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ESTUARINE FISH POPULATIONS AMONG RED MANGROVE PROP ROOTS OF SMALL OVERWASH ISLANDS

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Abstract: Previous estimates of fish density among the prop roots of the red mangrove, *Rhizophora mangle,* have varied widely, and assessment techniques used are often detrimental to the habitat. This study outlines a method for assessing estuarine fish densities among prop roots of overwash forests that greatly reduces the detrimental environmental effects of sampling in this habitat. Minnow seines were used to surround small overwash forests at high tide, such that fish were trapped in the nets as water receded. More fish species were present in the open water areas adjacent to mangrove stands than among the prop roots. Densities and distribution patterns of roots and hydrophysical characteristics measured at the overwash forests were not correlated with the density of fish inhabiting those sites. Fish density was correlated positively with species richness among small mangrove overwash forests. Similarity in species composition of fish assemblages was higher between prop root and open-water habitats sampled in this study than similar estuarine habitats examined previously. Estimates of fish density varied greatly between samples, however, suggesting high variability in habitat use among fish species inhabiting red mangrove overwash forests.

Key Words: block-seining, estuary, fish density, overwash forests, prop roots, red mangrove, *Rhizophora mangle,* species richness

INTRODUCTION

Only recently have quantitative studies assessed organisms inhabitating mangrove forests even though this habitat has been known to support a variety of aquatic and terrestrial species (Odum and Heald 1972). Where they are found in association with other mangrove species, red mangroves (*Rhizophora mangle* L.) are usually the most seaward, along the periphery of the forest, and as such are viewed as the best dispersers among mangrove species (Odum and McIvor 1990). *Rhizophora mangle* prop roots form a structural network below the canopy and function as nutrient sinks, making this habitat ideal for many fish species in search of shelter from predation and supplemental nutrition. Separate studies by Thayer et al. (1987), Morton (1990), Robertson and Duke (1990), Ley (1992), and Sheridan (1992) focused on the fish assemblages inhabiting mangrove forests or shorelines of these forests. However, techniques used for determining fish species composition and density have not been consistent, often because of logistical difficulties, and in some cases, can be detrimental to mangrove habitat.

To sample juvenile fish in a mixed-species Australian mangrove forest, Robertson and Duke (1990) used a trap net placed across small tidal creeks that cut into the forest. Their technique seems to underestimate fish density because water occasionally flowed over the net during exceptionally high tides; it also captured only those fishes that moved out on the ebbing tide via the creek. Sheridan (1992) employed a drop frame in *R. mangle* prop root habitat, but this technique requires cutting through prop roots and, in some cases, dismantling the canopy. Thayer et al. (1987) and Ley (1992) both used a block-seining technique for fishes among prop roots of *R. mangle* fringe forests (*sensu* Snedaker 1989) in Florida Bay. Their methods involved cutting small paths perpendicular to the shore through roots and low-lying branches. Ends of a net placed in these paths cut off the lateral escape of fishes into adjacent areas. Morton (1990) employed a similar technique along an *Avicennia marina* (Forsk.) fringe forest, although his sampling was limited to a single, large (3340 m^2) site. Thayer et al. (1987) and Ley (1992) additionally used rotenone to poison fishes and invertebrates, enhancing the probability that all individuals within the sampling area could be collected. In one study (Ley 1992), this sampling method was augmented by visual census or use of minnow traps. These latter methods, while logistically easier than assessing fish density and species composition among mangrove prop roots by block-seining with rotenone, were limited by low visibility through the water column and prop root matrix or trap avoidance by fishes.

This paper describes a method for quantitatively sampling fishes among prop roots of red mangrove overwash forests and discusses its merits relative to methods of other researchers (Thayer et al. 1987, Morton 1990, Ley 1992) sampling in similar habitats. The method described herein is most similar to that of Morton (1990) in that it relies on an ebbing tide to trap fish in a net erected around the habitat of interest. However, this study is the first to quantify fish communities of small overwash forests. I address the following questions. 1. Does fish species composition differ among prop roots and adjacent open-water areas? 2. Does fish density or species richness vary with prop root density of overwash forests? 3. What characteristics of *R. mangle* overwash forests contribute to variations in either fish density or species richness?

MATERIALS AND METHODS

To determine if fish density and species composition are functions of root density, I measured density and spatial arrangement of *R. mangle* prop roots in Placido Bayou (15 ha), Pinellas County, Florida (N27° 49′, W82° 38′) between 1 June and 4 August 1990. At randomly-selected sites ($n = 35$) along the edge of small overwash forests, a polyvinyl chloride (PVC) hoop was placed 1 m into the forest from the most peripheral root, such that the hoop encircled roots between 1 and 2 m deep into the forest. I counted all roots within the perimeter of the hoop to calculate root density and measured the diameter of each root to the nearest 0.1 mm with Vernier calipers at mean high water level.

