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Volume 68 Winter, 2005 Number 1

Geological Sciences

EXTENSIVE TEMPORARY EXPOSURES OF THE ANASTASIA FORMATION IN PALM BEACH COUNTY, FLORIDA

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ABSTRACT: *Construction during March and April of 2004 revealed extensive temporary exposures of the Anastasia Formation two kilometers inland from the Intracoastal Waterway in Boynton Beach, Florida. In addition to typical Anastasia shelly sands and conquioid limestones, the outcrops were characterized by a massive cap rock, 6 to 7 m above sea level, containing numerous solution holes believed to owe their rounding to wave abrasion during a higher stand of the sea.*

Key Words: Anastasia Formation, Palm Beach County, Boynton Beach, coquina, cap rock, solution holes, solution pipes, sea level.

THE Pleistocene Anastasia Formation crops out along the coast of Palm Beach and Martin Counties at many places (Lovejoy, 1998), and the major exposures have been described by Cooke (1945), Puri and Vernon (1964), and Perkins (1977). Cooke felt the Anastasia extended no more than five kilometers inland from the Intracoastal Waterway, but field work by Scott (1992) suggests that it may extend inland as much as 17 kilometers. Exposures of the Anastasia Formation west of the Intracoastal are rare, so it seems important to have a permanent record of some temporary exposures made in March and April of 2004 during the course of two excavations in the city of Boynton Beach (Fig. 1). These excavations lie within the area mapped as Anastasia Formation by Scott and co-workers (2001).

One excavation was for the construction of an apartment complex and the second for a warehouse area. Both were located at the Gateway Boulevard Exit (Exit

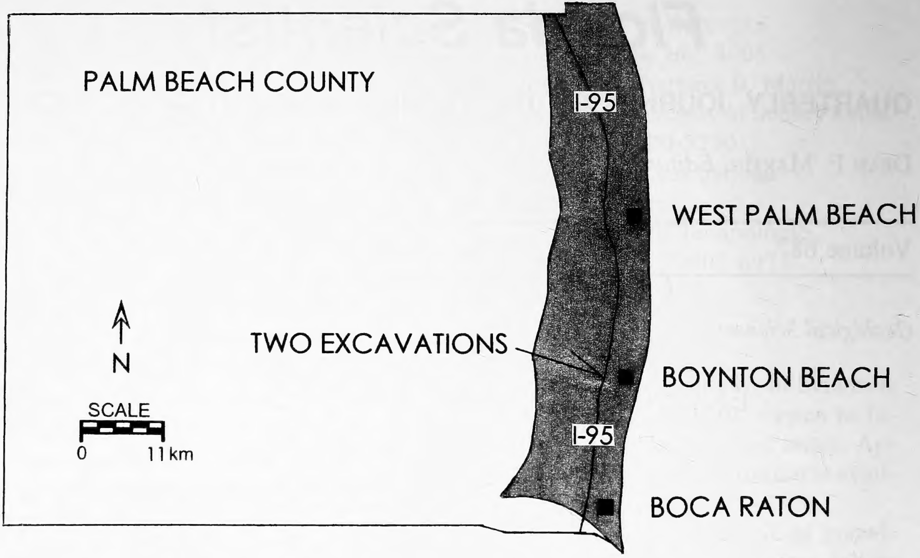

FIG. 1. Map of Palm Beach County, Florida showing the location of the two excavations in Boynton Beach. Shading indicates outcrop areas of the Anastasia Formation in Palm Beach County from Scott and co-workers, 2001.

59) of I-95 in Boynton Beach. The excavations were located on the west side of I-95, the first at the southwest corner of the Gateway Boulevard/High Ridge Road intersection (Lat. 26°32.901′ N. and Long. 80°04.480′ W.) and the second, one half kilometer south along High Ridge Road, on the east side of the road and just south

FIG. 3. Surface of coquinoid limestone in the Anastasia Formation showing broken and abraded mollusk shells. Diameter of coin is 2.4 cm.

of a railroad siding that crosses the pavement (Lat. 26°32.590′ N. and Long. 80°04.424′ W.).

Large boulders of the Anastasia Formation lined the south side of the excavation at the Gateway/High Ridge Road intersection. They displayed excellent examples of planar bedding (Fig. 2) and a "shell hash" that is typical of the Anastasia (Fig. 3). South of the railroad siding, an even larger excavation encountered a long exposure of Anastasia Formation cap rock, riddled with remarkably symmetrical solution holes (Fig. 4). Below the cap rock were poorly to well consolidated layers of coquina (Fig 5).

Lithology of the Anastasia Formation—At the area south of the railroad siding, the cap rock of the Anastasia Formation varied from 0.5 m to nearly 1.0 m in thickness, and its hardness proved to be a significant problem during excavation. The induration of the cap rock of the Anastasia is thought to be the result of case-hardening, similar to the case-hardening seen in outcrops of the formation that lie eastward along the coast.

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FIG. 2. Planar stratification in a solution hole penetrating the cap rock of the Anastasia Formation.

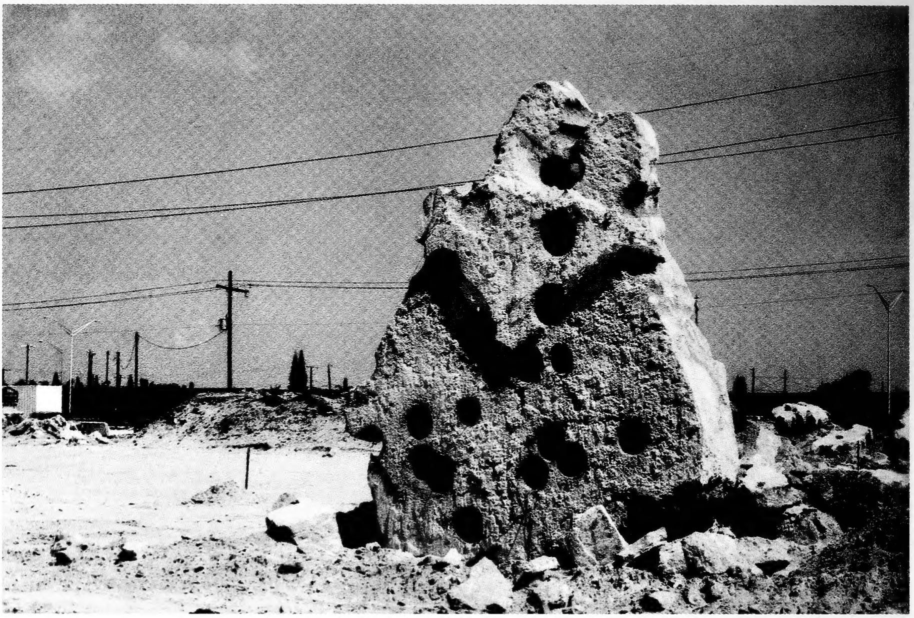

FIG. 4. Up-ended, twelve-foot long slab of Anastasia cap rock showing numerous circular solution holes.

Below the cap rock, the Anastasia Formation consists of variably consolidated, fine- to medium-grained sand, with sand-size shell fragments, and layers of coquinoid limestone containing broken and abraded mollusk shells up to 1.0 cm in diameter. The coquinoid layers have calcitic cement, and the abraded molluscan fragments, which are rarely more than 1.0 cm in diameter, suggest deposition in a high-energy beach or near-shore bar environment, similar to that found along the coast of Palm Beach County today. The sandy and coquinoid layers of the Anastasia can be cut with a shovel when first exposed, but prolonged exposure to rainwater causes them to harden as the calcium carbonate dissolved from the shells is re-precipitated between the sand grains.

The round holes found in the cap rock at both excavations are unique features of the exposures (Fig. 4 and 6). Similar holes are found elsewhere in the Anastasia, and Perkins (1977) has called them "solution pipes" when they penetrate the rock one meter or more. He proposed that they were caused by the downward percolation of acidic rainwater. The holes at the Boynton Beach excavations have nearly circular outlines, ranging in diameter from 0.25 to 0.5 m, and the interior surfaces of the holes are stained reddish brown. The remarkable smoothness of these holes suggests modification by wave abrasion.

Below the cap rock, the solution holes can be seen extending down into less well-indurated coquina. These solution holes are filled with a reddish-brown sand grading into a fine-grained, tan-colored sand in the center of the holes (Fig. 7). The sands differ significantly from the typical Anastasia lithology in that they are fine-

FIG. 5. Outcrop of variably consolidated Anastasia Formation in the excavation south of the railroad siding. Meter stick gives scale.

grained and contain no shell material. Plant rootlets extend down through the solution holes indicating that vegetation has utilized these openings in a search for water.

The stratification in the Anastasia Formation at the Boynton Beach excavations is planar and horizontal, with resistant layers standing out as ridges, while the less resistant layers are indented as grooves (Fig. 2). This stratification probably results from differences in grain size between layers, varying amounts of shell material, or changes in the degree of cementation from one layer to the next.

DISCUSSION—The rounded solution holes in the cap rock of the Anastasia Formation at both locations raise interesting questions regarding past sea level changes along the coast of Palm Beach County. Prior to the 2004 excavations in Boynton Beach, a long wooded ridge trended north-south between High Ridge Road and I-95, with its crest gradually rising to an elevation of 13 m. When excavation began, an overburden of 3 to 6 m of sand had to be removed, which probably represented an ancient beach or dune ridge deposit. The cap rock of the Anastasia Formation appeared beneath this overburden at an elevation of approximately 6 to 7 m.

If the rounding of the holes in the cap rock is due to wave abrasion, then it appears that sea level along the Palm Beach County coast has stood 6 to 7 m higher since the deposition of the Anastasia. McNeill (1985) estimates that this deposition took place 130,000 to 100,000 years ago. Based on the exposures in

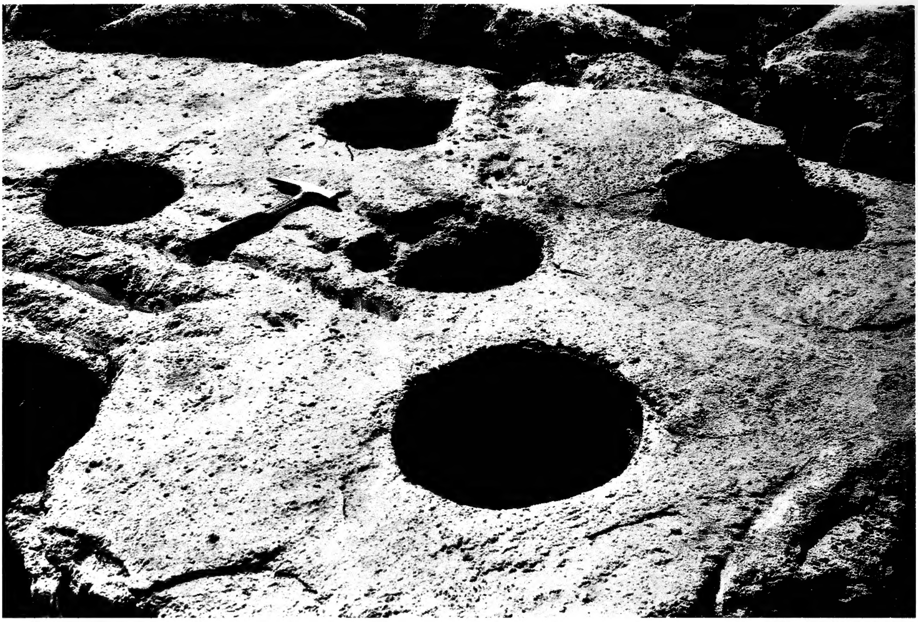

FIG. 6. Detail of the smoothly rounded solution holes in the Anastasia Formation at the excavation south of the railroad siding.

FIG. 7. Reddish-brown and tan-colored sand filling a V-shaped solution hole below the cap rock of the Anastasia Formation. Note plant rootlets.

Boynton Beach, he proposes (McNeill, 2004) that either the Anastasia was initially cemented as beachrock, with marine cements, and then eroded a short time after in the wave zone of the retreating sea, or that sea level during the Late Pleistocene (marine isotope stage 5e at ~ 130,000 ybp) had a couple of fluctuations. Between the two highest sea level events, the Anastasia could have been cemented by freshwater and subsequently eroded by wave action at a later highstand.

ACKNOWLEDGMENTS—Mikel Kahler, a former student, brought the excavations in Boynton Beach to the author's attention. Dave Connor, Project Manager for the excavation south of the railroad siding, and Mike Abbott, Superintendent at the excavation, provided helpful information and permitted the author to have access to the construction site for photographs. The author wishes to thank Donald F. McNeill for reviewing the manuscript and making many valuable comments.

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Biological Sciences

LOCALITY RECORDS FOR SOME LEPIDOPTERA IN THE FLORIDA KEYS

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ABSTRACT: *Florida Keys locality records for the moths* Eupseudosoma involutum floridum *(Arctiidae),* Acrolophus popeanellus *(Acrolophidae),* Spoladea recurvalis *(Crambidae),* Spodoptera dolichos *(Noctuidae),* Adaina ambrosiae, A. perplexus, A. simplicius, Exelastis montischristi, Hellinsia unicolor, Lantanophaga pusillidactylla, Lioptilodes parvus, Megalorhipida leucodactylus, Stenoptilodes brevipennis, S. taprobanes *(Pterophoridae),* Parachma ochracealis *(Pyralidae), and* Protambulyx carteri *(Sphingidae) are presented.*

Key Words: Acrolophidae, Arctiidae, Crambidae, Noctuidae, Pterophoridae, Pyralidae, Sphingidae

THE Florida Keys are part of the south Florida rockland ecosystem, with a flora composed of both temperate and tropical elements (Snyder et al., 1990). Herein are reported locality records and other data for some species of moths mostly collected during 2003 and 2004 in the Florida Keys. Disposition of voucher specimens is indicated for each species mentioned.

ARCTIIDAE—Eupseudosoma involutum floridum Grote, 1882: One specimen was taken on 4 March 2004, on Stock Island, Key West. Kimball (1965) lists no records of this species from the Florida Keys, although it is known from Homestead, in southern Dade County. The specimen was deposited into the Peabody Museum of Natural History, Yale University [YPM-ENT 214847].

ACROLOPHIDAE—Acrolophus popeanellus (Clemens, 1859): This burrowing sod webworm was very common on Vaca Key; numerous specimens were collected between November 2003 and May 2004. Two specimens were collected from Grassy Key in November 2003 and May 2004. Previously this moth was known from Key Largo and Key West (Kimball, 1965). Voucher specimens have been deposited into the Peabody Museum of Natural History, Yale University [YPM-ENT 214868 to 214881].

CRAMBIDAE—Spoladea recurvalis (Fabricuis, 1775): One specimen was collected in the Florida Keys on 28 August 2001; the island was not recorded. This species previously was known from the Dry Tortugas (Kimball, 1965). [YPM-ENT 214854]

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NOCTUIDAE—Spodoptera dolichos (Fabricius, 1794): One specimen of the sweetpotato armyworm, was collected on Vaca Key, 17 February 2004. This is one of nine *Spodoptera* species that occur in Florida (Heppner, 1998). [YPM-ENT 214867]

PTEROPHORIDAE—Some of the plume moths reported here might be new county records (Matthews et al., 1990). Only two of the species reported here were recorded from the Florida Keys by Kimball (1965). A comprehensive treatment of this family in Florida is in preparation (D. M. Lott, 2004). Common names are those given by Kimball (1965) and Goeden and Ricker (1976). Voucher specimens will be deposited into the Florida Museum of Natural History (D. M. Lott, 2004).

Adaina ambrosiae (Murdfeldt, 1880): Two specimens from No Name Key, February and May. This species is known as the ragweed plume moth (Goeden and Ricker, 1976).

Adaina perplexus (Grossbeck, 1917): One specimen from Vaca Key.

Adaina simplicius (Grossbeck, 1917): Frequently seen on No Name Key, one specimen from Vaca Key, November through March.

Exelastis montischristi (Walsingham, 1897): One specimen from No Name Key, July. Kimball (1965) reports records from Vaca Key in November (as *E. cervinicolor* Barnes & McDunnough, 1913).

Hellinsia unicolor (Barnes & McDunnough, 1938): Two specimens from Vaca Key, November and April; one specimen from No Name Key, July.

Lantanophaga pusillidactylla (Walker, 1864): Lantana plume moth: one specimen from Vaca Key, January.

Lioptilodes parvus (Walsingham, 1880): One specimen from Vaca Key, November.

Megalorhipida leucodactylus (Fabricius, 1793): One specimen from Long Key, July. Kimball reports a record from the Dry Tortugas (as *Trichoptilus defectalis* (Walker, 1864)).

Stenoptilodes brevipennis (Zeller, 1883): Taken on Vaca Key and No Name Key, December, January, February, April.

Stenoptilodes taprobanes (Felder & Rogenhofer, 1875): One specimen from Big Pine Key.

PYRALIDAE—Parachma ochracealis Walker, 1866: One specimen was collected on 6 April 2004 from No Name Key. Kimball (1965) reports records from Tavernier in August and September. [YPM-ENT 214866]

SPHINGIDAE—Protambulyx carteri Rothschild & Jordan, 1903: This species was seen twice on Vaca Key, once in the autumn of 2003 and again on the 27th of April 2004. Kimball (1965) reports records from Key Largo. One voucher specimen collected. [YPM-ENT 214850]

ACKNOWLEDGMENTS—D. Davis, Smithsonian Institution, identified the *Acrolophus popeanellus*. J. Heppner, Florida State Collection of Arthropods, identified the *Parachma ochracealis*. D.M. Lott, Gainesville, Florida, identified the Pterophoridae.

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HABITAT RELATED GROWTH OF JUVENILE FLORIDA APPLESNAILS (*POMACEA PALUDOSA*)

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ABSTRACT: *Human-induced changes in hydrology and nutrients are believed to be responsible for observed shifts in the remnant Everglades landscape from a sawgrass-slough mosaic to one increasingly dominated by emergent vegetation. We examined how changes in food availability caused by this vegetative shift might affect the growth and survival of the Florida applesnail* (Pomacea paludosa), *a key prey item for many native species. The quality of bulk samples of applesnail foods from slough* (benthic periphyton) *and sawgrass* (macrophyte detritus) *were analyzed for nutritional content (% ash, carbohydrate, protein, and lipid content). Newly hatched snails were reared in microcosms containing either periphyton or detritus, and changes in aperture length, shell length, and wet weight were measured after 30 days to calculate growth rates. Bulk periphyton was predicted to be the poorer quality food due to its high ash content and low protein content. But, increases in aperture length, shell length and wet weight were more than 2-fold greater for snails grown in periphyton as opposed to detrital microcosms. Significantly higher growth rates in periphyton microcosms suggests that slough habitats are the preferred environment for juvenile applesnail development. However, growth in both treatments showed that juveniles can assimilate plant detritus when periphyton availability is limited.*

Key Words: Applesnail, detritus, Everglades, food quality, growth, habitat mosaic, periphyton, *Pomacea paludosa*

MUCH of the remnant Florida Everglades consists of a mosaic of dense stands of the emergent macrophyte sawgrass (*Cladium jamaicense*) interspersed with periphyton (i.e., algae and associated bacteria and fungi)-dominated sloughs that provide a diverse resource base to aquatic consumers. This diversity is gradually being lost as dense macrophyte stands replace sparsely vegetated sloughs in response to nutrient enrichment and altered hydrology within this wetland (Davis et al., 1994). Phosphorus-enriched runoff entering the northern Everglades has caused the conversion of sloughs to dense stands of cattail (*Typha domingensis*) (McCormick et al., 2001). On a broader scale, the impoundment of much of the system during the 1950s and 60s altered water depths and flow regimes in ways that are believed to have favored the growth of sawgrass in areas previously dominated by sloughs (Davis et al., 1994). Slough habitats are characterized by high submerged primary productivity (McCormick et al., 1998), dissolved oxygen (DO) (Belanger and Platko, 1986), and invertebrate species richness and abundance (Rader, 1994), and are considered preferred foraging areas for wading birds (Bancroft et al., 2002). While few data exist with which to predict the consequences of observed habitat changes for most aquatic consumers other than wading birds, there is a consensus among scientists that reductions in slough habitat will negatively affect key Everglades animal populations and food web structure (Science Coordination Team, 2003).

