TRAPPING STUDY OF THE ENDANGERED KEY LARGO COTTON MOUSE (*PEROMYSCUS GOSSYPINUS ALLAPATICOLA*): A PROTOCOL FOR LONG-TERM POPULATION MONITORING

by

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(Under the Direction of Steven B. Castleberry and Michael T. Mengak)

ABSTRACT

The Key Largo cotton mouse (*Peromyscus gossypinus allapaticola*), a federally endangered subspecies of the cotton mouse, currently is restricted to less than 50% of its former habitat. Current sampling methods are labor intensive and budgetary and personnel constraints have led to infrequent population monitoring. My objective was to use a modeling approach to identify a subset of trapping grids from a total of 34 girds that will provide reliable population estimates with less time and effort than currently required. From the 3 trapping sessions in 2007, I was able to analyze 12 trapping grids and obtain density and total population estimates within 10% of the estimates from all trapping grids. I calculated density estimates from the 33 grids used in the analysis at 11.7 mice/ha (95% CI 10.7-12.6) in session 1, 17.5 mice/ha (95% CI 16.7-18.34) in session 2, and 23.2 mice/ha (95% CI 21.7-24.4) in session 3. Extrapolated total population estimates were 9,947 in the first session, 14,905 in the second session, and 19,757 in the third session. Analysis of the 12-grid subset in session 3 had the fewest number of grids necessary to monitor the population, with a density estimate of 21.9 mice/ha (95% CI 21.6-22.2) and total population estimate of 18,623. My results will allow managing agencies to monitor population trends within budgetary and personnel constraints in an effort to maintain or increase the Key Largo cotton mouse population.

INDEX WORDS: Key Largo cotton mouse, endangered, *Peromyscus gossypinus allapaticola*, hardwood hammocks, grid trapping, robust design, south Florida

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INTRODUCTION AND LITERATURE REVIEW

SUMMARY

The Key Largo cotton mouse (*Peromyscus gossypinus allapaticola*), endemic to the island of Key Largo, is the southernmost subspecies of its genus (Brown 1970). Anthropogenic habitat destruction on Key Largo in the late 19th century resulted in a loss of two-thirds of the original hardwood hammock habitat, contributing to population decline in many faunal species, including all rodents (U.S. Department of the Interior 1973, Hersh 1981, Barbour and Humphrey 1982, Keith and Gaines 2002, McCleery et al. 2006). Because of habitat loss and population declines, the United States Fish and Wildlife Service (USFWS) listed the Key Largo cotton mouse as an endangered subspecies in 1984 (U.S. Department of the Interior 1984).

Since being listed, all surveys for the cotton mouse and Key Largo woodrat (*Neotoma floridana smalli*), an endemic, endangered subspecies of the eastern woodrat (*N. floridana*), confirm that urbanization has restricted current populations to a small portion (795 – 850 ha) of their historic range. Remaining habitat is restricted to the northern half of Key Largo, almost exclusively within protected public lands of Crocodile Lake National Wildlife Refuge and Dagny Johnson Key Largo Hammock Botanical State Park. Most areas of the remaining habitat have some level of human disturbance. The nature of the habitat loss in many areas provides extremely limited potential for immediate habitat restoration or rehabilitation (U.S. Fish and Wildlife Service 1999) because of extensive fragmentation and degradation. The establishment of vegetation in many of these disturbed areas is limited because of the presence of buildings, roadways, canals, and scarified soils that extend to the caprock.

Key Largo cotton mouse habitat consists of tropical hardwood hammocks, a closed canopy forest that rarely experiences fire and is composed primarily of a West Indian plant community different than most plant assemblages of mainland Florida (Whitney et al. 2004). Previous studies have attempted to describe and classify suitable cotton mouse habitat according to hammock age (Brown 1970, Barbour and Humphrey 1982, Humphrey 1988, Keith and Gaines 2002, Sasso and Gaines 2002), but have produced conflicting results regarding which habitat types have the highest cotton mouse densities. No work on the Key Largo cotton mice has been conducted since the most recent density by Sasso and Gaines (2002) and total population by Humphrey (1988) were estimated, and changes in population status and habitat associations since the last surveys are unknown.

Given recent personnel and budgetary constraints, it is unrealistic for managing agencies to conduct annual extensive Key Largo cotton mouse trapping during multiple seasons. Yet, population structure and size are necessary elements in recovery efforts. Therefore, my objectives were to use trapping data to describe population structure, and to develop a standardized methodology that will allow agency personnel to reliably estimate the population within personnel and time constraints.

LITERATURE REVIEW

Key Largo Cotton Mouse Ecology and Distribution

The Key Largo cotton mouse was described by Schwartz (1952) as a distinct subspecies from peninsular Florida cotton mouse populations based on several morphological characteristics, including larger total length, tail length, and skull length than other cotton mice.

The Key Largo cotton mouse also has a reddish coloration, which, although present in other *P. gossypinus* of southeastern Florida counties, is brighter and overall more reddish than other Florida subspecies and therefore is considered a distinct morphological characteristic of *P. g. allapaticola* (Schwartz 1952).

The Key Largo cotton mouse historically ranged throughout Key Largo (Brown 1978, Barbour and Humphrey 1982), but today is limited to less than 50% of its historic range (U.S. Fish and Wildlife Service 1999) in the northern half of the island. In the late 19th century, hammock habitat throughout much of Key Largo was cleared to promote pineapple farming and timber harvest for furniture making and shipbuilding (Alexander 1953, Humphrey 1992, Ross et al. 2001). The agricultural industry experienced severe pineapple blight in 1906, and pineapple production ended by 1915. After agricultural abandonment, many cleared areas began reverting back to young hardwood forests. While hammocks in the northern half of Key Largo were regenerating, the southern half experienced extensive land clearing for commercial and residential development, particularly after World War II. Only a few forested lots remain south of the County Road 905 and US1 intersection, and are believed to no longer support cotton mice (Humphrey 1992). Several studies attempting to identify additional populations in the remaining hammocks of south Key Largo have been unsuccessful (Goodyear 1985, Humphrey 1992).

Although development occurred primarily in the southern half of Key Largo, the northern half also was heavily disturbed by development. During the 1970-80's, increased canal construction, several large-scale land clearings, and dredge and fill operations were initiated to advance the potential for increasing residential and commercial development. Additionally, a loan was secured with the intent to upgrade the electrical delivery capability, which would accelerate development in the remaining forested lands of northern Key Largo. These factors, along with population declines that had already occurred, resulted in the cotton mouse and woodrat receiving federal listing under the Endangered Species on August 31, 1984 to protect the remaining habitat from further alterations (U.S. Department of the Interior 1984).

Key Largo Cotton Mouse Habitat Selection

Flora of the Florida Keys are mostly tropical species derived either from sister populations of the West Indies or are endemic to South Florida (Tomlinson 2001, Whitney et al. 2004), with some species only occurring in the Florida Keys. Occurrence of many plant species in Key Largo is dependent on specific habitat conditions, primarily hammock age and elevation. Many of the largest hardwoods (e.g., *Lysiloma latisiliquum* [wild tamarind], *Coccoloba diversifolia* [pigeon plum], *Metopium toxiferum* [poisonwood], *Bursera simaruba* [gumbo limbo], *Swietenia mahagoni* [mahogany], and *Ficus citrifolia* [shortleaf fig]) are early successional species, decreasing in frequency as the habitat matures and are replaced by late successional species with smaller diameters (Ross et al. 2001).

Because of conflicting conclusions in past research, Key Largo cotton mouse habitat characteristics are not well understood. Brown (1970) suggested cotton mice were limited to "mature" hardwood hammocks and absent in younger age classes, but did not provided any criteria or hammock classification. Similarly, Barbour and Humphrey (1982) estimated 21.8 individuals/ha in mature hammock and approximately 1.2/ha in an intermediate seral stage. However, several years later Humphrey (1988) documented cotton mice in multiple habitat types, with an average of 21.2 individuals/ha for all habitats surveyed. Recent research supports results of Humphrey (1988), suggesting cotton mice have their highest densities in medium-aged hammocks (Sasso and Gaines 2002). Keith and Gaines (2002) used data from a line transect study to predict cotton mouse distribution and habitat characteristics using a Geographic

Information System (GIS). They concluded that 84%, or 790 of the 945 available hectares identified by Ross et al. (1992) of north Key Largo's hardwood hammock provided suitable habitat. Although they did not provide a population or density per hectare estimate, they reported that abundance was, on average, greater in medium-old hammocks, smaller fragments of hammock divided by road or development, and in hammocks without exotic vegetation.

Seasonal variation in plant growth and mast production can influence an animal's density or abundance (Pearson 1953, Hansson 1971, Miller and Getz 1977, Cole and Batzli 1978, Smith and Vrieze 1979, Diffendorfer et al. 1995, Sasso and Gaines 2002). The hammocks of Key Largo are heterogeneous and presently exist in a patchy environment represented by a variety of forest age structures and plant assemblages resulting from timing and intensity of disturbance. Many species of tropical hardwoods temporally vary in mast production (Tomlinson 2001), and therefore, cotton mouse population dynamics may be influenced by a patch's lack of resources necessary to sustain a population during certain seasons. Hammock maturity and how it relates to Key Largo's small mammal abundance has been addressed, but with the exception of Sasso and Gaines (2002), no research in Key Largo has reported seasonal or annual variation in density or abundance in cotton mice within habitat types.

