Transactions of the American Fisheries Society 126:1012–1020, 1997

Sampling Fishes in Vegetated Habitats: Effects of Habitat Structure on Sampling Characteristics of the 1-m² Throw Trap

FRANK JORDAN[1]

Departments of Biology and Marine Science, Jacksonville University 2800 University Boulevard North, Jacksonville, Florida 32211, USA

SEAN COYNE AND JOEL C. TREXLER

Department of Biological Sciences, Florida International University University Park Campus, Miami, Florida 33199, USA

Abstract.—Enclosure traps that quickly surround well-defined areas of habitat are perhaps the most widely used method for sampling fishes in vegetated habitats. However, relatively few data are available to evaluate the effects of habitat structure on sampling characteristics of enclosure traps. In this study, we determined how clearing efficiency and accuracy of 1-m^2 throw traps varied across a range of environmental conditions in the Florida Everglades by sampling within enclosed areas of marsh habitat. Throw trap clearing efficiency and sampling accuracy did not differ among two widely separated locations and appeared to be unaffected by variation in water depth, canopy height, plant cover, plant stem density, and periphyton volume. Sampling accuracy averaged 63% of fishes present after correcting for clearing efficiencies. On average, 83% of the fishes present in a throw trap were recovered. Therefore, it appeared that about 17% of the missing fishes may have burrowed into the substrate or been discarded with sorted detritus. In contrast, the remaining 20% of fishes probably avoided the throw trap. This is the first study to differentiate between potential sources of throw trap sampling errors. Importantly, density estimates obtained by throw traps were positively correlated (r = 0.82) with actual population densities. Mean fish lengths and fish size distributions obtained by throw trapping usually did not differ from actual mean lengths or fish size distributions. Finally, high concordance of fish species ranks indicated that throw traps accurately described fish community structure. Throw traps appeared to provide relatively accurate estimates of fish density, fish size, and community structure across a range of environmental conditions.

It is generally accepted that aquatic vegetation plays an important role in structuring aquatic communities, probably by providing prey species with refuge from predators and increased foraging opportunities (Downing 1991; Heck and Crowder 1991). However, considerable gaps remain in our understanding of the importance of aquatic vegetation, including questions such as How much vegetation is beneficial for aquatic systems? (Durocher et al. 1984; Hoyer et al. 1985; Hoyer and Canfield 1996a, 1996b; Maceina 1996); Do different plant species and plant growth forms differ in their importance to fishes? (Dionne and Folt 1991; Chick and McIvor 1994); Does the importance of aquatic vegetation change appreciably with changing hydrologic conditions? (Loftus and Eklund 1994). Advances in our understanding of the importance of aquatic vegetation have been slow to emerge largely because of the difficulties associated with accurately sampling fishes in vegetated habitats.

Traditional sampling techniques such as seine-netting, electrofishing, and underwater observation do not provide reliable estimates of fish densities in vegetated habitats (e.g., Freeman et al. 1984; Dewey et al. 1989). In contrast, enclosure traps that quickly surround a well-defined area of habitat have proven quite useful for sampling fishes (Rozas and Minello 1997). Two general classes of enclosure traps are presently in use. The first class of enclosure traps includes drop traps (e.g., Hellier 1958; Kushlan 1974, 1981; Kjelson et al. 1975; Gilmore et al. 1978), pull-up nets (e.g., Higer and Kolipinski 1967; Kushlan 1974), and buoyant pop nets (e.g., Larson et al. 1986; Serafy et al. 1988; Connolly 1994). Use of these enclosure traps usually requires erection of a sampling platform or alteration of habitat before use. Although these devices can provide quantitative data, habitat modification may profoundly affect fish behavior and produce spurious results (e.g., Loftus and Eklund 1994; Rozas and Minello 1997; also see Peterson and Black 1994).

[1] Present address: Department of Biological Sciences, Loyola University New Orleans, 6363 St. Charles Avenue, New Orleans, Louisiana 70118, USA.

