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RODENT POPULATION STUDY IN THE NORTH SHORE RESTORATION AREA, PART II (SURVEY OF RODENTS NEAR LAKE APOPKA)

by

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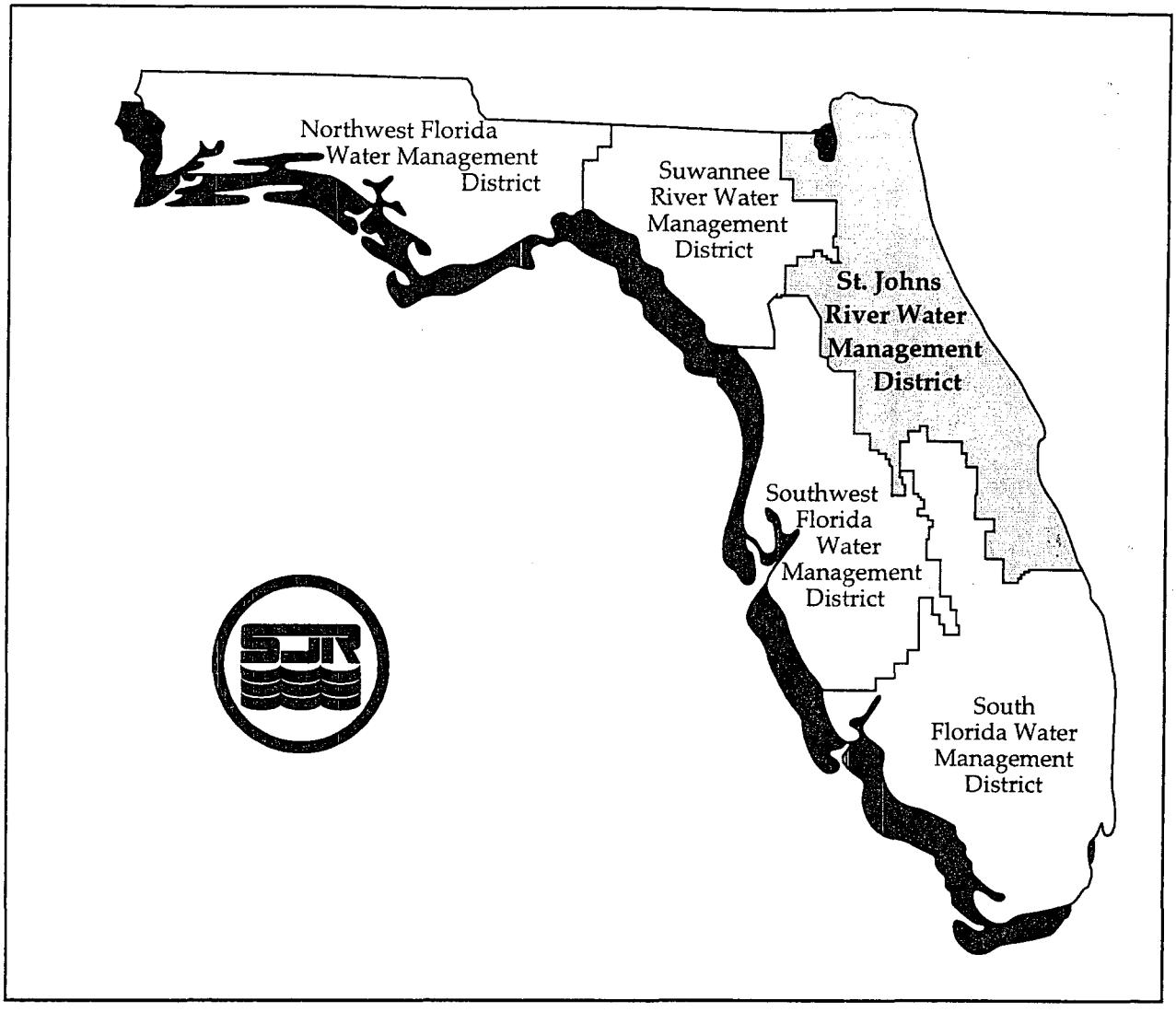

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EXECUTIVE SUMMARY

Eight small mammal trapping grids were established by stratified random placement within the 3,238-hectare North Shore Restoration Area (NSRA). Each grid was designed to sample approximately 0.5 hectare, with 49 Sherman traps spaced at 10-meter intervals. During phase I, traps were opened for two successive days at approximately 5-day intervals for a total of 8 days during November and December 1999. Limited trapping with Sherman live traps was conducted on transects and in farm buildings. A total of 3,456 trap nights were registered, and 1,319 rodents were captured. About 70% of the rodent captures were cotton rats (*Sigmodon hispidus*). Two hundred and thirty-four house mice (*Mus musculus*) were marked with numbered monel ear tags and released at the point of capture. All house mouse captures were marked on the grids. House mice were also ear-tagged on one trapping transect. The third species of rodent captured in the live traps was the rice rat (*Oryzomys palustris*).

Captures per trap night was used as a standard metric to compare grids and relative abundance of species among grids. Capture success was very high due to the extraordinary numbers of cotton rats present on the NSRA during phases I and II. Capture success of house mice was much lower than for cotton rats. Nonetheless, mark-recapture estimates suggested that modest to very high densities of house mice were present in 1999. Recapture success was fairly poor for tagged house mice and may suggest a large pool of individuals from which the live-trapped samples were derived. Alternatively, a negative trap response on the part of tagged individuals may explain the low recapture success.

High spatial variation in rodent abundance was observed. Food supply, vegetative cover, predators, and interactions among the rodents may have contributed to this variation. During phase I, reproduction was essentially halted. Lactating female house mice were not observed. Male house mice were not observed to be in reproductive condition. Some evidence of reproduction was observed in December when a single pregnant house mouse was captured.

Numbers of house mice trapped during phase II were modest. House mice were present in the NSRA during the period from March through

August 2000. However, trap success was very low in all months in the NSRA and in the adjacent uplands. Removal of cotton rats on two of the grids in the NSRA did not result in more captures of house mice. Efforts to document the movement of house mice across the interface between the NSRA and the adjacent uplands proved unsuccessful. The failure of the removal studies to demonstrate the presence of house mice beyond those numbers observed in the controls supports the view that house mice numbers were depressed in 2000 relative to the levels observed in 1999. In addition, no evidence of house mouse dispersal was obtained.

One possible explanation for the high numbers of rodents in 1999 may be the occurrence of two successive mild winters in 1997 and 1998. Food and cover may have been sufficient to allow the local rodent populations to outpace the normal limiting factors, for example, local predators and self-regulating mechanisms. The drought conditions at the NSRA during the first 6 months of 2000 resulted in an obvious reduction in plant growth and cover. The apparent lack of population growth by house mice during 2000 was correlated with low rainfall conditions. At the population level, the lack of food and cover is the most likely proximal explanation for the low numbers of house mice observed during 2000.

Future years may bring a resurgence of house mouse populations. Some limited monitoring may be prudent when higher than normal rainfall patterns coincide with frost-free winters. Control measures should be limited to the reduction of habitat along the eastern boundary of the NSRA.

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ACKNOWLEDGMENTS

Jack Eckdahl, James Peterson, and Harold Weatherman originally introduced us to the muck farms and the rodents living there. We especially thank Jim Peterson (field program supervisor) and Harold Weatherman (Division of Land Management technician) for explaining gates, roads and field access points to make the logistics of the study easier in the first weeks. Jim and Harold helped us retrieve a broken-down vehicle and saved us from further discomfort and frustration. William H. (Bill) Kern Jr., assistant extension specialist, shared ideas and offered advice on trapping approaches and techniques. William H. (Bill) Toth, program administrator, Epidemiology, Orange County Health Department, shared his knowledge of rodent disease threats and provided valuable lab results from field-caught animals. Dr. Terry J. Doonan, regional biologist, Florida Fish and Wildlife Conservation Commission, shared ideas concerning sampling strategies prior to the study. Dr. Jeff Gore, regional biologist, Florida Fish and Wildlife Conservation Commission, explained the findings of their trapping surveys in the uplands adjacent to the muck farms.

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During phase II of the project, it was necessary to monitor the abundance of small mammals on private lands. We thank the various land owners who allowed us to trap on their land.

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PURPOSE

The purpose of this study was to document the assemblage of small mammals presently inhabiting former muck farm land found along the North Shore Restoration Area (NSRA) of Lake Apopka, Florida. Particular attention was given to determine the relative abundance of the house mouse (*Mus musculus*) in several habitat settings: fallow fields, levees (canal banks), abandoned buildings, and nearby offsite upland habitat. Native rodent species, for example, cotton rat (*Sigmodon hispidus*) and rice rat (*Oryzomys palustris*), were not discussed in detail in the study.

During 1999, unusually dense populations of house mice were known to have been present in various structures adjacent to the NSRA, such as homes and businesses, as well as several miles away. It was not known how the house mice came to be distributed in the landscape. Further, it was not known when the house mouse population began to increase beyond the low numbers normally associated with agricultural areas, rural homes, subdivisions, and commercial developments. House mouse numbers apparently began to increase as early as November 1998.

In this study, intensive live trapping efforts were conducted at a number of study sites within the NSRA to document presence and relative abundance of house mice and other native rodents. Initial sampling occurred during November and December 1999. Results from this period of study will be referenced as phase I in this report (Stout and Clerico 2000). Sampling resumed in March 2000 and continued through August 2000 on the NSRA as well as on private lands in the adjacent uplands. Work done during 2000 will be referenced as phase II. This report provides an analysis and summary of the findings of phases I and II.

STUDY HYPOTHESES

PHASE I

The null hypothesis of this study was that no difference in house mouse abundance would be found among the three habitat strata selected for study (fallow fields, levees, and abandoned buildings).

The alternative hypothesis was that a significant difference would be found in the abundance of house mice among the three habitat strata.

It was expected that house mice numbers would be greatest in the abandoned buildings, with far fewer individuals present along the levees and fewer yet in the fallow fields.

PHASE II

The null hypothesis of this study was that no difference in house mouse abundance would be found among the habitat strata (fallow fields of the NSRA, upland citrus groves, upland old fields, and upland forests).