Key Largo Cotton Mouse Population Monitoring

In a resource publication on threatened wildlife of the United States, the U.S. Department of the Interior (USDI 1973) acknowledged that Key Largo cotton mice numbers had declined and the species was severely threatened by extinction. Although USDI (1973) reported density estimates for the Key Largo woodrat, they offered no estimates for the cotton mouse to validate a decline. No published estimates for the cotton mouse were available until Barbour and Humphrey (1982). Presently, the only total population estimate is from a mark-recapture study by Humphrey (1988) based on an estimated 851 ha of suitable habitat. Humphrey (1988) estimated the total cotton mouse population at approximately 18,000 individuals by extrapolating his density estimates to available habitat. Humphrey noted his total population estimate may be erroneous, as he may have misrepresented the true densities across all habitat types by assuming uniform distribution, although all available habitat may have not been entirely occupied.

According to the Fish and Wildlife Recovery Plan (U.S. Fish and Wildlife Service 1999), several actions are necessary for Key Largo cotton mouse recovery. These actions include, but are not limited to, continuing protection and enhancement of existing populations, habitat restoration, managing and protecting usable habitat, removal of exotic species (such as feral cats and fire ants), and establishing a protocol for long-term monitoring of population status and demographic parameters. Section 4 of the cotton mouse recovery plan identifies the following 3 components as necessary to develop a monitoring plan to detect population declines: (1) develop methods to monitor demographic parameters; (2) implement a long-term monitoring program; and (3) monitor demographic changes, including sex ratio, age structure, and survival (U.S. Fish and Wildlife Service 1999).

Population monitoring is a crucial component for the conservation of endangered species. Regular monitoring provides information necessary to identify management strategies that could be improved and to suggest possible solutions (Goldsmith 1991). In most situations, a total population census is not feasible; therefore a sample of the population is used to monitor a population. Detecting a change in the population size is the main parameter of interest, and the most efficient procedure to document such a change involves repeated population estimates (annual or other appropriate period) of the same sample of sites. To be effective, a population monitoring program must be efficient and provide reliable estimates of population change (Thomas 1996).

Management of Key Largo cotton mice with a standardized methodology should provide an efficient and reliable method to monitor population trends while making long-term monitoring economically feasible for management agencies. The monitoring plan should allow agency personnel to conduct surveys with increasing efficiency in the use of time and associated costs. Additionally, regular monitoring allows managers to evaluate effectiveness of their management strategies and update the plan to maximize the objective (Walters 1986, Williams et al. 2002). Monitoring plans using adaptive resource management allow for constant updating, which can ultimately increase the probability of persistence for a species.

OBJECTIVES

The recovery objective for the Key Largo cotton mouse is reclassification from endangered to threatened, and will require several actions (U.S. Fish and Wildlife Service 1999). Guidelines listed in the USFWS multiple species recovery plan state that determining size of the current population and cotton mouse distribution are the first necessary actions. After establishing a reliable population estimate, management agencies can identify potential habitat for reintroduction into areas within the cotton mouse's historic range. The objectives of my study fulfill a portion of the recovery plan's guidelines.

The objectives of this study were to:

1. Describe the population structure of the Key Largo cotton mouse.
2. Estimate cotton mouse density and total population in the hardwood hammocks of north Key Largo.

3. Develop a standardized methodology for reliably assessing long-term cotton mouse population trends given the economic and personnel constraints of the agencies conducting the fieldwork.

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CHAPTER 2

A METHODOLOGY FOR LONG-TERM POPULATION MONITORING FOR THE ENDANGERED KEY LARGO COTTON MOUSE [1]

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ABSTRACT

Since its listing, the Key Largo cotton mouse (*Peromyscus gossypinus allapaticola*) has been reported as having experienced population declines, but population monitoring has not been conducted on a regular basis due to personnel and budgetary constraints. Therefore, the extent of population declines and long-term population trends are uncertain. I used a modeling approach to develop a monitoring protocol that could be conducted more frequently under current personnel and budget constraints. I captured cotton mice on 33 trapping grids during 3 trapping sessions (1 March-11 May, 4 July-7 September, and 29 October-31 December) in 2007. I compared parameter estimates of subsets of trapping grids with parameter estimates from all 33 trapping grids to determine the lowest grid number that would produce estimates similar to the estimates produced by all trapping grids in each trapping session. Subsets within 10% of the 33 grid total population estimate were retained. The subset with the minimum number of grids that met this criterion was selected as the best subset to use for monitoring long-term cotton mouse population trends. There were insufficient captures in session 1 to produce a reliable population estimate. In session 2, 13 trapping grids were necessary to estimate density and total population within 10% of the 33 total grids. In session 3, 12 grids provided estimates within 10% of the 33-grid density and population estimate. My results suggest that a subset of 12 grids trapped during November and December will allow a 64% reduction in number of trapping grids necessary to provide a reliable population estimate. This protocol will provide managing agencies with a set of trapping grids that can feasibly be monitored by few employees in a relative short amount of time.

INTRODUCTION

The Key Largo cotton mouse (*Peromyscus gossypinus allapaticola*) is a subspecies of cotton mouse (*P. gossypinus*) endemic to the island of Key Largo, Florida. Since the late 19th century, anthropogenic habitat destruction resulted in a loss of nearly two-thirds of original cotton mouse habitat, contributing to an overall population decline (U.S. Department of the Interior 1973, Hersh 1981, Barbour and Humphrey 1982, Keith and Gaines 2002, McCleery et al. 2006). Population decline, in combination with loss of historic habitat, resulted in listing as an endangered subspecies by the United States Fish and Wildlife Service (USFWS) in 1984 (DOI; U.S. Department of the Interior 1984). At this time Humphrey (1988) estimated the total population at 18,000 individuals, but no subsequent population estimates are available.

Suitable cotton mouse habitat presently is restricted to the northern half of Key Largo, almost exclusively within protected public lands on Crocodile Lake National Wildlife Refuge and Dagny Johnson Key Largo Hammock Botanical State Park. Past studies (Brown 1970, Barbour and Humphrey 1982, Humphrey 1988, Keith and Gaines 2002) examined relationships between habitat characteristics and cotton mouse abundance, but varying results led to discrepancies regarding which habitat types have the highest occupancy. Brown (1970;1978) suggested that cotton mice were limited to mature hammock and absent in younger stands. Barbour and Humphrey (1982) estimated 21.8 individuals/ha in mature hammock and 1.2/ha in an intermediate seral stage. Both studies suggest that cotton mice primarily occupy mature hammocks, but none of the authors listed the criteria for habitat classification. Humphrey (1988) had different results, documenting cotton mice in multiple habitat types, with an average of 21.2 individuals/ha for all types of habitat surveyed. Although Humphrey (1988) did not list age of the hammock where he placed trapping grids, he stated that grids were placed in a variety of hammocks of different ages, both young and older. Similarly, Keith and Gaines (2002) concluded that 84%, or 790 of the 945 available hectares (Ross et al. 1992) of north Key Largo's hardwood hammock provided suitable habitat. Although they did not provide a population or density estimate, they reported higher mean abundance in medium-aged hammock, smaller fragments, and in hammocks without exotic vegetation. A concurrent study by Sasso and Gaines (2002) also reported medium-aged hammock as being optimal for cotton mice with a mean of 9.1 mice/ha (range 7.1-12.1 mice/ha).

Although the relationship between hammock maturity and Key Largo cotton mouse abundance has received much attention, there has been little focus on seasonal variation in density or abundance. Habitats in north Key Largo may vary geographically or temporally in their ability to sustain cotton mouse populations. Sasso and Gaines (2002) found Key Largo cotton mouse populations to peak during winter. Some habitats may be unsuitable to maintain cotton mice or may only support individuals during certain seasons, particularly if the resources such as food and mates are not present. Numerous studies suggested that food availability can influence rodent population fluctuations (Hansson 1971, Miller and Getz 1977, Cole and Batzli 1978, Smith et al. 1984, Ostfeld et al. 1996). Many tropical plants, such as those of Key Largo increase fruit production during the wet season (Lieberman 1982, Levey 1988, Bancroft et al. 2000), which could influence temporal variation in the cotton mouse population.

Data on Key Largo cotton mouse population and demographic structure are needed to estimate density and total population size and to effectively monitor population trends. Because trapping efforts are labor intensive and past efforts used different methods, an efficient, standardized methodology is needed to monitor population changes. Furthermore, given personnel and budget constraints, it is unrealistic for management agencies to conduct extensive trapping during multiple seasons to account for temporal variation in the cotton mouse population. Therefore, my objective was to develop a standardized methodology that will allow agency personnel to estimate cotton mouse population using an efficient trapping design at the time of year that will yield the most accurate population estimate. Additionally, data were used to describe population structure to increase our understanding of cotton mouse population dynamics.