The second class of enclosure traps includes throw traps of varying sizes and construction (Wegener et al. 1974; Chick et al. 1992; Rozas and Minello 1997). Throw traps are portable, do not require habitat modification before sampling, and have been used to sample fishes and other organisms in shallow habitats such as subtidal freshwater creeks (Rozas and Odum 1987), vegetated freshwater marshes (Kushlan 1981; Loftus and Eklund 1994), dense littoral vegetation (Miller et al. 1991; Chick and McIvor 1994), estuarine sea grasses (Sogard et al. 1987; Sogard and Able 1991), and montane ponds (Pfennig et al. 1991). The versatility of the throw trap provides a rich database for comparison of fish assemblages across a range of habitat types and aquatic systems. However, little effort has been made to determine the effects of variable habitat structure on the sampling characteristics of throw traps; that is, are data from different habitats and systems comparable?

The comparative sampling efficacy of different types of throw traps has been well studied (e.g., Kushlan 1981; Chick et al. 1992). Additional research has measured clearing efficiency of throw traps (i.e., the proportion of fishes removed from within a throw trap; also referred to as recovery efficiency; Rozas and Minello 1997). For example, Freeman et al. (1984) and Rozas and Odum (1987) recovered between 90–100% of the marked fishes that they released into throw traps. However, of much greater concern to aquatic ecologists is how closely estimates of fish densities derived from throw trap samples match the actual population densities of fishes in the habitats being sampled (i.e., accuracy; also referred to as catch efficiency; Rozas and Minello 1997). Kushlan (1981) found that throw traps were biased and only captured about 73% of the fishes present in emergent wet prairies. Jacobsen and Kushlan (1987) later hypothesized that evasion or flushing of fishes around the edges of a falling trap may reduce (≈81%) the effective sampling area of throw traps. Kushlan (1981) did not assess clearing efficiency, which could have affected his estimates of fish density (e.g., Freeman et al. 1984). Finally, Kushlan (1981) held conditions "as constant as possible" in his studies. Therefore, how clearing efficiency and accuracy of throw traps are affected by variation in habitat structure remains unclear.

In the present study, we assessed the effects of habitat structure on clearing efficiency and accuracy of 1-m^2 throw traps at two wet prairie sites in the Florida Everglades. This research complements earlier research on the sampling efficacy of throw traps (e.g., Kushlan 1981; Freeman et al. 1984; Jacobsen and Kushlan 1987) by differentiating between clearing efficiency and sampling accuracy and by sampling across a wide range of environmental conditions (water depth, periphyton volume, plant stem density, plant cover, and canopy height).

Methods

Study area.—Research was carried out in emergent wet prairies of Water Conservation Area 3A in the Florida Everglades during September 1996 when water temperatures ranged between 20°C and 25°C. We focused on wet prairies because these habitats are readily used by most Everglades fishes (Loftus and Kushlan 1987; Jordan 1996a) and because most long-term studies of marsh fish ecology have been performed in this type of habitat (e.g., Kushlan 1976; Loftus and Eklund 1994; Jordan 1996a, 1996b). Sampling characteristics of throw traps were examined at two wet prairie sites that represented a wide range of plant stem densities and environmental conditions (Table 1). More important, we feel that the results obtained from wet prairies are valid for other types of vegetated habitats amenable to throw trap sampling (e.g., sea grass meadows, littoral zones).

Throw trap methodology.—The 1-m^2 throw trap used in this study was identical to that described by Kushlan (1981). Copper pipe was used to construct a rectangular frame, and 1.5-mm-mesh netting was used to cover the sides of the frame. To collect fishes, the trap was thrown into position and then quickly pressed into the substrate. Water depth and canopy height were measured to the nearest centimeter, and then all emergent plants within the throw trap were identified and enumerated. Floating vegetation (periphyton, *Bacopa*, *Utricularia*) present in the throw trap was removed and measured volumetrically. After habitat structure was measured, a combination of bar seines (1.5-mm mesh) and dip nets (0.5- and 1.5-mm mesh) were used to remove fishes from within the emergent vegetation. The bar seine was used first to remove the bulk of fishes, and then dip nets were swept through the throw trap until ten consecutive empty sweeps were obtained. Additional information on construction and use of throw traps can be found in Kushlan (1974, 1981), Freeman et al. (1984), Chick et al. (1992), and Rozas and Minello (1997).

Field evaluation and analyses.—Clearing efficiency and sampling accuracy were determined by comparing the numbers of fishes collected in throw

TABLE 1.—Environmental characteristics and relative abundance (%) of plant species within eight block-netted study areas at two Everglades wet prairie sites used in this study. Asterisks denote habitat features that differed between the two sites (Mann–Whitney test, $P < 0.05$).

