



11  
FGFG3  
NH

# Florida Scientist

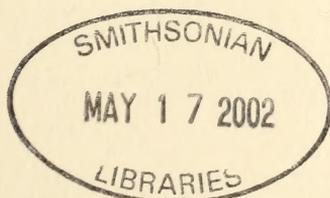
Volume 65

Spring, 2002

Number 2

## CONTENTS

Age-0 Spot ( <i>Leiostomus xanthurus</i> ) from Two Estuaries Along Central Florida's East Coast: Comparisons of the Timing of Recruitment, Seasonal Changes in Abundance, and Rates of Growth and Mortality .....	Richard Paperno	85
Re-evaluation of Off-Road Vehicle Management in Big Cypress National Preserve, Florida, After Twenty-Six Years of Management .....	Robert V. Sobczak and Antonio J. Pernas	100
Population Ecology of Three Species of Small Mammals on Key Largo, Florida .....	Christopher R. Sasso and Michael S. Gaines	115
Using Geographic Information Systems to Evaluate Available Habitat for Two Rodent Species on North Key Largo, Florida .....	Britt Keith and Michael S. Gaines	126
Evidence for the Use of Chemosensory Cues by the Alligator Snapping Turtle, <i>Macroclemys temminckii</i> , to Detect the Presence of Musk and Mud Turtles .....	Fred Punzo and Lisa Alton	134
Measuring Toxicity of Lead Samples Using a Microtox 500 Analyzer ....	Shengrong Chen, Melissa Derby, and Dean F. Martin	139
From the Editors .....		146



# FLORIDA SCIENTIST

QUARTERLY JOURNAL OF THE FLORIDA ACADEMY OF SCIENCES

Copyright © by the Florida Academy of Sciences, Inc. 2002

Editor: Dr. Dean F. Martin

Co-Editor: Mrs. Barbara B. Martin

Institute for Environmental Studies, Department of Chemistry, University of South Florida,  
4202 East Fowler Avenue, Tampa, Florida 33620-5250

Phone: (813) 974-2374; e-mail: [dmartin@chumal.cas.usf.edu](mailto:dmartin@chumal.cas.usf.edu)

Business Manager: Dr. Richard L. Turner

Department of Biological Sciences, Florida Institute of Technology,  
150 West University Boulevard, Melbourne, Florida 32901-6975

Phone: (321) 674-8196, e-mail: [rturner@fit.edu](mailto:rturner@fit.edu)

<http://www.floridaacademyofsciences.org>

---

The *Florida Scientist* is published quarterly by the Florida Academy of Sciences, Inc., a non-profit scientific and educational association. Membership is open to individuals or institutions interested in supporting science in its broadest sense. Applications may be obtained from the Executive Secretary. Direct subscription is available at \$45.00 per calendar year.

Original articles containing new knowledge, or new interpretations of knowledge, are welcomed in any field of science as represented by the sections of the Academy, viz., Biological Sciences, Conservation, Earth and Planetary Sciences, Medical Sciences, Physical Sciences, Science Teaching, and Social Sciences. Also, contributions will be considered which present new applications of scientific knowledge to practical problems within fields of interest to the Academy. Articles must not duplicate in any substantial way material that is published elsewhere. Contributions are accepted only from members of the Academy and so papers submitted by non-members will be accepted only after the authors join the Academy. Instructions for preparations of manuscripts are inside the back cover.

---

## Officers for 2001–2002

### FLORIDA ACADEMY OF SCIENCES

Founded 1936

*President:* Barry Wharton  
HDR Engineering, Inc.  
2202 N. Westshore Boulevard  
Suite 250  
Tampa, FL 33607-5711

*Past-President:* Dr. Maribeth Durst  
St. Leo University  
St. Leo, FL 33574

*Secretary:* Ronald Federspiel  
University of South Florida SCA400  
4202 E. Fowler Ave.  
Tampa, FL 33620

*Treasurer:* Mrs. Georgina Wharton  
11709 North Dr.  
Tampa, FL 33617

*Executive Director:* Dr. Gay Biery-Hamilton  
Rollins College  
1000 Holt Ave., 2761  
Winter Park, FL 32789-4499  
Natalie Smith, Secretary  
e-mail: [GBiery-Hamilton@osc.org](mailto:GBiery-Hamilton@osc.org)

*Program Chair:* Dr. Donald Lovejoy  
Department of Oceanography  
Palm Beach Atlantic College  
P.O. Box 24708  
West Palm Beach, FL 33416

# Florida Scientist

QUARTERLY JOURNAL OF THE FLORIDA ACADEMY OF SCIENCES

DEAN F. MARTIN, *Editor*

BARBARA B. MARTIN, *Co-Editor*

---

Volume 65

Spring, 2002

Number 2

---

*Biological Sciences*

## AGE-0 SPOT (*LEIOSTOMUS XANTHURUS*) FROM TWO ESTUARIES ALONG CENTRAL FLORIDA'S EAST COAST: COMPARISONS OF THE TIMING OF RECRUITMENT, SEASONAL CHANGES IN ABUNDANCE, AND RATES OF GROWTH AND MORTALITY.

RICHARD PAPERNO<sup>(1)</sup>

Florida Fish & Wildlife Conservation Commission, Florida Marine Research Institute,  
Indian River Field Laboratory, 1220 Prospect Ave, Suite 285, Melbourne, Florida 32901

**ABSTRACT:** *Data from fixed-station sampling conducted during 1991–1997 were used to determine the timing of recruitment, the seasonal changes in abundance, and the growth and mortality rates of age-0 spot (*Leiostomus xanthurus*) populations in the Indian River Lagoon (IRL) and Halifax River (HR) along the Atlantic coast of Florida. The magnitude of recruitment was greater in the HR system than in the IRL, particularly during the comparatively weak year-class of 1994. In the IRL, juvenile growth rates varied between years, with the instantaneous growth coefficient (G) ranging from 0.28 to 0.73. In the HR, however, growth varied little, with G ranging from 0.36 to 0.43. Estimates of mortality (Z) ranged from 0.02 to 0.08/d for the IRL and from 0.02 to 0.03/d for the HR. For age-0 spot, recruitment, growth, and mortality varied greatly between years and systems and may be strongly constrained by the impact advective processes have on larval supply to the estuary and by the distance to the nursery habitats has on the distribution and survival of settling juveniles within the estuary.*

**Key Words:** *Leistomus xanthurus*, spot, recruitment, growth, mortality

SPOT, (*Leiostomus xanthurus* Lacépede), is an often-studied member of the economically important family Sciaenidae. The species ranges from Massachusetts on the Atlantic coast of the United States to Mexico in the Gulf of Mexico and is a seasonally abundant inhabitant of estuarine waters (Hales and Van Den Avyle, 1982). Spot have a protracted spawning season that lasts from October through May. Peak spawning occurs offshore in winter (Dec. and Jan.), and juveniles subsequently recruit to shallow inshore areas (e.g., tidal creeks and seagrass flats). The status of the commercial harvest has been studied in Florida's coastal waters (Muller et al., 1996; McRae et al., 1997), but little is known about the early life history of spot, and no attempt has been made to estimate growth and mortality rates of age-0 fish during their residency in Florida estuaries.

Many aspects of the life history of spot from estuaries in the mid-Atlantic and the northern Gulf of Mexico have been studied (e.g. Sundararaj, 1960; McCambridge and Alden, 1984; O'Neil and Weinstein, 1987), but little attention has been given to populations along Florida's Atlantic or gulf coasts (Townsend, 1956; Springer and Woodburn, 1960). In the present study, I compare the timing of recruitment, the seasonal changes in abundance, and annual estimates of growth and mortality rates of two estuarine populations of age-0 spot along the Atlantic coast of Florida, USA.

**MATERIALS AND METHODS**—Spot were collected from two estuaries along Florida's Atlantic coast: the Halifax River estuary (HR) and the Indian River Lagoon (IRL; Fig. 1). The HR sampling area consisted of the Halifax River from Ponce de Leon Inlet north to the Tomoka River (29° 24' N) and south to include the Mosquito Lagoon (28° 44' N; Fig. 1A). The IRL sampling area consisted of the northern Indian River Lagoon (north of 28° 01' N), excluding the Mosquito Lagoon subbasin (Fig. 1B). In both systems, sampling stations were widely distributed geographically and were located in several different habitat types. In the HR, 27 stations (13 seine, 14 trawl) were sampled monthly from January 1993 to September 1997 (56 months). During January 1993 to December 1995, five consecutive seine or trawl hauls were made at stations 1 through 16, and three consecutive hauls were made at stations 17 through 27. In 1996 and 1997, three consecutive hauls were made at each of the 27 stations. Stations 1 through 8 were located approximately 30 kilometers to the north of Ponce de Leon Inlet in and around the Tomoka River. This area has a mud and detritus bottom, no submerged aquatic vegetation, and is influenced by tides (mean range: 0.2 m) and by freshwater input from the Tomoka River. Stations 9 through 16 were located in the vicinity of Ponce de Leon Inlet (Fig. 1A). The estuarine area around Ponce de Leon Inlet region is characterized by no submerged aquatic vegetation and a sand bottom that is heavily influenced by inlet dynamics (mean tidal range of 0.7 m; Taylor and Yanez, 1992). Stations 17 through 27 were located to the south of Ponce de Leon Inlet in the Mosquito Lagoon and ranged between 15 and 45 kilometers from the inlet. Mosquito Lagoon is a relatively shallow subbasin of the Indian River Lagoon with a vegetated mud-sand bottom. Tidal influence is negligible, and water circulation is predominantly wind driven. In the IRL, 20 stations (14 seine, 6 trawl) were sampled monthly from April 1991 to March 1996 (62 months). Stations in the IRL were located north of Sebastian Inlet and ranged from approximately 15 to 80 kilometers from the inlet. Both systems contain salt-marsh and spoil-island habitats that have shore vegetation comprised of salt marsh cordgrasses (*Spartina*

---

<sup>1</sup> richard.paperno@fwc.state.fl.us

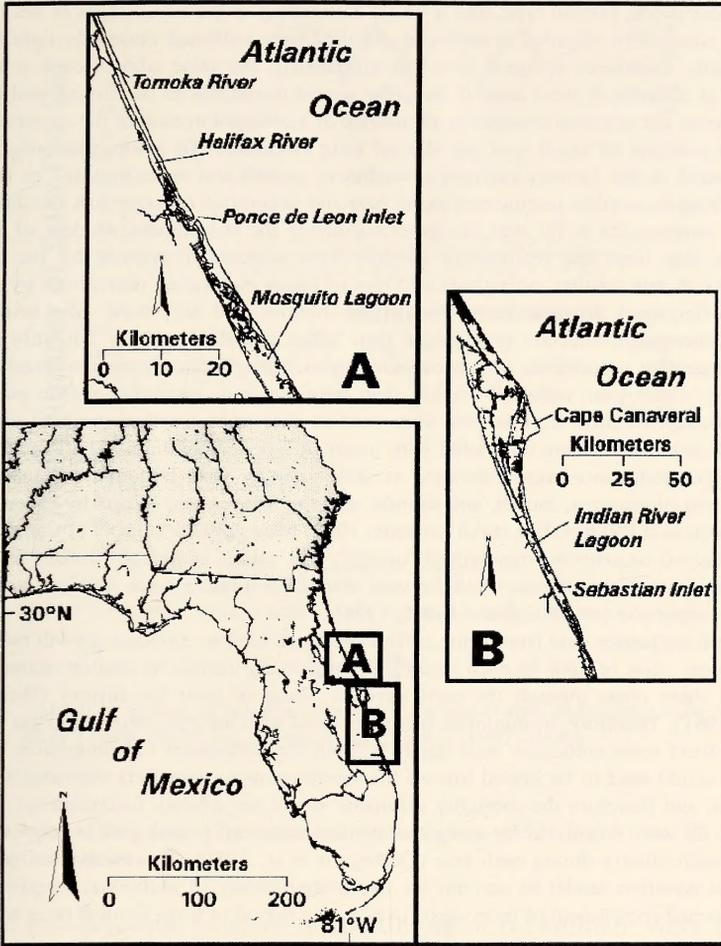


FIG. 1. Map of Florida showing the locations of the Halifax River-Mosquito Lagoon and Indian River Lagoon.

spp.), glasswort (*Salicornia* spp.), saltwort (*Batis maritima*), and mangroves (*Rhizophora mangle*, *Avicennia germinans*, *Laguncularia racemosa*).

In both estuaries, a 21.3-m center-bag seine with 3.2-mm mesh was deployed along shorelines in water depths less than 1.5 m. Gently sloping shorelines were sampled by manually dragging the seine 9.1-m perpendicular to the shore and then hauling the net onshore. Shallow offshore seagrass flats were sampled by manually dragging the seine 9.1-m and then hauling the poles together and retrieving the net offshore. Steeply banked shorelines were sampled by deploying the seine along the shore in an arc from the stern of the boat. In waters deeper than 1.8 m, a 6.1-m otter trawl with 3.2-mm mesh liner in the codend was towed at approximately  $3.7 \text{ km hr}^{-1}$  for five minutes (avg. distance = 0.185 km/sample).

For all hauls, fish were identified to the lowest taxa, enumerated, and up to 100 fish/taxa were measured to the nearest mm standard length (SL) prior to release. Large samples (>1000 individuals) were subsampled with a modified Motoda box splitter (Winner and McMichael, 1997), and the total number was estimated from the subsample. At each station, water temperature [ $^{\circ}\text{C}$ ] and salinity [ $\text{‰}$ ] measurements were collected with a Hydrolab® Surveyor II multi-

probe. Water depth, bottom type, and a visual assessment of the percentages of seagrass cover (for seine sites) were recorded at each site. All data were collected during daylight hours.

Monthly abundance of age-0 spot was estimated at the seine sites in each system; these estimates of abundance were used to describe annual variations in the timing and magnitude of recruitment and seasonal changes in abundance of age-0 spot in each of the estuarine systems. The mean numbers of age-0 spot per 100 m<sup>2</sup> were calculated. To ensure that only age-0 spot were included in the various analyses (abundance, growth and mortality) and to reduce bias resulting from incomplete recruitment to the gear and emigration of larger fish, the data included only spot between 20 to 60 mm SL collected during the recruitment window of January to April. The size limit and recruitment window were selected to account for the continuous recruitment of new smaller individuals and loss of larger emigrating individuals by comparing the length-frequency distributions of spot at the shallow- and deep-water sites in the two estuaries (Kolmogorov-Smirnov two-sample test; Sokal and Rohlf, 1981). Monthly length-frequencies based on proportions of fish collected in each length class were combined over years to describe within-year variability rather than between year variability within each system. Pearson product moment correlations were used to determine whether seasonal variations in age-0 spot abundances were correlated with mean surface temperatures. The annual variations in age-0 spot abundance were examined at seine sites by year, bottom type (mud or sand), percent cover of seagrass, month, and salinity, and the temperature effects by estuary. General linear models and PROC GLM (SAS Institute, 1988) were applied to  $\ln(x+1)$  transformed data prior to analysis to generate standardized monthly and annual abundance indices from the first haul at each site. Comparisons of the annual abundance indices were obtained with Tukey's multiple comparison test (Sokal and Rohlf, 1981).

Length-frequency data from seine collections were used to calculate growth rate estimates for each year class of spot in each estuary. Spot initially recruit to shallow-water areas and remain in these areas through the early juvenile phase of their life history (Weinstein and Walters, 1981). Therefore, to minimize bias associated with the emigration of larger age-0 spot, only data from seine collection were used. Without the adjustment for emigration, the growth estimates would tend to be biased toward the slower-growing (smaller) individuals within the population, and therefore the mortality estimates would be inflated. Instantaneous growth coefficients ( $G$ ) were calculated by using the average time that it took fish to grow to a certain length in each estuary during each year (DeAngelis et al., 1980). This method utilizes a partial differential equation model to account for the nonuniformity of individual lengths that result from protracted recruitment of individuals over a long period of time. Growth rates were derived (Eqn. 1):

$$\ln L_t = \ln L_0 + G \times (t/30), \quad (1)$$

where  $G$  = instantaneous growth coefficient;  $L_t$  = monthly mean length (mm SL);  $L_0$  = theoretical size at which spot recruit to each estuary; and  $(t/30)$  = time in days.

Mortality rates were estimated by combining length-frequency and abundance data from seine collections made in each estuary during each year. Mortality rates were estimated (Eqn. 2):

$$\ln(n_i) = a + m \times \ln(l), \quad (2)$$

where  $n_i$  = the total number of spot at length  $l$ ;  $l$  = length class  $i$ ;  $m$  = slope. The instantaneous daily mortality ( $Z$ ) could then be estimated (Eqn. 3):

$$Z = \{G(m + 1)\}/30, \quad (3)$$

where  $Z$  could be estimated from  $G$  and  $m$  (Deegan, 1990). To reduce the bias that results from incomplete recruitment of smaller individuals to the gear or emigration of spot as they grow

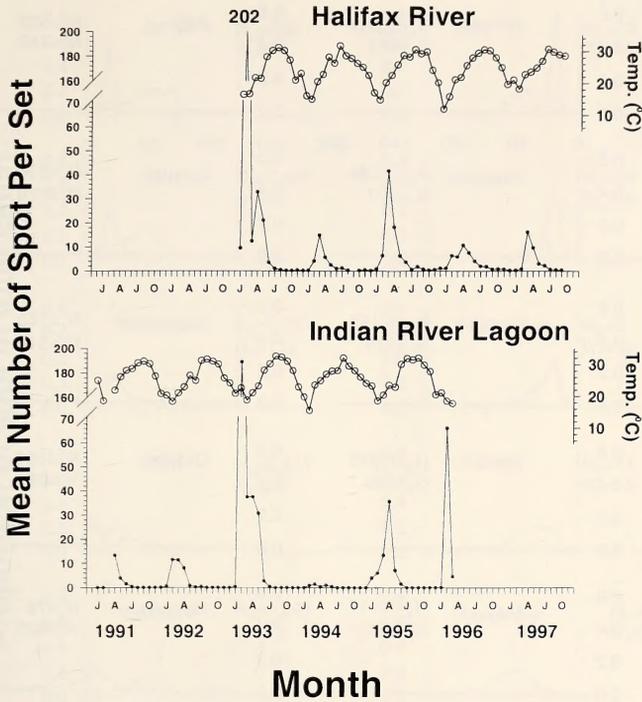


FIG. 2. Monthly indices of relative abundance for age-0 spot and mean temperature from the Halifax River (1993–1997) and Indian River Lagoon (1991–1996).

(as described above for growth rate estimates), only fish between 20 and 60 mm SL were used for mortality calculations.

**RESULTS**—Seasonal patterns of the timing of recruitment were found to be similar in the IRL and the HR systems (Figs. 2–4). In each system, spot began to be fully recruited between 15 to 20 mm SL in January as temperatures approached seasonal lows (18–20°C in the IRL and 15–18°C in the HR; Figs. 2–4). Annually, 1993 represented strong recruitment years in both systems. In addition, the magnitude of recruitment in the respective systems was different during the strong 1993 and weak 1994 year classes, with more spot being collected on average from the HR system than from the IRL (Fig. 2).

In the HR system, similar-sized age-0 spot were collected in seines and trawls from January to April (K-S test,  $P > 0.05$ ; Fig. 3). However by April, although few in number, spot  $> 60$  mm began to appear in trawl samples from the IRL (K-S test,  $P = 0.05$ ), but not in those from the HR (K-S test,  $P > 0.05$ ). After April, spot larger than 60 mm were collected in trawls in both systems, although in the IRL, spot of any size were completely absent or rare in samples collected after July (Figs. 3 and 4). In HR from May through December, the proportion of age-0 spot  $> 60$  mm collected in trawls

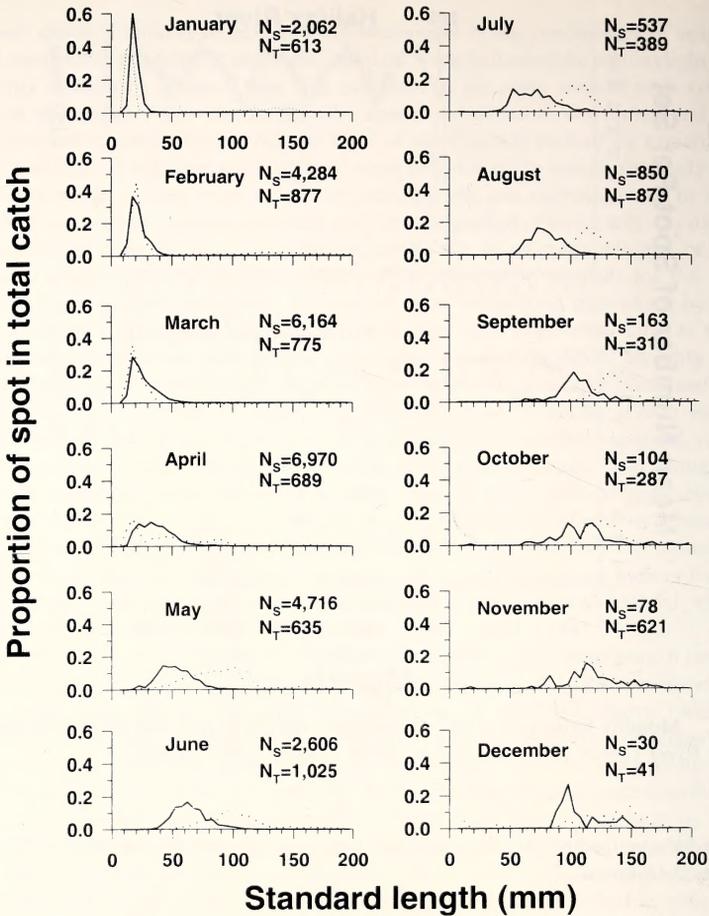


FIG. 3. Length-frequency distributions of spot captured at seine (—) and trawl (.....) stations in the Halifax River-Mosquito Lagoon from 1993 to 1997.  $N_S$  is the number of fish measured from seine samples.  $N_T$  is the number of fish measured from trawl samples.

was greater than those from seines (Fig. 3). Although the processes of immigration and emigration in the shallow-water areas (seine stations) can bias the rate if decline in abundance was used to estimate mortality, only data from months over which these processes appeared low (January–April) were used for subsequent growth and mortality estimates.