STUDY SITE

I conducted my research in the Rockland tropical hammocks (Snyder et al. 1990) of north Key Largo on lands managed by Crocodile Lake National Wildlife Refuge and Dagny Johnson Key Largo Hammock Botanical State Park. Hardwood hammocks in north Key Largo are characterized by closed-canopy, evergreen, broad-leaved forests growing on a Key Largo limestone substrate, formed during the Pleistocene between 130,000 and 200,000 years before present (Snyder et al. 1990, Ross et al. 1992). Soil layers on this substrate are poorly developed (Snyder et al. 1990, Ross et al. 1992, U.S. Fish and Wildlife Service 1999) and, because of the quick decomposition rate, little surface organic matter is present. The plant assemblage of the Florida Keys differs from the flora of most of mainland Florida. Most species are tropical in origin and are derived either from sister populations of the West Indies or are endemic to the Florida Keys or extreme southern mainland Florida (Whitney et al. 2004).

Key Largo hardwood hammocks contain one of most species-rich floral assemblages in North America with over 150 trees and shrubs (Snyder et al. 1990). Over 450 plant taxa have been reported for Dagny Johnson Key Largo Hammocks Botanical State Park (Gann and Duquesnel 2007). Of the 13 ecological site classes of the Florida Keys, the Rockland Hardwood Hammock ranks second in species diversity, and generally has the most tree species (Ross et al.

1992). Common tree species include: Bahama strongbark (*Bourreria ovata*), crabwood (*Ateramnus lucidus*), gumbo limbo (*Bursera simaruba*), marlberry (*Ardisia escallonioides*), pigeon plum (*Coccoloba diversifolia*), poisonwood (*Metopium toxiferum*), white stopper (*Eugenia axillaris*), wild tamarind (*Lysiloma latisiliquum*), and willow bustic (*Dipholis salicifolia*). Most areas have a closed canopy, which provides a shady, humid microclimate with little wind and temperature variation (U.S. Fish and Wildlife Service 1999). As a result of canopy closure, understory consists mainly of seedlings and saplings with sparsely distributed sub-canopy species of vines and shrubs (Snyder et al. 1990). Closer to the transition zone near the edge of the island, canopy height decreases and hardwoods abruptly change into a salt-tolerant transition zone and mangrove communities (Alexander 1953, Snyder et al. 1990).

METHODS

Capture and Handling

I placed 34 trapping grids throughout the approximately 851 ha (Humphrey 1988) of potential Key Largo cotton mouse habitat (Figure 2.1). I selected grid locations under a stratified random sampling design (Appendix A) with trapping grids proportionally allocated to 3 hammock age class strata based on time since last disturbance. Age classes were young (disturbed since 1971), medium (disturbed 1940-71), and old (disturbed before 1940) and were similar to the stratification used in recent studies (e.g.; Ross et al. 1995, McCleery et al. 2006). Approximately 11% of habitat was in young, 38% in medium, and 51% in old strata. I proportionally allocated grids to each stratum. Four grids were needed to sample young habitat, but I oversampled this stratum to include areas previously classified as disturbed, but today are more similar to young hammock. As a result, I established 6, 12, and 16 grids in young, medium, and old strata, respectively. Because of a lack of canopy closure and cotton mouse captures on one grid in young hammock, I only used 5 in the analysis for a total of 33.

Each grid consisted of 49 traps on a 7 x 7 grid arrangement with 10 m between traps (60 x 60 m grid), totaling 0.36 ha. Although I did not know the home range of the Key Largo cotton mouse, I established the grid size to be twice the size of another Florida cotton mouse population's estimate home range of 0.18 ha (Layne 1974). Cotton mice were captured using perforated Sherman livetraps (10.2 x 11.4 x 38.1 cm, H. B. Sherman Traps Inc., Tallahassee, Florida) equipped with raccoon (*Procyon lotor*)-proof door latches. Traps were baited with whole oats no later than 3 hours before sunset, and checked no later than 3 hours after sunrise. All captured individuals were double tagged using a #1 Monel metal ear tag (National Band and Tag Company, Newport, Kentucky) and a passive integrated transponder (PIT) tag (Biomark, Boise, Idaho, tag types TX1411SSL, TX1411SST, TX1411L, TX1400BM; 12.50mm X 2.07mm, 125 kHz, 0.1020g). Grids were trapped for 4 consecutive nights during 3 trapping sessions in 2007 (1 March to 11 May, 4 July to 7 September, and 29 October to 31 December). I did not trap when temperatures were expected to fall below 15.5ºC. Capture and handling was conducted under U.S. Fish and Wildlife endangered species permit nos. TE139405-0 and TE137411-0, Florida Fish and Wildlife Conservation Commission Permit no. WV06293, Florida Department of Environmental Protection Division of Recreation and Parks Research and Collecting Permit no. 5-07-20 and no. 5-08-34, and University of Georgia Institutional Animal Care and Use Permit no. A2006-10206-m1.

Statistical Analysis

I used Pollock's robust design (Pollock 1982) to estimate population size. The robust design estimates temporal variation in density and population size, allowing for sampling on 2 temporal scales, with short-term periods sampled during which the population is considered closed and longer-term sampling where the population is open (Cormack 1964, Jolly 1965, Seber 1965, Williams et al. 2002). I obtained estimates of abundance for each trapping session using 33 trapping grids. I pooled data across hammock age strata due to a lack of captures for each sex in each stratum.

To achieve the main objective of developing an efficient trapping design, I examined subsets of the total grid number to determine the lowest number of grids that would produce estimates as close as possible to estimates produced by all trapping grids in each trapping session. Subsets of trapping grids in each session were selected based on number of unique individuals and associated variance across sessions (Table 2.1). Grids having ≤3 mice in a given session were excluded to create initial subsets in each session. Subsets were further reduced one grid at a time by excluding grids with the highest variance. A population estimate was obtained for each subset each time a grid was removed using the robust design. Subset reduction continued until the robust design failed to properly estimate parameters, as indicated by high standard errors and confidence intervals ranging between or including 0 and 1. Subsets with estimable parameters were retained if density and total population estimates remained within 10% of the 33 grid estimates.

One of the fundamental assumptions in a mark recapture study is all individuals have an equal catchability. This assumption is often violated in wildlife studies due to heterogeneity, a byproduct of unequal capture probabilities for each individual, as well as a behavioral trap response between individuals (Pollock 1982). To determine if heterogeneity needed to be incorporated in the analysis, I estimated abundance in single trapping sessions using program CAPTURE (Otis et al. 1978, Rexstad and Burnham 1991) to identify the appropriate model for parameter estimation for all trapping grids. Results from program CAPTURE designated Chao's heterogeneity model M(h) (Chao et al. 1992) was the appropriate model for Session 2, indicating heterogeneity was a factor in the population, and Pollock and Otto's (1983) model with both behavior and heterogeneity, M(bh) was the appropriate model for Sessions 1 and 3. Because results from program CAPTURE indicated that cotton mice exhibited capture probabilities that varied with behavior and heterogeneity, I used the robust design's closed captures with full heterogeneity in program MARK 5.1 (White and Burnham 1999) to estimate abundance incorporating the demographic parameters for the Key Largo cotton mouse for survivorship, emigration, immigration, probability of mixture, sex, capture and recapture probabilities.

I developed 23 candidate models (Table 2.2) to estimate abundance for all grids and grid subsets in each trapping session. I developed models in program MARK with variation in survival, emigration, immigration, mixture distribution, and capture and recapture probabilities. Models were also tested with emigration and immigration parameters fixed to reduce the standard error and to increase precision in additional parameter estimates. I made adjustments for the number of total parameters in each model when program MARK failed to properly count the number of estimable parameters. For each subset analysis, I conducted a goodness of fit test to account for overdispersion. Because of overdispersion from parameter variation, AIC values were adjusted with a variance inflation factor ($\hat{c}$), derived from a goodness-of-fit test conducted in program RELEASE, where the chi-square statistic (χ^2) of test 2+3 was divided by its degrees of freedom (Burnham et al. 1987, Lebreton et al. 1992). Once corrected, the -2log likelihood was divided by the variance inflation factor, which provided a quasi-likelihood AIC (QAIC) value (Cooch 2008). As a result of the small sample size relative to the number of parameters estimated, a small sample size adjustment was incorporated into the QAIC value ($QAIC_c$), where a parameter penalty term was multiplied by a small sample correction factor. I then added 1 parameter to the total number of parameters for each model (Burnham and Anderson 2002). I compared model likelihoods using Akiake's Information Criterion (AIC; Akaike 1973). I then created a confidence set of models with a delta AIC ≤ 2 of the top model. In order to incorporate model selection uncertainty into models with similar AIC values, model averaged estimates were calculated for the confidence set (Cooch 2008). Remaining parameter estimates were used from the top model (Table 2.3).

Although session 1 was included in the MARK analysis, low number of captures prevented reliable estimation of demographic parameters using the robust design, with estimates containing high standard error and 95% confidence intervals that included 0. Because each individual was newly captured this session and use of open models was not necessary, I analyzed this session independently in program CAPTURE. I conducted a closed capture analysis with program CAPTURE within program MARK using Pollock and Otto's M(bh), and generated estimates incorporating behavior and heterogeneity.