Environmental characteristic	Site 1 areas				Site 2 areas			
	1	2	3	4	5	6	7	8
Water depth (cm)*	66	66		65				
Periphyton (mL/m^2)*	,300	8,833		6,333				
Stems/m^2	677	91		71				
Plant coverage (%)	60	40		50				
Canopy height (cm)*	20	38		27				
Relative plant abundance (%)								
Cladium jamaicense	0	0	0	6	0	0	0	0
Eleocharis cellulosa	1	77	0	58	42	50	75	76
Eleocharis elongata	97	0	0	0	0	0	0	0
Eriocaulon compressum	0	0	0	0	0	0	0	5
Hymenocallis sp.	1	4	2	0	2	2	10	1
Justicia ovata	0	0	0	0	0	0	0	1
Nymphaea odorata	0	0	51	10	0	7	0	0
Nymphoides aquatica	0	0	5	0	0	0	0	0
Panicum hemitomon	1	19	20	27	18	16	7	9
Paspaladium geminatum	0	1	5	0	0	0	1	2
*Rhynchospora tracyi**	0	0	16	0	35	24	7	6
Sagittaria lancifolia	0	0	0	0	4	0	0	0

traps with those inside four enclosed areas of wet prairie habitat at each of the two sampling sites. Block nets (25 × 1 m, 1.5-mm mesh) were used to enclose 25-m^2 areas of marsh. Block nets within a site were about 150 m apart, whereas the two sites were about 12 km apart. To prevent the escape of fishes, the heavily weighted bottoms of the block nets were pressed into the substrate, and the tops were supported by float lines. We allowed fishes to acclimate for 1 h and then simultaneously deployed three throw traps into the blocked-off area. Fishes were cleared from the first throw trap as described above, identified, and measured to the nearest millimeter for standard length (SL). A subset of fishes collected from the first throw trap were marked by fin-clipping and then released into the second throw trap. Similarly, a subset of the fishes removed from the second throw trap were fin-clipped and released into the third throw trap. All marked and nonmarked fishes were released back into the block net after the three throw traps were emptied.

After all three throw traps were emptied and removed, we removed as much vegetation as possible from within the block-net areas to minimize entrapment of fishes, which would have biased our estimates of fish population density. We then applied a fish toxicant (rotenone) to the area within the block net while vigorously agitating the water column to ensure adequate mixing and dispersal. Dead and dying fishes were collected periodically during the next 36 h to obtain estimates of fish population density. Fishes recovered from enclosures were identified and checked for fin clips, and their SL was measured to the nearest millimeter.

Three measures of throw trap sampling accuracy were calculated to facilitate comparison with earlier studies. First, we determined accuracy by dividing the mean density of fishes in throw traps by the density of fishes in block nets (accuracy 1; compare Kushlan 1981). Second, we adjusted population density estimates by dividing the mean density of fishes in block nets by mean recapture rates of marked fishes in block nets (i.e., block-net clearing efficiency). We pooled data for all species of marked fishes to calculate mean recapture rates because of similarities in size and behavior and because of unequal sample sizes among block nets. The mean density of fishes in throw traps was divided by this adjusted population density estimate to obtain a second measure of sampling accuracy (accuracy 2; compare Pihl and Rosenberg 1982). Third, we adjusted throw trap density estimates by dividing the mean density of fishes in throw traps by mean recapture rates of marked fishes in throw traps (i.e., throw trap clearing efficiency). Adjusted throw trap density estimates were then divided by adjusted population density estimates to obtain a third measure of sampling accuracy (accuracy 3). To minimize the number of estimates in our calculations, we used mean recapture rates to calculate measures of sampling accuracy.

Throw trap clearing efficiency, block-net clearing

TABLE 2.—Fish densities (individuals/m^2) and species richness (number of species collected for each method) for throw traps and block nets and three measures of throw trap sampling accuracy. Asterisks denote sampling characteristics that differed between the two wet prairie sites (Mann–Whitney test, $P < 0.05$).