Juvenile spot abundance varied significantly ( $P < 0.05$ ) between years in both estuarine systems. The final GLM models each had year as the only main effect with  $r^2 = 0.088$ – $0.139$  (Table 1). Annual spot abundance was generally greater in HR (2.4–28.2 fish/haul) than in the IRL (0.6–20.8 fish/haul; Fig. 5). There was also a difference in the variability associated with the annual abundance estimates. The 95% confidence intervals around the annual abundance estimates were smaller for the HR ( $< 1$  fish per set) than

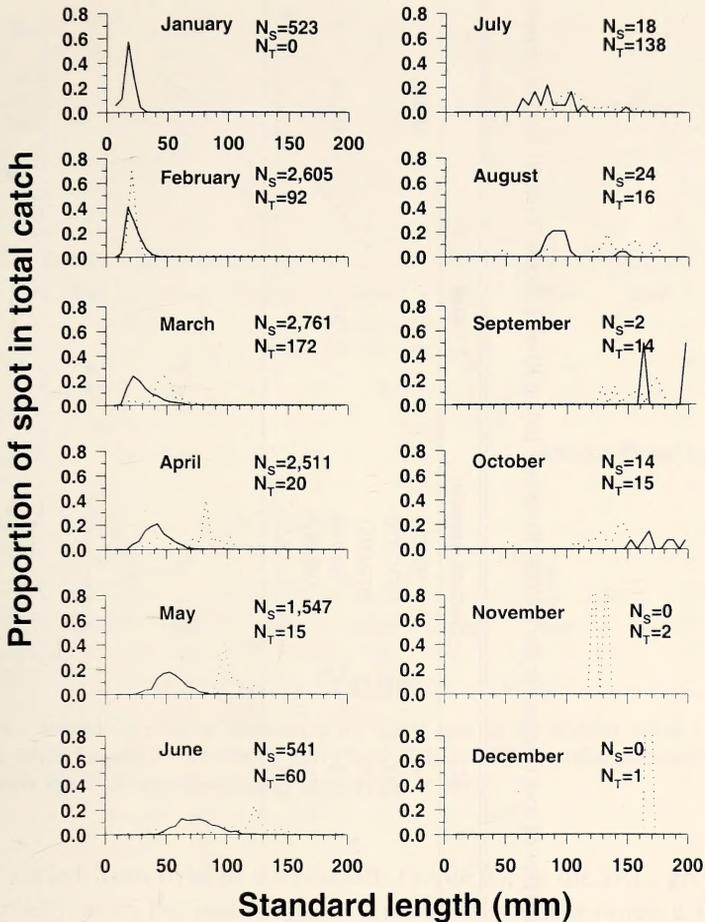


FIG. 4. Length-frequency distributions of spot captured at seine (—) and trawl (.....) stations in the Indian River Lagoon from 1991 to 1996.  $N_S$  is the number of fish measured from seine samples.  $N_T$  is the number of fish measured from trawl samples.

those for the IRL (Fig. 5). In both systems, 1993 and 1995 were strong recruitment years, whereas, 1994 was a poor recruitment year for juvenile spot (Fig. 5). Spot abundance in the HR from 1994 through 1997 was relatively stable but significantly lower than during 1993, which was a strong recruitment year. Abundance of age-0 spot in the IRL had a significant negative correlation ( $r = -0.26$ ,  $P < 0.05$ ) with temperature; fish were essentially absent during the months of September to December (Figs. 2 and 3). In the HR, the relationship was also negatively correlated ( $r = -0.21$ ) but not as statistically significant ( $P = 0.11$ ), and fish were collected more consistently throughout the year (Figs. 2 and 4).

Year-class growth rates varied between years and followed no discernible pattern in the two estuaries. In the HR, the instantaneous growth co-

TABLE 1. Final results of the general linear model analyses of spot catches for the Halifax River and Indian River Lagoon. Type III Sum of squares are shown.

Location	Source	df	Sum of squares	F-value	$r^2$
Halifax River	Model (Year)	4	94.381	5.82**	0.088
	Error	241	976.570		
	Corrected total	245	1070.951		
Indian River Lagoon	Model (Year)	5	88.748	3.75*	0.139
	Error	116	549.065		
	Corrected total	121	637.813		

\* =  $P < 0.01$ .

\*\* =  $P < 0.001$ .

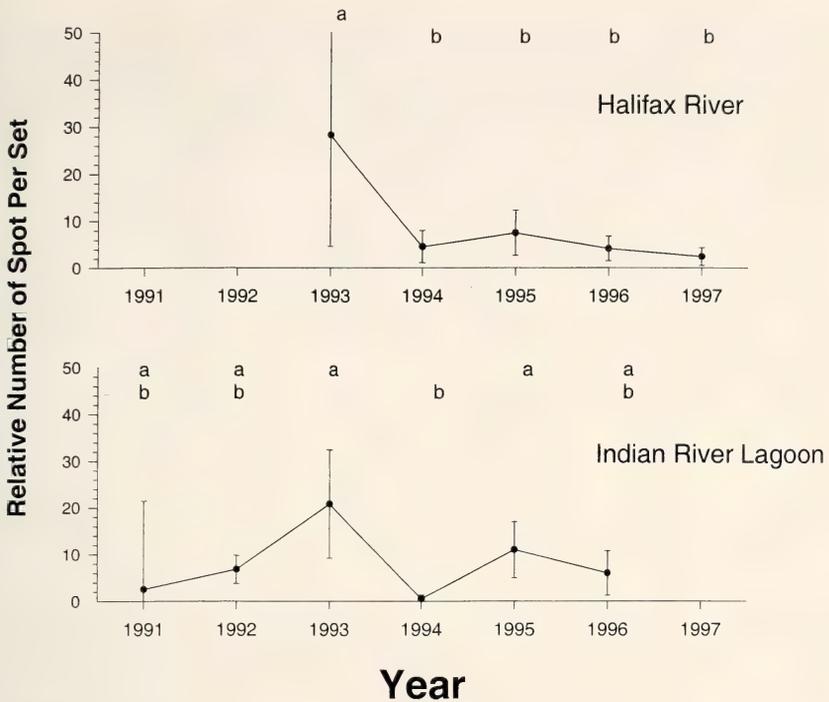


FIG. 5. Indices of relative abundance for age-0 spot in the Halifax River (1993–1997) and Indian River Lagoon (1991–1996). Error bars represent 95% confidence intervals. Values with the same letter are not significantly different at  $P < 0.05$ .

efficient varied from 0.36 to 0.43/month (Table 2). In the IRL, growth rates varied greatly, with the instantaneous growth coefficient ranging from 0.28 to 0.73/month (Table 2).

Mortality rates ( $Z$ ) were estimated for each year for each system. In each system the greatest mortality occurred during the strong recruitment year of 1993 (Table 3). As with growth,  $Z$  varied little between years in the HR (0.02–0.03/d) but varied greatly in the IRL system (0.02–0.08/d).

**DISCUSSION**—Spot, which have a spawning season that can last from October through May, recruit to shallow estuarine habitats during winter and early spring and may reside in the estuaries until fall. Although the onset of recruitment begins earlier in Florida than in more temperate estuaries (Springer and Woodburn, 1960), the general seasonal pattern of age-0 spot occurrence in the IRL and HR was consistent with the seasonal patterns of occurrence reported for spot in other systems along the western Atlantic and Gulf of Mexico (Sundararaj, 1960; Chao and Musick, 1977; McCambridge and Alden, 1984). Although the timing of recruitment events was found to be similar in both systems, the magnitude of the recruitment events was generally greater in the HR system. This may be due in part to the location

TABLE 2. Regression statistics for mean standard length (SL) versus month ( $m$ ) for age-0 spot. The regression equation takes the form:  $\text{Ln}(\text{SL}) = \text{ln}(L_0) + G \times m$  where  $\text{ln}(L_0)$  is the intercept and  $G$  is the instantaneous growth rate (slope). Only data for fish less than 60 mm SL were used. All slopes and intercepts were significantly different from zero ( $P < 0.05$ ).

Year	$\text{ln}(L_0)$	SE	$G$	SE	$r^2$
Indian River Lagoon					
1992	1.249	0.111	0.730	0.055	0.956
1993	1.982	0.182	0.435	0.062	0.874
1994	2.669	0.116	0.276	0.039	0.891
1995	2.252	0.090	0.394	0.028	0.966
1996	2.322	0.107	0.408	0.030	0.959
Halifax River Estuary					
1993	2.156	0.044	0.363	0.014	0.989
1994	1.927	0.112	0.434	0.045	0.931
1995	2.037	0.040	0.420	0.015	0.991
1996	2.175	0.102	0.360	0.033	0.943
1997	1.801	0.109	0.432	0.043	0.935

of Ponce de Leon Inlet within the HR sampling area, to differences in larval predation pressure between the areas, to differences in larval supply, or merely to a characteristic of the sampling sites. These four possibilities, singly or in combination, could result in differences in local population densities of settling juveniles.

Differences in larval supply of spot to the two systems may be due to a difference in the magnitude of spawning events or supply of spot that support each system or to less favorable conditions (wind, current, distance

TABLE 3. Regression statistics for total number versus length (SL) for age-0 spot. The regression equation takes the form:  $\text{Ln}(\text{total number}) = a + m \times \text{ln}(\text{length})$  where  $a$  is the intercept and  $m$  is the slope. Only data for fish less than 60 mm SL were used. Estimates of  $Z$  are calculated with equations in text.

Year	$\text{ln}(\text{total number})$	SE	$a$	SE	$r^2$	$Z$
Indian River Lagoon						
1992	12.742	1.163	-1.647	0.318	0.817	0.0644
1993	12.907	0.482	-4.585	0.368	0.963	0.0810
1994	7.260	5.645	-6.862	1.426	0.268	0.0171
1995	8.104	1.506	-0.813	0.412	0.394	0.0238
1996	12.599	0.696	-2.021	0.227	0.930	0.0411
Halifax River Estuary						
1993	12.656	0.763	-1.654	0.209	0.913	0.0322
1994	8.946	0.682	-0.873	0.187	0.785	0.0271
1995	8.581	0.718	-0.662	0.193	0.703	0.0232
1996	8.740	0.468	-0.772	0.128	0.858	0.0212
1997	5.852	1.485	-0.256	0.406	0.063	0.0181

to nursery area) for larval recruitment. Significant relationships have been demonstrated between larval supply and onshore and longshore winds, and current velocity and direction that suggests the magnitude and distribution of the larval supply to and within a nursery area may be related to complex interactions with the physical environment (Thorrold et al., 1994; Tilney et al., 1996; Epifanio and Garvine, 2001). Although Ponce de Leon Inlet (HR) has a more energetic tidal exchange than the Sebastian Inlet (IRL), conditions at Sebastian Inlet (net inflow) and in the intracoastal within the northern Indian River Lagoon appear to support transport to the northern reaches of the lagoon during late fall and early spring (Taylor and Yanez, 1992; Smith, 2001). It is also possible that internal northern transport mechanisms may not be sufficient in some years to overcome the difference in distance between the respective inlets and nursery grounds. Sebastian Inlet, which serves as the connection to the Atlantic for the northern IRL, is located approximately 15 km from the southern extremity of the IRL study area, whereas Ponce de Leon Inlet is located near the center of the HR study area. No evidence has been presented that indicate that spot spawn in estuaries, so this difference in distance to the respective nursery may have a significant effect on the comparative magnitude and variability of annual recruitment for spot and other estuarine-dependent species that spawn offshore, near HR and IRL. Since conditions in the northern IRL should support immigration into and distribution within the system, differences in recruitment between the HR and IRL systems may be a result of differences in advective transport of larvae from nearshore spawning areas to the estuaries and for spot may be compounded by distance to the nursery grounds. Differences in advective transport have been suggested to be the cause of variation in recruitment of bluefish to estuaries in the Mid-Atlantic Bight (McBride and Conover, 1991; Epifanio and Garvine, 2001).

Although the general seasonal timing of juvenile spot recruitment in Florida was found to coincide with the timing of spot recruitment in other areas, spot in Florida differed in cohort development. Evidence of distinct, multiple spawns was found in North Carolina (Weinstein and Walters, 1981), South Carolina (Beckman and Dean, 1984), and Virginia estuaries (McCambridge and Alden, 1984) but not in Gulf of Mexico or Florida coastal systems (Sundararaj, 1960; this study). In Florida estuaries, juvenile spot recruitment is a continuous process that can last from January through April. In general, the presence of multiple cohorts of juveniles throughout temperate nursery habitats may enhance year-class strength in the face of environmental conditions that occasionally extend beyond the range of tolerance of a particular cohort (Lambert, 1984; Lambert and Ware, 1984; Szedlmayer et al., 1990; Paperno et al., 2000). In Florida, however, environmental conditions (e.g., warm temperate climate) may not be such that this strategy is necessary to maintain the integrity of the year class, and other factors, such as predation rate or advective processes, may be more important in determining juvenile year-class strength (Epifanio and Garvine, 2001).

Distribution within and recruitment of fish to an estuary may be influenced by factors such as water temperature, salinity, food availability, predation, competition, and habitat structure or availability (Sogard, 1992; Miltner et al., 1995; Jones et al., 1996; Young et al., 1997). Age-0 spot (<60 mm SL) are ubiquitous within the IRL and HR systems even during poor years of recruitment. Juveniles inhabit both shallow-water habitats (<1.8 m) and deeper channels (>1.8 m), although they are more abundant in the shallows. Movement of fish out of the shallow-water areas to the channels was evident earlier in the IRL than in the HR system. The HR is a deeper water system than the IR is and has a smaller amount of shallow-water seagrass and sand-flat habitat. In the HR system, the deep water near shore may have a moderating effect on the water temperature there, which may explain why spot in the HR system move to deeper water later than spot in the IRL system do. In a thermally affected estuary, temperature has been demonstrated to have a direct effect on the distribution of some estuarine fishes: fish densities can decrease during warmer months and increase during cooler months (Jones et al., 1996). Thus lower ( $\sim 4^{\circ}\text{C}$ ) temperatures in late winter in the HR system, along with the potential deep water refugia, may be the principal reason that spot there remain in the estuary later in the season than spot in the IRL do.

Year-class growth rates of age-0 spot varied between years and followed no discernible pattern in the two estuaries. Growth rates estimated for spot from both systems were comparable with rates of spot in other estuarine systems. To compare growth rates for age-0 spot from this study ( $G = 0.28\text{--}0.73$ ) with those found from a more northern estuary, the same growth equation was applied to spot data presented by Weinstein and Walters (1981) for spot collected from the Cape Fear estuary, North Carolina. Instantaneous growth rates for spot from Cape Fear estuary ( $G = 0.23\text{--}0.31$ ) overlapped at the lower range with those from this study. This is not surprising when one considers that in 1994, the year that the lowest growth rates were found, was also the year of the lowest monthly mean temperatures. Thus, conditions in the northern Indian River Lagoon may have been similar to those during the Weinstein and Walters (1981) study.

Age-0 spot experienced similar rates of mortality in both east-central Florida systems during most years, but as with the growth rates, the interannual variation in the mortality rates was less in the HR than in the IRL. This difference in interannual stability may be a reflection of the relative influence of local environmental conditions on survival of juvenile fishes residing in a tidally driven system (HR) versus a shallow, wind-driven system (IRL). Daily mortality rates calculated for spot in this study ( $Z = -0.017$  to  $-0.081$ ) overlapped in range with mortality rates calculated for spot in several mid-Atlantic estuaries ( $Z = -0.023$  to  $-0.041$ ) (Weinstein and Walters, 1981; Weinstein, 1983; Currin et al., 1984; Miller et al., 1985).

The patterns observed in the rates of growth and mortality in age-0 spot from these two estuarine systems may indicate that the tradeoffs between

growth and survival necessary for success of a species may be different for fish in Florida estuarine systems than for fish in more temperate estuaries. For many species in temperate systems, optimal growth rates and minimal mortality rates are maintained through habitat selection or timing of spawning that result in reduced overwintering mortality (Sogard, 1997). Weinstein and Walters (1981) found that when temperatures were higher, spot ate less and thus grew at a slower rate than when temperatures were cool. As suggested for other species, the slower growth rates of spot in the southern estuaries may reflect the greater physiological constraints imposed by higher temperatures on southern populations (Conover and Present, 1990). In addition, the fact that northern and southern populations have similar mortality rates while they reside in nursery habitat may also suggest southern populations do not need to attain greater overwintering size because winter conditions are considerably less harsh in south Atlantic estuaries than in north Atlantic estuaries.

ACKNOWLEDGMENTS—I would like to thank personnel from the Florida Fish and Wildlife Conservation Commission (FWC) Indian River Field Laboratory (formerly with the Florida Department of Environmental Protection's [FDEP]), East Volusia County Mosquito Control District, St. John's River Water Management District, Florida Institute of Technology, Cape Canaveral National Seashore, Tomoka River State Park, FDEP's Bureau of Coastal and Aquatic Managed Areas, Merritt Island National Wildlife Refuge, Florida Sea Grant Extension Program, and Brevard Community College for their assistance in collecting and processing data for this study. I also thank Nick Funicelli of the U. S. Geological Survey for the loan of a research vessel during the first half of the project; Deborah Shelley and Russ Brodie of FDEP, John Stiner of Cape Canaveral National Seashore, and Paul Haydt of St. John's River Water Management District for their assistance with the organization of field staff; and Gary Nelson of FWC for assistance with the data analysis and Laurel Brant (FWC) for providing GIS data. I also thank Luis Barbieri, Rich Cailteux, Fred Vose, Rick Shaw, Judy Leiby, Jim Quinn, Llyn French and one anonymous reviewer for providing useful comments on the manuscript. This project was supported in part by funding from the Ponce de Leon Port Authority and in part by funding from the Department of the Interior, U.S. Fish and Wildlife Service, Federal Aid for Sportfish Restoration Project Number F-43.

#### LITERATURE CITED

- BECKMAN, D. W. AND J. M. DEAN. 1984. The age and growth of young-of-the-year spot, *Leiostomus xanthurus* Lacépede, in South Carolina. *Estuaries* 7 (4B):487–496.
- CHAO, L. N. AND J. A. MUSICK. 1977. Life history, feeding habits, and functional morphology of juvenile sciaenid fishes in the York estuary, Virginia. *Fish. Bull.*, US 75:657–702.
- CONOVER, D. O. AND T. M. C. PRESENT. 1990. Countergradient variation in growth rate: compensation for length of the growing season among Atlantic silversides from different latitudes. *Oecologia* 83:316–324.
- CURRIN, B. M., J. P. REED, AND L. M. MILLER. 1984. Growth, production, food consumption, and mortality of juvenile spot and croaker: a comparison of tidal and nontidal nursery areas. *Estuaries* 7:451–459.
- DEANGELIS, D. L., P. A. HACKNEY, AND J. C. WEBB. 1980. A partial differential equation model of changing sizes and numbers in a cohort of juvenile fish. *Envir. Biol. Fishes* 5(3):261–266.

- DEEGAN, L. A. 1990. Effects of estuarine environmental conditions on population dynamics of young-of-the-year gulf menhaden. *Mar. Ecol. Prog. Ser.* 68:195–205.
- EPIFANIO, C. E. AND R. W. GARVINE. 2001. Larval transport on the Atlantic continental shelf of North America: a review. *Est. Coast. Shelf Sci.* 52:51–77.
- HALES, L. S. AND M. J. VAN DEN AVYLE. 1982. Species profiles: life history and environmental requirements of coastal fishes and invertebrates (South Atlantic). U.S. Dept. of Interior Fish and Wildlife Service Biological Report 82(11.91).
- JONES, G. K., J. L. BAKER, K. EDYVANE, AND G. L. WRIGHT. 1996. Nearshore fish community of the Port River-Barker Inlet Estuary, South Australia. I. Effect of thermal effluent on the fish community structure, and distribution and growth of economically important fish species. *Mar. Freshwater Res.* 47:785–799.
- LAMBERT, T. C. 1984. Larval cohort succession in herring (*Clupea harengus*) and capelin (*Malotus villosus*). *Can. J. Fish. Aquat. Sci.* 41:1551–1564.
- , AND D. M. WARE. 1984. Reproductive strategies of demersal and pelagic spawning fish. *Can. J. Fish. Aquat. Sci.* 41:1565–1569.
- MCBRIDE, R. S. AND D. O. CONOVER. 1991. Recruitment of young-of-the-year bluefish, *Pomatomus saltatrix* to the New York Bight: variation in abundance and growth of spring- and summer-spawned cohorts. *Mar. Ecol. Prog. Ser.* 78:205–216.
- MCCAMBRIDGE, J. T., JR. AND R. W. ALDEN III. 1984. Growth of juvenile spot, *Leiostomus xanthurus* Lacépede, in the nursery region of the James River, Virginia. *Estuaries* 7:478–486.
- MCRAE, G., R. G. MULLER, AND R. PAPERNO. 1997. 1997 Update on Florida's Spot Fishery. Florida Marine Research Institute report to the Florida Marine Fisheries Commission. St. Petersburg, FL. 15 pp.
- MILLER, J. M., L. B. CROWDER, AND M. L. MOSER. 1985. Migration and utilization of estuarine nurseries by juvenile fishes: An evolutionary perspective. pp. 338–352. *In*: Rankin, M..A. (ed), Migration and Adaptive Significance. Contributions to Marine Science Supplement Volume 27. University of Texas, Austin, Texas.
- MILTNER, R. J., S. W. ROSS, AND M. H. POSEY. 1995. Influence of food and predation on the depth distribution of juvenile spot (*Leiostomus xanthurus*) in tidal nurseries. *Can. J. Fish. Aquat. Sci.* 52:971–982.
- MULLER, R. G., M. D. MURPHY, AND M. P. ARMSTRONG. 1996. Florida's Inshore and Nearshore Species: Status and Trends Report. Florida Marine Research Institute report to the Florida Marine Fisheries Commission. St. Petersburg, FL. 122 pp.
- O'NEIL, S. P. AND M. P. WEINSTEIN. 1987. Feeding habitats of spot, *Leiostomus xanthurus*, in polyhaline versus meso-oligohaline tidal creeks and shoals. *Fish. Bull.*, US 85(4):785–796.
- PAPERNO, R., T. E. TARGETT, AND P. A. GRECCAY. 2000. Spatial and temporal variation in recent growth, overall growth, and mortality of juvenile weakfish (*Cynoscion regalis*) in Delaware Bay. *Estuaries* 23:10–20.
- SAS INSTITUTE. 1988. Proc GLM procedures. p. 893–993. SAS/Stat user's guide, vol 2, release 6.03 ed. SAS Institute, Inc., Cary, NC.
- SMITH, N. P. 2001. Seasonal-scale transport patterns in a multi-inlet coastal lagoon. *Est. Coast. Shelf Sci.* 52:15–28.
- SOGARD, S. M. 1992. Variability in growth rates of juvenile fishes in different estuarine habitats. *Mar. Ecol. Prog. Ser.* 85:35–53.
- . 1997. Size-selective mortality in the juvenile stage of teleost fishes: A review. *Bull. Mar. Sci.* 60(3):1129–1157.
- SOKAL, R. R. AND F. J. ROHLF. 1981. Biometry. W. H. Freeman, New York, NY.
- SPRINGER, V. G. AND K. D. WOODBURN. 1960. An ecological study of the fishes of the Tampa Bay area. Florida Board of Conservation Marine Research Laboratory Technical Series 1. St. Petersburg, FL.
- SUNDARARAJ, B. I. 1960. Age and growth of the spot, *Leiostomus xanthurus* Lacépede. *Tulane Stud. Zool.* 8:40–62.