The alternative hypothesis was that important differences in the abundance of house mice would be found among these strata.

It was expected that house mice numbers would be greatest in the fallow fields of the NSRA, reduced in the upland old fields relative to the NSRA, and least abundant in the upland forested sites.

Another null hypothesis of this study was that conditions intrinsic to the local house mouse populations determined the likelihood of a population outbreak.

The alternative hypothesis was that habitat conditions (food, cover, abundance of competitors, dispersal avenues, or barriers) determined the likelihood of a population outbreak. For example, recovery of vegetative cover in the NSRA and upland habitats should be followed (with some lag time) by growth and recovery of the house mouse populations. Landscape features may function to favor or thwart population growth.

METHODS

STUDY AREAS

The study areas in phases I and II included portions of the NSRA (Figure 1). The southern extent of the NSRA begins at the levee south of Lust Road and continues in an arc to the north and west to the Duda farms. Approximately 3,643 hectares (ha) were included in the original study area. However, the Duda Farms were not included in this study. The remaining area was subdivided into eight units of roughly equal size. One study site was randomly selected within each unit prior to going into the field. Once the sites were located in the field, the exact position of the study area was moved, in some cases as much as 200 meters (m), to accommodate access and logistics.

The eight study sites were located on land that had sustained intensive agriculture for several decades (Table 1). All of the sites had been abandoned for more than a year and supported a dense growth of grasses, sedges, and herbs. The woody vegetation present was to be found near canals where water-primrose (*Ludwigia peruviana*) had spread into the fields. Elderberry (*Sambucus canadensis*) and saltbush (*Baccharis halimifolia)* were present at low densities on some of the study sites. Willow (*Salix caroliniana*) was found on one site. Vegetative cover tended to be very patchy, with single species dominance alternating from patch to patch. Patches were 3–8 m or slightly greater in width, and bare ground was generally not present.

Plants were identified according to Godfrey and Wooten (1981a, 1981b), Murphy et al. (1979), Stucky et al. (1981), and Tobe et al. (1998). The groundcover of the study sites included the following plants: cattail (*Typha domingensis*), nightshade (*Solanum* spp.), dogfennel (*Eupatorium capillifolium*), bedstraw (*Galium aparine* and *G. tinctorium*), water-primrose (*Ludwigia peruviana* and *L. leptocarpa*), morning glory (*Ipomoea* sp.), spreading dayflower (*Commelina diffusa*), sedges (*Cyperus* spp.), guineagrass (*Panicum maximum*), vaseygrass (*Paspalum urvillei*), knotroot foxtail (*Setaria geniculata*), spiny amaranth (pigweed), (*Amaranthus spinosus*), common beggarticks (*Bidens alba*), eclipta (*Eclipta alba*), curly dock (*Rumex crispus*), saltbush (*Baccharis halimifolia*), and sea-purslane (*Sesuvium portulacastrum*). Many additional plants were not identified

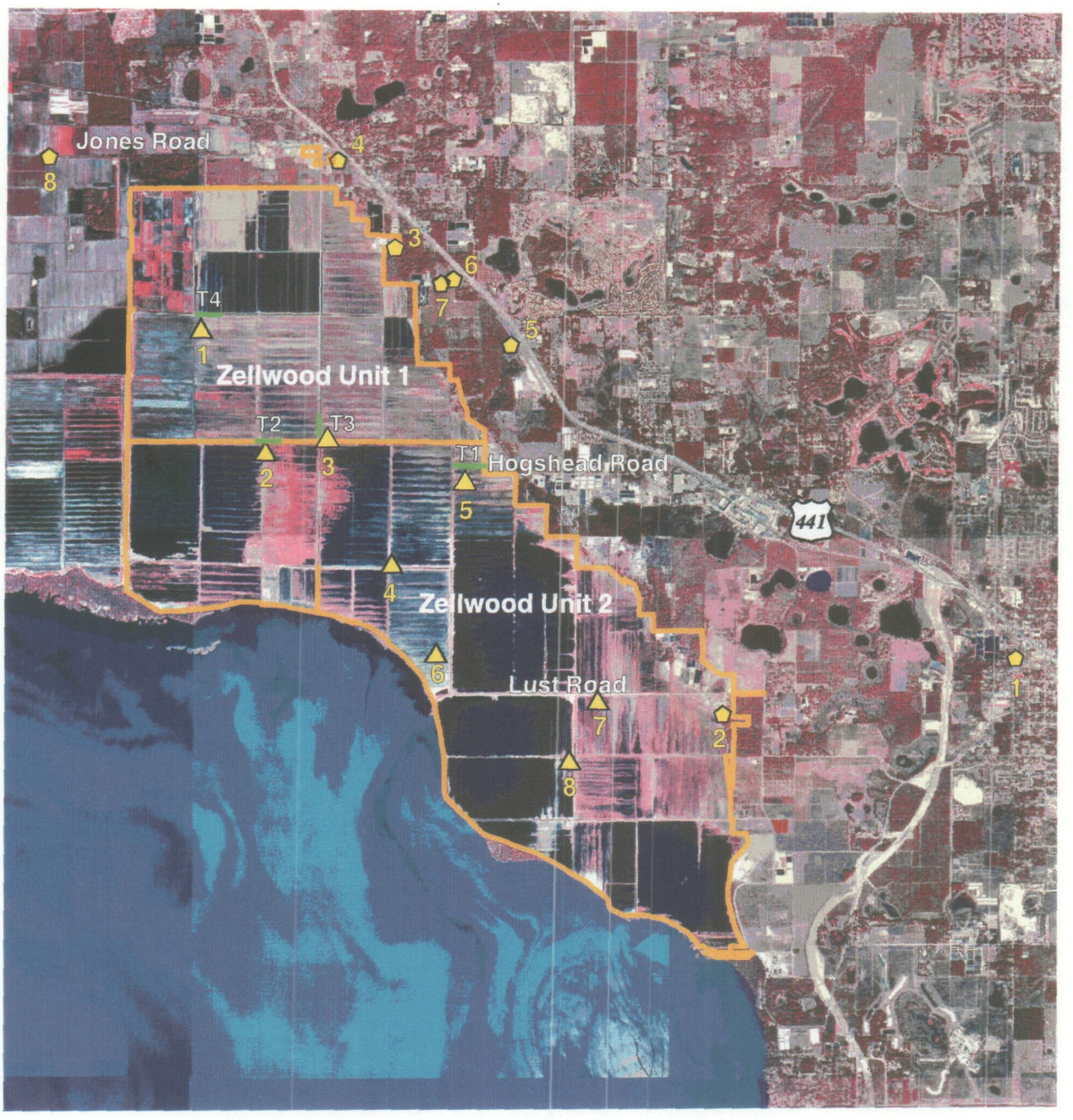

Figure 1. Location of sampling sites (grids and transects) for the North Shore Restoration Area (NSRA) and upland areas

Table 1. Location of eight study grids in the fallow fields of the North Shore Restoration Area

Grid	Latitude	Longitude
1	28 42 40	81 37 29
2	28 41 48	81 36 58
3	28 41 53	81 36 31
4	28 41 6	81 35 57
5	28 41 39	81 35 22
6	28 40 26	81 35 36
7	28 40 1	81 34 18
8	28 39 44	81 34 32

because of various conditions, for example, lack of flowers, but mostly herbaceous species dominated the study sites. Table 1 of Appendix 1 presents a list of dominant plant species observed in units 1 and 2 during the study period (compiled by Joy Marburger and Jack Stout).

In phase II, eight upland grids were live-trapped to determine if house mice were present. The sites were located on private lands between the NSRA and State Road 441 (see Figure 1). Vegetative cover and landscape context varied among the upland sites to a much greater extent than among the sites on the NSRA. The locations of the upland sites are presented in Table 2. The location array number was assigned by the Florida Fish and Wildlife Conservation Commission (FWC) in November 1999.

Upland 1—This site is an old field containing distinct vegetative patches. The largest area is composed of mature oaks (*Quercus* sp.), cabbage palm (*Sabal palmetto*), and exotic tree species mixed with various weedy shrub species such as saltbush. A smaller portion of the site, located nearest Hawthorne Road, is dominated by ruderal herbaceous species such as dog fennel and bahia grass (*Paspalum notatum*). Some maintenance occurs in the form of mowing in this portion of the site.

Upland 2—This site is dominated by planted slash pine (*Pinus elliottii*), with scattered cabbage palm. Although most of the site has a relatively dense canopy, the western edge has a reduced canopy. This area

Table 2. Location and description of upland trapping grids located east, northeast, and north of the North Shore Restoration Area

Area	Location	Latitude/Longitude
Upland 1 (array 110)	Hawthorne Road next to church in old field	28 40 22 / 81 31 04
Upland 2 (array 501)	Lust Road across from Command Center in pine stand	28 39 58 / 81 33 21
Upland 3 (array 306)	Hilltop northwest of airport in former sandhill	28 43 11 / 81 36 00
Upland 4 (array 217)	Southwest quadrant of State Road 441/Jones Road intersection in orange grove	28 43 47 / 81 36 27
Upland 5 (array 312)	End of airport runway in old field	28 42 30 / 81 35 04
Upland 6 (array 216)	Wesley Road (east of upland 7) in old field	28 42 59 / 81 35 30
Upland 7 (array 309)	Wesley Road (west of upland 6) in old field	28 42 57 / 81 35 37
Upland 8 (array 215)	Jones Road (Pokey's Farm) in orange grove	28 43 47 / 81 38 43

corresponds to a slight decrease in elevation. Groundcover includes a thick herbaceous layer composed of such species as lantana (*Lantana* sp.), common ragweed (*Ambrosia artemisiifolia*), and grasses. There is little or no shrub layer because those species most typically associated with the layer have not matured to the point of creating an obvious stratum.

Upland 3—This site is an historic sandhill community (*Pinus palustris* and *Quercus laevis*) located on a hill in a developed landscape. However, little in the way of original sandhill vegetation remains. The site is surrounded by fields that are planted with pasture grasses and regularly maintained. There is virtually no overstory or shrub component present. One mature cabbage palm occurs within the grid. Mature oak trees occur near the trapping grid, but none occur directly in the grid. Existing shrubs are primarily saltbush and saw palmetto (*Serenoa repens*). The herbaceous layer is relatively thick with a significant portion being bare sand. Herbaceous species include lantana and grasses and forbs.

