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# A DROP NET AND REMOVABLE WALKWAY USED TO QUANTITATIVELY SAMPLE FISHES OVER WETLAND SURFACES IN THE DWARF MANGROVES OF THE SOUTHERN EVERGLADES

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*Abstract*: We describe a 9 $m^2$ drop net and removable walkways designed to quantify densities of small fishes in wetland habitats with low to moderate vegetation density. The method permits the collection of small, quantitative, discrete samples in ecologically sensitive areas by combining rapid net deployment from fixed sites with the carefully contained use of the fish toxicant rotenone. This method requires very little contact with the substrate, causes minimal alteration to the habitat being sampled, samples small fishes in an unbiased manner, and allows for differential sampling of microhabitats within a wetland. When used in dwarf red mangrove (*Rhizophora mangle*) habitat in southern Everglades National Park and adjacent areas (September 1990 to March 1993), we achieved high recovery efficiencies (78–90%) for five common species <110 mm in length. We captured 20,193 individuals of 26 species. The most abundant fishes were sheepshead minnow *Cyprinodon variegatus*, goldspotted killifish *Floridichthys carpio*, rainwater killifish *Lucania parva*, sailfin molly *Poecilia latipinna*, and the exotic Mayan cichlid *Cichlasoma urophthalmus*. The 9 $m^2$ drop net and associated removable walkways are versatile and can be used in a variety of wetland types, including both interior and coastal wetlands with either herbaceous or woody vegetation.

*Key Words*: wetland, fishes, sampling method, mangrove, Everglades, drop net, walkways

## INTRODUCTION

The dwarf mangrove-dominated zone that forms the interface between the Everglades and Florida Bay is an important area for wildlife in southern Florida. This brackish water zone is the habitat of a variety of endangered species, including the American crocodile and West Indian manatee (McIvor et al. 1994), and is heavily used as a feeding ground by several protected species of wading birds during their nesting period (Bjork and Powell 1993). Historically, fresh water from the Everglades reached the Florida Bay mangroves via sheet flow. However, the hydrology of the mangrove zone has been strongly affected in recent decades by the construction of roads, canals, and levees upstream of Florida Bay (McIvor et al. 1994). There is considerable evidence that the ensuing changes in the quantity, quality, and timing of water

deliveries dramatically altered the Florida Bay ecosystem, including the mangrove zone (McIvor et al. 1994). In 1989, we began sampling nekton over the surface of a dwarf mangrove forest to investigate the relationship between water deliveries and the composition of the fish populations that make up the prey base for larger vertebrates (e.g., game fishes, wading birds, crocodilians) to determine if recent changes in hydrology could have resulted in lower prey abundance, thereby eroding the food web from the bottom up.

Dwarf (or scrub) mangrove forests are only one of six mangrove community types described by Lugo and Snedaker (1974) and differ from most other forest types in having widely spaced trees without an interlacing, complex array of prop roots. The lack of a closed forest canopy and predominance of open space between trees in the dwarf mangrove forests made it possible for fish to easily perceive movement in the habitat. We observed fish darting at the slightest movement, thereby causing us to underestimate densities made by any projectile trap. Similarly, fish tended to avoid a permanently placed but undeployed net that moved in the breeze. Fish maintained a close proximity to cover and, when startled, darted into the prop roots of the nearest mangrove. The substrate was very soft, unconsolidated carbonate marl covered by a 10–15 cm layer of light, flocculent, powdered marl. The bottom was easily disturbed; one person walking along the edge of a creek was enough to expose underground mangrove roots, and repeated excursions resulted in deep holes and permanent trenches. These and other unique characteristics of the study area had to be taken into account during the development of a sampling design.

Much of the problem associated with quantitative sampling of nekton on any wetland surface is identifying a gear type that will collect an unbiased sample without altering the habitat. Methods for sampling nekton previously designed for use in other wetland types were unsuited to the widely scattered single mangrove trees and easily disturbed marl sediments of dwarf mangrove forests of the southern Everglades. For example, block nets surrounding overwash mangrove isles (Morton 1990, Mullin 1995) and both flume nets (McIvor and Odum 1986) and flume weirs (Kneib 1991) used in vegetated intertidal marshes require a predictable tidal cycle not present in Northeast Florida Bay. Furthermore, the flume net is restricted to areas adjacent to permanent deep waterways, as is the 2.8 $m^2$ drop sampler described by Zimmerman et al. (1984) and Sheridan (1992). Although access to the dwarf mangrove zone was possible through permanent creeks, these collection devices could only sample creek and creek-edge microhabitats, leaving the microhabitat that dominated the area (i.e., the mangrove flats between the creeks) unsampled. Extrapolation of fish density estimates from creek-edge habitats to the entire wetland is questionable because nekton may differentially orient to the creek/wetland interface (Peterson and Turner 1994, McIvor and Rozas 1996).

Throw traps (Chick et al. 1992) proved to be ineffective because traps large enough to enclose a dwarf mangrove tree were prohibitively too large to throw. Furthermore, throw traps used in open areas between trees failed to capture even individual fish that were targeted prior to throwing, presumably because the targeted specimen perceived and readily avoided the trap (personal observation).

Rozas (1992) developed a versatile and inexpensive 6 $m^2$ pull-up net that could be used in a variety of habitats, especially in moderately to heavily vegetated areas. However, excavations similar to those needed for the pull-up trap visibly altered the wetland surface by creating a new microhabitat type. During preliminary studies, burying the lead line of a block net resulted in a trench approximately 0.5 m wide and 0.3 m deep, over which floated newly exposed subterranean mangrove roots. We felt that this disturbance, exacerbated by repetition in sampling, would create artificial habitat attractive to some fish species if we used any method that required excavations.

The unique structural features of this environment, combined with the special habitat value to a large and diversified guild of colonial wading birds (Bjork and Powell 1993) and other protected species, required that we develop a new sampling device that would (1) minimize permanent modifications of the substrate and thus preserve foraging habitat for wading birds; (2) sample microhabitats within the wetland system, i.e., flats as well as creek habitat; (3) sample within prop roots as well as open areas between plants; and (4) produce neither movements that would cause fish avoidance nor structure that might attract individual fishes. The 9 $m^2$ drop net we describe satisfies all these criteria.

## MATERIALS AND METHODS

### Study Area

We sampled fishes at four sites in dwarf mangrove forests in the southern Everglades (Figure 1). Three sites were within the boundaries of Everglades National Park (ENP) and were located north of Little Madeira Bay on Taylor River (TR), north of the eastern end of Joe Bay (JB), and on a tributary east of Highway Creek (HC). The site outside the national park boundary was west of the northern end of Card Sound Bridge on Barnes Sound (BS). Each site was charac-