- SZEDLMAYER, S. T., M. P. WEINSTEIN, AND J. A. MUSICK. 1990. Differential growth among cohorts of age-0 weakfish *Cynoscion regalis* in Chesapeake Bay. Fish. Bull., US 88: 745–752.
- TAYLOR, R. B. AND M. A. YANEZ. 1992. Ponce de Leon Inlet Management Plan. Taylor Engineering, Inc., Jacksonville, FL. 158 pp.
- THORROLD, S. R., J. M. SHENKER, E. M. MADDOX, R. MOJICA, AND E. WISHINSKI. 1994. Larval supply of shorefishes to nursery habitats around Lee Stocking Island, Bahamas. II. Lunar and oceanographic influences. Mar. Biol. 118:567–578.
- TILNEY, R. L., G. NELSON, S. E. RADLOFF, AND C. D. BUXTON. 1996. Ichthyoplankton distribution and dispersal in the Tsitsikamma National Park Marine Reserve, South Africa. South African J. Mar. Sci. 17:1–14.
- TOWNSEND, B. C., JR. 1956. A study of spot, *Leiostomus xanthurus* Lacépede, in Alligator Harbor, Florida. 43 p. M.S. Thesis. Florida State University, Tallahassee.
- WEINSTEIN, M. P. 1983. Population dynamics of an estuarine dependent fish, *Leiostomus xanthurus*, along a tidal creek-seagrass meadow coenocline. Can. J. Fish. Aquat. Sci. 40: 1633–1638.
- AND M. P. WALTERS. 1981. Growth survival and production in young-of-year populations of *Leiostomus xanthurus* Lacépede residing in tidal creeks. Estuaries 4:185–197.
- WINNER, B. L. AND R. H. MCMICHAEL, JR. 1997. Evaluation of a new type of box splitter designed for subsampling estuarine ichthyofauna. Trans. Am. Fish. Soc. 126:1041–1047.
- YOUNG, G. C., I. C. POTTER, G. A. HYNDES, AND S. DE LESTANG. 1997. The ichthyofauna of an intermittently open estuary: implications of bar breaching and low salinities on faunal composition. Est. Coast. Shelf Sci. 45:53–68.

Florida Scient. 65(2): 85–99. 2002

Accepted: August 22, 2001

## RE-EVALUATION OF OFF-ROAD VEHICLE MANAGEMENT IN BIG CYPRESS NATIONAL PRESERVE, FLORIDA, AFTER TWENTY-SIX YEARS OF MANAGEMENT

ROBERT V. SOBCZAK<sup>(1)</sup> AND ANTONIO J. PERNAS<sup>(2)</sup>

<sup>(1)</sup> National Park Service, Big Cypress National Preserve, Ochopee, FL 34141 USA,

<sup>(2)</sup> National Park Service, Everglades National Park Homestead, FL 33034 USA

*ABSTRACT:* In 2000, Big Cypress National Preserve, Florida, took a large step toward managing off-road vehicles (ORVs) for the preservation of natural resources, culminating in publication of a new ORV management plan. This paper describes events and conditions that led the National Park Service to develop the new plan. Photographic images, trail mapping, hydrologic conditions, legislation, and the advent of new technologies are discussed as rationale for restricting the level that ORVs have traditionally been allowed in the first twenty-six years of the preserve's existence.

**Key Words:** Big Cypress National Preserve, off-road vehicles, ecosystem protection

THERE has been growing awareness regarding the suitability of off-road vehicle (ORV) use within units of the National Park system—including snowmobiling in Yellowstone National Park (Wyoming, Montana, Idaho), dune buggies in Mohave National Preserve (California), and most recently, swamp buggies and airboats in Big Cypress National Preserve (Florida).

Big Cypress National Preserve (295,245 ha) comprises the eastern third of the Big Cypress Swamp in south Florida, USA. It was established in 1974 for the purpose of protecting the upstream watershed that is vital to western Everglades National Park and protecting the fragile Big Cypress Swamp from development threats (Fig. 1). The preserve is extremely flat (slope = 3 cm/km) and covered at the surface with a thin layer of calcium-rich soil called marl underlain by a limestone caprock (0–1 m depth). On a local scale, topographic variation as small as 60 cm separates uplands from wetland (Duever et al., 1979). This local-scale variation also tends to match the distribution of major vegetation types in the preserve—including upland pinelands and hardwood hammock, herbaceous prairie, cypress strands and domes, and marshes. An average of 133 cm of rain falls per year, sixty percent of which occurs from June to October (Klein et al., 1970). Poor drainage results in shallow inundation of the landscape during this period. Water levels gradually recede during the non-rainy season (November–

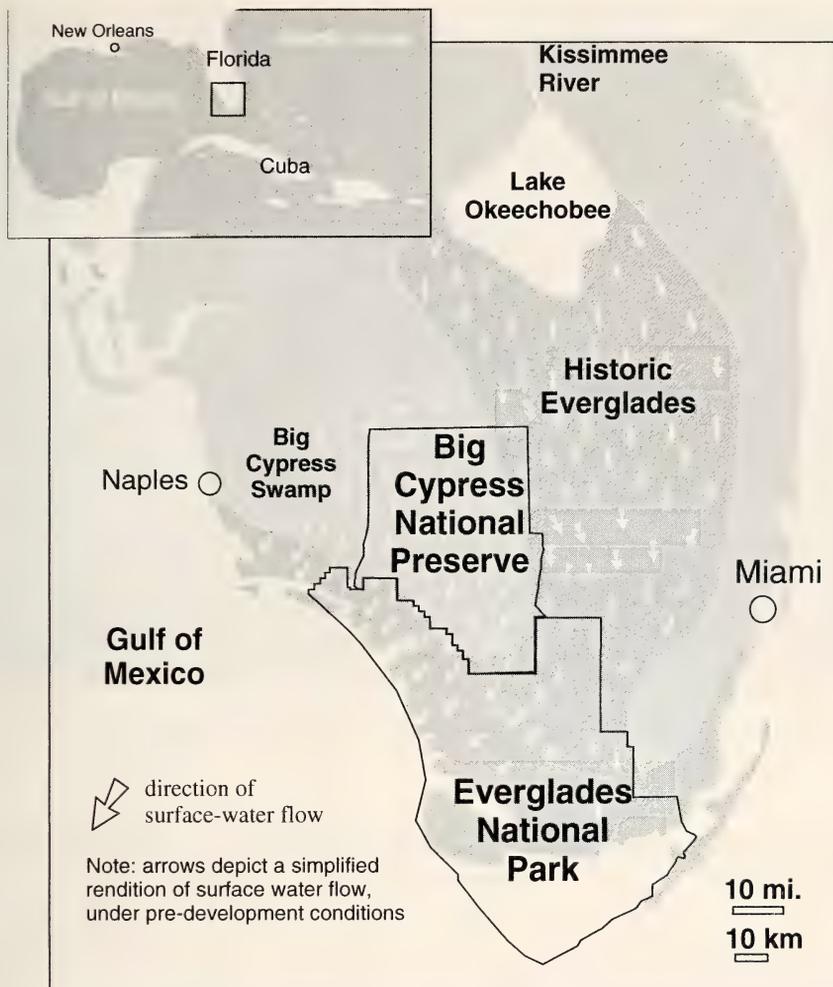


FIG. 1. Location of Big Cypress National Preserve.

April). All but the deepest water holes become dry by mid-winter or early spring, depending on the extent of rain received during the previous rainy season.

Types of ORVs used in the preserve include swamp buggies, airboats, street-legal four-wheel drive vehicles, and all-terrain vehicles (ATVs). Swamp buggies have oversized tires, heavy-duty construction, and high-torque engines that provide adequate traction across mudded and flooded areas (Fig. 2). Airboats are smooth, flat-bottomed boats that operate in extremely shallow water by means of a large propeller (2–5 meter width) that is fixed and caged on the back of the boat (Fig. 3). Typically, the propeller and engine that drive it are taken from airplanes, thus giving the boats their name. Street-legal four-wheel drive vehicles are also used along elevated-



FIG. 2. Photograph of a typical swamp buggy. Dimensions are approximately 3 m wide, 3–5 m long, and 3–5 m tall.

grade roads, but are not as common. Manufacturer-produced all-terrain vehicles (ATVs) have become more popular in recent times.

*DISCUSSION—Origination of ORVs in the Big Cypress Swamp*—The Big Cypress Swamp has historically been a remote and roadless environment. Use of ORVs in the Big Cypress predated establishment of the preserve. Their use first began in the 1920s in conjunction with construction of the primary roads and railroad grades that bisect the interior swampland of the Big Cypress Swamp (Tamiami Trail, State Road 29). Logging and oil/gas development operations became established along the roads and utilized ORVs to harvest natural and geologic resources. Recreational ORV use did not become common until the 1940s (Tebeau, 1966).

*Allowance and use pattern of ORVs in the preserve*—ORV operation is allowed within the preserve by virtue of the Enabling Legislation (Public Law 93–400) through which the United States Congress established the preserve in 1974, but is not a mandated activity nor are specific rules put forward on how to manage them. The Enabling Legislation states that “. . . the Secretary shall develop . . . such rules and regulations as he deems necessary and appropriate to limit or control the use of Federal lands and waters



FIG. 3. Photograph of a typical airboat. Dimensions are approximately 2 m wide, 3–5 m long, and 3–5 m tall.

with respect to: (1) motorized vehicles, . . .”, but does not provide further direction (U.S. Congress, 1973).

An unrestricted use pattern best describes the manner in which ORVs operated for the first twenty-six years of the preserve. Permitted ORV operators were given discretion to choose the access points and backcountry trails they wanted to use. Exceptions to this included large-scale spatial closures that were instituted in 1974 (Loop Unit) and 1988 (Deep Lake Unit), establishment of a 2,500 annual permit quota in 1991, designation of a trail network in the Bear Island unit, and periodic temporal closures enacted in response to extreme environmental conditions (Fig. 4). Water-filled borrow canals that lie adjacent to most elevated roadbeds also limited the total number of ORV access points to periodic structural or earthen bridges. In total, ORV operators have traditionally been able to gain access into the backcountry at approximately seventy locations.

ORV use is least apparent during summer months due to extreme heat, high water, and mosquitoes. Peak ORV use occurs in tandem with hunting season (November–December), a time period that coincides with the end of the rainy season and end of the growing season. The end of the rainy season marks a time when a thin layer of surface water still covers most of the preserve, but is receding due to lack of rain. The preserve’s calcium-rich

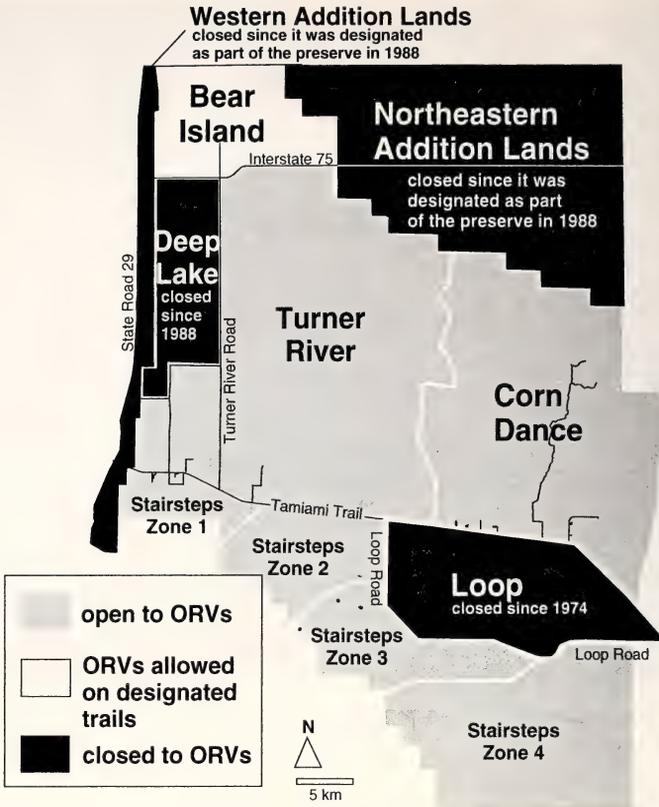


FIG. 4. Map showing boundaries of off-road vehicle use areas in the preserve from 1974 to 1999.

marl soils are soft and easily disturbed when saturated, and provide poor traction to wheeled ORVs. Heavily used trails often become excessively mudded and rutted out, thereby making them difficult to traverse. ORV operators tend to avoid these areas in favor of more vegetated areas, typically at the sides of existing trails (causing trails to widen) or by developing new trails. The end of the growing season marks a time when groundcover vegetation has ceased growing for the year, but is also at its maximum density. Duever and co-workers (1979) noted that occurrence of ORV activity at this time of year tends to minimize the level of ORV disturbance because vegetation cover and rootmass provide additional structure to the soil, but also creates a condition where visual impacts caused by ORVs persist until the onset of the next growing season. Fig. 5 summarizes the seasonal relationship between ORV use, water levels, and growing season.

*Environmental effects of ORV use*—Soils and herbaceous plant communities are most directly disturbed by ORVs use. Heavily used areas are

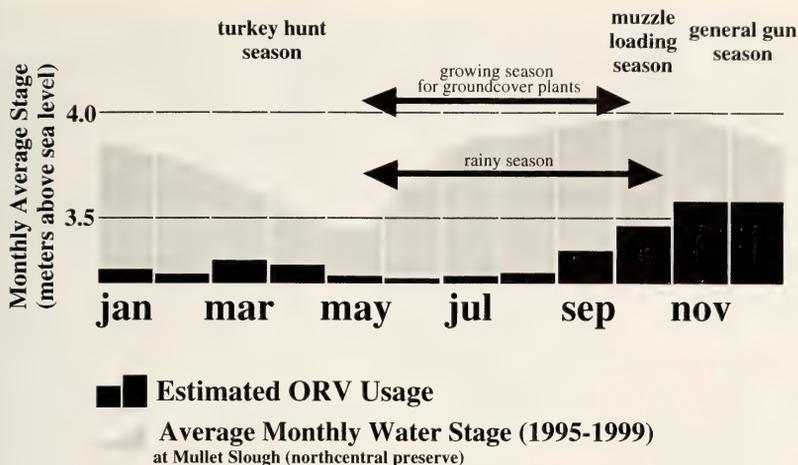


FIG. 5. Seasonal relationship among off-road vehicle (ORV) use, water levels, and growing season in the preserve. Note that ORV use is estimated from observation since quantitative data is not available.

damaged in ways that are visually apparent—including an irregular topographic surface, excessively muddied soils, and decreased to nonexistent plant cover. Long-term effects in these areas are thought to include loss of herbaceous prairie habitat (plant loss and marl disturbance), alteration of surface water regimes through channelization and increased exposure of surface waters to evapotranspiration, and decreased primary production due to destruction of floating algal mats called periphyton.

There has been an on-going debate regarding the extent that visual disturbance translates into long-term ecological effects. Schemnitz and Shortemeyer (1974) studied the effects of airboats and track vehicles in the Everglades, but this work was conducted on soil types not common in the Big Cypress Swamp. Duever and co-workers (1979) completed a resource-inventory for the preserve that described the history and pattern of ORV use in the Preserve. They showed an accretion of total ORV trail length over a three-decade period using high-altitude photography taken in 1947, 1953, and 1973. Stubbs (1979) described social aspects of ORV use in the preserve using a survey. Duever and co-workers (1981) used test plots to identify short-term impacts caused by various ORV and soil types. The study showed airboats to be the least damaging of all ORVs, and ATVs to the least damaging wheeled-ORV tested. Dwarf cypress and marl prairie were identified as being the most susceptible ORV-induced impacts because of their soil composition and relative lack of plant and root mass. Duever and co-workers (1986) revisited the test plots established in the 1981 study to provide an assessment of long-term effects. They concluded that once soils are displaced, there are few natural mechanisms capable of restoring the natural ground contour, and the tire ruts remain indefinitely. Welch and Madden

(1998) completed a database of ORV trails and high use areas. Farrell and co-workers (1998) described an ORV-use survey provided to off-road vehicle permit holders in the Preserve.

*Reconsideration of how ORVs are managed in the preserve*—With some modification, the first twenty-six years of the preserve saw a continuation of ORV activity largely as it had existed prior to its establishment. Possible causes of this continued use pattern may include the vague nature of guidance provided in the Enabling Legislation, lack of information suggesting otherwise, an ethos that ORV-induced disturbance could be minimized by encouraging a dispersed-use pattern, a desire to accommodate a major user group of the preserve, and a tendency to keep the status quo.

The presence of ORVs in the preserve was brought under increased scrutiny following a 1995 lawsuit filed against the National Park Service by the Florida Biodiversity Project, an environmental advocacy group. The lawsuit contended that the level of disturbance caused by ORV use was excessive and in violation of federal statutes. A settlement agreement between the two parties was reached in 1997, on the condition that National Park Service develop an off-road vehicle management plan that provides for improved management of the use.

As part of the process to reconsider its management of ORVs, the National Park Service identified five factors that provide rationale for restricting the level that ORVs have traditionally been allowed in the preserve during its first twenty-six years of existence. These factors are believed to show that existing levels of disturbance caused by ORVs are unacceptable, will increase over time if no action was taken, and contradicted legislative direction regarding ORV use provided during the establishment of the preserve.

*Photography of excessive disturbance*—Aerial and ground-level photography highlighted unacceptable levels of soil disturbance, vegetation loss, and alteration of surface water inundation and flow (Fig. 6). Disturbance was most apparent in herbaceous prairie habitats where lack of forested environment allowed for unconstrained expansion and widening of trail networks due to the absence of physical barriers (trees) and at major access points where concentrated ORV use occurred.

*Evidence of accumulated impacts over time*—Mapping work performed by previous investigators demonstrated that the magnitude and spatial extent of disturbed soils has increased over time. Duever and co-workers (1979) reported an incremental increase in ORV trails in the 30 years prior to the preserve's establishment by using high-altitude aerial photographs available from the USDA Soil Conservation Service for 1940 and 1953 (scale = 1:63,000) and Mike Hurd for 1973 (scale = 1:75,000) to map trails that were visible without magnification. This work estimated total trail lengths of 160,

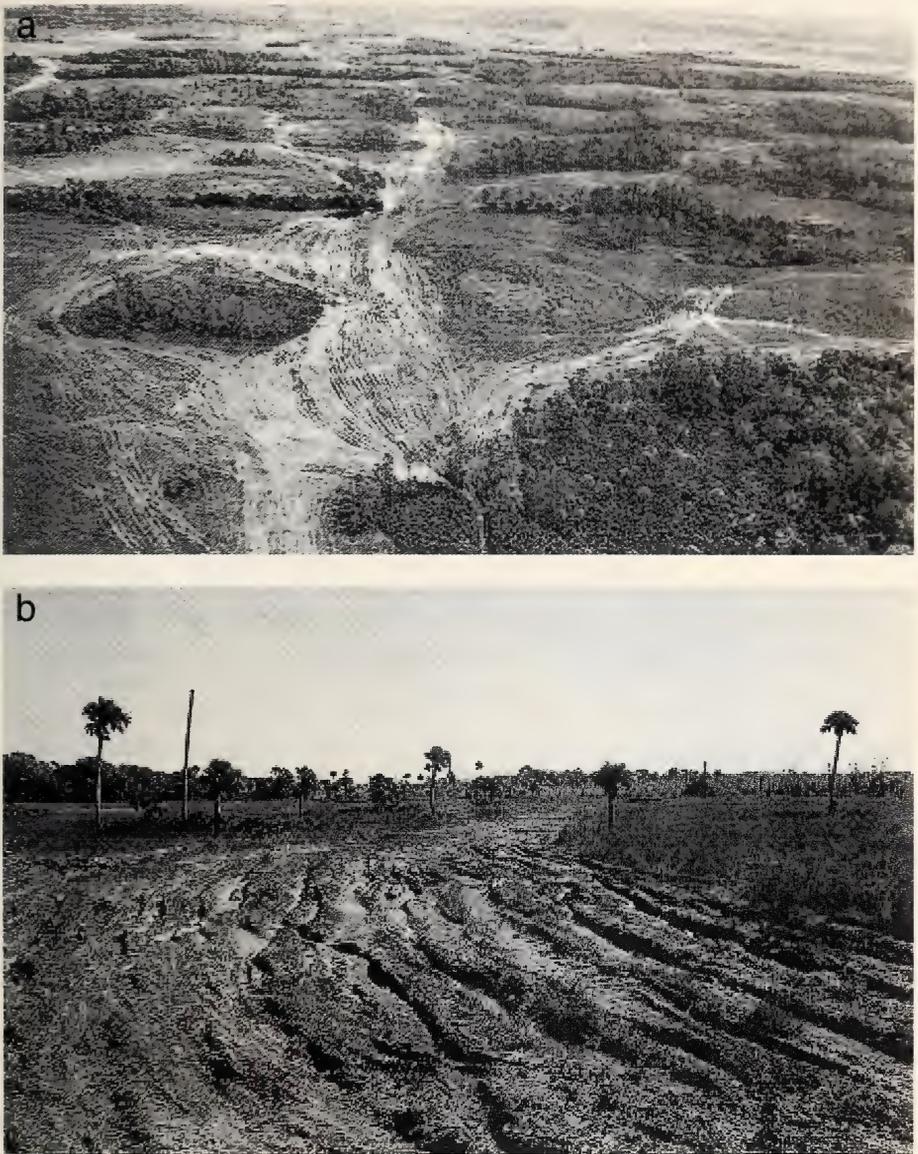


FIG. 6. (a) Aerial and (b) ground level photographs of off-road vehicle damage in the preserve.

250, and 1,100 km in 1940, 1953, and 1973, respectively, with the increase from 1953 to 1973 being explained almost exclusively as a result of recreational ORV use. Similar mapping techniques applied by NPS staff to 1:63,000 scale aerial photography taken in 1984 estimated 1,995 km of ORV trails. Duever and co-workers (1979) noted that additional trails would be visible through magnification or use of aerial photography taken at lower

TABLE 1. Total Off-road vehicle trail length as measured from aerial photography maps over time in Big Cypress National Preserve.