Upland 4—This site is an old citrus grove located at the intersection of U.S. Highway 441 and Jones Road. Aside from citrus trees, there are scattered oaks and exotic tree species. There is no shrub layer. Herbaceous species are predominantly ruderal colonizing species such as beggar's ticks (*Bidens alba*), lantana, common ragweed, and bahia grass.

Upland 5—This site is an old field dominated by ruderal low-growing herbaceous species including bahia, common ragweed, and other forbs. No shrub layer is present and there are only a few mature oaks scattered throughout the trapping grid. This site appears to be mowed regularly during the growing season.

Upland 6—This site has only occasional scattered mature oaks and shrubs. However, no trees or shrubs are located in the trapping grid. Herbaceous vegetation was generally less dense during the study period than that observed at other sites. Herbaceous species present included prickly pear cactus (*Opuntia* sp.), common ragweed, passionflower (*Passiflora* sp.), lantana, broomsedge (*Andropogon virginicus*), and other forbs. Gopher tortoise (*Gopherus polyphemus*) burrows were common.

Upland 7—This site is in close proximity to upland 6 and shares the same vegetative structure and composition. Some scattered trees are present, most notably cabbage palms. An additional difference is that upland 7 is located down a slight slope from upland 6 and is bordered to the west by a small forested fragment.

Upland 8—This site is a citrus grove that appears to be no longer used for agricultural purposes. Found among the citrus trees are cabbage palms, dog fennel, and saltbush. Separating the rows of citrus trees is a very poorly developed groundcover of bahia grass. Although not apparently used for agriculture at this time, the site appears to be regularly maintained.

Appendices 2 and 3 show typical vegetation cover of the NSRA and upland grid sites. Photographs of the sites were taken in August and September 2000.

Study Approach in Phase I

Existing map coverage of the NSRA was used to randomly locate study areas within the fallow fields. Once study areas in the fallow fields were

established, nearby levee habitat was selected for study. Buildings within the study area at the Hogshead Road entrance were sampled.

Fallow field study sites consisted of eight grids. Six grids contained 49 trap stations (7 rows, 7 columns). Two grids deviated from this configuration due to local land features, namely, grid 5 (5 rows, 10 columns) and grid 4 (10 rows, 5 columns). Stations were 10 m apart. A single Sherman live trap baited with large sunflower seeds was placed at each trap station. Traps remained in place on the grids for the duration of the study.

Traps were set in the late afternoon and checked the following morning. House mice were ear-tagged on all the study grids. Males were recorded as abdominal or descended with respect to the position of the testes. Females were examined for signs of lactation, pregnancy, or reproductive inactivity. Body weights of house mice were determined. Trap location was recorded for all individuals, and all captures were released at the site of capture as soon as processing was completed. Rodent captures other than house mice on grids 1–8 were recorded by species, age class, and site of capture and released alive; in addition, all captures of small mammals were ear-tagged on grid 8.

Canal levees and buildings were trapped following a slightly different protocol. Levees were sampled by transects (linear trap lines) of at least 25 Sherman traps at 10-m intervals for two successive days. Size and configuration of buildings determined the number and arrangement of Sherman traps within them. Buildings were trapped during three successive days.

STUDY APPROACH IN PHASE II

Eight trapping grids established in the NSRA in 1999 were re-sampled from March through August 2000. Grids 1, 4, 5, and 8 were trapped twice per month at roughly 2-week intervals, whereas grids 2, 3, 6, and 7 were trapped once per month. Grids 1, 4, 5, and 8 were trapped with the full complement of traps utilized in 1999. Grids 2, 3, 6, and 7 were reduced to the central 25 trapping stations.

The upland grids were located in approximately the same areas where FWC personnel had trapped mice in the fall of 1999. Location and trapping methods were intended to duplicate the prior efforts with the

exception that captures were ear-tagged and released alive. Each of these grids consisted of an array of 25 trap stations (5 rows x 5 columns) with a single Sherman trap baited with sunflower seed set for 1 night once per month. Trap stations were 10 m apart.

Two of the original eight NSRA grids were selected to test the hypothesis that trapping results were biased against house mice in favor of the cotton rats. Cotton rats are five to 10 times the body mass of house mice and may dominate the use of space. It is also possible that odors of cotton rats inhibit the entrance of house mice into a trap after the capture of a cotton rat. It is also possible that the 24-hour activity patterns of the cotton rat population resulted in trap competition between the small mammals, with the more nocturnal house mouse being less likely to encounter empty traps. Cotton rats were ear-tagged and removed from grids 5 and 8 from May through August (eight trap cycles at roughly 2-week intervals). NSRA grids 1 and 4 were trapped without removal of cotton rats during the same time periods to serve as controls. Cotton rats were released well beyond the original point of capture. Animals that returned to the trapping grid could be identified by ear tags. Reduced trap success for cotton rats and increased trap success for house mice would tend to support the original hypothesis. Rejection of the null hypothesis would occur if there were high trap success of cotton rats even after their removal.

Explanations of the house mouse plague in the Apopka-Zellwood region in 1999 varied in detail and mechanism among the parties involved. The private sector tended to favor the idea that the NSRA had served as a source of house mice that had dispersed into the uplands. Studies during 1999 demonstrated that house mice were present in both the NSRA and the uplands and at unusually high densities. Thus, studies in 1999 shed no light on the possible source of house mice in the uplands. A series of trapping grids and transects was established during 2000 to demonstrate the movement of house mice at the interface of the NSRA and the adjacent uplands. Local landscape conditions did not permit the pairing of trapping grids in the NSRA and the uplands, but to the extent possible, trapping efforts were similar in the two locations. All captures were ear-tagged and released at the point of capture. Recaptures elsewhere within the study area would give some measure of the frequency and magnitude of dispersal movements. Trapping methods followed exactly the procedures used elsewhere in the study.

Vertical and horizontal attributes of the vegetation on the eight NSRA trapping grids were measured during mid-summer. Twenty-five grid intersections were selected at random from the possible 48–50 intersections available per grid. Measurements were taken with reference to the actual location of the trap at each intersection. Vegetation within 2 m of the trap was measured. The height (in centimeters) of the tallest, dead, living non-woody, and living woody plants were recorded. Groundcover was assessed with a line transect 4 m long and centered on the trap with the compass direction randomly assigned. Cover was measured as living and dead. Dead material overarched by living material was ignored. An additional 10 points was assigned at random within the grid to represent places without traps. The four vegetative attributes were reduced to means (and standard deviations) for each grid.

DATA ANALYSIS IN PHASE I

Data reduction was done at the grid level. House mouse capture success per grid was expressed in terms of captures per trap night. Minimum numbers alive were used as a conservative estimate of abundance based on marked animals and their frequency of recapture. Population estimates were computed using the Lincoln Index when recaptures were available (Krebs 1999). Calculations were based on the following formula:

$$N = M\,C\,/\,R \qquad \textbf{(1)}$$

where

N = population estimate
M = number of marked individuals released in the first sample
C = number of marked and unmarked individuals caught in the second sample
R = number of marked individuals from the first sample caught in the second sample

In 1999, the trapping was done in four cycles: cycle 1 (November 6–8), cycle 2 (November 13–15), cycle 3 (November 19–22), and cycle 4 (December 4–9). Trap cycles 1, 2, and 3 were used as the mark phase of the population estimation procedure and cycle 4 as the recapture phase.

Densities were extrapolated from available population estimates. Area of the grids was calculated, with a border strip added to represent half the distance between trap stations, that is, 5 m. The logic of using a border strip approach was derived from the assumption that the traps sampled a larger area than that defined by the trap station corners (Krebs 1999). Densities were based on numbers per hectare and acres (1 ha = 2.47 acres).

All the trapping results were entered into a spreadsheet format for the collection of summary statistics. Central tendency and variation were expressed as sample means, with standard deviations when appropriate. Sex ratios of house mice were tested for departure from a 50:50 ratio with the chi-square test. Correlation and regression were used to examine trap success and habitat features. The program InStat was used to compute the latter statistics.

DATA ANALYSIS IN PHASE II

Abundance of small mammals was calculated as captures per trap night on the NSRA grids. A lack of recaptures of house mice makes the estimation of densities very problematic.

The relationship between cotton rats and house mice on the removal and central grids was evaluated with correlation analysis.

Vegetation attributes of the grids on the NSRA were treated as independent variables and small mammal trap success on the grids was regressed against the attributes.

RESULTS

RODENT CAPTURES IN GRIDS, PHASE I

Capture success in grids within the NSRA was about 46 rodents per 100 trap nights (1,319 captures per 2,856 trap nights = 0.4618). Capture success varied among the eight grids, with the lowest success in grid 7 (0.1088) and the highest success in grid 6 (0.6939) (Table 3). These numbers reflect the relative number of trappable rodents and not the absolute number of rodents because individuals might be recaptured on more than one trapping date.

Table 3. Total number of small mammal captures and captures per trap night by grid, North Shore Restoration Area, November–December 1999

Grid	Total Captures	Captures per Trap Night
1	162	0.4723
2	172	0.5015
3	207	0.6035
4	118	0.3073
5	161	0.4025
6	272	0.6939
7	320	0.1088
8	195	0.5462
Total	1,319	

Note: Overall trap success = 1319/2856 = 0.4618.

House mice were present in all eight grids. They represented 26.46% of the captures (Table 4). House mice were the dominant capture in grid 7, the grid with the fewest captures (23) over the period of study (Table 4). The greatest number of captures of house mice occurred in grid 5 (73).

Cotton rats were the most frequently captured rodent in five of the eight grids, often by overwhelming numbers (Table 4). Cotton rats made up

70.05% of the 1,319 captures. Cotton rats and house mice were nearly equal in frequency of capture in grids four and five.