The Florida applesnail (*Pomacea paludosa*) is the largest gastropod in the Everglades and an important food source for many species including the endangered snail kite (*Rostrhamus sociabilis*), wading birds such as the limpkin (*Aramus guarauna*) and white ibis (*Eudocimus albus*) (Cottam, 1936; Snyder and Snyder, 1969; Kushlan, 1974), juvenile alligators, turtles, amphibians and fish (Turner, 1994; Darby et al., 1999). Despite its potential importance to secondary production, little is known about the natural diet of *P. paludosa* in the Everglades. In general, snails are non-selective periphyton grazers (Pennak, 1989) and applesnail densities are typically higher in periphyton rich habitats (e.g., wet prairies and sloughs) than in dense stands of emergent macrophytes (Darby et al., 1997). Periphyton growth is limited in dense stands of sawgrass as a result of shading (Grimshaw et al., 1997; McCormick et al., 1998); thus, plant detritus is the principal food source for consumers foraging in this habitat. It is not clear to what extent differences in food availability affect applesnail population distribution and dynamics among Everglades habitats.

The objective of our study was to understand the extent to which applesnail survival and growth might be affected by available food resources. We assessed the relative quality of applesnail food sources in sloughs (periphyton) and sawgrass stands (detritus) by: 1) evaluating the nutritional value of periphyton and sawgrass detritus based on chemical composition; and 2) directly measuring the capacity of these two food sources to support growth and survival of juvenile applesnails.

METHODS—*Chemical analysis of food quality*—Benthic periphyton and macrophyte detritus were collected from slough and sawgrass habitats, respectively. The material was inspected using a dissecting microscope to remove any snails prior to either chemical analysis or addition to feeding microcosms (see below). The material was homogenized and an aliquot of each sample type was analyzed to determine the proportion of ash (undigestable inorganic matter), carbohydrates, protein and lipids (crude fats) in each food type using standard methods (AOAC, 1997).

Microcosm growth experiment—Twelve microcosms (15-L opaque plastic containers, 40 × 25 × 10 cm) were filled with 10L of ambient slough water collected from an interior location (26°17.169 N 80° 24.69 W) in Water Conservation Area (WCA) 2A. One L of either periphyton (slough) or detritus (sawgrass), inspected as described above, was added to each microcosm to produce 6 replicates of each food treatment. This volume was considered adequate to ensure that food quantity would not be limiting to snail growth. Microcosms were incubated outdoors in a large flow-through water bath to avoid extreme temperature fluctuations. Shade cloth was placed over each detrital microcosm to provide approximately 50% shading as occurs naturally within sawgrass stands (McCormick et al., 1998). Constant water levels were maintained, and temperature and DO were measured weekly between 1200 and 1500 hr.

Clutches of applesnail eggs attached to sawgrass leaves were collected from the margins of sawgrass habitats within the interior of WCA 2A and placed in a 47-L tank under natural environmental conditions (e.g., light and temperature). Both periphyton and detritus were added to the tank to serve as food for hatchling snails. Once hatched, juvenile snails were allowed to develop for at least 21 days. The aperture length, shell length, and wet weight were measured for 84 individuals, which were then grouped into five size classes (class 1 = 3.0–3.6, class 2 = 3.7–4.0, class 3 = 4.1–4.3, class 4 = 4.4–4.6, class 5 = 4.7–5.1 mm)

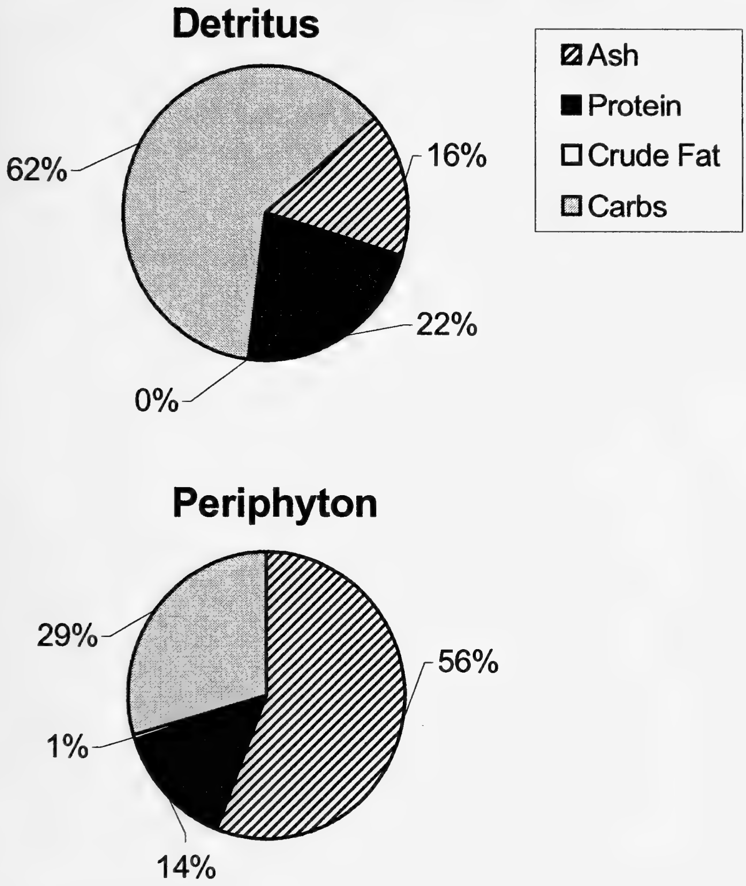


FIG. 1. Chemical composition of detritus and periphyton used as food resource. Measurements represent percent (by weight) composition of ash, protein, crude fat (lipids) and carbohydrates (carbs).

based on aperture length. The mean aperture length, shell length and wet weight were calculated for each size class. Seven individuals from a given size class were placed in each microcosm, except for three microcosms that received individuals from more than one size class due to a shortage of snails. In order to minimize handling of the juvenile snails, the size class means were used as the initial measurements.

After 30 days, survivorship and the mean aperture length, shell length and wet weight of surviving applesnails were determined for each microcosm. Growth was measured as the change in the mean length (mm) and mass (g) of applesnails in each microcosm. Differences in survivorship and growth between periphyton and detrital treatments were detected using a Student's t-test (Sokal and Rolf, 1995). The relationship between wet weight and aperture and shell lengths was evaluated using analysis of covariance (ANCOVA) to assess the use of allometric measurements as surrogates for changes in biomass (Sokal and Rolf, 1995). A significance value of $p = 0.05$ was used for all statistical tests.

RESULTS—*Chemical analysis of food quality*—Analysis of the chemical composition of the bulk periphyton and sawgrass detritus used in the microcosms generally indicated that detritus was the higher quality food resource (Fig. 1). Inorganic matter accounted for 56% and 16% of periphyton and detritus dry mass,

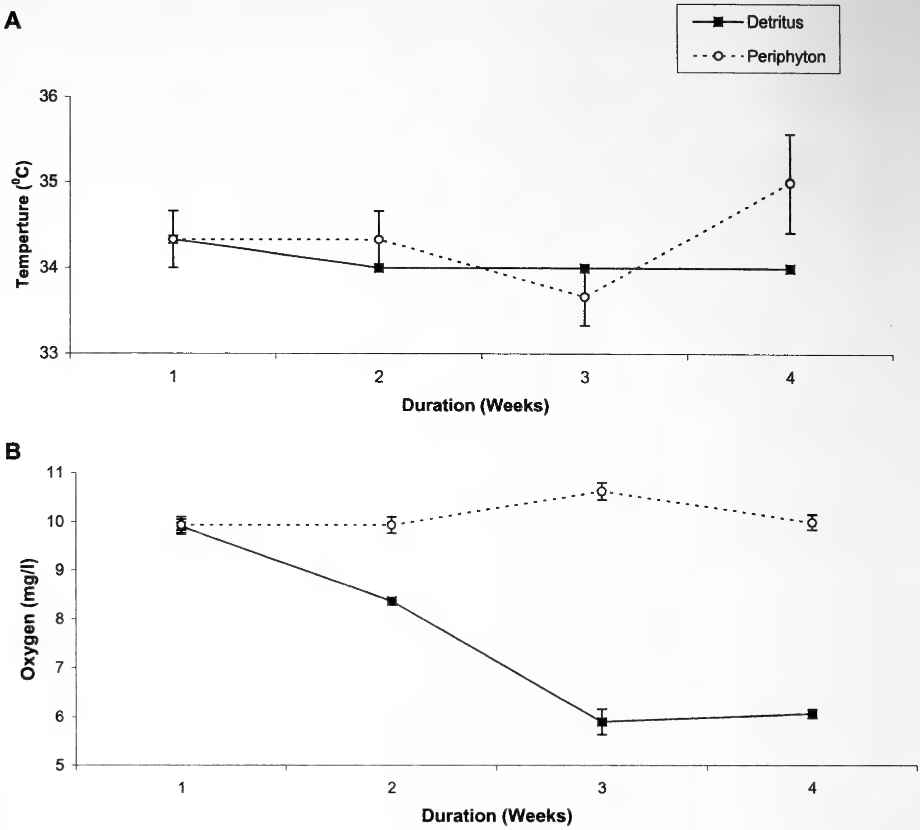


FIG. 2. Weekly temperature (A) and dissolved oxygen concentrations (B) in detritus (solid) and periphyton (dotted) treatments. Points are means ±1 SE.

respectively. The percentages of carbohydrate and protein within the bulk periphyton were lower than in detritus. However, crude fats (lipids) comprised 1% of the bulk periphyton but were undetectable in detritus.

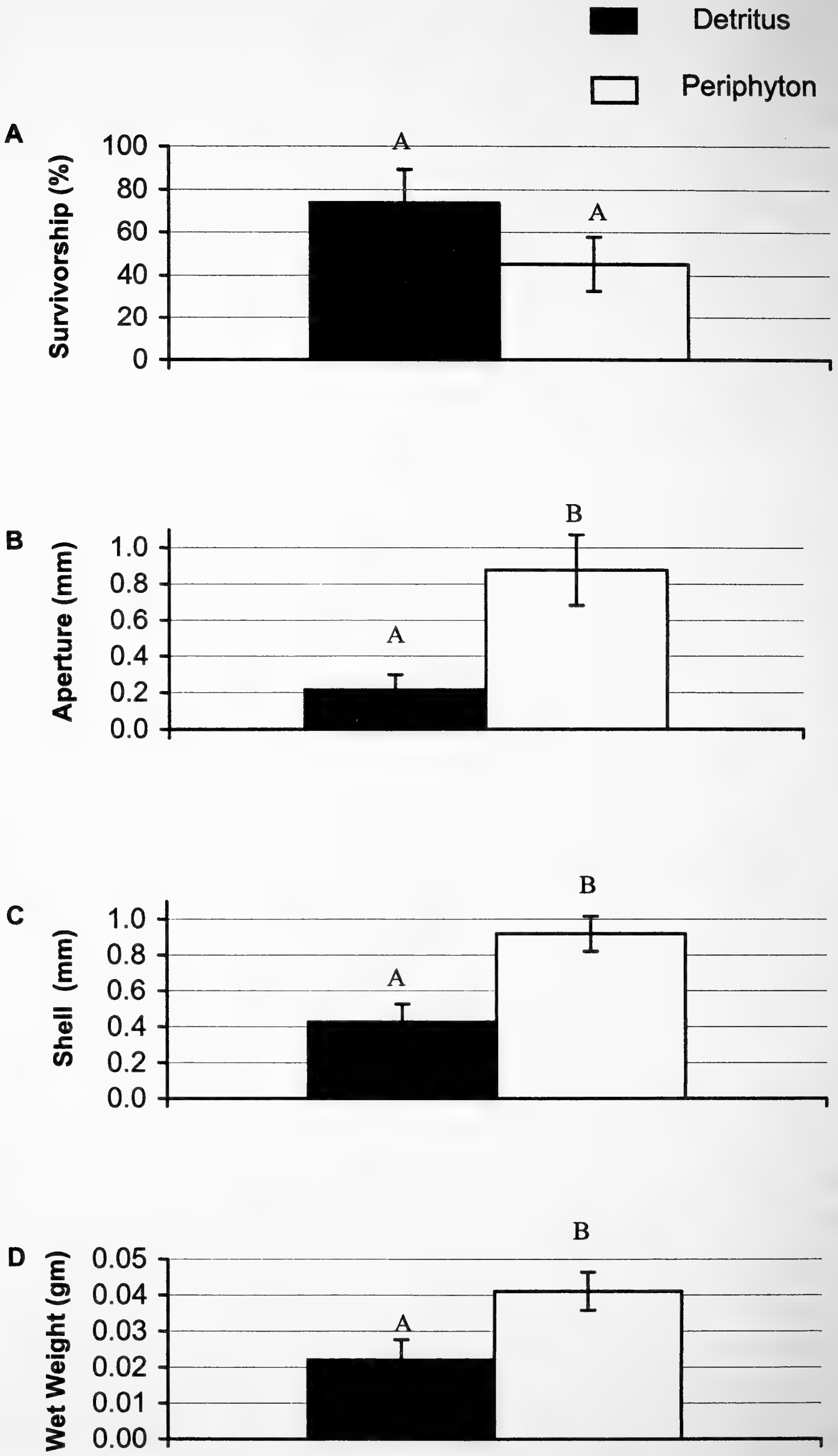
Microcosm growth experiment—Afternoon water temperatures averaged between 33 and 35°C (Fig. 2A) and were never significantly different between treatments ($p > 0.05$, Student's t-test). Maximum recorded temperatures were higher in the periphyton microcosms (36°C) than in the detrital treatment (34°C), but were still within the range of those recorded in Everglades sloughs during the same time of year (McCormick, unpubl. data). Afternoon water-column DO concentrations were consistently near or above 10 mg/L in the periphyton treatment but declined from near 10 mg/L to near 6 mg/L in the detritus treatment during the course of the study (Fig. 2B). The DO concentrations were significantly lower in the detritus treatment after the first week ($p < 0.05$, Student's t-test), but concentrations in both treatments were within the range of those experienced in Everglades sloughs that are minimally impacted by nutrient enrichment (McCormick and Laing, 2003).

Snail survival tended to be higher in the detritus microcosms (74%) than in periphyton microcosms (52%); however, this difference was not statistically significant (Fig. 3A). Snail growth occurred in both treatments; however, periphyton-reared snails exhibited significantly more growth than those fed detritus. Aperture lengths in periphyton microcosms increased four times as fast as those in detritus microcosms (Fig. 3B). Shell length and wet weight of snails raised on periphyton increased twice as fast as those fed detritus (Fig. 3C–3D).

The relationships between wet weight and shell and aperture length are presented (Fig. 4). ANCOVA indicated that the slope of the regressions for periphyton-reared and detritus-reared snails at day 51 were not different; thus, the data were pooled. The shell length–wet weight slope for snails at day 21 was significantly lower than for those at day 51 while the aperture length–wet weight slopes were similar. Despite the detected differences, wet weights were strongly related to shell length at 21 and 51 days ($r^2 = 0.72$ and 0.84, respectively) and to aperture lengths ($r^2 = 0.75$, pooled data).

DISCUSSION—The results of our study indicate that juvenile applesnails can assimilate resources found in both slough and sawgrass habitats. However, snails grew more rapidly on a diet of periphyton, which is the predominant food source in sloughs, than on detritus from adjacent sawgrass stands. Our findings are consistent with past studies showing that periphyton-rich habitats support higher growth of consumers (Benke and Wallace, 1980; Mayer and Likens, 1987; Wallace et al., 1987). Several studies have shown that *P. paludosa* is capable of consuming a variety of resources including *Utricularia* sp. (Martin, 1973; Sharfstein and Steinman, 2001), *Eleocharus* sp. (Sharfstein and Steinman, 2001), *Najas* sp., and *Chara* sp. (Hurdle, 1973), perhaps relying primarily on the periphyton associated with these plants. Results of other studies concur with our finding that food source and quality are important factors affecting snail growth and development. For instance, Martin (1973) showed that applesnails achieved faster growth, earlier sexual maturity, and greater fecundity when reared on commercially fertilized bladderwort (*Utricularia* sp.) than on unfertilized bladderwort. Hurdle (1973) found that diets of muskgrass (*Chara* sp.) and spiny naiad (*Najas* sp.) supported applesnail growth but not the achievement of sexual maturity. Thus, habitat changes that affect the availability of different food resources can affect applesnail population dynamics. Faster growth of juvenile snails reared on periphyton in our study suggests that sloughs provide a preferred nursery habitat for this species compared with sawgrass stands.