I used abundance estimates generated from the trapping grid analyses and extrapolated these estimates to the 851 hectares available to obtain a total population estimate for the study area. I used a naïve density estimate correction, mean maximum distance moved (Wilson and Anderson 1985), to account for edge effect and to correct for over estimation resulting from the effective trapping area being larger than the area of the trapping grids (Anderson et al. 1983). I plotted trap locations in ArcGIS 9.2 (Environmental Systems Research Institute, Redlands, California), and averaged maximum distance moved by each mouse captured more than once in a given session. Using mean maximum distance moved I increased the boundary width of the grid by one-half the estimated distance. The result was an estimate of abundance over a larger trapping area which, once corrected, adjusted the density and total population estimates extrapolated from abundance. With my original experimental design trapping grids were 7 x 7 in arrangement and 60 m by 60 m, or 0.36 ha. Using the mean maximum distance moved of 29.6 m, my effective trapping area was adjusted from 0.36 ha to 0.56 ha. I adjusted naïve abundance estimates to this area for calculating density and total population. Both density and total population were calculated by extrapolating abundance estimates to per hectare and total area available. I corrected variance estimates to account for decreasing the abundance estimates to determine new 95% confidence intervals.

RESULTS

I captured 558 unique Key Largo cotton mice in 1,530 total captures over 19,404 trap nights across all grids and seasons. All 33 trapping grids had cotton mice detected in 2 or more sessions. Sex ratio of all cotton mice was 1.95M:1F (369M:189F). Sex ratios were 1.56M:1F, 1.62M:1F, and 1.97M:1F in young (5 grids), medium (12 grids), and old (16 grids) strata, respectively. Capture and recapture probabilities for males were consistently higher than that of females for all sessions (Table 2.3). There was a progressive increase in numbers of new mice, unique individuals, and total captures, throughout the 3 sessions, and the population remained male biased (Table 2.4).

Population Estimates

Total population estimates indicated an overall increase over the 3 trapping sessions (Figure 2.2). In all analyses using the robust design, models ranked with the highest $QAIC_c$ weights were models with immigration and emigration parameters fixed (Table 2.2). Extrapolating abundance estimates from closed capture estimates in program CAPTURE, I calculated density in session 1 at 11.7 mice/ha (95% CI 10.7-12.6). I calculated a density of 17.5

mice/ha (95% CI 16.7-18.34) in session 2, and 23.2 mice/ha (95% CI 21.7-24.4) in session 3 using the robust design in program MARK. Extrapolated total population estimates were 9,947 in the first session, 14,905 in the second session, and 19,757 in the third session.

Grid Subsets

A subset of 16 grids was the maximum number of subsets that met the criteria (> 3 captures in each session) for analysis in session 1 (Table 2.5). Because it was appropriate to use program CAPTURE for the 33 grid analysis in session 1, I also used CAPTURE to obtain estimates from the subset. However, there were not enough capture data in the 16-grid subset to produce a reliable population estimate. The estimate of total population in session 1 from 16 grids was 16,336. With the fewest captures and fewest numbers of individuals in this session, this estimate is much lower than the total population estimate from the 33 grids and outside the 95% confidence intervals.

Sessions 2 and 3 had sufficient captures for subset parameter estimation using the robust design. A subset of 28 grids was the maximum number of subsets that met the criteria for analysis in session 2. After removing grids individually with the highest variance, subset analysis in session 2 allowed for a 61% percent reduction in total number of trapping grids. A minimum of 13 trapping grids (Table 2.6) was necessary to estimate density and total population with 10% of the 33 total grids estimates (Table 2.7). The subset analysis yielded a density estimate of 18.7 mice/ha (95% CI 18.4-18.9) and total population estimate of 15,883 cotton mice.

A 30 grid subset was the maximum number that met the criteria for analysis in session 3. After removing grids individually with the highest variance, session 3 allowed for a 64% percent reduction in the total trapping grids, with 12 grids (Table 2.8) providing estimates within the confidence intervals and within 10% of the density and total population estimate from all 33 grids (Table 2.9). The 12 grid density estimate was 21.9 mice/ha (95% CI 21.6-22.2) and a total population estimate of 18,623.

DISCUSSION

Grid subset reduction was successful in both the second and third trapping sessions. In both sessions, I was able to reduce the minimum number of grids needed to monitor the population number by over 60% to 13 grids in session 2 and 12 grids in session 3. Continued subset reduction produced wide confidence intervals and estimates out of the 10% range of the 33 grid estimate, which indicated the models were beginning to estimate with an insufficient amount of data. My grid reductions provide managing agencies with a set of trapping grids that can feasibly be monitored in a short amount of time while producing estimates similar to those from a larger sample size. These subsets are, however, a minimum number of grids necessary to estimate demographic parameters. If 2007 had a higher than typical population of cotton mice, additional grid(s) may be necessary in the future.

My cotton mouse density estimate of 23.2 mice/ha (95% CI 21.7-24.7) in session 3 is similar to estimates from Barbour and Humphrey (1982) of 21.8 cotton mice mice/ha and Humphrey (1988) of 21.2 cotton mice/ha. However, all of these estimates are much higher than the estimates of Sasso and Gaines (2002) who reported a mean of 9.1 mice/ha (range of 7.1-12.1 mice/ha). Sasso and Gaines established 4 trapping grids of which only 3 were monitored during the duration of the project because of an influx of fire ants on one grid. While it is possible the cotton mouse population had experience a decline during the period of their study, their lower density estimates likely resulted from the limited replication throughout the hammock and hammock strata. Additionally, they only trapped for 3 consecutive nights which may have reduced unique individual captures. During my study, 13.5% of new captures occurred on night 4. If a forth night of trapping by Sasso and Gaines had provided additional individuals as in my study, increased captures may have changed their detection probabilities and increased density estimates.

The population increase that occurred over the seasonal trapping sessions in 2007 may have resulted from seasonal changes in detection probabilities, seasonal changes in population, or both. Detection probabilities for both capture and recapture generally increased for both sexes through the trapping sessions (Table 2.3). Thus, the perceived population increase may be a behavioral effect where individuals are more likely to be captured later in the year, possibly as a result of differences in food availability and trap shyness. However, previous studies have noted variation in both density and reproduction with many populations of cotton mice. Multiple studies of *Peromyscus* have documented increases in population densities during autumn and winter (Pearson 1953, McCarley 1954, Lord et al. 1973, Bigler and Jenkins 1975, Smith and Vrieze 1979). Although Florida populations of cotton mice breed year-round, summer recruitment into the population may be minimal compared to winter (Bigler and Jenkins 1975, Smith and Vrieze 1979), contributing to the observed seasonal variation. While many *Peromyscus* species have their highest reproduction from spring to autumn (Banks 1967), Florida populations have been documented with highest reproduction in late autumn and early winter (Blair 1953, Lord et al. 1973, Bigler and Jenkins 1975).

Availability of food can influence rodent population fluctuations (Hansson 1971, Miller and Getz 1977, Cole and Batzli 1978, Smith et al. 1984, Ostfeld et al. 1996). In tropical Florida, November to March is considered the dry season and May to September the wet season (Tomlinson 2001). Mast production for tropical plants generally increases during the wet season

(Lieberman 1982, Levey 1988, Bancroft et al. 2000) and greater availability of food may support an increase in the cotton mouse population. Pearson (1953) found that cotton mouse populations in mesic hammocks of Levy County, Florida peaked from October to December. Smith and Vrieze (1979) estimated cotton mouse densities in the Taylor Slough of the Everglades – approximately 20 miles to the west of our study area on mainland Florida – as high as 254 mice/ha at the beginning of the dry season. In Key Largo, Sasso and Gaines (2002) also found Key Largo cotton mouse abundance peaked during early winter.

The Key Largo cotton mouse population appears to be male biased, ranging between 61.3-66.2% males in all trapping sessions. A skewed sex ratio is not uncommon for *P. gossypinus*; other studies yielded similar results with sex ratios up to 2.67:1 (Pournelle 1950, Pearson 1953, Bigler and Jenkins 1975). A bias towards males may reflect the actual population sex ratio, but also may result from a difference in detection probabilities between sexes. In my study, males exhibited higher capture and recapture probabilities than females in all 3 trapping sessions (Table 2.3). Although the population was male-biased in all seasons in my study, a recent study by Sasso and Gaines (2002) found captures to be 58.5 ± 3.3% male during the wet season but 46.6 ± 3.7% during the dry season, suggesting that sex ratios may vary annually.

Previous researchers reached different conclusions about cotton mouse occupancy among habitat strata (see: Brown 1978, Barbour and Humphrey 1982, Humphrey 1988, Keith and Gaines 2002, Sasso and Gaines 2002). Brown (1978) suggested cotton mice were only found in old hammock, but each subsequent study found increasing cotton mice abundance in younger habitat. Sasso and Gaines (2002) and Keith and Gaines (2002) suggested medium-old hammock was optimal for cotton mice. My inability to estimate abundance in each habitat stratum may have biased the pooled density and total population estimates. My trapping grids were randomly selected in each stratum to have to have proportional allocation to the available habitat, not randomly established in all cotton mouse habitat. Standardized capture numbers (number of unique individuals for all sessions divided by number of grids in each stratum) suggest that cotton mouse are most abundant in medium hammock, with 13.2, 19.1, and 16.4 mice/grid in young, medium, and old hammock, respectively, and as a result, this may have over or underestimated the true population. While these results support those found in the most recent literature suggesting that medium-aged stratum is the optimal age, young and old strata also appear to support substantial cotton mouse populations.