Year	Total length of mapped ORV trails	Scale of source map	Person/group who measured trail length
1940	160 km	1:63,000	Duever et al., 1979
1953	250 km	1:63,000	Duever et al., 1979
1973	1,100 km	1:75,000	Duever et al., 1979
1984	1,995 km	1:63,000	NPS staff
1998	46,700 km	1:10,000*	Welch and Madden, 1998

\* work is currently being performed to field check result.

altitudes. Welch and Madden (1998) completed a comprehensive inventory of ORV trails that involved magnification of 1:40,000 scale aerial photography taken in 1993 to 1:10,000 scale and mapped all discernable ORV features, for a total of 46,700 km of trails. Welch and Madden have more recently initiated a field program to verify the accuracy of their estimate. The increase in measured trail length over time is summarized in Table 1.

The trend highlighted by Table 1 suggests that ORV-induced disturbance is occurring faster than the natural system is capable of restoring itself, leading to a condition where impacts have accumulated over time. Duever and co-workers (1986) noted that once soils are disturbed, few natural mechanisms are capable of restoring the marl soils of the preserve. An analog to ORV-induced impacts can be made with past farming operations. Farming operations were extensive along the Tamiami Trail and Loop Road prior to establishment of the preserve, and occurred mostly in marl soils. There was no clearing before cultivation other than burning and furrows were established by modification of the surficial soil (as opposed to rock tilling). Decades later these furrows are still clearly visible (from the air and on the ground), suggesting that soil impacts resulting from ORV use will have similar persistence over time.

*Wetter conditions of the 1990s relative to the previous two decades—* Analysis of water level data shows that generally wetter hydrologic conditions have prevailed in the 1990s relative to the first two decades of the preserve's existence (1970s and 1980s). The degree of disparity between the 1990s and the previous two decades is illustrated with stage duration curves calculated for daily water levels collected at three locations within and adjacent to the preserve—P34, Bridge 105, and Bridge 84 (Fig. 7). The vertical axis reports water level in meters above sea level and the horizontal axis reports the time frequency that water levels were at or below the reported value. The approximate land-surface elevation is graphically reported for each site at the horizontal interface between dark and light background shading. Elevation of the land surface does not factor in the spatial variability of the surrounding landscape, but is thought to provide a consistent com-

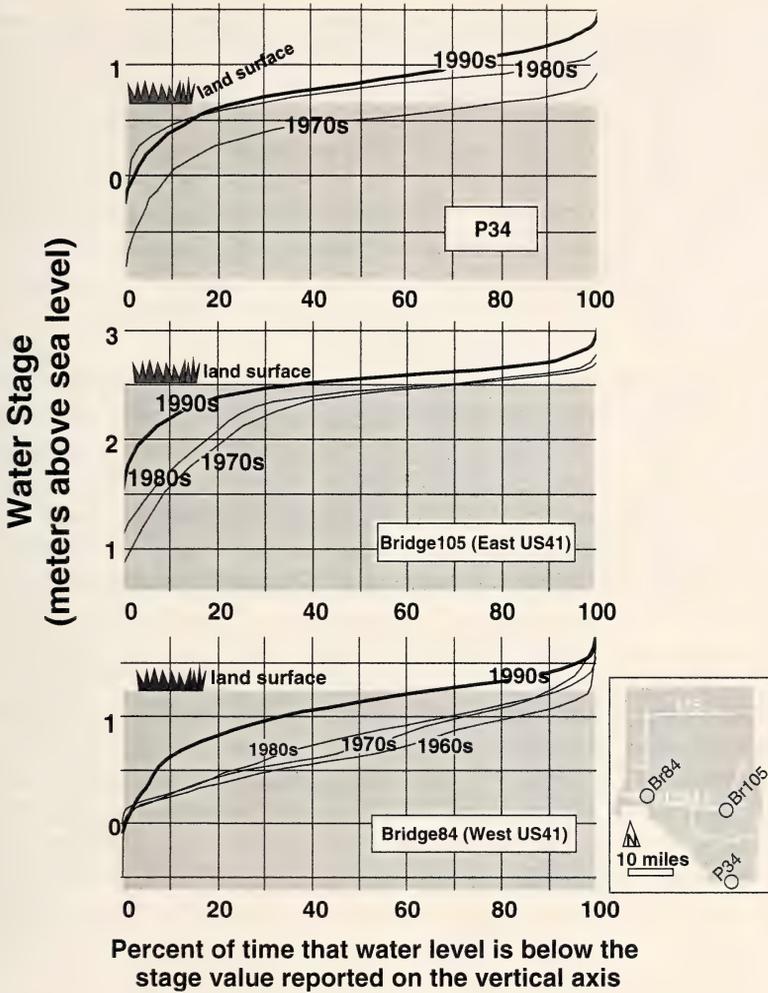


FIG. 7. Stage duration curves shown for ten-year intervals of 1970–1979, 1980–1989, and 1990–1999 at three long-term monitoring stations in the preserve. Land surface elevation is also shown for the purpose of comparing frequency of surface water flooding among the three decades. Daily average stage values were used as the baseline data source.

parison for measuring the duration of surface water inundation among the three decades. In the 1990s, standing water is shown to be present 78, 63, and 36 percent of the time at P34, Bridge 105, and Bridge 84, respectively, in comparison to 25, 30, and 10 percent of the time in the 1970s. Table 2 reports the duration of surface water inundation at the three stations over the past three decades.

The wetter conditions in the 1990s can be attributed to three factors. (1) Increased rainfall: Three years of the 1990s (1994, 1995, 1999) experienced rainfall amounts of greater than 50 cm of the average in comparison to no

TABLE 2. Summary of surface water flooding duration during the 1970s, 1980s, and 1990s at three long-term monitoring stations in Big Cypress National Preserve. Daily average stage values were used as the baseline data source.

Station	Duration of surface water flooding (percent of time)		
	1970s	1980s	1990s
Bridge 84	10	8	34
Bridge 105	30	30	61
P34	21	71	75

similar events in the 1970s and 1980s according to the Miami Airport rainfall station (Fig. 8). Drought rainfall seasons of less than 20 cm of the yearly average were recorded 10 times in the 1970s and 1980s, with no occurrence in the 1990s. (2) Modifications to upstream water management operations: Drainage patterns in south Florida were drastically altered in the 1970s by the cumulative impacts of physical (canals, levees) and operational (flow structures, pump-enhanced drainage, back-pumping) modifications implemented by the U.S. Army Corps of Engineers (USACE) and South Florida Water Management District (SFWMD) from 1947 to the mid 1970s. Mounting evidence that the new system put too little water into Everglades National Park led to the development of new operational rules and structures in the 1980s and 1990s. The wetter conditions documented at P34 in the 1980s and 1990s are likely a result of modifications to increase flow to Shark River Slough in the central park region and to prevent excessive flooding of Cape Sable Seaside Sparrow habitat along the east and west banks of the slough. (3) Removal of physical barriers or artificial conduits to flow: Increased stage levels recorded at Bridge 84 in the 1990s can be largely at-

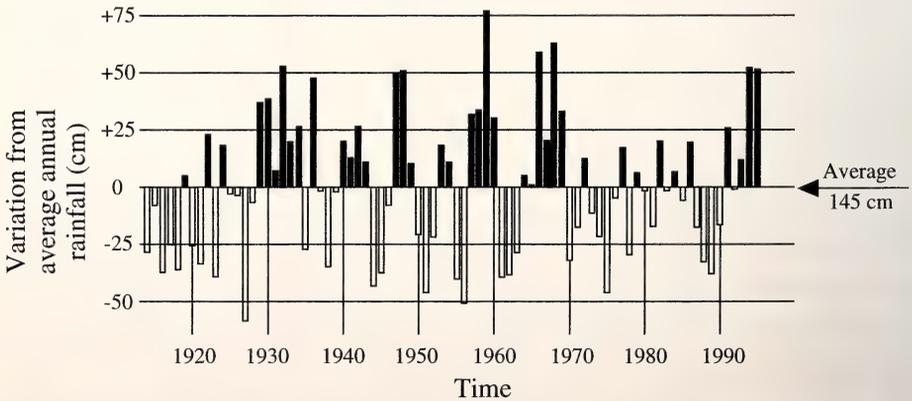


FIG. 8. Historic rainfall record at Miami International Airport, reported relative to deviation from the historic average annual year. This graph was modified from a South Florida Water Management District poster.

tributed to infilling/plugging of the Turner River Canal—a 32 km long canal constructed in the late 1950s that was draining interior portions of the swamp.

The persistence of high water in the 1990s is believed to have created a condition where soils were inundated with surface water deeper and longer, thereby increasing their susceptibility to rutting, trail widening, and establishment of new trails from wheeled ORVs. Airboat country has probably been less affected, but has created a condition where new trails have been developed that were historically too shallow for airboat use. The relative dryness of decades preceding the 1990s also leads one to speculate that the rise of recreational ORV-use coincided during an era when water levels were artificially lower than current levels, and probably caused less visual impacts because vast areas were dried down during the hunting season.

Major restoration activities underway in south Florida, and expected to continue for the next several decades, are anticipated to further improve natural flow regimes in the central everglades and adjacent ecosystems, including the Big Cypress Swamp. These activities will likely lead to increased surface-water stage duration and flow in the eastern portion of the preserve.

*Federal statutes*—While only limited guidance was provided in the preserve's Enabling Legislation (PL 93-400), the Legislative History of this law provides a greater level of detail regarding ORV management. As excerpted below, there is an expectation that the preserve will be returned to a wilderness character and that ORV use should be managed in tune with this principle.

“Since the area included in the preserve is largely undeveloped at the present time and because it will be managed in a manner which will assure its return to the true wilderness character which once prevailed, it will offer many outdoor recreation opportunities to the visiting public. During significant portions of the year, primitive camping, hiking, and sightseeing will be popular activities. Naturalists and wildlife observers will come to see the flora and fauna in their natural setting and hunters and fishermen will continue to find the area popular. While the use of all-terrain vehicles must be carefully regulated by the Secretary to protect the natural, wildlife and wilderness values of the preserve, the bill does not prohibit their use along designated road and trails (U.S. Congress, 1974).”

The Legislative History also provided guidance on how preserves, as a new unit of the national park system, should be managed in general—by merit of Big Thicket National Preserve, Texas, and Big Cypress National Preserve, Florida, being the first areas designed as this new unit type in 1974. The Legislative History states: “(t)he principal thrust of these areas should be the preservation of the natural values which they contain.” It also states:“(n)ational preserves may accommodate significant recreational uses without impairing the natural values, but such public use and enjoyment would be limited to activities where, or periods when, such human visitation

would not interfere with or disrupt the values which the area was created to preserve (U.S. Congress, 1974).”

Further guidance regarding ORV management on federal lands is also provided in Executive Order 11644, “Use of Off-Road Vehicles on the Public Lands,” EO 11990. The order states that trails and areas permitting motorized ORV use must be administratively designated in a way that minimizes disturbance to natural resources. It also allows for closures or vehicle restrictions where adverse impacts are occurring, or where important resources are threatened. The order also calls for federal agencies to monitor the effects of ORVs on lands under their jurisdiction.

*Technological advances since 1974*—Technological developments since the inception of the preserve have raised new concerns regarding ORV use in the preserve. Swamp buggies and airboats have become more powerful and more reliable over the past quarter century. In addition, a new type of ORV called all-terrain vehicles (ATVs) now offer a low-maintenance, high-speed alternative for accessing the backcountry. Cell phones and global positioning systems have also become more commonly available. All of these developments improve the navigational abilities of ORV operators, allowing them to penetrate into unknown territory or previously inaccessible interior lands of the preserve.

**CONCLUSIONS**—Looking back on 26 years of ORV use in the preserve suggests that impacts have been increasing over time. While debate may continue on the extent that visual disturbance translates into long-term ecological damage, the discussion of photographic imagery, trail mapping, hydrologic conditions, legislation, and the advent of new technologies provided in this paper are believed to provide strong rationale for modifying the manner in which ORVs have been traditionally used in the preserve over the past 26 years. Failure to make such changes would cause a continued accumulation of disturbance over time, in new areas, and with significant uncertainty regarding long-term ecological consequences. Moreover, failure to act would be in violation of the laws that were enacted by the United States Congress to establish the preserve.

Big Cypress National Preserve completed a new Off-road Vehicle Management Plan in Fall 2000 and is currently in the process of implementing it. The plan is believed to meet the challenge of protecting the fragile natural resources of the preserve in the spirit of fostering its return to a more wilderness character, while still providing access. The major piece to the plan will be the establishment of a designated trail system, ending the era of unrestricted ORV access throughout the preserve (Fig. 9). Other components of the plan include enacting temporal and spatial closures (heavily disturbed areas, Cape Sable Seaside Sparrow habitat, pristine areas), a new three-pronged permit system (vehicle permit, ORV operator permit, backcountry permit), and initiation of monitoring, research, and restoration.

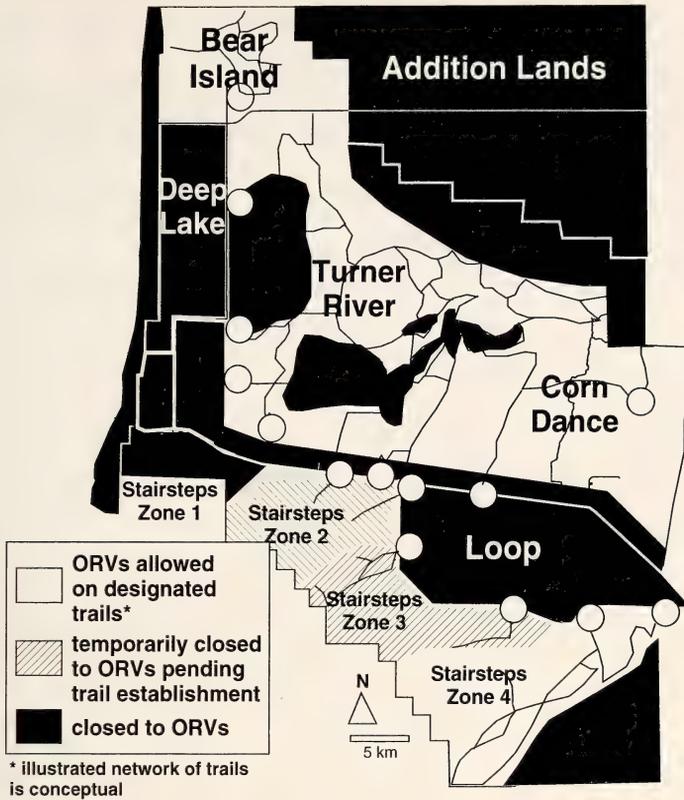


FIG. 9. Map showing off-road vehicle use areas and trails currently being implemented in the preserve's new Off-Road Vehicle Management Plan completed in 2000. Note that the illustrated trail network is conceptual.

#### LITERATURE CITED

- DUEVER, M. J., J. E. CARELSON, J. F. MEEDER, L. C. DUEVER, L. H. GUNDERSON, L. A. RIOPELLE, T. R. ALEXANDER, R. L. MYERS, AND D. P. SPANGLER. 1979. Resource Inventory and Analysis of the Big Cypress National Preserve. Final Report to the National Park Service. Center for Wetlands, University of Florida. Gainesville, FL.
- , J. E. CARLSON, AND L. A. RIOPELLE. 1981. Off-Road Vehicles and their Impact in the Big Cypress National Preserve, Report T-614. Everglades National Park. Homestead, FL.
- , L. A. RIOPELLE, AND J. M. MCCOLLOM. 1986. Long Term Recovery of Experimental Off-Road Vehicle Impacts and Abandoned Old Trails in the Big Cypress National Preserve, Report SFRC-86/09. Everglades National Park. Homestead, FL.
- FARRELL, T., A. KENDRA, J. ROGGENBUCK, T. HALL, AND J. MARION. 1998. Off-road Vehicle Riders in Big Cypress National Preserve: Results from a Survey of Permit Holders. Draft Research Report, Virginia Tech, Department of Forestry, Blacksburg, VA.
- KLEIN, H., W. J. SCHNEIDER, B. F. MCPHERSON, AND T. J. BUCHANAN. 1970. Some hydrologic and biologic aspects of the Big Cypress Swamp drainage area. USGS Open-File Report. 70003.
- SCHEMNITZ, S. D. AND J. L. SCHORTEMAYER. 1974. The Impact of Half Tracks and Airboats on the Florida Everglades Environment. Proceedings of the 1973 Snowmobile and Off The

- Road Vehicle Research Symposium, Technical Report No. 9. Michigan State University, East Lansing, MI.
- STUBBS, T. H. 1979. A Social and Environmental Perspective on Off-Road Vehicle Traffic in the Big Cypress National Preserve. Florida Audubon Society, Maitland, Florida.
- TEBEAU, C. W. 1966. Florida's Last Frontier: The History of Collier County. University of Miami Press, Coral Gables, FL.
- U.S. CONGRESS, HOUSE. 1973. Establishing the Big Cypress National Preserve in the State of Florida, and for Other Purposes. 93rd Cong., 1st sess., September 13, H. Rept. 93-502. Interior and Insular Affairs Committee
- U.S. CONGRESS, SENATE. 1974. Big Cypress National Preserve—Establishment. 93rd Cong., 2nd sess., August 22, S. Rept. 93-1128. Interior and Insular Affairs Committee.
- WELCH, R. AND M. MADDEN. 1998. Off-road Vehicle Trail Database for Big Cypress National Preserve. Final Research Report, University of Georgia, Center for Remote Sensing and Mapping Science, Athens, GA.

Florida Scient. 65(2): 100–114. 2002

Accepted: September 18, 2001

## POPULATION ECOLOGY OF THREE SPECIES OF SMALL MAMMALS ON KEY LARGO, FLORIDA

CHRISTOPHER R. SASSO AND MICHAEL S. GAINES

Department of Biology, University of Miami,  
P. O. Box 249118, Coral Gables, Florida 33134-0421

**ABSTRACT:** *Population dynamics and home range in populations of the Key Largo woodrat (Neotoma floridana smalli), Key Largo cotton mouse (Peromyscus gossypinus allapaticola) and the introduced black rat (Rattus rattus) were investigated in four tropical hardwood hammocks on Key Largo, Florida. The hammocks represented three different age classes: medium (disturbed between 1940 and 1959), medium-old (disturbed between 1926 and 1940), and old (disturbed before 1926). N. floridana in medium-old hammock had the highest population size and high female reproduction, where R. rattus was absent. N. floridana, in old-aged hammock, had low recruitment, low female reproduction, seasonal male reproduction, and a larger home range compared to other sites. In the presence of R. rattus, N. floridana had low population size, reduced survivorship, and a male biased population. Medium-aged hammocks had the highest abundance of P. gossypinus. However, the presence of R. rattus caused P. gossypinus to reduce their home range size in those hammocks. R. rattus was only present in a medium-aged grid, where it had high population size and recruitment.*

**Key Words:** Population ecology, Key Largo, *Neotoma*, *Peromyscus*, *Rattus*

ENDANGERED species can be managed successfully only if their population dynamics and habitat requirements are well understood. Unfortunately, the necessary data are not available for many endangered species. For those species where data are available, they often consist of nothing more than abundance or density in a particular area. Thus, natural resource managers may be forced to make critical management decisions on the basis of information.

Population density may be a poor indicator of habitat quality in small mammals (Van Horne, 1983; Ostfeld, 1992). To assess the suitability of a habitat, one needs to consider a variety of demographic variables such as density, survivorship, recruitment, age structure, reproduction, and space use.

In addition to demography, space use has been shown to vary with habitat quality. Home range and movement decreased in food supplementation studies of *Peromyscus maniculatus* (Smith, 1971; Taitt, 1981), *Clethrionomys rufocanus* (Ims, 1987), and *Microtus townsendii* (Taitt and Krebs, 1981). Animals living in a patchy habitat also should adjust their home range and movement accordingly. Diffendorfer and co-workers (1995)

reported that movement of three small mammal species increased as habitat patchiness increased.

In the tropical hardwood hammocks of Key Largo, Monroe County, Florida, high density has been observed to be indicative of habitat quality for small mammals by Barbour and Humphrey (1982) and Goodyear (1985). The endangered Key Largo woodrat (*Neotoma floridana smalli*) and the Key Largo cotton mouse (*Peromyscus gossypinus allapaticola*) reside in the tropical hammock forest of Key Largo that has been characterized as medium-to-high productivity rockland hammock (Ross et al., 1992). Along with the woodrat and cotton mouse, the black rat (*Rattus rattus*) occurs in some of the hardwood hammocks on Key Largo (Hersh, 1981).

The greatest threat to both of these endangered subspecies is habitat loss. The species were formerly distributed throughout the island but are currently found only on the northern half of Key Largo. There are also potential threats from exotic species such as black rats, feral cats, and fire ants.

There are approximately 945 hectares (ha) of forest on the northern half of Key Largo (Ross et al., 1995). However, not all of this habitat may be suitable for woodrats and cotton mice. The greatest densities of woodrats and cotton mice have been found in mature hammocks (Barbour and Humphrey, 1982; Goodyear, 1985).

Mature hammocks are characterized by little undergrowth, a high degree of shade, continuous canopy, and a substantial leaf litter and soil layer. In mature hammocks, woodrats nest in the vicinity of tree roots, but will also make stick nests if tree root sites are not available. Cotton mice also nest around tree roots, in the periphery of woodrat stick nests, and in burrows in the leaf litter (Goodyear, 1985).

Immature hammocks have large amounts of undergrowth with less developed root systems, a discontinuous canopy, and a shallow leaf litter. Immature hammocks are less suitable habitat than mature hammocks for both species because of fewer suitable nest sites (Goodyear, 1985; Humphrey and Barbour, 1979).

Hersh (1981) estimated woodrat densities on Key Largo to be 2.2 woodrats per ha in a tract of mature hammock, with little seasonal variation between August and May. Humphrey (1988) found 0.3 to 16.4 (mean 7.6) woodrats per ha and 3.0 to 44.1 (mean 21.2) cotton mice per ha at six sites on Key Largo during the dry season (November through April). He calculated totals of 6,500 woodrats and 18,000 cotton mice for the 851 ha of habitat he estimated as available.

All previous studies on the density of the Key Largo woodrat and cotton mouse suggest that mature hammock is optimal habitat for both species. However, other demographic variables such as survivorship, reproductive activity, age structure, and sex ratio were not considered.

Additionally, Ross and co-workers (1995) classified the hammocks of Key Largo into five age classes according to the time since last disturbance.

