmsted et al. 1996). No quantitative studies of small mammals have been conducted in the southwest Everglades. Information obtained from my study can be used for future comparison in order to evaluate the consequences of proposed hydrologic restoration, as well as to increase understanding of Everglades' faunal communities.

Study Sites

This study was concentrated in the southwestern portion of Shark River Slough, an area that was composed primarily of mangroves, marsh and mangrove-marsh ecotones.

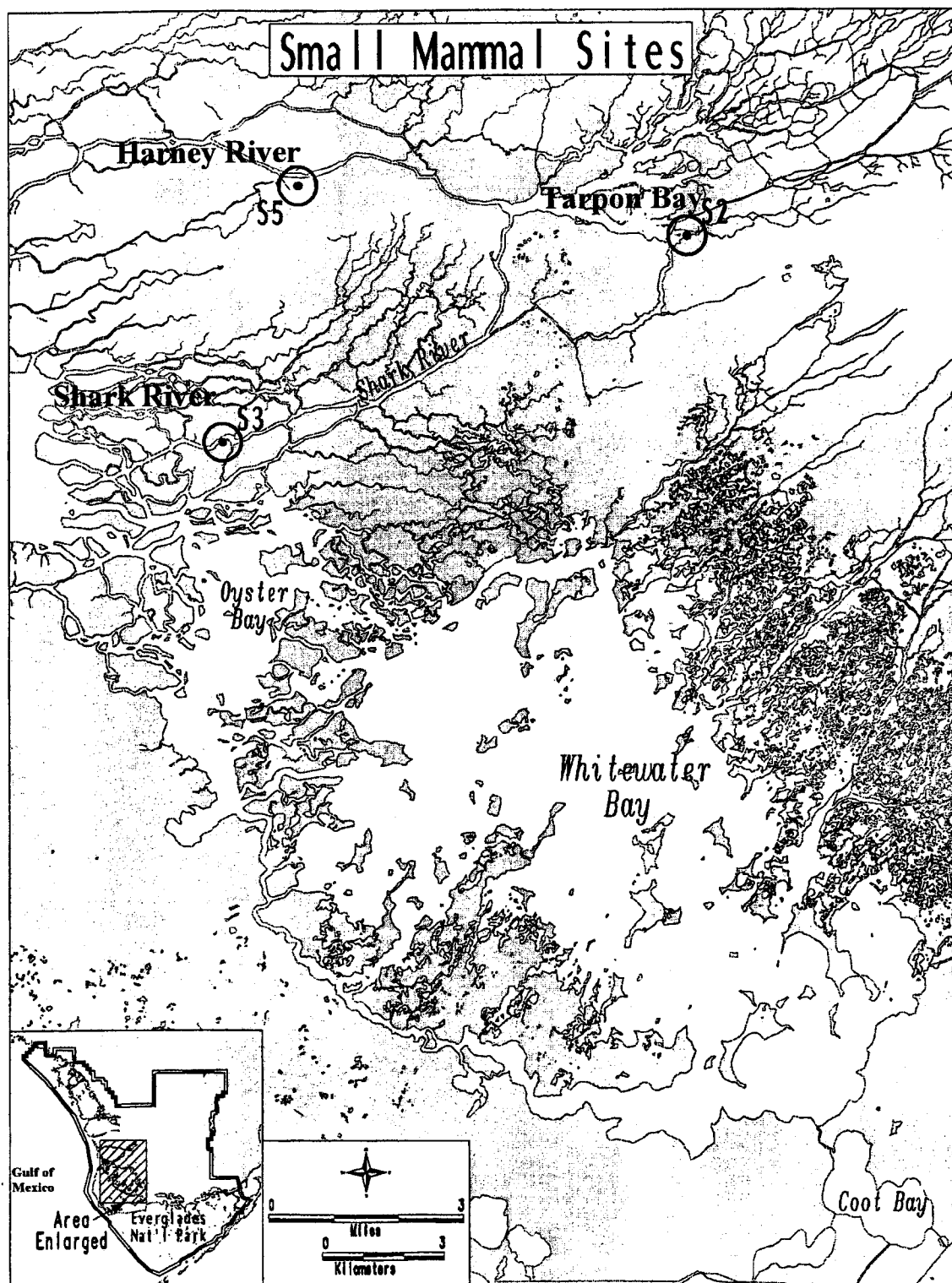


Figure 1: Sampling locations along the Shark River salinity gradient.

Three independent sites (Figure 1) were set up along the Shark River salinity gradient. The Tarpon Bay (S2) site was north and the water was mostly fresh, the Harney River site (S5) was mid-river and brackish, and the Shark River site (S3) was south where the water was saline.

Trapping sites were selected because I was able to obtain detailed hydrologic information from monitoring stations, location in reference to fresh water flow, powerboat accessibility, and suitability of mammalian habitat. All three sites were sampled on the same days with equal trapping effort. Each site contained a transect of nine trap stations, with each trap station containing a cluster of three Sherman live traps (Figure 2). The transect configuration cannot be used to estimate small mammal density (Wilson et al. 1996), but was chosen over other methods such as grids because species occurrence was the objective of this study. I present data on the relative abundance for small mammals at the three study sites. The length of the transect was determined by the distance needed to get the most representative habitat types for each site (mangrove, marsh or ecotone). Trap station spacing of approximately ten meters was based not only on the size of home ranges of small mammals, but also on habitat features (Wilson et al. 1996).

Macrohabitat communities at each trapping station were classified as mangrove, marsh or mangrove-marsh ecotone. Macrohabitat classifications were based upon percent cover of each of the dominant vegetative species. If the trap station collectively contained over 75% red (*Rhizophora mangle*), white (*Laguncularia racemosa*) or black (*Avicennia germinans*) mangrove, it was classified as a mangrove. Stations that collectively

contained over 75% sawgrass (*Cladium jamaicense*) or juncus (*Juncus roemarianus*) were classified as a marsh. If there was a fairly equal proportion of dominant vegetation, and a close proximity to mangrove or marsh, I classified the station as an ecotone.

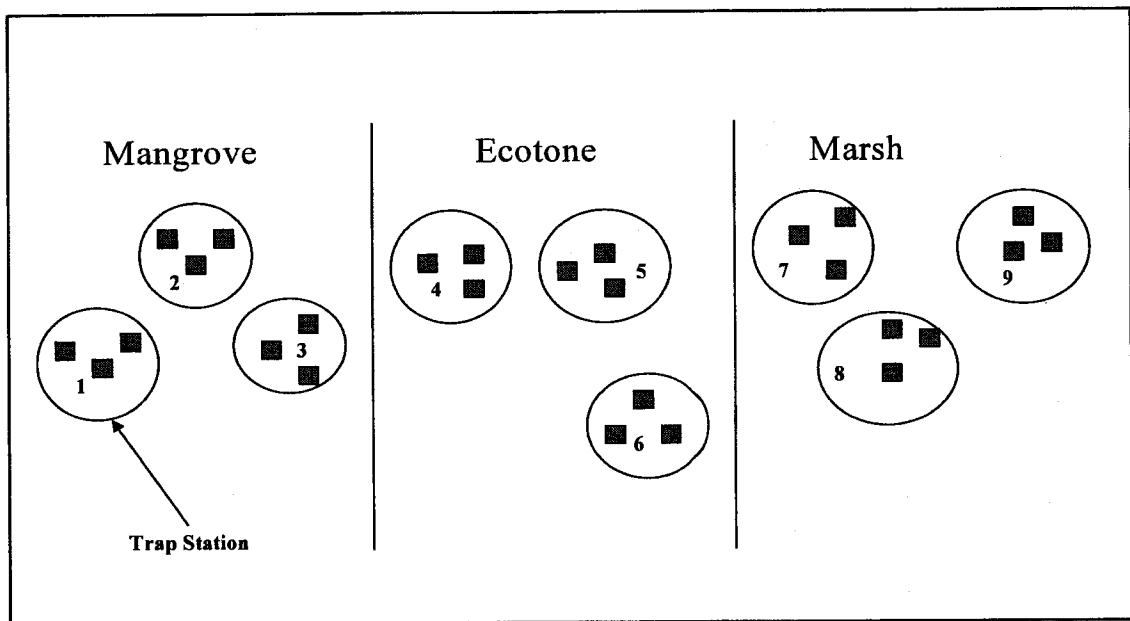


Figure 2: Diagram of trapping design illustrating three traps per station, three stations per macrohabitat type and nine stations per site.

Tarpon Bay Site (S2)

In relation to the other sites, the Tarpon Bay site can be expected to have the largest freshwater input from the Shark River. Annually, the salinity of surface water varies from 0 to approximately 16 practical salinity units, and surface water depths vary from 0.0 to approximately 0.6 meters (Figure 3). Fluctuations in salinity and water depth are primarily due to seasonal changes in precipitation.

Trap stations one, two, eight and nine were placed in the mangrove, three through five were in the ecotone, and six and seven were in the marsh (Table 1). The marsh stations were composed primarily of sawgrass (*Cladium jamaicense*), and juncus (*Juncus roemerianus*), with sparse amounts of red bay (*Persea borbonia*) and rubber vine (*Rhabdadenia biflora*). The ecotone stations contained fairly equal proportions of buttonwood (*Conacarpus erectus*), white mangrove (*Laguncularia racemosa*), sawgrass, rubber vine and juncus. Mangrove trap stations were composed primarily of red (*Rhizophora mangle*) and white mangrove, with sparse amounts of sawgrass, juncus and rubber vine intermixed.

Elevations are relatively constant throughout the site, but higher at the third ecotone station and the eighth and ninth mangrove station than at the other stations (Figure 4). The marsh and some of the ecotonal areas at this site are lower and therefore stay wet much of the year, due to precipitation and freshwater flow from Shark Slough.

Harney River Site (S5)

The Harney River site includes a 150 m boardwalk which runs almost due south, parallel to the small mammal transect and perpendicular to the river. Macrohabitat

Tarpon Bay

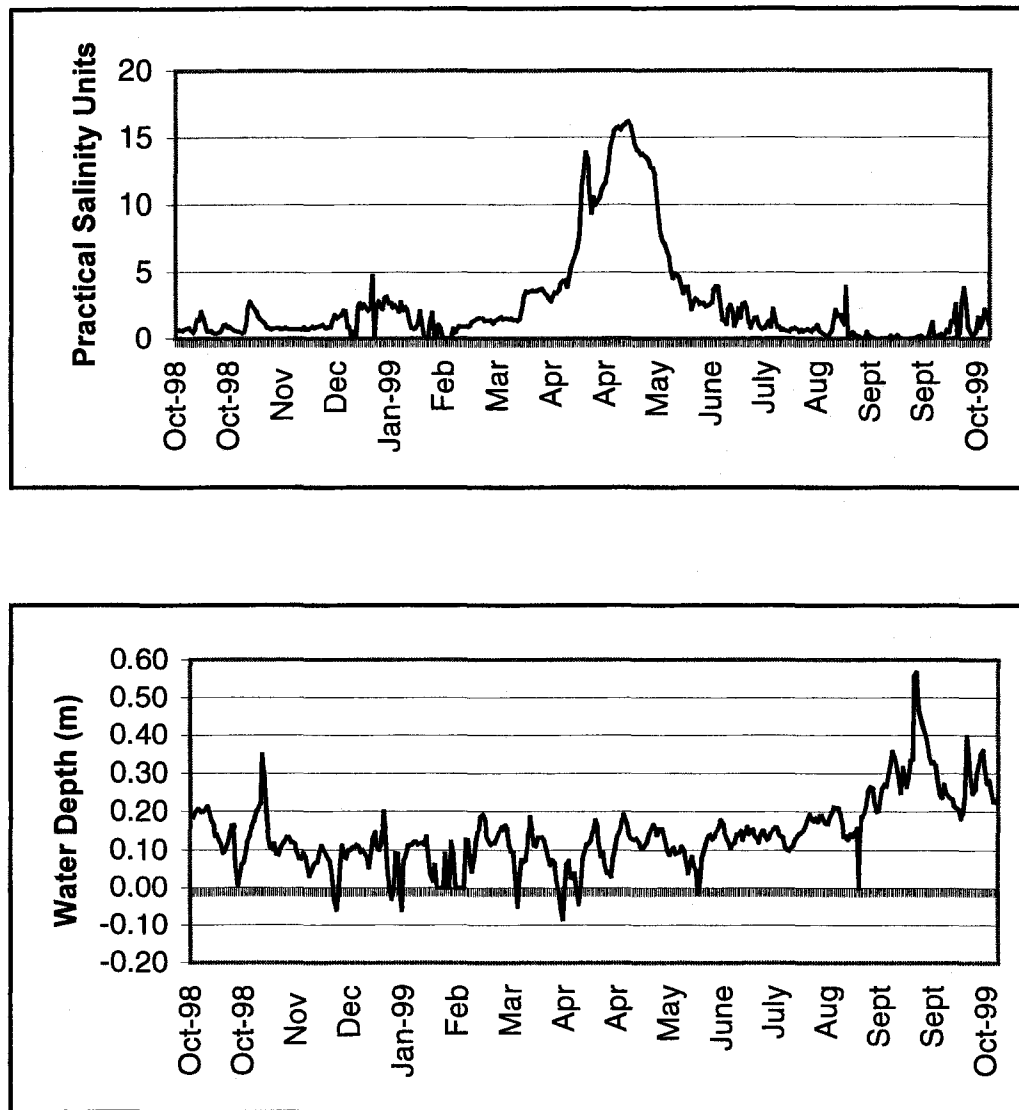


Figure 3: Salinity and water depth at Tarpon Bay (S2) for October '98 to October '99.

Table 1: Summary of nine trap stations at Tarpon Bay (S2)

Tarpon Bay (S2)					
Station #	Macrohabitat Type	Dominant Vegetation	Elevation (m)	Latitude (N)	Longitude (W)
1	Mangrove	Red, White, Sawgrass, Juncus, Rubber vine	0.511	25° 24' 35.53030"	80° 57' 47.73331"
2	Mangrove	Red, White, Sawgrass, Juncus, Rubber vine	0.476	25° 24' 35.92742"	80° 57' 47.98178"
3	Ecotone	Buttonwood, White, Sawgrass, Rubber vine, Juncus	0.483	25° 24' 35.92742"	80° 57' 48.37261"
4	Ecotone	Buttonwood, White, Sawgrass, Rubber vine, Juncus	0.527	25° 24' 36.29564"	80° 57' 46.65140"
5	Ecotone	Buttonwood, White, Sawgrass, Rubber vine, Juncus	0.690	25° 24' 36.06359"	80° 57' 46.77435"
6	Marsh	Sawgrass, Juncus, Red Bay, Rubber vine	0.598	25° 24' 36.36787"	80° 57' 47.35833"
7	Marsh	Sawgrass, Juncus, Red Bay, Rubber vine	0.629	25° 24' 36.61991"	80° 57' 47.62880"
8	Mangrove	Red, White, Sawgrass, Juncus, Rubber vine	0.614	25° 24' 37.36363"	80° 57' 47.25986"
9	Mangrove	Red, White, Sawgrass, Juncus, Rubber vine	0.622	25° 24' 37.34063"	80° 57' 47.46918"

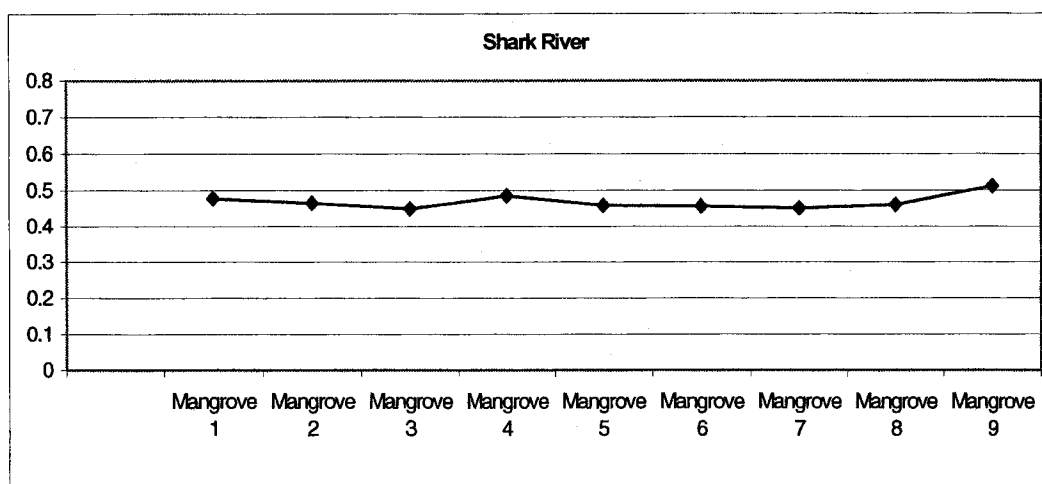
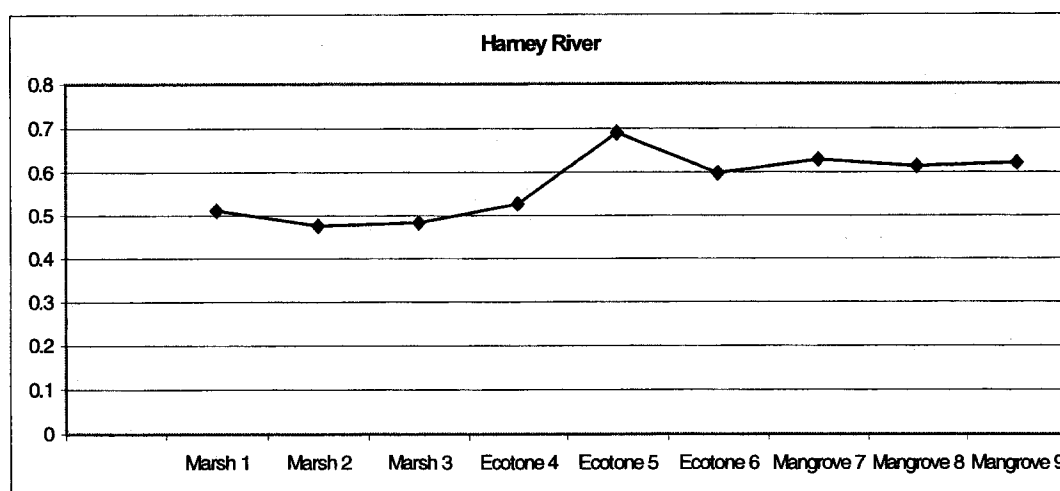
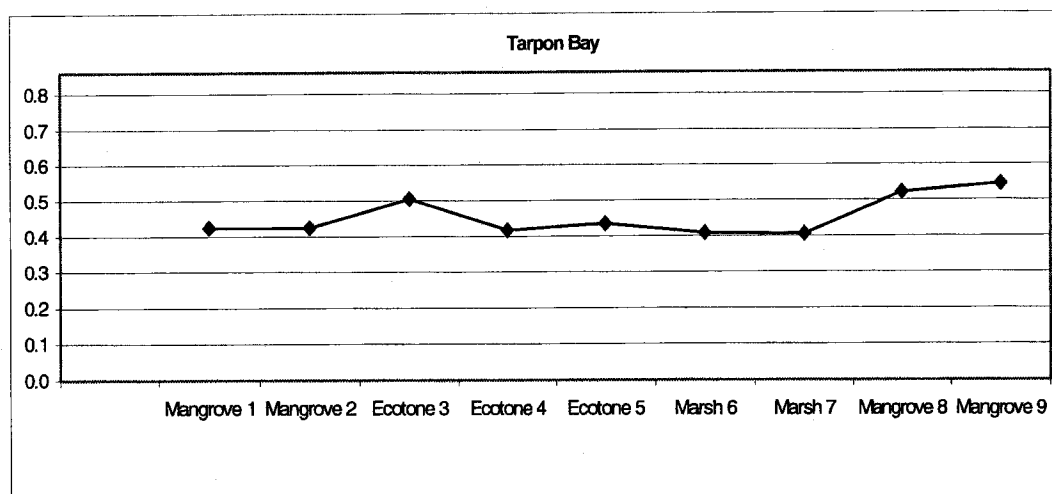


Figure 4: Elevation in meters and macrohabitat type for nine stations at each of the three sites.

communities sampled at this site were mangrove, marsh and mangrove-marsh ecotones. Salinity of surface water varies from 0 to approximately 21 practical salinity units, and surface water depth varies from 0.0 to approximately 0.3 meters (Figure 5). The variability in salinity and water depth at this site is partially tidal, but mostly due to seasonal effects from a change in precipitation and freshwater flow from Shark River Slough.