My population estimates maybe conservative and represents only one year, while other research on *Peromyscus* species has indicated both season and annual fluctuations in the population size (Miller and Getz 1977, Smith and Vrieze 1979). However, seasonal peaks in cotton mouse abundance during fall and winter is consistent with several other *Peromyscus* studies (Pournelle 1950, Pearson 1953, Bigler and Jenkins 1975, Smith and Vrieze 1979).

MANAGEMENT IMPLICATIONS

I recommended monitoring the cotton mouse population in November or December because the increase in capture data will allow for reliable parameter estimation. According to the subset analyses conducted with 2007 cotton mouse data, the population can be monitored with a minimum of 12 trapping grids. Data can be analyzed using a closed capture method which is simpler than the robust design because survival, emigration, and immigration estimates are not necessary. Because fewer parameters are estimated, closed capture analyses can produce reliable estimates when conducted with fewer captures numbers.

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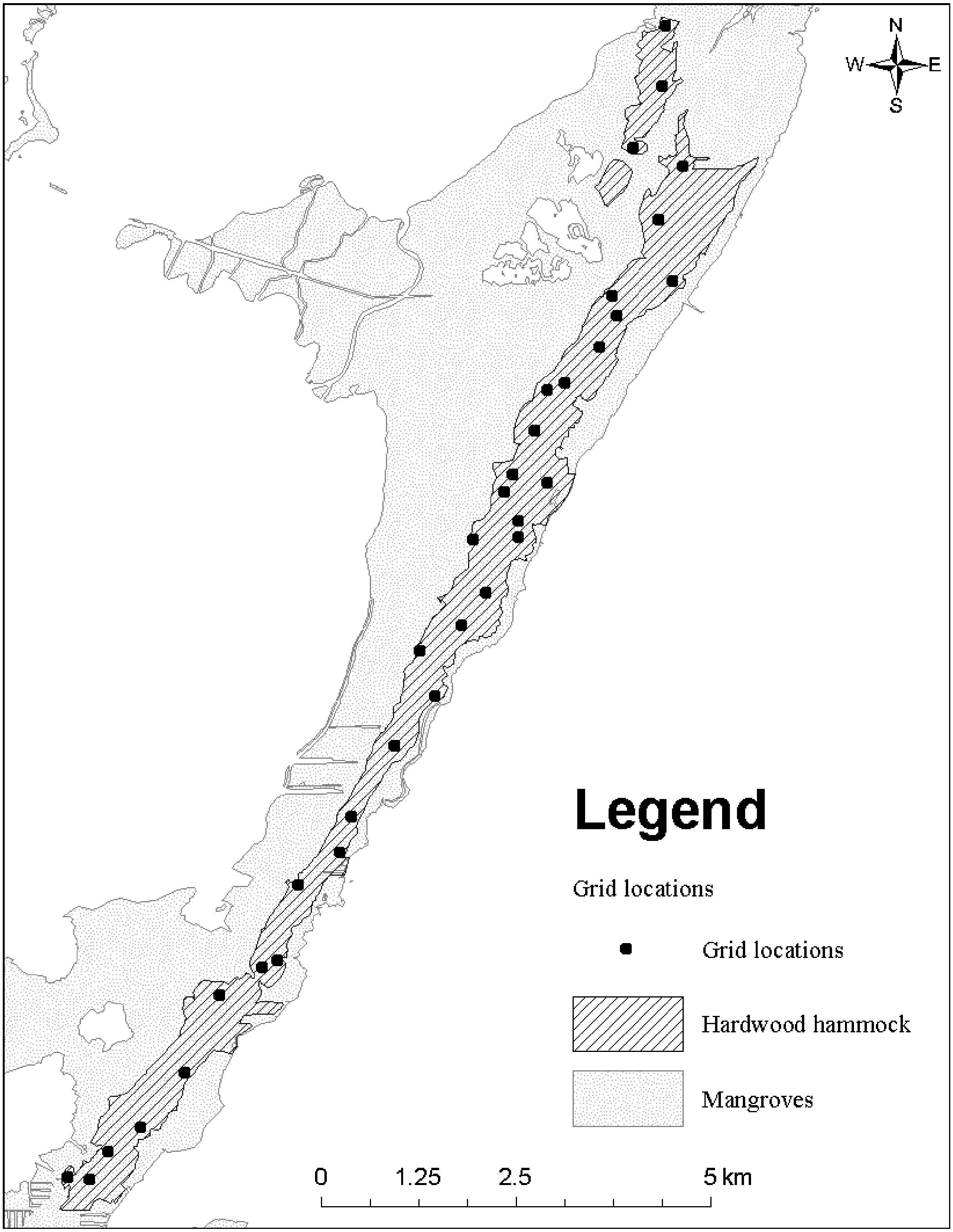

Figure 2.1. Locations of 33 trapping grids used to develop a standardized methodology for estimating Key Largo cotton mouse population abundance on north Key Largo, Florida, USA, 2007.

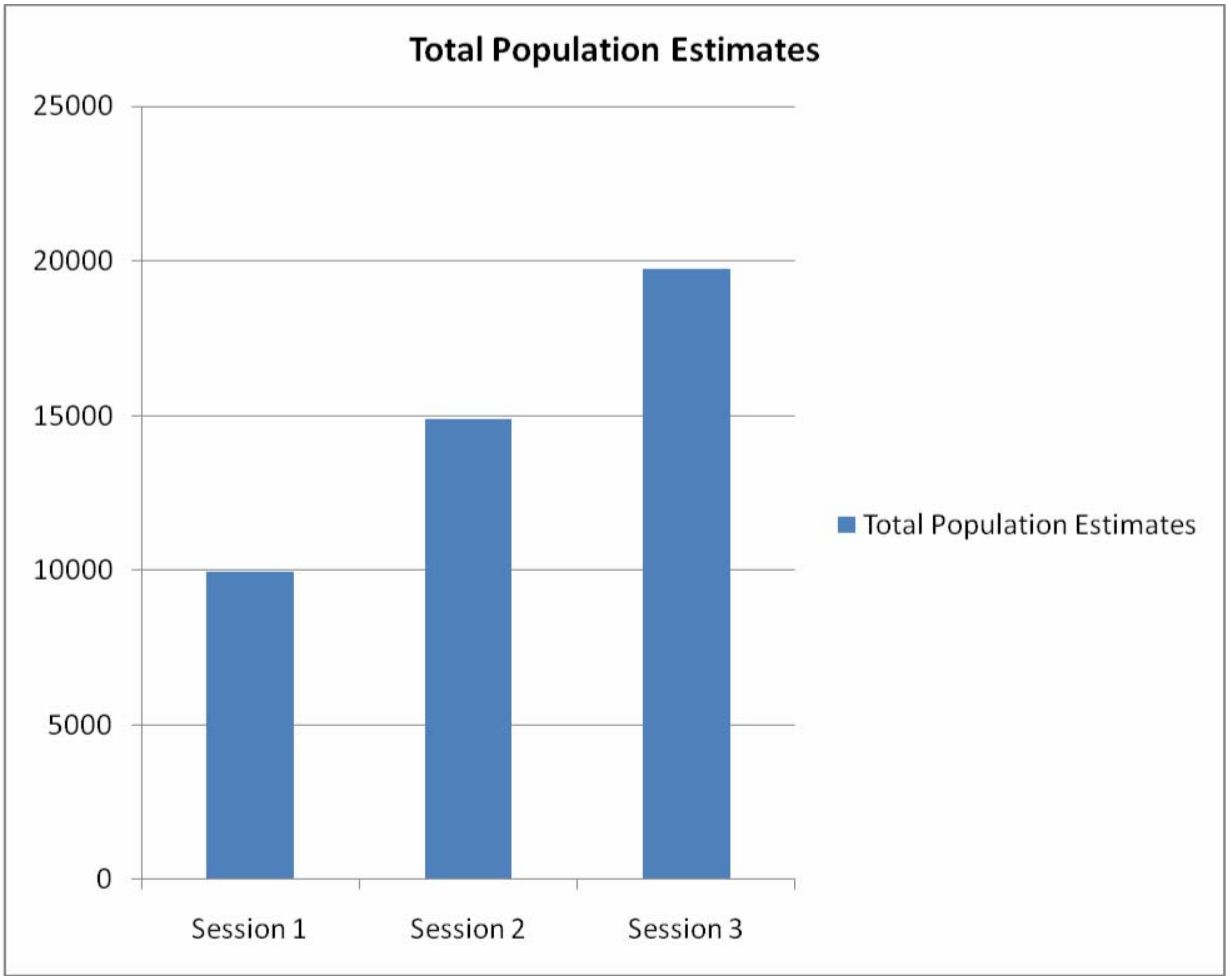

Figure 2.2. Key Largo cotton mouse population estimates in 3 trapping sessions in Key Largo, Florida, USA, 2007. Session 1 was from 1 March to 11 May; Session 2 from 4 July to 7 September; and Session 3 from 29 October to 31 December. Error bars represent standard error.