To quantify root spatial arrangement, I measured the distance (to the nearest 1.0 cm) from randomly-chosen points within the hoop to the closest root; this procedure was repeated as many times as there were roots encircled by the hoop. From these data, I calculated Pielou's Index (PI) of spatial arrangement:

$$PI = (a_i)^2(m)(\pi)$$

where a_i is the mean distance from a random point to the closest root and m is the density of roots. Pielou's (1959) test statistic was used to determine the dispersion pattern of roots.

Once a week, I measured several physical characteristics at a haphazardly-chosen subsample of sites among those used to estimate root density. Light intensity below the mangrove canopy was measured at 30 min following sunrise, midday, and 30 min prior to sunset by holding a luxmeter (Luxtron model LX-101) directly skyward at the center mark of each site (1.5 m into the mangrove canopy from the most peripheral root). At the tidal extremes of the same day, I collected surface water samples at these sites to determine pH and dissolved oxygen concentration (APHA et al. 1989). Field measurements of salinity at these sites were obtained using a refractometer.

To determine fish species composition and density among *R. mangle* prop roots, I block-seined fish among small overwash forests ($n = 6$) on those days when the low tides fell below -0.1 m (NOAA 1990). Two people encircled each site with two 20-m minnow seines (3.2-mm mesh opennings) at maximal high tide, such that the ends of one net overlapped those of the other by at least 1 m. To ensure that fishes did not escape as the water level fell, I draped the top of the net along low mangrove branches and weighted the bottom line down with lead weights and large clumps of oysters (*Crassostrea virginica* Gmelin).

At maximal low tide, or when the entire substrate of the overwash forest had drained, fish species trapped against the net were identified and counted before releasing them. Interior areas of the forest were searched to ensure that none of the fish had become stranded as the water receded. Each overwash forest sampled was roughly circular in shape, so that by measuring the circumference of each island along the most peripheral roots, its area and the density of fish among the prop roots of each island could be calculated.

Only one overwash forest was block-seined at any one time, and nets were always erected during daylight hours (fish collection and identification at low tide could occur in either day or night, depending on the tidal cycle). Some sites were sampled repeatedly during the study, occasionally on consecutive days. The tide height at the time the overwash forest was encircled, the number of replicates, and the time between replicates were not fixed for samples collected at the same site. Other motile species of the prop root community (e.g., decapods) were not considered in this study. At least two samples of root density and spatial arrangement and hydrophysical characteristics were obtained from each overwash island sampled for fish species composition and abundance.

A qualitative sampling technique modified from Miller (1985) was used to determine fish species present in open areas adjacent to the mangroves, dominated by *Thalassia* spp. growing on a sandy substrate. One end of a 20-m seine was held in a fixed position, while I

Table 1. Means, standard errors (SE), and sample sizes (n) for physical characteristics measured among small overwash and large overwash and fringe forests of *Rhizophora mangle* used in assessing fish density in Placido Bayou, Florida, between 1 June and 4 August 1990.

Characteristic	Small Overwash			Large Overwash/Fringe		
	Mean	SE	n	Mean	SE	n
Root density (number·m^{-2})	31.6	3.5	10	29.3	2.6	25
Root dispersion (PI)	0.8	0.1	6	0.9	0.1	23
Salinity (ppt)	29.9	0.4	24	30.3	0.3	48
pH	7.1	0.1	24	7.1	<0.1	48
Dissolved O_2 (ml·L^{-1})						
high tide	8.7	0.2	22	8.6	0.3	16
low tide	5.4	0.3	4	3.2	0.2	4
Light level (lx)						
mid-day	2134.2	216.2	35	3033.4	415.7	22
dawn/dusk	175.5	26.0	47	334.9	70.5	29

walked a complete circle around that point with the net extended. Fish species caught in the seine were identified and released. Samples were taken from haphazardly-chosen sites in the estuary, at mid-tide during the period when overwash forests were sampled. I also recorded those species that were not caught in the seine, but which I observed in open areas of the estuary.

Similarity in species composition between overwash forest and open area habitats was determined using Jaccard's Index (Ludwig and Reynolds 1988). Because data did not meet the criteria allowing use of parametric tests, I used Spearman's rank correlations ($\alpha \leq 0.05$) to determine if fish density was correlated with species richness, root density, or area of the island. I also correlated fish density and species richness with the hydrophysical characteristics obtained from the islands sampled (Steel and Torrie 1980).