Sampling characteristics	Site 1 areas				Site 2 areas				Mean areas 1–8
	1	2	3	4	5	6	7	8	
(A) Throw trap clearing efficiency (%)	90			86	83			100	
(B) Block-net clearing efficiency (%)	90			71	100			67	
(C) Mean throw trap fish density*	38			36	26			15	
(D) Estimated throw trap fish density (C/A)*	46			43	31			18	
(E) Block-net fish density*	51			56	29			27	
(F) Estimated block-net fish density (E/B)*	67			73	38			35	
Accuracy 1 (C/E)	75			64	90			56	
Accuracy 2 (C/F)	57			49	69			43	
Accuracy 3 (D/F)	69			59	82			50	
Throw trap species richness	5			6	6			6	
Block-net species richness	9			10	7			11	

efficiency, and measures of accuracy were correlated with mean habitat structure data (water depth, periphyton volume, stem density, plant cover, and canopy height) by using Pearson's correlation coefficient to test for independence of sampling and environmental characteristics. Given our sample size ($N = 8$) and an alpha level of 0.05, correlation coefficients (r) would have to be larger than 0.795 to reject the null hypothesis of no relationship between sampling and environmental characteristics. Finally, correlation coefficients for each measure of accuracy are equivalent since we used mean recapture rates (i.e., constants) to produce these estimates.

A central goal of this study was to determine whether the fish assemblage sampled by throw traps represented the actual fish assemblage present in our study area (Loftus and Kushlan 1987; Jordan 1996a; F. Jordan and J. C. Trexler, unpublished data). Accordingly, we examined how size structure and species composition differed between throw traps and block nets. First, we used a two-way analysis of variance (ANOVA) to test for the effects of collection method (throw trap versus block net) and sampling location (location of the eight block nets) on the mean SL of fishes. Each block-net location was considered independent for this and other analyses because preliminary ANOVAs indicated that SL did not differ consistently between our two study sites. Standard lengths obtained with each collection method were then compared via least-squares (LS) means for each sampling location because of a significant interaction between collection method and sampling location. The relative importance of sparsely distributed, large fishes to overall size structure may be overestimated by comparing mean lengths. Therefore, we used the Kolmogorov–Smirnov (KS) test to compare size distributions obtained for pairs of throw trap and block-net collections ($N = 8$). Finally, Kendall's test was used to measure concordance of species ranks between throw trap and block-net collections ($N = 8$). Statistical procedures generally follow the methods of Sokal and Rohlf (1995).

Results

The two wet prairie sites differed with respect to water depth, periphyton volume, and canopy height but were similar with respect to overall plant species composition and plant stem densities (Table 1). Sites were difficult to distinguish from one another because there was considerable variation among block nets within each wet prairie site. At our first wet prairie site, for example, plant stem densities ranged from 18 to 677/m^2, and the relative abundance of floating water lily *Nymphaea odorata* ranged from 0% to 51%. Overall, it appears that our eight block-net samples varied considerably with respect to habitat structure.

Both throw trap and block-net estimates indicated that fish densities differed between wet prairie sites, whereas estimates of fish species richness did not differ between wet prairie sites (Table 2). More importantly, no evidence indicated that throw trap clearing efficiency, block-net clearing efficiency, or throw trap accuracy varied between wet prairie sites (Table 2). No significant correlations were found between habitat structural features and sampling characteristics (Table 3) at the $P < 0.05$ level. This lack of significant correlations is striking considering that we did not control the probability of making a type I error by adjusting our experimentwise error rate for the 25 multiple

TABLE 3.—Pearson correlations between sampling characteristics (Table 2) and environmental characteristics (Table 1). Replicate throw traps were averaged for this analysis, and $N = 8$ for all correlations. None of these correlations were significant at the $P < 0.05$ level.

Sampling characteristic	Depth	Periphyton	Stems	Cover	Canopy

comparisons in Table 2 (e.g., the Bonferroni method; Sokal and Rohlf 1995).

Accuracy 1 (82%) estimated how closely throw trap and block-net estimates matched, assuming 100% clearing efficiency of fishes from within block nets (after Kushlan 1981). However, recapture rates were low for block nets (77%). Accuracy 2 (63%) included an estimate of population density that had been corrected for low clearing efficiency of fishes from block nets (after Pihl and Rosenberg 1982). Therefore, throw trap density estimates were about 37% lower than actual population densities. Approximately 17% of this difference appears to result from low clearing efficiency (83%) of fishes from within throw traps. Including this source of sampling error, it appears that throw traps captured about 80% (i.e., 63% + 17%) of the marsh fishes present. Density estimates derived from throw trap and block-net data were positively correlated ($r = 0.82$, $P = 0.0130$).