Table 2.1. Unique number of cotton mice captured by grid and session on 34 trapping grids used to develop a standardized methodology for estimating Key Largo cotton mouse population abundance on north Key Largo, Florida, USA, 2007.

Grid Number	1 March-11 May	4 July-7 September	29 October-31 December	Variance
1	4	12	12	21.3
2	3	5	8	6.3
3	1	8	16	56.3
4	6	10	12	9.3
5	1	3	12	34.3
6	2	12	16	52.0
7	3	5	10	13.0
8	2	6	10	16.0
9	9	10	7	2.3
10	1	7	5	9.3
11	2	5	12	26.3
12	2	0	2	0.0
13	13	15	18	6.3
14	3	1	0	2.3
15	4	6	2	4.0
16	1	15	9	49.3
17	3	6	10	12.3
18	0	7	5	13.0
19	8	7	10	2.3
20	4	3	8	7.0
21	8	11	10	2.3
22	8	13	10	6.3
23	13	11	9	4.0
24	11	8	11	3.0
25	3	4	13	30.3
26	8	8	11	3.0
27	3	1	7	9.3
28	5	17	23	84.0
29	6	9	16	26.3
30	7	13	8	10.3
31	2	15	10	43.0
32	3	4	4	0.3
33*	0	0	1	0.3
34	11	10	14	4.3

[a] Grid 33 not used in analysis because it was atypical habitat.

Table 2.2. Quasi-Akaike's Information Criteria for small sample size (QAICc), difference in QAICc values between models and with the lowest QAICc weight (Δ QAICc), Akaike weights (w_i), and number of parameters (k) for the 23 candidate models with estimates from the 33 grid analysis used to develop a standardized methodology for estimating Key Largo cotton mouse population abundance on north Key Largo, Florida, USA, 2007. A variance inflation factor of 1.588 was used to estimate parameters. Immigration and emigration were fixed in models not including Gamma" and Gamma'.

Model[a]	QAICc	ΔQAICc	w_i	k
S(sex)(.)pi(sex)p(pr*h)c(pr*h)	-863.306	0.000	0.521	21
S(sex)pi(sex)p(pr*h)c(pr*h)	-861.644	1.662	0.227	22
S(.)pi(sex)p=c(pr*h)	-861.047	2.259	0.168	15
S(sex*t)pi(sex)p(pr*h)c(pr*h)	-859.115	4.191	0.064	24
S(.)pi(sex)p=c(sex*h)	-856.246	7.060	0.015	21
S(.)gamma"(sex*t)gamma'(sex*t)pi(sex)p(pr*h) c(pr*h)	-853.373	9.933	0.004	27
S(sex)gamma"(sex*t)gamma'(sex*t)pi(sex)p(pr*h)c(pr*h)	-851.295	12.011	0.001	28
S(sex*t)gamma" (sex*t)gamma'(sex*t)pi(sex)p(pr*h)c(pr*h)	-847.130	16.176	0.000	30
S(sex)(.)pi(.)p(pr*h)c(pr*h)	-840.693	22.613	0.000	20
S(sex)pi(sex)p(h)=c(h)	-840.605	22.700	0.000	12
S(.)pi(sex)p=c(Sex(.)*h	-839.517	23.789	0.000	13
S(.)pi(sex)p(sex*h)c(sex*h)	-833.526	29.779	0.000	17
S(sex)gamma"(sex)gamma'(sex)pi(sex)p(h)=c(h)	-832.467	30.838	0.000	16
S(sex*t)gamma"(sex*t)gamma'(sex*t)pi(sex)p(h)=c(h)	-824.413	38.893	0.000	20
S(sex*t)gamma"(sex*t)gamma'(sex*t)pi(sex)p(h)c(h)	-821.852	41.454	0.000	22
S(.)Pi(sex)c=p(pr*sex)	-794.494	68.811	0.000	15
S(sex)(.)Pi(pr*sex)c=p(pr*sex)	-786.297	77.008	0.000	19
S(sex)(.)gamma"(.)gamma'(.)Pi(pr*sex)c=p(pr*sex)	-782.570	80.736	0.000	21
S(sex)(.)pi(sex)p(pr)c(pr)	-776.781	86.524	0.000	15
S(sex)(.)*t)pi(sex)p(pr*h)c(pr*h)	-762.416	100.890	0.000	22
Global	-757.154	106.152	0.000	106
S(sex)pi(sex)p(.)=c(.)	-744.662	118.644	0.000	11
S(sex)gamma"(sex)gamma'(sex)pi(sex)p(.)=c(.)	-739.565	123.741	0.000	15

[a] S = Survival, gamma" = emigration, gamma' = immigration, pi = mixture distribution, p = capture, c = recapture, (.) = constant, t = time, h = heterogeneity, pr = primary periods (trapping session).

Table 2.3. Parameter estimates from the top model, unconditional standard errors, and 95% lower (L) and upper (U) confidence intervals (CI) from the top models for 33 trapping grids used to develop a standardized methodology for estimating Key Largo cotton mouse population abundance on north Key Largo, Florida, USA, 2007. Gamma'' and Gamma' parameters were fixed and are therefore not present.

Parameter[a]	Estimate	SE	L 95% CI	U 95% CI
S M	0.597	0.059	0.478	0.706
S F	0.550	0.057	0.438	0.658
pi 1 March-11 May F	0.461	0.114	0.257	0.678
pi 1 March-11 May M	0.787	0.061	0.643	0.884
p 1 March-11 May F	0.050	0.046	0.008	0.258
p 1 March-11 May M	0.387	0.108	0.205	0.606
p 4 July-7 September F	0.288	0.068	0.174	0.437
p 4 July-7 September M	0.630	0.121	0.382	0.825
p 29 October-31 December F	0.229	0.050	0.145	0.341
p 29 October-31 December M	0.760	0.093	0.538	0.896
c 1 March-11 May F	0.025	0.146	0.000	1.000
c 1 March-11 May M	0.765	0.069	0.604	0.874
c 4 July-7 September F	0.288	0.054	0.195	0.403
c 4 July-7 September M	0.490	0.066	0.364	0.618
c 29 October-31 December F	0.260	0.061	0.159	0.396
c 29 October-31 December M	0.815	0.045	0.712	0.887
N 1 March-11 May F	112.472	31.403	50.923	174.021
N 1 March-11 May M	297.109	146.398	10.168	584.049
N 4 July-7 September F	116.538	8.097	100.668	132.409
N 4 July-7 September M	207.403	21.594	165.078	249.727
N 29 October-31 December F	132.404	11.246	110.361	154.447
N 29 October-31 December M	303.358	34.737	235.273	371.443

[a] S = Sex, pi = mixture distribution, p = capture, c = recapture, N = abundance estimate.

Table 2.4. Numbers of new captures, unique captures, total captures, and sex ratios in 3 sessions from the 33 trapping grids used to develop a standardized methodology for estimating Key Largo cotton mouse population abundance on north Key Largo, Florida, USA, 2007.

Captures	1 March-11 May	4 July-7 September	29 October-31 December
New captures	161	197	201
Unique captures	161	259	334
Total captures	333	486	721
Sex ratio	1.58:1	1.62:1	1.96:1

Table 2.5. Grid number, habitat stratum, and ownership of the 16 trapping grids that met the criteria for subsampling in session 1 from 1 March-11 May 2007. Ownership of the grid locations are Crocodile Lake National Wildlife Refuge (CLNWR) and Dagny Johnson Key Largo Hammock Botanical State Park (DJKLHBSP).

Grid number	Habitat stratum	Ownership
1[a]	Medium	DJKLHBSP
4	Medium	DJKLHBSP
9	Old	DJKLHBSP
13	Medium	CLNWR
15	Old	CLNWR
19	Old	DJKLHBSP
20	Medium	DJKLHBSP
21	Young	DJKLHBSP
22	Old	DJKLHBSP
23	Medium	DJKLHBSP
24[b]	Old	CLNWR
26	Medium	CLNWR
28	Old	DJKLHBSP
29	Medium	CLNWR
30	Medium	DJKLHBSP
34[c]	Young	DJKLHBSP

[a] Grid was located on the Bayside, but on state-owned property.
[b] Grid was located on the Bayside, but on state-owned property leased to the refuge.
[c] Grid was reclassified from a disturbed to young stratum.

Table 2.6. Grid number, habitat stratum, and ownership of the 13 trapping grids that were selected as the best subset for subsampling in session 2 from 4 July-7 September 2007. Ownership of the grid locations are Crocodile Lake National Wildlife Refuge (CLNWR) and Dagny Johnson Key Largo Hammock Botanical State Park (DJKLHSP).

Grid number	Habitat stratum	Ownership
2	Young	DJKLHBSP
4	Medium	DJKLHBSP
7	Medium	DJKLHBSP
9	Old	DJKLHBSP
17	Medium	CLNWR
19	Old	DJKLHBSP
21	Young	DJKLHBSP
22	Old	DJKLHBSP
23	Medium	DJKLHBSP
24[a]	Old	CLNWR
26	Medium	CLNWR
30	Medium	DJKLHBSP
34[b]	Young	DJKLHBSP

[a] Grid was located on the Bayside, but on state-owned property leased to the refuge.
[b] Grid was reclassified from a disturbed to young stratum.