Their five levels of hammock age are: old (disturbed prior to 1926), medium-old (disturbed 1926–1940), medium (disturbed 1940–1959), medium young (disturbed 1959–1971), and young (disturbed post 1971). Hammock age-classes over the entire island was represented as follows: old 27%, medium-old 25%, medium 40%, medium-young 2%, and young 6%. This more detailed classification of the hammocks, in conjunction with population demography, can now be used to more accurately describe the habitat utilized by the small mammal community.

The aim of this study was to determine population dynamics and space use of *N. floridana* and *P. gossypinus* on Key Largo in hammocks of different age classes and compare them to previous studies. Our results on the population ecology of these two species should lead to better management plans for these two species by providing managers with information on how populations of the two native rodents have responded to the protection of lands on north Key Largo.

**METHODS**—This study was conducted on grids in two hammocks on the Crocodile Lake National Wildlife Refuge (CLNWR) and two hammocks in the Key Largo Hammocks State Botanical Site (KLSBS) on Key Largo, FL from July 1996 to April 1998. Grid 1 was in a medium-aged hammock located in CLNWR that covers 16 ha, grid 2 was in a 49 ha old hammock in CLNWR, grid 3 was in a 68 ha medium aged hammock in KLSBS, and grid 4 was in a 29 ha medium-old hammock in KLSBS. Trapping was suspended on grid 1 in July 1997 due to an influx of fire ants at the location.

Medium-young and young age class hammocks were not included in this study because they only accounted for only 8% of total hammock area and occurred in patches too small for adequate sampling.

Grids (1.8 ha) were a 10X10 block design with stations spaced 15 m apart. Each station had a Sherman XLF-15 (4" × 4.75" × 15") live trap. Grids were trapped for three nights every four weeks. Captured animals were marked with a uniquely numbered ear tag. On first and subsequent captures trap location, body mass, and reproductive condition were recorded. Males were considered reproductively active if testes were descended into the scrotum (scrotal). Two of the three following characteristics were considered indications of reproductive activity for females: perforate vagina, open pubic symphysis, and medium to large nipples size. Age class of animals (juvenile or adult) was defined by body mass at which they first became reproductive as follows: cotton mice > 22 g, woodrats > 190 g, and black rats > 110 g.

We used the Jolly-Seber method (Jolly, 1965) to estimate demographic parameters for these species. Population parameters estimated for each site were abundance, survivorship, recruitment (number of newly tagged animals), sex ratio (% male) of all captures, percent reproductive for both sexes, and age structure (% adult).

Home range size was estimated using the minimum convex polygon method (Mohr, 1947) with the program CALHOME (Kia et al., 1996). Ninety-five percent minimum convex polygons were used as an estimate of home range size. Only adult individuals with a minimum of five captures in successive trapping sessions were included in home range analyses.

One-way ANOVAs with Tukey's pairwise comparisons were used to test for differences among grids for all variables. Differences of demographic variables for within a grid between the wet (May–October) and dry (November–April) seasons were examined using two-sample *t*-tests. All proportions and percentages were arcsine square root transformed (Sokal and Rohlf, 1995). Data not normally distributed were log transformed.

**RESULTS**—*Population size*—Woodrats and cotton mice were captured on all four grids, but black rats only were captured on grid 1. *N. floridana*

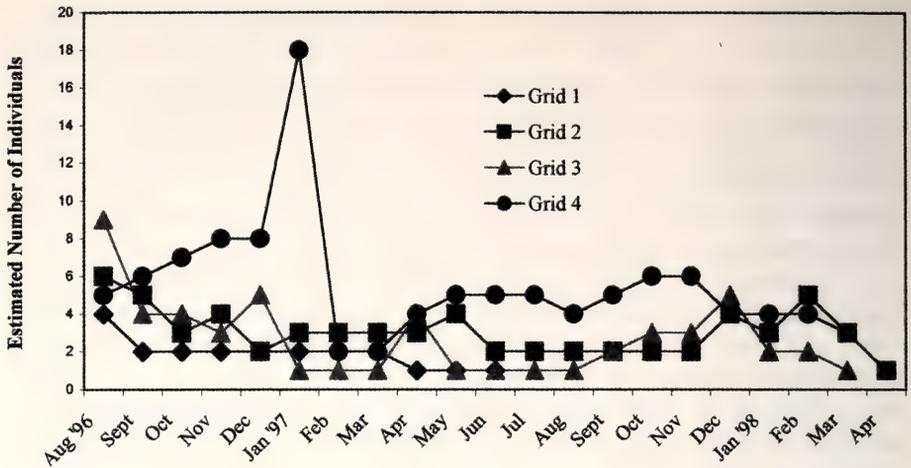


FIG. 1. Population size estimates for *N. floridana* on four grids in tropical hammocks of Key Largo, Florida from July 1996 to April 1998. Estimates are Jolly-Seber estimates of population size.

abundance (Fig. 1) was significantly different among grids ( $F = 12.90$ , d.f. = 3, 68,  $P < 0.001$ ) with no differences within grids between seasons (grid 1:  $t = 0.76$ , d.f. = 6,  $P = 0.48$ ; grid 2:  $t = -0.22$ , d.f. = 16,  $P = 0.83$ ; grid 3:  $t = 0.31$ , d.f. = 12,  $P = 0.76$ ; grid 4:  $t = -0.40$ , d.f. = 10,  $P = 0.70$ ). Tukey's pairwise comparisons indicated that the population on grid 1 was significantly smaller than grids 2, 3, and 4, grid 2 was significantly smaller than grid 4, and grid 3 was significantly smaller than grid 4. Mean number of individuals  $\pm 1$  SE on the grids were as follows: grid 1,  $1.7 \pm 0.3$ ; grid 2,  $3.02 \pm 0.3$ ; grid 3,  $2.7 \pm 0.5$ ; and grid 4,  $5.5 \pm 0.8$ .

*P. gossypinus* abundance (Fig. 2) also differed significantly among grids ( $F = 10.73$ , d.f. = 3, 68,  $P < 0.001$ ), with Tukey's pairwise comparisons revealing that grid 1 had higher populations than grids 2 and 4, grid 2 had a smaller population than grid 3, and grid 3 had a larger population than grid 4. Populations generally peaked in early winter. Mean number/grid  $\pm 1$  SE was as follows: grid 1,  $21.1 \pm 2.2$ ; grid 2,  $14.0 \pm 0.9$ ; grid 3,  $21.7 \pm 1.5$ ; and grid 4,  $14.8 \pm 0.7$ . A significant difference in numbers between seasons within a grid was found on grid 2 ( $t = -2.40$ , d.f. = 17,  $P = 0.028$ ) and grid 4 ( $t = 3.28$ , d.f. = 12,  $P = 0.006$ ). Grid 2 had higher mean numbers in the dry season (15.87 vs. 12.04) while grid 4 had higher numbers in the wet season (13.02 vs. 16.86).

Mean population abundance of *R. rattus* was  $22.9 \pm 7.8$  individuals. Numbers peaked in late fall and declined during the summer, although the difference between seasons was not significant.

*Survivorship*—*N. floridana* survivorship was not significantly different among grids (Table 1) or within any grid between seasons (grid 1:  $t = -0.14$ ,

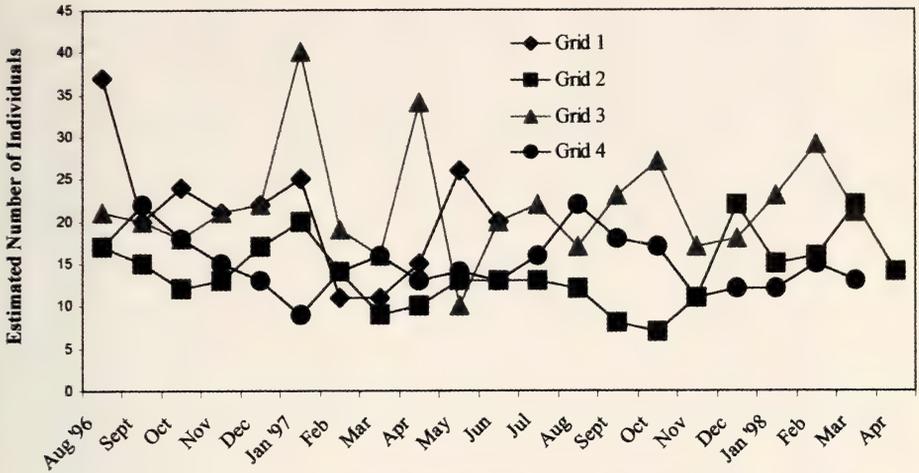


FIG. 2. Population size estimates for *P. gossypinus* on four grids in tropical hammocks of Key Largo, Florida from July 1996 to April 1998. Estimates are Jolly-Seber estimates of population size.

d.f. = 7,  $P = 0.90$ ; grid 2:  $t = 0.50$ , d.f. = 16,  $P = 0.63$ ; grid 3:  $t = -0.08$ , d.f. = 10,  $P = 0.94$ ; and grid 4:  $t = -1.61$ , d.f. = 14,  $P = 0.13$ ). *P. gossypinus* survivorship was not significantly different between grids (Table 1) or between seasons (grid 1:  $t = -1.39$ , d.f. = 6,  $P = 0.21$ ; grid 2:  $t = 0.58$ , d.f. = 14,  $P = 0.57$ ; grid 3:  $t = -0.25$ , d.f. = 13,  $P = 0.81$ ; and grid 4:  $t = 0.46$ , d.f. = 16,  $P = 0.65$ ). Monthly survivorship for *R. rattus* was  $0.933 \pm 0.275$  with no significant difference between seasons ( $t = 0.24$ , d.f. = 3,  $P = 0.83$ ).

**Recruitment**—*N. floridana* recruitment was not significantly different among grids (Table 1) or within any grid between seasons (grid 1:  $t = -0.27$ , d.f. = 6,  $P = 0.80$ ; grid 2:  $t = -0.13$ , d.f. = 17,  $P = 0.90$ ; grid 3:  $t = -0.41$ , d.f. = 15,  $P = 0.69$ ; and grid 4:  $t = -0.62$ , d.f. = 10,  $P = 0.55$ ). *P. gossypinus* recruitment was significantly different by site (Table 1) with grids 1 and 2 having significantly greater recruitment than grids 3 and 4. There was no significant seasonal difference within any grid (grid 1:  $t = -0.41$ , d.f. = 7,  $P = 0.69$ ; grid 2:  $t = -0.50$ , d.f. = 13,  $P = 0.63$ ; grid 3:  $t = 0.13$ , d.f. = 16,  $P = 0.90$ ; and grid 4:  $t = -1.25$ , d.f. = 15,  $P = 0.23$ ). *R. rattus* recruitment on grid 1 was consistently high with a mean of  $10.7 \pm 5.74$  new individuals per trapping period, with no significant seasonal differences ( $t = -0.41$ , d.f. = 6,  $P = 0.69$ ).

**Age structure**—*N. floridana* age-structure was not significantly different among grids (Table 1) or within any grid between seasons (grid 1:  $t = 0.38$ , d.f. = 9,  $P = 0.71$ ; grid 2:  $t = -0.46$ , d.f. = 20,  $P = 0.65$ ; grid 3:  $t = -0.20$ , d.f. = 19,  $P = 0.84$ ; and grid 4:  $t = 0.09$ , d.f. = 16,  $P = 0.93$ ). In

TABLE 1. Estimates of *N. floridana* and *P. gossypinus* survivorship over 28 day periods; recruitment (% of new individuals/month); age structure (% adult); sex ratio (% male); and percentage of reproductively active individuals on four grids in tropical hammocks of Key Largo, Florida. Hammock ages are in parentheses (see text for description). All data are means  $\pm$  1 SE.

	Grid 1 (medium)	Grid 2 (old)	Grid 3 (medium)	Grid 4 (medium-old)	Significance among gr (ANOVA)
Survivorship					
<i>N. floridana</i>	0.70 $\pm$ 0.09	0.93 $\pm$ 0.06	0.94 $\pm$ 0.10	0.86 $\pm$ 0.05	$F = 0.82$ , d.f. = 3, 55, $P = 0$ .
<i>P. gossypinus</i>	0.71 $\pm$ 0.05	0.68 $\pm$ 0.04	0.78 $\pm$ 0.05	0.74 $\pm$ 0.03	$F = 1.00$ , d.f. = 3, 60, $P = 0$ .
Recruitment					
<i>N. floridana</i>	0.0	0.0	0.0	1.0	$F = 1.58$ , d.f. = 3, 18, $P = 0$ .
<i>P. gossypinus</i>	5.0	5.0	1.0	1.0	$F = 26.14$ , d.f. = 3, 62, $P < 0$ .
Age Structure					
<i>N. floridana</i>	55.80 $\pm$ 13.30	63.80 $\pm$ 9.50	64.80 $\pm$ 10.00	62.20 $\pm$ 6.70	$F = 0.15$ , d.f. = 3, 76, $P = 0$ .
<i>P. gossypinus</i>	76.29 $\pm$ 4.09	77.60 $\pm$ 4.32	86.68 $\pm$ 2.07	89.61 $\pm$ 2.34	$F = 3.14$ , d.f. = 3, 76, $P = 0$ .
Sex Ratio					
<i>N. floridana</i>	69.23 $\pm$ 12.06	61.59 $\pm$ 9.40	46.59 $\pm$ 9.73	31.10 $\pm$ 5.05	$F = 2.73$ , d.f. = 3, 76, $P = 0$ .
<i>P. gossypinus</i>	51.64 $\pm$ 2.29	52.26 $\pm$ 2.76	55.86 $\pm$ 2.89	64.31 $\pm$ 2.89	$F = 4.26$ , d.f. = 3, 76, $P = 0$ .
Reproductively Active					
<i>N. floridana</i>					
male	30.8 $\pm$ 12.1	26.1 $\pm$ 9.4	31.80 $\pm$ 9.1	15.9 $\pm$ 7.6	$F = 0.63$ , d.f. = 3, 76, $P = 0$ .
female	—	25.0 $\pm$ 9.0	40.9 $\pm$ 10.7	78.8 $\pm$ 6.8	$F = 8.72$ , d.f. = 3, 76, $P < 0$ .
<i>P. gossypinus</i>					
male	77.92 $\pm$ 5.16	73.78 $\pm$ 4.62	64.05 $\pm$ 3.55	69.66 $\pm$ 4.72	$F = 1.95$ , d.f. = 3, 76, $P = 0$ .
female	45.44 $\pm$ 7.35	44.76 $\pm$ 6.01	57.47 $\pm$ 5.97	58.17 $\pm$ 5.73	$F = 1.65$ , d.f. = 3, 76, $P = 0$ .

*P. gossypinus*, grids 1 and 2 had a significantly lower proportion of adults than grid 4. Age structure for this species varied by season on grid 2 ( $t = 4.12$ , d.f. = 17,  $P < 0.001$ ) with a mean of  $91.6 \pm 3.4\%$  adults in the wet season and  $64.8 \pm 5.6\%$  adults in the dry season and grid 4 ( $t = 3.69$ , d.f. = 16,  $P = 0.002$ ) with a mean of  $96.8 \pm 1.7\%$  in the wet season and  $83.6\% \pm 3.2$  adults in the dry season. *R. rattus* also had an adult-biased population (overall mean =  $72.1\% \pm 11.0$ ) with no difference between seasons ( $t = 0.71$ , d.f. = 10,  $P = 0.50$ ).

*Sex ratio*—*N. floridana* sex ratio was significantly different among grids (Table 1), with grid 1 with a male biased ratio differing from grid 4 with female biased sex ratio. There were no significant differences between seasons within any grid (grid 1:  $t = 2.40$ , d.f. = 6,  $P = 0.053$ ; grid 2:  $t = -1.70$ , d.f. = 19,  $P = 0.11$ ; grid 3:  $t = 0.39$ , d.f. = 19,  $P = 0.70$ ; and grid 4:  $t = 0.88$ , d.f. = 19,  $P = 0.39$ ). It should be noted that only two females (one recaptured once) were caught on grid 1 during the entire study.

*P. gossypinus* sex ratio was also significantly different among grids (Table 1), with grid 4 having a higher proportion of males than grids 1 and 2. Grid 2 was the only grid to have a significant difference in sex ratio between seasons ( $t = 2.39$ , d.f. = 20,  $P = 0.027$ ) with males accounting for  $58.5 \pm 3.3\%$  of the captures in the wet season and  $46.6 \pm 3.7\%$  in the dry season.

The overall sex ratio of *R. rattus* on grid 1 was  $57.1 \pm 8.7\%$  male, with no significant difference between seasons ( $t = -1.08$ , d.f. = 10,  $P = 0.30$ ).

*Reproduction*—The overall percentage of *N. floridana* with scrotal testes did not differ significantly among grids (Table 1). Only on grid 2 was there a significant difference in the percentage of reproductively active males ( $t = 2.08$ , d.f. = 15,  $P = 0.05$ ), with a mean of  $45.5 \pm 16.0\%$  of reproductively active individuals in the wet season versus  $8.3 \pm 8.3\%$  in the dry season. The overall percentages of reproductively active *N. floridana* females differed significantly among the three grids for which samples were available, with the greatest level of reproductive activity on grid 4 (Table 1). There was no difference in reproductive activity between seasons within any grid (grid 2:  $t = 0.00$ , d.f. = 20,  $P = 1.0$ ; grid 3:  $t = -0.08$ , d.f. = 19,  $P = 0.94$ ; and grid 4:  $t = 0.63$ , d.f. = 18,  $P = 0.53$ ).

The percentage of reproductively active *P. gossypinus* males was not significantly different among grids (Table 1). Reproductively active males occurred throughout the year with a drop in frequency during the late winter/early spring. The seasonal difference was significant on grid 2 with a mean of  $85.4 \pm 3.3\%$  in the wet season and  $63.1 \pm 7.1\%$  ( $t = 2.84$ , d.f. = 15,  $P = 0.012$ ) in the dry season and on grid 3 with a mean of  $73.9 \pm 2.5\%$  in the wet season and  $55.8 \pm 5.1\%$  ( $t = 3.17$ , d.f. = 15,  $P = 0.006$ ) in the dry season. *P. gossypinus* female reproductive activity did not differ significantly among grids (Table 1) or within grids between seasons (grid 1:  $t = -1.11$ ,

TABLE 2. Estimates of home-range size for *N. floridana* on four grids and overall in tropical hammocks of Key Largo, Florida. All data are means  $\pm$  1 SE.

Grid	Sex	N	Home range area (m <sup>2</sup> )
Grid 1	Male	1	1575
	Female	0	—
Grid 2	Male	2	6413 $\pm$ 900
	Female	1	1013
Grid 3	Male	2	2138 $\pm$ 450
	Female	2	619 $\pm$ 169
Grid 4	Male	5	2475 $\pm$ 518
	Female	6	1463 $\pm$ 346
Combined	Male	10	3105 $\pm$ 628
	Female	9	1225 $\pm$ 257

d.f. = 8,  $P = 0.30$ ; grid 2:  $t = 0.29$ , d.f. = 15,  $P = 0.78$ ; grid 3:  $t = -0.95$ , d.f. = 15,  $P = 0.36$ ; and grid 4:  $t = 0.35$ , d.f. = 19,  $P = 0.73$ ).

For male *R. rattus* on grid 1, 69.4 $\pm$ 10.2% were reproductively active with no significant difference between seasons ( $t = -0.68$ , d.f. = 9,  $P = 0.52$ ). Among females, 57.7 $\pm$ 12.3% were reproductively active with no significant difference between seasons ( $t = 0.90$ , d.f. = 10,  $P = 0.39$ ).

*Home range*—Male *N. floridana* had a significantly larger home range size than females for all grids combined ( $F = 7.07$ , d.f. = 1,17,  $P = 0.017$ ; Table 2). Male ranges also differed significantly among grids ( $F = 10.34$ , d.f. = 2,6,  $P = 0.011$ ), with a significantly larger mean size on grid 2 than grids 3 and 4. Female home range did not differ significantly among grids ( $F = 1.75$ , d.f. = 1,6,  $P = 0.234$ ; Table 2).

*P. gossypinus* male home-range was significantly larger ( $F = 18.55$ , d.f. = 1,106,  $P < 0.001$ ) than that of females (Table 3). Male range size was not significantly different among grids ( $F = 0.76$ , d.f. = 3,53,  $P = 0.524$ ),

TABLE 3. Estimates of home-range size for *P. gossypinus* on four grids and overall in tropical hammocks of Key Largo, Florida. All data are means  $\pm$  1 SE.

Grid	Sex	N	Home range area (m <sup>2</sup> )
Grid 1	Male	8	2672 $\pm$ 667
	Female	12	947 $\pm$ 221
Grid 2	Male	13	3920 $\pm$ 710
	Female	13	2259 $\pm$ 521
Grid 3	Male	17	4553 $\pm$ 876
	Female	18	2288 $\pm$ 399
Grid 4	Male	19	3932 $\pm$ 634
	Female	10	2633 $\pm$ 590
Overall	Male	57	3938 $\pm$ 383
	Female	53	2042 $\pm$ 232

although there was a suggestion of smaller home range on grid 1 compared with grids 2, 3, and 4 (Table 3). Female home-range size (Table 3) differed significantly among grids ( $F = 4.72$ ,  $d.F. = 3,49$ ,  $P = 0.006$ ), with grid 1 having significantly smaller home range size than grids 2, 3, and 4.

*R. rattus* on grid 1 had a mean home-range of  $1538 \pm 582$  m<sup>2</sup>. *R. rattus* were only captured on grid 1, therefore comparisons among grids were not possible.

DISCUSSION—Previous studies on Key Largo have suggested that the most mature hammocks are optimal habitat because of the greater abundance of woodrats and cotton mice found there (Barbour and Humphrey, 1982; Goodyear, 1985). Hersh (1981) estimated woodrat densities on Key Largo to be 2.2 woodrats per ha in a tract of mature hammock, with little seasonal variation between August and May. Humphrey (1988) found 0.3 to 16.4 (mean 7.6) woodrats per ha and 3.0 to 44.1 (mean 21.2) cotton mice per ha at six sites on Key Largo during the dry season (November through April). Humphrey (1988) sampled in a variety of hammocks of different ages, but did not describe those ages. He noted a north-south gradient with woodrats and cotton mice being less abundant in the northern part of Key Largo.

Densities in our study ranged from 0.9 to 3.1 (mean 1.8) woodrats per ha and 7.8 to 12.1 (mean 9.9) cotton mice per ha with no north-south gradient as reported by Humphrey (1988). The results presented here for woodrats are consistent with those reported by Hersh (1981). These differences may be due to natural fluctuations in population size over time or reflective of the quality of the habitat sampled.

In our study, *N. floridana* population size was greatest in medium-old hammock, intermediate in medium and old hammock, and lowest in a medium hammock where *R. rattus* was present. Recruitment was highest in medium-old hammock, which also had greater female reproduction with a female-biased sex ratio. The medium hammock with *R. rattus* had the lowest survivorship, a low proportion of adults, and a population that was essentially all male.