Growth results contrasted with those of chemical analyses, which suggested that sawgrass detritus, not periphyton, should be the more nutritional food source. The apparent low nutritional value of periphyton resulted from the high ash content of this material relative to sawgrass detritus. This ash is composed largely of calcite and other mineral precipitates associated with filamentous cyanobacteria, which are a major component of this periphyton community (McCormick et al., 1998). Snails likely avoid cyanobacteria in favor of diatoms, which are the second major algal component of the Everglades periphyton community and are generally considered to be a high quality food resource (Lamberti et al., 1989). Thus, selective feeding by gastropods may allow them to consume the highest quality food within a mixture. Chemical


Detritus
Periphyton
A
Survivorship (%)
100
80
60
40
20
0
A
A
B
Aperture (mm)
1.0
0.8
0.6
0.4
0.2
0.0
B
A
C
Shell (mm)
1.0
0.8
0.6
0.4
0.2
0.0
B
A
D
Wet Weight (gm)
0.05
0.04
0.03
0.02
0.01
0.00
B
A

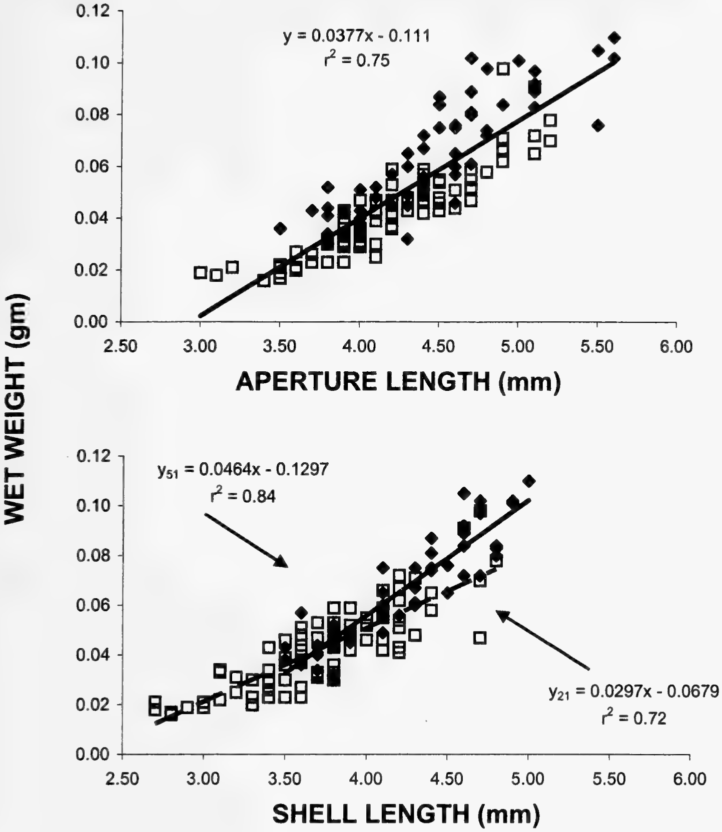


FIG. 4. Length – weight relationships for 21 (open squares) and 51 (closed diamonds) day old *P. paludosa*.

analysis cannot resolve differences among food items within bulk material and, as shown here, may yield erroneous predictions of food quality for selective grazers.

The slope of the shell length-wet weight regression in 51 day old snails was greater than 21 day old snails. This difference in slope suggests that as snails age, they experience slower shell elongation as biomass increases. Beissinger (1984) showed a similar relationship between the standard shell length and dry weight of adult snails. In contrast, there was no difference between slopes of the aperture length–wet weight regressions of 21 and 51 day old applesnails suggesting that the aperture length can be used to predict biomass during early development of applesnails, thereby eliminating the need to sacrifice juveniles for growth data.

←

FIG. 3. Change in percent survival (A), aperture length (B), and shell length (C) and wet weight (D) of applesnails reared in detritus (black) and periphyton (white) treatments after 30 days. Bars are means of six replicate microcosms ±1 SE. Different letters indicates statistically significantly differences between treatments.

Further studies are needed to determine if this pattern holds for adult snails across a wide range of size classes.

Management implications—The maintenance of a habitat mosaic is considered to be an important aspect of wetland management because of its positive influence on invertebrate production, which sustains higher trophic levels (Weller, 1994). For example, applesnails in the Everglades likely require different habitats during various stages of their life cycle. Our findings suggest that periphyton-rich habitats such as sloughs may be important nursery habitats for young applesnails. By contrast, emergent macrophyte habitats provide the physical habitat structure required for egg deposition (Hanning, 1979; Turner, 1996) and a likely source of protection from predation (Crowder and Cooper, 1982; Heck and Crowder, 1991; Jordan et al., 1996) and, therefore, may be an important habitat for slower-growing adult snails. Thus, the current state of understanding supports the view that restoration and maintenance of the slough-sawgrass mosaic should be key goals of future Everglades management efforts.

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EFFECT OF LIGHT QUALITY ON THE GROWTH OF DUCKWEED, *LEMNA MINOR* L.

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Abstract: *The effect of colored plastic panels was studied on a model system, duckweed,* Lemna minor L., *to determine if light could control emergent aquatic plants. Wavelengths of incident light were controlled using three different colored plastics (red, green, and blue), for which the UV-visible spectrum was evaluated using a spectrophotometer. Plants were exposed to light passing through the plastic, and their growth was compared with ordinary light of the same intensity (100 $\mu Es/m^2/sec.$ as measured by a light meter). Temperature was maintained at 25° ± 0.2°C. Growth was measured by the number of fronds produced as a function of time, a relationship between frond count, fresh weight, and dry weight was established . Plants grown under green plastic (420–580 nm) and blue plastic (400–470 and 620–660 nm) grew less than control samples; plants under red plastic (550–700 nm) grew better than control samples.*

Key Words: Duckweed, control, Aquashade®, light, plant growth

Management of excess aquatic vegetation by light control was considered for submersed plants. In particular, a patent was granted (Wilson, 1977) for a mixture of two food dyes, Acid blue 9 and Acid yellow 23 (Spencer, 1984). This patent led to a product called Aquashade® that was originally marketed by Aquashade, Inc. and is currently sold in a modified version by Applied Biochemists (Milwaukee, WI). Previously, Martin and Martin (1992) published an annotated bibliography summarizing studies describing its use as a control agent.

Unfortunately, while the product has advantages for submersed vegetation and provides an attractive "water blue" color at the same time, it has limited effectiveness against emergent species, e.g. duckweed, for which control over a limited area might be desirable.

Duckweed (*Lemna* spp.) has been proven to be effective in wastewater treatment (Bonomo et al., 1997). The ability of duckweed to remove nutrients was studied and two species (*Lemna minor* and *L. gibba*) proved to be most effective in managing nutrients (Körner and Vermaat, 1998; Vermaat and Hanif, 1998). Of the two, *L. minor* is the most common species found in Florida (Long and Lakela, 1976), and may pose a nuisance because of its excessive growth.

The present investigation considered the possibility of using light of different wavelengths to evaluate control of emergent aquatic vegetation, and *Lemna minor* was selected as a model system for study.

Materials and Methods—*Source of duckweed*—Duckweed (*Lemna minor* L.) was obtained from Carolina Biological Supply (Charlotte, NC). Stock duckweed was grown in plastic trays in a 100%

TABLE 1. Properties of colored panels used to test effect the growth of *Lemna minor* L., together with related information.

Panel color	Wavelength, nm*	Absorbance, max
Blue	400–470	~3.1–4.0
	620–660	3.0–3.5
Green	420–580	~3.1–4.0
Red	550–700	~4.0
PAR**	390–440; 650–77	

* Based on absorption spectra using a Cary 3E UV/VIS spectrophotometer.

** PAR: photosynthetically active region, e.g., region of absorbance by chlorophyll *a* (Osborne, 1979; Caldwell et al., 1998).

Hillman growth medium (Hillman, 1959a, b). Growth medium was changed every three days to protect against loss of nutrients and the proliferation of algae.

Plastic—Red, green, and blue plastic panels (3 mm thick) were purchased from Faulkner/Cadillac Plastics, Tampa, and used without further treatment. A portion of each sample was cut with a bandsaw to fit into a spectrometer and the relative absorbance was determined as a function of wavelength using a Cary 3E double beam UV-VIS spectrometer (Table 1).

Study system—Each duckweed system was studied for a period of 15 days under each color. The test consisted of 25 fronds of duckweed placed in a 1.5 pint plastic freezer container (10 × 10 × 8 cm) containing about 750 mL Hillman solution (Hillman, 1959a,b). Another set of 25 fronds was placed in a separate container to be the control. Both systems, test and control, were exposed to a constant light intensity of 100 μEs/m^2/sec, measured with a LiCor model LI-185A photometer, at 25°C ± 0.2°C, and with a relative humidity of 63%. However, each control was studied under fluorescent light, while each test was studied under respective wavelengths set by blue, green, and red colored panels A light source was used to provide illumination, 12 hours light and 12 hours dark. For this purpose, a fluorescent lamp (Commercial Electric, 42W Model ES42) was placed on top of each container within an adjusted distance of 25–35cm from the culture. To match the 100 μEs/m^2/sec light intensity on each test system, layers of fiberglass mesh were placed on the surface of each control container to reduce the light intensity and allow the plant to receive air.

Cultures of lemna were maintained in an environmental growth chamber (Phytotron, Environmental Growth Chamber, Chagrin Falls, OH) at a constant temperature of 26°C, 80% relative humidity, and a 12-hour photoperiod with a light intensity of 190 μEs/m^2/sec. For study systems in the laboratory, the Hillman solution was replaced every three days and duckweed fronds were counted every other day. For this procedure, it was important to count every visible frond including the small tips arising from mother fronds.

Fresh weight was also related to the frond count, using appropriate data (Smith et al., 2004) as indicated (Eqn. 1).

$$\text{Fresh weight} = 0.0015 + 0.0566\ (\text{fronds}) \tag{1}$$

In addition, dry weight (D.W.) was previously related (Smith et al., 2004) to fresh weight (F.W.) for the samples of *Lemna minor* (Eqn. 2)

$$\text{D.W. (in g.)} = 0.0566 * (\text{F.W., in g.}) + 0.0015 \tag{2}$$

Here, D.W. = Dry weight and F.W. = Fresh weight (in g.)

Regression analysis was applied to the data, frond number as a function of time in days, using PSI-Plot (version 7, Poly Software International, P. O. Box, Pearl River, NY 10965), and results are listed in Table 2. Regression analyses were checked using Excel, and plots were made using this program.

TABLE 2. Summary of characteristics of the effect of colored plastic panels on the growth of *Lemna minor* L. Fronds = a + b time (days).

System	N	a	b	t-test, p**
Green panel	16	23.3 ± 1.25*	6.33 ± 0.15	4.9×10^{-4}
Control	16	19.8 ± 2.0	8.62 ± 0.24	
Blue panel	16	22.8 ± 1.5	7.02 ± 0.17	1.8×10^{-5}
Control	16	25.7 ± 1.5	8.23 ± 0.18	
Red panel	16	26.7 ± 4.2	13.36 ± 0.5	02.7×10^{-5}
Control	16	25.5 ± 2.1	8.77 ± 0.26	

* ±standard deviation of the estimate.
** Test vs. control, paired t-test.

RESULTS AND DISCUSSION—*Panel characteristics*—The three panels used covered the visible range, as indicated in Table 1. Here, also, we indicate the comparison of the maximum absorption region for each plastic panel with the reported portion of the spectrum for blue, green, and red.

Growth characteristics—We measured the response of the duckweed to light in terms of the number of fronds as a function of time. Previous workers (Smith et al., 2004) established a linear relationship between frond count and fresh weight (Eqn. 1), and the relationship between fresh weight and dry weight (Eqn. 2) was also established.

The growth for plants under each of the three panels was measured in duplicate and in comparison with control samples as a function of time. Plots of frond count (average of two determinations) as a function of time in days appeared to be linear and good linear correlation coefficients (i.e., greater than 0.99) were obtained. Results are shown (Fig. 1) for the red panel vs. control. Equally good results were obtained for linear plots for the green and blue panels versus their control samples.

The precision of the measurements appeared to be good as indicated by comparison of the three sets of duplicate control studies (Table 2) for which the slopes (frond count as a function of time) were 8.62, 8.23, and 8.77, giving a mean and standard deviation of 8.5 ± 0.21 (and a relative standard deviation of 2.5%). The agreement between the two methods of regression analysis was identical within about 0.1% (which reflects rounding errors).

Effect of color panels—We measured test and control systems under constant conditions of temperature and light intensity. That we were successful for the control systems is indicated by the precision of the three control systems. As noted earlier, test (growth under a colored plastic panel) and control systems were exposed to same amount of light. Data comparing slopes of the growth plots using a given panel versus a control (Table 2) indicated that there was an effect of which colored panel was used versus the control system. The slopes of the green and the blue panel systems were both less than the controls (6.33 vs. 8.62 and 7.02 vs. 8.23, respectively), but growth under the red panel was considerably more favorable, as indicated by the slopes for test (13.4) and control (8.77). The standard deviations of the slopes were calculated (Table 2) and used to test for statistically significant differences. Differences between

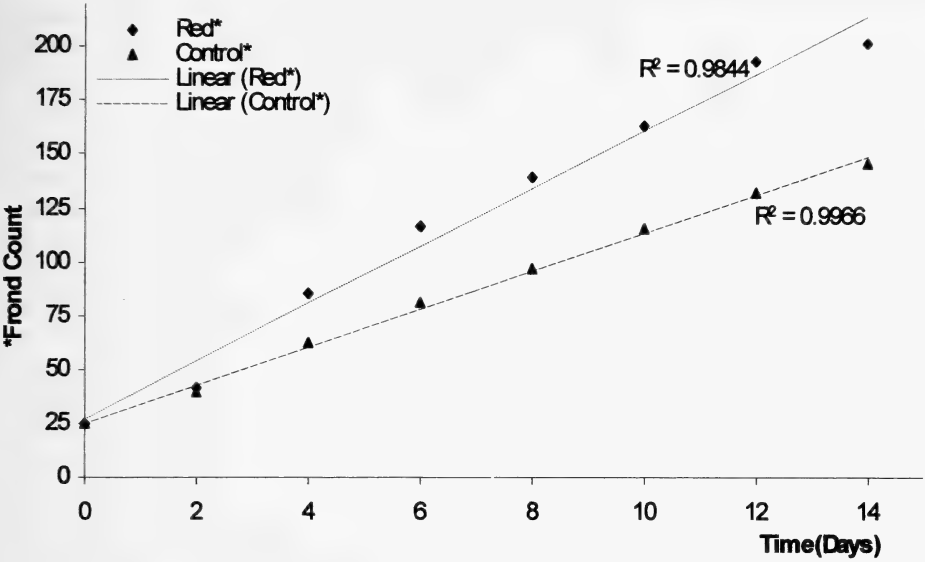

FIG. 1. Plot of average frond count vs. elapsed time (in days) for control and test under red light.

the slopes (e.g., green panel vs. green control, blue panel vs. blue control, etc) were statistically significant, based on Student's t-test (Table 2).

These results are consistent with other available information. First, the adverse effect observed from exposure to the blue panel is consistent with the effect of Aquashade®, which is a mixture of dyes giving a blue appearance, as noted previously, and in the case of the blue panel covering much of the visible spectrum (Table 1) and effectively blocking the photosynthetic active region (PAR), which is taken to be 400–700 nm (Caldwell et al., 1998). The green panel (Table 1) also interferes with the PAR region, though the intensity of absorption is less than what was observed for the blue panel. The red panel, in contrast had the least interference with the PAR, and this was reflected in the greater slope, and in fact, the growth was greater than the control value.

One implication of this study is that it is possible to duplicate, in a general way, the effect of Aquashade® and limit the amount of PAR light of plants, an observation previously made by Osborne (1979), who noted the material absorbed most strongly at 600–650 nm. The results also indicate the nature of the effectiveness of this material, consisting of a mixture of blue and yellow dyes, which in the correct proportion should duplicate a mixture of green and blue. In addition the results suggest that proper shielding with an appropriate plastic might limit the growth of emergent plants in crucial areas. One example might be the management of giant salvinia (*Salvinia molesta* D.S. Mitchell), and other exotic nuisance plants in limited, but critical areas, e.g. water intake areas. That appropriate plastic worked for *Lemna minor* in the laboratory conditions is no guarantee of effectiveness under natural conditions, but the results certainly point the way to future studies.

Finally, a third implication is that one plastic panel (red) enhanced the growth of lemna in a significant manner (50% increase in the slope of growth as a function of time in days). This is significant in instances for which lemna is desirable as biomass, and one example is a description of the potential use of lemna in fuel cells (Carvalho-Knighton et al., 2004). For this application, growing the plants in controlled conditions would be logical as would increasing growth rates by altering the quality of light through the use of plastic panels.

Plants capture light not only for the energy it carries, but for the information that it evidently provides as well. Yanovsky and Casal (2004) note a number of examples of this ability to dissect specific wavelengths of light. One interesting example that was cited was the ability of certain plants to sense the ratio of red to far-red light. Densely populated shaded environments are "rich" in far-red wavelengths that are reflected by plants, but contain much less red light, a color absorbed by the other plants. With shading plants around, the red to far-red ratio would be low, but given supplementary red light, plants could be tricked into sensing that they had unlimited space to grow.

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PREDATION VULNERABILITY OF TWO GOBIES (*MICROGOBIUS GULOSUS*; *GOBIOSOMA ROBUSTUM*) IS NOT RELATED TO PRESENCE OF SEAGRASS

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Abstract: *In this laboratory experiment, the influence of structural complexity on susceptibility to predation by toadfish,* Opsanus beta, *was examined for two gobies:* Microgobius gulosus *and* Gobiosoma robustum. *These two gobies exhibit some habitat partitioning in Florida Bay:* Gobiosoma robustum, *a non-burrowing species, is generally found associated with seagrass; however,* Microgobius gulosus, *a burrower, is generally found in mud with little or no associated seagrass. A previous experiment showed that both species preferred seagrass to sand; however,* G. robustum *was competitively dominant and could displace* M. gulosus *to sand. It was hypothesized that* G. robustum *was attracted to seagrass as it ameliorated predation, whereas* M. gulosus *was protected from predation by its burrowing habit and therefore less strongly attracted to seagrass. Surprisingly, there was no effect of seagrass on predation rates.* Microgobius gulosus *was significantly more likely to be preyed upon than* G. robustum. *There was no substrate X species interaction, indicating that that the predation success of toadfish on gobies did not differ across substrate types. Predation is generally ameliorated in structurally complex habitats, and can structure the distribution and density of prey species. However, this appears not to be the case for* M. gulosus *and* G. robustum.

Key Words: Gobiidae, seagrass fishes, predation, experimental ecology

Predation has been invoked as a primary force structuring assemblages of seagrass fishes (Heck and Orth, 1980; Orth et al., 1984). Generally, prey fishes are more abundant in seagrass than unstructured (e.g., bare sand, mud flat) habitats (Ferrell and Bell, 1991; Sogard and Able, 1991; Arrivillaga and Baltz, 1999; Hughes et al., 2002; Travers and Potter, 2002). Because structurally complex habitats can confer an advantage to prey fishes by reducing the foraging effectiveness of predators (Werner and Gilliam, 1984; Savino and Stein, 1982, 1989), predation has been suggested as the cause of the correlation between increased faunal densities and seagrasses.

Microgobius gulosus and *Gobiosoma robustum* are common estuarine fishes in the Gulf of Mexico and along the Atlantic coast of the southern U. S. Both species inhabit a wide range of habitat types, including both structured (e.g., oyster, vegetation) and unstructured (e.g., bare mud/sand) environments. However, in a previous laboratory study (Schofield, 2003), both species showed strong selection for a structurally complex habitat (i.e., artificial seagrass) versus an unstructured one

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(i.e., bare sand). *Gobiosoma robustum* showed exceptionally strong affinity for artificial seagrass over sand, and could displace *M. gulosus* from this preferred habitat (Schofield, 2003). These results correlate with field distributions in Florida Bay: *Gobiosoma robustum* is more common in seagrass-dominated habitats (in southern, central and western Florida Bay) while *M. gulosus* is more abundant in the sparsely-vegetated northeastern region of Florida Bay (Sogard et al., 1987, 1989).