Table 2.7. Quasi-Akaike's Information Criteria for small sample size (QAICc), difference in QAICc values between models and with the lowest QAICc weight (Δ QAICc), Akaike weights (w_i), and number of parameters (k) for the 23 candidate models with estimates from the 13 grid subset analysis of session 2 from 4 July-7 September, 2007. Estimates were used to develop a standardized methodology for estimating Key Largo cotton mouse population abundance on north Key Largo, Florida, USA. A variance inflation factor of 1.026 was used to estimate parameters. Immigration and emigration were fixed in models not including Gamma" and Gamma'.

Model[a]	QAICc	ΔQAICc	w_i	k
S(sex)(.)pi(sex)p(pr*h)c(pr*h)	-18.6759	0.0000	0.81236	21
S(sex)pi(sex)p(pr*h)c(pr*h)	-14.3802	4.2957	0.09483	22
S(sex*t)pi(sex)p(pr*h)c(pr*h)	-12.9558	5.7201	0.04652	24
S(sex)(.)pi(.)p(pr*h)c(pr*h)	-12.5946	6.0813	0.03883	20
S(.)gamma"(sex*t)gamma'(sex*t)pi(sex)p(pr*h) c(pr*h)	-8.0148	10.6611	0.00393	27
S(sex)gamma"(sex*t)gamma'(sex*t)pi(sex)p(pr*h)c(pr*h)	-7.5314	11.1445	0.00309	28
S(.)pi(sex)p=c(pr*h)	-1.6178	17.0581	0.00016	15
S(sex*t)gamma" (sex*t)gamma'(sex*t)pi(sex)p(pr*h)c(pr*h)	-1.4530	17.2229	0.00015	30
S(sex)pi(sex)p(h)=c(h)	-0.4823	18.1936	0.00009	12
S(.)pi(sex)p=c(Sex(.)*h	1.5286	20.2045	0.00003	13
S(.)pi(sex)p(sex*h)c(sex*h)	6.4147	25.0906	0.00000	17
S(sex)gamma"(sex)gamma'(sex)pi(sex)p(h)=c(h)	7.8922	26.5681	0.00000	16
S(.)pi(sex)p=c(sex*h)	11.4248	30.1007	0.00000	21
S(sex)(.)pi(sex)p(pr)c(pr)	14.2199	32.8958	0.00000	15
S(sex*t)gamma"(sex*t)gamma'(sex*t)pi(sex)p(h)=c(h)	15.2877	33.9636	0.00000	20
S(sex*t)gamma"(sex*t)gamma'(sex*t)pi(sex)p(h)c(h)	17.8818	36.5577	0.00000	22
S(sex)(.)*t)pi(sex)p(pr*h)c(pr*h)	28.0866	46.7625	0.00000	22
S(.)Pi(sex)c=p(pr*sex)	32.8946	51.5705	0.00000	15
S(sex)(.)Pi(pr*sex)c=p(pr*sex)	41.3446	60.0205	0.00000	19
S(sex)(.)gamma"(.)gamma'(.)Pi(pr*sex)c=p(pr*sex)	45.5670	64.2429	0.00000	21
S(sex)pi(sex)p(.)=c(.)	47.6657	66.3416	0.00000	11
S(sex)gamma"(sex)gamma'(sex)pi(sex)p(.)=c(.)	54.7368	73.4127	0.00000	15
Global	97.7778	116.4537	0.00000	106

[a] S = Survival, gamma" = emigration, gamma' = immigration, pi = mixture distribution, p = capture, c = recapture, (.) = constant, t = time, h = heterogeneity, pr = primary periods (trapping session).

Table 2.8. Grid number, habitat stratum, and ownership of the 12 recommended trapping grids for obtaining population estimates of Key Largo cotton mouse abundance in session 3 from 29 October-31 December 2007. Ownership of the grid locations are Crocodile Lake National Wildlife Refuge (CLNWR) and Dagny Johnson Key Largo Hammock Botanical State Park (DJKLHBSP).

Grid number	Habitat stratum	Ownership
2	Young	DJKLHSP
4	Medium	DJKLHSP
9	Old	DJKLHSP
17	Medium	CLNWR
19	Old	DJKLHSP
21	Young	DJKLHSP
22	Old	DJKLHSP
23	Medium	DJKLHSP
24[a]	Old	DJKLHSP
26	Medium	CLNWR
30	Medium	DJKLHSP
34	Young	DJKLHSP

[a] Grid located on bayside within Refuge but on state-owned property leased to CLNWR

Table 2.9. Quasi-Akaike's Information Criteria for small sample size (QAICc), difference in QAICc values between models and with the lowest QAICc weight (Δ QAICc), Akaike weights (w_i), and number of parameters (k) for the 23 candidate models with estimates from the 12 grid subset analysis of session 3 from 29 October-31 December, 2007. Estimates were used to develop a standardized methodology for estimating Key Largo cotton mouse population abundance on north Key Largo, Florida, USA. A variance inflation factor of 1.081 was used to estimate parameters. Immigration and emigration were fixed in models not including Gamma" and Gamma'.

Model[a]	QAICc	ΔQAICc	w_i	k
S(sex)(.)pi(sex)p(pr*h)c(pr*h)	22.2291	0.0000	0.82068	21
S(sex)pi(sex)p(pr*h)c(pr*h)	26.7501	4.5210	0.08560	22
S(sex)(.)pi(.)p(pr*h)c(pr*h)	27.4247	5.1956	0.06109	20
S(sex*t)pi(sex)p(pr*h)c(pr*h)	29.2572	7.0281	0.02444	24
S(.)gamma"(sex*t)gamma'(sex*t)pi(sex)p(pr*h) c(pr*h)	33.8705	11.6414	0.00243	27
S(.)pi(sex)p=c(pr*h)	34.0226	11.7935	0.00226	15
S(sex)pi(sex)p(h)=c(h)	34.5708	12.3417	0.00171	12
S(sex)gamma"(sex*t)gamma'(sex*t)pi(sex)p(pr*h)c(pr*h)	36.0608	13.8317	0.00081	28
S(.)pi(sex)p=c(Sex(.)*h	36.0764	13.8473	0.00081	13
S(sex*t)gamma" (sex*t)gamma'(sex*t)pi(sex)p(pr*h)c(pr*h)	40.4627	18.2336	0.00009	30
S(.)pi(sex)p(sex*h)c(sex*h)	41.7583	19.5292	0.00005	17
S(sex)gamma"(sex)gamma'(sex)pi(sex)p(h)=c(h)	42.9649	20.7358	0.00003	16
S(.)pi(sex)p=c(sex*h)	44.9499	22.7208	0.00001	21
S(sex*t)gamma"(sex*t)gamma'(sex*t)pi(sex)p(h)=c(h)	51.0050	28.7759	0.00000	20
S(sex*t)gamma"(sex*t)gamma'(sex*t)pi(sex)p(h)c(h)	54.5326	32.3053	0.00000	22
S(sex)(.)pi(sex)p(pr)c(pr)	54.8813	32.6522	0.00000	15
S(.)Pi(sex)c=p(pr*sex)	68.0511	45.8220	0.00000	15
S(sex)(.)*t)pi(sex)p(pr*h)c(pr*h)	69.2646	47.0355	0.00000	22
S(sex)(.)Pi(pr*sex)c=p(pr*sex)	76.5249	54.2958	0.00000	19
S(sex)pi(sex)p(.)=c(.)	80.2607	58.0316	0.00000	11
S(sex)(.)gamma"(.)gamma'(.)Pi(pr*sex)c=p(pr*sex)	80.6051	58.3760	0.00000	21
S(sex)gamma"(sex)gamma'(sex)pi(sex)p(.)=c(.)	87.2000	64.9709	0.00000	15
Global	143.4987	121.2696	0.00000	106

[a] S = Survival, gamma" = emigration, gamma' = immigration, pi = mixture distribution, p = capture, c = recapture, (.) = constant, t = time, h = heterogeneity, pr = primary periods (trapping session).

CHAPTER 3

CONCLUSIONS AND MANAGEMENT RECOMMENDATIONS

Although the Key Largo cotton mouse (*Peromyscus gossypinus allapaticola*) was listed as federally endangered in 1984 and remaining habitat was purchased for protection under state and federal management, there is an overall lack of information about cotton mouse population structure and habitat requirements. Initial listing under the Endangered Species Act was based on a purported population decline, but there has been little evidence in the literature to support this decline. The cotton mouse was jointly listed with the Key Largo woodrat (*Neotoma floridana smalli*), another rodent endemic to Key Largo. Woodrat population decline is well-documented, and as a result, the majority of research and funding has been dedicated to monitoring woodrat populations.

Given an overall lack of understand about the current population status of the cotton mouse, the goals of my research were to describe the population structure and to develop a methodology for long-term population monitoring. With estimates established from trapping data, the methodology will provide managing agencies with a protocol for efficient monitoring given personnel and budgetary constraints.