Table 4. Composition of small mammal captures by grid, North Shore Restoration Area, November–December 1999. *Totals may include recaptures of individuals on successive nights.*

Grid	House Mouse	Cotton Rat	Rice Rat
1	37	124	1
2	37	134	1
3	12	188	7
4	56	54	8
5	73	85	3
6	45	227	0
7	23	8	1
8	66	104	25
Total	349	924	46

The rice rat was a relatively minor component of the rodent assemblage in seven of the eight grids. Twenty-five captures were made in grid 8, and this represented 12.82% of the captures at that site (Table 4). Across all the grids, the rice rat made up 3.49% of the captures over the period of study.

Rodent Captures in Grids, Phase II

Small mammals trapped between March and August 2000 included cotton rats, rice rats, house mice, and two species of shrews. In this period, 1,436 captures were registered. During phase I, between November and December 1999, 1,319 captures were made. The total number of rodents captured in phases I and II was 2,755 (Table 5). While not adjusted for trap effort, these data reveal that a large number of rodents were present on the grids. Cotton rats dominated the capture statistics in both study periods, with 41.49% of their captures in 1999 and a total of 2,227 captures (80.8%) out of the 2,755 records. House mice represented 17.02% of all captures; 74.41% of these occurred in the 1999 period. Rice rats were relatively uncommon and accounted for 2.14% of the total captures; 77.97% of these occurred in the 1999 period. Single captures of the

southern short-tailed shrew (*Blarina carolinensis*) and the least shrew (*Cryptotis parva*) were made in March.

Table 5. Composition of small mammals captured by month on grids 1–8, North Shore Restoration Area. *Totals include recaptured individuals.*

Period	House Mouse	Cotton Rat	Rice Rat	Total
1999				
Nov–Dec	349	924	46	1,319
2000				
March	32	108	6	146
April	35	210	4	249
May	19	267	2	288
June	4	277	0	281
July	12	252	1	265
August	18	189	0	207
Total	469	2,227	59	2,755

Capture Patterns for Phases I and II

Examination of capture patterns at the grid level during the entire study suggests some consistent trends. For example, in grid 7 there were never many trappable rodents (Table 6). Capture success for cotton rats was 10 per 100 trap nights, which was the lowest success among the grids. Grid 3, with the fewest captures of house mice (2 per 100 trap nights), appeared to be an outlier relative to the other grids. Only grids 3, 4, and 8 had modest populations of trappable rice rats. In contrast to the other rodents, cotton rats were abundant on seven of the eight grids, with 34 to 49 captures per 100 trap nights; grid 7 was the exception.

Rodent Captures in Transects

Transect sampling revealed that trappable numbers of rodents varied widely in the landscape. Transect 1 immediately south of Hogshead Road and north of grid 5 yielded 21 captures, or 0.0933 captures per trap night. North of Hogshead Road, a transect in a mowed strip between the NSRA and private land produced no captures of rodents during 50 trap nights.

Table 6. Composition of small mammals captured on grids 1–8, North Shore Restoration Area, November–December 1999 and March–August 2000. *Totals include recaptured individuals with an index of abundance (captures per trap night).*

Grid (trap cycles per month)	House Mouse	Cotton Rat	Rice Rat	Total
1 (2x)	62 (0.06)	412 (0.42)	1 (0.001)	475
2 (1x)	43 (0.07)	186 (0.34)	1 (0.001)	230
3 (1x)	14 (0.02)	267 (0.49)	7 (0.012)	288
4 (2x)	81 (0.08)	328 (0.34)	16 (0.016)	425
5 (2x)	97 (0.09)	369 (0.36)	7 (0.007)	473
6 (1x)	49 (0.09)	234 (0.43)	0 (0.000)	283
7 (1x)	29 (0.05)	55 (0.10)	2 (0.003)	86
8 (2x)	94 (0.09)	376 (0.38)	25 (0.025)	495
Total	469	2,227	59	2,755

Note: The number of trap cycles per grid per month varied in the period March–August 2000. A complete trap cycle represents a date when all traps on the grid were opened for one night.

Transects 2, 3, and 4 were located on levees or elevated land used as roadways. Captures per trap night were as follows: transect 2, 0.6200; transect 3, 0.6800; and transect 4, 0.3733. These results were comparable or slightly higher than the average trap success on the grids (0.4618).

Species composition and relative abundance of captures on transects tended not to reflect that of the adjacent grids. The ratio of house mouse to cotton rat captures was 0.0877 for transect 2 and 0.2761 for grid 2. The ratio for transect 3 was 0.4667, whereas for grid 4 it was 1.0371. Transect 4 had a ratio of 0.04737 while for grid 1, the ratio was 0.2984. In contrast to the other transects, transect 1 registered 10 captures of house mice and 11 captures of cotton rats (ratio = 0.9090), which was in close agreement with grid 5 (20-m distant), where the ratio was 0.8588.

In summary, house mouse captures from transects (levees) were slightly greater (mouse:cotton rat ratio = 0.4333) than from grids in the fallow fields (ratio = 0.3777).

HOUSE MOUSE ABUNDANCE BY GRID, PHASE I

A total of 234 individual house mice were tagged and released in the eight grids. The average number of mice released per grid was 29.25 (SD = 15.03). Of 233 individuals for which sex was determined, 146 were males and 87 were females. A chi-square test based on the hypothesis that the sex ratio was even yielded a value of 14.939. This was significant at $p < 0.01$ and suggested more males than females existed in the trappable population. Table 7 presents data for eight grids from November through December 1999.

Table 7. House mouse abundance on grids within the North Shore Restoration Area, November–December 1999

Grid	Grid Area (hectares)	Mean Number House Mice per Trap Night	Lincoln Index (population estimate)	Density (number per hectare)
1	0.49	0.094	74.6	152.3
2	0.49	0.091	42.5	86.7
3	0.49	0.031	—	—
4	0.48	0.143	41.4	86.3
5	0.50	0.175	127.5	255.0
6	0.49	0.102	55.0	112.2
7	0.49	0.051	45.0	91.8
8	0.49	0.160	58.8	122.5

Note: — = no data

Grid 1

From grid 1, 25 individual house mice were captured 33 times. The recapture success was 0.3684 based on 20 individuals marked in the first six trapping events. The mark-recapture estimate was 74.6 individuals in the population. Estimated house mouse population density was 152.3 per hectare or 61.6 per acre. Among the marked individuals, 15 were males and nine were females; one individual was not sexed.

Grid 2

From grid 2, 23 individual house mice were captured 32 times. The recapture success was 0.2381 based on 21 individuals marked in the first six trapping events. The mark-recapture estimate was 42.5 individuals in the population. Estimated house mouse density was 86.7 per hectare or 35.1 per acre. Fourteen males and nine females were marked.

Grid 3

From grid 3, 11 house mice were marked and released. None was recaptured. No house mice were captured November 6 and 7, 1999, and single captures were registered November 14, 1999, and November 21, 1999. Three mice were marked on November 22, 1999, five on December 5, 1999, and one on December 6, 1999. Six males and five females were marked and released.

Grid 4

From grid 4, 32 individual mice were marked and released. The probability of recapture was 0.448. Mark-recapture estimate of the population was 41.42 mice. This density extrapolated to 86.3 per hectare or 34.9 per acre. Twenty-two males and 10 females were in the marked population.

Grid 5

From grid 5, 58 mice were tagged and released. This was the largest number of animals released among the grids. The probability of recapture was 0.155 and represented the lowest likelihood of recapture observed with the exception of grid 3. The population was estimated to be 127.5 individuals. This population density was estimated to be 255.0 per hectare or 103.2 per acre. Thirty-four males and 24 females were marked and released.

Grid 6

From grid 6, 25 mice were tagged and released. The probability of recapture was 0.4091. The population was estimated to be 55.0. Estimated density was 112.24 per hectare or 45.44 per acre. The marked population included 19 males and six females.

Grid 7

From grid 7, 17 mice were tagged. The probability of recapture was 0.2727. The population was estimated to be 45.0. Estimated population density was 91.83 per hectare or 37.1 per acre. The trapped population consisted of eight males and nine females.

Grid 8

From grid 8, 43 mice was tagged. The probability of recapture was 0.2619. The population estimate for the grid was 58.80. Estimated population density was 122.5 per hectare or 49.59 per acre. The marked population consisted of 28 males and 15 females.

House Mouse Captures by Season and Grid, Phases I and II

During phases I and II, a total of 469 house mice were captured (Table 8).

Table 8. Captures of house mice, North Shore Restoration Area, by month

Month	Total Captures	Captures per Trap Night
1999		
Nov–Dec	349	0.1113
2000		
March	32	0.0650
April	35	0.0711
May	19	0.0386
June	4	0.0081
July	12	0.0244
August	18	0.0366
Total	469	

Note: Results represent seasonal trends on grids 1–8.

During phase II, the majority of the 120 mice captured were captured in March and April 2000. The 349 captures made during November and December 1999 of phase I accounted for 74.41% of the total number of trapped mice. The seasonal trend in captures during 2000 was for a decline from late winter to a low in June, followed by an increasing number of captures in July and August. The trend during phases I and II began with house mouse capture success at about 11 per 100 trap nights in November–December 1999 and ended with about three per 100 trap nights in August 2000.

House mouse numbers on grid 3 remained low throughout phase II of the study (Table 9). However, captures per 100 trap nights varied from five to nine for the remaining grids.

Table 9. Captures of house mice, North Shore Restoration Area, by grid, 1999 and 2000

Grid	Total Captures (recaptures)	Captures per Trap Night
1	62 (37)	0.0633
2	43 (37)	0.0793
3	14 (12)	0.0258
4	81 (56)	0.0844
5	97 (73)	0.0970
6	49 (45)	0.0904
7	29 (23)	0.0535
8	94 (66)	0.0959

Response of House Mice to the Removal of Cotton Rats, Phase II

Grids 5 and 8 were trapped at 2-week intervals from March through August 2000. Beginning in May, for the duration of phase II trapping, all captures of cotton rats were ear-tagged and removed from these grids and released elsewhere on the NSRA. None of the removed individuals returned to the grids. Capture success for cotton rats on grid 5 remained in the range of 50–60 per 100 trap nights during May and June before slowly declining to about 20 per 100 trap nights in mid-August. The house mouse population remained extremely low throughout the period, even

after cotton rats were removed. The correlation between house mouse and cotton rat captures from May to August was extremely weak ($r = 0.068$) and not significant ($p > 0.05$).