Trap stations one through three were placed in the marsh, four through six were in the ecotone and seven through nine were in the mangrove (Table 2). The marsh trap stations were composed primarily of sawgrass (*Cladium jamaicense*). The ecotone stations have an equal proportion of sawgrass, white mangrove (*Laguncularia racemosa*), buttonwood (*Conocarpus erectus*), leather fern (*Acrostichum aureum*), and brazilian pepper (*Schinus terebinthifolius*). The mangrove trap stations were composed primarily of red (*Rhizophora mangle*), black (*Avicennia germinans*) and white (*Laguncularia racemosa*) mangroves.

Elevations at the Harney River transect are relatively lower in the marsh than in the ecotone and mangrove (Figure 4). Except for a peak in elevation at ecotone trap station number five, trap stations that occurred in the mangrove had the highest elevations.

Shark River Site (S3)

Relative to the other two sites, the Shark River site has the highest salinity and highest degree of tidal fluctuation. Because of the high salinity, only mangroves occur along the transect. This site is a mangrove island, and the only freshwater input comes from rainfall. Partial data suggests that salinity varies from approximately 14 to 37 practical

Harney River

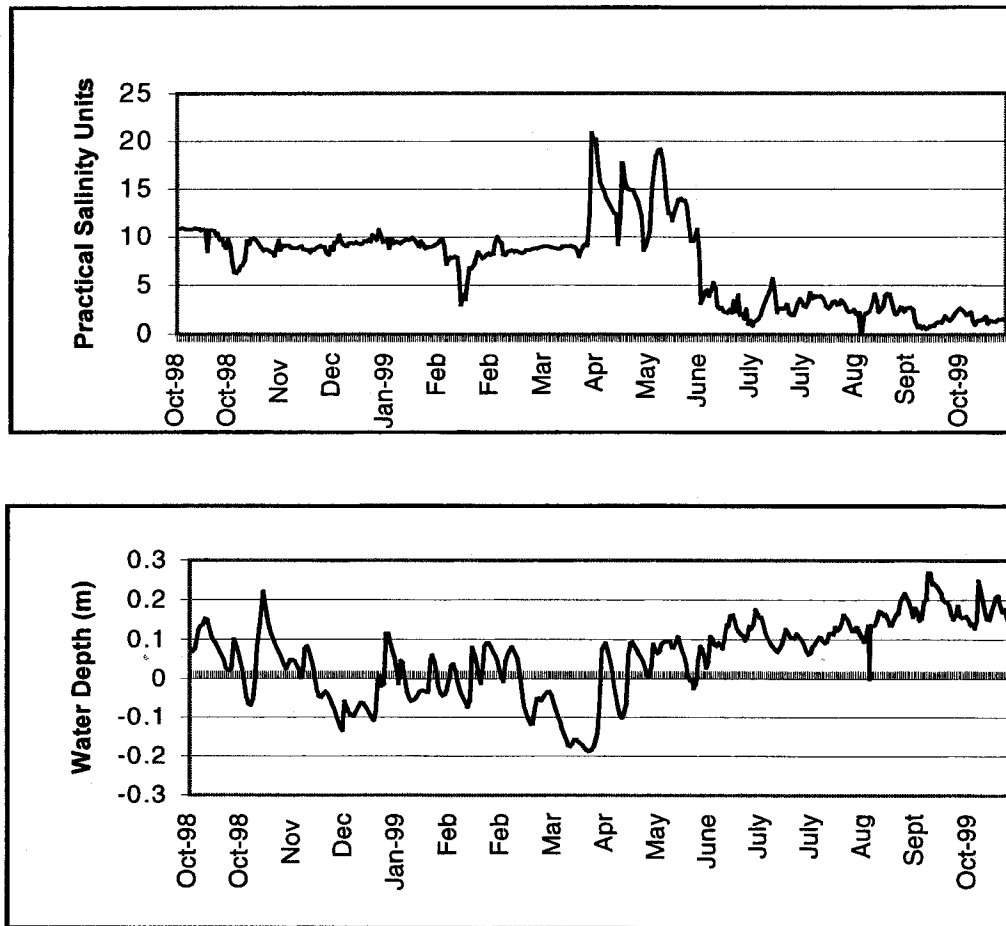


Figure 5: Salinity and water depth at Harney River (S5) for October '98 to October '99.

Table 2: Summary of nine trap stations at the Harney River (S5)

Harney River (S5)					
Station #	Macrohabitat Type	Dominant Vegetation	Elevation (m)	Latitude (N)	Longitude (W)
1	Marsh	Sawgrass	0.511	25° 25' 16.66718"	81° 03' 34.82713"
2	Marsh	Sawgrass	0.476	25° 25' 17.12054"	81° 03' 35.09760"
3	Marsh	Sawgrass	0.483	25° 25' 17.43097"	81° 03' 35.24513"
4	Ecotone	Sawgrass, White, Buttonwood, Leather fern, Brazilian Pepper	0.527	25° 25' 17.87203"	81° 03' 35.23899"
5	Ecotone	Sawgrass, White, Buttonwood, Leather fern, Brazilian Pepper	0.690	25° 25' 18.30671"	81° 03' 35.62102"
6	Ecotone	Sawgrass, White, Buttonwood, Leather fern, Brazilian Pepper	0.598	25° 25' 18.74781"	81° 03' 35.82982"
7	Mangrove	Red, Black, White	0.629	25° 25' 19.16589"	81° 03' 36.07531"
8	Mangrove	Red, Black, White	0.614	25° 25' 19.70068"	81° 03' 36.37621"
9	Mangrove	Red, Black, White	0.622	25° 25' 20.16941"	81° 03' 36.77030"

salinity units (Figure 6). Since surface water is tidal, daily averages range from 0.0 to approximately 0.3 meters, and maximum water depth varies from 0.3 to 0.9 meters (Figure 6).

All trap stations (one through nine) occurred in the mangrove where the vegetation was only red (*Rhizophora mangle*), black (*Avicennia germinans*) and white (*Laguncularia racemosa*) mangroves (Table 3). Elevations are fairly constant throughout the transect, with only a few centimeter difference at the fourth and ninth trap station (Figure 4).

Small Mammal Trapping

Each trap station consisted of three (7.62cm x 8.89cm x 22.86cm) ventilated Sherman live-traps. All traps were baited with crimped oats and had a Styrofoam float (1.27cm x 22.86cm x 30.48cm) attached with duct tape. The Styrofoam float served to ensure that trapped rodents did not drown during tidal fluctuations or unexpected rainfall.

Trapping began in October 1998 and ended in October 1999, for a total of 2,919 trap nights. Because of a lapse in my collecting permit, I was unable to trap in April 1999. Once each month, usually during the new moon, the traps were set in place and opened for three consecutive nights. Falkenberg and Clarke (1998) conducted an experiment that showed activity in deer mice (*Peromyscus maniculatus*) decreased as moonlight increased. By trapping during the new moon, trap success should be high and the time interval between trapping events remained fairly constant.

Shark River

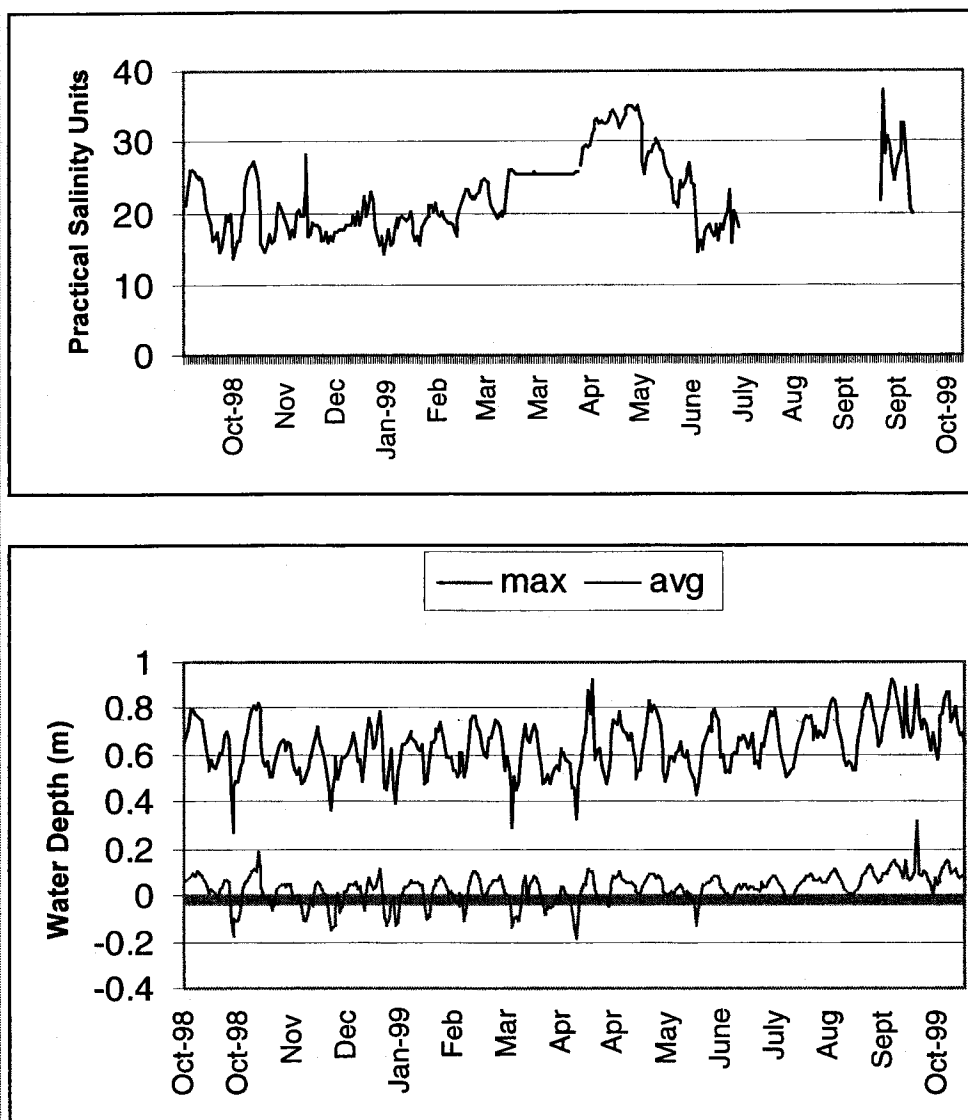


Figure 6: Salinity and water depth at Shark River (S3) for October '98 to October '99. Since water depth is tidal, maximum and average water depth are shown to compare daily fluctuations. Practical salinity units are missing from July '99 to September '99 and most of October '99 due to an equipment malfunction.

Table 3: Summary of nine trap stations at the Shark River (S3).

* Note: The trees at this site were too high and dense to obtain GPS coordinates.

Shark River (S3)				
Station #	Macrohabitat Type	Dominant Vegetation	Elevation (m)	* Lat/Long
1	Mangrove	Red, Black, White	0.478	N/A
2	Mangrove	Red, Black, White	0.466	N/A
3	Mangrove	Red, Black, White	0.450	N/A
4	Mangrove	Red, Black, White	0.486	N/A
5	Mangrove	Red, Black, White	0.459	N/A
6	Mangrove	Red, Black, White	0.457	N/A
7	Mangrove	Red, Black, White	0.451	N/A
8	Mangrove	Red, Black, White	0.461	N/A
9	Mangrove	Red, Black, White	0.513	N/A

Since it took approximately two hours of travel time (by car and boat) to reach the sites, it was important to factor in this time requirement, so that all traps at all sites could be checked before early afternoon on the same day. This was especially important during summer months. No animal on this project died of heat exhaustion, however six animals died from accidental drowning and three animals were taken from traps by a predator (possibly a bobcat). When an accidental drowning did occur, the animal was collected as a specimen and will be deposited in the museum at Everglade's South Florida Natural Resource Center. These specimens are in addition to the voucher specimens collected for the identification and verification of each species. A melanistic individual *Sigmodon hispidus* (cotton rat) was collected at the Harney River site in September 1999 and will also be deposited at the museum.

Small Mammal Data Collection

Upon arrival at each site, the date, time and approximate temperature were noted. Weather conditions (e.g., rain the night before and amount of air movement) were recorded. Ancillary data such as birds, reptiles, amphibians and other mammals observed in the area were also noted. When a trap contained a rodent, the animal was emptied into a dark cloth bag and weighed. The trap number was noted so that this information could be linked to macrohabitat and microhabitat variables associated with each trap station. The rodent was then identified to species and marked with a uniquely numbered ear tag.

After the rodent was tagged, measurements in centimeters of head, body and tail were taken. All animals were sexed and their reproductive condition was assessed. Female

reproductive condition was one of three categories: perforated, lactating or pregnant. The testes of males were either descended or not descended. Age estimates were one of three categories: post-natal, juvenile or adult. Post-natal individuals were considered to be less than one month old and sparsely haired. Juveniles were smaller and lighter than adults and often had a different color pelage. If an individual was in a reproductive phase or considered an average size and weight for that species, it was classified as an adult. If a captured rodent was tagged, it was recorded as a recapture and the number was noted.

The presence and location of ectoparasites such as ticks and chiggers were noted. Comments such as pelage variations, scrapes, cuts and anything considered unusual or unfamiliar were also noted. After processing, the animals were released at the capture location.

Microhabitat Variables

Four criteria guided selection of the microhabitat variables for measurement: 1) each variable should provide a measure of the structure of the environment which is either known or reasonably suspected to influence the distribution and local abundance of small mammals; 2) each variable should be quickly and precisely measurable with nondestructive sampling procedures; 3) each variable should have intra-season variation that is small relative to inter-season variation; and 4) each variable should describe the environment in the immediate vicinity of the capture site (Dueser and Shugart 1978).

Each trap station had a radius of 1.78 meters for a total area of 10 m². To measure the structural variation at each station, I laid out two measuring tapes so that each

measuring tape had a diameter of 3.56 m (1.78 x 2 m). Each measuring tape crossed the other measuring tape at the center of the station, or at 1.78 m. Sixteen microhabitat variables (Table 4) were measured within this 10 m² area. Strata were defined as either canopy (woody, diameter at breast height (dbh) > 10 cm), midstory (woody, dbh < 10 cm), shrub (woody or herbaceous, < 2.5 m in height) or herbaceous (vegetation, < 2 m in height).

Cover at each station was measured in all four strata. I also determined how much bare ground and litter were present at each station. Cover was subjectively estimated as percent coverage within a small circle above the center of each station. I first calculated the total vegetative percent cover (less than or equal to 100%) and then assigned each strata part of the total percentage. Cover for small mammals was inferred from litter depth and the abundance of large sized logs or stumps. Litter depth was recorded as the average of four measured depths within the center of the circle. Log and stump coverage was tallied as the number of logs and stumps greater than 10 cm in diameter.

Canopy and midstory heights were each measured with a planimeter and then averaged to obtain mean heights. Shrub and herbaceous heights were measured with a measuring tape and also averaged. The dbh (diameter at breast height) of canopy and midstory trees was measured with a dbh tape, while shrub dbh was measured with calipers. Diameter at breast height measurements were averaged to obtain mean dbh for canopy, midstory trees and shrubs at each trap station.

Table 4: Microhabitat (structural) variables measured at each trap station.

Microhabitat Variables

Description of 16 microhabitat variables that were measured at each trap station

3 traps per station (1 trap station = 10 sq. meters)

9 trap stations per site

3 sites

VARIABLE	DEFINITION
COVCAN	Subjective estimate of percent vegetative cover (as a proportion) of the canopy, ranges from 0.00 to 1.00.
COVMID	percent vegetative cover of the midstory
COVSHB	percent vegetative cover in the shrub layer
COVHRB	percent herbaceous cover
COVLIT	percent ground covered by litter
LOGS	Number of logs > 10 cm. diameter
ELEV	Elevation in m at station point
CANHGT	Mean height (m) of canopy trees
CANSIZE	Mean dbh (cm) of canopy trees
MIDHGT	Mean height (m) of midstory trees
MIDSIZE	Mean dbh (cm) of midstory trees
SHRBHGT	Mean height (m) of shrubs
SHRBSIZE	Mean basal diameter of shrubs
HERBHGT	Mean height (m) of herbs
VINES	Number of vines that pass through trap station
LITTER	Litter depth in cm at station point

Elevation was measured at the center of each trap station with a Topcon laser leveler. Since true elevation benchmarks have not been surveyed in this area of the Everglades, all relative elevations are tied to the U.S. Geological Survey hydrologic monitoring stations located at each site.

Statistical Analyses

I used T-tests to compare body mass of the same species captured at different sites. Chi-Square analysis was used to detect a significant site relationship with population structure and reproductive status. Spearman Rank Correlations compared significant relationships between species richness and abundance with salinity and water depth information. The multivariate technique of Principal Components Analysis, ordinated macrohabitat stations and microhabitat variables. Step-wise Regression was used to determine which principal components were important to species' distributions. Principal components important to species distribution were used in linear and multiple regression analyses to determine microhabitat selection. Analyses of residuals examined the suitability of each model for predicting species' distribution and abundance.

I used Sigma Stat (1995) to compute T-tests, Chi-Square, Spearman Rank Correlation, Regression and residual analyses. A multivariate statistical software package for the analysis of ecological data, PC-ORD (1995) was used for all Principal Components Analysis.

To calculate macrohabitat (niche) overlap, both between and within habitats at the Tarpon and Harney Sites, I used Pianka's (1974) modification of MacArthur and Levins (1967) equation:

$$O_{jk} = \frac{\sum(P_{ij} \times P_{ik})}{(\sum P_{ij}^2 \times \sum P_{ik}^2)^{1/2}}$$

where;

O_{jk} = Niche overlap

P_{ij} = Proportion of each resource state occupied by species j

P_{ik} = Proportion of each resource state occupied by species k

RESULTS

Species Distribution and Abundance

From October 1998 to October 1999, I sampled on 2,919 trap nights at three sites, within three macrohabitat types, with a total of 27 trap stations. Because of a lapse in my permit, I was unable to trap in April 1999. Trapping results yielded 228 individuals from four different species. I had 249 recaptures of these individuals for a grand total of 477 captures (Table 5). Each species had a recapture rate of approximately 50%.

Oryzomys palustris and *Sigmodon hispidus* were captured most frequently, 78 and 76 individuals, respectively (Table 5) at the Tarpon Bay (S2) and Harney River Sites (S5). *Rattus rattus* was the third most abundant species with 49 individuals (Table 5) from the Tarpon Bay (S2) and Shark River Sites (S3). Twenty-five individuals of *Peromyscus gossypinus* were captured at the Harney River Site (S5)(Table 5).

Table 5: Number of captures and recaptures for individuals of each species.