The old and medium hammock without *R. rattus* had high survivorship and intermediate population density, with female reproductive activity higher in the medium than in the old hammock. The higher percentage of females in reproductive condition suggests that medium hammock is of higher quality than old. Also, home-range in the old hammock was greater than on other age classes which also suggests that old hammock is lower quality habitat.

For *P. gossypinus* population size was highest in medium aged hammock. Although both medium age hammocks had high population size, recruitment was more variable in the hammock where *R. rattus* was present. The high abundance of individuals in medium hammocks suggests that this age class is optimal habitat for *P. gossypinus*. The low density and female

reproductive activity on grid 2 suggests that old hammock was the sub-optimal for *P. gossypinus*.

The population dynamics of *N. floridana* and *P. gossypinus* on grid 1 were potentially affected by the presence of *R. rattus*. The proximity to human development of grid 1 may account for the abundance of *R. rattus*. It should be noted that *R. rattus* was reproductively active individuals were recaptured in the hammock and are not a floating population of non-reproductive animals as reported by Humphrey (1992). *N. floridana* had the lowest survivorship, lowest proportion of adults, and a highly male-biased sex ratio on grid 1 (Table 1). Although both *N. floridana* and *P. gossypinus* were possibly affected by the presence of *R. rattus*, the extremely poor performance of *N. floridana* is of particular concern as *R. rattus* has been implicated in the extinction of several rodents throughout the Greater and Lesser Antilles (Woods, 1989). The results presented here suggest that *P. gossypinus* can coexist with *R. rattus* far better than *N. floridana*.

If intermediate post-disturbance stages of tropical hammock are the best quality habitat for *P. gossypinus* and *N. floridana*, as suggested by the data, this indicates that periodic hurricanes may play a role in maintaining optimum habitat quality for these species. Duever and co-workers (1994) stated that the Florida Keys experience a major hurricane every 27 years. Disturbance by hurricanes will result in the necessary heterogeneous matrix of habitat allowing source populations of both species to persist and colonize suitable hammock stages during post-hurricane recovery.

Two other factors potentially affecting populations of these species on Key Largo are the presence of *R. rattus* and fire ants (*Solenopsis wagneri*). The latter appear to be colonizing new areas on Key Largo. Fire ants were not present on grid 1 at the start of the study, but became so abundant that trapping could not continue on the area.

ACKNOWLEDGMENTS—We would like to thank Britt Keith for her assistance in the field. The Florida Department of Environmental Protection and U. S. Fish and Wildlife Service allowed the research to be done on their land. Michael Rosenzweig, Don Deangelis, Ted Fleming, and Dave Janos edited an earlier manuscript.

#### LITERATURE CITED

- BARBOUR, D. B. AND S. H. HUMPHREY. 1982. Status and habitat of the Key Largo woodrat and cotton mouse (*N. floridana smalli* and *P. gossypinus allipaticola*). *J. Mammal.* 63:144–148.
- DIFFENDORFER, J. E., M. S. GAINES, AND R. D. HOLT. 1995. Habitat fragmentation and movements of three species of small mammals. *Ecology* 76:814–826.
- DUEVER, M. J., J. F. MEEDER, L. C. MEEDER, AND J. M. MCCOLLOM. 1994. The climate of south Florida and its role in shaping the Everglades ecosystem. Pp. 225–248. *In*: DAVIS, S. M. AND J. C. OGDEN (eds.). *Everglades: the Ecosystem and Its Restoration*. St. Lucie Press, Delray Beach, FL.
- GOODYEAR, N. C. 1985. Results of a study of Key Largo woodrats and cotton mice: Phase I, spring and summer 1985. Unpubl. report to U.S. Fish and Wildlife Service, 3100 University Boulevard, South Suite 120, Jacksonville, FL. 76 pp.

- HERSH, S. L. 1981. Ecology of the Key Largo woodrat. *J. Mammal.* 62:201–206.
- HUMPHREY, S. R. 1988. Density estimates of the endangered Key Largo woodrat (*N. floridana smalli*) and cotton mouse (*P.gossypinus allapaticola*) using the nested grid approach. *J. Mammal.* 69:524–531.
- . 1992. Key Largo woodrat. Pp. 119–130. *In:* HUMPHREY, S. R. (ed.). *Rare and Endangered Biota of Florida, Vol. I: Mammals*. FCREPA. Univ. Press of Fla. Gainesville, FL.
- AND D. B. BARBOUR. 1979. Status and habitat of eight kinds of endangered and threatened rodents in Florida. Special Scientific Report No. 2. Office of Ecological Services, Fla. State Mus. Gainesville, FL. 17 pp.
- IMS, R. A. 1987. Responses in spatial organization and behavior to manipulations of the food resource in the vole *Clethrionomys rufocanus*. *The J. Anim. Ecol.* 56:585–596.
- JOLLY, G. M. 1965. Explicit estimates from capture-recapture data with both death and dilution-stochastic model. *Biometrika* 52:225–247.
- KIA, J. G., J. A. BALDWIN, AND C. J. EVANS. 1996. CALHOME: a program for estimating animal home ranges. *Wild. Soc. Bull.* 24:342–344.
- MOHR, C. O. 1947. Table of equivalent populations of North American Mammals. *Am. Mid. Nat.* 37:223–249.
- OSTFELD, R. S. 1992. Small mammal herbivores in a patchy environment: Individual strategies and population responses. Pp. 43–74. *In:* HUNTER, M. D., T. OHGUSHI, AND P. W. PRICE (eds.). *Effects of Resource Distribution on Animal-Plant Interactions*. Academic Press, Inc. New York, NY.
- ROSS, M. S., J. J. O'BRIEN, AND L. J. FLYNN. 1992. Ecological site classification of Florida Keys terrestrial habitats. *Biotropica* 24:488–502.
- , J. F. MEEDER, G. TELESNICKI, AND C. WEEKLEY. 1995. Terrestrial ecosystems of the Crocodile Lakes National Wildlife Refuge: The effects of Hurricane Andrew. Final report to the Department of the Interior, U. S. Fish and Wildlife Service, Washington D.C.
- SMITH, M. H. 1971. Food as a limiting factor in the population ecology of *Peromyscus polionotus* (Wagner). *Ann. Zool. Fenn.* 109–112.
- SOKAL, R. R. AND F. J. ROHLF. 1995. *Biometry*. W. H. Freeman and Company. New York, New York.
- TAITT, M. J. 1981. The effect of extra food on small rodent populations: I. Deermice (*Peromyscus maniculatus*). *J. Anim. Ecol.* 50:111–124.
- , AND C. J. KREBS. 1981. The effect of extra food on small rodent populations: Voles (*Microtus townsendii*). *J. Anim. Ecol.* 50:125–137.
- VAN HORNE, B. 1983. Density as a misleading indicator of Density. *J. Wild. Manage.* 47:893–901.
- WOODS, C. A. 1989. Endemic rodents of the West Indies: the end of a splendid isolation. Pp. 11–19. *In:* W.Z. LIDICKER, JR. (ed.). *Rodents: a World Survey of Species of Conservation Concern*. Occasional papers of the IUCN Species Survival Commission.

Florida Scient. 65(2): 115–125. 2002

Accepted: October 24, 2002

## USING GEOGRAPHIC INFORMATION SYSTEMS TO EVALUATE AVAILABLE HABITAT FOR TWO RODENT SPECIES ON NORTH KEY LARGO, FLORIDA.

BRITT KEITH AND MICHAEL S. GAINES

University of Miami, Department of Biology, Cox Science Building Room 215,  
1301 Memorial Drive, Coral Gables, FL 33146

**ABSTRACT:** We used Geographic Information Systems (GIS) as an assessment tool to predict the amount and distribution of available habitat for the *Neotoma floridana smalli* (Key Largo woodrat) and the *Peromyscus gossypinus allapaticola* (Key Largo cotton mouse) on North Key Largo, Florida. Three times as many cotton mice were live trapped in the hammock than were woodrats. None of the habitat variables used in the analyses; hardwood hammock age class, fragment size, runway density and presence of exotic vegetation, were significantly associated with Key Largo woodrat abundance estimates. Key Largo cotton mouse abundance was highest in medium-old hammocks, smaller fragments, hammocks with high runway densities and in hammocks where the exotic vegetation was absent. A stepwise multiple regression analysis revealed that hammock age class and fragment size explained most of the variation in cotton mice abundance. ArcView's Spatial Analyst GIS was used to analyze the stepwise multiple regression equations of the four habitat variables. The output was a map of the habitat which predicted areas of high (greater than 30) and low (less than 30) cotton mice abundance.

**Key Words:** GIS, habitats, *Neotoma floridana smalli*, *Peromyscus gossypinus allapaticola*

IN 1994 the Florida Game and Fresh Water Fish Commission and the United States Fish and Wildlife Service listed *Neotoma floridana smalli* (Key Largo woodrat) and *Peromyscus gossypinus allapaticola* (Key Largo cotton mouse) as endangered. These two small mammal subspecies have been of concern to wildlife biologists because they are in danger of becoming extinct due to habitat destruction and possible competition by invading exotic species.

The Key Largo woodrat and the Key Largo cotton mouse are the southernmost subspecies of their respective genera (Brown, 1970) and are completely isolated on North Key Largo, Florida (Fig. 1). Habitat requirements of the two species in North Key Largo are sketchy. Among others, a major factor that may be influencing the habitat requirements of these animals is the maturity level of the hardwood hammocks. Brown (1978 a, b) claimed that woodrats and cotton mice are limited to mature hardwood hammocks, and that both species are absent in medium to young age stands. However, Goodyear (1985) has trapped both species in both mature and immature hammocks.



FIG. 1. Map showing the study site of North Key Largo.

The objective of this study is to utilize Geographic Information Systems (GIS) to identify where the most suitable habitat occurs for woodrats and cotton mice in North Key Largo.

**METHODS AND MATERIALS—Study area**—All fieldwork took place within the tropical hardwood hammocks in North Key Largo. There are no continuous stretches of undisturbed hammock, due to roads and development in the area, therefore the study area was divided into nine fragments that varied in size from 25–85 ha.

**Trapping methods**—We determined the distribution of woodrats and cotton mice by conducting systematic line transect sampling over the entire extent of the hardwood hammock in North Key Largo. The total number of transects for the study site was 35. Each transect was sampled once. Stations were flagged at 10-m intervals along a transect for a total of 25 stations per transect. Two ventilated Sherman XLF-15 small mammal live traps were placed at each station. The traps were opened and baited in the evenings, and checked for occupancy in the early mornings. Each animal caught was ear tagged for future identification using individually numbered Monel ear tags.

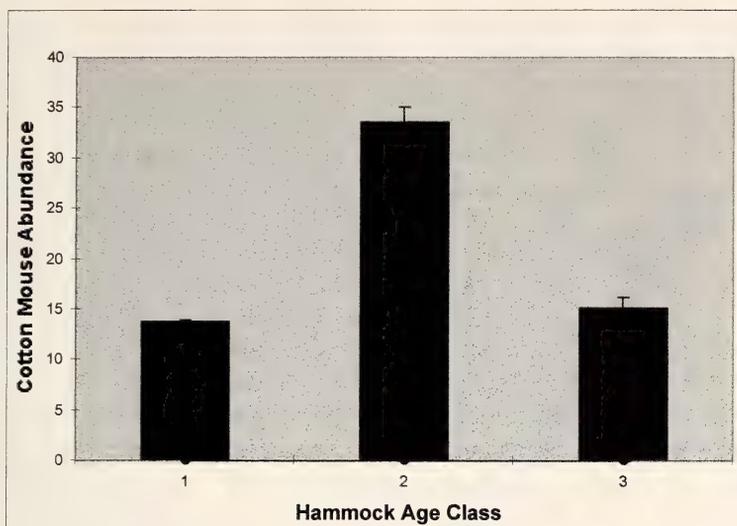
**Abundance estimates**—The Schnabel method of abundance estimation (Krebs, 1989) was calculated for both species at each transect. Ross and co-workers (1995), classified the hardwood hammock into five different age classes related to when they were last disturbed. These five classes are old (undisturbed since 1926), medium-old (disturbed 1926–1940), medium (disturbed 1940–1959), medium-young (disturbed 1959–1971) and young (disturbed since 1971). These age classes were the primary habitat features used for the analysis. Because the habitat is severely fragmented, a regression analysis was performed using fragment size as the independent variable and the abundances of each species as the dependent variable.

**Runway densities**—Anecdotal evidence during field trapping indicate that animals use runways for escape. Runways are defined as fallen branches, logs, vines, rocks, or any combination of the four. The density of runways was recorded in the field at every line transect. An analysis of variance (ANOVA) was used to detect any statistically significant differences of runway densities on the transects in the five hammock age classes. In addition, a regression analysis was performed with runway densities as the independent variable and the abundances of each species as the dependent variable. A regression analysis was also performed with fragment size as the independent variable and runway density as the independent variable.

Goodyear (1985) reported that exotic vegetation might have a negative in this area. Therefore, we incorporated exotic vegetation as a structural feature of the habitat. For the analysis, we used presence or absence, without considering the densities of exotics.

**GIS methods**—ArcView GIS is the software used throughout this study. All transects were mapped using a Trimble GPS unit. This transect layer was overlaid onto an existing digital line map of North Key Largo. In addition, layers and their corresponding attribute tables were created for each habitat variable used in this study. Hammock age class, fragment size, runway density and the presence or absence of exotic vegetation were potential candidates for GIS map construction. A stepwise multiple regression analysis was performed using these candidates as the independent variables, and the abundance data as the dependent variable. The resulting regression equations were input directly into ArcView to create a suitability map of the habitat, ranked according to the predicted abundance of animals in different areas.

**RESULTS**—Woodrats were captured on 21 of the 35 transects. ANOVA's and regressions found no statistically significant differences in woodrat abundance among hammock age classes ( $F = 1.59$ ,  $df = 3,30$ ,  $p = 0.211$ ),



- 1 = old hammock  
2 = medium-old hammock  
3 = medium hammock

Fig. 2. Bar graph showing the relationship between cotton mouse abundance and hammock age class.

fragment size ( $F = 0.24$ ,  $df = 1,5$ ,  $p = 0.64$ ,  $R^2 = 0.046$ ), runway density ( $F = 0.10$ ,  $df = 1,5$ ,  $p = 0.760$ ,  $R^2 = 0.020$ ) or whether or not exotic vegetation was present on or near the transects ( $F = 3.28$ ,  $df = 1,33$ ,  $p = 0.079$ ).

Cotton mice were captured on 27 of the 35 transects. Three times as many cotton mice were captured than woodrats (153 as opposed to 47). An ANOVA detected a statistically significant difference of cotton mice when hammock age classes were lumped, favoring higher abundance estimates in medium-old hammock over old and medium ( $F = 6.39$ ,  $df = 2,5$ ,  $p = 0.042$ , Fig. 2). There was a statistically significant negative relationship when cotton mice abundance was regressed as the dependent variable on fragment size, the independent variable ( $F = 6.25$ ,  $df = 1,7$ ,  $p = 0.041$ ,  $R^2 = 0.472$ ). There was also a statistically significant difference favoring higher cotton mice abundance estimates where exotic vegetation was absent on the transects ( $F = 4.87$ ,  $df = 1,33$ ,  $p = 0.034$ ).

Runway densities varied across the site and between each hammock age class. When cotton mice abundance was regressed on runway density there was a statistically significant relationship ( $F = 5.33$ ,  $df = 1,7$ ,  $p = 0.054$ ,  $R^2 = 0.432$ ). There were statistically higher runway densities occurring in the medium-old hammock age class, compared to medium, old and young hammocks respectively ( $F = 3.93$ ,  $df = 3,29$ ,  $p = 0.018$ ). There was also

a statistically significant negative relationship when fragment size was regressed on runway densities ( $F = 7.14$ ,  $df = 1,7$ ,  $p = 0.032$ ,  $R^2 = 0.505$ ).

Unfortunately, a habitat suitability map for the woodrats could not be created because of small sample sizes. The ANOVA's for the different independent habitat variables (hammock age class, fragment size, runway density and presence/absence of exotics) showed no significant differences in woodrat abundance estimates. However, significant results for the cotton mice provided sufficient information for a GIS map using the habitat variables. An estimated 790 ha of the total 945 ha was classified as suitable for the cotton mice. A stepwise multiple regression using all habitat variables approached statistical significance ( $F = 5.22$ ,  $df = 4, 4$ ,  $p = 0.069$ ,  $R^2 = 0.678$ ). This regression equation was used when creating the GIS model due to its potential biological significance. The stepwise multiple regression revealed that hammock age class and fragment size were the only statistically significant variables in the model. Together they explained 76.6% of the variation ( $F = 9.83$ ,  $df = 2, 6$ ,  $p = 0.013$ ). Figure 3 shows the results of the stepwise multiple regression GIS models, showing predicted areas of high ( $>30$ ) and low ( $<30$ ) cotton mice abundance.

DISCUSSION—There have been only a few studies documenting the habitat requirements of the Key Largo woodrat and the Key Largo cotton mouse. The literature states that woodrats are more specific in their habitat requirements than cotton mice (Goodyear, 1985; Brown, 1970). Our results indicate the reverse. There was no clear association of habitat variables with woodrat abundance. This could have been due to their small sample size and that the habitat variables that we chose may not be ecologically relevant to the organisms. However, cotton mice did show significant differences in abundance for different habitat variables. Thus, we will focus on cotton mice.

Several authors have claimed that cotton mice prefer the most mature hammocks. Our results do not support claims in the literature that cotton mice prefer only the oldest hammocks. In our study, cotton mice were trapped on 77% of the transects. Medium-old, old and medium hammock age classes all had a statistically significantly higher abundance of cotton mice than medium-young and young age classes. Runway densities are also significantly higher in medium and medium-old age classes compared to old hammocks. Higher runway densities were also positively correlated with higher abundances of cotton mice. One possible explanation for this is that the medium age class probably provides enough cover for these animals, but the canopy allows enough light penetration for the growth of additional plants and vines which provide runways. Old hammocks have a closed canopy, therefore an open understory and less variability.

In addition to the individual regressions with the habitat variables, the stepwise multiple regressions revealed some interesting results. When all of the variables were included, the model approached statistical significance. It is the co-linearity of these variables that may complicate which variables



FIG. 3. A map of the hardwood hammock in North Key Largo, produced by the stepwise multiple regression analysis, predicting areas of hammock which have a low (0-30) and high (30-60) abundance of cotton mice.

most affect the animals. Although hammock age class explains the most variation in cotton mouse abundance (56%), the issue is whether these animals prefer the oldest hammocks, which is assumed in the literature. This study reveals that the medium old age classes had the highest cotton mice abundances.

The final GIS map highlighted areas in the hardwood hammock where the models predict different cotton mouse abundances. There are approximately 945 ha of hammock on North Key Largo. The map identified 790 of the 945 total ha of hammock deemed suitable for cotton mice. These are areas where the suitability of the hammock increases as the values of cotton mice abundance also increase. Thus, a large percentage of the hardwood hammock on North Key Largo is deemed suitable at varying degrees for cotton mice, according to the GIS model (Fig.3). It takes into account all of the habitat variables that were initially predicted as important in a statistical sense to these animals. If this model were to be validated in the field, the areas represented in black should yield an abundance of at least 30 cotton mice per transect. This model was tested against the abundance estimates found in this study, yielding a 68% concordance with the data. That is, 68% of the areas predicted to have at least 30 cotton mice in fact did, according to the original trapping data collected.

Geographic Information Systems are quickly evolving to produce more finite and accurate results, particularly in the field of ecology. At present, the technology works best on large-scale landscapes where many habitat types may be classified, including a plethora of variables. Although this North Key Largo study was done on a smaller scale, it still provides useful information to agencies trying to manage this parcel of land. We are hopeful the map generated from this study will help to identify areas of special concern. This may allow the agencies to more easily customize the guidance given to the biologists working to protect and upgrade the ecosystem and endangered species in North Key Largo.

ACKNOWLEDGMENTS—We would like to acknowledge S. Schultz, P. Keating, H. Beck-King and M. Caldwell for their constructive criticism of the manuscript. P. Frank from the Florida Fish and Wildlife Conservation Commission, J. Duquesnel from the Florida Park Service and F. Percival from the United States Fish and Wildlife Service all gave useful advice during the development of this study. We owe special thanks to Lori Lind and particularly Chris Sasso for helping in the field. Many thanks to V. Petersen, K. Schaefer, R. Keith, and especially T. Pedersen for their help, without which this project would not have been as successful.

#### LITERATURE CITED

- BROWN, L. N. 1970. Unique mammals found in the Florida Keys. *Florida Naturalist*, 43:146–147.
- 1978a. Key Largo woodrat. *Rare and Endangered Biota of Florida*. University of Florida Press, Gainesville, Florida.
- 1978b. Key Largo cotton mouse. *Rare and Endangered Biota of Florida*. Florida: University of Florida Press, Gainesville, Florida.

- GOODYEAR, N. C. 1985. Results of a study of Key Largo woodrats and cotton mice: Phase 1, spring and summer 1985. Unpublished report. 76 pp.
- KREBS, C. J. 1989. Ecological Methodologies. Addison-Wesley Educational Publishers. Boston, MA. 576 pp.
- ROSS, M. S., J. F. MEEDER, G. TELESNICKI AND C. WEEKLY. 1995. Terrestrial ecosystems of the Crocodile Lakes National Wildlife Refuge: the effects of Hurricane Andrew. Final report to Dept. of Interior, U.S. Fish and Wildlife Service. Dade County, Florida.