The numbers of cotton rats caught per 100 trap nights on grid 8 actually increased after the removal treatment began in May. Capture success remained near 60 per 100 trap nights during June and July and declined to slightly below 50 per 100 trap nights in mid-August. The house mouse population remained extremely low throughout the period when cotton rats were removed. No correlation was found between house mouse and cotton rat captures from May to August ($r = 0.417$, $p > 0.05$). The null hypothesis that trapping methods were biased against house mice was rejected.

Population trends of cotton rats and house mice on the control grids (1 and 4) were biologically indistinguishable from the removal grids (5 and 8).

House Mouse Captures Relative to Vegetation, Phases I and II

The grids were markedly different in terms of plant species composition and in the extent of species cover. Field observations suggested the nature of the plant cover, particularly that the height of the vegetation might have influenced the capture success. The relationship between the average height of the vegetation at the trap sites (grid average) and the trap success for house mice (grid average) was examined by correlation. The correlation coefficient (r) was 0.6468 and suggested 41.8% of the variation in trap success was explained by variation in vegetation height. However, a regression analysis of capture success on vegetation height did not yield a significant relationship. That is, the slope was not significantly different from zero ($F^1 = 4.3148$, $p^2 = 0.0831$, 7 df^3). Thus, plant cover may have influenced the capture success of house mice, but a more detailed study of horizontal and vertical structure, as well as species composition through time, is necessary.

During phase II, a more detailed assessment of the vegetative cover on the grids was completed in July and August 2000 (Table 10; Appendices 1–3).

[1]F test of significance
[2]Probability
[3]Degrees of freedom

Table 10. Characteristics of vegetation within 2 meters of randomly selected points (n = 35) on grids 1–8, North Shore Restoration Area, mid-summer 2000 (in centimeters as means [standard deviation])

Grid	Height, Tallest Dead	Height, Tallest Living Non-woody	Height, Tallest Living Woody	Groundcover	
				Dead	Living
1	121.97	173.4	0.0	171.97	228.60
	(48.01)	(88.86)	(0.0)	(21.70)	(21.66)
2	100.29	65.94	0.0	137.66	267.34
	(22.64)	(45.84)	(0.0)	(70.72)	(70.72)
3	125.89	219.57	26.2	158.91	241.09
	(70.25)	(76.40)	(49.69)	(94.67)	(94.67)
4	71.51	53.97	31.34	164.83	232.31
	(46.40)	(18.57)	(77.35)	(119.95)	(118.56)
5	95.63	165.77	24.31	199.91	200.86
	(50.05)	(102.30)	(74.97)	(146.78)	(146.78)
6	42.94	60.54	12.29	267.2	132.8
	(39.77)	(55.41)	(50.66)	(94.12)	(94.12)
7	64.57	31.97	22.14	341.26	58.74
	(27.64)	(47.47)	(64.91)	(84.31)	(84.31)
8	79.71	167.03	39.86	15.71	383.11
	(52.37)	(84.09)	(102.30)	(45.54)	(45.44)

Note: Height is vertical height, in centimeters. Groundcover is based on line intercept, in centimeters.

Ground-level live vegetation (grasses and herbs) was not found to be correlated with captures of house mice from March through August ($r^4 = 0.511$, $p > 0.05$). Likewise, no relationship was apparent between the height of the tallest non-woody vegetation and captures of house mice ($r = 0.270$, $p > 0.05$).

Small Mammal Captures in the Uplands, Phase II

Eight grids in the uplands were trapped from March through August 2000 to monitor abundance (Table 11). Captures in the uplands included house mice, cotton rats, roof rats (*Rattus rattus*), and rice rats. House mice were never captured on grids 1, 2, 4, and 8. A total of eight individuals were captured on the remaining grids. Grid 6 accounted for four of the eight captures. At least one cotton rat was captured on each grid, with as many

[4]Correlation coefficient

Table 11. Species composition of small mammal captures on upland grids 1–8, March–August 2000

Grid*	House Mouse	Cotton Rat	Roof Rat	Total
1	0	1	0	1
2	0	4	0	4
3	2	8	0	11†
4	0	10	2	12
5	1	2	0	3
6	4	6	0	10
7	1	4	0	5
8	0	2	0	2
Total	8	37	2	48

*Grids located between the North Shore Restoration Area and State Road 441.
†Only one rice rat was captured in August.

as 10 captures on grid 4. Two roof rats were captured on grid 4. A single rice rat was captured on grid 3. Seasonal factors may have influenced capture success of rodents in the uplands, since 83% of all rodents captured were recorded in July (n = 13) and August (n = 27) (Table 12).

Table 12. Species composition of small mammal captures by month on upland grids 1–8

Month	House Mouse	Cotton Rat	Roof Rat	Total
March	0	1	1	2
April	1	1	0	2
May	0	1	0	1
June	1	1	1	3
July	2	11	0	13
August	4	22	0	27*
Total	8	37	2	48

Note: Grids located between the North Shore Restoration Area and State Road 441.

*Only one rice rat was captured during August, on grid 3.

However, the rodent populations were not surveyed for the entire year, so seasonal effects might be determined in a longer term study.

MOVEMENTS OF SMALL MAMMALS AT THE INTERFACE OF THE NORTH SHORE RESTORATION AREA AND THE UPLANDS, PHASE II

No movements of individually tagged small mammals were detected to demonstrate emigration or immigration between uplands and NSRA grids (Table 13). In spite of the fact that a large number of individuals were tagged and released alive near the interface of the two contrasting habitats, only one house mouse was recaptured; its movement was between trap stations (straight-line distance of about 14 m) within grid 2 of the NSRA.

Table 13. Results of mark-recapture studies during summer 2000 to document movements of house mice at the interface of the former muck farms (North Shore Restoration Area [NSRA]) and the adjacent uplands

Study Area	Number of Trap Nights	Number of Individuals per 100 Trap Nights	Number of Dispersers
Ponkan Road Group			
North Muck 1	100	0.07	None
North Muck 2	100	0.13	1*
North Upland 1	52	0.02	None
North Upland 1†	48	0.04	None
North Upland 2	100	0.01	None
Hogs Head Road Group			
Mid-Muck 1	100	0.04	None
Mid-Muck 2	100	0.07	None
Mid-Upland 1	100	0.12	None
Mid-Upland 2	100	0.04	None
Lust Road Group			
South Muck 1	100	0.01	None
South Upland 1a	36	0.00	None
South Upland 1b	64	0.02	None
South Upland 1cb	16	0.00	None
South Upland 2a	48	0.04	None
South Upland 2b	52	0.00	None
South Upland 3	100	0.03	None
South Upland 4	100	0.04	None
South Upland 5	100	0.01	None
South Upland 6	0	0.02	None

Note: Study areas are reported from north to south within the NSRA; see text for descriptions of study areas and exact methods employed.

*Movement occurred within a grid; straight-line distance between captures was 14 meters.
†These traps were placed in abandoned buildings.

DISCUSSION

OVERVIEW OF HOUSE MOUSE POPULATION BEHAVIOR AND DYNAMICS

Feral house mice have been introduced into nearly every environment occupied by mankind. Outbreaks of house mice have been reported in association with agriculture in Australia, China, southeastern Russia, and North America (Singleton and Redhead 1990). The mouse plagues of Australia are perhaps the most widely reported and studied population outbreaks in agricultural landscapes (Singleton and Redhead 1990, Brown and Singleton 1999). These plagues occur at intervals of 1 to 7 years with an average of 4 years between events for any particular region. Plagues occur in different years within the agricultural regions of southern and eastern Australia. Economic loss in 1993 was estimated at 64.5 million Australian dollars. House mice remained in the agricultural lands between plagues, but at much lower abundances.

Detailed studies of house mice in wheat fields in Australia have been reported over the years. Newsome (1969a) found the mice did not abandon the fields after harvest and drought periods associated with the typical rainfall patterns of his study areas. Mice bred to the limit of their food supply and when breeding ceased, the populations tended to crash. Mice lived in reed beds (*Phragmites communis*) near the wheat fields and re-invaded the superior habitat as the wheat crop developed (Newsome 1969b). Newsome induced a mouse plague with food supplementation. He concluded that shelter and food availability were closely associated with plague events.

Outbreaks of house mice in Australia are not always associated with wheat fields. Newsome and Crowcroft (1971) provided details on a plague that occurred in 1965 in south Australia. About 515 square kilometers (198.9 square miles) of wheat fields were invaded. In addition, a pine plantation was destroyed by a local house mouse outbreak. An isolated wheat stack (identified as 4 years old) supported more than 500 mice, based on individual captures. But in spite of abundant food, mice in the wheat stack ceased to reproduce.

Newsome and Corbett (1975) claimed that favorable conditions for plant growth set the stage for house mice population irruptions in Australia.

Regardless of plant growth, they found that the density and biomass of house mice declined as density and biomass of native rodents increased in four habitats under study.

Experiments in arid regions where food and water were provided resulted in large increases of house mouse populations, but a decline occurred in spite of the supplemental feeding (Newsome et al. 1976). Other rodents apparently did not play a role in the decline. Bomford (1987b) used supplementary feeding to stimulate breeding in spring when controls without extra food did not breed.

House mice in Australia may remain in the low phase of the population cycle for 1–3 years (Krebs, Chitty et al. 1995). It is not clear why house mice numbers may remain low for a year or more when extrinsic factors appear to be favorable for population growth. Krebs, Chitty et al. (1995) suggested that changes in the social organization may be a necessary condition for triggering a mouse plague. Two models are offered to examine social mechanisms as limitations to population growth.

Radio-tracking of house mice in agricultural areas in Australia has increased information related to home range, movements, and the relationship between adult males and females (Chambers et al. 2000). Males have slightly larger home ranges that female, and both sexes were site-attached during the breeding season. Females tended to exclude both males and other females from their home ranges. Mice were wider ranging when in the non-breeding season, more gregarious, and appeared to be nomadic when densities were low.