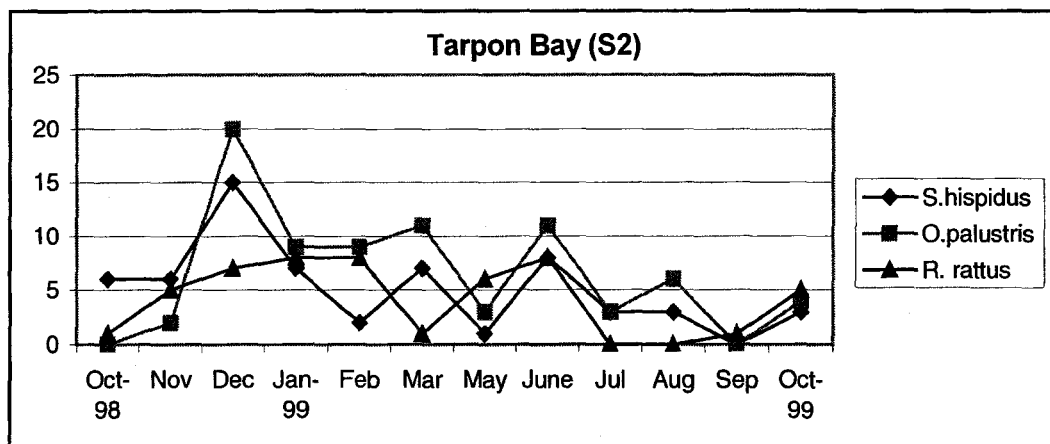
# Times Captured	<i>Oryzomys palustris</i>	<i>Peromyscus gossypinus</i>	<i>Rattus rattus</i>	<i>Sigmodon hispidus</i>
1	43	12	33	38
2	18	7	4	18
3	13	1	3	10
4	3	1	3	1
5	0	1	3	5
6	0	1	1	0
7	0	1	1	0
8	0	0	1	1
9	0	1	0	3
10	0	0	0	0
11	1	0	0	0
Number of Individuals	78	25	49	76
Total Individuals				
228				
Total Recaptures				
249				
Total Captures				
477				

Some species had a few individuals that were captured eight or more times (Table 5). For example; an individual *R. rattus* was captured eight times, one *P. gossypinus* and three *S. hispidus* were captured nine times, while one *O. palustris* was captured 11 times. Although 11 times might be considered a "trap happy" individual, the male *O. palustris* was captured over an eight-month period, started as a juvenile and went through a reproductive phase, gained 35 grams and traveled at least 50 meters from its initial capture point.

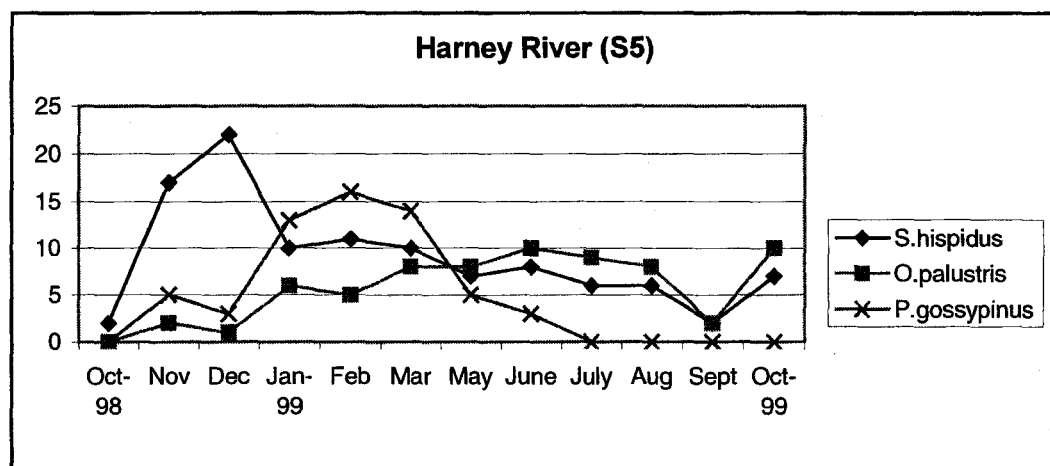
My highest capture success occurred in December 1998 when I captured 20 *O. palustris* at the Tarpon Bay Site, 22 *S. hispidus* at the Harney River Site and nine *R. rattus* at the Shark River Site (Figure 7). Overall, *O. palustris* seemed to dominate the Tarpon Bay Site. *Sigmodon hispidus* was consistently captured more frequently at the Harney River Site, however when *P. gossypinus* was present during the dry season this species was the most abundant. Only *R. rattus* was captured at the Shark River Site. On 21 September 21 1999, Tropical Storm Harvey (a strong wind and rain event from the west) pushed water up the coastal estuary. My September sampling occurred just two days after this event, while all three sites were still flooded. It is possible that the high waters that resulted from Harvey were responsible for the low capture success I experienced at all sites in September 1999 (Figure 7).

Proportionally, *S. hispidus* accounted for 35.4% of all captures, *O. palustris*: 31.4%, *R. rattus*: 21.0% and *P. gossypinus*: 12.2% (Table 6). Out of all macrohabitat types at all sites, the ecotone at the Harney River (S5) had the highest percentage of captures (25.8%). The mangrove at Tarpon Bay (S2) had the second highest capture rate

A



B



C

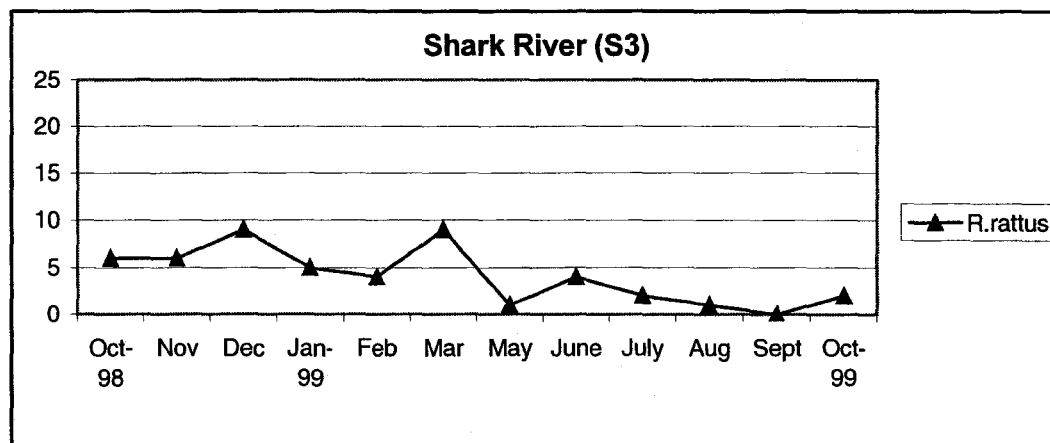


Figure 7: Number of each species at each site from 10/98 through 10/99. Because of a lapse in the permit, no trapping occurred in April '99. Tropical Storm Harvey (Sept. '99) flooded all three sites so that very few animals were captured in September '99.

Table 6: Number of captures by macrohabitat and species. Individuals captured at the same trap station and within the same 3-day trapping event were not counted. Macrohabitats are listed from freshwater to saline. The sites are indicated by the following abbreviations:

S2 = Tarpon Bay Site S5 = Harney River Site S3 = Shark River Site

The rodent taxa are indicated by the following abbreviations:

Op = *Oryzomys palustris* Sh = *Sigmodon hispidus*
Rr = *Rattus rattus* Pg = *Peromyscus gossypinus*

The Shark River Site (S3) did not contain marsh or ecotone.

Macrohabitat	Op	Sh	Rr	Pg	Total	Proportion of Total
Mangrove S2	20	31	33	0	84	0.177
Mangrove S5	20	9	0	33	62	0.130
Mangrove S3	0	0	50	0	50	0.105
Marsh S2	27	12	5	0	44	0.092
Marsh S5	25	23	0	2	50	0.105
Ecotone S2	34	18	12	0	64	0.134
Ecotone S5	24	76	0	23	123	0.258
Total	150	169	100	58	477	
Proportion of Total	0.314	0.354	0.210	0.122		

(17.7%) while the marsh at Tarpon Bay (S2) had the fewest captures (9.2 %) (Table 6).

Mass and Size Comparisons

The mean mass of each species is shown in Figure 8. In order of decreasing body mass, *R. rattus* captured at the Shark River had the greatest body mass, followed by *S. hispidus* (both sites), then *R. rattus* at Tarpon Bay, followed by *O. palustris* (both sites), and *P. gossypinus* was the smallest species overall. When I compared the same species captured at different sites with t-tests, only *R. rattus* proved to be significantly heavier at the Shark River Site than at the Tarpon Bay Site ($t = 9.386$, $df = 58$, $P = < 0.001$). In order to pass normality testing, body masses were $\log_{10}$ transformed prior to analysis. Since *P. gossypinus* was captured only at the Harney Site (S5), no mass or size comparisons can be made for this species.

I took measurements of the length of head and body and then tail, of all animals captured. Since the length measurements of the adult individuals of the same species captured at different sites seemed fairly equivalent (Table 7), I combined species to compare mean lengths (Figure 9). Head and body length is greater than tail length for *S. hispidus* (13.67 and 9.87, respectively); head and body length is less than tail length for *O. palustris* (11.18 and 13.97, respectively); head and body length is less than tail length for *R. rattus* (16.67 and 20.11, respectively); and head and body length exceed tail length for *P. gossypinus* (8.19 and 6.65, respectively).

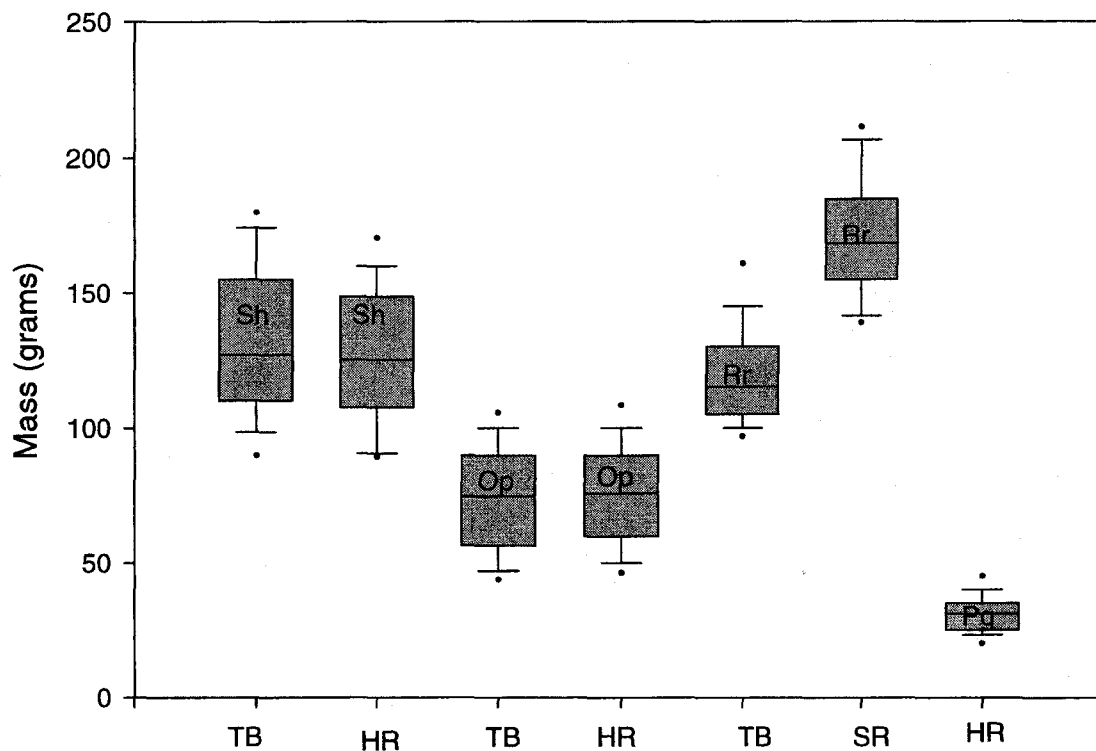


Figure 8: Comparison of body mass for adults of each species captured at each site. Sh = *Sigmodon hispidus*; Op = *Oryzomys palustris*; Rr = *Rattus rattus*; Pg = *Peromyscus gossypinus*; TB = Tarpon Bay; HR = Harney River; SR = Shark River. The ends of the boxes define the 25th and 75th percentiles, with a line at the median and error bars defining the 10th and 90th percentiles. The dot is an average of suspected outliers.

Table 7: Comparison of adult individuals of the same species captured at different sites. Only *Rattus rattus* captured at the Shark River Site is significantly heavier than *Rattus rattus* captured at the Tarpon Bay Site. All weights are in grams and measurement is in centimeters.

Species Captured and Site	Mass (Std Dev)	Head & Body (Std Dev)	Tail (Std Dev)	Sample Size (N)
<i>Sigmodon hispidus</i>				
Tarpon Bay (S2)	131.88 (28.26)	14.15 (1.59)	10.00 (1.20)	50
Harney River (S5)	126.81 (26.95)	13.20 (1.20)	9.75 (1.81)	88
<i>Oryzomys palustris</i>				
Tarpon Bay (S2)	73.54 (20.25)	11.20 (1.29)	13.89 (1.22)	65
Harney River (S5)	74.39 (18.49)	11.16 (1.22)	14.05 (0.97)	62
<i>Rattus rattus</i>				
Tarpon Bay (S2)	119.56 (19.43)	15.84 (1.20)	19.82 (1.36)	38
Shark River (S3)	172.36 (23.18)	17.51 (0.97)	20.40 (0.88)	22
<i>Peromyscus gossypinus</i>				
Harney River (S5)	31.96 (7.14)	8.19 (0.63)	6.65 (0.72)	46

Mean Lengths for Each Species

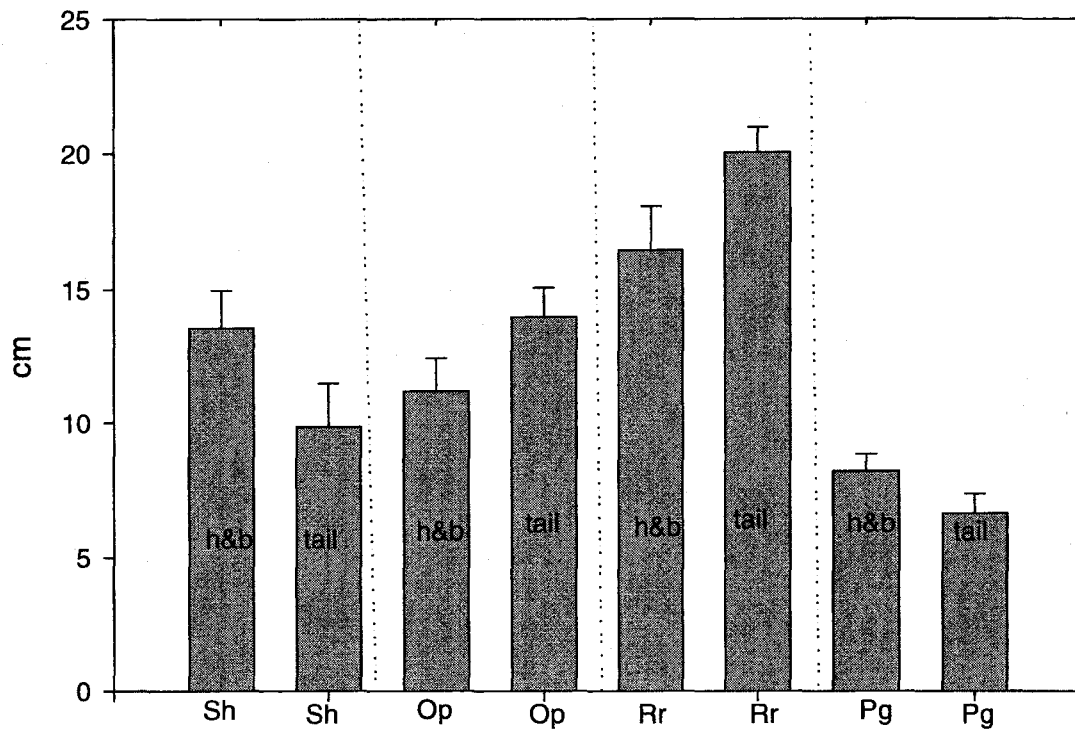


Figure 9: Comparison of head & body (h&b) and tail lengths (tail) for adults of each species captured. Sh = *Sigmodon hispidus*; Op = *Oryzomys palustris*; Rr = *Rattus rattus*; Pg = *Peromyscus gossypinus*. Error bars indicate standard deviation.

Population Structure

When I compared males, females and juveniles of *S. hispidus*; males were captured more frequently at both the Tarpon Bay and Harney River Sites (68% and 60%, respectively) (Figure 10 A & B). Juvenile *S. hispidus* were captured more frequently in the winter at both the Tarpon and Harney Sites. There was no significant association between site and population structure for *S. hispidus* ($X^2 = 1.145$, $df = 2$, $P = 0.564$).

Female *R. rattus* were captured more frequently at Tarpon Bay (62%), while males were captured more frequently at the Shark River Site (62%) (Figure 11 A & B). Capture rates were low for *R. rattus* at both sites, and the juveniles captured at Tarpon were negligible (Figure 11 A). Juveniles at the Shark River Site were captured from October 1998 to January 1999 and in October 1999. There was no significant association between site and population structure for *R. rattus* ($X^2 = 4.385$, $df = 2$, $P = 0.112$).

For *O. palustris*, more males than females were captured at both the Tarpon and Harney Sites (70% and 69%, respectively). Juvenile *O. palustris* were captured in the winter and spring at Tarpon (Figure 12 A), but overall very few juveniles were captured at the Harney River Site (Figure 12 B). There was no significant association between site and population structure for *O. palustris* ($X^2 = 3.204$, $df = 2$, $P = 0.201$). *Peromyscus gossypinus* had an almost 50:50 ratio between males and females, with juveniles being captured most often in the winter at the Harney River Site (Figure 13).