Florida Scient. 65(2): 126–133. 2002

Accepted: November 6, 2001

EVIDENCE FOR THE USE OF CHEMOSENSORY CUES  
BY THE ALLIGATOR SNAPPING TURTLE,  
*MACROCLEMYS TEMMINCKII*, TO DETECT THE  
PRESENCE OF MUSK AND MUD TURTLES

FRED PUNZO<sup>(1)</sup> AND LISA ALTON<sup>(2)</sup>

<sup>(1)</sup>Dept. of Biology, University of Tampa, 401 W. Kennedy Blvd., Tampa, FL 33606

<sup>(2)</sup>1367 Johnson St., Ferguson, MO 63135

**ABSTRACT:** *The alligator snapping turtle, *Macroclemys temminckii*, is capable of detecting and responding to the presence of chemosensory cues from two naturally-occurring prey species, the Mississippi mud turtle, *Kinosternon subrubrum*, and the common musk turtle, *S. odoratus*. Preference tests were conducted in an experimental chamber in which juveniles of *M. temminckii* were exposed to dechlorinated water in one-half of the chamber and an odor plume from water that had been occupied by either *S. odoratus* or *K. subrubrum*. Juveniles of *M. temminckii* spent significantly more time in water containing prey odor cues and also exhibited more rapid movements and more frequent episodes of gular pumping, as compared to those exhibited by turtles in untreated water. The ability to utilize odor cues is discussed with respect to detection of prey and patch residence time.*

**Key Words:** Chemosensory cues, *Macroclemys*, predator recognition, turtles

PREVIOUS research has shown that many animals can reduce the risk of predation by utilizing chemosensory cues associated with potential predators (see review by Kats and Dill, 1998). Most of the research has focused on certain invertebrate species (Chivers et al., 1996) as well as fish (Hara, 1992), larval amphibians (Petranka et al., 1987; Manteifel, 1995) and mammals (Kats and Dill, 1998; Barreto and Macdonald, 1999). Among the reptiles, the use of odor cues to detect predators has been reported for lizards (Cooper, 1990; Phillips and Alberts, 1992; Van Damme and Castilla, 1996) and snakes (Burger, 1989). Turtles, in contrast, have received far less attention (Jackson, 1990).

Less well known, but equally important, is the ability of predators to utilize chemosensory cues to locate potential prey. This has been well established in many species of mammals (Galef et al., 1994) and carrion-feeding birds (Kare and Mason, 1986). Punzo and Kakoyi (1997) showed that wolf and lynx spiders can learn to recognize odor cues associated with naturally-occurring prey species, and furthermore, the presence of these cues increases patch residence time for these spiders.

---

<sup>1</sup> Author to whom all correspondence should be addressed

Although most species of turtles possess a well-developed visual capacity (Mrosovsky and Boycott, 1966), they are also capable of utilizing chemosensory cues to locate preferred microhabitats (Yeomans, 1995; Quinn and Graves, 1998) and food (Burghardt and Hess, 1966; Hatanaka and Matsuzaki, 1993). Jackson (1990) showed that musk turtles (*Sternotherus minor peltifer* and *S. carinatus*) utilized chemical cues to detect and avoid a naturally-occurring predator, the alligator snapping turtle (*Macroclemys temminckii*). The purpose of this study was to determine whether or not *M. temminckii* can utilize chemical cues to detect the presence of musk and mud turtles.

**METHODS**—All turtles used in this study were obtained from eggs hatched in captivity. The eggs were deposited by females originally collected at several locations in Livingston Parish, LA, in July, 1999. Eggs were obtained from 5 females of *M. temminckii* (clutch size ranged from 12–31 eggs), 8 females of *Kinosternon subrubrum* (Mississippi mud turtle; 2–5 eggs per female), and 6 females of *Sternotherus odoratus* (common musk turtle; 2–8 eggs per female). Alligator snapping turtles are known to feed on musk and mud turtles (Allen and Neill, 1950; Jackson, 1990).

After collection, eggs were incubated in a Havabator incubator (Bush Herpetological Supply, Neodosha, KS) at 27°C and 72% relative humidity. After hatching, juvenile turtles were maintained individually in 7-gallon aquaria containing dechlorinated water, artificial plants, a gravel substrate, and a rock on which the animals could climb to get out of the water. Water in the aquaria was changed twice per week. Turtles were maintained on a diet of Reed's Turtle Food (Bush Herpetological Supply) and mealworms (*Tenebrio molitor*). All turtles were 2 weeks old when tested and they were all naive (i.e.—none had prior exposure to any other turtle prior to testing).

Experimental trials were conducted in a stainless steel chamber (135 × 80 × 35 cm) based on the design described by Jackson (1990). To summarize, the chamber was filled with 105L of dechlorinated water replenished at a rate of 10L / min. A 95 × 25 cm piece of clear plastic was affixed to the floor of the chamber, standing on its long edge at the upstream end at the midline of the tank width. This effectively divided the tank into 39.4 cm wide halves, except at the downstream end of the chamber. The inflow of water to each half of the chamber entered through 1 mm holes in a capped plastic pipe and was directed into a submerged trough which was buffered with plastic dowels so that the entering water did not cause any turbulence. Water exited through 6 mm diam. holes in the downstream end wall. The addition of colored food dye verified the presence of laminar flow characterized by a distinct boundary where the flows of each half were in contact downstream from the plastic divider. In several test runs, no color could be detected in the chamber 10 min after adding the dye. All observations were recorded with a Panasonic MV50 video camera from behind a one-way mirror to minimize disturbance to the animals.

At the beginning of each trial, an individual *M. temminckii* was given a choice between plain dechlorinated water (control) or dechlorinated water containing 2% of water from an aquarium that had housed 5 individuals of either *S. odoratus* or *S. subrubrum* for a 3-day period (treatments). Before water reached the experimental chamber each perforated trough also received 100 ml / min of water via gravity flow from either the control or one of the two treatments. The flows of treatment and control water were stopped at the end of each trial, but mass flow of water continued for at least 20 min between trials. Control and treatment inputs were renewed 20 min before the next trial was initiated.

Each trial started by placing one *M. temminckii*, facing upstream, at the midline of the chamber halfway between the downstream end of the chamber and the downstream end of the plastic divider. The movements of the turtle were recorded and quantified for a 20-min period

TABLE 1. The time (as proportion of total), mean speed (cm/min), and frequency of episodes of gular pumping (EGP) of *Macrochelys temminckii* in the two halves of the experimental chamber as a function of the type of stimulus (dechlorinated water vs. prey species: *Kinosternon subrubrum* and *Sternotherus odoratus*). Data expressed as means (N = 45). Values in parentheses represent ( $\pm$ SD). See text for details.

Parameter	<i>S. odoratus</i>		<i>K. subrubrum</i>	
	Water	Prey	Water	Prey
Time	0.14 ( $\pm$ 0.06)	0.86 ( $\pm$ 0.23)	0.12 ( $\pm$ 0.12)	0.88 ( $\pm$ 0.26)
Speed	15.3 ( $\pm$ 4.2)	29.6 ( $\pm$ 5.7)	12.9 ( $\pm$ 3.7)	32.4 ( $\pm$ 4.9)
EGP	1.2 ( $\pm$ 0.11)	5.7 ( $\pm$ 2.2)	0.9 ( $\pm$ 0.04)	6.2 ( $\pm$ 3.1)

using a grid coordinate system (comprised of 1-cm square grids) affixed to the walls of the chamber. In this way, we were able to determine the amount of time spent in treated vs. untreated halves of the chamber and the speed at which the turtle moved (cm / min). We also recorded the presence or absence of gular pumping by each subject since this behavior is known to increase as a function of locomotor activity (Hatanaka and Matsuzaki, 1993).

Two replicates were conducted on 25 and 20 *M. temminckii* during these experiments. Subjects were chosen randomly from all of the hatchling turtles. We utilized a completely randomized block design. Each turtle received one trial with one of the two treated water supplies as an alternative. The proportions of time spent in each half of the chamber were subjected to an arcsine transformation and did not deviate significantly from normality (Sokal and Rohlf, 1995). When variances were almost equal, two-tailed t tests were used to determine differences between means. When variances were not equal, we used Welch's approximation to the t test (Sokal and Rohlf, 1995). We measured speed of movement by calculating the number of cm a turtle moved per min. Data from turtles that were inactive or were absent from either half of the chamber were not used in the determination of speed.

**RESULTS AND DISCUSSION**—All of the juvenile alligator snapping turtles exhibited ambulatory movements within the experimental chamber. The results shown in Table 1 indicate that *M. temminckii* did not spend equal amounts of time in treated vs. untreated halves of the chamber; rather, this predator spent significantly more time in the area of the chamber containing cues from the prey species ( $P < 0.004$  for both *S. odoratus* and *S. subrubrum*). Individuals of *M. temminckii* also moved more quickly in the presence of prey chemosensory cues ( $P < 0.01$  for both prey species).

The frequency of episodes of gular pumping by *M. temminckii* also increased significantly in the presence of prey cues (Table 1) as shown by a two-tailed t test ( $P < 0.001$  for both prey species). In many trials (N = 34), individual alligator snapping turtles in the area of the chamber containing dechlorinated water would begin to move toward the boundary of the water containing prey cues and immediately increase their pumping of the gular region before proceeding into the treated water.

These experiments demonstrate that alligator snapping turtles are capable of detecting and responding to the chemosensory cues of musk and mud turtles. In its natural habitat, *M. temminckii* is a cryptic predator that typically chooses a patch and remains motionless waiting for prey to pass close by (Allen and Neill, 1950). However, it also moves slowly along the bottom of

ponds, lakes, and rivers searching for food (Ashton and Ashton, 1985). It uses its worm-mimicking tongue to lure fish, but can also sieze turtles and crustaceans that come within striking distance (Ernst and Barbour, 1972). Based on the results of this study, *M. temminckii* may utilize chemosensory cues from potential prey species to make decisions concerning patch choice and patch residence time. An earlier study by Burghardt and Hess (1966) on the common snapping turtle, *Chelydra serpentina*, showed that this species is capable of responding to the odors of certain foods that it experiences early in life, resulting in a preference for those food types later in life. Similar findings have been reported for some insects (Kats and Dill, 1998), spiders (Punzo and Kakoyi, 1997), and other vertebrates (Burger, 1989; Cooper, 1990; Hara, 1992; Galef et al., 1994).

The increased rate of gular pumping exhibited by *M. temminckii* in the presence of prey odor cues is in agreement with previous research suggesting that aquatic turtles utilize gular pumping to enhance their ability to chemically sample the surrounding water (Manton, 1979).

In conclusion, predators utilize chemosensory cues to detect the presence of prey species or habitats (patches) recently occupied by prey (Punzo and Kakoyi, 1997; Cooper, 2000). Likewise, prey species utilize chemosensory cues to avoid potential predators (Manteifel, 1995; Chivers et al., 1996; Kats and Dill, 1998). Musk turtles are capable of detecting the presence of *M. temminckii* by utilizing chemosensory cues associated with this predator (Jackson, 1990). This study shows that *M. temminckii* can, in a similar fashion, detect the presence of musk and mud turtles.

The detection of chemosensory cues can also influence the rate of movement of prey and predators. Prey animals frequently stop moving or move at slower speeds after they have encountered predator odor cues (Jackson, 1990; Weldon, 1991). In this study, predators increased their rate of movement (appetitive behavior) in the presence of odor cues associated with prey.

Because these experiments were conducted on naive juvenile turtles, the preference for water containing musk turtle chemosensory cues may be innate in this species. Future studies should attempt to determine whether this preference can be modified based on past experience as well, and whether or not *M. temminckii* can detect and respond to odor cues from other prey species.

ACKNOWLEDGMENTS—We would like to thank D. Martin, L. Johnson, and anonymous reviewers for providing critical comments on an earlier draft of the manuscript, and B. Garman for consultation on statistical analyses.

#### LITERATURE CITED

- ALLEN, E. R. AND W. T. NEILL. 1950. The alligator snapping turtle, *Macrolemys temmincki*, in Florida. Spec. Publ. No. 4, Ross Allen's Reptile Institute, Silver Springs, FL.
- ASHTON, R. E. AND P. S. ASHTON. 1985. Handbook of Reptiles and Amphibians of Florida. Part 2: Lizards, Turtles, and Crocodylians. Windward Publ., Inc., Miami, FL, 191 pp.

- BARRETO, G. R. AND D. W. MACDONALD. 1999. The response of water voles, *Arvicola terrestris*, to the odours of predators. *Anim. Behav.* 57:1107–1112.
- BURGER, J. 1989. Following of conspecific and avoidance of predator chemical cues by pine snakes (*Pituophis melanoleucus*). *J. Chem. Ecol.* 15:799–806.
- BURGHARDT, G. M. AND E. H. HESS. 1966. Food imprinting in the snapping turtle, *Chelydra serpentina*. *Science* 151:108–109.
- CHIVERS, D. P., B. D. WISENDEN, AND R. J. SMITH. 1996. Damselfly larvae learn to recognize predators from chemical cues in the predator's diet. *Anim. Behav.* 52:315–320.
- COOPER, W. E., JR. 1990. Chemical detection of predators by a lizard, the broad-headed skink (*Eumeces laticeps*). *J. Exp. Zool.* 256:162–167.
- . 2000. Chemical discrimination of potential food items by a xantusid lizard, *Lepidophyma flavimaculatum*. *J. Herpetol.* 34:323–325.
- ERNST, C. H. AND R. W. BARBOUR. 1972. *Turtles of the United States*. Univ. Press of Kentucky, Lexington, KY, 347 pp.
- GALEF, B. G., M. MAINARDI, AND P. VALSECCHI. 1994. Behavioral Aspects of Feeding: Basic and Applied Research in Mammals. Harwood Acad. Publs., Singapore, 389 pp.
- HARA, T. J. (ed.). 1992. *Fish Chemoreception*. Chapman and Hall, New York, NY, 417 pp.
- HATANAKA, T. AND O. MATSUZAKI. 1993. Odor responses of the vomeronasal system in Reeve's turtle *Geoclemys reevesii*. *Brain Behav. Evol.* 23:183–186.
- JACKSON, J. F. 1990. Evidence for chemosensory-mediated predator avoidance in musk turtles. *Copeia* 1990:557–560.
- KARE, M. R. AND J. R. MASON. 1986. The chemical senses in birds. Pp. 59–67. *In: STURKIE, P. D. (ed.). Avian Physiology*. 4th ed. Springer, NY.
- KATS, L. B. AND L. M. DILL. 1998. The scent of death: chemosensory assessment of predation risk by prey animals. *Ecoscience* 5:361–394.
- MANTEIFEL, Y. 1995. Chemically-mediated avoidance of predators by *Rana temporaria* tadpoles. *J. Herpetol.* 29:461–463.
- MANTON, M. L. 1979. Olfaction and behavior. Pp. 289–301. *In: HARLESS, M. AND MORLOCK, H. (eds.). Turtles: Perspectives and Research*. J. Wiley and Sons, NY, 368 pp.
- MROSOVSKY, N. AND B. B. BOYCOTT. 1966. Intra- and interspecific differences in phototactic behavior of freshwater turtles. *Behaviour* 26:215–227.
- PETRANKA, J. W., L. B. KATS, AND A. SIH. 1987. Predator-prey interactions among fish and larval amphibians: use of chemical cues to detect predatory fish. *Anim. Behav.* 35:420–425.
- PHILLIPS, J. A. AND A. C. ALBERTS. 1992. Naive oophagous lizards recognize and avoid venomous snakes using chemical cues. *J. Chem. Ecol.* 18:1775–1783.
- PUNZO, F. AND O. KAKOYI. 1997. The effects of prey chemical cues on patch residence time in the wolf spider, *Trochosa parthenus* Chamberlin (Lycosidae) and the lynx spider, *Oxyopes salticus* Hentz (Oxyopidae). *Bull. Br. Arachnol. Soc.* 10:323–327.
- QUINN, V. S. AND B. M. GRAVES. 1998. Home pond discrimination using chemical cues in *Chrysemys picta*. *J. Herpetol.* 32:457–461.
- SOKAL, R. R. AND F. J. ROHLF. 1995. *Biometry*. 2nd ed. W. H. Freeman, New York, NY, 818 pp.
- VAN DAMME, R. AND A. M. CASTILLA. 1996. Chemosensory predator recognition in the lizard *Podarcis hispanica*: effects of predation pressure relaxation. *J. Chem. Ecol.* 22:13–22.
- WELDON, P. J. 1991. Responses by vertebrates to chemical signals from predators. Pp. 500–521. *In: MACDONALD, D. MULLER-SCHWARZ, AND S. E. NATYNEZUK (eds.). Chemical Signals in Vertebrates*. Vol. 5. Oxford Univ. Press, Oxford, UK.
- YEOMANS, R. S. 1995. Water-finding in adult turtles: random search or oriented behaviour? *Anim. Behav.* 49:977–987.

## MEASURING TOXICITY OF LEAD SAMPLES USING A MICROTOX 500 ANALYZER

SHENGRONG CHEN, MELISSA DERBY, AND DEAN F. MARTIN

Institute for Environmental Studies, Department of Chemistry,  
University of South Florida, 4202 East Fowler Avenue, Tampa, FL 33620-5205

*ABSTRACT: Typically total lead has been taken as a measure of the toxicity of lead in a sample, whereas a direct measurement of toxicity would seem to be a more meaningful measure. This study summarizes analysis of lead using a Microtox 500 toxicity analyzer. The instrument examines the effect of samples on the luminescent bacterium *Vibrio fischeri*. We compared the effect of standard solutions of aqueous lead nitrate with soil samples containing known amounts of lead nitrate. The  $LD_{50}$  for soluble lead was about 2 ppm. There was no notable difference between a control sample (lead-free soil) and high-organic soil containing about 1000 ppm lead. The  $LD_{50}$  for both samples was about 50,000 ppm. The latter value is likely a function of the nature of the soil type and the organic content, but it does demonstrate that high-organic soil is capable of absorbing soluble lead. It also demonstrates the need for a specific measurement of toxicity as a guide to bioavailability and bioaccumulation.*

*Key Words:* Bioaccumulation, humic acids, lead, Microtox, soil, toxicity

LEAD compounds, their speciation, and their distribution, constitute a widespread health problem in urban areas (Hafen and Brinkmann, 1996; Mushak, 1992, U.S. Senate, 1990; Mielke et al., 1989). Lead-based disorders are thought to be the most common environmentally caused health problems in the United States (CDC, 1985; U.S. Senate, 1990). Samples of lead compounds are found in such common sources as lead-based paints, lead-based solder in water pipes, and automobile exhaust particulates in soils (Hafen and Brinkmann, 1996). A study of lead in soils adjacent to an interstate highway near the USF Tampa campus found that over one-third of the samples contained lead concentrations ( $>500 \mu\text{g/g}$ ) considered to be hazardous by the Environmental Protection Agency (Hafen and Brinkman, 1996).

One aspect that deserves more consideration is the speciation of lead and the bioavailability of the lead in a given sample. In short, if the lead were present as the lead equivalent of apatite,  $\text{Pb}_5(\text{PO}_4)_3\text{OH}$ , a highly insoluble form of lead, it is unlikely that its bioavailability would be very high. Comparatively little attention has been given to organically bound lead, despite the greater toxicity (Grandjean and Grandjean, 1984), and such species have been found in wine (Lobinski et al., 1994). And thus, the toxicity of lead samples may be of as much interest as the total lead concentration.

One of the key problems of toxicity testing often has been the need for

a reliable, rapid method. One such method is the use of a Microtox analyzer, which exposes a luminescent bacterium, *Vibrio fischeri*, to aqueous samples and measures the change of light output by the test organism (cf. Hao et al., 1995, 1996; Guzella et al., 1996; Chen et al., 1997; Devalls et al., 1997). The bacterium is grown under optimal conditions by the same firm that produces the instrument. When needed, the lyophilized bacterium is rehydrated with a reconstitution solution to provide a suspension of organisms. The analyzer measures the light output of the bacteria after they have been exposed to a sample and compares this number to the light output of a control (reagent blank). The difference in the light output between the test sample and the control is attributed to the effect on the organism. Each cuvette contains approximately a million test organisms, and the system measures the simultaneous light output of all the test organisms.

This study describes the use of a Microtox analyzer to assay the toxicity of lead in water and soil samples and the results that were obtained.

**MATERIALS AND METHODS—Reagents and materials**—Lead nitrate (analytical grade) was obtained from J.T. Baker. Nitric acid (69.6%), hydrogen peroxide (30%), and hydrochloric acid (35%) were reagent grade chemicals purchased from Fisher Scientific. Soil was commercial potting soil from K-Mart and was stored in Pyrex containers.

Samples of *Vibrio fischeri* were obtained from Azur Environmental and maintained in freeze-dried form at  $-30^{\circ}\text{C}$  until ready for use, where upon a given ampoule was treated with Azur Reconstituting Solution, as directed. Diluent was added to the sample and control cuvettes, and Osmotic Adjusting Solution was added to the control cuvette.

**Instrumentation**—A Microtox 500 analyzer, obtained from Azur Environmental, was coupled to a Gateway 2000 computer and Hewlett Packard 610C printer. The Microtox instrument measures both acute and chronic toxicity; in these studies, acute toxicity was measured, using a 5-min study period.

**Analysis of soil samples—Water content** was determined as loss on drying at  $70^{\circ}\text{C}$  for 24 h to constant weight. The weight loss was taken as the weight of moisture and the percentage weight loss is 100 times the weight loss divided by the weight of the initial sample. **Organic content** was determined by the Ball procedure (Ball, 1964). The dried sample in a tared container was placed in a muffle furnace, and the temperature raised to and held at  $375^{\circ}\text{C}$  for 17 hours. Organic carbon was taken as the loss in weight of a dried sample (Eqn. 1).

$$\text{Percent organic carbon} = (\text{loss in weight/weight of original sample}) \times 100 \quad (1)$$

**Lead content**—Soil was mixed with an aqueous solution of lead nitrate, the mixture was stirred for four hours, and dried in an oven ( $70^{\circ}\text{C}$  for 24 hours). Lead content was determined using atomic absorption spectrometry, following an extraction procedure (McGrath and Culliffe, 1985; Hafen and Brinkmann, 1996). Specifically, a 2-g sample of soil in a 150 mL beaker was treated with 10 mL of dilute nitric acid (8 M) and heated at  $95^{\circ}\text{C}$  for 15 min. The solution was cooled, and 5 mL of conc. nitric acid (16 M) was added and heated for an additional 30 minutes at  $95^{\circ}\text{C}$ . The last step was repeated and the volume was reduced to about 5 mL by evaporation. The sample was cooled, and treated with 2 mL of deionized water and 3 mL of 30% hydrogen peroxide. The sample was heated gently to initiate the reaction, then 5 mL of conc. HCl (16 M) and 10 mL of deionized water were added, and the sample warmed to near boiling. The sample was then allowed to cool to room temperature and was filtered through

TABLE 1. Effect of lead nitrate in water in five minutes, using a Microtox 500.

Lead concentration (ppm)	%Effect* on the bacteria <i>Vibrio fischeri</i> (5min-test)			
	Dilution (5.625%)	Dilution (11.25%)	Dilution (22.50%)	Dilution (45%)
10	17.47	29.95	46.26	68.12
9	20.74	41.17	53.68	72.75
8	9.362	31.86	48.39	72.24
7	13.39	26.75	47.09	64.53
6	15.95	30.37	46.03	58.52
5	11.56	14.75	34.75	59.62
4		14.87	21.53	54.54
3	—**	—	13.64	32.71
2	—	10.07	25.36	41.41
1	—	—	—	—

\* % bacteria killed.

\*\* —: No valid results were obtained.