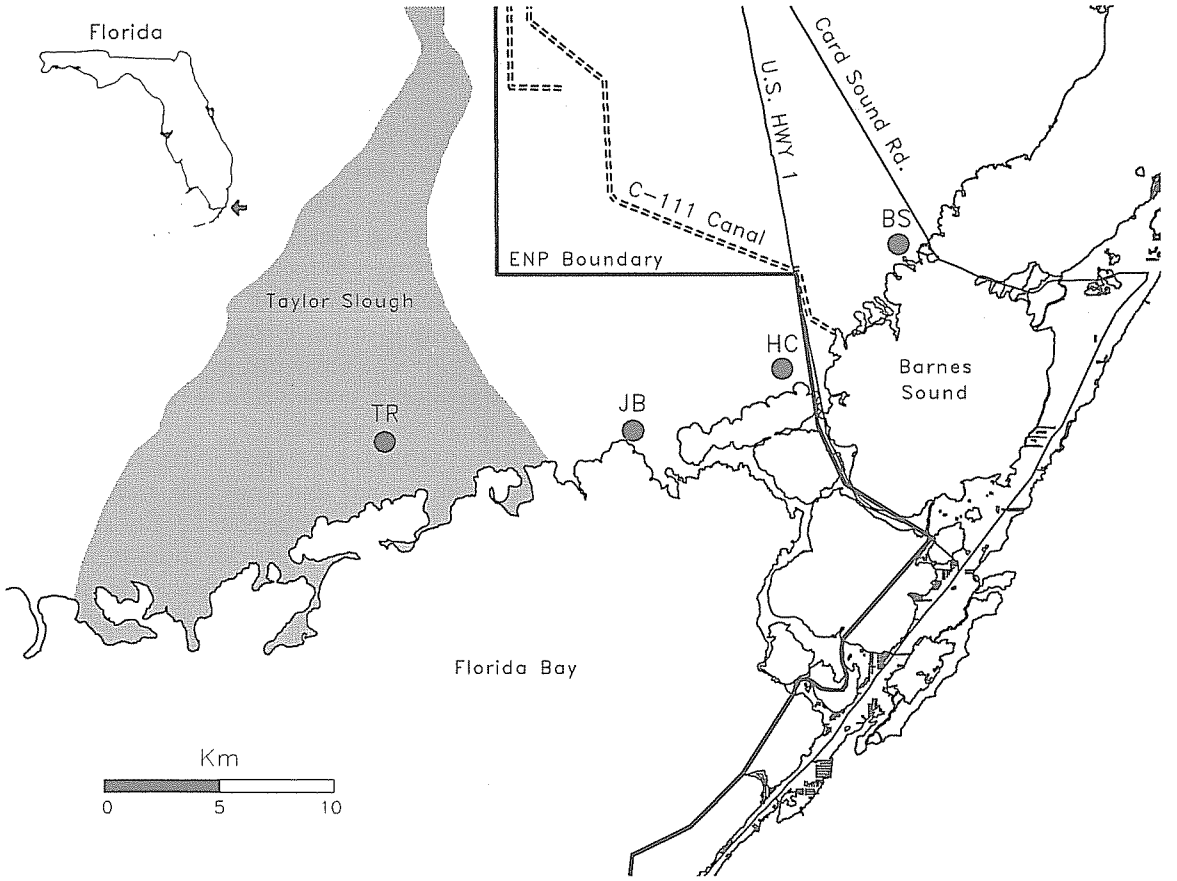


Figure 1. Map of southeastern tip of Florida, USA indicating the location of sites and pertinent topographical features. Sampling sites were Taylor River (TR), Joe Bay (JB), Highway Creek (HC), and Barnes Sound (BS).

terized by a deep central creek surrounded by extensive, shallow, inundated flats that become seasonally exposed.

Sites were characterized by widely-spaced dwarf red mangrove (*Rhizophora mangle* L.) trees with very little vegetation between individuals. Individual trees were separated by 0.5 to 3 m and varied from 0.5 to 2 m in height. Seasonal occurrences of the spike rush, *Eleocharis sp.,* and of the calcareous macroalgae, *Chara sp.,* were common, but neither taxa was abundant.

Water depth ranged from 15 cm to 65 cm in the creeks and from dry to 35 cm on the flats. Fluctuations in water level were seasonal, with the highest levels occurring in the wet season (May–October). During the dry season (November–April), water level was predominantly determined by wind-driven tides. Only one site (BS) was influenced by diurnal tides.

Salinity varied greatly within and between sites (Table 1). Although all sites fluctuated between fresh and hypersaline conditions, the mean salinity at each site indicated a west-to-east gradient of increasing salinity, a gradient that can be explained by the pattern of input of fresh water from the Everglades (McIvor et al. 1994). TR is located on the eastern edge of Taylor Slough (Figure 1), the central drainage basin for the Southeastern Everglades, and has the greatest amount of fresh water input of the sites. Of the two center sites, JB is closest to Taylor Slough and HC is further east (Figure 1) indicating that, historically, JB probably received more fresh water than HC. However, operation of southern Florida's extensive canal system

Table 1. Salinity profile of sampling sites. Mean, minimum (Min), and maximum (Max) are in parts per thousand. Std Err is the standard error of the mean, and "n" is the number of salinity samples collected. Salinity samples were collected on the same day that fish were sampled using a salinity meter and an optical refractometer.

| Site | Mean | Std Err | n | Min | Max |
|---|---|---|---|---|---|
| TR | 5.12 | 2.86 | 16 | 0 | 41 |
| JB | 12.38 | 2.67 | 28 | 0 | 42 |
| HC | 10.72 | 2.26 | 28 | 0 | 43 |
| BS | 20.56 | 3.17 | 14 | 3 | 39 |

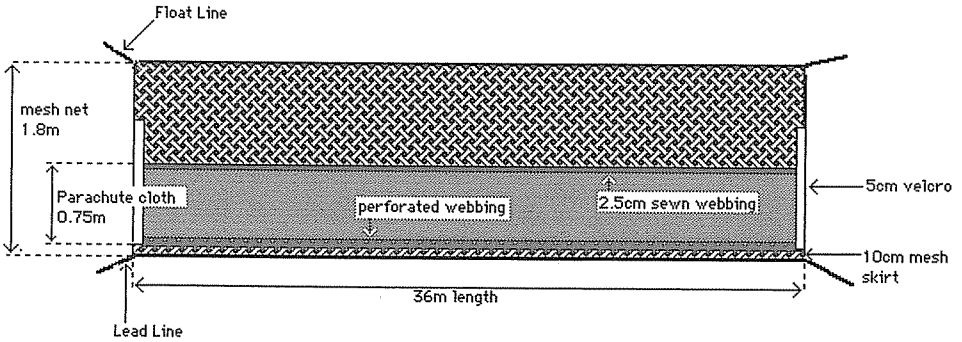


Figure 2. Diagram indicating the various components of the net.

has altered the distribution of fresh water flow, and the two sites now have a relatively similar salinity regime. The eastern-most site, BS, is impounded by roadways that cut off the historic fresh water flow from the Everglades (Figure 1) and only received fresh water as localized rainfall. As a result, the site is most heavily influenced by tidal input from the marine environment of Barnes Sound.

## Net Design and Site Preparation

Nylon parachute material treated with water-sealing vinyl paint was sewn to the lower portion of sampling nets (36 m × 1.8 m; 1.6-mm mesh) to ensure containment of the toxicant used to clear the net (Figure 2). The parachute cloth was about 75 cm deep and was attached to the net about 10 cm above the leadline. Canvas webbing (2.5-cm-wide strips) was used at the seams between the net and the parachute cloth to facilitate sewing. At the lower end of the net, the webbing was perforated every 3 cm along its length by burning small holes with a soldering iron. Five-cm-wide velcro strips were sewn to each terminal end of the net so that the ends could be fastened together, thereby forming an enclosure.

Nets were hung on square frames (3 m on each side) constructed of #3 steel reinforcement bar (1 cm diameter) with 3.0-cm (outside diameter) polyvinyl chloride (PVC) pipe uprights at each corner (Figure 3). In constructing the frame, a loop was formed at both ends of each of the sides (hereafter called crossbars) by bending it around a 8.5-cm steel pipe. When installed at the sampling sites, these loops would loosely encircle the PVC supports (Figure 4). Cotter pins (15 cm long) were inserted through holes in each PVC support pole so that the crossbars were supported approximately 1 m above the surface of the water (Figure 3). Five 15-cm-long, V-shaped wire prongs were attached at equal distances along the length of each crossbar, with the open end of the "V" turned upwards. The

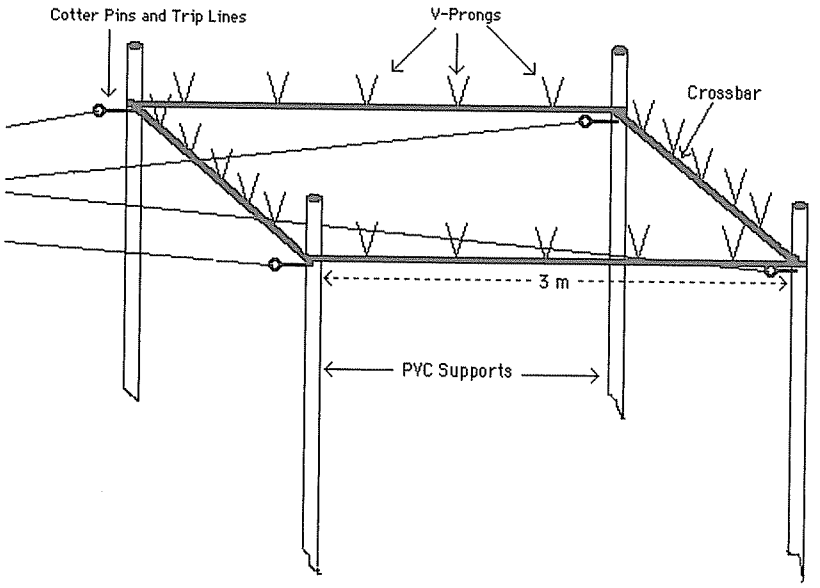


Figure 3. Diagram indicating the various components of the net frame.