Table 2. Fish species caught or observed exclusively in open areas adjacent to *Rhizophora mangle* stands at Placido Bayou, Florida between 1 June and 4 August 1990. 1 = estuarine resident species, 2 = estuarine dependent species. Taxonomy follows Robins et al. (1980, 1986).

Species
Rhinoptera bonasus (Mitchill)
Elops saurus Linnæus
Strongylura marina (Walbaum)
Syngnathus scovelli (Evermann and Kendall)[1]
Oligoplites saurus (Schneider)
Diapterus auratus Ranzani
Bairdiella chrysoura (Lacepède)[1]
Cynoscion nebulosus (Cuvier)[2]
Sciænops ocellata (Linnæus)[2]
Chætodipterus faber (Broussonet)
Mugil cephalus Linnæus[2]
Chilomycterus schœpfi (Walbaum)[1]

RESULTS AND DISCUSSION

Rhizophora mangle prop root density in Placido Bayou ranged from 11.5 to 72.6 roots m^{-2} (mean ± one standard error = 29.9 ± 12.3; n = 35), and root diameters ranged from 0.48 to 5.98 cm (n = 341). Dispersion of *R. mangle* prop roots within 1-m plots was random (mean PI = 0.8 ± 0.1; n = 29). Use of a circular hoop reduced sampling bias attributable to edge effects (Krebs 1989). Measured environmental variables remained fairly constant throughout the study. Comparable data collected in large overwash forests and fringe forests during this study did not differ from those for small overwash forests (Table 1; Kolmogorov-Smirnov tests, $p \geq 0.08$), indicating that the physicochemical conditions in the overwash forests of this study were representative of mangrove forests throughout Placido Bayou. The varying density and spatial arrangement of *R. mangle* prop roots make this habitat structurally heterogenous, providing an ideal refuge from predation for a variety of estuarine fish species (*sensu* Heck and Crowder 1991).

Tidal extremes during the study period were 0.9 and −0.3 m for high and low tides, respectively; the mean spring and neap high tides measured 0.7 and 0.4 m, respectively. Block-seined overwash forests ranged in area from 12.0 to 57.6 m^2, and water depth at the forest edge ranged between 0.6 and 0.9 m at the time of net deployment. Proximity between sampled overwash forests varied from 4 to 250 m and was assumed to have no effect on fish density estimates.

Of the 31 species of fish recorded in Placido Bayou, 19 were caught while block-seining overwash forests (only *Achirus lineatus* was exclusive to this habitat), 30 were caught or observed in open sandy or seagrass bed areas adjacent to mangrove stands (12 exclusively; Table 2), and 18 were found in both habitats. Most of

Table 3. Means ± one standard error and range of densities (no. m^{-2}), and frequency of occurrence (number of times out of 24) for fish species caught among the prop roots of small overwash *Rhizophora mangle* stands at Placido Bayou, Florida between 1 June and 4 August 1990. A total of 1,285 fish were caught; 1 = estuarine resident species, 2 = estuarine dependent species. Taxonomy follows Robins et al. (1980, 1986) and Trewavas (1989).

Species	Densities		Frequency of Occurrence
	Mean ± 1 S.E.	Range	
Brevoortia gunteri Hildebrand[2]	0.18 ± 0.13	0.05–0.31	0.08
Anchoa mitchelli (Valenciennes)[2]	0.23 ± 0.15	0.03–0.51	0.13
Cyprinodon variegatus Lacepède[1]	1.14 ± 0.54	0.04–6.48	0.54
Floridichthys carpio (Günther)[1]	0.06 ± 0.02	0.02–0.14	0.25
Fundulus grandis Baird and Girard[1]	0.21 ± 0.05	0.02–0.69	0.88
Fundulus similis (Baird and Girard)[1]	0.08 ± 0.04	0.02–0.23	0.21
Lucania parva (Baird)[1]	0.06 ± 0.02	0.02–0.08	0.17
Pœcilia latipinna (Lesueur)[1]	0.26 ± 0.09	0.02–1.41	0.67
Menidia spp.[1]	0.54 ± 0.35	0.03–1.20	0.13
Chloroscombrus chrysurus (Linnæus)	0.04 ± 0.01	0.03–0.05	0.08
Dipaterus plumieri (Cuvier)	0.02 ± 0.004	0.02–0.03	0.08
Eucinostomus argenteus Baird	0.07 ± 0.02	0.02–0.23	0.46
Archosargus probatocephalus (Walbaum)	0.04 ± 0.01	0.02–0.08	0.54
Lagodon rhomboides (Linnæus)[1]	0.05 ± 0.02	0.02–0.18	0.29
Leiostomus xanthurus Lacepède[2]	0.03 ± 0.00	0.03–0.03	0.04
Sarotherodon melanotheron (Rüppell)	0.23 ± 0.07	0.03–1.28	0.79
Gobiosoma robustum Ginsburg[1]	0.08 ± 0.03	0.02–0.15	0.21
Microgobius gulosus (Girard)[1]	0.02 ± 0.00	0.02–0.02	0.13
Achirus lineatus (Linnæus)[1]	0.04 ± 0.00	0.04–0.04	0.04
Total organisms sampled	1.40 ± 0.42	0.05–8.47	—