Strong selection for seagrass by *G. robustum* may result from a number of factors, such as increased food availability or decreased predation susceptibility. When compared to unvegetated habitats, seagrass beds generally contain higher densities of small invertebrates (Heck et al., 1995) that are food for opportunistic meso-carnivores (such as many goby species). Alternatively, *G. robustum* may be more susceptible to predation over unvegetated substrates, and finds shelter from predators in seagrass. Unlike *G. robustum*, *M. gulosus* is a burrowing species (Birdsong, 1981). The use of burrows may allow *M. gulosus* to use unvegetated substrates while avoiding predators. Toadfish (Batrachoididae, *Opsanus* spp.) are voracious predators that feed readily on fishes and invertebrates, (e.g., Schwartz and Dutcher, 1963). Indeed, Gudger (1908) noted of the toadfish, "all is grist that comes to his mill" (p. 1088). Gulf toadfish (*Opsanus beta*) are common throughout Florida Bay (Sogard et al., 1989) and feed readily on gobies (pers. obs.) Herein, I determine the relative influence of structural complexity (i.e., seagrass) in a laboratory experiment on susceptibility to predation by gulf toadfish for *M. gulosus* and *G. robustum*.

METHODS—I collected *M. gulosus* from Davis Cove (25° 12.2′ N 80° 32.2′ W; salinity = 30 psu) in northeastern Florida Bay. Mud was also collected from Davis Cove as substrate in experimental aquaria. In the southeastern region of Florida Bay, I collected *G. robustum* from Crab Key (24° 59.9′ N 80° 39.7′ W; salinity = 40 psu). At both sites, fish were collected with a 1-m^2 throw trap (Kushlan, 1981), which is the most effective gear for sampling demersal organisms on the shallow, soft mudbanks of Florida Bay (Powell et al., 1986; Jordan et al., 1997). Toadfish were collected by otter trawl in seagrass beds near Cedar Key, Florida (29° 6.5′ N 83° 04′ W; salinity = 32 psu).

Fishes were transported to the laboratory (U.S. Geological Survey, Gainesville, FL) and maintained in holding tanks prior to being used in a trial. Holding aquaria (36-liter) were filled with water adjusted to 32 psu (= de-ionized water + synthetic sea salts [Forty Fathoms©, Aquatic Ecosystems, Inc.]). A few artificial plants were added to the holding aquaria, but no substrate was provided for the fish. Gobies were fed a mixture of live foods (oligochaetes and brine shrimp) during the holding period. Toadfish were fed live fishes (goldfish [*Carassius auratus*] and mosquitofish [*Gambusia* spp.]) ad lib until 24 h before the beginning of a trial. Toadfish that were unwilling to feed 24 h before an experimental trial were not used for that particular trial. Individual gobies were used only once during the experiments, whereas toadfish were re-used for a number of trials.

Experimental aquaria were filled with water adjusted to 32 psu and 5–7 cm of mud. A perforated, clear-plastic partition was placed 10 cm from one end of each aquarium to separate the sponge filter and stand pipe from the experimental arena. Two structure treatments were used: 1) bare mud and 2) mud with artificial seagrass. In both treatments, mud collected from Florida Bay was used as a substrate. This substrate also contained pieces of seagrass roots and other small woody debris. Artificial seagrass blades (strips of 0.8 mil black plastic sheeting designed to mimic *Thalassia testudinum*) were 7.5 cm tall, 0.5 cm wide, and planted at a density of approximately 2,000 blades m^{-2} to simulate the morphometrics of seagrass canopy in Florida Bay (Sogard et al., 1987). Artificial seagrass eliminates the influence of epibionts and other potential prey on fish behavior and provides a good mimic of natural seagrass (Shulman, 1985; Bell et al., 1987, 1988; Sogard, 1989). Artificial seagrass blades were tied in bundles of four to stainless steel wing-nuts and these bundles were spread over the substrate of the aquaria roughly evenly. Using wing-nut anchors for the seagrass blades (versus tying them to mesh that covered the bottom of the aquaria) allowed the fish to burrow unobstructed into the mud.

Gobies were measured (standard length [SL]) and weighed (to nearest 0.01 g), then placed in experimental aquaria (one goby per aquarium) and allowed to habituate for 3–7 d. During this time, gobies were fed oligochaetes and brine shrimp. *Microgobius gulosus* burrowed readily into the substrate, generally constructing burrows within their first 12 h in the experimental aquaria. For each trial, a blind was placed around all four sides of the experimental aquarium and one toadfish was introduced. The toadfish was left in the aquarium for 24 h then removed. After a trial was completed, the goby (if remaining) was removed from the aquarium. For the mud + seagrass treatment, this entailed removing all the seagrass after each trial and re-distributing it over the substrate for the next trial. All burrows were flattened and the substrate was carefully smoothed before the next trial began.

Over the course of the experiment, trials were run in a total of 12 aquaria. Treatments (substrate and species) were not specifically designated to individual aquaria. Instead, they were interspersed amongst aquaria haphazardly and were changed after each trial. Nine trials were run for each *M. gulosus* X substrate (mud or mud + grass) treatment, as well as the *G. robustum* mud + grass treatment. Eight trials were run for the *G. robustum* mud only treatment.

The two goby species were similar in length (*M. gulosus* mean = 36.17 ± 3.2 SD, range 31–43 mm; *G. robustum* mean = 31.12 ± 5.4 SD, range 20–40 mm) and mass (*M. gulosus* mean = 0.66 ± 0.25 SD, range 0.28–1.41 g; *G. robustum* mean = 0.53 ± 0.21 SD, range 0.27–0.99 g). Toadfish averaged 103.1 mm (± 3.3 SD, range 70–150) and 29.73 g (± 25.1 SD, range 8.7–70.8).

Logistic regression (Hosmer and Lemeshow, 2000) was used to evaluate overall differences in predation success of the six toadfish, differences between goby species (*M. gulosus* versus *G. robustum*), substrate differences (mud versus mud + grass) and interactions between these factors. Predation by toadfish for each trial (successful or unsuccessful) was designated as the dichotomous dependent variable in the regression model. Predation success (successful or unsuccessful) was predicted by three main effects (overall success of each toadfish, species, and substrate) and their interactions.

RESULTS—Based on univariate analysis, susceptibility to predation was not related to the presence of grass ($P = 0.826$; $X^2 = 0.05$, df = 1); however, there was a significant species effect ($P = 0.018$, $X^2 = 5.61$, df = 1). *Microgobius gulosus* were more susceptible to predation by toadfish than *G. robustum* (Fig. 1). The predation success of the six toadfish differed ($P = 0.008$; $X^2 = 15.58$, df = 5), but differences between the species were still evident after accounting for this effect in the model ($P = 0.012$; $X^2 = 6.32$, df = 1). No toadfish X species interaction was detected ($P = 0.733$; $X^2 = 2.78$, df = 5). Thus, overall variation in the individual predation success of toadfish did not vary among prey species. Similarly, there was no toadfish X substrate interaction ($P = 0.582$, $X^2 = 3.78$, df = 5). Therefore, individual toadfish did not differ in their success as predators on the two substrate types. Finally, there was no species X substrate interaction ($P = 0.241$; $X^2 = 1.38$, df = 1), indicating that the predation success of toadfish on gobies did not differ across substrate types.

DISCUSSION—The presence of predators influences habitat selection in many fish species, and studies have shown that fishes will move from open to sheltered sites upon detection of a predator (Utne et al., 1993; Sogard and Olla, 1993; Jordan et al., 1996; Sackley and Kaufman, 1996; Steele, 1998; Laegdsgaard and Johnson, 2001). Selection for dense vegetation is thought to confer an advantage on prey species by making them less susceptible to predation. Examination of experimental studies that compare predation susceptibility in vegetated versus unvegetated substrates in estuarine habitats indicated that predation is ameliorated by the presence of

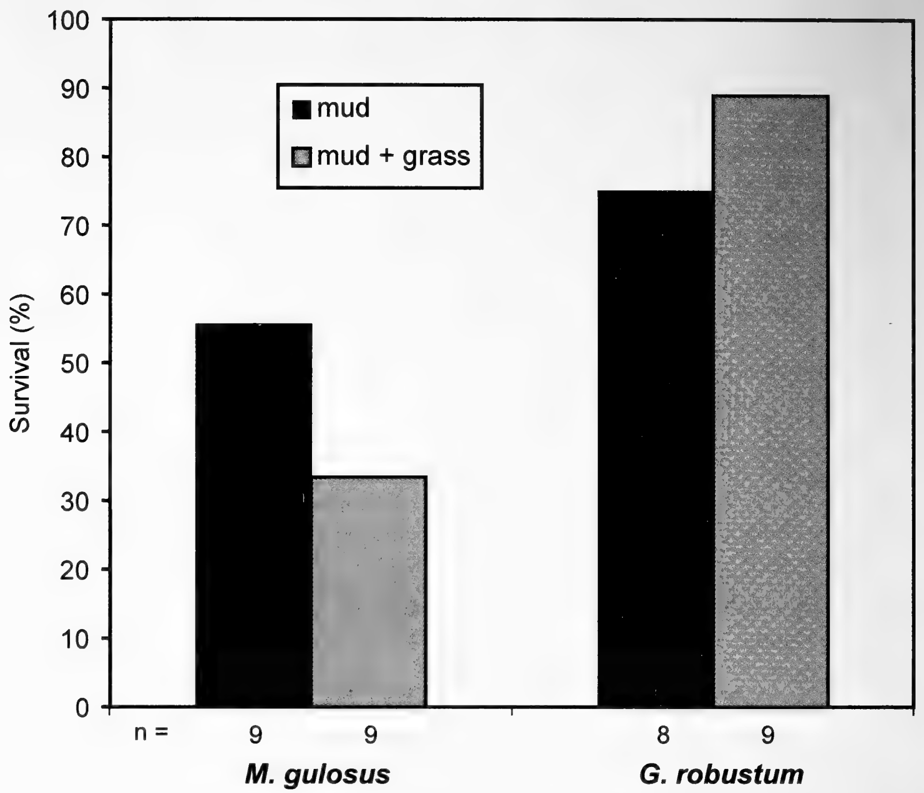

FIG. 1. Survival of *M. gulosus* and *G. robustum* in predation trials with toadfish (*O. beta*) over two substrates (mud, mud + grass). Number of trials (n) is given below each bar.

vegetation in most studies (Table 1). Although the two species in this study have been shown to select structured (seagrass) over unstructured (bare sand) substrates in a previous laboratory study (Schofield, 2003), their attraction to seagrass was not correlated with reduced predation in this study. Instead, predation did not vary for either *M. gulosus* or *G. robustum* whether grass was present or not. These results are similar to the field study of Levin and co-workers (1997) and the lab study of Jordan and McCreary (1996), which showed that pinfish (*Lagodon rhomboides*) and flagfish (*Jordanella floridae*), respectively, preferred vegetated habitats even though the presence of vegetation did not affect their vulnerability to predation. Although few published studies report similar results, it is impossible to know what percentage of such studies were not published that show so-called "negative results" (i.e., weak effects of predation; Connell, 1983; Hall et al., 1990).

Although the "bare mud" treatment used in my experiment lacked vegetation, it was not devoid of structural complexity. The mud used in this experiment contained seagrass root fragments that either species could have used as shelter. The reason for using mud from the field was not to make a stark comparison of predation rates between structured and completely unstructured habitats, but to compare relative

TABLE 1. Experimental studies conducted in estuarine areas or with estuarine fauna that compare susceptibility of organisms to fish predation in vegetated versus non-vegetated habitats. Field studies are designated with superscripts as either (1) tethering or (2) enclosure studies.

Study	Prey	Habitat types compared	Type of experiment	Predator	Habitat of highest predation risk
Wiederholm, 1987	*Pomatoschistus minutus* and *P. microps*	*Zostera marina* &. bare sand	lab	Gadus morhua	bare sand
Rozas & Odum, 1988	*Fundulus heteroclitus*	*Najas* & bare mud	field^1	various	bare mud
Jordan & McCreary, 1996	*Jordanella floridae*	artificial vegetation & no substrate	lab	dragonfly larvae (*Anax junius*)	no difference
Levin et al., 1997	*Lagodon rhomboides*	artificial seagrass & bare sand	field^2	various; primarily blue crab *Callinectes sapidus*	no difference
Rooker et al., 1998	*Sciaenops ocellatus*	*Thalassia testudinum*, *Halodule wrightii*, & bare sand	mesocosm	*Lagodon rhomboides*	bare sand
Manderson et al., 2000	*Pseudopleuronectes americanus*	*Zostera marina*, *Ulva lactuca* & bare sand	lab	*Paralichthys dentatus*	bare sand
Stunz et al., 2001	*Sciaenops ocellatus*	*Spartina alterniflora*, *Halodule wrightil*, *Crassostrea virginica* (oyster) & bare sand	mesocosm	*Lagodon rhomboides*, *Cynoscion nebulosus*	bare sand
Unehan et al., 2001	*Gadus morhua*	*Zostera marina* & sand/gravel	field^1	various	sand/gravel
Jordan, 2002	*Lucania parva*	artificial *Vallisneria americana* & bare sand	lab	*Micropterus salmoides*	bare sand
Hindell et al., 2002	*Sillaginodes punctata*	*Heterozostera tasmanica* & bare sand	field^2	*Arripis truttacea*	bare sand

rates of predation across two habitats similar to the ones encountered by these fishes in Florida Bay. Further experimental work is needed to fully understand the possible role of micro-shelters, such as seagrass-root fragments, as it has been suggested that small benthic attributes (e.g., pebbles, worm tubes, etc.) are far more important in structuring densities and distributions of mobile benthos than previously considered (Norse and Watling, 1998; Diaz et al., 2003).

Besides selecting structured habitats, fishes may use other behavioral modifications to reduce predation intensity. Prey accessibility to predators is determined by prey shape, color, and behavior (e.g., Zaret and Kerfoot, 1975; Stein and Magnuson, 1976). Some gobies reduce foraging rates and swimming activity in the presence of predators (Magnhagen, 1988; Steele, 1998). Moody (1996) reported that *G. robustum* reduced foraging activity in the presence of a predator (sea trout, *Cynoscion nebulosus*) and was observed to "freeze" in place. In my study, experimental aquaria were fully blinded to reduce external disturbances to the fishes, so I was unable to collect data on the movement patterns of either goby species. Thus, it is unknown whether a reduction in activity for *G. robustum* in the presence of the toadfish predator led to its increased survival relative to *M. gulosus*. Further studies including behavioral observations may explain differences in predation rates between *M. gulosus* and *G. robustum*.

If results from this study are reflective of field conditions, *G. robustum* is at least as capable as *M. gulosus* of coexisting with toadfish in habitats devoid of seagrass. Thus, the rarity of *G. robustum* in northeastern Florida Bay may not be related to increased predation pressure (at least by toadfish) resulting from a lack of vegetation. This experiment only examined predation by toadfish. Other fish species are known to prey on gobies in Florida Bay: *Microgobius gulosus* have been reported from the stomach contents of greater barracuda (*Sphyraena barracuda*; Schmidt 1989), and *G. robustum* are documented food items of sea trout, grey snapper (*Lutjanus griseus*), and greater barracuda (Hettler, 1989; Schmidt, 1989). Sea trout and grey snapper occur in the seagrass beds of the southern and western regions of Florida Bay and in the sparsely vegetated northeastern region, although they are not as common as toadfish (Sogard et al., 1987, 1989). Other fish predators, such as needlefish (*Strongylura* spp.), small jacks (*Caranx* spp., *Oligoplites saurus*) and grunts (*Haemulon* spp.) occur primarily in the seagrass beds and mangrove-root habitats of the southern and western portions of Florida Bay (Sogard et al., 1989). Thus, overall predation pressure from fishes is likely reduced in the northeastern portion of the bay relative to southern and western regions. This further reinforces the hypothesis that *G. robustum* is probably not restricted from northeastern Florida Bay by fish predators. Field experiments have provided some evidence that predation by birds may exert a stronger influence on distributions of intertidal benthos than fish predators in some ecosystems (Quammen, 1984). Wading birds (e.g., roseate spoonbill *Ajaja ajaja*) are common in Florida Bay and habitually consume small fishes (Dumas, 2000). However, it is unclear whether the presence of seagrass would confer an advantage on gobies relative to predation by wading birds. Further research on the influences that birds and/or piscivorous fishes exert on gobies would help explain the overall role of predation and habitat complexity in structuring the abundances of these fishes.

Correlative studies showing increased faunal densities in seagrass versus unvegetated habitats, combined with experimental studies showing the amelioration of predation by complex physical structure of seagrasses, were the foundations of the hypothesis that predation played a strong role in structuring seagrass fish assemblages (Heck and Orth, 1980; Orth et al., 1984). However, in his review of the importance of fish feeding on benthic communities, Choat (1982) documented that many of the arguments used to show that feeding by fishes structured prey assemblages lacked the benefit of data on the fishes themselves, were contrary to the evidence obtained, or were of an *ad hoc* nature with dubious explanatory power. Recent experimental studies suggest that although predation may vary amongst habitat types, these results may be largely unimportant in explaining overall abundances of prey species when viewed in the context of other processes such as competition, food acquisition, or recruitment. For example, Connell (2001) found that predation on an assemblage of invertebrate epibionts was intense and varied amongst habitat types; however, the influence of variable recruitment was so strong that it swamped the effects of predation. Steele (1999) showed that preference for shelter by gobies was not necessarily related to predation risk, and that fishes may select shelter sites for other activities (e.g., nesting, feeding). Seagrasses support greater standing crops of invertebrate fauna than adjacent unvegetated areas (Orth et al., 1984; Heck et al., 1995; Webster et al., 1998), and fish may exhibit increased growth rates in the presence of seagrass versus non-vegetated habitats (Levin et al., 1997). Thus, selection of seagrass habitats by *M. gulosus* and *G. robustum* may relate to its value as a feeding ground.

The indirect effects of predation on community structure must also be considered in the context of species' distributions and densities. Traditionally, community models only considered the direct effects of predation (e.g., Hutchinson, 1959; Menge and Sutherland, 1987); however, the indirect effects of predation on community structure and population regulation can also be strong (e.g., Paine, 1966; Kneib, 1988; Bax, 1998). For example, Kuhlmann (1997) showed that the dynamics of a predator-prey relationship between a gastropod and a bivalve indirectly influence populations of a blenny (*Chasmodes saburrae*) that used the discarded bivalve shells as nesting sites. Kneib (1988) showed that predation by killifish on grass shrimp significantly benefited an anemone that was otherwise heavily preyed on by the shrimp. Batzer and co-workers (2000) showed that predation by fishes was intense on a chironomid assemblage in a marsh weedbed. However, the exclusion of predators led to a decrease in chironomid density as midge competitors and invertebrate predators flourished in the absence of the fish predators.