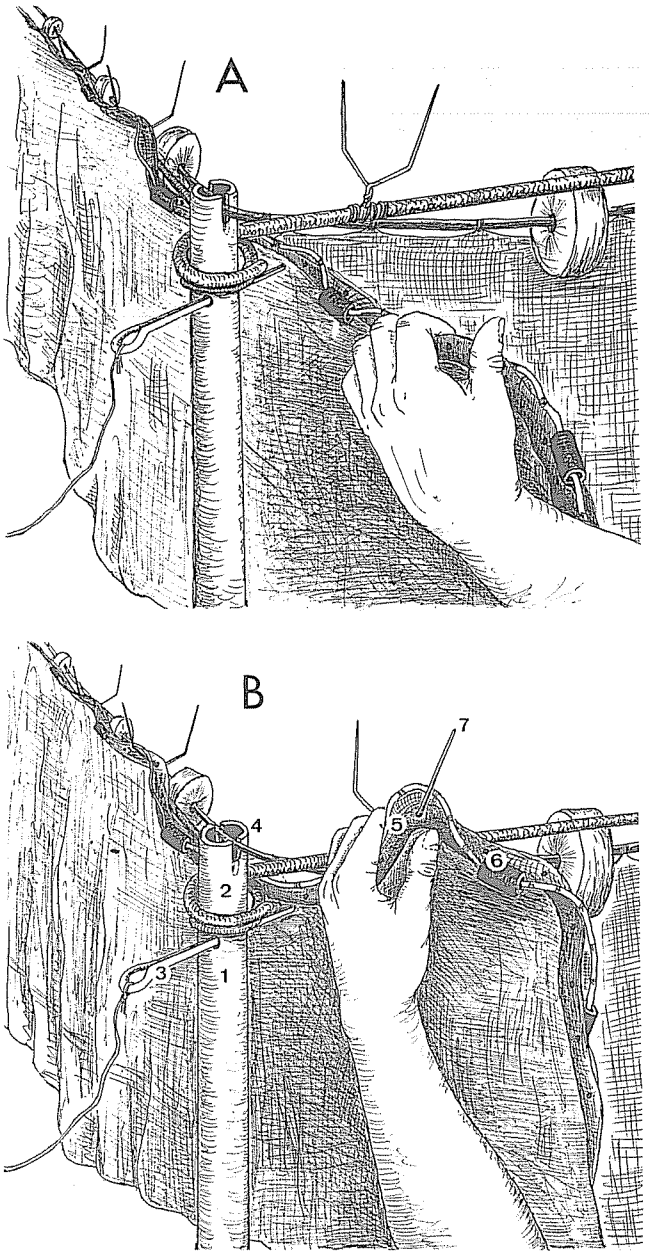


Figure 4. Details of corner supports, crossbars, and net attachment. (A) The float line is suspended from the corner supports so that the net hangs to the inside of the frame. (B) The bottom of the net is lifted from under the crossbars and attached to the outer arm of the V-staples. Net components: 1) PVC corner support, 2) reinforcement bar crosspiece encircling PVC corner support, 3) Cotter pin and pull line, 4) Float line inserted through slot in PVC support, 5) perforated canvas webbing, 6) leadline (note that 10 cm skirt is not apparent in this drawing), 7) V-prongs.

net frames surrounded an individual dwarf mangrove (Figure 5) and were left in place for the duration of the project.

Nets were moved from site to site and attached to the permanent frames. It took about 0.5 hrs to place the net on the frame. The float line was inserted through slots cut in the top of each PVC corner pole so that the float line hung loosely inside the frame (Figure 4A). To attach the net to the crossbars, the lower end of the net was lifted from under the crossbar and the holes in the webbing fitted over the outside arm of each of the V prongs (Figure 4B). The bulk of the net was then furled and cradled into the "V" of the upward turned prongs, thereby preventing it from blowing in the wind or touching the surface of the water (Figure 5A). This method of attachment causes a 10-cm skirt of net and leadline to remain free below the point of attachment of the net to the frame (Figure 5A). The nets were left in position overnight to ensure that disturbances caused during set-up were not a factor in the sample.

Nets were triggered from a distance of 4–5 m by lines attached to each of the four cotter pins (Figure 5A). When tripped, the steel crossbars drop, thereby forcing the lower end of the net to sink through the water very quickly and to settle onto the sediment, effectively trapping fish inside the net (Figure 5B and 5C). The 10-cm skirt with attached lead line prevented fish from escaping through any small depressions in the sediment.

Nets were triggered as early in the morning as possible (1–2.5 hours after sunrise) to control for possible diurnal variations in fish distributions. At that time of day, the shadows of the nets were long and appeared to be indistinguishable from those cast by nearby vegetation.

Nine nets were deployed at each site. Nets were arranged so that three nets were used in each of three microhabitats: creek, creek-flats interface, and flats. Samples were collected at HC and JB starting in September 1990. TR was first sampled in December 1991, and the sampling began at BS in February 1992. Results are presented through March 1993.

## Net-Clearing Procedure

Powdered rotenone was first dissolved in water from the site to make a concentrated slurry. This slurry was added to the enclosed area at a final target concentration of 1 ppm active ingredient. Powdered rotenone was chosen instead of emulsified rotenone to avoid the adverse effects to non-target invertebrates that are frequently seen with emulsified rotenone (Gilmore et al. 1981). To ensure that the 1-ppm dose was effective, standard wire minnow traps (placed near each net during set up) were used to collect fish from the vicinity. Three to five fish of various species were marked by clipping the caudal fin (in case of escape) and placed in a minnow trap inside the net before rotenone ap-

plication (Figure 5C). These trapped fish tested the effectiveness of the rotenone application; if the indicator fish were not dead 30 min after application, more rotenone was added. No dead or dying fish observed outside the nets after rotenone application indicated that the water-proofed parachute cloth prevented rotenone from escaping from the net, thus ensuring an accurate 1-ppm dose of the toxicant. Furthermore, periodic use of dyes mixed with the rotenone indicated that nets showed no signs of leakage even after several months of field sampling.

Dead and dying fish were collected with a dip net from inside the net after rotenone application (Figure 5B). After 15–30 min, fish stopped surfacing, and the interior of the net was treated with a dose of potassium permanganate ($KMnO_4$) four times that of the rotenone to neutralize the toxicant (Lawrence 1956). Each net was then covered with a 3-cm-mesh nylon net to prevent avian predators from eating uncollected specimens.

In most cases, all of the remaining uncollected fish floated to the surface after 24 hours. Because the exact time it takes for dead fish to float is dependent on water temperature (Parker 1970), it was necessary to use float indicators. The fish placed in the minnow trap to test rotenone effectiveness were left in the minnow trap overnight. When 95% of these fish floated, the final collection was made. During the final collection, water inside the net was stirred and the flocculent marl layer gently agitated with a plastic rake to loosen fish that may have burrowed or been trapped beneath submerged objects before death. After the final collection was completed, the nets were removed from the frame.