My density and total estimates from 2007 were similar to past estimates, particularly for session 3. The session 3 density estimate was 23.2 mice/ha (95% CI 21.7-24.7), similar to the estimates by Barbour and Humphrey (1982) of 21.8 cotton mice/ha and 21.2 cotton mice/ha by Humphrey (1988). Humphrey estimated the cotton mouse population at 18,000, which is similar to my third session estimate 19,757. It is unknown what changes the cotton mouse populations have experience since listing, but given the similarities between estimates, it is plausible to assume the population has remained stable since populations were last surveyed.

I caution that my data describes only one year of cotton mouse population variation and may not be representative of other years. While other research on *Peromyscus* species have indicated yearly fluctuations in populations, (Miller and Getz 1977, Smith and Vrieze 1979), I cannot compare the changes in my 2007 population estimates to year-to-year seasonal and annual variation. Additionally, without multiple years of abundance estimates, it is difficult to know how these estimates compare to other years. However, my results of cotton mouse abundance peaking in the fall and winter is consistent with several other *Peromyscus* studies (Pournelle 1950, Pearson 1953, Bigler and Jenkins 1975, Smith and Vrieze 1979). Although Florida populations of cotton mice breed year-round, summer recruitment into the population may be minimal compared to winter (Bigler and Jenkins 1975, Smith and Vrieze 1979), contributing to the observed seasonal variation I observed. While many *Peromyscus* species have their highest reproduction from spring to autumn (Banks 1967), Florida populations have been documented with highest reproduction in late autumn and early winter (Blair 1953, Lord et al. 1973, Bigler and Jenkins 1975).

Previous researchers reached different conclusions about cotton mouse occupancy among habitat strata (see: Brown 1978, Barbour and Humphrey 1982, Humphrey 1988, Keith and Gaines 2002, Sasso and Gaines 2002). Brown (1978) suggested cotton mice were only found in old hammock, but each subsequent study found increasing cotton mice abundance in younger habitat. Sasso and Gaines (2002) and Keith and Gaines (2002) suggested medium-old hammock was optimal for cotton mice. My inability to estimate abundance in each habitat stratum may have biased the pooled density and total population estimates. My trapping grids were randomly selected in each stratum to have to have proportional allocation to the available habitat, not randomly established in all cotton mouse habitat. Standardized capture numbers (number of unique individuals for all sessions divided by number of grids in each stratum) suggest that cotton mouse are most abundant in medium hammock, with 13.2, 19.1, and 16.4 mice/grid in young, medium, and old hammock, respectively, and as a result, this may have over or underestimated the true population. While these results support those found in the most recent literature suggesting that medium-aged stratum is the optimal age, young and old strata also appear to support substantial cotton mouse populations.

Monitoring Protocol

Continuing population monitoring is a fundamental part of managing for Key Largo cotton mice. With the exception of the few studies on the cotton mouse in the past 3 decades, the overall lack of monitoring has created uncertainty as to actual population status and trends. Only with regular monitoring can managers understand seasonal and annual cotton mouse population changes. To monitor the population trends overtime, my selection of grid subsets was chosen from grids with an established population during each trapping session. First, I retained grids with >3 individuals in a trapping session. Second, I removed grids having the highest variance between numbers of unique individuals in a session.

Grid subset reduction was successful in both the second and third trapping sessions. In both sessions, I was able to reduce the minimum number of grids needed to monitor the population number by over 60% to 13 grids in session 2 and 12 grids in session 3. A subset of 28 grids was the maximum number of subsets that met the criteria for analysis in session 2. After removing grids individually with the highest variance, subset analysis in session 2 allowed for a 61% percent reduction in total number of trapping grids. A minimum of 13 trapping grids was necessary to estimate density and total population with 10% of the 33 total grids estimates. The subset analysis yielded a density estimate of 18.7 mice/ha (95% CI 18.4-18.9) and total population estimate of 15,883 cotton mice.

A 30 grid subset was the maximum number that met the criteria for analysis in session 3. After removing grids individually with the highest variance, session 3 allowed for a 64% percent reduction in the total trapping grids, with 12 grids providing estimates within 10% of the density and total population estimate from all 33 grids. The 12 grid density estimate was 21.9 mice/ha (95% CI 21.6-22.2) and a total population estimate of 18,623.

My grid reductions provide managing agencies with a set of trapping grids that can feasibly be monitored in a short amount of time while producing estimates similar to those from a larger sample size. These subsets are, however, a minimum number of grids necessary to estimate demographic parameters. If 2007 had a higher than typical population of cotton mice, additional grid(s) may be necessary in the future.

My selection criteria only support the grid choice for 2007 data, and still need to be tested for future monitoring. Because a year's population is independent of other years, it is possible the subsets will require updating, with possible change in locations or number of grids necessary to efficiently monitor the population. Continued monitoring the grid subset will facilitate an understanding of annual variation in cotton mouse abundance, and results may suggest fewer or additional grids to be included in monitoring.

My trapping protocol can be effectively implemented with 2 people. With only 3 hours available for checking traps and processing animals as stipulated in the U.S. Fish and Wildlife endangered species permit, a trapping crew of 2 should not set more than 2 grids the first night, and should set a third grid the second night. This allows time for processing a large number of new animals receiving marks the first night, and reduces the chance of exceeding the 3 hour requirement. With uncertainly in how many animals will be captured on any of the trap nights, it is not recommended to trap more than 3 grids per night. I found 4 nights of trapping to be sufficient to estimate demographic parameters. Since 13.4% of all new cotton mice on the fourth night, a fifth night of trapping should be considered. Having an additional trap night per grid would likely help decrease error in parameter estimates. If 3 or more people checked individual trap lines on a grid, then the increased efficiency would allow for trapping 3 grids on the first night. This would also allow for work to be completed in a normal Monday-Friday work week, a benefit for state or federal employees. Weather permitting, traps would need to be set on Monday evening and checked the mornings of Tuesday to Friday. This would require 4 weeks to trap the 12 grids, but less time if additional crews were simultaneously trapping subsets.

My trapping grids were 7 x 7 in arrangement with a trap placed every 10 m. I did not know the home range of the Key Largo cotton mouse, so I initially established the grid size to be twice the size of another Florida cotton mouse population's estimate home range of 0.18 ha (Layne 1974). Using the mean maximum distance moved for all recaptured mice of 29.62 m, my uncorrected effective grid size (60 m x 60 m) was twice the length of this movement, suggesting it was an appropriate size.

When monitoring the population, traps should be baited with whole oats no more than 3 hours before sunset, and animals released no more than 3 hours after sunrise. I was concerned about trap disturbance and mortality, I did not use other bait such as fruits or peanut butter. Disturbance occurred on only 1.5% of the 19,992 total trap nights and each of the 4 nights had similar disturbance rates (nights 1-4: 80; 62; 69; and 91 traps disturbed, respectively).

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Appendix A. Habitat stratum, grid number, ownership, and Universal Transverse Mercator (UTM) coordinates of the 34 trapping grids used to estimate Key Largo cotton mouse abundance. UTM coordinates represent the center of the grid, with trapping grid lines oriented along the cardinal directions. Grids listed as bayside are managed by Crocodile Lake National Wildlife Refuge (CLNWR), and grids listed as oceanside are managed by Dagny Johnson Key Largo Hammock Botanical State Park (DJKLHBSP). UTM coordinates are in NAD83 datum.

Strata	Grid Number	Ownership	Easting NAD83	Northing NAD83
Medium	1[a]	DJKLHBSP	570872	2799230
Young	2	DJKLHBSP	570828	2798482
Old	3	DJKLHBSP	570019	2795106
Medium	4	DJKLHBSP	570785	2796735
Old	5	DJKLHBSP	571102	2797426
Old	6	DJKLHBSP	570966	2795956
Medium	7	DJKLHBSP	570254	2795500
Medium	8	CLNWR	569607	2794642
Old	9	DJKLHBSP	568982	2792659
Old	10	DJKLHBSP	568987	2792859
Old	11	CLNWR	568901	2793460
Old	12	CLNWR	568796	2793238
Medium	13	CLNWR	569191	2794028
Young	14	DJKLHBSP	569348	2793345
Old	15	CLNWR	568405	2792624
Old	16	DJKLHBSP	568563	2791946
Medium	17	CLNWR	567719	2791192
Old	18	DJKLHBSP	567905	2790614
Old	19	DJKLHBSP	566840	2789067
Medium	20[b]	DJKLHBSP	566678	2788596
Young	21	DJKLHBSP	565874	2787218
Old	22	DJKLHBSP	565691	2787122
Medium	23	DJKLHBSP	563705	2784749
Old	24[c]	CLNWR	563180	2784455
Medium	25	DJKLHBSP	563471	2784405
Medium	26	CLNWR	566142	2788185
Young	27	CLNWR	569330	2794574
Old	28	DJKLHBSP	570458	2797667
Medium	29	CLNWR	565131	2786762
Medium	30	DJKLHBSP	564685	2785773
Old	31	DJKLHBSP	568253	2791529

Old	32	DJKLHBSP	567388	2789977
Young	33[d]	DJKLHBSP	570185	2795762
Young	34[d]	DJKLHBSP	564125	2785067

[a] Grid was located on the Bayside, but on state-owned property.
[b] Grid was offset at 50-degrees East
[c] Grid was located on the Bayside, but on state-owned property leased to the refuge.
[d] Grid was reclassified from a disturbed to young stratum.