Clearly, the role of predation in the organization of benthic assemblages cannot be simply described, and can vary significantly from one species to another (e.g., Steele, 1998). However, simple laboratory experiments such as this one have been shown to correlate well with distributions of predator and prey species in the field (Azevedo-Ramos et al., 1999). My study suggests that predation by toadfish alone may not explain the distributions of *M. gulosus* and *G. robustum* relative to their selection for seagrass-dominated habitats. Further research on the direct and indirect effects of other fish predators and birds would help clarify the importance of predation overall for these gobies. Information is also needed on the value of seagrass habitats as feeding grounds for these species to further evaluate the adaptiveness of selection of seagrass habitats.

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HABITAT RELATIONSHIPS AND SEASONAL ACTIVITY OF THE GREENHOUSE FROG (*ELEUTHERODACTYLUS PLANIROSTRIS*) IN SOUTHERN FLORIDA

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Abstract: *Habitat relationships and seasonal activity of the greenhouse frog,* Eleutherodactylus planirostris, *were studied at Archbold Biological Station in south-central Florida and Everglades National Park in south Florida. In addition to its occurrence in developed areas, the species is well established in natural habitats in both study areas, occurring in mesic habitats in ENP and both mesic and xeric habitats, particularly long-unburned sites with well-developed tree canopy and a dense understory, on the ABS. The prevalence of* E. planirostris *in long-unburned sandy uplands of south-central Florida historically subject to relatively frequent (e.g. sandhill) or infrequent but intense (e.g. sand pine scrub) wildfires is in contrast to the negative effect of fire exclusion on the xeric-adapted native plant and animal species characteristic of these associations. In both study areas, this species is nearly active year-round, with a September–December peak in numbers that included the appearance of young individuals. Calling is seasonal and correlated with warm and humid conditions defined by monthly temperature minima and rainfall. Based on threshold values of temperature and rainfall, predicted calling seasons in different geographic regions are longest (7–10 months) in extreme southern Florida and the West Indies, shorter (6–7 months) in southern, central, and much of northern Florida, and shortest (5 months) in extreme northern Florida and Mobile, Alabama, a coastal community where we expect the species to colonize.*

Key Words: amphibians, Archbold Biological Station, *Eleutherodactylus planirostris*, Everglades National Park, greenhouse frog, vegetation associations

The greenhouse frog, *Eleutherodactylus planirostris*, is among the earliest to be introduced and geographically most widespread of the 40 established exotic amphibians and reptiles in Florida (Meshaka et al., 2004). In addition to its extensive distribution in the state, it occurs in a wide range of habitats but is most often associated with mesic forest (Meshaka et al., 2004). Its reproductive biology has been studied in greatest detail in the Gainesville area, Alachua County, in north-central Florida (Goin, 1947). Observations on its habitat relationships and aspects of reproduction in other Florida localities are provided by Carr (1940), Deckert (1921), Dalrymple (1988), Duellman and Schwartz (1958), Enge and Wood (1999, 2001), Lazell (1989), Meshaka and co-workers (2000, 2004), and Wright and Wright (1949).

We examined habitat relationships and the seasonal pattern of calling activity of this species at the Archbold Biological Station (ABS), Highlands County, in south-central peninsular Florida and at Everglades National Park (ENP), Miami-Dade and Monroe counties, in extreme south Florida. The goals of the study were to provide a more detailed assessment of the habitat relationships and seasonality of reproduction of the species in different parts of its range in Florida.

Description of study areas—The climate, vegetation, soils, and microclimatic characteristics of different vegetative associations of the ABS were described by Abrahamson and co-workers (1984). Mean minimum air temperatures in summer (June–August) and winter (December–February) were 19.6–21.4°C and 8.7–9.5°C, respectively, over a 29-year period. Mean annual rainfall over a 49-yr interval was 1374 mm, with a well-marked rainy season from June through September accounting for 61% of annual precipitation.

The predominant terrestrial vegetative associations are xeric southern ridge sandhill, sand pine scrub, and scrubby flatwoods, with more mesic low flatwoods and bayhead being less extensive. In long-unburned areas (>50 yr), sand pine scrub has the densest tree canopy, followed by sandhill, and scrubby flatwoods has the most open overstory. All three associations have a dense shrub layer of oaks and other species. Low flatwoods tend to have an open overstory of slash pines (*Pinus eliottii*) and a variously developed shrub and ground layer ranging from dense shrubs to open cutthroat grass (*Panicum abscissum*) glades. The bayhead association has a nearly closed tree canopy composed primarily of sweetbay (*Magnolia virginiana*), red bay (*Persea borbonia*), and loblolly bay (*Gordonia lasianthus*) and shrub and ground layers dominated by young individuals of the same species as well as various shrubs, vines, and ferns. The xeric habitat types are characterized by sandy, well-drained soil; low flatwoods soils have a hardpan layer leading to wet or even flooded conditions during the rainy season; and bayhead soils are also poorly drained and capped with a muck layer. On the basis of increased moderation of daily and seasonal microclimate, the habitats rank in microhabitat variability from least to most as: Bayhead, scrub, low flatwoods, sandhill, scrubby flatwoods.

The vegetation, climate, and soils of the Florida Everglades are detailed by Beard (1938), Davis (1946), Lodge (1998), and Myers and Ewel (1991). The Everglades is a comparably young system comprised of shallow wetlands of varying hydroperiods, open and closed upland habitats, and mangrove forest. Annual rainfall averages 127–152.4 cm, with most occurring during May–October. The wet season is bimodal with a short mid-summer drought in July. Soil types are mostly histosols and entisols with an underlying layer of marl or limestone. Specific to this study in the southern Everlgades, habitats covered all major types and were described and photographed by Meshaka (2001).

METHODS—At ABS, habitat distribution and seasonality of calling were documented by general observations and systematic recording of calling frequency in the early morning on four days in January, April, July, and October from 1967–1994 in sandhill, scrub, scrubby flatwoods, and bayhead vegetation. Additional data on habitat distribution, relative abundance, and seasonal activity were provided by pitfall traps and drift-fence arrays. A 0.16-ha grid of 22.7 l plastic buckets with raised plywood covers spaced at 6.7 m intervals in long-unburned sandhill association was monitored at different times of the year over the period 1979–1994 (Meshaka and Layne, 2002). Sandhill, scrub, scrubby flatwoods, low flatwoods with cutthroat grass ground cover, low flatwoods with palmetto shrub layer, and mixed bayhead/low flatwoods associations were sampled with lines of ten 4.5 l cans with elevated covers spaced at 15-m intervals along

TABLE 1. Number of records or captures of *Eleutherodactylus planirostris* in different habitat types on the Archbold Biological Station, Highlands County, south-central Florida. Percentage frequency of occurrence given in parentheses in cases where two or more habitats were sampled by a given method.

	Method					
	Records of individuals or calls	Calls on grids	Small pitfalls captures	Pitfall grid captures	Arrays captures[1]	
Habitat					Unburned	Burned
Sandhill	6 (40.0)	10 (33.3)	0	12	—	—
Sand pine scrub	3 (20.0)	7 (23.3)	0	—	126	85
Scrubby flatwoods	0	1 (3.3)	0	—	—	—
Low flatwoods	0	—	0	—	—	—
Bayhead/low flatwoods	2 (13.3)	12 (40.0)	2 (100.0)	—	—	—
Edificarian	4 (26.7)	—	—	—	—	—

[1] Counts for period 1985–1996 following burning of sites of 2 arrays in January 1985.

the edges of jeep trails or firelanes and checked for various numbers of days throughout the year from August 1968 to June 1976. In the case of both small and large pitfalls, the traps were closed between sampling periods by turning the covers upside down. Scrub habitat was sampled with four drift-fence arrays for 668 days during 1984–1988 and 1994–1996. Each array consisted of four 7.3 m × 0.4 m aluminum drift fences extending N, S, E, and W from a center point with 27.7 l plastic buckets at each end and a cylindrical screen-wire trap (71 cm long × 25 cm in diameter) with a funnel opening at each end located on each side at the middle of the drift fence. Two of the arrays (250 m apart) were in an area burned in January 1985 and two (195 m apart) were in an unburned control plot separated from the burned area by 130 and 141 m across a wide bare sand firelane. Specimens captured by the various sampling methods were measured for snout-vent length (SVL) in mm, toe-clipped for individual recognition, and released. Most *Eleutherodactylus* found in pitfalls were clinging to the sides and presumably could easily climb out, suggesting that the pitfalls were utilized as refuge sites by this species.

At ENP, presence or absence of the species based on calling was recorded from a wide range of wetlands that included marsh and prairie; uplands that included mangrove forest and pineland; tropical hardwood hammock; and former agricultural lands dominated by Brazilian pepper (*Schinus terebinthifolius*). Sites were surveyed biweekly during 1991–1996 for standardized method and opportunistically so during 1991–1998 at night for periods of 15–20 minutes during which time occurrence of calling was noted and the ambient air temperature and relative humidity were recorded.

Climatological data for localities in different parts of the range from which seasonal calling activity of *E. planirostris* was recorded were obtained from the Southeast Regional Climate Center and Pearce and Smith (1990).

Means are followed by one standard deviation.

RESULTS—*Habitat and abundance*—At ABS, *E. planirostris* was recorded in relatively xeric (sandhill, sand pine scrub, scrubby flatwoods) and mesic (bayhead/low flatwoods) natural vegetation associations, as well as in and around buildings (Table 1). Opportunistic records and frequency of calls when checking grids indicated that the species was more abundant in denser sandhill, scrub, and bayhead/low flatwoods than in the more open scrubby flatwoods association. On both the sandhill pitfall grid and scrub arrays, individuals were captured in every month except February, with an increase in captures on the sandhill pitfall grid during September–October and during September–December in the scrub arrays (Fig. 1). Arrays in both unburned and burned scrub sites exhibited a prominent peak in capture frequency during 1986–1987 (Fig. 2), which was associated with unusually high rainfall in

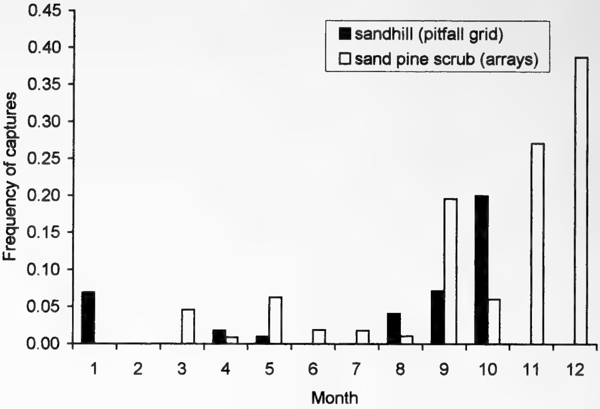

FIG. 1. Seasonal activity (frequency of captures) of the greenhouse frog, *Eleutherodactylus planirostris*, in sandhill (pitfall grid) and sand pine scrub (arrays) associations on the Archbold Biological Station, Highlands Co., Florida, during 1984–1996.

1986. The numbers of total captures in arrays, including original and recaptures, were consistently higher in the unburned than burned sites (Table 1, Fig. 2). The proportion of individuals recaptured was higher in the burned sites (15.0%) than in unburned sites (10.1%) but not significantly so ($p > 0.05$) with the use of a χ^2 test. For all arrays combined, 70.4% of the individuals were taken in pitfalls compared with 29.6% in funnel traps. A significantly higher proportion (78.3 vs. 65.4%; $x^2 = 4.06$, df $= 1$, $p < 0.05$) of individuals were taken in pitfalls in the burned site, perhaps reflecting reduction of ground litter and other refugia as the result of the fire.

Mean body size of 170 individuals captured in arrays was 20.0 ± 3.3 mm (range = 11–28) and did not differ significantly (t-test; $p > 0.05$) among arrays. In the combined sample of captures on the pitfall grid in sandhill and arrays in scrub, mean survivorship (1.9 ± 2.3 mo.; range = 0.03–6.6) of 17 unsexed individuals (21.3 ± 3.1 mm SVL; range = 16–28) was low.

Growth and maturity—Based on Goin's (1947) estimates of incubation time (13–20 days), hatchling size (4.3–5.7 mm SVL), and minimum body size for adult males (15.0 mm SVL) and adult females (19.5 mm SVL), the concentration of juveniles and young adults during September–December in this study (Fig. 3) suggests a summer peak in egg laying and an age at sexual maturity of six to eight months in the ABS population.

Calling season—The calling season at ABS extended from April to September, with most calling during June–September (Fig. 4). The calling season at ENP normally extended from April to September, with a major May–June peak and a second, smaller peak in September (Fig. 4). Calling occurred when the air was warm (mean = 25.2 ± 1.7°C; range = 23–30; N = 29) and the humidity was high (96.8 ± 4.7% RH; 84–100; 30), and generally after rain (mean = 1.8 ± 2.1 cm; range = 0.0–8.0; N = 28).

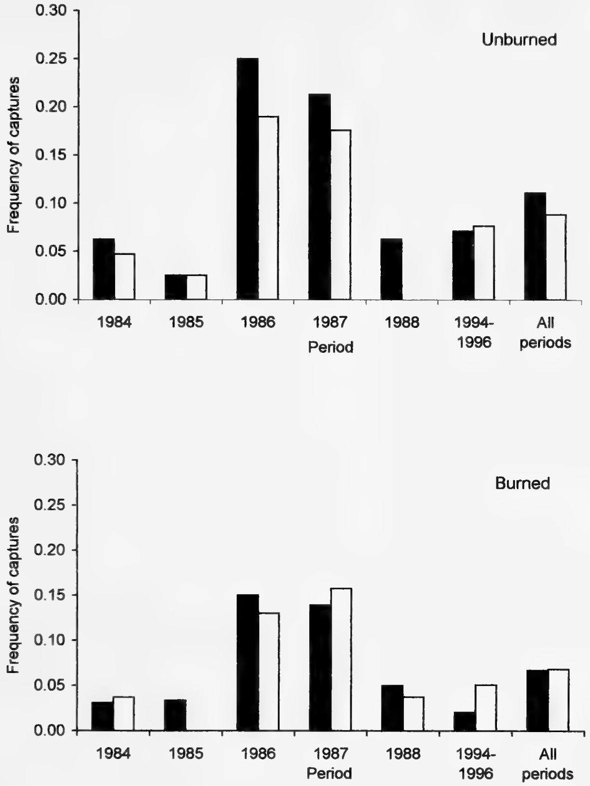

FIG. 2. Frequency of capture of the greenhouse frog, *Eleutherodactylus planirostris*, in sand pine scrub vegetation during 1984–1996 in two (solid and clear) long-unburned sites (upper) and in two (solid and clear) sites before and after a prescribed fire in January 1985 (lower) at the Archbold Biological Station, Highlands Co., Florida.

DISCUSSION—Results of this study agree with findings by others that in Florida (Meshaka et al., 2004 and citations therein) and in the West Indies (Schwartz and Henderson, 1991) the species is most often associated with mesophytic forest habitats. Its abundance in densely vegetated, long-unburned xeric uplands as we observed at ABS, coupled with the historically increased extent of such habitats resulting from widespread fire suppression, help explain the colonization success of this small-bodied and strongly moisture-limited species in Florida. Another factor contributing to its ability to occupy relatively xeric habitats is its extensive utilization of gopher tortoise (*Gopherus polyphemus*) burrows with their humid microclimate (Lips, 1991). An important consequence of fire suppression in sandy uplands in Florida that benefits *E. planirostris* is the deleterious impact on native amphibian and reptile species adapted for the more open conditions maintained by the historic natural fire regimes (Enge and Wood, 2001; Meshaka and Layne, 2002).

In both the south-central and extreme southern Florida localities, the species was active nearly continuously throughout the year. Numbers of captures on the pitfall grid and arrays at ABS exhibited a marked fall-winter peak, which followed

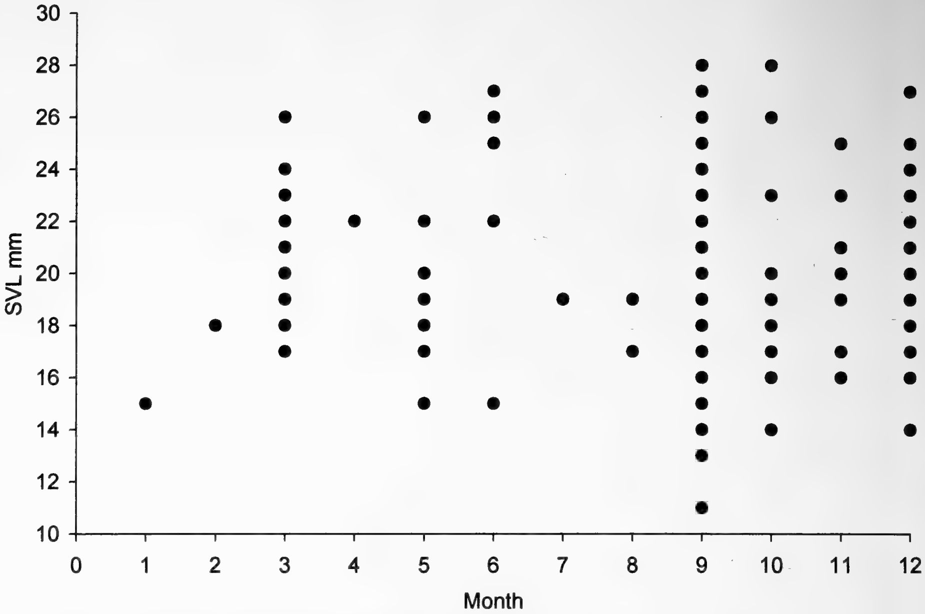

FIG. 3. Monthly distribution of snout-vent lengths of individuals of the greenhouse frog, *Eleutherodactylus planirostris*, captured on a pitfall grid in sandhill habitat and arrays in sand pine scrub at the Archbold Biological Station, Highlands Co., Florida, during 1984–1996.

high levels of monthly rainfall and increasing cumulative rainfall and ended with a sharp decline in monthly precipitation and minimum air temperature. The difference between the seasonal pattern of captures in the sandhill and scrub habitat, with a later peak in the scrub, probably reflects the more moderate winter microclimate of the mature scrub association. The fall-winter increase in captures reflects the recruitment of juveniles into the population and may also be associated with an increase in movements. Support for the latter suggestion is the fact that in year-round monitoring of anurans found in a swimming pool adjacent to ABS, *E. planirostris* occurred only during September–January (Meshaka et al., 2004). The degree to which this species can tolerate extended periods of cold weather at more northern latitudes, which ultimately will limit its range expansion, is unknown, but presumably will depend upon such factors as availability of cold-weather refugia as well as general climatic conditions. For example, its ability to occupy buildings may allow it to extend its range beyond the limits imposed by temperatures in natural habitats. Climatic warming is also a factor in the long-term trend in northward range expansion of the species.