## Walkways

Where water depth permitted, all of the activities (setting-up, deployment, clearing and take down) were done from small aluminum jon boats to avoid altering the sediments and causing associated biases. Unfortunately, mangrove flats could not be reached by boat because the individual dwarf mangroves were too close together and the water too shallow. As a consequence, we developed a system of boardwalks and removable walkways to access these areas.

Boardwalks of various lengths were installed from the edge of the creek to within 3 m of the net site. Removable walkways were used to access the net frames from the boardwalk because placing boardwalks permanently around the nets would have created an artificial attractant to fish, thus biasing the flats samples. Walkways were constructed of three 3.3-m lengths of 4-cm-diameter, galvanized, chain link fence toprail pipes attached lengthwise to 3.3 m × 35 cm strips of 1.3-cm-thick plywood (Figure 5D). The toprail pipes were attached to the wood using galvanized screws that would act as sacrificial anodes (i.e., the screws would oxidize, leaving the pipe structurally sound). As a result, screws had to be occasionally replaced over the course of the study. Because deployment of these walkways would damage the substrate, wooden supports (4 × 9 cm) were hammered down to limestone bedrock and cut so that a 30-cm-long wooden cross beam attached to each pair of supports would lie just below the sediment surface. Each walkway required 3 supports (15 per net). The hollow fence toprail allowed the walkways to float when first placed in the water, providing time to maneuver them into position around the net. As water filled the pipes, the walkways sank, settling on the supports. After the nets were set up, the walkways were easily removed, and no sediment damage was apparent the following day. The nets were triggered from the end of the boardwalk, and the walkways were again set in place so that fish could be removed from the net (Figure 5).

## Bias Test

We tested for net bias (fish avoidance or attraction to nets) through direct observation. Bias tests were performed at the HC site because water clarity was excellent, thus allowing visual identification and consistent counts of fish. Tests were performed on ten dates between June 10, 1990 and July 6, 1990. Two 1 $m^2$ plots, approximately 3 m apart, were marked off using small (<2.0 $cm^2$) styrofoam floats anchored to the sediment. A 9 $m^2$ frame and undeployed net were set up around one of the plots. The other was the control. A stepladder was placed midway between the two plots as an observation post. To facilitate observations, the trap was set so that the 1 $m^2$ plot fell along the outer edge of the trap closest to the observation point. Since any attraction to or avoidance of the trap by fishes would be expected to occur along the periphery of the trap, placement of the 1 $m^2$ observation area along the periphery of the trap also ensured that differences in fish use would be quantified. After a 15-minute acclimation period, the species and number of fish inside both plots were recorded. Counts were made every 3 minutes for a total of one hour (20 observations). Upon completion of the first hour, the control and the experimental plots were switched (i.e., the frame and net were moved to enclose the $m^2$ plot that served as the control in the first set of observations). The observation process was then repeated.

No more than 2 hours of observations were made on any day for a total of 4 hours per day (2 hours control and 2 hours experimental). Preliminary tests determined that fish did not respond to the long shadows cast by the net and observer shortly after sunrise as opposed to later in the day when fish were observed to react to more

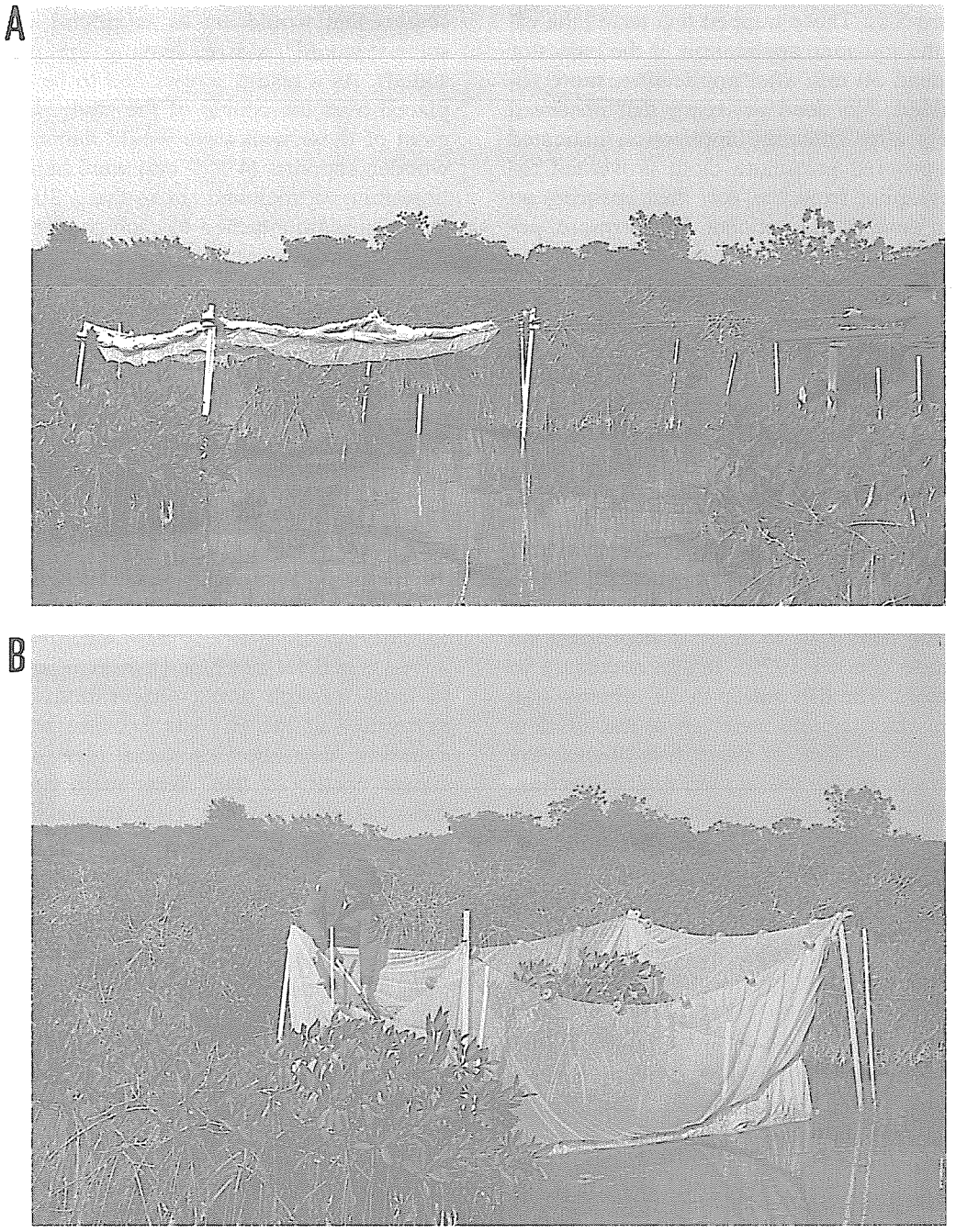


Figure 5. Deployment of the 9 m² drop net. A) First author preparing to trigger a net from the end of a boardwalk. B) Deployed net being cleared from removable walkways. C) Deployed net enclosing a dwarf mangrove tree. D) Installation of portable walkways clearly showing the basic design.

strongly defined shadows. As a result, observations were performed in the first four hrs following sunrise, and deployment of nets was restricted to the first 3 hours after sunrise for the duration of the study.