Whatman No. 42 filter paper. Samples were then analyzed using a Varian atomic absorption spectrometer, equipped with a lead lamp.

**TOXICITY TESTING—General procedure**—An Azur Microtox 500 unit was to test the toxicity, and the so-called “wizard” test or guideline procedure (part of the instrumental software) was used to decide which Microtox test was suitable for a given sample type. Acute toxicity of lead was measured by a basic test in these experiments.

The test sample was aqueous lead nitrate, which was prepared from an amount of reagent grade lead nitrate in deionized water to obtain 100 ppm lead standard solution (0.000483 M). Then the standard solution was diluted to series solutions.

**RESULTS AND DISCUSSION—Data treatment**—Following the Microtox procedures gives percentage effect as a function of percentage dilution for a test of a given duration (typically 5 minutes). Take for example aqueous lead nitrate using a five-minute test (Table 1). The table lists four serial dilutions (45, 22.5, 11.25, and 5.625 %) of a given concentration (ranging from 1–10 ppm Pb), and summarizes percentage of the organisms that were destroyed (for a given dilution of a particular initial concentration of aqueous lead nitrate). In addition, a longer reaction time (15 min.) was also used to test for toxicity of lower concentrations (Table 2).

Next, probit analysis (Finney, 1971) was used to calculate the effective concentration needed to kill 50% of the sample, LD<sub>50</sub>. This process transforms a S-shape survival curve to a linear plot, and the LD<sub>50</sub> is easier to obtain from the linear plot because a probit of 5 corresponds to a 50% kill or survival. The percentage killed values were converted to probits, using an available table (Finney, 1971), and the results are given (Fig. 1). Individual concentrations could be tested, but pooling the data (N = 34) gave an LD<sub>50</sub> of 1.9 ppm, which was consistent with the values obtained for smaller numbers of samples of given concentrations.

TABLE 2. Effect of lead nitrate in water in fifteen minutes, using a Microtox 500.

Lead concentration (ppm)	%Effect* on the bacteria <i>Vibrio fischeri</i> (15min-test)			
	Dilution (5.625%)	Dilution (11.25%)	Dilution (22.50%)	Dilution (45%)
10	48.17	70.67	83.16	90.47
9	83.87	89.93	90.72	90.89
8	76.53	88.59	90.63	92.02
7	72.97	85.89	90.40	91.36
6	71.48	84.85	89.86	90.12
5	60.97	79.41	89.09	91.6
4	27.52	71.38	99.96	90.33
3	—**	37.72	75.24	84.52
2	6.821	56.27	80.68	88.87
1	—	—	9.036	11.76

\* % bacteria killed.

\*\* —: No valid results were obtained.

*Lead analyses—homogeneity*—It is necessary to make sure that the soil sample was homogeneous with respect to lead distribution before analyzing for toxicity. Accordingly, ten samples were extracted with 1M nitric acid solution, a more rapid, but less efficient, method than the EPA-based method. Using the simpler procedure, the mean lead content was found to be 5.16

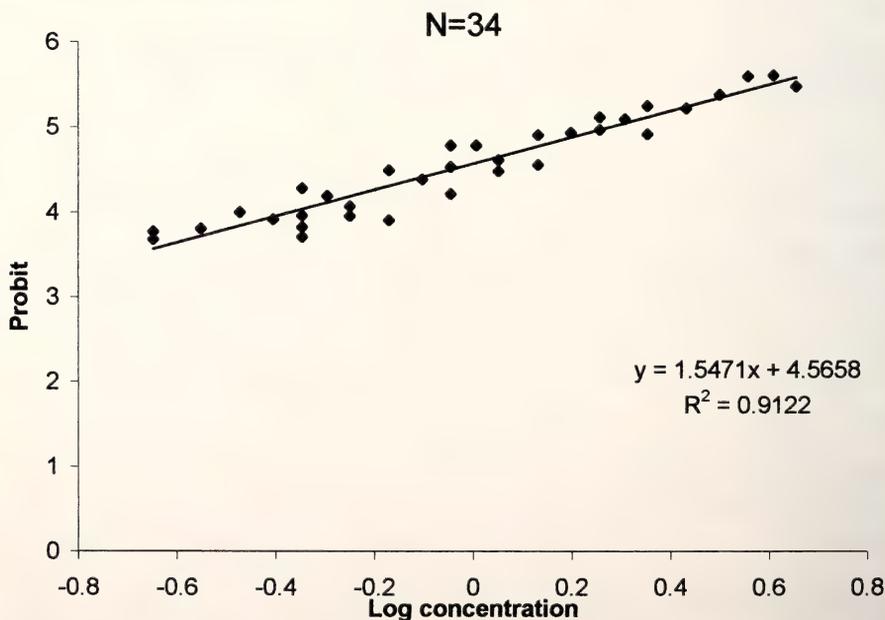


FIG. 1. Probit analysis of all Microtox data ( $N = 34$ ) for effect of aqueous lead solution on *V. fischeri*. Here,  $y = 1.5471 + 4.5658$ ;  $r^2 = 0.9122$ ; when  $Y = 5$  (50% kill),  $LD50 = 1.9$  ppm  $Pb^{++}$ .

TABLE 3. Toxicity of original soil for five- and fifteen-minute runs using a Microtox 500.

Sample	Soil conc., ppm	5-min % Effect* on <i>Vibrio fischeri</i>	15-min % Effect on <i>Vibrio fischeri</i>
Control	0		
1	386.7	10.89	0.485
2	773.4	11.82	1.805
3	1547	13.37	3.800
4	3094	18.25	9.760
5	6188	23.51	9.655
6	12380	29.79	24.17
7	24750	39.51	37.67
8	49500	55.80	56.96
9	99000	74.21	59.02

\* % bacteria killed.

ppm with a relative standard deviation of 5.1%. This indicated the homogeneity of the sample. Unfortunately, the calculated value was 6.24 ppm, so the mean percent extraction was 82.7%. Subsequently, using the EPA-based method, two analyses gave 90 and 97.8% extraction.

*Toxicity of lead samples*—The data for toxicity of lead-containing soil were treated similarly to the data for aqueous lead. The basic solid-phase test was used. This allows contact between the bacterial medium and the solid sample and provides quantitative data on solid samples.

First, untreated soil samples were tested because of the assumption that soil could have toxic substances present. Second, treated samples of soil (containing 996 ppm Pb) were studied and the effect was measured as a function of time (Table 4). The results appear to be consistent for 5-, 15-, and 30-minute exposures and fairly consistent results were obtained for the greater concentrations and the results were similar to those obtained for plain

TABLE 4. Toxicity of lead-treated soil (996 ppm Pb) for five- and fifteen-minute runs using a Microtox 500.

Sample	Soil conc., ppm	5-min % Effect* on <i>Vibrio fischeri</i>	15-min % Effect on <i>Vibrio fischeri</i>	30-min % Effect on <i>Vibrio fischeri</i>
Control	0			
1	386.7	6.080	3.040	1.380
2	773.4	2.040	3.365	9.740
3	1547	7.400	9.040	1.590
4	3094	9.170	16.25	5.850
5	6188	11.54	17.12	37.45
6	12380	22.20	29.20	31.10
7	24750	38.60	44.65	45.56
8	49500	44.95	56.08	55.48
9	99000	50.15	61.95	68.12

\* % bacteria killed.

(untreated) soil. Compare, for example, the data for 49,500 ppm soil for which the results at 5- and 15 min tests were 56% and 57% respectively, as compared with the results for lead treated soil for which results were 46% (5-min), 56% (15 min) and 55% (30 min).

The most significant observation concerning the effect of soil on the test bacteria show the results for the two different soils (without and with lead) is that there is only slight difference between the two. This conclusion supports the view that this amount of soluble lead (996 ppm) in this high-organic soil does not differ in toxicity from untreated soil. In contrast, 2 ppm soluble lead in water was the LD<sub>50</sub> for the test bacteria.

It should not be greatly surprising that soluble lead would become unavailable in soil with a high organic content. Other metals could have been present; the point made here is that the soluble lead became unavailable, and there was no difference between test and control for treated lead. High-organic soils are known to have significant amounts of chelating entities that can entrap metal ions (Langford et al., 1983; Tuschall and Brezonik, 1983; Weber, 1983). What would be surprising would be to discover such high-organic soils very widely distributed in Florida, which seems to be covered with a fine-grained quartz sand of low mineral content.

ACKNOWLEDGMENTS—We are grateful to Azur Environmental for a grant to assist in purchasing the Microtox 500, and we are grateful to Dr. Michael J. Zaworotko for his assistance in obtaining additional funding. Mrs. Barbara B. Martin served as consulting editor.

#### LITERATURE CITED

- BALL, D. F. 1964. Loss-on-ignition as an estimate of organic matter and organic carbon on non-calcareous soils. *J. Soil Sci.* 15(1): 84–92.
- CDC (CENTERS FOR DISEASE CONTROL). 1985. Preventing lead poisoning: A Statement of the Centers for Disease Control U. S. Dept Health and Human Services Washington, DC.
- CHEN, C. Y., J. B. HUANG, AND S. D. CHEN. 1997. Assessment of the microbial toxicity test and its application for industrial wastewaters. *Water Sci Technol.* 36(12): 375–382.
- CHEUNG, Y. H., A. NELLER, K. H. CHU, N. F. Y. TAM, C. K. WONG, Y. S. WONG, AND M. H. WONG. 1997. Assessment of sediment toxicity using different trophic organisms. *Arch. Environ. Contam. Toxicol.* 32(3): 260–267.
- DEVALLS, T. A., L. M. LUBIAN, J. M. FORJA, AND A. GOMEZPARRA. 1997. Comparative ecotoxicity of interstitial waters in littoral ecosystems using Microtox® and the Rotifer *Brachionus-Plicatilis*. *Environ. Toxicol. Chem.* 16(11): 2323–2332.
- GUZZELLA, L., C. BARTONE, P. ROSS, G. TARTARI, AND H. MUNTAU. 1996. Toxicity identification evaluation of Lake Orta (Northern Italy) sediments using the Microtox system. *Ecotox. Environ.* 35(3): 231–235.
- HAFEN, M. R. AND R. BRINKMANN. 1996. Analysis of lead in soils adjacent to an interstate highway in Tampa, Florida. *Environ. Geochem. Health* 18: 171–179.
- HAO, O. J., C. F. LIN, F. T. JENG, AND C. J. SHIH. 1995. A review of Microtox® test and its applications. *Toxicol. Environ. Chem.* 52(1–4): 57–114.
- , C. J. SHIH, C. F. LIN, F. T. JENG, AND Z. C. CHEN. 1996. Use of the Microtox® tests for screening industrial waste-water toxicity. *Water Sci. Technol.* 34(10): 43–50.
- FINNEY, D. J. 1971. *Probit Analysis* (3rd ed). Cambridge Univ. Press, Cambridge.
- GRANDJEAN, P. AND E. C. GRANDJEAN (eds.) 1984. *Biological Effects of Organolead Compounds*. CRC. Boca Raton, FL.

- LANGFORD, C. H., D. S. GAMBLE, A. W. UNDERWOOD, AND S. LEE. 1983. Interaction of metal ions with a well characterized fulvic acid. Pp. 219–237. *In*: CHRISTMAN, R. F. AND E. T. GJESSING (eds.) Aquatic and Terrestrial Humic Materials, Ann Arbor Science, Ann Arbor, MI.
- LOBINSKI, R., C. WITTE, F. C. ADAMS, P. L. TEISSEDE, J. C. CABANIS, AND C. F. BOUTRON. 1994. Organolead in wine. *Nature* 370: 24.
- MCGRATH, S. P. AND C. H. CUNLIFFE. 1985. A simplified method for the extraction of the metals Fe, Zn, Cu, Ni, Cd, Pb, Cr, Co, and Mn from soils and sewage sludges. *J. Environ. Quality* 12: 579–584.
- MIELKE, H. W., J. L. ADAMS, P. L. REGAN, AND P. W. MEILKE, JR. 1989. Soil-dust lead and childhood lead exposure as a function of community size and community traffic flow: the case for lead abatement in Minnesota. *Environ Geochem. Health* 9: 253–271.
- MUSHAK, P. 1992. Defining lead as the premier environmental health issue for children in America: criteria and their quantitative application. *Environ. Res.* 59: 281–309.
- TUSCHALL, J. R. AND P. E. BREZONIK. 1983. Complexation of heavy metals by aquatic humus: A comparative study of five analytical methods. Pp. 275–294. *In*: CHRISTMAN, R. F. AND E. T. GJESSING (eds.) Aquatic and Terrestrial Humic Materials, Ann Arbor Science, Ann Arbor, MI.
- U. S. SENATE COMMITTEE ON ENVIRONMENT AND PUBLIC WORKS. 1990. Health Effects of Lead Exposure: Hearing Before the Subcommittee on Toxic Substance, Environmental Oversight, Research and Development. U. S. Government Printing Office, Washington, D. C.
- WEBER, J. H. 1983. Metal ion speciation studies in the presence of humic materials. Pp. 315–331. *In*: CHRISTMAN, R. F. AND E. T. GJESSING (eds.) Aquatic and Terrestrial Humic Materials, Ann Arbor Science, Ann Arbor, MI.

Florida *Scient.* 65(2): 139–145. 2002

Accepted: November 28, 2002

## FROM THE EDITORS—Those Who Make It Possible—II

When you look at this copy of your journal, it may seem obvious who is responsible—The authors and, oh yes, the Editors. True enough, but the truth doesn't go far enough in this instance. Reviewers, dedicated volunteers, willing to share their expertise and time are vital, as we try to acknowledge annually. In addition, when you see the mention of Allen Press below the masthead (on the inside front cover), most readers don't realize the large number of persons there who help us and strive for a quality product. These include Ms. Suzanne Wood and her colleagues at Allen Press. Also on the masthead is the name of a major player, Dr. Richard Turner, the dedicated, able Business Manager, who worries about money matters and reminds one of the revised truism, "We aren't in business to make money, but we must make [recover some] money to remain in business." From time to time, Dr. Richard Turner will arrange for advertisements that will appear in an issue and help provide the financial support that is a must for continued operation; one ad appears in this issue. We hope that more such supporters will come forward.

In supporting roles are other important players—Dr. Gay Biery-Hamilton and Ms. Natalie Smith in the Executive Secretary's office keeping track of members and sending out reminder notices. We have valued the leadership of presidents, past and present. Most recently, we have been delighted by the support of President Barry Wharton, whose leadership role led to the Academy web page and to obtaining space for the *Florida Scientist* abstracts on APT On Line, a web page connected to our web page. This is a web site where interested persons can efficiently search Abstracts and authors so that work published in the *Florida Scientist* becomes more accessible and more widely used. And it was President Wharton who encouraged the listing of some five past years of the *Florida Scientist*. In this he was supported by members of the Academy Council. And finally, since the journal is an official publication of the Academy, we are grateful to all the members, a portion of whose dues make it possible to continue. And so to all who are involved in the publication of *Florida Scientist*, our sincerest thanks for your support.

DFM  
BBM

## Grasshoppers of Florida



John L. Capinera, Clay W. Scherer, and Jason M. Squitier

*The first volume in the  
Invertebrates of Florida series!*

### Grasshoppers of Florida

John L. Capinera, Clay W. Scherer,  
and Jason M. Squitier

"Florida naturalists will be delighted by *Grasshoppers of Florida*. This wonderfully presented book unlocks an amazing world that previously was unavailable to most backyard and weekend naturalists."—Richard Franz, Florida Museum of Natural History

This first field guide to the grasshoppers of Florida provides identification of the 70 species known to occur in Florida. The authors present the biology, behavior, ecological significance, and damage potential of grasshoppers and emphasize their interrelationship with Florida's fauna. A straightforward, detailed description of each species is accompanied by a distribution map. Nearly all species are pictured in color, and detailed line drawings help distinguish among those more difficult to identify.

176 pp. 102 color plates, 42 drawings, 70 distribution maps. Flexibind, \$34.95

Order through full-service  
booksellers, our website at  
[www.upf.com](http://www.upf.com), or with  
VISA or M/C toll free:  
1-800-226-3822

### The Cuban Treefrog in Florida

*Life History of a Successful  
Colonizing Species*

Walter E. Meshaka, Jr.

"The abundance of data cited in this study not only characterizes the Cuban Treefrog but establishes it as a model of a successful colonizer. This latter feature vastly increases the importance of this work by providing wildlife biologists with a list of characteristics that can be applied to other introduced species to determine the likelihood of successful establishment and expansion in non-native habitats—particularly those severely altered by human activity."—Robert Powell, Carnegie Museum of Natural History, author of *A Key to the Amphibians and Reptiles of the Continental United States and Canada*

Walter Meshaka presents the natural history of the Cuban Treefrog from the perspective of its phenomenal success, in terms of sheer numbers and geographic range, as a colonizer in South Florida and, in particular, the Everglades. It supplies a methodology for evaluating and setting priorities for the threats facing Florida's amphibian and reptile populations and identifies the most vulnerable species, providing a base for management decisions. It also presents and interprets a large data set associated with patterns of colonization and predictions.

208 pp. 83 figures, 71 tables. Cloth, \$69.95

### André Michaux in Florida

*An Eighteenth-Century Botanical  
Journey*

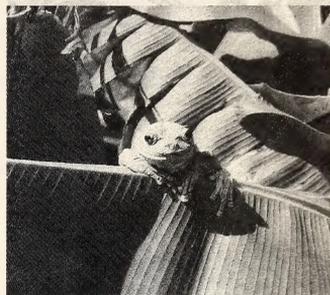
Walter Kingsley Taylor  
and Eliane M. Norman

"The appeal of *André Michaux in Florida* lies in its interest and usefulness to both professional and amateur botanists, horticulturalists, gardeners, field naturalists, and historians."

—Ronald L. Stuckey, Museum of Biological Diversity, Ohio State University

March. 288 pp. 30 b&w photos, 16 maps.  
Cloth, \$39.95

## The Cuban Treefrog in Florida



*Life History of a Successful Colonizing Species*

Walter E. Meshaka Jr.

### El Niño in History

*Storming Through the Ages*

César N. Caviedes

"A staggering amount of historical research to pinpoint El Niño events in time and space, interpret them using physical theory, and correlate them with human history."—Betty J. Meggers, Smithsonian Institution

César Caviedes provides the first comprehensive historical account of El Niño. Combining scientific accuracy with readable presentation, he brings together all existing information, references, and clues about past El Niño occurrences and their impact on political, military, social, economic, and environmental history.

304 pp. 4 tables, 64 drawings, 12 color photos.  
Cloth, \$24.95

### Florida Hurricanes and Tropical Storms

*1871-2001, Expanded Edition*

John M. Williams and Iver W. Duedall

From reviews of the first edition: "A comprehensive, factual, concise book on Florida hurricanes. . . . Land and space photographs and storm trajectory maps are especially informative."—*Choice*

June. 176 pp. 76 b&w photos, 20 color photos,  
4 tables, 13 tracking charts.  
Paper, \$14.95



## INSTRUCTION TO AUTHORS

This information is available at two web sites:

- (1) **IES site:** <http://www.cas.usf.edu> (click on "Centers and Institutes", then select "Institute for Environmental Studies", then select "Florida Scientist").
- (2) **FAS site:** [www.floridaacademyofsciences.org](http://www.floridaacademyofsciences.org) (select "Florida Scientist").

It is possible to search for papers and abstracts of papers for the past six years: Go the FAS site (above), select "Allen Press". When the link is complete, select "Advanced Search" and follow the directions.

The Florida Academy of Sciences Web page, indicated above, allows interested persons to join the Florida Academy of Sciences and pay dues.

## FLORIDA ACADEMY OF SCIENCES

CORPORATE MEMBER  
Tierra Verde Consulting, Inc.

### INSTITUTIONAL MEMBERS

Archbold Biological Station  
Disney's Animal Kingdom  
Duke University  
Florida Community College at Jacksonville  
Florida Fish and Wildlife Conservation  
Commission (Panama City)  
FFWCC (Ocala)  
Florida Marine Research Institute  
Hillsborough Community College

NIOZ-Netherlands Institute for Sea Research  
Science Library, University of Chicago  
South Florida Water Management District  
University of North Florida  
University of Washington  
US EPA Library  
Virginia Institute of Marine Science  
Virginia Polytechnic University  
WDI Florida

Membership applications, subscriptions, renewals, and changes of address should be addressed to the Executive Secretary, Florida Academy of Sciences, Orlando Science Center, 777 East Princeton St., Orlando, FL 32803. Phone: (407) 514-2079

Send purchase orders, payments for reprints and publication charges, orders for back issues and other journal business matters to the Business Manager, Dr. Richard L. Turner, Department of Biological Sciences, FIT, 150 W. University Blvd., Melbourne, FL 32901-6975 [(321) 674-8196; e-mail [rturner@fit.edu](mailto:rturner@fit.edu)].



3 9088 01354 2105

## PUBLICATIONS FOR SALE

by the *Florida Academy of Sciences*

Complete sets. Broken sets. Individual numbers. Immediate delivery. A few numbers reprinted by photo-offset. All prices strictly net. Prices quoted include domestic postage. Some issues may not be available. All are \$20 per volume or \$5 per issue, except for symposium issues.

PROCEEDINGS OF THE FLORIDA ACADEMY OF SCIENCES (1936–1944)

Volumes 1–7

QUARTERLY JOURNAL OF THE FLORIDA ACADEMY OF SCIENCES (1945–1972)

Volumes 8–35

FLORIDA SCIENTIST (1973–)

*Florida's Estuaries—Management or Mismanagement?—Academy Symposium*

FLORIDA SCIENTIST 37(4)—\$5.00

*Land Spreading of Secondary Effluent—Academy Symposium*

FLORIDA SCIENTIST 38(4)—\$5.00

*Solar Energy—Academy Symposium*

FLORIDA SCIENTIST 39(3)—\$5.00 (includes do-it-yourself instructions)

*Anthropology—Academy Symposium*

FLORIDA SCIENTIST 43(3)—\$7.50

*Shark Biology—Academy Symposium*

FLORIDA SCIENTIST 45(1)—\$8.00

*Future of the Indian River System—Academy Symposium*

FLORIDA SCIENTIST 46(3/4)—\$15.00

*Second Indian River Research Symposium—Academy Symposium*

FLORIDA SCIENTIST 53(3)—\$15.00

*Human Impacts on the Environment of Tampa Bay—Academy Symposium*

FLORIDA SCIENTIST 58(2)—\$15.00

Please send payment with order. If required, an invoice will be sent on purchases over \$20 from a recognized institution. Please include Florida sales tax if shipped to a Florida address, unless a copy of a valid Florida Consumer's Sales Tax Certificate is enclosed.