Reproductive Status

Reproductive male and female *S. hispidus* were captured almost year-round at both

Sigmodon hispidus

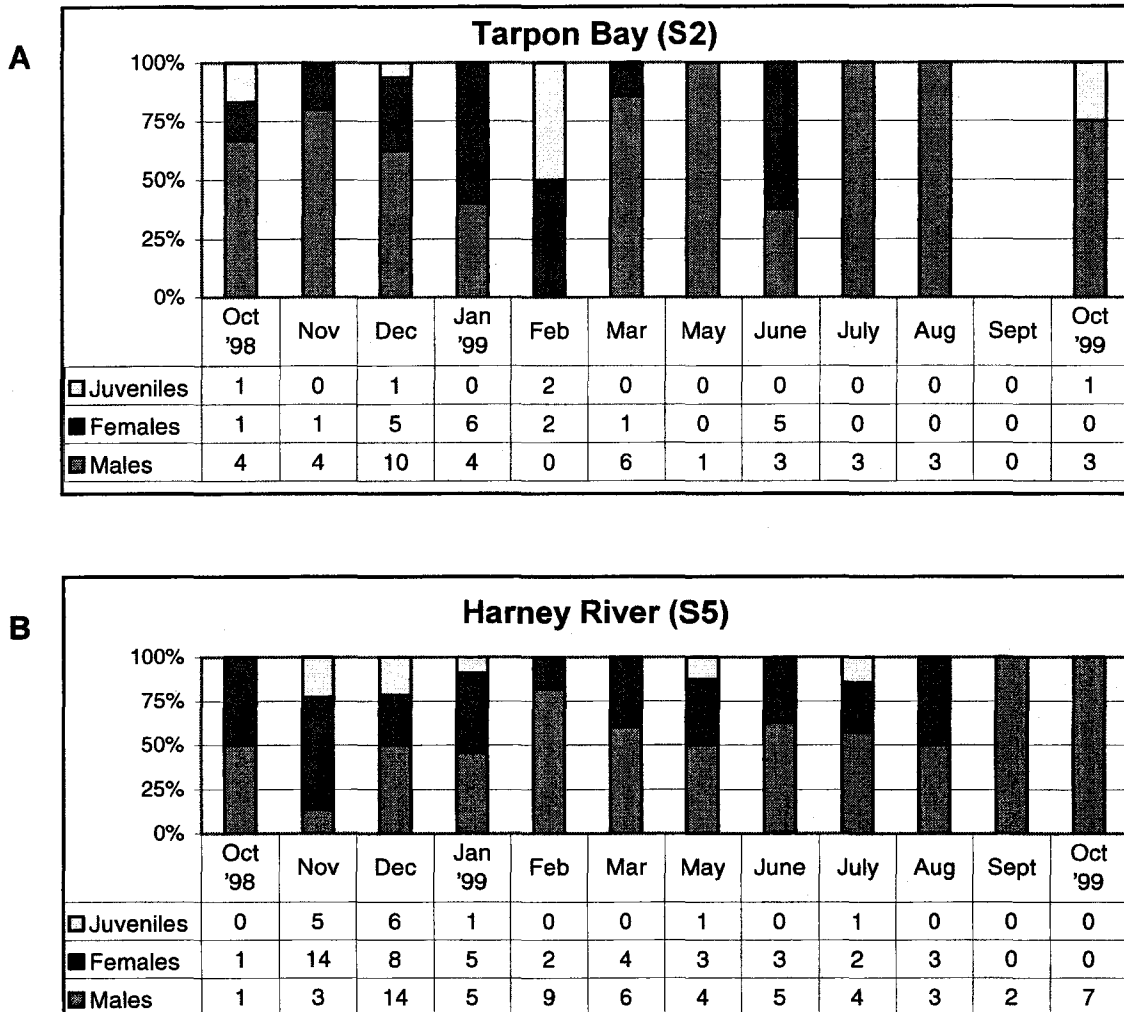


Figure 10: Population structure of *Sigmodon hispidus* at Tarpon Bay and Harney River Site. No animals were captured at the Tarpon Bay Site in September '99, most likely due to high water from Tropical Storm Harvey.

Rattus rattus

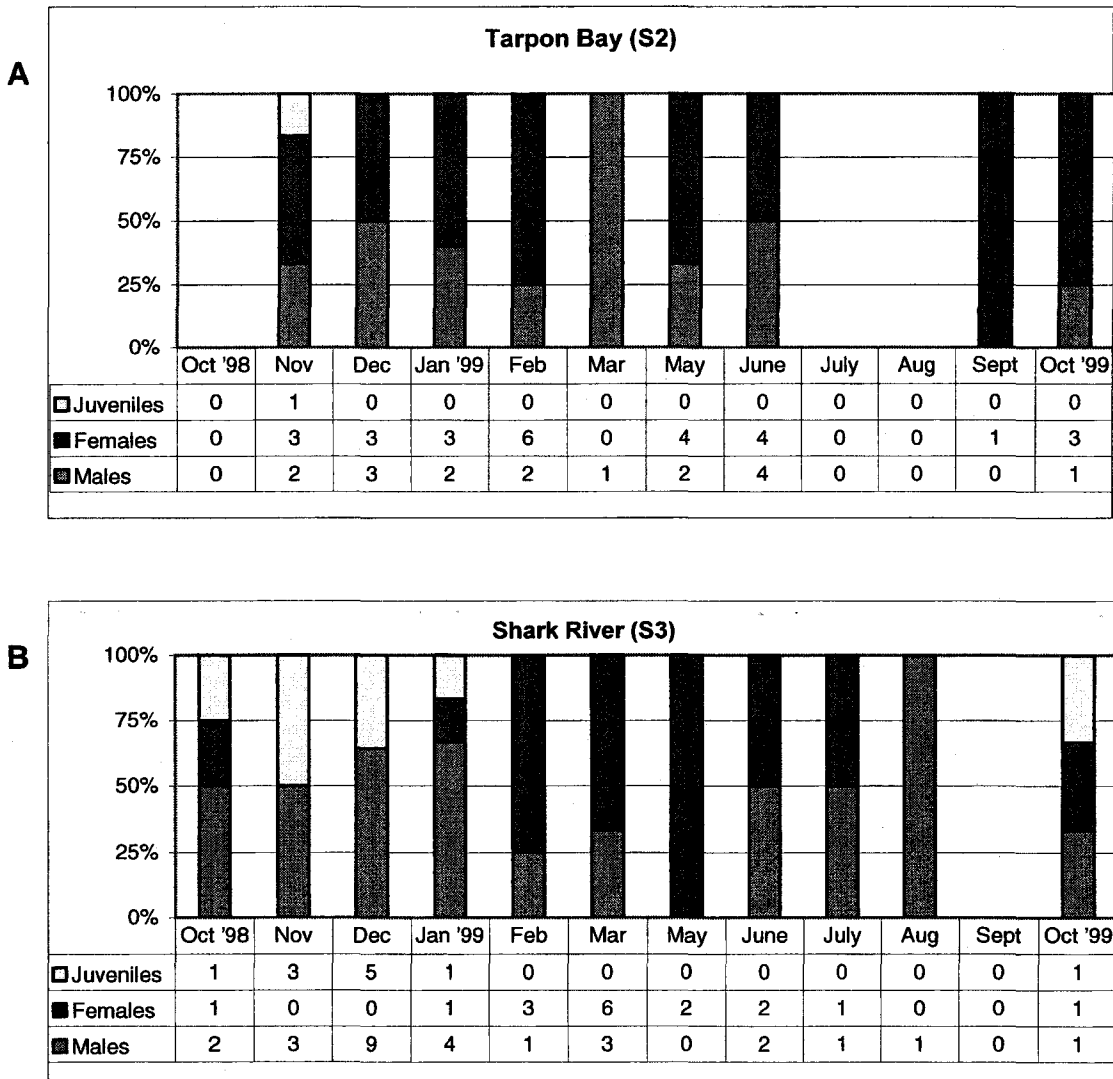


Figure 11: Population structure of *Rattus rattus* at the Tarpon Bay and Shark River Sites. Most juveniles at the Shark River were captured between October '98 and January '99. Not enough juveniles were captured at the Tarpon Bay Site to compare Tarpon juveniles with juveniles captured at the Shark River Site. No animals were captured at the Shark River Site in September '99, presumably due to high water from Tropical Storm Harvey.

Oryzomys palustris

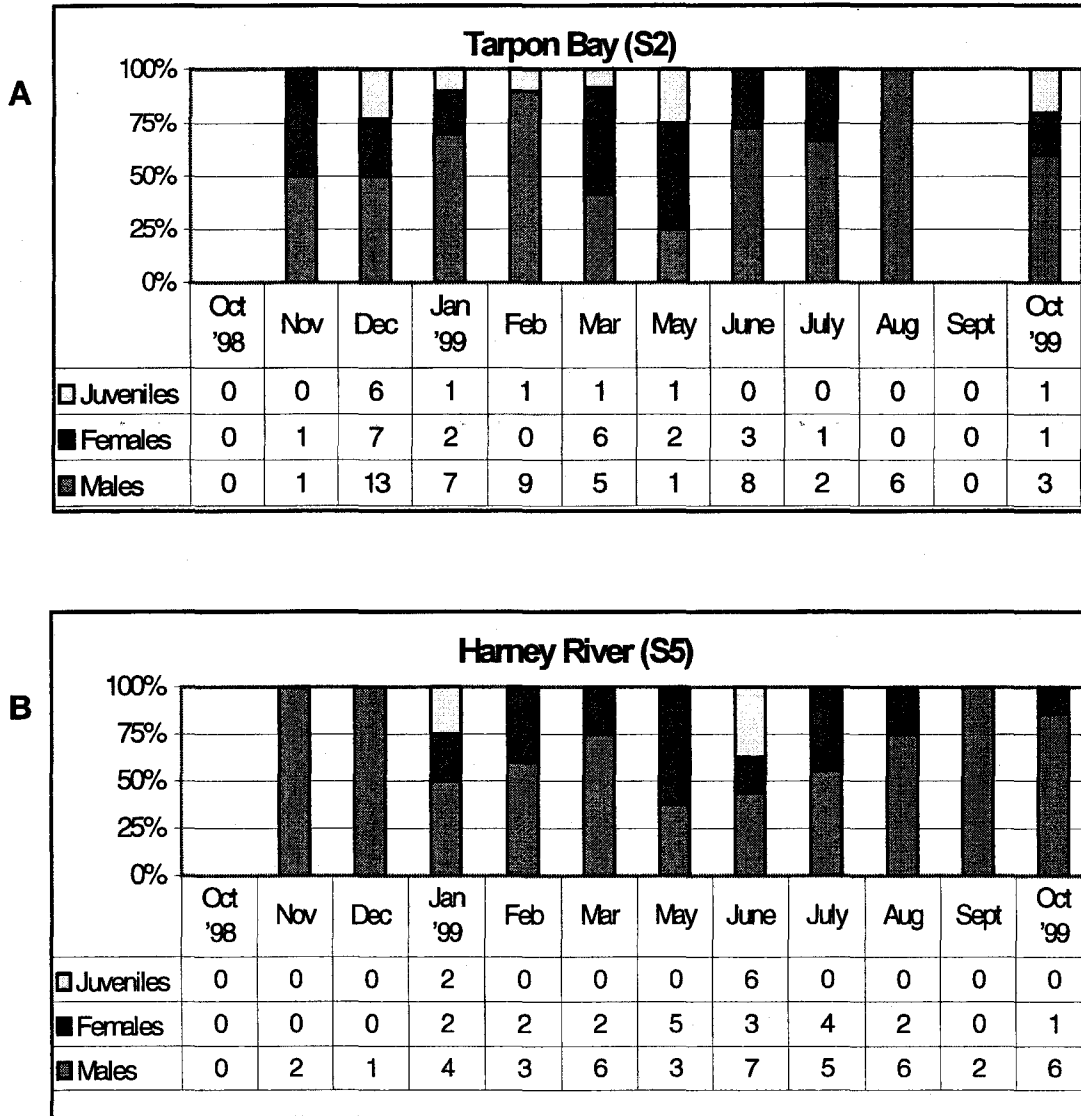


Figure 12: Population structure of *Oryzomys palustris* at Tarpon Bay and Harney River Sites. Overall, males were captured more frequently at both sites.

Peromyscus gossypinus

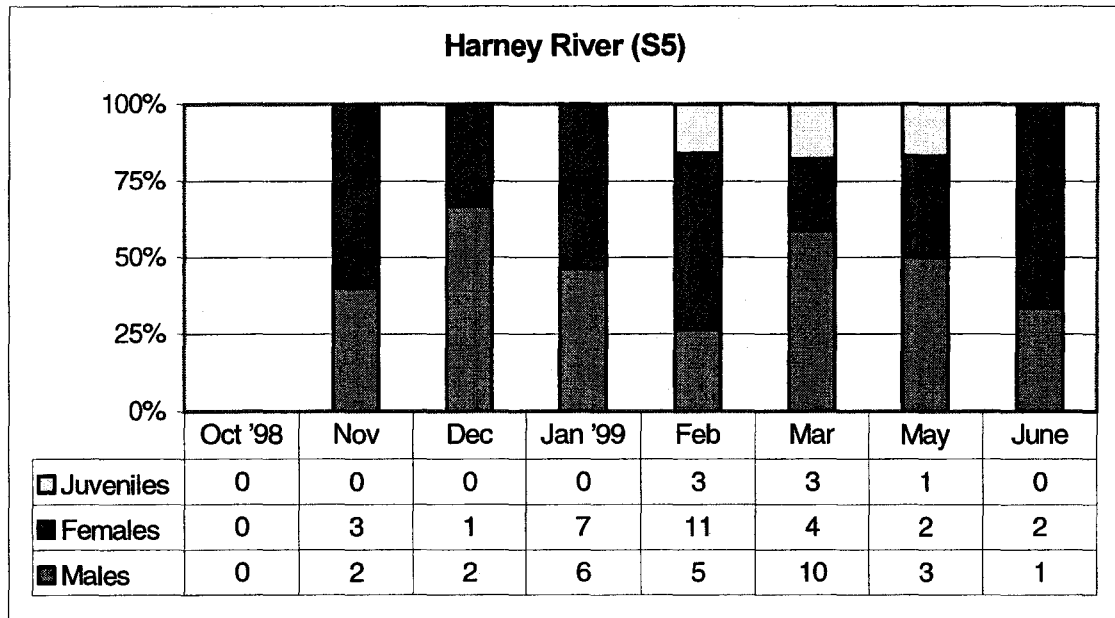


Figure 13: Population structure of *Peromyscus gossypinus* at the Harney River. This was the only site where *P. gossypinus* was captured. No animals were captured in Oct '98 or July '99 to Oct '99; this was possibly due to higher water levels that occurred in the rainy season.

the Tarpon and Harney Sites (Figure 14 A & B). There was a significant association between site and reproductive status for *S. hispidus* ($X^2 = 6.994$, $df = 1$, $P = 0.008$).

Reproductive male and female *R. rattus* were captured at the Tarpon and Harney Sites in almost every month that I trapped (Figure 15 A & B). There was a significant association between site and reproductive status for *R. rattus* ($X^2 = 6.994$, $df = 1$, $P = 0.008$).

Reproductive male and female *O. palustris* were captured from May to August 1999 at Tarpon, and from November 1998 to June 1999 at the Harney River Site (Figure 16 A & B). There was a significant association between site and reproductive status for *O. palustris* ($X^2 = 12.185$, $df = 1$, $P = <0.001$). Reproductive male and female *P. gossypinus* were captured primarily in the winter at the Harney (Figure 17).

Melanistic Sigmodon hispidus

On 24 September 1999 at approximately 1100 h, I captured a melanistic *Sigmodon hispidus* in the mangroves at the Harney River Site. The male was in reproductive phase and good physical condition. The melanistic male weighed 185 g, had a head and body length of 13.5 cm, and its tail was 11.0 cm long. The voucher specimen will be deposited at the South Florida Natural Resources Museum within Everglades National Park. To my knowledge this is the only record of a melanistic *Sigmodon hispidus* from Florida and possibly elsewhere in the United States.

Sigmodon hispidus

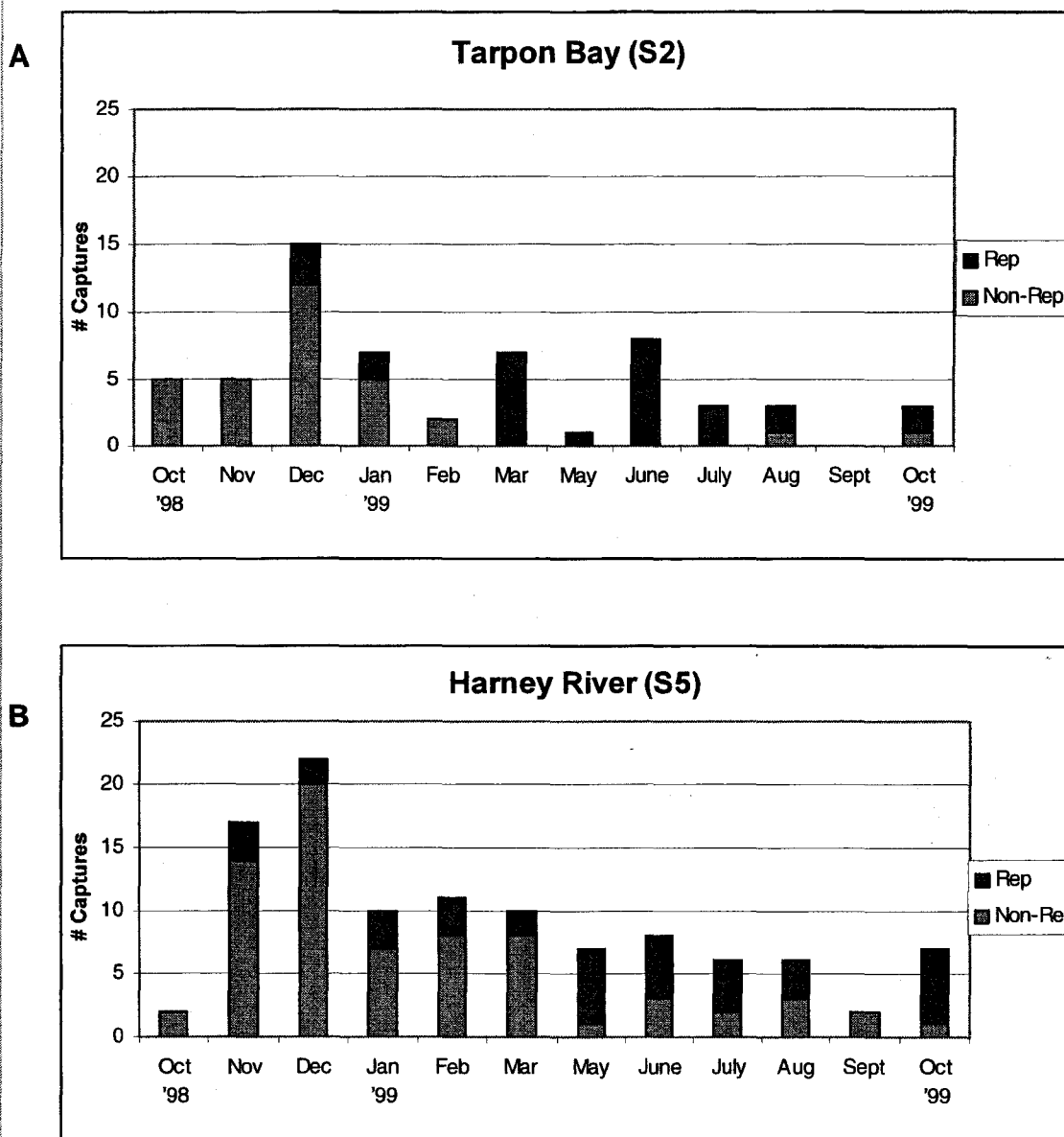


Figure 14: Comparison of reproductive vs. non-reproductive adult *Sigmodon hispidus* captured at two independent locations during the same time frame.