Since individual fish could remain in the plot for two or more consecutive observations, each observation could not be considered independent. For this reason, an average number for each species was calculated from each hour of data (i.e., each hour of observation generated two data points, one for the control plot and one for the experimental plot, for each species). These averages were analyzed using a two-tailed paired t-test for each species. The null hypothesis was no significant difference in the number of fish (total and individual species) between the area under the undeployed net and an adjacent area without a net. Be-

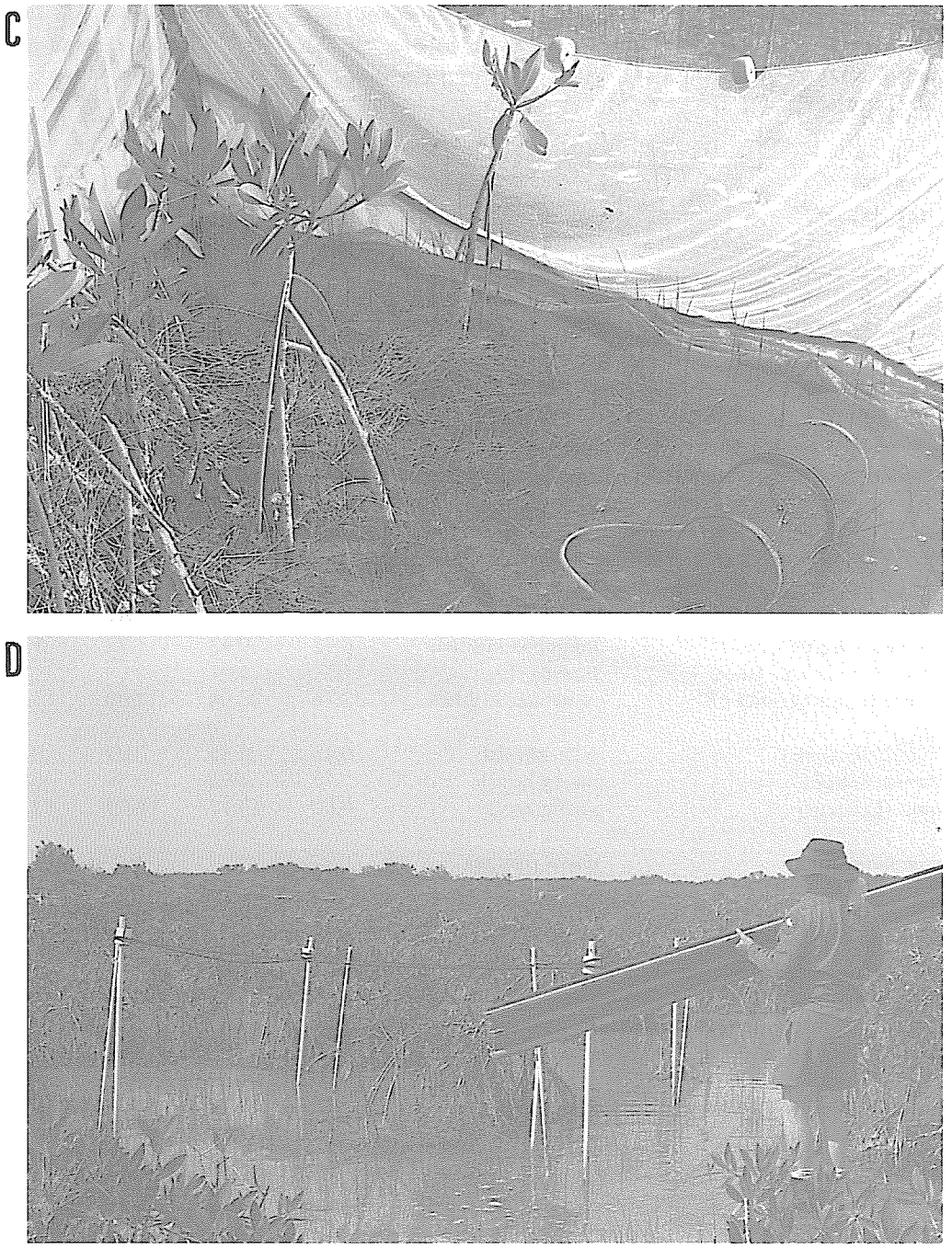


Figure 5. Continued.

cause we were most concerned about making a Type II error (accepting the null hypothesis when it was false), we set alpha at 0.15 instead of the "traditional" 0.05 in an attempt to balance Type I and Type II error rates (Sokal and Rohlf 1981).

### Clearing Efficiency Tests

The effectiveness of the clearing procedure was periodically tested by a second set of indicator fish. Fish of all species captured in minnow traps were marked (caudal fin diagonally clipped) and released directly into the enclosed area after the nets had been triggered. The ratio of fish recovered to fish released provided a measure of net clearing efficiency.

### Recolonization of Sampling Area

To demonstrate that application of rotenone and $KMnO_4$ had only short-term impacts on fish distribu-

Table 2. Fish species collected at four dwarf red mangrove sites in South Florida. Site abbreviations as in text. Numbers are percent of total catch at each site. Tot is the percent of catch for all sites combined. Exotic species (E) and species exclusively represented by juveniles (J) are indicated after the generic name. Species are listed in phylogenetic order.

| Family<br>Genus Species | Common Name | TR % | JB % | HC % | BS % | Tot % |
|---|---|---|---|---|---|---|
| Ictaluridae | | | | | | |
| *Ameiurus natalis* (Lesueur) | yellow bullhead | | 0.01 | | | <0.01 |
| Clariidae | | | | | | |
| *Clarius batrachus* (Linnaeus) (E) | walking catfish | | 0.01 | 0.03 | | 0.02 |
| Batrachoididae | | | | | | |
| *Opsanus beta* (Goode and Bean) (J) | gulf toadfish | | 0.03 | 0.02 | 0.41 | 0.08 |
| Atherinidae | | | | | | |
| *Menidia peninsulae* (Goode and Bean) | tidewater silverside | 0.93 | 2.93 | 0.94 | 8.58 | 2.90 |
| Belonidae | | | | | | |
| *Strongylura notata* (Poey) | redfin needlefish | 0.06 | 0.08 | 0.05 | 0.13 | 0.07 |
| Cyprinodontidae | | | | | | |
| *Adenia xenica* (Jordan and Gilbert) | diamond killifish | | 0.21 | 1.32 | 0.03 | 0.52 |
| *Cyprinodon variegatus* Lacepede | sheepshead minnow | 3.76 | 20.61 | 35.27 | 11.21 | 20.70 |
| *Floridichthys carpio* (Gunther) | goldspotted killifish | 2.14 | 3.14 | 13.01 | 22.25 | 8.88 |
| *Fundulus chrysotus* (Gunther) | golden topminnow | | 0.01 | | | <0.01 |
| *F. confluentus* Goode and Bean | marsh killifish | 0.12 | 2.48 | 4.93 | 0.03 | 2.43 |
| *F. grandis* Baird and Girard | gulf killifish | 0.30 | 4.36 | 12.54 | 2.69 | 5.85 |
| *F. similis* (Baird and Girard) | longnose killifish | 0.12 | 0.43 | 1.32 | 1.55 | 0.82 |
| *Jordanella floridae* Goode and Bean | Florida flagfish | | 0.01 | | | <0.01 |
| *Lucania parva* (Baird and Girard) | rainwater killifish | 32.36 | 28.98 | 12.49 | 13.74 | 22.28 |
| Poeciliidae | | | | | | |
| *Belonesox belizanus* Kner (E) | pike killifish | 0.18 | 0.35 | 0.07 | 0.03 | 0.19 |
| *Gambusia holbrooki* Girard | mosquitofish | | 1.72 | 0.39 | 0.60 | 0.87 |
| *Poecilia latipinna* (Lesueur) | sailfin molly | 8.00 | 13.17 | 12.09 | 12.60 | 11.91 |
| Syngnathidae | | | | | | |
| *Syngnathus louisianae* Gunther | chain pipefish | | | | 0.16 | 0.03 |
| Gerreidae | | | | | | |
| *Eucinostomus* sp. | mojarras | 0.03 | 0.08 | 0.03 | 5.79 | 0.95 |
| Gobiidae | | | | | | |
| *Lophogobius cyprinoides* (Pallas) | crested goby | 4.27 | 0.01 | | | 0.71 |
| *Microgobius gulosus* (Girard) | clown goby | 16.03 | 2.40 | 0.47 | 20.07 | 6.84 |
| Centrarchidae | | | | | | |
| *Lepomis* spp. (J) | sunfish species | 1.56 | 0.83 | 0.02 | | 0.58 |
| Cichlidae | | | | | | |
| *Cichlasoma bimaculatum* (Linnaeus) (E) | black acara | | 0.01 | | | <0.01 |
| *C. urophthalmus* (Gunther) (E) | Mayan cichlid | 29.83 | 17.99 | 4.84 | | 13.24 |
| *Tilapia mariae* (Boulenger) (E) | spotted tilapia | 0.30 | 0.14 | | | 0.11 |
| Soleidae | | | | | | |
| *Trinectes maculatus* (Bloch and Schneider) | hogchoker | | 0.03 | | 0.09 | 0.03 |
| TOTAL NUMBER FISH COLLECTED | | 3325 | 7744 | 5965 | 3159 | 20193 |
| NUMBER OF NETS SAMPLED | | 99 | 183 | 172 | 94 | 548 |
| NUMBER OF DATES SAMPLED | | 13 | 25 | 25 | 11 | 74 |