Overall, the mean length of fishes did not differ between throw traps and block nets ($F = 0.2$; df = 1, 8,871; $P = 0.6643$). In contrast, mean length varied considerably among sampling locations ($F = 21.3$; df = 7, 8,871; $P = 0.0001$). There was an interaction between collection method and sampling location ($F = 3.8$; df = 7, 8,871; $P = 0.0004$), which indicated that collection methods should be evaluated separately for each sampling location (Figure 1). Fishes collected by throw traps were, on average, 1.4 mm shorter than fishes collected in block net 7 (LS means, $t = 2.4$, df = 771, $P = 0.0158$). In contrast, fishes collected by throw traps were 2.7 mm longer than fishes collected in block net 5 (LS means, $t = -4.0$, df = 807, $P = 0.0001$). The mean lengths of fishes collected with throw traps and block nets did not differ at the other six sampling locations.

Comparison of size distributions revealed similar patterns to those of mean length data. The cumulative distribution of fish lengths collected by throw traps was indistinguishable from the cumulative distribution of fish lengths collected by block nets (KS test, $\chi^2 = 5.6$, $P = 0.1241$). Size distributions of fishes collected by throw traps differed from size distributions collected by block

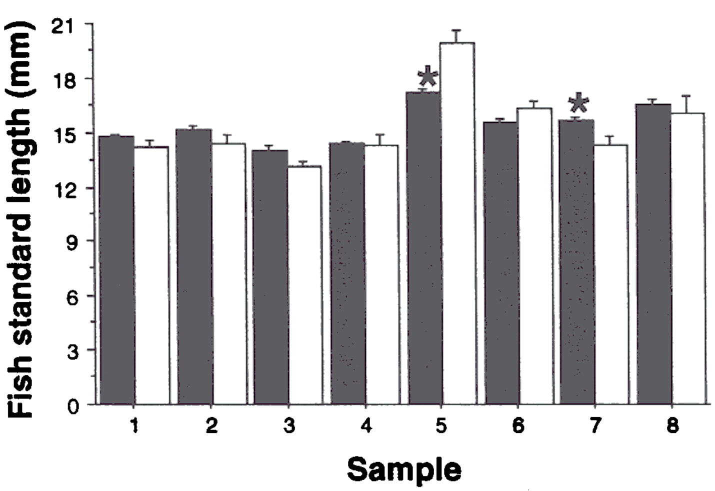

FIGURE 1.—Mean (+SE) standard length (mm) of fishes collected with throw traps (open bars) and block nets (solid bars) in eight sampling areas. Asterisks denote means that are significantly different between collection methods (least-squares means, $P < 0.05$).

TABLE 4.—Relative abundance (%) of fishes collected with throw traps and block nets in the Everglades wet prairie sites.

Common name	Scientific name	Throw traps	Block nets
		0.00	0.02
		0.00	0.02
		0.00	0.08
Everglades pygmy sunfish		0.66	0.56
Bluespotted sunfish	*Enneacanthus gloriosus*	0.00	0.01
Lake chubsucker	*Erimyzon sucetta*	0.00	0.07
Golden topminnow	*Fundulus chrysotus*	8.34	6.02
Eastern mosquitofish	*Gambusia holbrooki*	32.55	42.56
Least killifish	*Heterandria formosa*	37.82	30.16
Flagfish	*Jordanella floridae*	4.23	4.00
Brook silverside	*Labidesthes sicculus*	0.00	0.06
Sunfishes	*Lepomis* spp.	1.25	1.32
Bluefin killifish	*Lucania goodei*	14.12	14.74
Tadpole madtom	*Noturus gyrinus*	0.00	0.02
Sailfin molly	*Poecilia latipinna*	1.03	0.35

TABLE 5.—Concordance of fish species ranks between throw traps and block nets.

Block net	Kendall's tau	*P*
	0.79	0.0004
2	0.90	0.0001
3	0.82	0.0003
4	0.84	0.0001
5	0.88	0.0001
6	0.91	0.0001
7	0.94	0.0001
8	0.80	0.0002

nets at plots 5 (KS test, χ^2 = 14.2, P = 0.0016) and 7 (KS test, χ^2 = 7.9, P = 0.0393). Small-sized species, such as eastern mosquitofish, least killifish, and bluefin killifish, dominated the wet prairie fish assemblages sampled (Table 4). Species ranks were highly concordant between pairs of throw traps and block nets (Table 5), indicating that these two collection methods sampled the same fish assemblage.