Rattus rattus

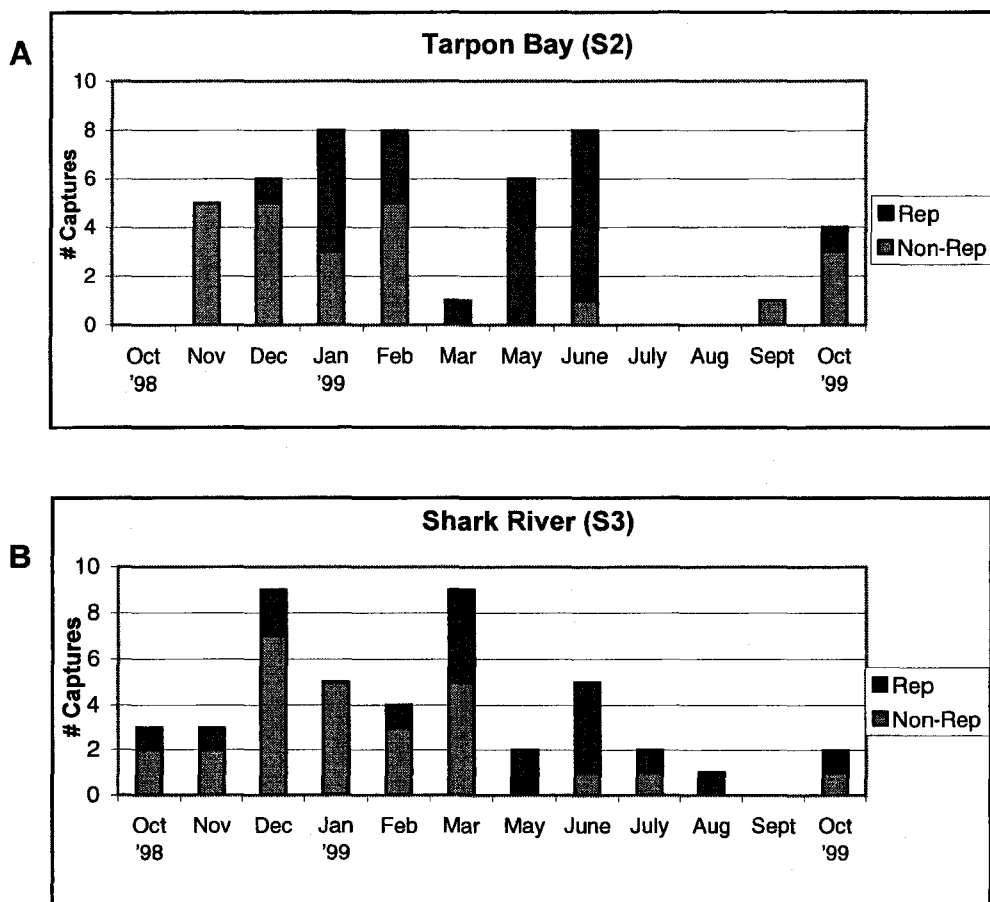


Figure 15: Comparison of reproductive vs. non-reproductive adult *Rattus rattus* captured at two independent locations during the same time frame.

Oryzomys palustris

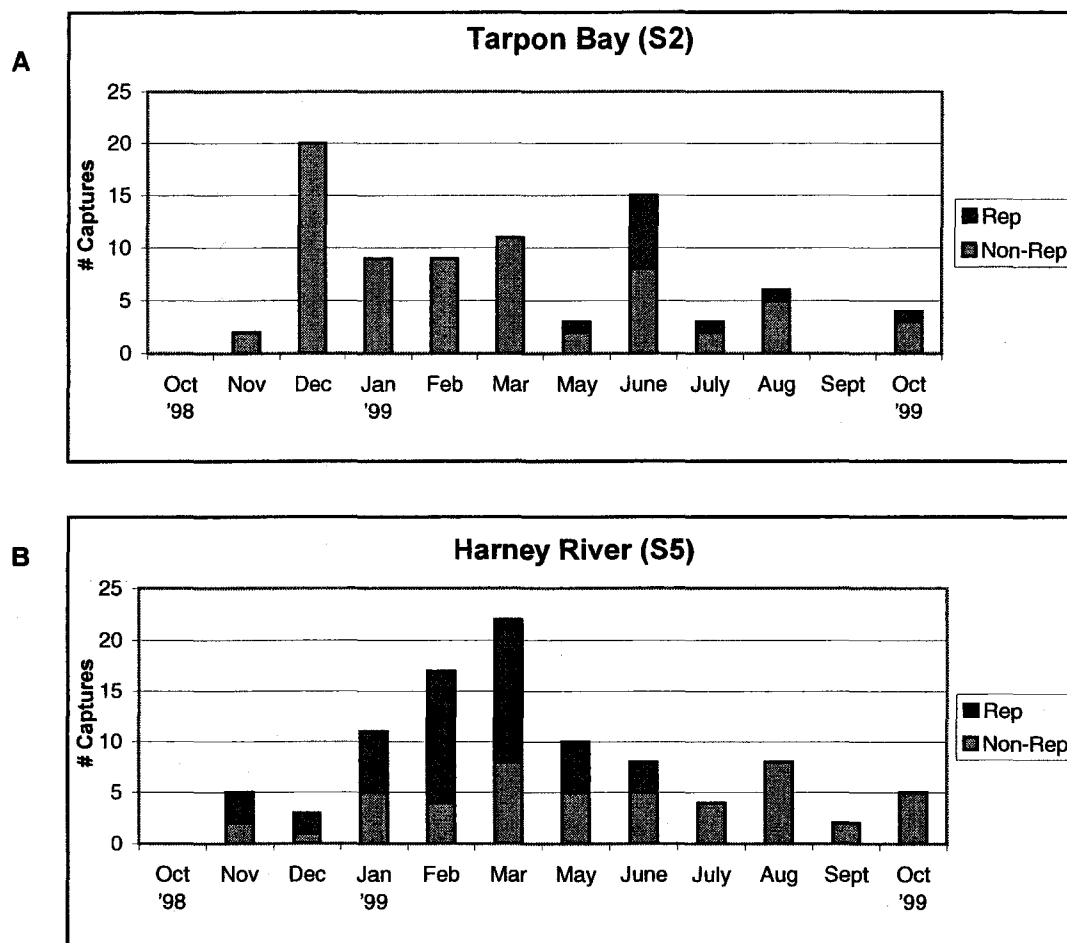


Figure 16: Comparison of reproductive vs. non-reproductive adult *Oryzomys palustris* captured at two independent locations during the same time frame.

Peromyscus gossypinus

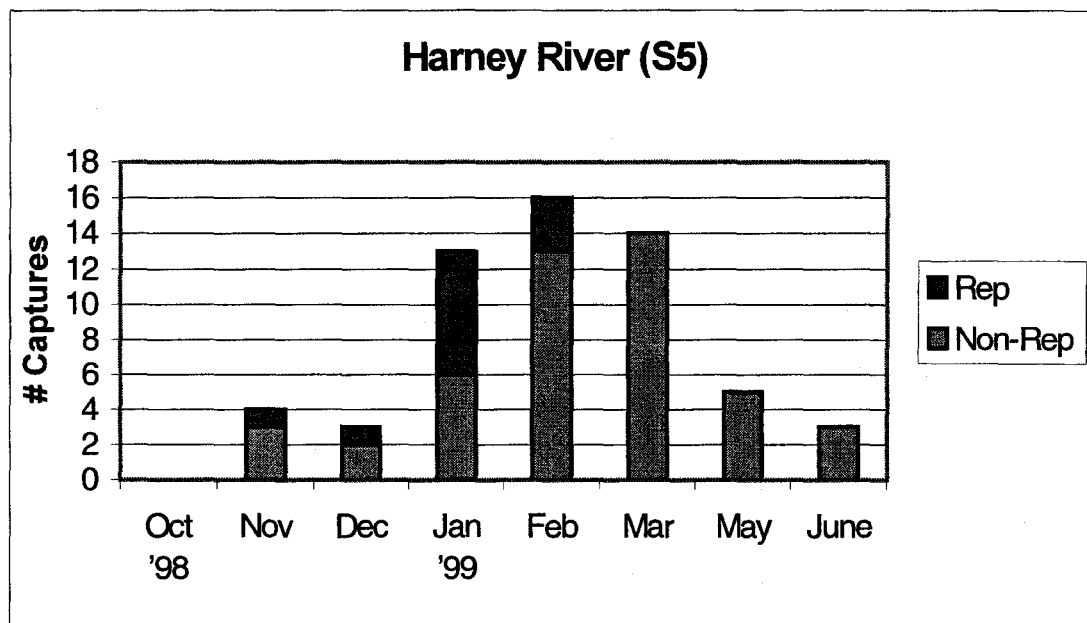


Figure 17: Reproductive vs. non-reproductive *Peromyscus gossypinus* captured at the Harney River Site (S5). *Peromyscus gossypinus* was not captured in October '98 or between July '99 and October '99. This was the only site where *P. gossypinus* was captured.

Capture Frequencies Compared to Water Depth and Salinity

At Tarpon Bay, *S. hispidus* and *O. palustris* were frequently captured when water depths and salinity were low (Figure 18 A & B), however *O. palustris* was also captured when water depths were high (Figure 18 A). At the Harney River Site, *S. hispidus* and *P. gossypinus* were frequently captured at low water depths and salinities, while *O. palustris* was often captured at high water depths with low salinities (Figure 19 A & B). Daily water depths at the Shark River Site are controlled almost entirely by tidal fluctuations. For this reason, daily and monthly average water depths at this site remain fairly constant. Although the monthly capture success of *R. rattus* was consistently low, partial hydrologic data show that it was especially low during a period of high salinity (Figure 20 A & B).

I used a Spearman Rank Correlation to compare species richness, abundance, water depth and salinity for each site (Table 8). Results showed significant and non-significant correlations, however only significant results will be illustrated and discussed. At the Tarpon Bay Site, the abundance of *O. palustris* was positively correlated with the abundance of *S. hispidus* ($R = 0.664$, $P \text{ value} = 0.017$) (Figure 21 A). This positive correlation suggests that *O. palustris* and *S. hispidus* were frequently captured during the same time period. *Sigmodon hispidus* abundance was negatively correlated with water depth ($R = -0.731$, $P \text{ value} = 0.005$) (Figure 21 B). As water depths increased at Tarpon Bay the capture frequency of *S. hispidus* decreased.

Tarpon Bay (S2)

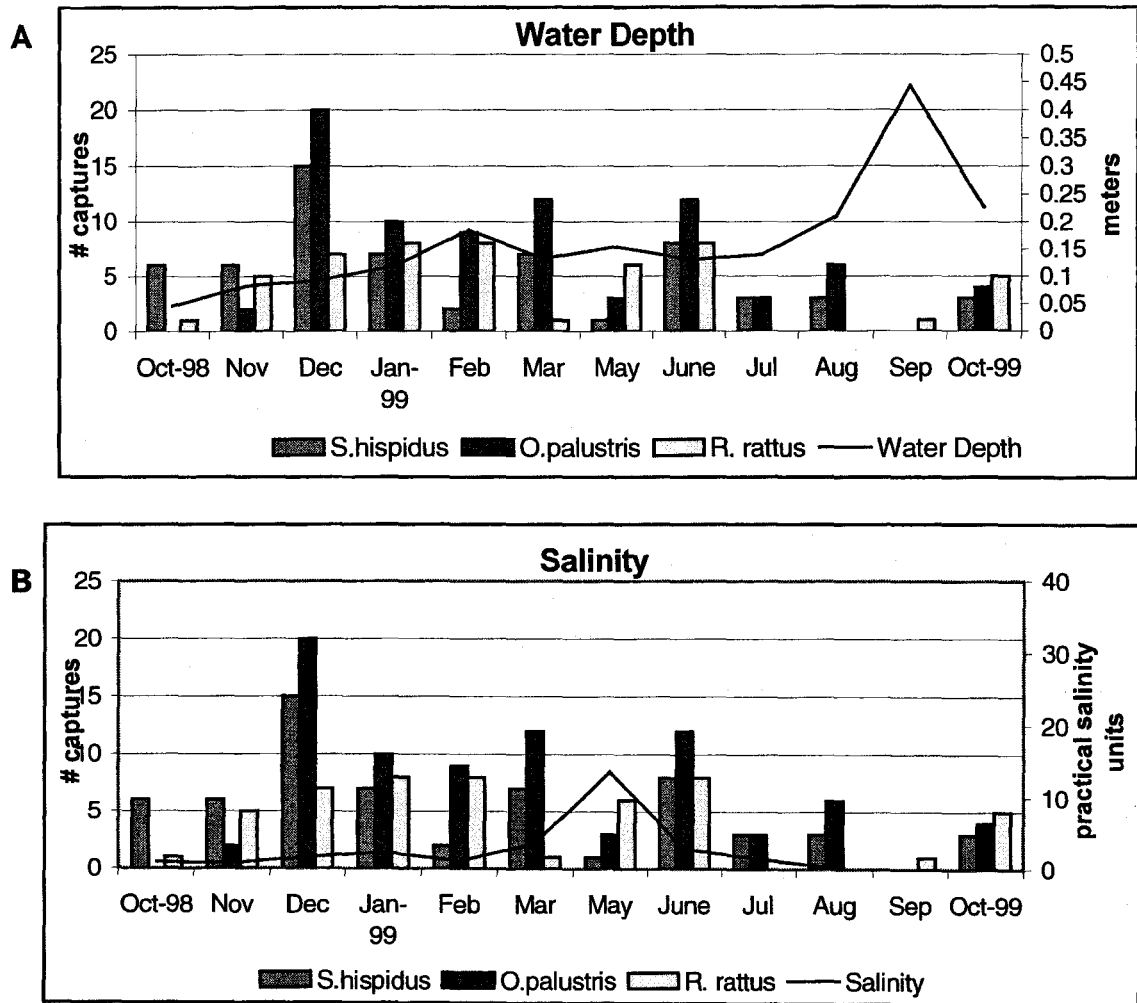


Figure 18: Average water depth and salinity at Tarpon Bay (S2) compared to number of captures during that trapping event. This site is partially influenced by tidal fluctuations, but most of the changes in water level and salinity are due to changes in precipitation.

Harney River (S5)

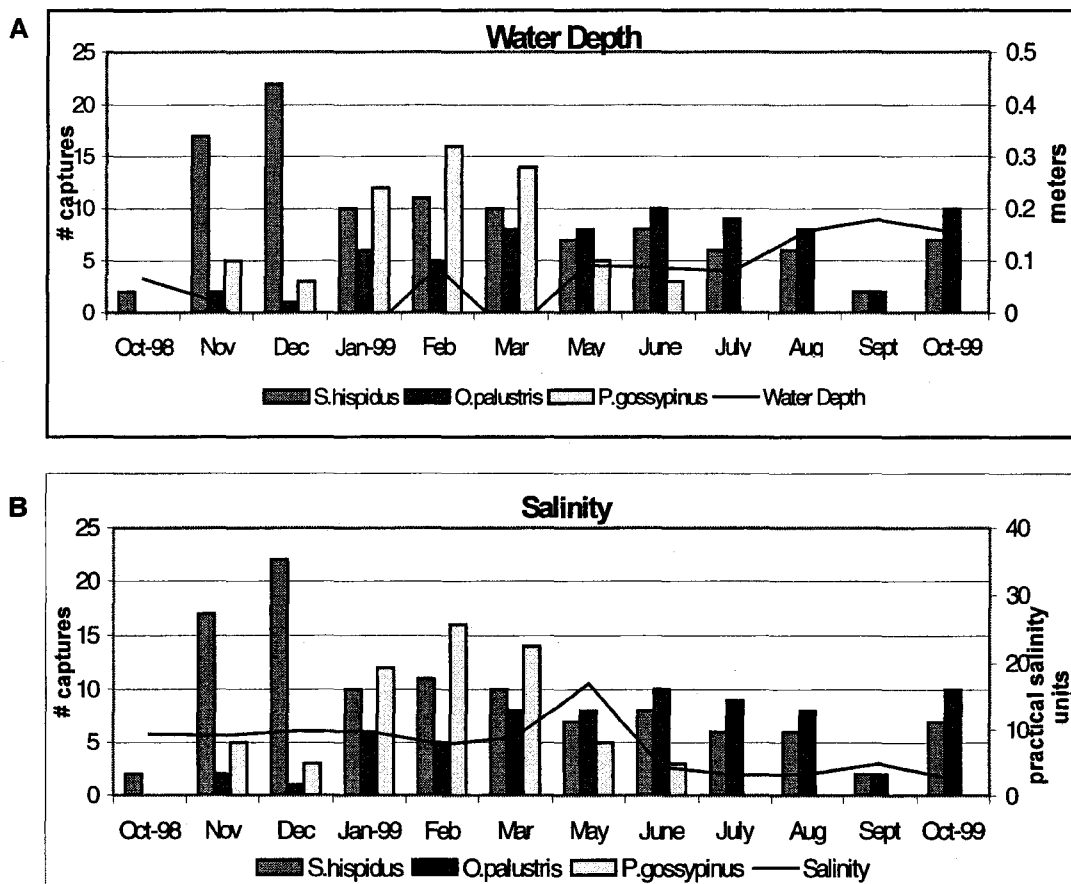


Figure 19: Average water depth and salinity at the Harney River (S5) compared to number of captures during that trapping event. This site is partially influenced by tidal fluctuations, but most changes in water level and salinity are due to changes in precipitation.

Shark River (S3)

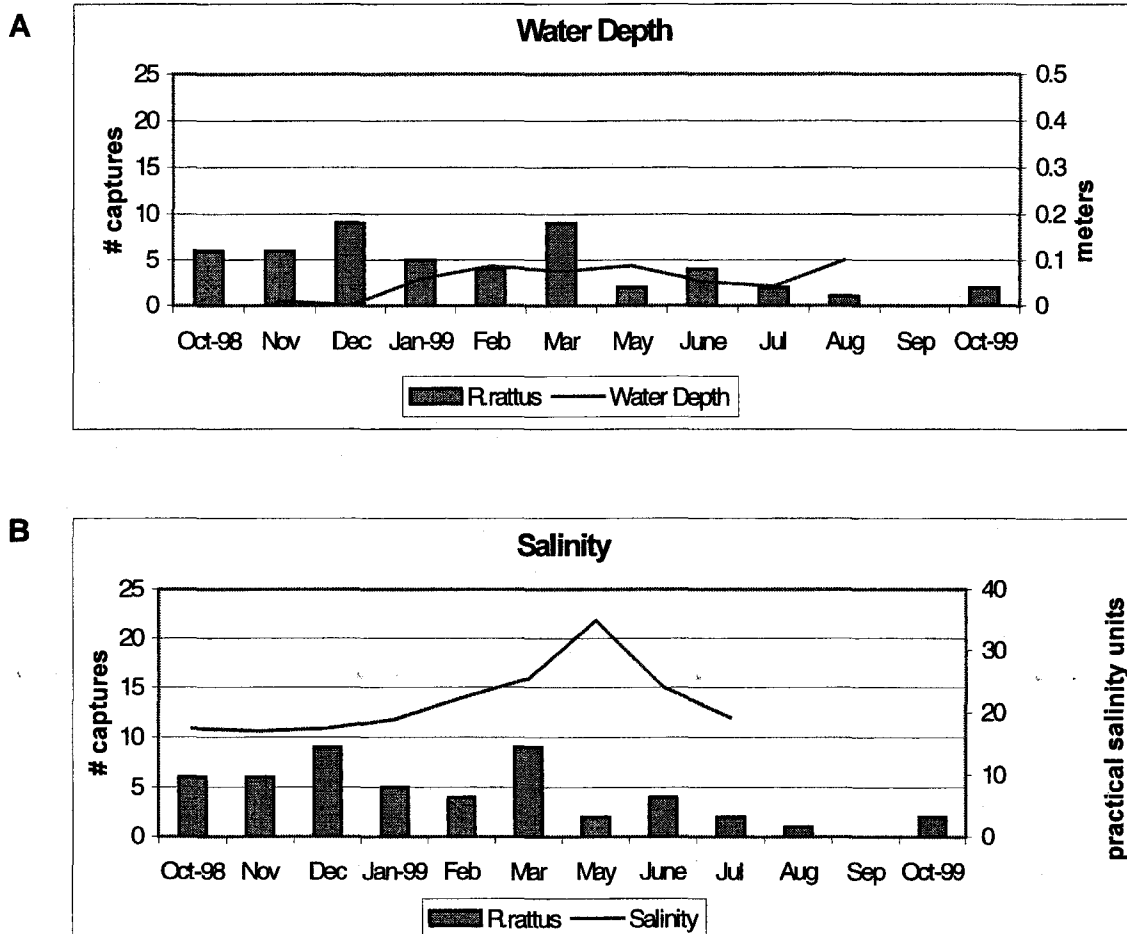


Figure 20: Average water depth and salinity at Shark River (S3) compared to number of captures during that trapping event. Since this site has daily tidal fluctuations, salinity and water depth are positively related. In September, 1999 Tropical Storm Harvey produced very high water levels that shut down the hydrology station and most likely contributed to the lack of rodent captures.