In Gainesville in north-central Florida, eggs are laid during late May–late September, with a July peak, and hatchlings first appear by mid-June (Goin, 1947). In southern Florida, Lazell (1989) reported neonates from Key West during late May–early June, and Deckert (1921) found eggs in Miami-Dade County in May. Although we did not capture hatchlings in this study, a typical egg laying season during June–September at Archbold could produce hatchlings as late as October.

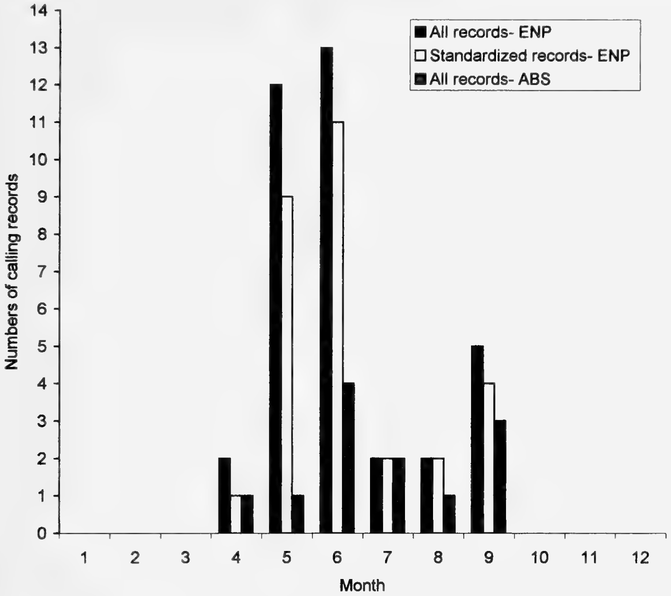

FIG. 4. Seasonal distribution of calling of the greenhouse frog, *Eleutherodactylus planirostris*, at the Archbold Biological Station, Highlands Co., Florida and Everglades National Park, Miami-Dade and Monroe counties, Florida, during 1991–1998.

This being the case, males would mature in about five months during November–March and females in about eight months during February–June.

Thus, assuming a similar annual reproductive schedule as in north-central Florida (Goin, 1947), the ABS population should likewise be comprised of adults and hatchlings in mid June, hatchlings, half-grown individuals, and adults during late August–early September, half-grown individuals and adults late in the year, subadults and adults during early spring, and only adults in spring. Our scattergram (Figure 3) conforms closely with this expectation, with the exception that some ABS females could be nearly mature in the spring. In ENP, with a typical egglaying season overlapping the reliably strong calling season of May–September would produce adults as early as October (males) and January (females).

In southern Florida, *E. planirostris* required warm, humid, but not necessarily wet conditions, in order to call. Although peak reproductive activity occurs during the rainy season in Florida (Goin, 1947; this study), vocalization occurred over a longer season in the southern peninsular region: April–September at ABS and in natural habitats at ENP, and February–November in downtown Homestead (Meshaka et al., 2004). Carr (1940) noted breeding (unclear if calling or egg laying) as late as December in Miami-Dade County. Collectively, our calling data from southern Florida exhibited a bimodal pattern, with a major peak during May–June and a smaller peak in September. This pattern suggests that courtship activity of *E. planirostris* in southern Florida was most intense in the early part of the wet season, with a decline associated with egg-laying and nesting activity of females and perhaps

TABLE 2. Known and predicted calling seasons of the greenhouse frog, *Eleutherodactylus planirostris*, at various localities throughout the range. Predicted calling seasons are provided without parentheses. Known calling seasons and latitudes are in parentheses. Known calling seasons provided for Homestead (Meshaka et al., 2004), Flamingo (this study), ABS (this study), and Gainesville (Goin, 1947).

Location	Calling season
Cuba	
Havana (23:08:00N)	April–January
The Bahamas	
Nassau (25:03:00N)	April–November
Florida	
Key West, Monroe Co. (24:33:46N)	May–November
Flamingo, Monroe Co. (25:08:29N)	May–November (April–September)
Homestead, Miami-Dade Co. (25:27:43N)	April–November (February–November)
Miami, Miami-Dade Co. (25:46:32N)	March–November
Archbold Biological Station, Highlands Co. (27:17:49N)	May–October (April–September)
Ft. Myers, Lee Co. (26:37:50N)	May–October
Tampa, Hillsborough Co. (27:57:32N)	May–October
Orlando, Orange Co. (28:30:17N)	April–October
Gainesville, Alachua Co. (29:40:27N)	May–October (April–September)
Jacksonville, Duval Co. (30:20:04N)	May–October
Tallahassee, Leon Co. (30:27:25N)	May–September
Carrabelle, Franklin Co. (29:50:53N)	May–September
Alabama	
Mobile, Mobile Co. (30:40:39N)	May–September

reduced territoriality of males, followed by a modest resurgence of breeding in late fall. If so, further examination might reveal different aged cohorts in the two peaks.

The lowest monthly mean minimum temperature and rainfall associated with April–September calling during Goin's (1947) study were 15.8°C and 6.9 cm, respectively, compared with 16.0°C and 7.4 cm at ENP. These data provide minima of 15.8 ± 0.3°C and 6.9 ±1.3 cm as thresholds to predict calling seasons within the geographic range of the species as done for the eastern narrowmouth toad, *Gastrophryne carolinensis* (Meshaka and Woolfenden, 1999). Using these data, we predict that calling is possible over the greatest number of months in extreme southern Florida and selected West Indian sites (7–10 months), shorter in southern and central Florida, (6–7 months), and shortest in northern Florida (5–6 months) (Table 2). In Mobile, Alabama, where we expect this species to eventually colonize, calling would probably be restricted to the same five months as in extreme northern Florida (Table 2).

We note that these predictions must be taken as guides, which are qualified, as they do not take into account variation in microclimate of the specific habitat types occupied by frogs in the various regions. For example, at ABS annual mean minimum air temperature in 5 major vegetation types ranged from 9.1°C (monthly range = −1.0–18.5°C) in scrubby flatwoods to 12.5°C (monthly range = 3.2–21°C) in sand pine scrub (Abrahamson et al., 1984). Furthermore, man-modified habitats, such as gardens and other developed areas, as noted in the Homestead region (Meshaka et al., 2004), provide thermal and moisture-related advantages that are absent in other habitats.

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SOLUBLE PROTEIN, MOLAR C:N RATIO, AND AMINO ACID COMPOSITION IN GREEN *VS.* DECAYED SEAGRASS LEAVES (*THALASSIA TESTUDINUM*)

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Abstract: *Chemical analyses of green vs. decayed (fully-necrotic) leaf tissues of* Thalassia testudinum *revealed significant differences in mean (± 1 S.D.) percent dry weight/wet weight, 12.1 ± 6.9% (green)* vs. *23.1 ± 16.6% (decayed), and in mean molar C:N ratio, 19.0 ± 4.2 (green)* vs. *39.2 ± 8.8 (decayed). Conversely, there was an insignificant difference in mean in mean soluble protein, 8.2 ± 1.1 mg/ml (green)* vs. *6.8 ± 5.0 mg/ml (decayed). In an amino acid derivatization analysis using HPLC, we detected 12 amino acids; valine and serine were detected in decayed leaves but not in green leaves, while proline and methionine were detected in green leaves but not in decayed leaves.*

Key Words: *Thalassia testudinum*, seagrass, soluble protein, C:N ratio, amino acid derivatization, HPLC, mass spectometry

Tropical and subtropical seagrass meadows are important components in complex coastal ecosystems. Their roles in sediment ecology (Morse et al., 1987; Short, 1987; Mellors et al., 2002), nutrient cycling (Tomasko and Lapointe, 1991; Fourqurean et al., 1995), and algal-faunal abundances and biodiversities (Twilley et al, 1985; Greenway, 1995; Maciá, 2000) have long been subjects of research (Duarte, 1999; Valentine et al., 2003). Turtle grass (*Thalassia testudinum* Banks ex König) is the dominant subtidal seagrass found near Key Biscayne in Biscayne Bay, South Florida (Maciá, 2000), and as such, has attracted the attention of many researchers and ecosystems modelers (for example, see Fong and Harwell, 1994).

The chemistry and chemical compositions of *T. testudinum* tissues are of special importance, given the central role of seagrasses in the trophic structure of these complex coastal communities. Comparatively few herbivorous species consume *T. testudinum* tissues directly; most of the annual net primary production of the seagrass enters detrital trophic pathways (Newell et al., 1984; Thayer et al., 1984; Newell et al., 1986; Duarte and Cebrian, 1996), though some researchers have emphasized the role of grazing on live *T. testudinum* tissues by sea urchins (Heck and Valentine, 1995; Valentine and Heck, 1999, 2001). Other researchers have noted the potentially

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large impact of intensive grazing by sea turtles, manatees and other large-bodied vertebrates in coastal food webs (Kirsch et al., 2002).

Dawes (1986) and Duarte (1990) emphasized the importance of caloric and protein components made available during *T. testudinum* decomposition and detritus production, yet much remains unknown concerning amino acid and protein chemistry within *T. testudinum* leaves. Recent studies have examined the chemical cycling of nitrogen within *T. testudinum* tissues (Martins and Bandeira, 2002; Marba et al., 2002; Yamamuro et al., 2003), as well as the roles of dissolved nitrogen and phosphorus uptake in *T. testudinum* chemistry (Lee and Dunton, 2000; Fourqurean and Zieman, 2002; Gras et al., 2003).

In this paper, we report statistical estimates on concentration of soluble protein, molar C:N ratio, and amino acid composition within green and decayed (fully-necrotic) leaves of *T. testudinum*.

MATERIALS AND METHODS—Our data were recorded during five months of lab-bench measurements (June-July 1996, October-November 1996, and June 1998). In June 1996 we collected approximately one kg of *T. testudinum* leaves from the Bear Cut Channel along the northern shore of Key Biscayne (25°44′ N and 80°10′ W). Following a method used by Newell and co-workers (1984), all blades were rinsed in freshwater, and portions were cut and sorted into approximately two-gram pieces of green (unblemished) tissues *vs.* fully-decayed (fully-necrotic) tissues ($n = 8$ two-gram portions of each type). We carefully stripped away any epiphytic macroalgae and loosely attached debris, but left undisturbed the necrotic tissues and firmly attached microflorae. The wet tissues were weighed, then dried at 60°C for 48 hours. Dry weights were calculated as a percentage of wet-weight (after Montague et al., 1995).

In a second collection of leaf tissues (approximately one kg) during June 1998, dried tissues were ground in a Wiley cutting mill and the powders were collected using a 40-mesh screen. These powders were used to determine %-soluble protein ($n = 3$ each for green and decayed), molar C:N ratio ($n = 15$ for green, $n = 10$ for decayed), and amino acid composition ($n = 3$ each for green and decayed).

We used the method of standard addition (Lowry et al., 1951) to determine soluble protein content as percent of dry weight. Individual samples of milled seagrass powder (50 mg each) from the July 1996 period were homogenized in one ml of 0.5% tritonex detergent, then centrifuged at 14,000 RPM for five minutes. Supernatent aliquots (100 μl per sample) were placed in sample wells and Bovine Serum Albumin (BSA) was added to each well in 0, 20, 40, 60, 80, and 100 μl amounts. Working solution (200 μl per well) and dionized water were added to bring the final volume to 310 μl per well. After 30 minutes, the absorbency of UV light was read to determine relative absorbance values, and linear regression was performed between standard added *vs.* absorbance. The concentration of soluble protein (mg/ml: expressed as % protein in the solution) was calculated by determining the x-intercept using only those linear regressions in which the coefficient of determination (r^2) ≥ 0.90. This cautious restriction meant that we had to discard the results of over two dozen additional samples in which $r^2 < 0.90$.

For the July 1996 period we analyzed samples (approximately 1–2 μg each) of milled seagrass powder with a Carlo Erba™ 1108 elemental analyzer, a mass spectrometry detector that reported %N and %C within samples combusted at 1,000°C. Known weights for five standards (78% C, 10% N) were used with each batch of seagrass samples. The results were converted to molar C:N ratio values by the function [molar C:N = (%C/12)/(%N/14)].

For the July 1996 period we used the method by Godel and co-workers (1984) for the determination of L-amino acids by HPLC with OPA-mercaptoethanol reagent ($n = 3$ each for milled powders of green *vs.* decayed leaf tissue). The OPA (*o*-phthaldialdehyde) mercaptoethanol buffer was mixed by adding 10 mg of OPA in 1.0 ml methanol + 20 μl 2-mercaptoethanol + 1.0 ml sodium borate buffer 0.5 M, and adjusting the pH to 9.7. The derivatization of amino acid standards used 10–20 μl of a mix of AA's containing L-amino acids (0.2 μmol/ml each) + 20 μl of 0.1 N NaOH (to bring the pH to 9–10) + 40 μl of OPA-mercaptoethanol-Na borate buffer. Our column was a C-18, 0.45 × 25 cm, Supelco. Solvent-A was 10% acetonitrile in 30 mM Na-Acetate buffer, pH 5.5. Solvent-B was 70% acetonitrile in 30 mM

TABLE 1. Statistical comparison of samples (H_0: no significant difference between samples). The parametric t-test was used when sample variances were homogenous, the non-parametric Mann-Whitney test when not.

Variable	Green	Decayed	Test	Result	Prob. H_0 is true	Decision
% dry wgt/wet wgt	mean = 12.1	23.1	t-test	t = −1.726	p = .026	reject
	S.D. = 6.9	16.6		d.f. = 14		
	n = 8	8				
Soluble protein (mg/ml = %)	mean = 8.2	6.8	t-test	t = 0.488	p = .651	non-reject
	S.D. = 1.1	5.0		d.f = 4		
	n = 3	3				
molar C:N ratio	mean = 19.0	39.2	Mann-Whitney	T = 205	p < .001	reject
	S.D. = 4.2	8.8		n(small) = 10		
	n = 15	10		n(big) = 15		

Na-acetate buffer, pH 5.5. The gradient was 0–40% B in 10 min; 40% B to 100% B in 10 min; 100% B for 3 min; 100% B to 0% B in 1 min (return to 100% A); 100% A for 3 min (to equilibrate in A). The flow rate was controlled at 1.2 ml/min throughout. Detection was fluorimetric, with excitation at 330 nm and emission at 450 nm.

Our null hypotheses addressed the two-sample comparison (green tissues *vs.* decayed tissues) for each variable (%-dry weight, %-organic matter, %-soluble protein, and molar C:N ratio), *i.e.*, H_0: there was no significant difference between samples. We used SigmaStat™ 3.0 (2003) software to compare either sample means by parametric t-test (in cases when variances were homogenous) or sample medians by non-parametric Mann-Whitney rank-sum test (in cases when variances were not homogenous). All statistical decisions used the $p < 0.05$ criterion for statistical significance (Zar, 1996).

RESULTS—The comparison of sample means and/or medians is shown in Table 1. We found that the decayed leaf tissue had nearly twice the mean % dry weight of the green tissue (23.1% *vs.* 12.1%, p = .026).

We found no significant difference in mean soluble protein between green (8.2%) and decayed (6.8%) leaves (p = .651).

The mean molar C:N ratio for decayed leaves (39.2) was over twice the value for the green leaves (19.0), and this difference was significant ($p < .001$).

The mean percent values of total amino acids are shown in Fig. 1. Valine and serine were undetected in all three of the green leaf samples, while proline and methionine were undetected in all three of the decayed leaf samples.

DISCUSSION—Our results are based on some arguably small sample sizes, and this always brings the risk of Type-II error (failure to reject a false null hypothesis). We certainly recognize this risk, but following Zar's caution against discarding valid data (Zar, 1996; p. 258), we allowed SigmaStat™ (2003) to test the differences between samples.

Our data revealed interesting features in the carbon and nitrogen abundances within *T. testudinum* tissues, yet much detail remains unknown about the cycling of these nutrients among the biotic and abiotic reservoirs within tropical seagrass beds. The more commonly reported variable for nitrogen content in plant tissues (%N, *e.g.*, Fourqurean and Zieman, 2002) estimates total nitrogen that might enter

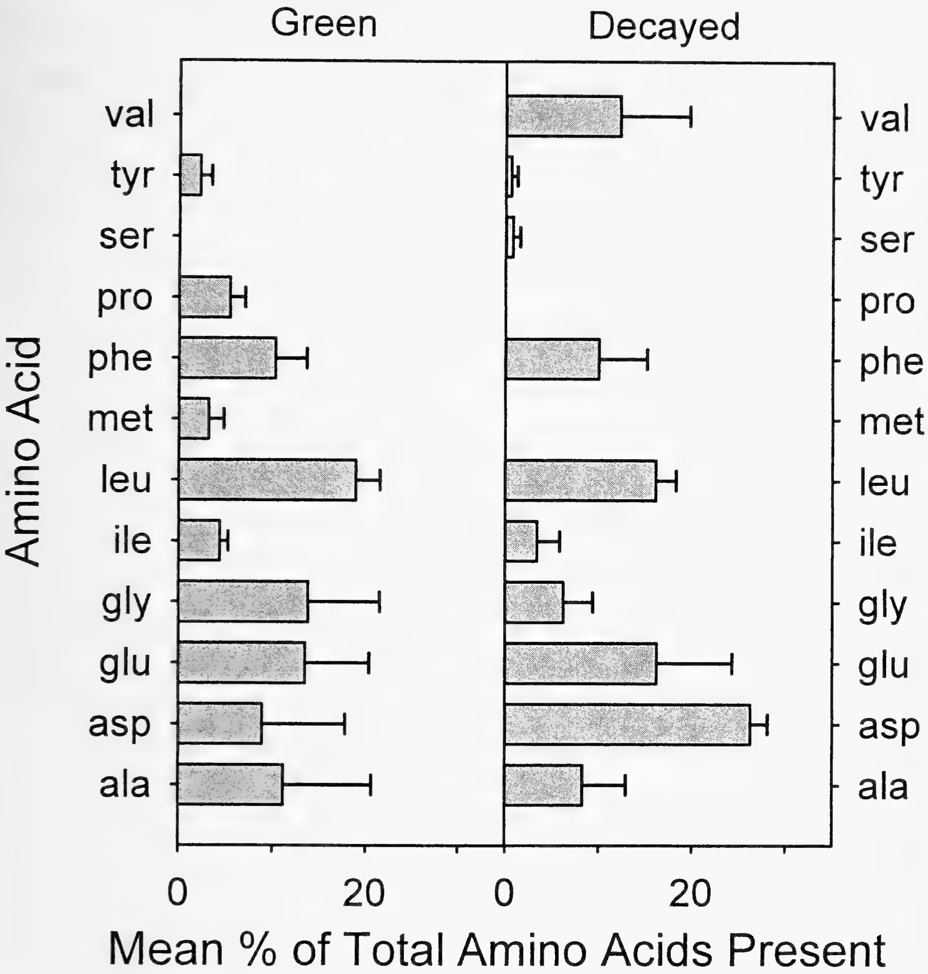

FIG. 1. Mean (+ 1 S.D.) values for percent of total amino acids present per leaf type (n = 3 each for milled samples of seagrass tissues).

various consumer and decomposer pathways. But %N does not apportion the nitrogen available within leaves into usable *vs.* unusable categories for animals, such as protein *vs.* NH_4^+. For this reason we have measured the more particular (and less reported) variable of soluble protein.