tion, overnight recolonization of the sampling areas was examined. Three traps were collected on successive dates at our BS sites during two sampling periods (October and December 1994). Traps were triggered and treated with rotenone followed by $KMnO_4$. After about six hours, the traps were reset. The following morning, the traps were triggered and a second collection made.

## RESULTS

We collected 20,193 individuals of 26 fish species in 548 samples (Table 2), giving an average estimated density of 4.09 fish/m$^2$. The most abundant species were rainwater killifish *Lucania parva,* sheepshead minnow *Cyprinodon variegatus,* Mayan cichlid *Cichlasoma urophthalmus,* and sailfin molly *Poecilia lati-*

Table 3. Mean number (± 1 S.E.) of fish per square meter in paired experimental (w/ net) and control (w/o net) plots, the differences between the two (w/ − w/o), and the results of a paired t-test performed for each species and for the total count. Twenty hourly means were used to generate the overall means used in this analysis (n = 20 pairs).

| Species | Mean #/m2 w/ net | Mean #/m2 w/o net | Difference (w/ − w/o) | Paired t Value | p (2-tail) |
|---|---|---|---|---|---|
| *Cyprinodon variegatus* | 19.50 (4.94) | 20.19 (4.96) | −0.69 | −0.491 | 0.63 |
| *Fundulus confluentus* | 5.43 (1.71) | 4.30 (1.24) | 1.12 | 1.298 | 0.21 |
| *Poecilia latipinna* | 0.61 (0.23) | 0.62 (0.20) | −0.01 | −0.103 | 0.92 |
| *Menidia peninsulae* | 2.16 (0.85) | 2.57 (1.04) | −0.41 | −0.531 | 0.60 |
| *Fundulus grandis* | 0.17 (0.06) | 0.23 (0.04) | −0.06 | −1.201 | 0.24 |
| *Fundulus similis* | 0.36 (0.11) | 0.22 (0.08) | 0.13 | 1.205 | 0.24 |
| *Strongylura marina* | 0.10 (0.22) | 0.16 (0.05) | −0.06 | −1.397 | 0.18 |
| Total | 28.40 (6.45) | 28.62 (5.88) | −0.22 | −0.124 | 0.90 |

*pinna*. With the exception of the Mayan cichlid, which was not collected at BS, these species occurred at all four sites.

The fauna is further characterized as almost totally estuarine resident species: juveniles of estuarine transient species often found in mangrove forests were poorly represented in the dwarf red mangrove forests in southeast Florida. Adults of transient species were frequently observed in the deepest open water areas and were probably too mobile to be collected with this method. A second noteworthy feature of the fauna was the frequent occurrence of individuals of non-native species, in particular, the Mayan cichlid. This exotic species was very abundant at TR where it made up nearly 30% of the catch; it was also common at JB and HC (Table 2).

### Bias Test

We interpret the data from the bias test as showing no significant differences between the control and the experimental plots for any species or total number of fish. From the results of the two-tailed paired t-test based on 20 hours of observation (Table 3), we conclude that nets had no significant effect on the distribution of fish in the sample area and that the presence of the net did not cause a bias in our density estimates.

### Clearing Efficiency Tests

Net clearing efficiencies ranged between 78% and 90% for the most common fish species. The average rate for all marked and released fish was 86% (Table 4).

### Recolonization of Sampling Area

Table 5 compares the species and number of fish collected from the same trap on consecutive days. Results clearly show that the trap area was recolonized after less than a 24-hr period.

## DISCUSSION

The dominance of euryhaline specialists (Table 2) is a likely reflection of the wide range of salinities experienced at each site (Table 1). However, an examination of the less common fauna at the sites reflects the east-west gradient in mean salinity of the study area. The presence of sunfishes *Lepomis spp.* (Loftus and Kushlan 1987) and spotted tilapia *Tilapia mariae* (Courtenay et al. 1984), and the high percentage of Mayan cichlids (Martinez-Palacios and Ross 1992) reflects the low mean salinity at TR. At BS, the site with highest mean salinity (Table 1), these species were ab-

Table 4. Results of clearing efficiency tests for the five most frequently used species.

| Species | Size Range (mm) | Total Fish | Total Nets | Efficiency (% ± SE) |
|---|---|---|---|---|
| *Cyprinodon variegatus* | 20–40 | 521 | 175 | 87 ± 2.1 |
| *Cichlasoma urophthalmus* | 20–70 | 609 | 141 | 87 ± 2.3 |
| *Fundulus grandis* | 35–110 | 279 | 132 | 90 ± 2.4 |
| *Lucania parva* | 15–25 | 216 | 115 | 78 ± 3.6 |
| *Poecilia latipinna* | 20–45 | 169 | 96 | 88 ± 2.8 |
| Total all fish | 15–120 | 2301 | 324 | 86 ± 1.1 |

Table 5. Number of fish per species collected on consecutive days at BS in the flats microhabitat.

| Date | Species | Net F1 | | Net F2 | | Net F3 | | Total | |
|---|---|---|---|---|---|---|---|---|---|
| | | Day 1 | Day 2 | Day 1 | Day 2 | Day 1 | Day 2 | Day 1 | Day 2 |
| Oct 94 | *Floridichthys carpio* | 0 | 2 | 11 | 7 | 3 | 8 | 14 | 17 |
| | *Lucania parva* | 0 | 1 | 6 | 3 | 3 | 6 | 9 | 10 |
| | *Microgobius gulosus* | 0 | 3 | 16 | 1 | 13 | 0 | 29 | 4 |
| | *Gerridae spp.* | 0 | 16 | 0 | 11 | 0 | 2 | 0 | 28 |
| | *Menidia peninsulae* | 3 | 0 | 4 | 0 | 0 | 0 | 7 | 0 |
| | *Poecilia latipinna* | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 0 |
| | *Cyprinodon variegatus* | 0 | 0 | 0 | 0 | 2 | 0 | 2 | 0 |
| | *Fundulus confluentus* | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 0 |
| | TOTAL | 3 | 22 | 37 | 22 | 23 | 16 | 63 | 59 |
| Dec 94 | *Floridichthys carpio* | 4 | 14 | 8 | 15 | 16 | 11 | 28 | 40 |
| | *Lucania parva* | 2 | 1 | 2 | 2 | 4 | 0 | 8 | 3 |
| | *Microgobius gulosus* | 7 | 1 | 2 | 5 | 4 | 1 | 13 | 7 |
| | *Gerridae spp.* | 0 | 7 | 0 | 4 | 0 | 13 | 0 | 24 |
| | *Menidia peninsulae* | 0 | 0 | 0 | 2 | 0 | 2 | 0 | 4 |
| | *Gambusia holbrooki* | 0 | 0 | 0 | 1 | 1 | 0 | 1 | 1 |
| | TOTAL | 13 | 23 | 12 | 29 | 25 | 27 | 50 | 79 |