Correlation Matrices

A. Tarpon Bay (S2)

	<i>O. palustris</i>	<i>R. rattus</i>	Salinity	Water Depth
<i>S. hispidus</i>	0.664 0.0169 12	0.315 0.306 12	0.244 0.450 11	-0.731 0.00540 12
<i>O. palustris</i>		0.496 0.0944 12	0.420 0.188 11	-0.130 0.667 12
<i>R. rattus</i>			0.407 0.199 11	-0.228 0.456 12
Salinity				-0.191 0.557 11

B. Harney River (S5)

	<i>O. palustris</i>	<i>P. gossypinus</i>	Salinity	Water Depth
<i>S. hispidus</i>	-0.128 0.683 12	0.746 0.00398 12	0.494 0.116 11	-0.670 0.0154 12
<i>O. palustris</i>		-0.0846 0.783 12	-0.769 0.00368 11	0.399 0.189 12
<i>P. gossypinus</i>			0.492 0.116 11	-0.531 0.0705 12
Salinity				-0.835 0.000 11

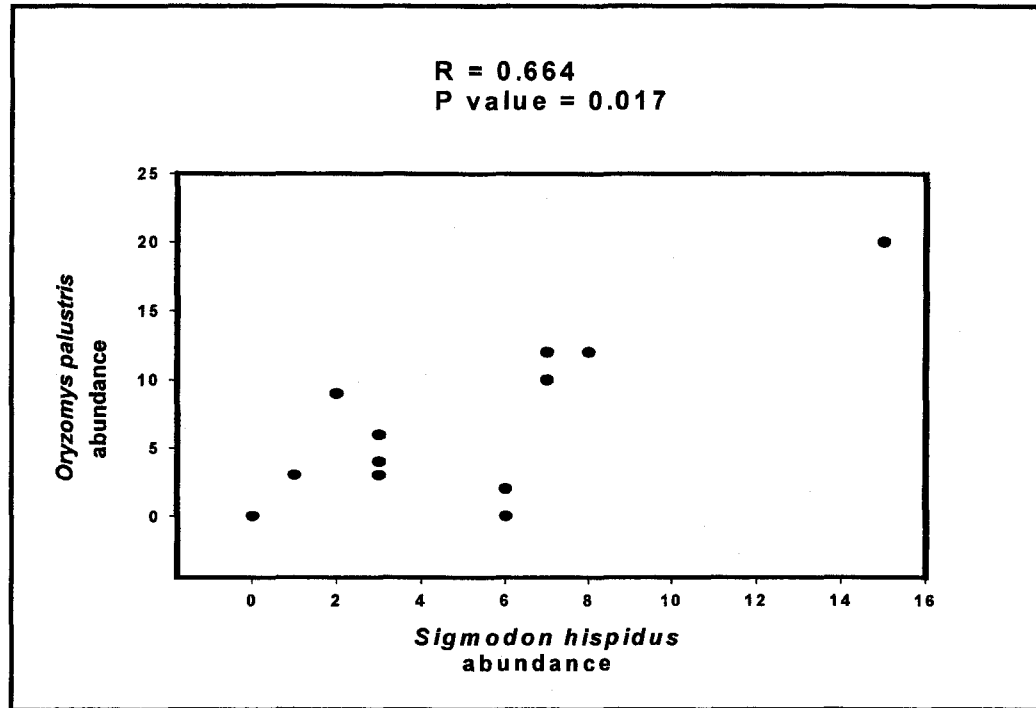
C. Shark River (S3)

	Salinity	Water Depth
<i>R. rattus</i>	-0.595 0.0599 10	-0.684 0.0186 11
Salinity		0.817 0.00393 9

Table 8: Spearman Rank Correlations for species abundance, salinity and water depth at each site. Significant correlations and P-values are shown in bold. The third number is the number of samples.

Tarpon Bay (S2)

A



B

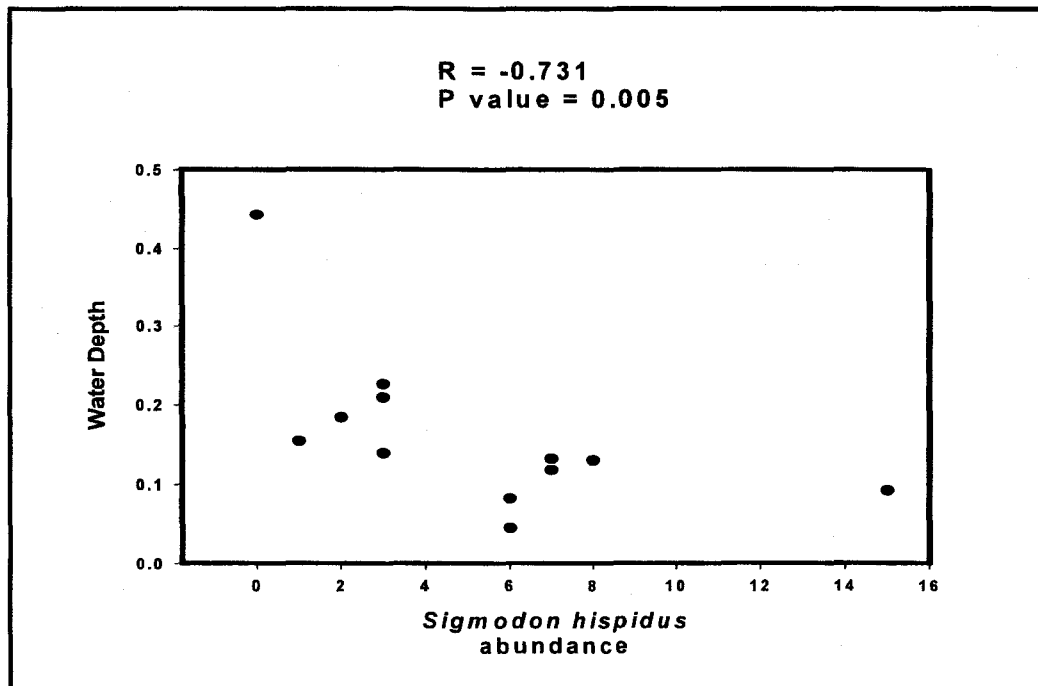


Figure 21: Spearman Rank Correlation between species, salinity and water depth. There is a positive correlation between the captures of *O. palustris* and *S. hispidus*. There is a negative correlation between *S. hispidus* and water depth.

At the Harney River Site, the abundance of *S. hispidus* was positively correlated with the abundance of *P. gossypinus* ($R = 0.746$, $P \text{ value} = 0.004$) (Figure 22 A). The abundance of *S. hispidus* was negatively correlated with water depth ($R = -0.670$, $P \text{ value} = 0.015$) (Figure 22 B), while the abundance of *O. palustris* was negatively correlated with salinity ($R = -0.769$, $P \text{ value} = .004$) (Figure 22 C). Salinity was negatively correlated with water depth at the Harney River Site ($R = -0.835$, $P \text{ value} = 0.000$) (Figure 22 D).

At the Shark River Site, the abundance of *R. rattus* was negatively correlated with water depth ($R = -0.684$, $P \text{ value} = 0.018$) (Figure 23 A). Salinity was positively correlated with water depth ($R = 0.817$, $P \text{ value} = 0.003$) (Figure 23 B). It should also be noted that the abundance of *R. rattus* was negatively correlated with salinity at the Shark River Site ($R = -0.595$, $P \text{ value} = 0.0599$).

Macrohabitat Distribution and Overlap

Sigmodon hispidus was captured most frequently in the mangroves at the Tarpon Bay Site (Figure 24 A), but at the Harney River Site (Figure 24 B) it was captured most frequently in the ecotone (51% and 70%, respectively) (Figure 24 B). *Oryzomys palustris* had an almost identical and equal capture rate between macrohabitats and sites (approximately 30% for each macrohabitat type at each site) (Figure 24 A & B). *Rattus rattus* was captured most often in the mangroves at the Tarpon Bay Site (66%) (Figure 24 A) and in the mangroves at the Shark River Site. *Peromyscus gossypinus* was also captured most often in the mangroves at the Harney River Site (57%) (Figure 24 B).

Harney River (S5)

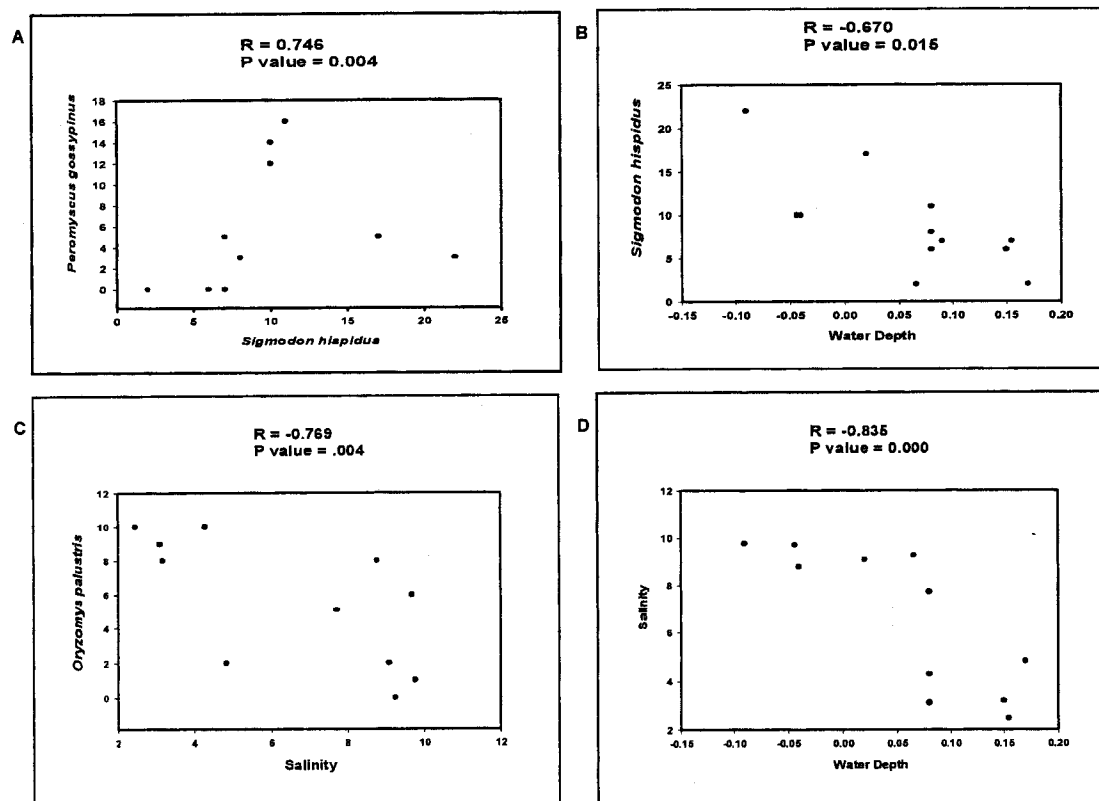


Figure 22: Spearman Rank Correlations between species, salinity and water depth. There is a positive correlation between *S. hispidus* and *P. gossypinus*. There is a negative correlation between *S. hispidus* and water depth. *O. palustris* has a negative correlation with salinity. There is also a negative correlation between salinity and water depth.

Shark River (S3)

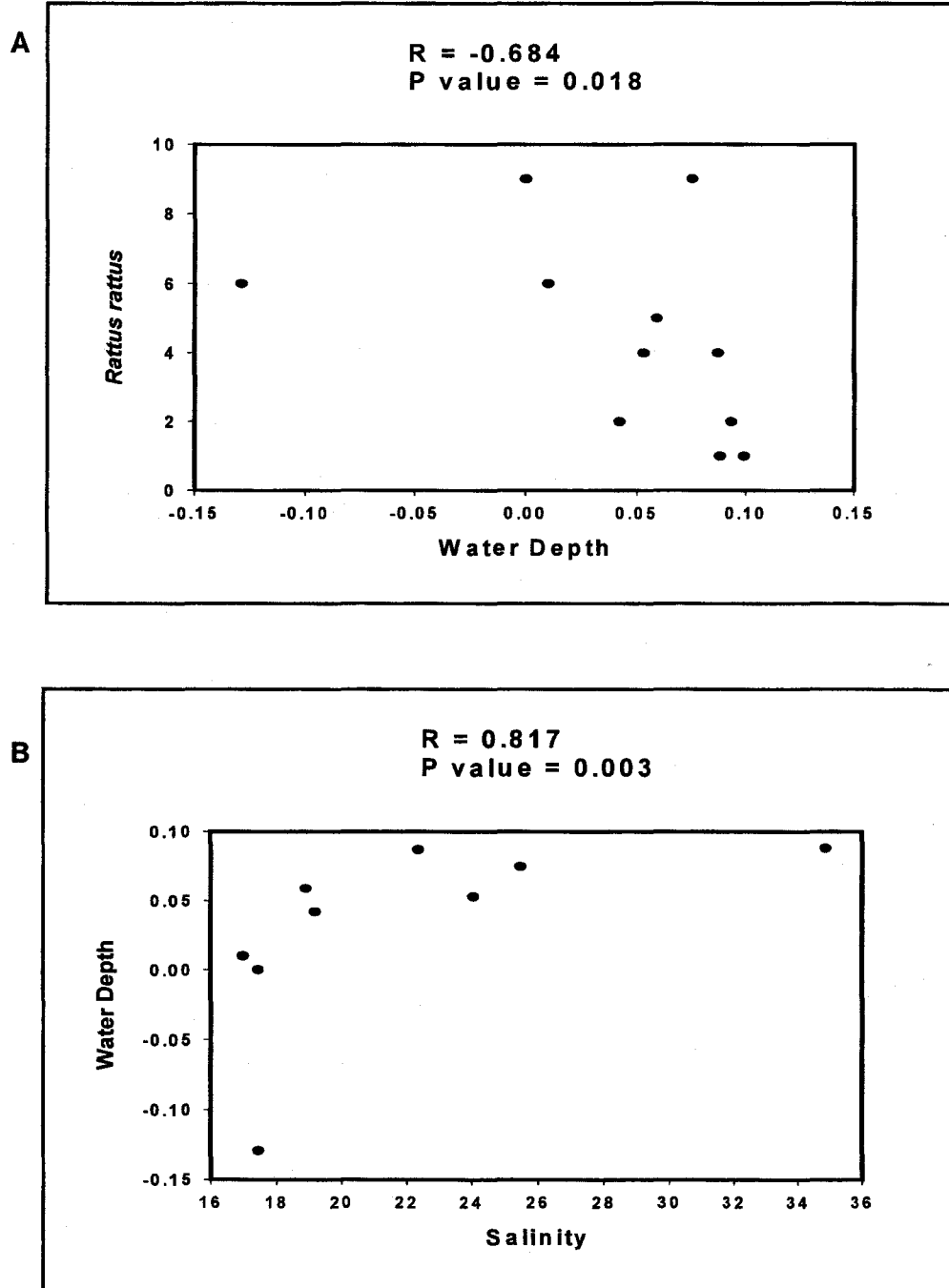
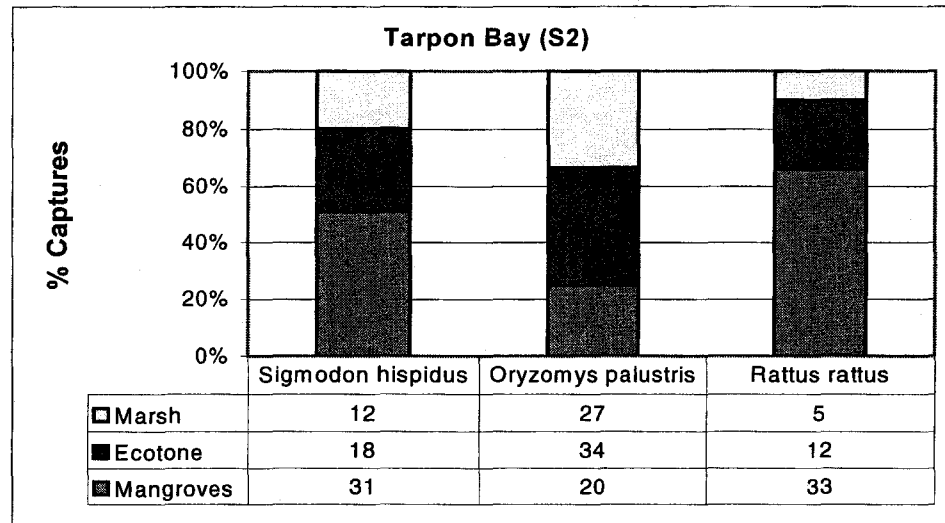


Figure 23: Spearman Rank Correlation between species, salinity and water depth. A negative correlation exists between *R. rattus* and water depth. There is a strong positive correlation between salinity and water depth due to tidal fluctuations at the mouth of the Shark River.

Macrohabitat Summaries

A



B

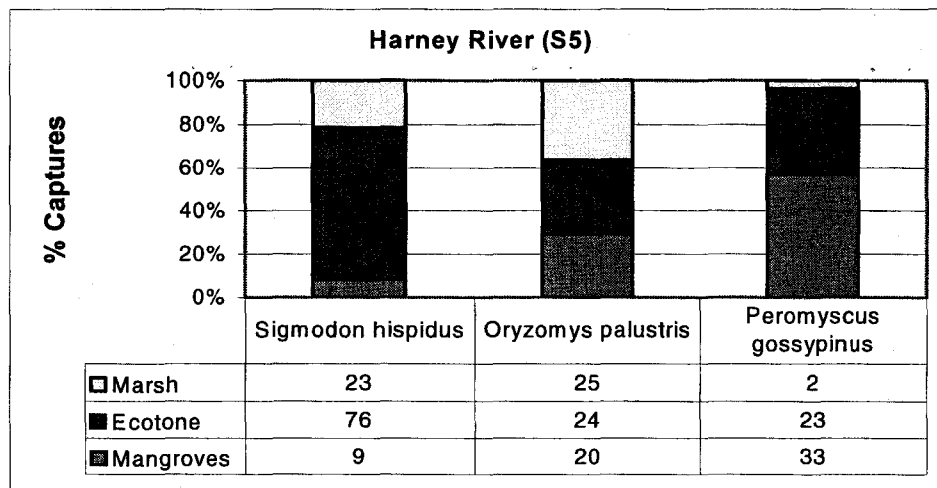


Figure 24: Number of captures for each site, species and macrohabitat type. Only *Rattus rattus* was captured at the Shark River Site (S3), so this figure is not shown.

Macrohabitat overlap is high (>60%) between all species in all habitat types at the Tarpon Bay and Harney River Sites (Table 9 A&B). At the Tarpon Bay Site (Table 9 A), overlap is highest between *S. hispidus* and *R. rattus*. At the Harney River Site (Table 9 B), overlap is highest between *S. hispidus* and *O. palustris*. Only one species (*R. rattus*) was captured in one macrohabitat type (mangroves) at the Shark River Site.

A. Tarpon Bay	Overlap
<i>S. hispidus</i> x <i>O. palustris</i>	86.7%
<i>S. hispidus</i> x <i>R. rattus</i>	96.7%
<i>O. palustris</i> x <i>R. rattus</i>	71.4%
B. Harney River	Overlap
<i>S. hispidus</i> x <i>O. palustris</i>	80.6%
<i>S. hispidus</i> x <i>P. gossypinus</i>	64.8%
<i>O. palustris</i> x <i>P. gossypinus</i>	78.2%

Table 9: The proportion of macrohabitat overlap between each species at the Tarpon and Harney Sites.