the 12 species not found within overwash forests were either too large to maneuver through the complex root structure, even at high tide (e.g., *Rhinoptera bonasus* and adult *Chætodipterus faber*), or were habitat specialists, occupying *Thalassia* beds adjacent to the mangrove stands (e.g., *Chilomycterus schæpfi*). The total number of species recorded in either habitat was less than values obtained for similar habitats in previous studies (e.g., 48 species in Ley [1990] and 64 species among prop roots in Thayer et al. [1987]). However, habitats in these studies were over 2° latitude south of Placido Bayou and contained tropical species of fish not observed in the present study.

Fish density among the prop roots of small overwash islands ranged from 0.05 to 8.47 fish m^{-2} (mean = 1.40 ± 0.42; n = 24). Sheepshead minnow (*Cyprinodon variegatus*) was the most abundant fish among the 19 species caught among prop roots, although occasionally gulf killifish (*Fundulus grandis*), sailfin molly (*Pœcilia latipinna*), silverside (*Menidia* spp.), and juvenile black-chin tilapia (*Sarotherodon melanotheron*, after Trewavas 1989) were also common (Table 3). Gulf killifish were block-seined from overwash forests with the greatest frequency, although typically at low densities. Sailfin molly, black-chin tilapia, sheepshead minnow and sheepshead also seemed to show a degree of affinity to prop root habitat based on frequency of capture. Few fish seemed to have escaped during deployment of the nets, as they were most often observed swimming toward the middle of the overwash forest.

The mean fish density for sampled overwash mangrove forests differed from values reported in other studies (e.g., 0.7 to 8.0 fish m^{-2} in Thayer et al. 1987, Morton 1990, Thayer and Sheridan, in press). Since the volume of water within the perimeter of the island at high tide varied among samples, I expected fish density to vary with levels of tidal inundation. However, fish density was neither correlated with root density in overwash forests (r_s = 0.11, p = 0.81), nor with any other characteristic measured at those sites. A lack of correlation with the hydrophysical characteristics is not unexpected, since these measurements showed little variation among the sites sampled. Because previous studies indicate that such a relationship between fish density and root density may exist (Thayer et al. 1987), the absence of any correlation in the present study may be caused by differences in habitat type (small overwash forests in this study, compared to fringe forests in previous studies).

Island biogeography theory (MacArthur and Wilson 1967) suggests that larger islands should support a greater diversity of species, provided that all other conditions are held constant. While fish density was pos-

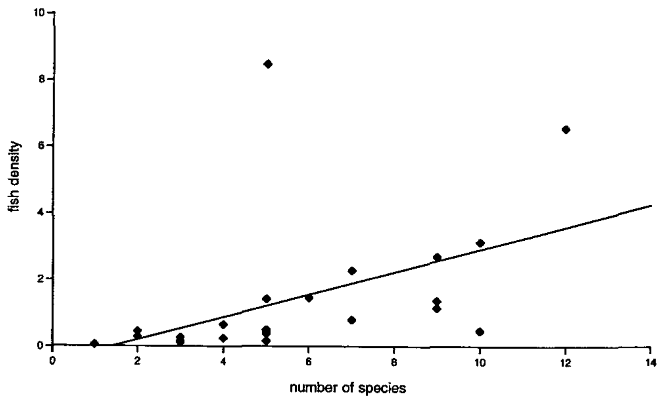

Figure 1. Mean fish density (no. m^{-2}) as a function of the number of species caught in each block-seining sample obtained from small overwash *Rhizophora mangle* forests in Placido Bayou, Florida between 1 June and 4 August, 1990. r_s=0.75.

itively correlated ($r_s = 0.75$, $p \leq 0.01$) with the number of species caught (Figure 1), there was no correlation with the size of the overwash forest ($r_s = -0.26$, $p = 0.23$) nor volume of water sampled ($r_s = -0.32$, $p = 0.13$). Variation of other factors among islands (i.e., nutrient or microhabitat availabilty) not examined in this study may account for differences in habitat use among estuarine fish and negate the principles of island biogeography theory.