Discussion

Aquatic systems such as wetlands are composed of diverse habitats that differ with respect to plant species composition, plant cover, canopy height, stem density, plant biomass, periphyton volume, and other structural features (Loveless 1959; Gunderson 1994; Jordan et al. 1994, 1996, 1997). Aquatic macrofauna (e.g., fishes, decapod crustaceans, insects) probably move about within these habitats, searching for foraging opportunities and potential mates and avoiding potential predators and competitors (Wiens 1976). To characterize the spatial ecology and dynamics of aquatic macrofauna, aquatic ecologists need versatile sampling methods that are effective (i.e., precise and accurate) across a range of environmental conditions (Loftus and Eklund 1994; Rozas and Minello 1997). Our data, and previous research (Kushlan 1981; Freeman et al. 1984; Jacobsen and Kushlan 1987; Chick et al. 1992), indicate that throw traps are a versatile and effective method for sampling fishes in vegetated habitats. Specifically, data obtained with throw traps corresponded well with the actual density, size structure, and relative abundance of fish populations sampled. More important, accuracy of throw traps did not appear to be related to habitat structural complexity across the range of environmental conditions experienced in this study. Larger sample sizes might have produced significant correlations between environmental conditions and sampling accuracy, but we do not believe that the strength of observed correlations (e.g., $r = -0.46$ or $r^2 = 0.21$) is sufficient to mask biologically meaningful differences in fish abundance among habitats. Data from different habitats and systems can probably be compared without adjusting for variation in habitat structure; certainly data collected from wet prairies and sloughs throughout the Everglades system (Gunderson 1994; Jordan et al. 1997) with throw traps are comparable. The relatively light Kushlan-type throw trap cannot be used effectively in thick, stiff vegetation such as *Cladium, Juncus, Phragmites, Spartina,* or *Typha*; however, throw traps constructed from heavy aluminum or sheet metal have proven useful in these habitats (Chick et al. 1992; Jordan 1996a).

Our data indicate that throw traps capture about 63% (accuracy 2) of the fishes present in a habitat and that throw trap density estimates are strongly, positively correlated with actual population densities. This estimate of accuracy is 10% lower than earlier estimates provided by Kushlan (1976). Our clearing efficiency data suggest that Kushlan's estimates of actual population densities (measured within 190–369-m^2 enclosures) were too high. By using a clearing efficiency from the throw trap of 77%, Kushlan's population density estimate is lowered to 60%, which is close to our estimate. This adjustment is probably conservative, given that clearing efficiency of small fishes declines with increasing enclosure size (Shireman et al. 1981; Miller et al. 1991). Pihl and Rosenberg (1982) reported throw trap accuracy of 97% for samples obtained in estuarine sand flats. This value is higher than ours, possibly because (1) a relatively sedentary benthic fish was studied, (2) only one comparison was performed, and (3) 63% of the enclosure area was sampled by throw trapping (versus 12% in our study and 8% in Kushlan 1976).

Reductions in sampling accuracy arise for a variety of reasons, and this is the first study to distinguish between different sources of error. We found that 17% of the fishes enclosed in throw traps were not recovered (i.e., 83% throw trap clearing efficiency). These fishes possibly burrowed (Frederick and Loftus 1993) or were discarded with sorted detritus (Freeman et al. 1984). Discarding of fishes seems unlikely because we carefully sorted through detritus in each sweep of the bar seine and dip nets. Similar clearing efficiencies (≈70–90%) have been reported for throw traps (reviewed by Rozas and Minello 1997). Clearing efficiency may be improved by (1) using a solid-walled throw trap; (2) removing all vegetation before emptying the throw trap; (3) pumping out and filtering water inside a solid-walled throw trap; or (4) more rigorous sorting of plants and detritus in the laboratory (Freeman et al. 1984; Jordan 1996a). Although no earlier studies measured both throw trap clearing efficiency and sampling accuracy, it was often implied that high throw trap clearing efficiency translated into high accuracy (i.e., clearing efficiency was the only source of sampling error). Our results indicated that an additional 20% (i.e., 100% population density − 63% sampling accuracy − 17% throw trap clearing efficiency) of the fishes present in a given location somehow avoided throw traps. Mean length, size distribution, and species composition data obtained by throw trapping were highly concordant with actual population parameters. Therefore, avoidance of throw traps did not appear to be size-based or to reflect avoidance behavior of individual species. Fishes greater than 100 mm in SL are rare in the Everglades marshes we studied (Loftus and Kushlan 1987; Jordan 1996a; Jordan and Trexler, unpublished data). A very large number of 1-m^2 samples would be required to determine if these large specimens are accurately sampled by throw traps. However, this study does not indicate that these fishes are poorly sampled by throw traps. The reduction in accuracy that we observed is very close to the 19% reported by Jacobsen and Kushlan (1987). These authors hypothesized that throw traps had a reduced effective sampling area (0.81 m^2) because fishes near the edges of a descending trap actively avoided the trap or were passively flushed outside. Our data and field observations also suggest that this is the most parsimonious explanation for reduced sampling accuracy of throw traps.