Our estimates for mean soluble protein (mg/ml = approximately 6–8%) are consistent with estimates for decomposing *T. testudinum* leaf litter in South Florida reported by Rublee and Roman (1982), and for photosynthetically active tissues reported by Dawes and Lawrence (1980, 1982), though these authors did not distinguish between soluble and insoluble fractions in their protein preparations.

Dawes and Lawrence (1982) reported winter-summer fluctuations in the protein content. We suspect a sizable (thought currently unknown) portion of the summertime protein content in *T. testudinum* leaves would be devoted to carbon fixation. A clearer picture of the photosynthetic pathways in *T. testudinum* might reveal the bases of fluctuations in the carbon-nitrogen ratios in the leaves of these plants.

The carbon chemistries of seagrasses, particularly in the photosynthetic pathways are not well-known. Keulen (2004) noted the ^{14}C pulse-chase experiments of Beer and Wetzel (1982) indicating C3 chemistry for most species of seagrasses but some sort of intermediate C3–C4 Hatch-Slack chemistry for sugar production in *T. testudinum*. The Mediterranean seagrass *Cymodocea nodosa* was the only species reported by Beer and Wetzel (1982) as unambiguously C4 in its chemistry.

Is *T. testudinum* really a C4 plant? The Beer and Wetzel conclusion was based on relatively high initial fixation rates of HCO_3^- into malic acid in *T. testudinum* (a C4 feature) rather than on any particular structural or morphological indicators within the leaves, (*e.g.*, presence *vs.* absence of bundle-sheath cells). As noted by Beer and Wetzel (1982), the terrestrial advantages of C4 chemistry include the conservation of water in warmer, more desiccating environments, but such advantages are lost in aquatic environments. However, the additional advantage of C4 chemistry in minimizing carbohydrate losses during photorespiration could explain why such aquatic plants might thrive in relatively bright light near the surface. On the other hand, C4 chemistry might be adaptive in seagrasses if it increases the efficiency of dissolved CO_2 uptake, an adaptive benefit reported by Reinfelder and co-workers (2000) for the marine diatom *Thalassiosira weissflogii*.

The relationship between photosynthetic chemistry and aquatic ecosystem trophic structure is complex. The C3 and C4 chemistries in some freshwater stream plants have been examined (Clapcott and Bunn, 2003), and while aquatic C4 plants tend to be relatively abundant and productive in aquatic ecosystems, they contribute relatively little to freshwater food webs. The unique structural and anatomical features of C4 leaves (*e.g.*, bundle-sheath cells) make them generally low in the nutritional quality available to aquatic herbivores (Caswell et al., 1973), though this applies most clearly to examples of aquatic macro-herbivores such as so-called "*shredding*" insects (those that consume plant tissues through cutting or chewing). While grazing herbivores are generally rare in marine ecosystems, Valentine and co-workers (1997) noted the important stimulating effect of sea urchin grazing in the productivity of *T. testudinum*. Also, the microbial degradation and leaching of C4 (or intermediate C3–C4) tissues in seagrass meadows might release considerably more carbon and nitrogen into the coastal food webs (as suggested by Newell et al., 1986) than might be predicted from simple reference to freshwater ecosystems.

Our observed means for molar C:N ratio (Table 1) fall within the range of seagrass leaf C:N ratios reported by Duarte (1990; C:N values of approximately 10–50). Duarte noted that the carbon fluctuation tends to be relatively small compared with the nitrogen fluctuation in the measurement of this ratio. Our values also fall within the C:N ratios reported by Fourqurean and Zieman (2002; median = 24.5, range approximately 14–50). On the other hand, our mean value for C:N ratio in decayed leaves (mean = 39) is higher than those reported by Newell and co-workers (1984; C:N ratio values of approximately 15). However, the decomposing leaf samples analyzed by Newell and co-workers (1984) had been left in the field litterbags for roughly 2–3 months prior to analysis, allowing for mechanical (water turbulence) and various biological and chemical factors to accelerate decomposition. Our decayed portions were cut from intact leaves in the field that were subjected to arguably different stresses than tissues stored in field litterbags. Lastly, Zieman and co-workers (1984) reported ranges of C:N ratios in *T. testudinum* leaves of approximately 13–19 in green tissues and approximately 28–42 in decayed tissues.

Low molar C:N ratio in green seagrass leaves may play an important role in rates of subsequent tissue degradation. Mfilinge and co-workers (2002) reported that subtropical mangrove (Eudicotyledon) leaves of relatively low C:N ratios decay at a faster rate compared with those of higher ratio, suggesting the rate of leaf decay in seagrasses could be contingent on initial C:N ratio within fresh tissue.

Anderson and Fourqurean (2003) noted the variability in C:N isotope data collected from *T. testudinum* tissues in Florida Bay, suggesting that seasonal fluctuations in microfloral abundances and abiotic factors such as water temperature or currents may significantly affect the sequestering or release of carbon and nitrogen by the living plant tissues.

Our observations on the presence of proline and methionine in green tissues but their absence in decayed tissues (as well as the absence of valine and serine in green tissues but their presence in decayed tissues) seem puzzling at first glance. One might not expect amino acids to appear and disappear in such a fashion within plant tissues. However, we should consider the important (but largely unknown) role of autotrophic and heterotrophic microflorae that attach epiphytically and somehow contribute to the decomposition of *T. testudinum* leaves. The selective addition or removal of amino acids in *T. testdinum* leaves by microbes has yet to be fully explored.

Zieman and co-workers (1984) detected 15 amino acids in *T. testudinum* leaves using the Hare method (a hydrolysis and HPLC-fluorometric detection procedure), as opposed to our detection of 12 amino acids using the Godel method. They used sample sizes comparable to ours ($n = 3$), though they included more field sites in their analysis. While they detected histidine, lysine, arginine and threonine, we did not. Interestingly, they did not report the detection of proline in their samples of decomposing leaves (a finding consistent with our data in Fig. 1). They did, however, detect variable amounts of methionine in their decomposing leaves (a finding not consistent with our results).

Zieman and co-workers (1984) also reported a general decrease in total amino acid concentration (measured in μmols of amino acids/gDW) during the decomposition of *T. testudinum* leaves, though the concentration of D-glutamic acid showed relatively less fluctuation during decomposition. This finding is somewhat consistent with our measurements of glutamic acid concentration in green *vs.* decayed tissues (Fig. 1), though our method focused on the detection of L-glutamic acid.

Udy and co-workers (1999) reported proline, asparagine and glutamine as the most abundant amino acids in leaves from several species of seagrasses; these three compounds made up approximately 85% of the total amino acids detected in fresh leaves of the Australian seagrass *Halodule uninervis*. Interestingly, Udy and co-workers (1999) did not detect proline in fresh leaves of the sympatric species *Syringodium isoetifolium*.

The ecological role of epiphytic algae has been examined in tropical *T. testudinum* (Frankovich and Zieman, 1994); high epiphytic loads of prokaryotic cyanobacteria and eukaryotic rhodophytes (particularly the dominant coralline red algae *Melobesia membranacea* and *Fosliella farinose*) are correlated with high productivities in the turtle grass beds of Florida Bay. Louda (2002), however, argued that the production of epiphytic red algae fluctuates irregularly over time and may be less important than epiphytic diatoms (Bacillariophyta) in the productivities of Florida Bay *T. testudinum.*

In summary, we found intriguing patterns of carbon and nitrogen variabilities within *T. testudinum* leaf tissues, though our arguably small sample sizes and limited spatial and temporal sampling add uncertainty to our conclusions. The precise relationships of these variabilities to broader structure and function in the seagrass ecosystem remain unclear, but we look forward to new observations and experiments.

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SPATIAL PICTURE OF A GECKO ASSEMBLAGE IN FLUX

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ABSTRACT: *With a focus on geckos, building-dwelling amphibians and reptiles at Savannas Preserve State Park in Martin and St. Lucie counties, Florida, were intensively censused over a four month winter-spring period so as to determine the status of exotic species on 10 buildings of this rural-urban park encapsulated by suburban development. Our findings supported the hypothesis that invasion by* Hemidactylus mabouia *was recent, and that it was incapable of stable co-existence with its ecologically analogous congener on buildings. Our findings also underscore the rapid pace at which ecological processes can occur in non-indigenous faunal communities.*

Key Words: colonization, ecology, exotic species, *Hemidactylus garnotii*, *H. mabouia*, Florida, Savannas Preserve State Park

COLONIZATION of the wood slave (*Hemidactylus mabouia*) in Florida is at the expense of other hemidactylines, and perhaps sphaerodactyline geckos as well (Meshaka et al., 2004). As a superior competitor and potential predator of the Indo-Pacific gecko (*H. garnotii*) on buildings, *H. mabouia* rapidly replaces or marginalizes its congener with many more individuals of itself than of previous numbers of *H. garnotii* (Meshaka, 2000). Knowing that *H. garnotii* has been in Florida longer than *H. mabouia*, and that *H. mabouia* is not thought to yet be ubiquitous in Martin County, we undertook an intensive winter survey at a 2104.4 hectare rural park in Martin and St. Lucie counties, completely encapsulated by suburban development, to evaluate the status of both species and test the notion that *H. mabouia* was a recent colonizer of the area.

METHODS—Seventeen visits were made to ten buildings at Savannas Preserve State Park, Florida during 22 December 2003 – 1 March 2004. In the same fashion as Meshaka (2000, 2001), geckos and other amphibians and reptiles on buildings were counted during a single walk around each one after dark and on nights with less than 3/4 moon. Vouchers of geckos from each building were collected for verification of species identification and were deposited in the State Museum of Pennsylvania in Harrisburg. Exceptionally, buildings No. 1 and 2 were surveyed only five times (22 December 2003 – 4 January 2004) and results of those censuses are considered qualitative in nature. Data were available for No. 6 from ten visits and for No. 9 from 13 visits. Relative abundances are presented as means of the total counts. Means are followed by standard deviation.

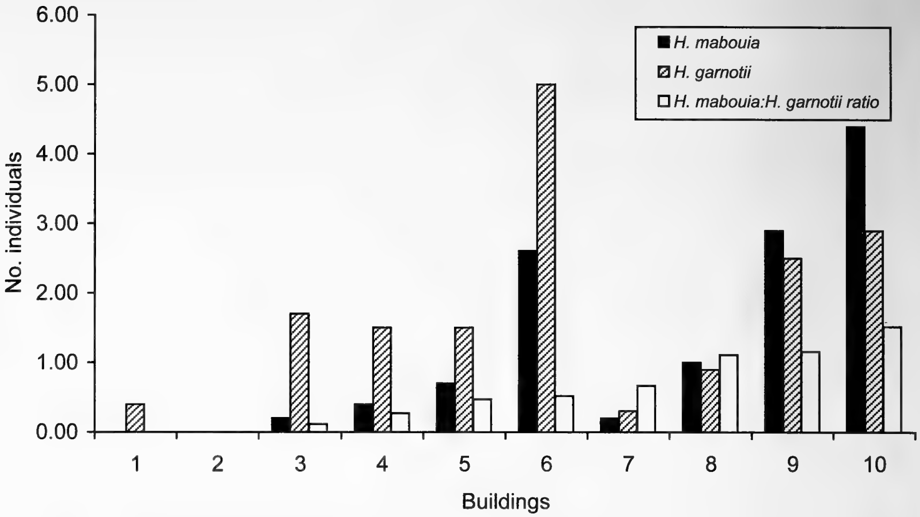

FIG. 1. Relative abundance of the wood slave (*H. mabouia*) and Indo-Pacific gecko (*Hemidactylus garnotii*) and the ratio of both species on ten buildings at Savannas Preserve State Park, Martin and St. Lucie counties, Florida.

RESULTS AND DISCUSSION—*Hemidactylus mabouia* was found on eight buildings, and *H. garnotii* was found on nine buildings (Fig. 1). Relative abundances of these two gecko species varied among sites (2 × 10 Contingency table; $X^2 = 48.21$; df = 2; $p < 0.001$). No geckos were found on No. 2, whose survey, like that of No. 1, was cut short due to logistical constraints. Only *H. garnotii* was detected on No. 1 (Fig. 1). Excluding No. 1 and 2 because of limited sampling, *H. mabouia* was greatly outnumbered by *H. garnotii* on four buildings (No. 3–6), was similar in abundance to *H. garnotii* on three buildings (No. 7–9), and exceeded *H. garnotii* in abundance on one building (No. 10) (Fig. 1). Physical conditions associated with nightly activity were similar between the two species. For example, an F-test (F = 1.10) and a two-tailed t-test assuming equal variance (t = −1.29) revealed no significant difference ($p > 0.05$) in the air temperature associated with active individuals of *H. mabouia* (20.0 ± 2.1°C; range = 14.5–23.4; N = 179) and *H. garnotii* (19.8 ± 2.2°C; range = 14.5–23.4; N = 234). Likewise, an F-test (F = 1.07) and a two-tailed t-test assuming equal variance (t = −0.81) also revealed no significant difference ($p > 0.05$) in the relative humidity associated with active individuals of *H. mabouia* (73.1 ± 8.1%; range = 58–84; N = 179) and *H. garnotii* (72.4 ± 8.3%; range = 58–84; N = 234).

The conflicting findings of species dominance and the overlap of physical conditions associated with activity conform to the notion that these two species are ecologically analogous to one another and do not stably co-exist (Meshaka, 2000). Among the predators of geckos, the Cuban treefrog (*Osteopilus septentrionalis*) was found (1.60 ± 1.20; range = 0–3; N = 17) on No. 10. This species, found on what was the largest building, could serve to suppress population densities of the superior competitor, thereby stalling the faunal turnover and staving off complete replacement as noted elsewhere (Meshaka, 2000, 2001). Another confirmed predator of geckos (Meshaka et al., 2004), the corn snake (*Elaphe guttata*), was found once on each of two buildings (No. 3 and 8) during February. Among the potential competitors for food on buildings (Meshaka, 2001), the green treefrog (*Hyla cinerea*) on No. 4 (0.06 ± 0.24; range = 0–1; N = 17) and No. 9 (0.50 ± 0.72; range = 0–2; N = 17), and the squirrel treefrog (*H. squirella*) on No. 9 (0.40 ± 0.70; range = 0–2; N = 17) were negligible in abundance.

Replacement by *H. mabouia* can occur quickly, resulting in more *H. mabouia* than the previous numbers of *H. garnotii* (Meshaka, 2000). The distribution of geckos on these buildings as seen by increasing *H. mabouia*:*H. garnotii* ratio (Fig. 1) points to a very recent invasion of *H. mabouia* of what was otherwise a well-colonized site by *H. garnotii*. For example, No. 3–6 represented the earliest stages of colonization, where *H. mabouia* was still greatly outnumbered by *H. garnotii* (Fig. 1). Among those four buildings, No. 6, with the highest *H. mabouia*:*H. garnotii* ratio (0.52) indicated a replacement episode farther along than those of No. 3–5 where *H. garnotii* was still far more numerous than *H. mabouia*. On the other hand, No. 10, with a *H. mabouia*: *H. garnotii* ratio of 1.52:1, represented the most advanced stage of replacement among the park buildings and may well have been the first building colonized by *H. mabouia* at the park. Buildings No. 7–9 represented an intermediate stage between initial colonization (No. 3–6) and dominance (No. 10) by *H. mabouia*. Thus, even as the spatial distribution of increasing *H. mabouia*:*H. garnotii* ratio across buildings revealed assemblage instability, the increasing *H. mabouia*:*H. garnotii* ratio that progressed from No. 3 to No. 10 should also be read as the temporal pattern to replacement by *H. mabouia* and a glimpse into the future of this site as the *H. mabouia*:*H. garnotii* ratio continues to increase over time. Such being the case, we have every expectation that future visits to these same buildings will, like those elsewhere, be greeted with *H. mabouia* as the dominant species. As more species of geckos attempt to colonize Florida and as species already established in Florida attempt to colonize new areas within the state, it remains to be seen which species will be capable of persisting in these artificially novel and increasingly numerous combinations of building-dwelling species.

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Oceanographic Sciences

2003 SUMMER UPWELLING EVENTS OFF FLORIDA'S CENTRAL ATLANTIC COAST

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Abstract: *During the summer of 2003, an uncharacteristically high number of intense upwelling events occurred along the east central coast of Florida. A bottom-mounted temperature logger collected hourly seawater temperatures on hard-bottom habitat 0.4 km offshore of North Hutchinson Island from 29 May to 21 August 2003. During this time, six upwelling events occurred in which low temperatures ranged between 16–21°C. Early and late summer upwelling events averaged 12.3 and 5.3 days, respectively. A series of Pearson correlations between time series data from the logger and those of surface estimates from SeaWiFS suggest that the longer upwelling events in early summer eventually resulted in similar surface and bottom temperatures. In turn, the shorter upwelling events during late summer appear to have resulted in stronger thermoclines because of less time for mixing between surface and bottom waters. Analysis of local meteorological data suggests that wind stress was not upwelling favorable during most of the summer yet may have played a supplementary role in producing some of the upwelling events.*

Key Words: upwelling, seawater temperature, satellite imagery, SeaWiFS, Florida nearshore reefs

Seasonal upwelling has often been reported over the past 50 years in Atlantic shelf waters off the east central Atlantic Coast of Florida (Green, 1944; Taylor and Stewart 1958; Blanton, 1971; Atkinson, 1977; Lee et al., 1981; Smith, 1981; 1982; 1983; Reed and Mikkelsen, 1987; Pitts, 1993; Pitts and Smith, 1997). These intrusions of cold, deep, nutrient-rich water onto the continental shelf can decrease seawater temperatures 6°–10°C for 1–3 wks during mid- to late-summer although additional short-term cooling events sometimes occur throughout the summer (Smith, 1981; 1982; Pitts and Smith, 1997). Upwelling events most likely occur when the Florida Current meanders to the west and contacts the continental shelf, which facilitates a shoreward–directed pressure gradient in the benthic boundary layer and onshore advection of cooler water onto the shelf (Smith, 1981; 1982; 1983; Pitts, 1993; Pitts and Smith, 1997). Also, wind forcing encourages upwelling when wind directions are persistently out of the SE quadrant (Smith, 1981; 1982; 1983; Pitts, 1993; Pitts and Smith, 1997).