sent from the fauna, and two euryhaline species reported as being most commonly found in medium and low salinities were underrepresented: marsh killifish *Fundulus confluentus* (Lee et al. 1980) and diamond killifish *Adenia xenica* (Foster 1967). Additionally, typically marine species made up a comparatively large percentage of the catch at BS: goldspotted killifish *Floridichthys carpio* (Foster 1967), tidewater silverside *Menidia peninsulae* (Robins et al. 1986), gulf toadfish *Opsanus beta* (Robins et al. 1986), and mojarras Gerridae (Robins et al. 1986). Described as euryhaline species, the sheepshead minnow (Loftus and Kushlan 1987), gulf killifish *Fundulus grandis* (Loftus and Kushlan 1987), diamond killifish (Foster 1967), and marsh killifish (Lee et al. 1980) made up more of the catch at JB and HC than at either of the sites at the salinity extremes. Additionally, the above-mentioned marine and freshwater associates made up a smaller percentage at these two sites than at BS and TR, respectively.

Efficiency estimates for the 9 $m^2$ drop net (78–90%) compare favorably with those for flume nets (53–80%; McIvor and Odum 1986) and the bottomless lift net (58–93%; Rozas 1992) in coastal marshes, and for a throw trap (93–100%) in a tidal creek containing submerged vegetation (Rozas and Odum 1987). Our clearing efficiency estimates greatly exceed those previously reported for rotenone in tidal marsh creeks (29–58%; Weinstein and Davis 1980) or for the capture of similar-sized fishes from fringing red mangrove shoreline using larger block nets cleared with rotenone (36–68%, Ley 1992; 33–88%, Thayer et al. 1987). Our greater efficiency with rotenone may be attributed to the containment of toxicant inside the net by the parachute cloth, thereby ensuring an accurate and undiluted dose. Additionally, the relatively small sampling area allows the researcher to view and collect from all parts of the net from any position around the perimeter.

The protocol described herein differs from previous net designs in two primary ways: (1) it combines the best mechanical features of a drop trap (remote triggering of a rapidly falling fixed frame and net) with the (2) fast-acting immobilizing features of the chemical rotenone. Further, by effectively containing the fish toxicant within the 9 $m^2$ sample area and using fish constrained within minnow traps placed within the drop net as indicators of rotenone effectiveness, it is possible to obtain precise estimates of fish density for fishes < ca 110 mm TL.

We did not directly test the accuracy of this method in estimating densities of fishes in mangrove prop roots. We did try performing a visual count similar to our bias tests before nets were triggered, but the visual count always significantly underestimated our rotenone collection, even when the test was conducted over non-vegetated areas. This discrepancy was probably due to the cryptic coloration and burrowing habits of the resident fish species. We believe that our method is accurate because it does not affect the overall distribution of fish and because fish trapped within the net are efficiently collected. An additional but unknown source of sampling error would be fish escaping from the target area between the time the pins are pulled and the time the net settles into the bottom. At our sampling sites, we believe this factor to be a minor source of error because fish inside the net perimeter were observed to flee away from the disturbance caused by the falling net and toward the refuge of the

enclosed mangrove while fish outside the perimeter would move away from the falling net. Similar responses would be expected in any vegetated wetland. Furthermore, the weight of the reinforcement bar results in the net quickly settling to the bottom.

Our sampling technique has many of the same advantages discussed by Rozas (1992) for the 6 $m^2$ lift net. The 9 $m^2$ drop net does not significantly damage nor alter the habitat like throw traps (Kushlan 1981) and pull-up traps (Higer and Kolipinski 1967). Gentle use of the garden rake to dislodge fishes trapped within the sample area redistributed mangrove detritus but did not uncover mangrove roots or uproot infrequent herbaceous vegetation. The drop net does not impede the movements of those organisms to be sampled (McIvor and Odum 1986, Hettler 1989), nor is it limited to areas accessible by creeks or open water (Zimmerman et. al. 1984). Sampling sites can be selected anywhere accessible by a boardwalk, so differential use of wetland microhabitats can be quantified.

Compared to Rozas' (1992) lift net, our drop net has the advantage of not appreciably altering the wetland surface. Repeated excavations such as those described by Rozas (1992) to bury the lift net would create progressively deeper and wider trenches on our sites. Furthermore, since our nets are removed and inspected after each sample, net damage is less likely to occur and more likely to be seen and repaired. Another advantage is that the lift net (Rozas 1992) requires two people to deploy, whereas the drop net only needs one. Also, the overall collection efficiency was somewhat lower for the pull-up net than for the 9 $m^2$ drop net in the habitats tested. Finally, Rozas' (1992) method requires a predictable tide to clear the net, whereas the net described herein can be used whether or not the wetland is predictably tidal. Thus, the 9 $m^2$ drop net could be effectively used in fresh water wetlands as well.

A drawback of the 9 $m^2$ drop net is that it requires visiting a site on 3 consecutive days to completely collect a sample. Also, when powdered rotenone is used to clear the net in nontidal environments, the drop net cannot be used to sample crustaceans or other invertebrates because these organisms are either not killed by the rotenone concentrations used for fish (Gilmore et al. 1981), or they remained buried in the sediment.

Use of our method in mangrove community types other than dwarf forests would require variable amounts of habitat modification. Specifically, prop roots or pneumatophores would initially have to be cut to permit the net to fall freely. Such initial site preparation was necessary to use a 2.8 $m^2$ drop trap in dense red mangroves that fringed shorelines in Rookery Bay, FL (Sheridan 1992).

Use of fish toxicants is an accepted method of collecting fishes for scientific study (Davies and Shelton 1983). In our particular case, every effort was made to ensure that rotenone and $KMnO_4$ were contained and detoxified within the nets so that no unintentional damage was done to this environmentally sensitive area. The water-proof cloth barrier around the lower section of the net was specifically designed to prevent the kill of non-target fishes outside the netted area. Further, a large mesh (ca. 3 cm) nylon net was used to cover each net between the initial and second day collection to prevent nesting birds from foraging on floating fish and thereby potentially carrying the toxicant back to their young. The application of $KMnO_4$ ensured that no active rotenone would be released into the environment when the net was removed (Lawrence 1956, Davies and Shelton 1981). The 24-hr period between application of $KMnO_4$ and net removal further ensured the oxidation of rotenone and the reduction of $KMnO_4$. The success of these precautions for fish was evident from a complete lack of observed bykill or aberrant behavior of fishes outside the net. Furthermore, samples collected from the same traps on consecutive dates indicated that fishes used the trap area less than 24 hrs after the nets were raised and chemicals allowed to diffuse without any apparent ill effects. As in most other fish studies, impacts on invertebrates or of fishes eating invertebrates killed or impaired by rotenone or potassium permanganate remain uninvestigated.

A common criticism of repeatedly sampling the same area is that the organisms removed may result in depletion in the overall community or localized extirpation of populations. This situation would bias any statistical analyses applied to the data set. Such was not the case for fishes in the dwarf mangrove forests. Consideration of the scale of the watersheds being sampled indicates that an insignificant number of fish were removed to affect the local population. The smallest watershed (Barnes Sound) was conservatively estimated to have a wetted area of 375,000 $m^2$. The 81 $m^2$ sampled every four to six weeks made up about 0.02% of the habitat available to the target species. Hypothetically, if fish were distributed uniformly and no recruitment or mortality occurred, it would take more than 20 years of sampling once a month before even a 5% reduction in the community would be seen using this method. Further evidence of the negligible impact of sampling on the community comes from the quick recolonization of sampled areas. Fish were observed to enter the sampled area almost immediately after the nets were removed, and traps collected on consecutive days indicated that fishes were using the trap area less than 24 hrs after the nets were raised. Although there were some differences in the compo-

sition of the community on consecutive days, we feel this falls within the normal variance of the community structure. Also, the variability in the community composition between samples follows a wet season/dry season oscillation in density and biomass that is typical of many pulsed ecosystems (Odum et al. 1995). For these reasons, we conclude that individual samples are independent of one another through time (i.e., samples had no tangible impact on subsequent collections).