Microhabitat Variables and Principal Components Analysis

In order to describe the microhabitat configuration for each rodent species captured, Principal Components Analysis first ordinated the data which were subsequently analyzed using regression analyses. Principal Components Analysis made a few uncorrelated linear combinations of the original microhabitat (structural) variables. These linear composites or Principle Components captured most of the information in the original structural variables.

All 27 trap stations (three sites), with 16 structural variables per trap station were ordinated in a Principal Components Analysis. Only factor loadings with values greater than 0.3 and station scores greater than 2.0 within the first 4 axes were interpreted (Table 10). Table 11 shows the first 10 axes extracted with their associated variance explained. The first four axes accounted for 78.1% of the total variance of the 16 original variables.

The first axis or principal component is interpreted as a contrast between canopy, mid-canopy and herb (Figure 25 A). The second axis has a positive association with shrub, litter and higher elevation (Figure 25 B). Axis three contrasts shrub with canopy, litter and elevation (Figure 25 C). The fourth axis contrasts mid-canopy, vines and litter with shrub (Figure 25 D).

The 27 trap stations were ordinated against axes one and two in microhabitat space (Figure 26). Most of the marsh macrohabitat stations clustered in the herbaceous space. The Shark Sites were composed of mangrove macrohabitat and clustered within the canopy and mid-canopy space (Figure 26). The ecotonal stations fell between axes one and two (Figure 26) and therefore seemed to share characteristics indicative of both axes.

Microhabitat Configuration

The relationship between each species captured and each of the four axes retained was examined with Step-wise Regression. In order to attain normality and a constant variance, the number of animals captured was first $\log_{10}(n + 1)$ transformed. For an axis to be considered important to species distribution it had to increase the F-value by 4.00 and

Table 10: Factor loadings and scores for all 27 stations at three sites. Variable scores greater than 0.3 and station scores greater than 2.0 for the first 4 axes were interpreted.

Principal Components Analysis

Factor Loadings Variable	Eigenvector					
	1	2	3	4	5	6
COVCAN	-.2209	.1043	.4317	.1295	.3477	.2654
COVMID	-.2350	-.0750	-.1751	-.5175	.1431	-.3561
COVSHB	-.0212	.4173	-.3024	.0249	.0274	.1018
COVHRB	.3641	-.1501	-.0157	.0283	.1117	.0600
COVLIT	.0188	.4428	.3343	-.0709	.1175	-.1071
LOGS	-.2084	.0342	-.0366	.2255	-.7446	.1536
ELEV	-.0786	.4347	.3184	-.1527	-.1412	-.1429
CANHGT	-.3865	-.0169	.0572	.0281	.1967	.1887
CANSIZE	-.3778	.0131	.0609	.0471	.2103	.2285
MIDHGT	-.3540	-.1137	-.2506	-.1968	.0922	-.0217
MIDSIZE	-.3250	-.1684	-.2500	-.1318	-.0295	.1149
SHRBHGT	.0441	.3964	-.4217	.1435	.1233	.0569
SHRBSIZE	.0104	.3027	-.3986	.3156	.2088	-.0095
HERBHGT	.3696	-.0556	-.0685	-.1883	.2165	-.0400
VINES	.2262	.0042	-.0527	-.3682	-.0177	.7914
LITTER	.0131	.3270	-.0174	-.5334	-.2425	.0253

Scores of Stations	Axis (Component)					
	1	2	3	4	5	6
1 STA 1-T	1.3528	-.3246	-2.2263	-.7492	.8282	-.6700
2 STA 2-T	2.2101	-.1159	-1.8513	-.2794	.6252	.1428
3 STA 3-T	1.5956	1.5949	-1.5016	-2.0734	-.1355	-.4849
4 STA 4-T	2.8787	-.2515	-.7385	-.8582	-.4237	.6251
5 STA 5-T	1.8640	-.8969	-.8852	-.2216	.2460	-1.0563
6 STA 6-T	3.1410	-2.6010	-.1906	-.6057	-.0045	1.2159
7 STA 7-T	3.7940	-2.3451	.0226	-.9918	.0424	2.4558
8 STA 8-T	1.1388	2.3953	.5777	1.5669	1.3107	.3760
9 STA 9-T	.1238	.5833	4.1080	1.1840	1.3633	.5834
10 STA 1-S	-2.2071	-1.4854	1.1465	.8029	.2553	.3760
11 STA 2-S	-3.0855	-1.6529	.7746	-.0992	.6644	.0584
12 STA 3-S	-3.0831	-1.9062	.1427	.0300	-.4351	-.0063
13 STA 4-S	-3.3457	-1.5965	.5175	-.7026	.6585	-.4059
14 STA 5-S	-.3001	-1.7099	.1609	1.7541	-4.1407	-.2519
15 STA 6-S	-3.0805	.4160	-2.6953	1.1091	.4954	.8042
16 STA 7-S	-3.2660	.5831	-2.5582	2.3011	.4322	.8017
17 STA 8-S	-3.3739	-2.1588	.1107	-.8444	.8445	-.6011
18 STA 9-S	-3.4002	-.9803	.1710	-1.8094	-.4325	-.2859
19 STA 1-H	3.0874	-1.1822	1.3531	.7301	-.1513	-1.1053
20 STA 2-H	3.1249	-1.3893	1.2014	.8029	-.0840	-1.0373
21 STA 3-H	2.7477	1.0044	-1.1242	2.1608	.5968	-.8416
22 STA 4-H	1.1008	-.0525	.1321	-.0508	.1277	-1.7112
23 STA 5-H	-.5520	3.1855	.7642	-2.0109	-.4593	-.3592

Table 11: First 10 axes of vegetative structure variables. Only the first four axes (78.1% of the total variance) were retained for comparison with species distribution and abundance.

VARIANCE EXTRACTED, FIRST 10 AXES

AXIS	Eigenvalue	% of Variance	Cum.% of Var.	Broken-stick Eigenvalue
1	5.866	36.665	36.665	3.381
2	3.270	20.436	57.101	2.381
3	2.005	12.530	69.631	1.881
4	1.357	8.478	78.109	1.547
5	1.068	6.674	84.783	1.297
6	0.732	4.574	89.357	1.097
7	0.478	2.988	92.345	0.931
8	0.416	2.599	94.944	0.788
9	0.249	1.554	96.498	0.663
10	0.213	1.328	97.826	0.552

FIRST FOUR AXES

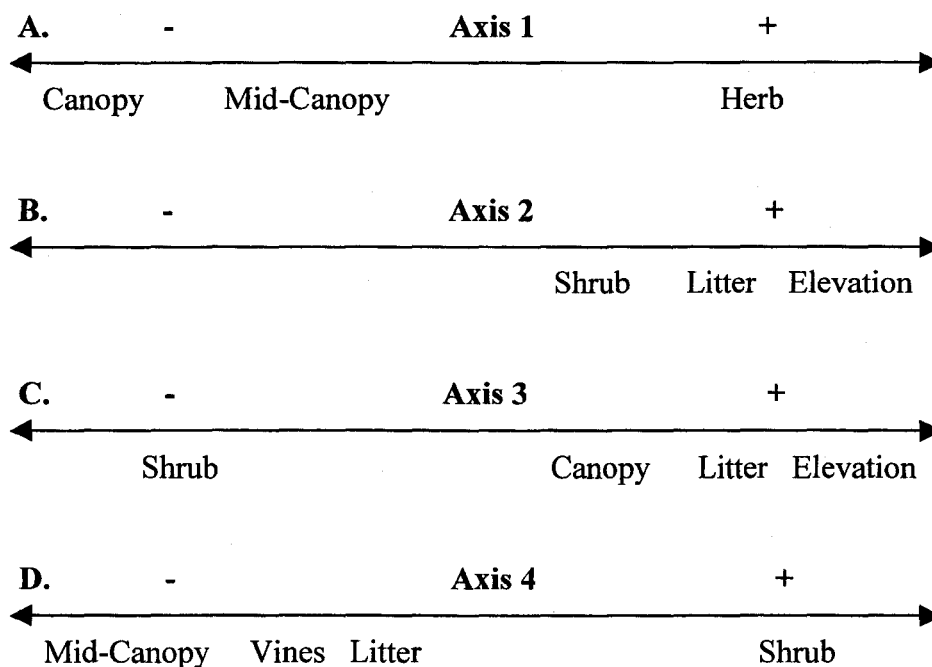


Figure 25: First four axes retained and their associated vegetative structure.

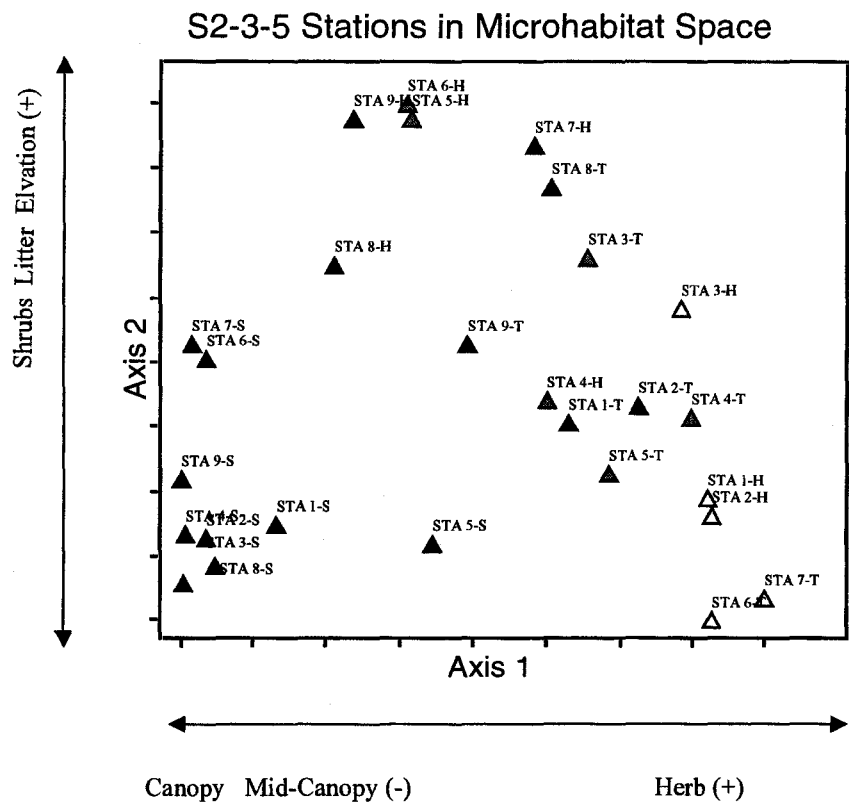


Figure 26: Ordination of macrohabitat trap stations against axes one and two. Black stations = mangrove; gray stations = ecotone; white stations = marsh.

have a P-value less than or equal to 0.05. The first, second and fourth axes (principal components) are important to the distribution of *O. palustris* ($F = 16.437$, $P < 0.001$; $F = 4.732$, $P = 0.041$; $F = 5.984$, $P = 0.023$; respectively). Axes one, two and three are important to the distribution of *S. hispidus* ($F = 9.915$, $P = 0.005$; $F = 9.651$, $P = 0.005$, $F = 5.280$, $P = 0.032$; respectively). Axis two is important to the distribution of *P. gossypinus* ($F = 12.185$, $P = 0.002$). Statistical analysis for *P. gossypinus* resulted in an unequal variance and so did not pass assumptions for parametric testing. The distribution of *Rattus rattus* did not have a significant relationship with any axis (the first six axes were tested).

A multiple regression of *O. palustris* and axes one, two and four showed that the number of animals captured could be predicted from the combination of herb, shrub, litter and elevation ($R^2 = 0.772$, $P < 0.05$) (Table 12). A multiple regression of *S. hispidus* and axes one, two and three showed that the number of *S. hispidus* can be predicted from a combination of herb, shrub, litter, elevation and canopy ($R^2 = 0.704$, $P\text{-value} < 0.05$) (Table 12). A linear regression of *P. gossypinus* and axis two showed that the number of *P. gossypinus* could be predicted from the amount of shrub, litter and elevation in an area ($R^2 = 0.486$, $P\text{-value} < 0.001$) (Table 12). By analyzing the residuals of each regression model, I have examined the difference between the observed and predicted value for each species (Figure 27, 28 and 29). The interpretation of residuals will follow in the microhabitat configuration section of the discussion.

Table 12: Multiple and linear regression equations showing the principal components (axes) important to the abundance and distribution of each species. The number of individuals can be predicted from the amount of structural variation in an area. HERB = herbaceous; SH = shrub; LIT = litter; EL = elevation; CAN = canopy

A.

$$\text{Log}_{10} (O. palustris + 1) = 0.596 + (0.160 * \text{AXIS } 1) + (0.0709 * \text{AXIS } 2) - (0.110 * \text{AXIS } 4)$$

$$\text{Log}_{10} (O. palustris + 1) = 0.596 + (0.160 * \text{HERB}) + (0.0709 * \text{SH,LIT,EL}) - (0.110 * \text{SH})$$

$$R = 0.879 \quad R^2 = 0.772 \quad \text{Standard Error} = 0.251$$

$$F = 25.942 \quad P < 0.001 \quad N = 27$$

B.

$$\text{Log}_{10} (S. hispidus + 1) = 0.590 + (0.133 * \text{AXIS } 1) + (0.141 * \text{AXIS } 2) - (0.106 * \text{AXIS } 3)$$

$$\text{Log}_{10} (S. hispidus + 1) = 0.590 + (0.133 * \text{HERB}) + (0.141 * \text{SH,LIT,EL}) - (0.106 * \text{CAN,LIT,EL})$$

$$R = 0.839 \quad R^2 = 0.704 \quad \text{Standard Error} = 0.307$$

$$F = 18.212 \quad P < 0.001 \quad N = 27$$

C.

$$\text{Log}_{10} (P. gossypinus + 1) = 0.230 + (0.160 * \text{AXIS } 2)$$

$$\text{Log}_{10} (P. gossypinus + 1) = 0.230 + (0.160 * \text{SH,LIT,EL})$$

$$R = 0.697 \quad R^2 = 0.486 \quad \text{Standard Error} = 0.309$$

$$F = 23.591 \quad P < 0.001 \quad N = 27$$

Note: Constant variance test failed for *P. gossypinus*

Oryzomys palustris

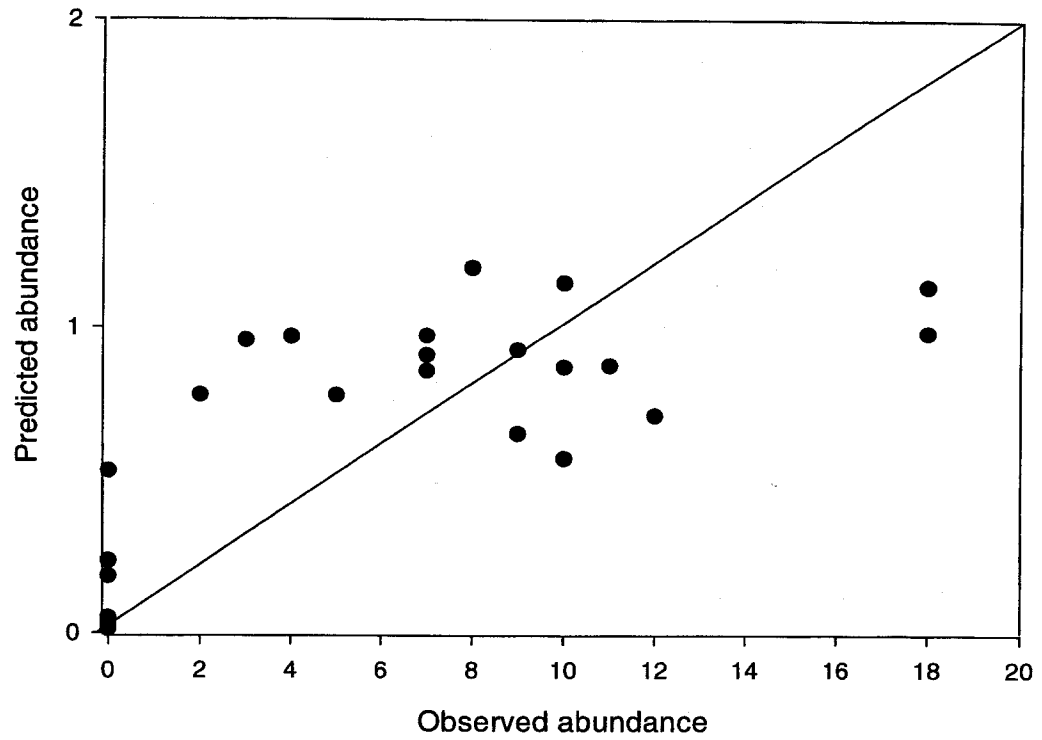


Figure 27: A comparison of observed and predicted abundance of *Oryzomys palustris*, using the regression equation in Table 12 A.

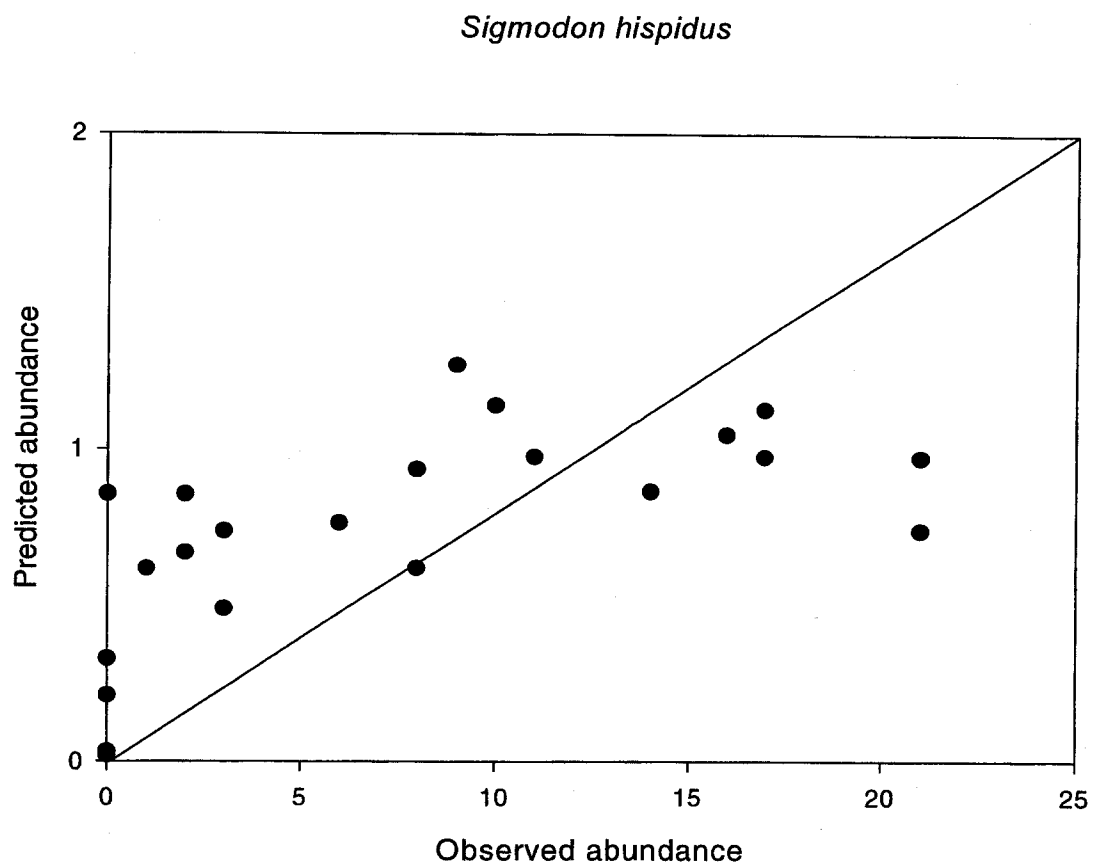


Figure 28: A comparison of observed and predicted abundance of *Sigmodon hispidus*, using the regression equation in Table 12 B.