Acknowledgments

Casey Caulkins, Jane Jimeian, Betty Jordan, Kate Moss, Heather Soulen, and Andy Turner provided assistance in the field. Dale Gawlik, Wiley Kitchens, Franklin Percival, and the Florida Cooperative Fish and Wildlife Research Unit provided logistical support. Dale Gawlik, Lawrence Rozas, and an anonymous reviewer provided helpful comments on earlier drafts of this paper. Research was supported by contract C-E6636 from the South Florida Water Management District. This paper is contribution 49 of the Southeast Environmental Research Program.

References

Chick, J. C., 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 Freshwater Ecology 7:353–361.

Chick, J. C., and C. C. McIvor. 1994. Patterns in the abundance and composition of fishes among beds of different macrophytes: viewing a littoral zone as a landscape. Canadian Journal of Fisheries and Aquatic Sciences 51:2873–2882.

Connolly, R. M. 1994. Comparison of fish catches from a buoyant pop net and a beach seine net in a shallow seagrass habitat. Marine Ecology Progress Series 109:305–309.

Dewey, M. R., L. E. Holland-Bartels, and S. J. Zigler. 1989. Comparison of fish catches with buoyant pop nets and seines in vegetated and nonvegetated habitats. North American Journal of Fisheries Management 9:249–253.

Dionne, M., and C. L. Folt. 1991. An experimental analysis of macrophyte growth forms as fish foraging habitat. Canadian Journal of Fisheries and Aquatic Sciences 48:123–131.

Downing, J. A. 1991. The effect of habitat structure on the spatial distribution of freshwater invertebrate populations. Pages 87–106 *in* S. S. Bell, E. D. McCoy, and H. R. Mushinsky, editors. Habitat structure: the physical arrangement of objects in space. Chapman and Hall, New York.

Durocher, P. P., W. C. Provine, and J. E. Kraai. 1984. Relationship between abundance of largemouth bass and submerged vegetation in Texas reservoirs. North American Journal of Fisheries Management 4:84–88.

Frederick, P. C., and W. F. Loftus. 1993. Cold-weather behavior of estuarine and freshwater marsh fishes as a determinant of nesting success in wading birds in the Everglades of Florida. Estuaries 16:216–222.

Freeman, B. J., H. S. Greening, and J. D. Oliver. 1984. Comparison of three methods for sampling fishes and macroinvertebrates in a vegetated freshwater wetland. Journal of Freshwater Ecology 2:603–610.

Gilmore, R. G., and five coauthors. 1978. Portable tripod drop net for estuarine fish studies. U.S. National Marine Fisheries Service Fishery Bulletin 76:285–289.

Gunderson, L. H. 1994. Vegetation of the Everglades: determinants of community composition. Pages 323–340 *in* S. M. Davis and J. C. Ogden, editors. Everglades: the ecosystem and its restoration. St. Lucie Press, Delray Beach, Florida.

Heck, K. L., Jr., and L. B. Crowder. 1991. Habitat structure and predator-prey interactions in vegetated aquatic systems. Pages 281–299 *in* S. S. Bell, E. D. McCoy, and H. R. Mushinsky, editors. Habitat structure: the physical arrangement of objects in space. Chapman and Hall, New York.

Hellier, T. R. 1958. The drop-net quadrat, a new population sampling device. Publications of the Institute of Marine Science, University of Texas 5:165–168.