Brown and Singleton (1999) provided a definition of mouse plagues in Australia. They stated that (1) populations increase in density and spread into new habitats (places where they were absent or unrecorded);(2) population increase is synchronous over a large area (more than 50,000 ha [123,500 acres]); (3) during plagues, house mouse densities exceed 500 individuals per ha and typical densities exceed 1,000 per ha; and (4) plague conditions may exist for 1 to 2 years before declines or crashes occur. No literature exists that reports comparable population behavior in the United States or, indeed, elsewhere in the world. The land associated with high densities of house mice in Zellwood and Plymouth, Florida, includes only 6,477 ha (15,998 acres).

The scientific literature on feral house mice in the United States is somewhat limited relative to that of other regions, such as Australia. Sizable populations of house mice have been encountered in natural and disturbed habitats in California. The earliest known outbreak in California was documented by Hall (1927) and Piper (1928) in Kern County. This outbreak occurred in herbaceous vegetation that invaded a former lake bed. Two local outbreaks of house mice in grasslands near Berkeley were reported by Pearson (1963). Local populations of house mice reached densities of 200–300 per acre (494–741 per ha). The mouse population increases were correlated with unusually warm weather and winter and spring breeding. Lidicker (1966) studied house mice on an island in San Francisco Bay. He observed that the population decreased from about 121 mice per ha to extinction over a 14-month period; no one factor could account for the decline. DeLong (1966) worked nearby on the mainland during the same period as Lidicker. He reported evidence that the survival of young house mice was apparently reduced by the presence of California voles (*Microtus californicus*). DeLong (1967) was interested in the factors (extrinsic or intrinsic) that regulated house mice on the mainland. Based on six populations under study, he concluded that house mice were not limited by external factors. Rather, he stressed that intrinsic factors or mechanisms limited house mice populations.

Feral house mice in Maryland occupied corn and wheat and hay fields that existed in a habitat mosaic (Stickel 1979). These populations increased through the summer during the breeding season from May to October. Live trapping revealed that the mice tended to live less than 5 months. Stickel (1979) claimed the mice moved within the habitat mosaic as crops were harvested. House mice in Virginia moved into old field habitat when the resident population was removed (Staples and Terman 1977).

Bronson (1979) summarized information on house mice, with an emphasis on their reproductive ecology. He recognized two categories of house mice populations. First, feral populations were associated with natural and disturbed habitats where the numbers of individuals tended to be variable in time and space. Second, commensal populations were found associated with buildings and other man-made structures. Commensal populations exhibited more population stability that the feral populations. Available evidence was interpreted to indicate that male house mice forced the dispersal of the young. Rapid colonization of all suitable habitats could result from this behavior. For example, of more than 3,000 house mice tagged and released on a 100-ha Welsh island, more than 20%

bred in areas distant from where they were born (Berry and Jakobson 1974).

Behavior and Dynamics of Local House Mice

The first recorded evidence of house mice in Florida occurred in 1894 (Layne 1997). However, Layne suggested that the mice had been in the state since the colonial period. The presence of stable house mice populations in native habitat is not commonly reported, but presence of house mice in disturbed habitats and coastal dunes is frequently reported.

Rodents were common-to-abundant on all the trapping grids established in the area of former muck farms along the northeast shore of Lake Apopka. Trap success was about 46% over the course of phase I. During phase II, trap success was 28% in March, exceeded 50% in May, June, and July, and declined to 41% in August. Typical trap success in native Florida vegetation (habitats) may be expected to vary from 1 to 10%, with occasional trapping events yielding 30–60% success (Stout, pers. observ. since 1973). B. Toland (cited as pers. com. in Layne 1997) reported a 60% trap success for house mice in open herbaceous/grassy habitat on reclaimed phosphate mine land in Polk County, Florida, during the 1980s.

Cotton rats were the most frequently trapped rodents on the majority of the grids in phase I. House mice were the second most frequently captured species . House mice were present on all the grids. However, considerable variation in abundance was documented over the complete study area. Rice rats were present in extremely low numbers. Perhaps the most common native Florida small mammal in many habitats, namely, the cotton mouse (*Peromyscus gossypinus*), was not observed in the study.

Cotton rats remained the dominant rodent in terms of captures on all the NSRA grids in phase II. Captures of house mice rarely exceeded those of cotton rats. Rice rats generally disappeared from the grids as revealed by frequency of live trapping.

Mark-recapture methods were used to estimate the abundance of house mice on the eight grids in phase I. Two hundred thirty-four house mice were ear-tagged and released alive on the study grids. Recapture success averaged 0.2691 across the grids and varied from 0.0 to 40% among grids. No marked animals were recaptured on grid 3. Mark-recapture estimates such as the Lincoln Index carry several assumptions (Krebs et al. 1994;

Krebs 1999). One assumption is that an equal probability of capture exists between tagged and untagged individuals, an assumption that was most likely not met by the data presented here. The sex ratio of trapped mice favored males ($p < 0.05$), as found by most other workers, for example, Drickamer et al. (1999). Prior studies have reported recapture rates of marked house mice to range from 0 to 20% (Krebs et al. 1994). Exceptions to the low recapture success pattern do exist. For example, DeLong (1967) reported recapture rates of 75–100% at 2-week intervals in annual grasslands in California.

Krebs et al. (1994) radio-tracked house mice to determine the reason or reasons low recapture rates are observed. Their results suggested that during periods of reproduction, breeding individuals remained fairly restricted to home ranges, but were not very trappable. During the non-breeding season, nomadic movements reduced the likelihood of recaptures. Other studies have shown that trappability of house mice declined from adults to sub-adults to juveniles (Drickamer et al. 1999). It was not clear if these results applied to the data collected on the NSRA in phase I. These data represented a non-breeding season sample. Thus, nomadic movements might account for the low ability to trap house mice. However, with the exception of grid 3, where no recaptures were observed, the grid populations appeared to be resident as opposed to transient in behavior.

House mice captures per trap night provided a standardized index for comparisons among the grids in phase I. Trap success showed that grid 3 had the fewest captures (3 per 100 trap nights), followed closely by grid 7 (5 per 100 trap nights). In contrast, grids 5 (17 per 100 trap nights) and 8 (16 per 100 trap nights) had the highest success among the grids. The only grid with poor trap success for house mice (5 per 100 trap nights) and poor trap success overall (10 per 100 trap nights) was grid 7.

The density estimates of house mice for the grids indicated the degree of variation that existed among the study sites. The estimates are undoubtedly inflated because of the small number of recaptures. Drickamer et al. (1999) suggested that data generated by live trapping must be interpreted with caution and reservation. Alternative methods for computing population sizes and densities are available, but could not be applied in the time available to prepare this report. These alternative methods will be applied to the data in the future (Pollock 1982).

Some patterns appeared to emerge based on past land use and known locations of abundant house mice populations west or north of the NSRA. Grid 1 was in the northwest portion of the study area and near sites that had remained in agriculture through the growing season of 1999. The Lincoln Index estimate for grid 1 was the second highest among the grids. Grid 2 was also relatively near grid 1 but the house mouse population estimate was about half as large as the one associated with grid 1. Grids 3 and 4 were more interior in the NSRA relative to the off-site uplands where house mice were known to be very abundant. Very few house mice were trapped on grid 3, and numbers on grid 4 were similar to those estimated for grid 2. Grid 5 was adjacent to Hogshead Road and near private homes and businesses. This grid had the highest trap success for house mice and the highest population estimate. Modest numbers of house mice were captured on transect 1, which was located immediately north of grid 5. Interestingly, only one house mouse was captured on grid 5 and recaptured in transect 1; this result suggested that the mice were resident during the period of study as opposed to being prone to dispersal. Farther south within the NSRA, grids 6 and 8 were relatively isolated from the uplands but supported relatively high numbers of house mice. In contrast, grid 7 near Lust Road had the second lowest trap success for house mice (5 per 100 trap nights) and trailed grids 6 and 8 in terms of population estimate and density. Large populations of house mice were known to exist along Lust Road in the upland areas to the east of the NSRA.

Local variation in the abundance of house mice within the area of the NSRA may be expected due to the natural variation in populations in local habitats. Many potential variables may be linked with the explanation for this variation. Vegetation as a source of food and as cover from predators may be important (Newsome and Corbett 1975). In Australia, Brown and Singleton (1999) found that house mouse populations increased following high rainfall and decreased following low rainfall. Under the most favorable conditions, the house mouse populations could double in about 38 days.

Plant growth that provided food and cover may be correlated with rainfall. Because rainfall variation has been somewhat atypical in central Florida since 1998, it may prove useful to examine association of rainfall patterns with house mouse abundance.

Local predation pressure may have played a role in suppressing or releasing the rodent populations. Based on the general lack of sign (tracks and scats), medium-sized mammals appeared to be very uncommon on the NSRA (Stout and Clerico, pers. observ.). In contrast, avian predators were common-to-abundant during October, November, and December 1999. For example, migrating northern harriers (*Circus cyaneus*) were very abundant in early November. An American kestrel (*Falco sparverius*) was observed holding a house mouse (Stout and Clerico, pers. observ.). Relatively few snakes were observed during phases I and II.

The presence of large numbers of cotton rats in all the fallow fields that were trapped suggests food and shelter were abundantly available for these generalist herbivores. Grasses are the preferred food of cotton rats, but dicots are also ingested (Randolph et al. 1991). House mice feed on plant parts, seeds, and insects and other invertebrates (Bomford 1987a). Casual observation suggested that there was abundant food for the omnivorous house mouse. Thus, interactions between the cotton rat and the house mouse would be more likely to involve competition for space rather than for food supply.

Interactions of house mice and cotton rats remained unclear during phase II of the study. Removal of cotton rats from grids 5 and 8 did not result in any change in the status of house mice on the grids. The abundance of cotton rats during the removal period suggested that the removal effort was not sufficient to demonstrate a possible interaction between the two species. Further study of the existing data on site of capture may reveal some relationship at the grid level. On Virginia barrier islands, house mice occurred in mixed habitats of grassland and shrub-dominated areas. Scott and Dueser (1992) found house mice in grasslands, whereas deer mice (*Peromyscus leucopus*) inhabited the shrub thickets. Reciprocal-removal experiments did not result in significant habitat shifts by either species. Layne (1997) reported very few captures of house mice in native habitats at the Archbold Biological Station, Highlands County, Florida. He noted, however, that the house mice captures tended to coincide with periods of low abundance of native mice.