Peromyscus gossypinus

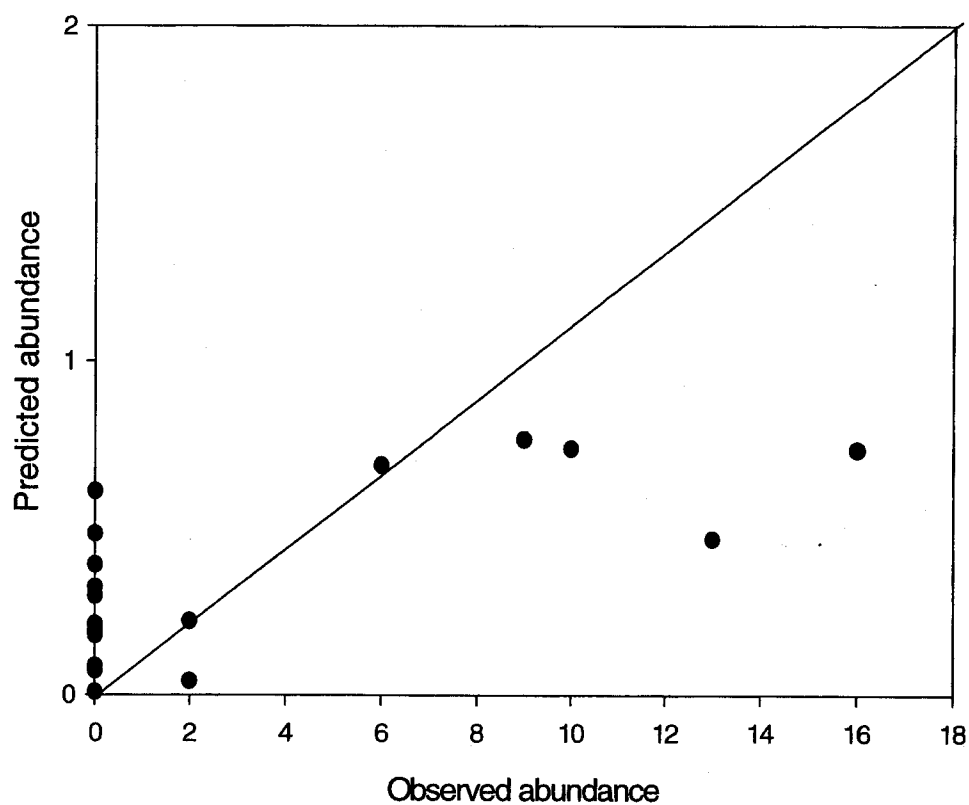


Figure 29: A comparison of observed and predicted abundance of *Peromyscus gossypinus*, using the regression equation in Table 12 C.

DISCUSSION

Species Distribution and Abundance

Of the four species captured, three are native (*Oryzomys palustris*, *Sigmodon hispidus* and *Peromyscus gossypinus*) and one is introduced (*Rattus rattus*). No more than three species were captured at any one site. At the Tarpon Bay Site (S2): *S. hispidus*, *O. palustris* and *R. rattus* were captured. At the Harney River Site (S5): *S. hispidus*, *O. palustris* and *P. gossypinus* were captured. The only species captured at the Shark River Site (S3) was *R. rattus*.

My results show that *S. hispidus* had the highest relative abundance at all sites and all macrohabitat types. It is not surprising that this species had the highest number of captures since *S. hispidus* is by far the most ubiquitous mammal in South Florida (Layne 1974b). This species is found in a wide variety of Florida habitats from pine flatwoods, tropical hardwood hammocks and tree islands to mangrove forests (Layne 1974a; Smith and Vrieze 1979; Gaines, et al. 2000; pers. observation).

Sigmodon hispidus was captured most often in the ecotone at the Harney River (S5) and the mangroves at Tarpon Bay (S2). Both of these macrohabitats have relatively high elevations, structural diversity and high plant species richness. Although there are no previous studies on small mammals in this section of the southwest Everglades to compare my results with, Smith and Vrieze (1979) found seasonal differences in habitat use by *S. hispidus* in Everglades hammocks. Their results showed that *S. hispidus* moved to higher elevations during the wet season. *Sigmodon hispidus* was one of three species that were found in large numbers within these two macrohabitats. Mangroves at Tarpon

Bay and the Harney River ecotone seem to support a high species richness and abundance of small mammals due to the variety of niches that a combination of vegetative and geomorphologic heterogeneity provides.

Oryzomys palustris had the second highest number of captures and this was rather surprising in that it was captured almost evenly amongst the three macrohabitat types.

Oryzomys palustris is not restricted to the marsh as its common name may suggest (marsh rice rat). *Oryzomys palustris* is an opportunistic species that uses different macrohabitats at different times of the year. For example, when Tarpon Bay was flooded in June 1999, *O. palustris* was one of the few species captured in the marsh. However it was also true that *O. palustris* was frequently captured in the ecotone at the Tarpon Bay Site when conditions were relatively dry such as they were in December 1998.

Rattus rattus was the third most abundant species and was captured almost exclusively in the mangroves at both the Tarpon and Shark River Sites. It was interesting that this was the only species captured at the Shark River Site: a mangrove with high salinity and strong tidal fluctuations. Blair (1935) captured a *R. rattus* specimen from Flamingo at the edge of a mangrove swamp. Schwartz (1952) captured a *R. rattus* specimen from the Middle Cape (Sable) at the margin of a dense hammock and swamp. Although these references are dated, it seems likely that *R. rattus* is well suited to life in the mangroves. Since the Shark River Site was the only site of its kind within my study, I am uncertain as to the extent of the range and total abundance that *R. rattus* encompasses within the southwest Everglades.

Peromyscus gossypinus had the lowest relative abundance in that it was captured at

only one site (Harney River) and only during the dry season. *Peromyscus gossypinus* was most abundant in the mangroves, but was also captured in the ecotone. These results agree with other studies of *P. gossypinus* in that this species seems to prefer high elevations close to dense canopy (Frank and Layne 1991; Smith and Vrieze 1979). *Peromyscus gossypinus* is strictly nocturnal and requires daytime refugia that are normally close to the ground (Frank and Layne 1991). It is likely that an increase in water levels during the wet season would result in movement to higher elevation microsites.

Small mammals seldom live more than one year in the wild, but can live for three to four years in captivity (Brown 1997). The longest-lived individual on any of my trap lines was a male *Oryzomys palustris* that was recaptured over an eight-month period. While it would be impossible to know from my study whether this animal died or simply moved out of trapping range, it is my feeling that these animals do not live very long in the wild. Predators are numerous (bobcat, hawks and snakes) and resources are limited (seasonal mast production) so it is likely that population numbers are low.

My highest capture rate at all sites occurred in December 1998, while my lowest capture rate occurred in September 1999. I am not sure why the number of captures in December was so high, but environmental conditions for that month were cold and dry. It could be that the captured animals were seeking cover from the cold in the live-traps. In September, precipitation and a storm surge from Tropical Storm Harvey resulted in approximately 45 cm of standing water at my sites. I caught only two individuals (*Oryzomys palustris* and *Sigmodon hispidus*) at all three sites in September 1999. It is

reasonable to believe there is a threshold where water levels are too high for rodents, even for adept swimmers such as *O. palustris*. In October 1999 (the month following Harvey) I recaptured animals that were captured prior to September 1999. Although I am uncertain as to what happened to the rodents from all three sites during the storm surge, apparently they moved out of the flooded areas and then moved back again as the water receded. This seems to demonstrate a certain degree of philopatry amongst these species.

Mass and Size Comparisons

Rattus rattus should have had the greatest average body mass (150 - 250 g) and size (32 - 43 cm) (Brown 1997) of all four species captured. It did, in fact have the largest body size, however body mass was only greatest when *R. rattus* was captured at the Shark River Site. *Rattus rattus* captured at the Tarpon Bay Site actually weighed less than the average *S. hispidus*. A t-test showed there was a significant difference between the body mass of *R. rattus* captured at the Tarpon and the body mass of *R. rattus* captured at the Shark River Site.

The Tarpon Bay Site has the greatest amount of freshwater available, the habitat is fairly heterogeneous and *R. rattus* coexisted with the two native species (*Sigmodon hispidus* and *Oryzomys palustris*). Although many times an exotic species will 'out-compete' a native species, this did not seem to be the case at Tarpon Bay. Abundance and mass of *R. rattus* at Tarpon Bay were low, together with what appeared to be a physically poor condition for *R. rattus*. In contrast, *S. hispidus* and *O. palustris* were captured in high numbers at the Tarpon Bay Site and seemed to be of 'normal' body mass and health.

It is possible that the native species at Tarpon Bay 'out-compete' the exotic species at this site.

The poor physical appearance of *R. rattus* at the Tarpon Bay Site sharply contrasted the healthy physical appearance of *R. rattus* at the Shark River Site where it was the only species captured. The Shark River Site is composed of only mangroves and has very little freshwater. Although the abundance of *R. rattus* was still low, the animals captured at the Shark River Site had greater body mass and fewer ectoparasites than *R. rattus* captured at the Tarpon Bay Site.

Another possible explanation for this variation in mass is that although the Shark River Site appears to be a harsh environment, it may provide *R. rattus* with certain advantages unavailable at the Tarpon Bay Site. These advantages could come in the form of high quality nesting sites, high protein food, and a lack of ectoparasites. *Rattus rattus* nests in the canopy of trees and the average tree height at this site is 17 m. Gastropods and crustaceans such as *Melampus sp.* (mangrove snail), and *Aratus sp.* (mangrove crab) are abundant, and it is possible that ticks are incapable of surviving in this environment.

Population Structure

Chi-square analyses showed no significant association between site and population structure. For most species at most sites, males were consistently captured more frequently than females. Female rodents occupy favorable habitats during the breeding season, and only allow males to share this habitat after the breeding season is over (Bowers and Smith 1979; Monamy and Fox 1999). It is possible that the higher ratio of

males to females was a result of differential habitat use by the sexes.

Reproductive Status

The rodents that I captured in the southwest Everglades breed throughout the year, but it is likely that their peak breeding times occur primarily in the spring and fall (Britt Keith, pers. comm). Gestation time varies among species, but is approximately 28 days with an average of four young per litter (Brown 1997).

I found significant associations between site and reproductive status for all species. White et al. (1997) showed that mean monthly rainfall was positively related to reproductive activity in the hairy-footed gerbil, *Gerbillurus paeba*. O'Connell (1989) showed that while Neotropical rodent species bred year-round most exhibited a reproductive peak in the wet season.

Although it is likely that all three sites in the southwest Everglades are affected by similar precipitation, each site has a different vegetative community structure, and therefore would be expected to respond differently to the same changes in precipitation. Precipitation affects the production of seeds and herbaceous plants that in turn affect rodent abundance and ultimately reproductive strategies. In other words, precipitation may cause some plants to fruit and provide food for rodents at one site, while it may take a few more months for different plants to provide food resources at another site. This difference in vegetative community structure among sites is a possible explanation for a variation in food resources that ultimately cause a variation in the reproductive phase of the same species at different sites.

Melanism

In Florida, melanism has been reported for bobcats (*Lynx rufus*; Hutchinson and Hutchinson 2000), fox squirrels (*Sciurus niger* L.; Kiltie 1992) and marsh rabbits (*Sylvilagus palustris*; Robertson and Kushlan 1997). The melanistic *Sigmodon hispidus* I captured in the southwest Everglades adds to this list. It is possible that Florida has a higher abundance of melanistic animals than other parts of the United States (James Layne, pers.comm). Melanism has been suggested to be an advantage against predation and a form of natural selection in action (Kettlewell 1959; Kiltie 1992). I observed the melanistic *S. hispidus* for a few days before I euthanized it, and it seemed to be nocturnal. *Sigmodon hispidus* is considered to be both nocturnal and diurnal and it is likely that melanism is an added advantage to nocturnal activity.

Effects of Water Depth and Salinity on Distribution and Abundance

The abundance of *Oryzomys palustris* was correlated with the abundance of *Sigmodon hispidus* suggesting that these species have similar ecologies, phenologies or patterns of habitat use. *Sigmodon hispidus* abundance in the southwest Everglades was negatively correlated with water depth and this relationship has been observed elsewhere in Florida (Layne 1974a; Smith and Vrieze 1979; Gaines et al. 2000). *Oryzomys palustris* is usually associated with freshwater marshes, so it was reasonable that this species had a negative correlation with salinity. It was however, unexpected that *R. rattus* had a negative correlation with water depth and a slightly negative correlation with salinity. *Rattus rattus* was fairly abundant at a site where water depth and salinity were high. In addition, *R. rattus* has been called the 'ship rat' and has frequently been captured in coastal areas of

high salinity (Layne 1997). It seems possible that *R. rattus* has developed a tolerance for high water depths and salinities, but that there is a threshold at which point salinity and water depth become a hindrance to this species.

Macrohabitat Summaries and Overlap

Sigmodon hispidus was captured most often in the mangroves at Tarpon Bay and in the ecotone at the Harney River Site. Both macrohabitats have high elevations and literature has suggested that *S. hispidus* prefers high elevations (Layne 1974a; Smith and Vrieze 1979; Gaines et al. 2000). *Oryzomys palustris* was captured almost evenly among all three habitat types suggesting that this species uses mangrove, marsh and ecotone equally. *Rattus rattus* and *Peromyscus gossypinus* were both captured primarily in the mangroves. Macrohabitat overlap was high between all species at a site, suggesting that in order to avoid competition and efficiently utilize resources, these rodents may partition microhabitat use.

Microhabitat Variables and Principal Components Analysis

There are certain 'rules of thumb' or criteria designed to help decide how many principal components to retain. Kaiser (1960) recommends dropping those principle components with eigenvalues less than one. Jackson (1993) states that if the broken-stick eigenvalue is less than the actual eigenvalue for an axis, then that axis contains more information than expected by chance and should be considered for interpretation. If I followed Kaiser's interpretation I would have kept the first five axes, for Jackson it would

have been the first three. I decided however, to retain the first four principal components since they proved to be important to the abundance and distribution of species.

When I ordinated the trap stations against the first and second axes, the marsh stations clustered by the herbaceous end of axis one. The mangrove stations of the Shark River clustered toward the canopy and mid-canopy end of axis one. The ecotone stations together with a few mangrove and one marsh station were somewhat in the middle of both axes one and two. This suggests that these stations closely resemble the structural characteristics of the axis they are associated with.

Microhabitat Configuration

Although *Oryzomys palustris* was captured almost equally among macrohabitat types, results demonstrated that *O. palustris* has a marked microhabitat selection of herbs, shrub, litter and elevation. *Sigmodon hispidus* had a microhabitat preference of herbs, shrub, litter, elevation, and canopy. *Peromyscus gossypinus* could be predicted from the amount of shrubs, litter and elevation in an area. Because of the unequal variance, these results are a suggestion. I feel that this microhabitat configuration describes the structural habitat where *P. gossypinus* was captured and that the lack of equal variance was due to small sample size. *Rattus rattus* is rather surprising in that although it appeared to be a macrohabitat specialist (mangroves), it showed no significant microhabitat preference. This would suggest that this species is adapted to use a variety of structural variables and is a possible explanation for its success as an invasive species. It is also rather curious that this species is captured in a mangrove site (Shark River Site) where no other species

are found. There are two possible explanations; the first is that *R. rattus* utilizes habitat that is unsuitable to other species, and the second is that *R. rattus* previously extirpated other species from the Shark River Site.

In examining the residuals of the regression models for the three species, it is possible that some influential factors were not measured or that species' distributions can be stochastic (Figures 27, 28, 29). The regression line for *O. palustris* overestimates the number of animals for small values of *O. palustris*, and underestimates the number of animals for large values (Figure 27). Variation is fairly symmetric about the mean when the number of animals is between six and fourteen. Since *O. palustris* was captured in only two of the three sites, zeros are included in the data and fall directly on the y-axis. *Sigmodon hispidus* has a residual distribution similar to *O. palustris*, in that variation increases for small and large numbers of *S. hispidus* (Figure 28). *Sigmodon hispidus* was captured in two of the three sites, so that zero values again line up on the y-axis. The predicted value of *P. gossypinus* is underestimated when the observed values are large (Figure 29). *Peromyscus gossypinus* was captured in only one of three sites so there are a large number of zeroes on the y-axis. Although the regression coefficient is low and only a few points hold this line, I feel that this microhabitat configuration adequately describes the area where *P. gossypinus* was captured.

CONCLUSION

The goals of this study were to describe the distribution and abundance of small mammals of the southwest Everglades and to determine the influence of habitat on this distribution and abundance. Since the small mammal communities of the mangrove, marsh and ecotones within the southwest Everglades had not yet been described, it was important to first gather baseline data on this assemblage.

Heterogeneous landscapes should reflect a greater diversity of small mammals than homogeneous areas (Brown et al. 1995; Burnett et al. 1998). The ecotones within my study area supported many plants and had a high geomorphologic heterogeneity (high elevation with varying water depths). As predicted, ecotones supported a higher species richness and relative abundance of small mammals than most mangrove and marsh habitats. It was also important to describe the small mammal community of ecotones, in that the position of an ecotone can change as a result of changes in water level and climatic temperature. Since this ecotonal shift has already been observed in certain areas of the southwest Everglades (T.J. Smith III, pers. comm.), it was important to gather baseline data before further changes occur.

Although there is no doubt that rodent species are distributed in some habitats more than in others, a question that remains uncertain is at which scale species select their habitats (Morris 1987). Some studies indicate that small mammals discriminate by macrohabitat, in other words selecting habitats at larger scales than microhabitat (Morris 1987). However, other authors suggest that many rodent species segregate at fine spatial scales (McCloskey 1976; Dueser and Shugart 1978; Seagle 1985; Haering and Fox 1995).

Many habitat variables have been shown to influence small mammal distribution and abundance in the southwest Everglades. My research showed that macrohabitat type, surface water, salinity, elevation and vegetative structure had significant effects on small mammal distribution and abundance.

Although *Oryzomys palustris* appeared to use each macrohabitat equally, my results showed that vegetation structure measured at the microhabitat scale influenced distribution of *O. palustris*. *Sigmodon hispidus* appeared to utilize two macrohabitats almost equally, however upon closer inspection it became clear that it was responding to the same high elevation and vegetation structure found in the two macrohabitats (mangrove and ecotone). *Peromyscus gossypinus* also responded to structural variables at the microhabitat scale. *Rattus rattus* appeared to exhibit macrohabitat preference, but did not show any significant microhabitat selection. It is possible that *R. rattus* does not respond to structural variables at the microhabitat level because it is a habitat generalist and therefore capable of adapting to many types of structural variables. This is also a possible explanation for *R. rattus*'s success as an exotic species. It is my conclusion that small mammal studies should be measured at the macrohabitat and microhabitat scale. My results showed that most species had a macrohabitat preference and also exhibited a microhabitat selection. I feel it is ecologically important to associate species distributions with both macrohabitat and microhabitat variables.

Although species richness for small mammals in the southwest Everglades is low (four), abundance is high. I have described the small mammal distribution and abundance along with associated habitat influences in the southwest Everglades. Additional

questions that need to be addressed include; "Why is the introduced species, *R. rattus* absent at the Harney River Site?" and, "Why was *R. rattus* the only species captured at the Shark River Site?" More small mammal research is needed to fully answer these questions.

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