The similarity in species assemblage structure, measured by Jaccard's Index, between prop root and adjacent open water habitats was 0.61. Between one and 12 fish species were caught in each sample, although there was no correlation between species richness of small overwash forests and root density of those forests. Mean Jaccard's indices of Thayer et al. (1987) and Morton (1990) equal 0.31 and 0.35, respectively; both are smaller values for species affinity between the two habitats than I observed. Mangrove communities may appear less similar to adjacent open-water habitats in Florida Bay when compared to Placido Bayou because a larger number of species were found exclusively among mangrove prop roots in the former habitat. Differences in community assemblage between this study and that of Morton (1990) may be attributable to differences in sampling locale and Morton's use of a single site and larger mesh size (18 mm) net, targeting commercially and recreationally important fish species.

Block-seining was restricted to overwash islands of *R. mangle* measuring less than 60 m² in area, which could be encircled quickly (in less than two minutes) at high tide. By sampling only overwash islands, I reduced the sampling bias caused by edge effects (Krebs 1989) experienced when sampling along fringe forests as researchers have done in the past (Thayer et al. 1987, Morton 1990, Ley 1992). Lack of variation in hydrophysical characteristics and of any correlation between fish density and island size suggests that attempting to sample fish populations among prop roots of extremely large overwash forests in Placido Bayou using the method outlined in this study would have been wasted effort. Enclosing the overwash islands concentrated prey species of fish for predators, occasionally observed within the perimeter of the net. Such predators (crabs and birds) may have lowered estimates of fish density and species richness by consuming fish prior to my counting them at maximal low tides. Monitoring the nets constantly when water levels approach maximal low tide may prevent predation of stranded fish as the water level drops.

Although my methods were similar to those used previously by Thayer et al. (1987) and Ley (1992), I did not use rotenone to poison the fish while block-seining overwash forests. Addition of rotenone within the encircled islands would have increased the probability that all fish within the perimeter of the prop roots would be captured (possibly increasing the accuracy of fish density estimates), but the poison might have adversely affected non-target species. Since not all fish may succumb to the effects of rotenone (E.D. McCoy, University of South Florida, pers. comm.), this method may underestimate fish density among mangrove prop roots. To ascertain the trade offs between sampling accuracy and environmental impact, further replication and comparison of techniques outlined in this study to those employed previously is warranted. Morton's (1990) study is the only one to date that uses marked individuals to quantify recovery efficiency rates (mean rate = 88.1 %); such future investigations should include similar mark-recapture techniques to assess recovery efficiencies of the sampling method.

Other techniques used for quantitatively sampling fish populations, such as buoyant nets (Bagenal 1974), drop nets or frames (Kushlan 1974, Sheridan 1992), or trap nets (Robertson and Duke 1990), would not be as effective as block-seining due to logistical considerations of sampling around red mangrove islands, biased sampling effort toward one region of the mangrove island, or damage to the habitat required by use of the gear. Ley's (1992) use of direct observation of fish among the prop roots could prove beneficial to further assessment of fish density among *R. mangle* stands in Placido Bayou but is limited by water visibility and the breadth of the forest. It should be noted that, in spite of their respective limitations, all of these studies have contributed important information on a habitat that is difficult to sample and that represents an invaluable fishery resource (Thayer and Sheridan, in press).

The technique for sampling fish among mangrove prop roots described in this study is most similar to that of Morton (1990) in its use of nets to prevent the escape of fish leaving interior areas of a mangrove forest on an ebbing tide. In both cases, nets were left in place until water had completely receded from the sampling area before fish were collected. While the present study examined fish populations among small overwash forests, Morton sampled a single tract of fringe forest. As such, similar to the work of Thayer et al. (1987) and Ley (1992), Morton cut paths into the forest perpendicular to the shoreline for net placement to prevent lateral escape of fish. Additionally, in using a larger pore size net (Morton 1990), smaller fish (perhaps some juvenile forms of the commercially-targeted species) were probably overlooked.

This study demonstrates a technique that may be used to sample estuarine fish inhabiting isolated overwash mangrove forests without causing unnecessary environmental damage. Further work should be directed toward comparing species composition and abundance between different types of mangrove forests. Because all boundaries of overwash forests should have an equal probability of fish encountering them, these habitats may have higher species richness and abundance than fringe forests. Smaller species may prefer inhabiting fringe forests, however, because the landward side of the forest provides a shallow refuge from larger fish species (possible predators), and this may explain the generally higher densities reported by Thayer and Sheridan (in press). In addition to increased sampling among *R. mangle* forests, further research should examine interactions of fish species migrating towards and away from mangrove prop roots.

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