Time and cost estimates to build and deploy nets are moderate. It takes one person about one day to assemble each net. The cost of an individual net ($US in 1996) is ca. $225.00 (professional sewing included) if six or more nets are made. Each frame costs about $20 and about 3–4 hrs to prepare and set up on site. Walkways cost about $30 each ($150 per net) and 0.5 hrs to assemble. The cost of the walkway supports depends on the type and depth of sediment. More detailed information about costs, products, suppliers, or specific assembly techniques is available from the first author.

In summary, the method we describe requires very little contact with the substrate, does not appreciably alter the habitat being sampled, does not alter the distribution of fishes in the general sample area, avoids undesirable kills outside the confined sample area, and allows sampling of microhabitats within wetlands. Because of these combined features, this method offers a unique approach to estimating fish densities in wetlands favorable to its use. The 9 $m^2$ drop net is another alternative in the growing list of methodologies for sampling fishes in both coastal and inland wetland habitats.

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## LITERATURE CITED

Bjork, R. D. and G. V. N. Powell 1993. Relationships between hydrological conditions and quality and quantity of foraging habitat for roseate spoonbills and other wading birds in the C-111 basin. Final report to the South Florida Research Center. Everglades National Park, Homestead, FL, USA.

Chick, J. H., F. Jordan, J. P. Smith, and C. C. McIvor. 1992. A comparison of four enclosure traps and methods used to sample fishes in aquatic macrophytes. Journal of Fresh water Ecology 7: 353–361.

Courtenay, W. R., D. A. Hensley, J. N. Taylor, and J. A. McCann. 1984. Distribution of exotic fishes in the continental United States. p. 41–77. *In:* W. R. Courtenay and J. R. Stauffer (eds.) Distribution, Biology and Management of Exotic Fishes. The Johns Hopkins University Press, Baltimore MD, USA.

Davies, W. D. and W. L. Shelton. 1981. Sampling with toxicants, p. 199–213. *In*: L. A. Nielsen, D. L. Johnson and S. S. Lampton (eds.). Fisheries Techniques. American Fisheries Society, Bethesda, MD, USA.

Foster, N. R. 1967. Comparative studies on the biology of killifishes (Pisces, Cyprinodontidae). Ph. D. Dissertation. Cornell University, Ithaca, NY, USA.

Gilmore, R. G., P. A. Hastings, G. R. Kulcycki, and B. L. Jennison. 1981. Crystalline rotenone as a selective fish toxin. Florida Scientist 44:193–203.

Hettler, W. F. 1989. Nekton use of regularly-flooded salt marsh cordgrass habitat in North Carolina, USA. Marine Ecology-Progress Series 56:111–118.

Higer, A. L. and M. C. Kolipinski. 1967. Pull-up trap: a quantitative device for sampling shallow water animals. Ecology 48:1008–1009.

Kneib, R. T. 1991. Flume weir for quantitative collection of nekton from vegetated intertidal habitats. Marine Ecology-Progress Series 75:29–38.

Kushlan, J. A. 1981. Sampling characteristics of enclosure fish traps. Transactions of the American Fisheries Society 110:557–562.

Lawrence, J. M. 1956. Preliminary results on the use of potassium permanganate to counter the effects of rotenone on fish. Progressive Fish Culturalist 18:15–21.

Lee, D. S., C. R. Gilbert, C. H. Hocutt, R. E. Jenkins, D. E. McAllister, and J. R. Stauffer. 1980. Atlas of North American fishes. North Carolina State Museum of Natural History, Raleigh, NC, USA. Publication #1980-12.

Ley, J. A. 1992. Influences of changes in fresh water flow on the use of mangrove prop root habitat by fishes. Ph.D. Dissertation. University of Florida, Gainesville, FL, USA.

Loftus, W. F. and J. A. Kushlan. 1987. Fresh water fishes of southern Florida. Bulletin of the Florida State Museum, Biological Sciences 31:147–344.

Lugo, A. E. and S. C. Snedaker. 1974. The ecology of mangroves. Annual Review of Ecology and Systematics 5:39–64.

Martinez-Palacios, C. A. and L. G. Ross. 1992. The reproductive biology and growth of the Central American cichlid *Cichlasoma urophthalmus* (Gunther). Journal of Applied Ichthyology 8:99–109.

McIvor, C. C., J. A. Ley, and R. D. Bjork. 1994. Changes in fresh water inflow from the Everglades to Florida Bay including effects on the biota and biotic processes: a review. p. 117–146. *In*: S. M. Davis and J. C. Ogden (eds.). Everglades: the Ecosystem and Its Restoration. St. Lucie Press, Delray Beach, FL, USA.

McIvor, C. C. and W. E. Odum. 1986. The flume net: a quantitative method for sampling fishes and macrocrustaceans on tidal marsh surfaces. Estuaries 9:219–224.

McIvor, C. C. and L. P. Rozas. 1996. Utilization of intertidal saltmarsh by fishes in the southeastern United States: A review. p. 311–334. *In*: K. F. Nordstrom and C. T. Roman (eds.). Estuarine Shores: Evolution, Environments, and Human Alterations. John Wiley & Sons, Ltd., Chichester, England.

Morton, R. M. 1990. Community structure, density and standing crop of fishes in a subtropical Australian mangrove area. Marine Biology 105:385–394.

Mullin, S. J. 1995. Estuarine fish populations among red mangrove prop roots of small overwash islands. Wetlands 15:324–329.

Odum, W. E. 1971. Pathways of energy flow in a South Florida estuary. University of Miami Sea Grant Program, Miami, FL, USA. Sea Grant Technical Bulletin 7.

Odum, W. E., E. P. Odum, and H. T. Odum. 1995. Nature's pulsing paradigm. Estuaries 18:547–555.

Parker, R. O. 1970. Surfacing of dead fish following application of rotenone. Transactions of the American Fisheries Society 4:805–807.

Peterson, G. W. and R. E. Turner. 1994. The value of salt marsh edge verses the interior as habitat for fish and decapod crustaceans in a Louisiana tidal marsh. Estuaries 17:235–262.

Robins, C. R., G. C. Rey, J. Douglass, and R. Freund. 1986. Atlantic Coast Fishes. Houghton Mifflin Company, Boston, MA, USA.

Rozas, L. P. 1992. Bottomless lift net for quantitatively sampling nekton on intertidal marshes. Marine Ecology-Progress Series 89: 287–292.

Rozas, L. P. and W. E. Odum. 1987. Fish and crustacean use of submerged plant beds in tidal fresh water marsh creeks. Marine Ecology-Progress Series 38:101–106.

Sheridan, P. F. 1992. Comparative habitat utilization by estuarine macrofauna within the mangrove ecosystem of Rookery Bay, FL. Bulletin of Marine Science 50(1):21–39.

Sokal, R. R. and F. J. Rohlf. 1981. Biometry. W.H. Freeman and Company, San Francisco, CA, USA.

Thayer, G. W., D. R. Colby, and W. F. Hettler, Jr. 1987. Utilization of the red mangrove prop root habitat by fishes in south Florida. Marine Ecology-Progress Series 35:25–38.

Weinstein, M. P. and R. W. Davis. 1980. Collection efficiency of seine and rotenone samples from tidal creeks, Cape Fear River, NC. Estuaries 3:98–105.

Zimmerman, R. J., T. J. Minello, and G. Zamora. 1984. Selection of vegetated habitat by brown shrimp, *Penaeus aztecus*, in a Galveston Bay salt marsh. Fishery Bulletin (U.S.) 82:325–336.

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