Ants, including the imported fire ant (*Solenopsis invicta*), are extremely common on the NSRA. Young of some mammals are killed by fire ants while they are confined to nests on the ground. The question arose as to why this source of mortality has not acted to limit numbers of cotton rats

and house mice. For reasons that are not clear, ants were not an important source of trap mortality in either phase I or phase II.

HYPOTHESIS TESTING

Phase I—*The null hypothesis was that no difference in house mouse abundance would be found among the three habitat strata (fallow fields, levees, and abandoned buildings) selected for study.*

The working hypothesis of phase I was not rejected. House mice were controlled in the buildings available for study, yet mice were still present. House mice were apparently as numerous on levees and roadsides as in fallow fields. However, house mice were not uniformly abundant in any of the habitats sampled. The results suggest that levees may have served as a source habitat (refuge) for house mice that occupied the fallow fields. This argument must assume that even with flooding, some of the levees remained as suitable habitat.

Phase II—*The null hypothesis was that no difference in house mouse abundance would be found among the habitat strata (fallow fields of the former muck farms, upland citrus groves, upland old fields, and upland forest).*

The working hypothesis of phase II was not accepted. House mice were either absent or in extremely low numbers in the upland habitats, whereas resident populations were encountered on the grids in the NSRA.

Phase II of the study provided some preliminary answers to other questions that had been posited. Another hypothesis was that house mouse populations would recover during the spring and summer of 2000 with the result that densities would be similar across the various habitats under study. The data from the NSRA, habitats representing the interface between the NSRA and the uplands, and the uplands all suggest the house mouse populations failed to recover to levels of abundance observed in phase I of the study. Small numbers of house mice resided on the NSRA, but there was no evidence of a sharp population buildup in 2000. Likewise, monthly monitoring of the uplands from March to August 2000 did not suggest any recovery of house mouse populations.

Conditions (e.g., abundant food, cover, rainfall) required to promote rapid growth, high densities, and plague behavior by the house mouse were apparently lacking during phase II (Brown and Singleton 1999). A late

winter, spring, and early summer drought certainly delayed or reduced plant growth on and near the NSRA during 2000. House mouse populations crashed following a drought in southern Australia and were unable to respond to rainfall for at least two subsequent years (Brown and Singleton 1999).

The opposite suite of environmental conditions occurred during phase II of the study compared to conditions hypothesized to explain the house mouse plague of 1999. Abundant rainfall and a lack of killing frosts in 1997 and 1998 may have been critical to the population buildup in 1999.

A significant question that remained unanswered after phase I: What was the role of dispersal in the population dynamics of house mice over the past 2 years in the Apopka-Zellwood-NSRA? Two views may be offered: (1) resident animals in all the various habitats in the area increased in response to favorable extrinsic and intrinsic factors with the result that the population growth was temporarily synchronized or (2) populations in the NSRA increased to the extent that individuals dispersed from established breeding groups to habitats that were previously unoccupied. In turn, these newly established breeding groups then increased to plague levels. It is not possible to directly test either of these views with the existing data from the NSRA. Synthesis of prior studies and existing data may help to clarify some possible explanations.

Dispersal of house mice has been the subject of several studies (Lidicker 1995). Lidicker and Patton (1987) reported the maximum recorded dispersal distance of *Mus musculus* as 1,500 m (4,921 ft). This record suggests mice could move nearly a mile from the edge of the NSRA to settle in an upland habitat. Because the direction of dispersal movements has not been studied adequately, some small number of individuals might achieve this right angle distance from the source habitat, for example, the edge of the NSRA. Animals at successively greater distances from the habitat edge (that is toward the interior of the source habitat) may also achieve this right angle dispersal distance. Because the interior animals have farther to go before entering the upland habitat, places near the habitat edge would have a greater likelihood of accumulating dispersers.

During phase II, a considerable effort was made to document movements of small mammals at the interface between the NSRA and the adjacent uplands. The general lack of captures in these upland habitats near the edge of the NSRA during the summer of 2000 does not support the

hypothesis that a significant amount of dispersal was taking place. However, it can be argued that dispersal is seasonal and depressed in the summer months relative to other periods.

Dispersal of house mice has not been found to be density-dependent. In test enclosures under laboratory conditions, Butler (1980) found the same percentage of individuals emigrating from small and large groups within an area. These results suggest a density proportional response, for example, 10% emigrate regardless of the population size. A more complex study of dispersal of house mice was done in an outdoor, simulated landscape with corridors (Lorenz and Barrett 1990). Mice were stocked in the 0.1-ha enclosures in two groups of four enclosures each (0.4 ha total). In each group of enclosures, a vegetation strip was maintained; in addition, one strip had a split rail fence. Movements of mice were recorded in the two series of enclosures. Differences in movements between the two groups of enclosures were not related to the density of mice in the enclosures.

Dispersal movements of house mice may be expected to vary with season. During summer and fall seasons, significantly more mice moved along corridors with a split rail fence than along a corridor with only vegetation in simulated landscapes, whereas equal numbers dispersed along these corridors during other seasons (Lorenz and Barrett 1990).
Krebs, Kenney, and Singleton (1995) found that most house mice in an agricultural landscape became nomadic after the breeding season. Nomadic movements are a subset under the more general notion of dispersal and generally reflect a population response to scattered resources.

The likelihood of dispersal varies with the age and sex of house mice. Significantly more adult male mice dispersed than did adult females in the enclosures used by Lorenz and Barrett (1990). In a series of replicated experiments to study social mechanisms leading to emigration, Gerlach (1990) found dispersal of house mice to be male-biased. In these experiments, dominant males forced the emigration of subdominant males. At high densities, females did not breed until after emigration.

MANAGEMENT RECOMMENDATIONS

Recommendations for management of house mice in the NSRA are constrained by legal, ethical, economic, and ecologic considerations. Chambers et al. (1997) suggested that there were two principal means for managing rodent pest populations—increase mortality or decrease fertility. Practical chemical means to curb reproduction are not available. Various chemical control methods used to increase mortality elsewhere in the world are unacceptable at the NSRA due to the threat to non-target native organisms. Chambers et al. (1997) summarized the general problems associated with use of chemical control as follows:

1. Residues can contaminate the environment.

2. Non-target deaths may occur due to primary poisoning from consumption of the bait or from secondary poisoning when target rodents are consumed by others.

3. Large areas need to be treated to achieve results.

4. There are ethical and animal welfare issues associated with the use of poisons.

It is not economically reasonable to eliminate the habitat used by house mice at the NSRA by reducing the vegetative cover. To do so would require mowing throughout the growing season. The only practical method of limiting the risk of significant movements of breeding age house mice from the NSRA to the uplands is to create a cleared barrier strip along the outer boundary between the NSRA and upland/private holdings. Careful maintenance of a mowed barrier to reduce house mouse movements should achieve this goal. Canals and canal sides would have to be included in barrier clearing because the canal sides would otherwise act as habitat corridors from the interior (Peles et al. 1999). The width of the barrier should be 20 m (66 ft) or roughly twice the width of the home range of a house mouse.

Should the NSRA remain unflooded for several years in the future, some monitoring of house mice might be prudent. Monitoring of mouse breeding through fall and winter could be done to determine reproductive

success of the house mouse in the NSRA. The extrinsic conditions setting the stage for year-round breeding are assumed to be warm and wet conditions that promote development of abundant food and shelter. Studies in Australia have shown that the house mouse is capable of increasing very rapidly under favorable circumstances.

If winter breeding is common, clearing of vegetation at the interface of the NSRA and the uplands should be expanded to a strip100 m (330 ft) wide.

REFERENCES

Berry, R.J., and M.E. Jakobson. 1974. Vagility in an island population of the house mouse. *Journal of Zoology*, London 173:341–354.

Bomford, M. 1987a. Food and reproduction of wild house mice I. Diet and breeding seasons in various habitats on irrigated cereal farms in New South Wales. *Australian Wildlife Research* 14:183–196.

———. 1987b. Food and reproduction of wild house mice II. A field experiment to examine the effect of food availability and food quality on breeding in spring. *Australian Wildlife Research* 14:197–206.

Bronson, F.H. 1979. The reproductive ecology of the house mouse. *The Quarterly Review of Biology* 54:265–299.

Brown, P.R., and G.R. Singleton. 1999. Rate of increase as a function of rainfall for house mouse *Mus domesticus* populations in a cereal-growing region in southern Australia. *Journal of Applied Ecology* 36:484–493.

Butler, R.G. 1980. Population size, social behaviour, and dispersal in house mice: A quantitative investigation. *Animal Behaviour* 28:78–85.

Chambers, L.K., G.R. Singleton, and G.M. Hood. 1997. Immunocontraception as a potential control method of wild rodent populations. *Belgium Journal of Zoology* 127(Sup. 1):145–156.

Chambers, L.K., G.R. Singleton, and C.J. Krebs. 2000. Movements and social organization of wild house mice (*Mus domesticus*) in the wheatlands of northwestern Victoria, Australia. *Journal of Mammalogy* 81:59–69.

DeLong, K.T. 1966. Population ecology of feral house mice: Interference by *Microtus*. *Ecology* 47:481–484.

———. 1967. Population ecology of feral house mice. *Ecology* 48:611–634.

Drickamer, L.C., G.A. Feldhamer, D.G. Mikesic, and C.M. Holmes. 1999. Trap-response heterogeneity of house mice (*Mus musculus*) in outdoor enclosures. *Journal of Mammalogy* 80:410–420.

Gerlach, G. 1990. Dispersal mechanisms in a captive wild house mouse population (*Mus domesticus* Rutty). *Biological Journal of the Linnean Society* 41:271–277.

Godfrey, R.K. and J.W. Wooten. 1981a. *Aquatic and wetland plants of southeastern United States. Monocotyledons.* Vol. I. Athens, Ga.: University of Georgia Press.

———. 1981b. *Aquatic and wetland plants of southeastern United States. Dicotyledons.* Vol. II. Athens, Ga.: University of Georgia Press.

Hall, E.R. 1927. An outbreak of house mice in Kern County, California. University of California Publication. *Zoology* 30:189–203.

Krebs, C. 1999. *Ecological methodology.* 2nd ed. Menlo Park, Calif.: Addison Wesley Longman, Inc.