During the summer of 2003, there were an unusual number and intensity of upwelling events off the Atlantic coast of central Florida with reports of negative effects on local marine fauna. During upwelling events, there were lower numbers of loggerhead turtles nesting, and hatchlings were often observed to be cold-stunned shortly after entering the water (Martin, 2003). In addition, there were observations

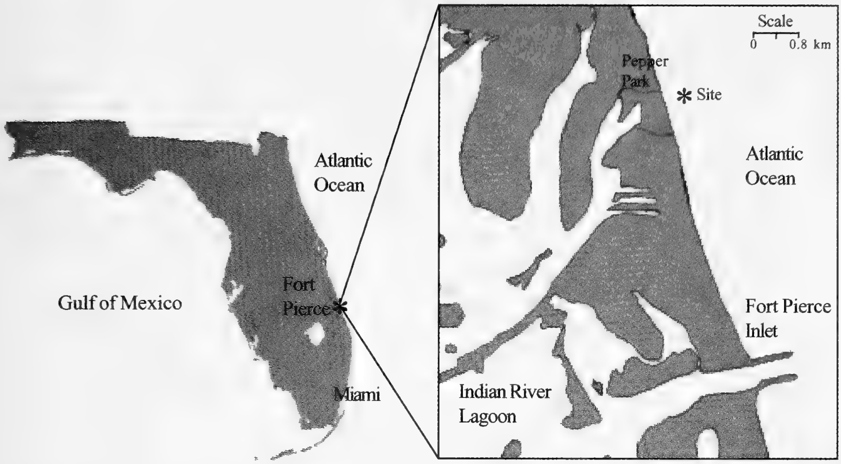

FIG. 1. Map of Florida showing Fort Pierce. Inset shows close up of Pepper Park with location of data logger. The ONSET temperature logger was cable-tied to a PVC-framed, vexar cage, which was nailed to the hard bottom with masonry nails.

of bottom-dwelling reef fish either being found dead, or swimming sluggishly near the water's surface or in the surf zone (Reed, 2003). Although it appears likely that these upwelling events were responsible for observed biological effects, attempts to relate water temperature and biological effects are usually done with time-series data obtained from satellite imagery. Sea surface satellite imagery is useful for showing spatial patterns, but has the following limitations of: 1) not always being available due to cloud cover or satellite problems, 2) only providing surface water temperatures, and/or 3) sometimes not being accurate because of atmospheric effects such as humidity. Time-series data from nearshore *in situ* devices are generally rare yet important, because they provide a more continuous data set as well as subsurface temperatures. Further, they can be used with satellite techniques to obtain a more accurate picture of seasonal changes of seawater temperature throughout the water column.

The main objectives of this paper are to report 2003 summer, subsurface seawater temperatures for the Pepper Park location, and compare such data with satellite estimates (SeaWiFS) of surface temperatures for the same area. An additional objective is to explore the role of wind stress in producing the observed upwelling events.

METHODS—During the summer of 2003, weekly field experiments were conducted on hard-bottom habitats off Pepper Park (Fort Pierce), Florida (27°29.872′ N; 080°17.775′ W) (Fig. 1). A temperature logger (ONSET HOBO Water Temp Pro; Accuracy = ~0.2–0.33°C) was deployed 0.4 km offshore in 3 m depth on hard-bottom habitat from 29 May 2003 to 21 August 2003. Seawater temperatures were recorded every hour during this period. Satellite estimates of seawater temperatures for this same location and period were derived several times per day from infrared observations collected by the Advanced Very High Resolution Radiometer (AVHRR) sensors flown on the National Oceanic and Atmospheric Administrations Polar Orbiting Environmental Satellite (SeaWiFS; Accuracy = ~0.5°C; Spatial Resolution = 1.5 × 1.3 km). Daily seawater temperature means were separately computed for satellite

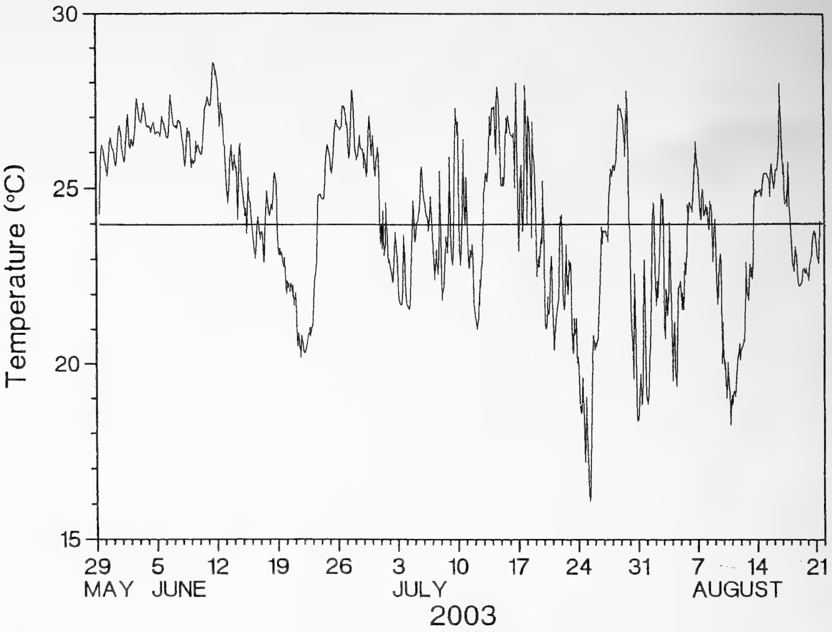

FIG. 2. Hourly seawater temperatures recorded at the study site at Pepper Park during May 29–Aug. 21, 2003. The line in the plot represents the threshold temperature for an upwelling event..

estimates and the temperature loggers by averaging respective data available for each day. Correlation analysis was used to examine how closely both techniques documented the seawater temperatures and upwelling events that occurred during the summer. An upwelling event was defined as occurring during any time period where the daily mean seawater temperature went below 24°C. This value was chosen as the threshold because normal "warm" water periods of the summer generally vary between 25 and 29°C (Smith, 1981; 1982; 1983; Pitts, 1993; Pitts and Smith, 1997). Because there were time periods of rapid temperature changes that were likely related to cold water moving in and out of the immediate area of the logger, an upwelling event was considered clearly over if the daily mean temperature exceeded 24°C for more than two consecutive days.

The role of wind stress in producing these observed upwelling events was explored by obtaining hourly wind speeds and directions from the Vero Beach Municipal Airport (17 km NW of the study site) for the same time period as the logger data. Since the airport is ~6 km inland, wind speeds were increased to better approximate over-water conditions (Hsu, 1981). Wind data were then converted to wind stress vectors using a drag coefficient developed by (Wu (1969) for moderate wind speeds. The wind stress vector was decomposed into longshore and cross-shelf components that were smoothed using an exponential filter (emphasizes the most recent wind stress but incorporates to a lesser extent winds recorded earlier). The longshore components were then compared with the seawater temperature series using regression analyses.

RESULTS AND DISCUSSION—Six upwelling events were recorded at the study site from 29 May to 21 August 2003 (Figs. 2 and 3). Subsurface temperatures ranged between 24.5 and 28.7°C from May 29 to June 10. The first upwelling event occurred from 15 to 23 June (9 d) with a low temperature of 20.5°C. After this upwelling event, the temperature increased back to 24.5–28.7°C. A second upwelling event occurred from 1–12 July (12 d) with a low of 21°C. After a brief

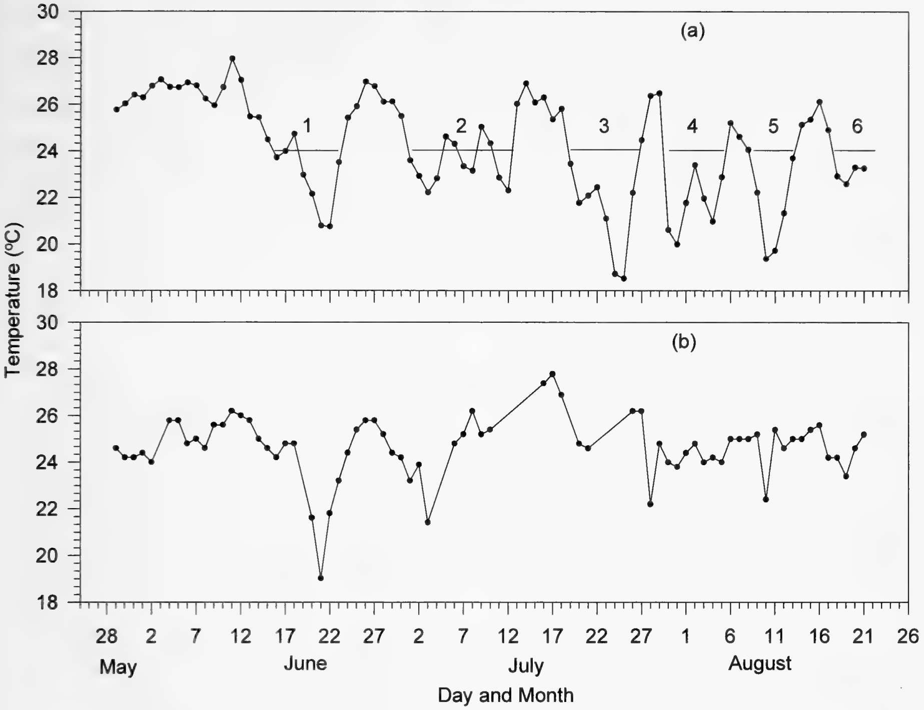

FIG. 3. A comparison between Pepper Park daily means of seawater temperatures obtained by ONSET logger (3 m depth) (a) and SeaWiFS (surface waters) (b). Note that high cloud cover during 10–26 July limited the availability of SeaWiFS data. The numbered lines represent periods of upwelling.

return to warmer temperatures, the upwelling with the lowest temperature (16.0°C) of the summer was recorded during 19–26 July (8 d). The following temperature increase reached 24.5–28.0°C and remained at those temperatures between the upwelling events that occurred on 30 July–5 August (6 days), 9–13 August (5 d) and 17–21 August (5 d). In the final 3 events, minimum seawater temperatures ranged between 18.0 and 23.0°C. In addition, the final upwelling event may have lasted longer but I recovered the data logger before its completion.

Comparison of satellite and logger temperatures were generally similar throughout the summer, yet were more strongly correlated during early summer (Fig. 3). A Pearson Correlation (SYSTAT for Windows: Statistics, 1992) revealed that daily mean seawater temperatures of the satellite estimates and logger were moderately correlated ($r = 0.480$; $p < 0.001$; $n = 71$) during the entire summer. However, from May until the time period where there were numerous gaps in the satellite data (July 10–26), the logger data were 1.0–2.0°C warmer than that provided by the satellite, and showed a much stronger similarity in pattern ($r = 0.860$; $p < 0.001$; $n = 43$). A comparison of the data sets after July 26 show that the logger data are generally 2.0–5.0°C cooler than that of the satellite data, yet have no similarity in pattern ($r = 0.236$; Not significant; $n = 26$).

Observed differences between the daily averaged seawater temperature data of the satellite estimates and those of the logger may be related to inaccuracies between these methods, or the existence of a thermocline as influenced by upwelling duration. From May 29 to July 10 (when there was complete overlap between satellite and logger data), the significant correlation between the data sets may have been due to the relatively long duration of upwelling events (mean = 12.3 d; s.d. = 3.5; n = 3) that allowed for more uniform cooling throughout the water column. The generally warmer logger temperatures during this time may be a result of either instrument accuracy differences or an air-cooling effect on surface waters. From July 10–26, the low number of satellite data points (due to cloud cover) clearly prevents a good assessment of temperature changes using SeaWiFS, although the few satellite data points generally correspond to those of the logger. However, after July 26 when the satellite data had no gaps, the difference between surface and subsurface temperatures is greater and reversed. Errors in satellite estimates may have occurred because of increased atmospheric affects related to humidity that may occur during the late summer. However, surface and subsurface temperatures during this time may not have been the same. Further, during this time the correlation between the logger and satellite temperatures becomes non-significant which may be because upwelling events were shorter (mean=5.33 days; s.d.=0.58; n=3). This short duration may not have allowed enough time for cool subsurface waters to mix with the surface before being withdrawn back into deeper waters. Indeed, I encountered the highest number of thermoclines or patches of cold water when scuba diving at Pepper Park during August.

Regression analysis revealed that the wind stress vector having the strongest relationship ($r^2 = 0.09459$, $p < 0.01$) with seawater temperature was the longshore component 127°–307°. Figure 4 shows time-plots of the exponentially-filtered, longshore component of wind stress and Pepper Park bottom seawater temperatures. Negative values in the upper plot indicate longshore stress to the Northwest, which is upwelling favorable. Results show that during most of the summer, wind stress is upwelling unfavorable. However, four times during the summer (June 2, 9–10, and 19–24; August 6–8) winds were upwelling favorable although generally weak in strength. Only one of the upwelling events recorded corresponded in time to a period of upwelling-favorable wind stress (June 19–24).

In summary, six upwelling events occurred with minimum temperatures values within 16–22.5°C. While there were numerous reports of similar events occurring along the east Florida coast (Martin, 2003; Reed, 2003), these results may not necessarily reflect the exact same patterns as observed at other locations, because upwelling events can be very localized (Smith, 1983; Pitts, 1993). The most intense of the observed upwelling events occurred from 19–26 July. Early summer upwelling events generally were longer than those during late summer. Seawater temperatures from the *in situ* logger and satellite estimates were most similar during early versus late summer. This may be because the longer upwelling events in early summer allowed for more time for surface and bottom waters to mix and become less stratified. Finally, winds were generally not upwelling favorable during the summer yet may have played a supplementary role in producing some of the upwelling events particularly during mid-June.

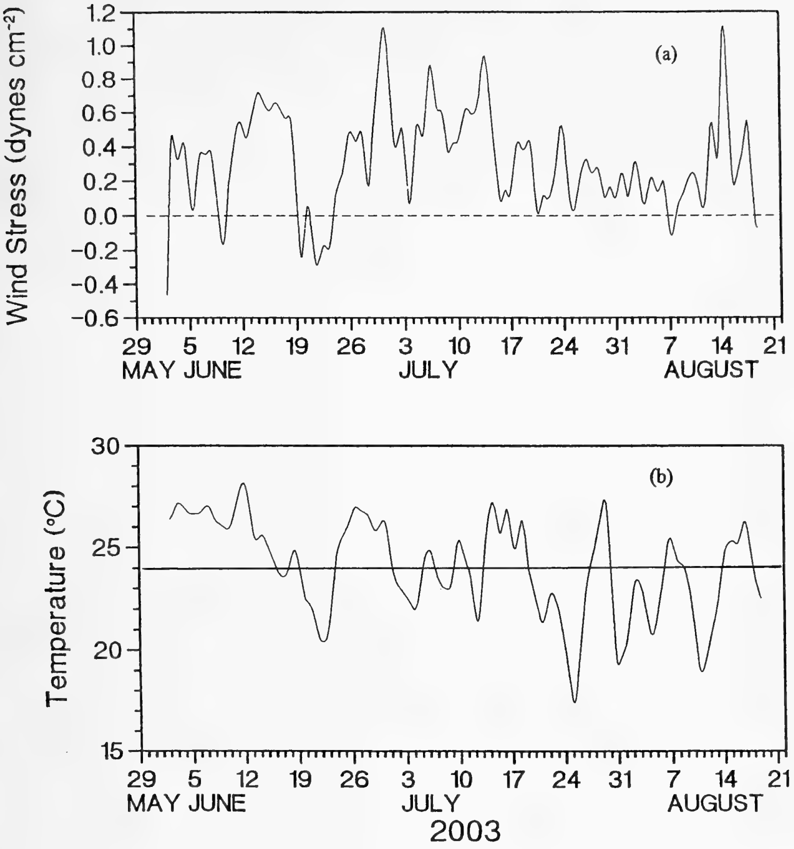

FIG. 4. Time-plots of exponentially-filtered, longshore component of wind stress (dynes/cm^2) (a) and Pepper Park seawater temperatures (b) from May 29 to August 21, 2003. Negative values in the top plot indicate upwelling-favorable winds. The line in the bottom plot represents the threshold temperature for an upwelling event.

ACKNOWLEDGMENTS—I thank Frank Muller-Karger for his assistance collecting seawater temperature data through SeaWiFS. I also thank Ned P. Smith for his assistance with data analysis and manuscript suggestions. This research is Smithsonian Marine Station at Fort Pierce contribution number 592.

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REVIEW

George Gaylord Simpson, Anne Roe and Richard C. Lewontin, *Quantitative Zoology: Revised Edition,* Dover Publications, Mineola, N.Y. Pp. 440. Paper, $26.95.

This classic text, written in 1939 and revised in 1960, has been reprinted by Dover Publications. The original text by Simpson and Roe exposed zoologists to numerical techniques (statistics) that were primarily unknown to researchers; it had simple, algebraic explanations of the tests accompanied by familiar zoological examples. In 1960 Lewontin revised the text, strengthening the statistical techniques and incorporating the use of computer science. The revised edition has been well received by older individuals with limited mathematical backgrounds and by undergraduate students looking for explanation of statistical methods described in the literature.

However, with the rapid development of statistical methods and more powerful computers that have accompanied technological development in the last 30 years, the text is somewhat dated. It was never intended to cover all of the statistical or biometrical techniques that a zoologist might need for his/her research, but the absence of many of the newer methods are serious shortcomings. For example, a modern zoologist might need a number of techniques that are not included such as: non-parametric statistics, repeated measures analyses of variance, comparison of simple regressions, multivariate analyses, cladistics, Monte Carlo sampling experiments, and model building. Moreover, these are common components of many of the statistical computer programs available to students.

Quantitative Zoology is an excellent text for a beginning undergraduate student. But for graduate students and professional biologists, there are a number of excellent statistics and biometry texts, in hardbound or paperback versions, which may be more appropriate.—Bruce C. Cowell, University of South Florida, Tampa, FL.

REVIEW

Faraday, M. 2004 (reprint of 1914 book). *Experimental Researches in Electricity* Dover. Paper 21.5 × 13.5 cm. xiv+ 338 pp. $19.95. ISBN 0-486-43505-9

THIS is an unabridged reproduction of a volume published by J. M. Dent & Sons, Inc., London, in 1914, and was evidently published in three volumes between 1839 and 1855. The value of the present volume is mainly for the insight that it provides to the person interested in the history of science. Faraday was noted for his clear direct language, both in his writing and in his lecturing at the Royal Institution where he served.

The writing shows Faraday's impressive sense of organization. He had a habit of numbering each paragraph in his work, and the last paragraph of his private notes was numbered 16,041. He used this system to unify the paragraphs, citing in paragraph 947, number 955, and vice versa. The writing is interesting, and the expositions are impressive for the clarity and lack of extensive mathematical treatment. The reader is exposed to a simpler time when the apparatus was simple, but the powers of observation were truly impressive. It is also possible to recognize an early use of such terms as anode and cathode, as Faraday retained the consulting services of William Whewell, an expert in Greek. The book also has a biographical note written by John Tyndall in 1869, who noted the financial sacrifices that Faraday made by focusing on science instead of becoming more involved in commercial ventures. When the annual salary of a governess was about £30, Tyndall noted that "Faraday had to choose between a fortune of £150,000 on the one side and undowered science on the other. He chose the latter, and died a poor man." We are beneficiaries of that choice and the sacrifice that it represented, and it is useful to read about the subject that inspired Faraday.—Dean F. Martin, University of South Florida, Tampa.

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