Krebs, C.J., G.R. Singleton, and A.J. Kenney. 1994. Six reasons why feral house mouse populations might have low recapture rates. *Wildlife Research* 21:559–567.

Krebs, C.J., A.J. Kenney, and G.R. Singleton. 1995. Movements of feral house mice in agricultural landscapes. *Australian Journal of Zoology* 43:293–302.

Krebs, C.J., D. Chitty, G. Singleton, and R. Boonstra. 1995. Can changes in social behaviour help to explain house mouse plagues in Australia? *Oikos* 73:429–434.

Layne, J.N. 1997. Nonindigenous mammals. In *Strangers in Paradise,* D. Simberloff, D.C. Schmitz, and T.C. Brown, eds. Chapter 10. Washington, D.C.: Island Press.

Lidicker, W.Z., Jr. 1966. Ecological observations on a feral house mouse population declining to extinction. *Ecological Monographs* 36:27–50.

Lidicker, W.Z., Jr., ed. 1995. *Landscape approaches in mammalian ecology and conservation.* Minneapolis: University of Minnesota Press.

Lidicker, W.Z,. Jr., and J.L. Patton. 1987. Patterns of dispersal and genetic structure in populations of small rodents. In *Mammalian Dispersal Patterns,* B.D. Chepko-Sade and Z.T. Halpin, eds. Chapter 10. Chicago: The University of Chicago Press.

Lorenz, G.C., and G.W. Barrett. 1990. Influence of simulated landscape corridors on house mice (*Mus musculus*) dispersal. *American Midland Naturalist* 123:348–356.

Murphy, T.R., D.L. Colyin, R. Dickens, J.W. Everest, and D. Hall. 1979. Weeds of southern turfgrasses. SP-79. Florida Cooperative Extension Service, Institute of Food and Agricultural Sciences, University of Florida, Gainesville, Fla.

Newsome, A.E. 1969a. A population study of house-mice temporarily inhabiting a south Australian wheatfield. *Journal of Animal Ecology* 38:341–359.

———. 1969b. A population study of house-mice permanently inhabiting a reed-bed in south Australian. *Journal of Animal Ecology* 38:361–377.

Newsome, A.E., and L.K. Corbett. 1975. Outbreaks of rodents in semi-arid and arid Australia: Causes, preventions, and evolutionary considerations. In *Rodents in desert environments*, I. Prakash and P.K. Ghosh, eds. The Hague, Netherlands: Dr. W. Junk.

Newsome, A.E., and P. Crowcroft. 1971. Outbreaks of house-mice in south Australia in 1965. CSIRO. *Wildlife Research* 16:41–47.

Pearson, O.P. 1963. History of two local outbreaks of feral house mice. *Ecology* 44:540–549.

Peles, J.D., D.R. Bowne, and G.W. Barrett. 1999. Influence of landscape structure on movement patterns of small mammals. In *Landscape ecology of small mammals*, G.W. Barrett and J.D. Peles, eds. Chapter 3. Springer, N.Y.

Piper, S.E. 1928. The mouse infestation of Buena Vista Lake Basin, Kern County, California, September 1926 to February 1927. Department of Agriculture, State of California. Monthly Bulletin 17:538–560.

Pollock, K.H. 1982. A capture-recapture sampling design robust to unequal catchability. *Journal of Wildlife Management* 46:752–757.

Randolph, J.C., G.N. Cameron, and J.A. Wrazen. 1991. Dietary choice of a generalist grassland herbivore, *Sigmodon hispidus*. *Journal of Mammalogy* 72:300–313.

Scott, D.E., and R.D. Dueser. 1992. Habitat use by insular populations of *Mus* and *Peromyscus*: What is the role of competition? *Journal of Animal Ecology* 61:329–338.

Singleton, G.R., and T.D. Redhead. 1990. Structure and biology of house mouse populations that plague irregularly: An evolutionary perspective. *Biological Journal of the Linnean Society* 41:285–300.

Staples, P.P., and C.R. Terman. 1977. An experimental study of movement in natural populations of *Mus musculus, Microtus pennsylvanicus,* and *Microtus pinetorum. Researches on Population Ecology* 18:267–283.

Stickel, L.F. 1979. Population ecology of house mice in unstable habitats. *Journal of Animal Ecology* 48:871–887.

Stout, I.J., and R. Clerico. 2000. *Rodent population study in the North Shore Restoration Area, part I (survey of rodents near Lake Apopka).* Special Publication SJ2000-SP2. Palatka, Fla.: St. Johns River Water Management District.

Stucky, J.M., T.J. Monaco, and A.D. Worsham. 1981. Identifying seedling and mature weeds common in the southeastern United States. The North Carolina Agricultural Research Service and the North Carolina Agricultural Extension Service, North Carolina State University, Raleigh.

Tobe, J.D., et al. 1998. *Florida wetland plants: An identification manual.* Tallahassee, Fla.: Florida Department of Environmental Protection.

APPENDIX 1—PLANT LIST

Table 1. List of dominant vascular plants encountered in units 1 and 2 of the North Shore Restoration Area, October 1999–August 2000 (list compiled by Joy Marburger and Jack Stout)

Genus	Species	Common Name	Date	Form*	Exotic/ Native
Albutilon	*indicum*	Velvetleaf	11 Feb 00	H	E
Amaranthus	*spinosus*	Spiny amaranth	30 Oct 99	H	E
Baccharis	*halimifolia*	Saltbush	30 Oct 99	S	N
Brassica	*juncea*	Indian mustard	11 Feb 00	H	E
Chenopodium	*alba*	Lamb's quarters	11 Feb 00	H	E
Cinnamomum	*camphora*	Camphor tree	23 Feb 00	T	E
Cleome	*rutidosperma*	Spiderflower	25 Aug 00	H	E
Commelina	*diffusa*	Spreading dayflower	30 Oct 99	H	N
Conyza	*canadensis*	Horseweed	25 Aug 00	H	N
Cyperus	*involucratus*	Umbrella sedge	30 Oct 99	H	E
Cyperus	*rotundus*	Nutsedge	25 Aug 00	H	E
Digitaria	spp.	Crabgrass	25 Aug 00	H	E
Eclipta	*alba*	Eclipta	30 Oct 99	H	N
Eicchornia	*crassipes*	Waterhyacinth	11 Feb 00	H	E
Eleusine	*indica*	Indian goosegrass	25 Aug 00	H	E
Enterolobium	*contortisiliquum*	Earpod tree	23 Feb 00	T	E
Eupatorium	*capillifolium*	Dog fennel	11 Feb 00	H	N
Galium	*aparine*	Bedstraw	30 Oct 99	H	E
Galium	*tinctorium*	Pigweed	30 Oct 99	H	N
Geranium	*caroliniana*	Carolina geranium	11 Feb 00	H	E
Indigofera	*hirsute*	Hairy indigo	15 Feb 00	H	E
Ipomoea	spp.	Morning glory	30 Oct 99	H	?
Kummerowia	*striata*	Common lespedeza	11 Feb 00	H	E
Lantana	*camara var. mista*	Lantana	15 Feb 00	H	E
Leucaena	*leucocephala*	Lead plant	15 Feb 00	T	E
Ludwigia	*leptocarpa*	Seedbox	11 Feb 00	H	N
Ludwigia	*peruviana*	Primrose willow	15 Sep 99	S	E
Malva	*neglecta*	Cheeses	11 Feb 00	H	E
Melilotus	*alba*	White sweet clover	23 Feb 00	H	E
Neyraudia	*reynaudiana*	Burma reed	15 Feb 00	H	E
Oenothera	*laciniata*	Cutleaf evening primrose	25 Aug 00	H	N
Panicum	*maximum*	Guineagrass	30 Oct 99	H	E

Table 1—*Continued*

Genus	Species	Common Name	Date	Form*	Exotic/ Native
Parietaria	*pensylvanica*	Pellitory	11 Feb 00	H	E
Paspalum	*urvillei*	Vasey grass	25 Aug 00	H	E
Pistia	*stratiotes*	Waterlettuce	11 Feb 00	H	E
Rumex	*crispus*	Curly dock	11 Feb 00	H	E
Rumex	*hastatulus*	Heartwing sorrel	23 Feb 00	H	N
Rumex	*obovatus*	Tropical dock	23 Feb 00	H	E
Rumex	*obovatus*	Tropical dock	25 Aug 00	H	E
Salix	*caroliniana*	Coastal plain willow	11 Feb 00	S	N
Sambucus	*canadensis*	Elderberry	11 Feb 00	S	N
Schinus	*terebinthifolius*	Brazilian pepper	23 Feb 00	S	E
Senecio	*glabellus*	Golden ragwort	11 Feb 00	H	N
Sesuvium	*portulacastrum*	Sea-purslane	30 Oct 99	H	N
Setaria	*geniculata*	Knotroot foxtail	30 Oct 99	H	N
Sicyos	*angulatus*	Bur cucumber	15 Feb 00	H	N
Solanum	spp.	Nightshade	11 Feb 00	H	E
Solanum	*chenopodioides*	Black nightshade	30 Oct 99	H	N
Sonchus	*asper*	Spiny-leaved sow thistle	11 Feb 00	H	E
Sorghum	*halpense*	Johnsongrass	25 Aug 00	H	E
Typha	spp.	Cattail	30 Oct 99	H	N
Urochloa	*texana*	Texas millet	25 Aug 00	H	N (Texas)
Urtica	*dioica*	Stinging nettle	11 Feb 00	H	E

Note: H = herb
S = shrub
T = tree

APPENDIX 2—TYPICAL VEGETATIVE COVER IN MAMMAL TRAPPING GRIDS 1–8 IN UNITS 1 AND 2 OF THE NORTH SHORE RESTORATION AREA

(Photographs taken in August 2000)

Grid 1

Grid 2

Grid 3

Grid 4

Grid 5

Grid 6

Grid 7

Grid 8

APPENDIX 3—TYPICAL VEGETATIVE COVER IN UPLAND TRAPPING GRIDS 1, 2, 4, 6, 7, AND 8

(Photographs taken in September 2000)

Upland 1

Upland 2

Upland 4

Upland 6

Upland 7

Upland 8