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

Hoyer, M. V., and D. E. Canfield, Jr. 1996a. Largemouth bass abundance in aquatic vegetation in Florida lakes: an empirical analysis. Journal of Aquatic Plant Management 34:23–32.

Hoyer, M. V., and D. E. Canfield, Jr. 1996b. Lake size, aquatic macrophytes, and largemouth bass abundance in Florida lakes: a reply. Journal of Aquatic Plant Management 34:48.

Hoyer, M. V., D. E. Canfield, Jr., J. V. Shireman, and D. E. Colle. 1985. Relationships between abundance of largemouth bass and submersed vegetation in Texas reservoirs: a critique. North American Journal of Fisheries Management 5:613–616.

Jacobsen, T., and J. A. Kushlan. 1987. Sources of sampling bias in enclosure fish trapping: effects on estimates of density and diversity. Fisheries Research 5:401–412.

Jordan, F. 1996a. Spatial ecology of decapods and fishes in a northern Everglades wetland mosaic. Doctoral dissertation. University of Florida, Gainesville.

Jordan, F. 1996b. An assessment of fish and decapod crustacean responses to hydrology, habitat complexity, and marsh management history. Final Report to the St. Johns River Water Management District, Palatka, Florida.

Jordan, F., K. J. Babbitt, C. C. McIvor, and S. J. Miller. 1996. Spatial ecology of the crayfish *Procambarus alleni* in a Florida wetland mosaic. Wetlands 16: 134–142.

Jordan, F., H. L. Jelks, and W. M. Kitchens. 1994. Habitat use by the fishing spider *Dolomedes triton* in a northern Everglades wetland. Wetlands 14:239–242.

Jordan, F., H. L. Jelks, and W. M. Kitchens. 1997. Habitat structure and plant community composition in a northern Everglades wetland landscape. Wetlands 17:275–283.

Kjelson, M. A., W. R. Turner, and G. N. Nelson. 1975. Description of a stationary drop-net for estimating nekton abundance in shallow waters. Transactions of the American Fisheries Society 104:46–49.

Kushlan, J. A. 1974. Quantitative sampling of fish populations in shallow, freshwater environments. Transactions of the American Fisheries Society 103: 348–352.

Kushlan, J. A. 1976. Environmental stability and fish community diversity. Ecology 57:821–825.

Kushlan, J. A. 1981. Sampling characteristics of enclosure fish traps. Transactions of the American Fisheries Society 110:557–662.

Larson, E. W., D. L. Johnson, and W. E. Lynch, Jr. 1986. A buoyant pop net for accurately sampling fish at artificial habitat structures. Transactions of the American Fisheries Society 115:351–355.

Loftus, W. F., and A. M. Eklund. 1994. Long-term dynamics of an Everglades small-fish assemblage. Pages 461–483 *in* S. M. Davis and J. C. Ogden, editors. Everglades: the ecosystem and its restoration. St. Lucie Press, Delray Beach, Florida.

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

Loveless, C. M. 1959. A study of the vegetation of the Florida Everglades. Ecology 40:1–9.

Maceina, M. J. 1996. Largemouth bass abundance in aquatic vegetation in Florida lakes: an alternative interpretation. Journal of Aquatic Plant Management 34:43.

Miller, S. J., and six coauthors. 1991. Comparison of Wegener ring and 0.08-hectare block net samples of fishes in vegetated habitats. Proceedings of the Annual Conference Southeastern Association of Fish and Wildlife Agencies 44(1990):67–75.

Peterson, C. H., and R. Black. 1994. An experimentalist's challenge: when artifacts of intervention interact with treatments. Marine Ecology Progress Series 111:289–297.

Pfennig, D. W., M. L. G. Loeb, and J. P. Collins. 1991. Pathogens as a factor limiting the spread of cannibalism in tiger salamanders. Oecologia 88:161–166.

Pihl, L., and R. Rosenberg. 1982. Production, abundance, and biomass of mobile epibenthic marine fauna in shallow waters, western Sweden. Journal of Experimental Marine Biology and Ecology 57: 273–301.

Rozas, L. P., and T. J. Minello. 1997. Estimating densities of small fishes and decapod crustaceans in shallow estuarine habitats: a review of sampling design with focus on gear selection. Estuaries 20:199–213.

Rozas, L. P., and W. E. Odum. 1987. Fish and macrocrustacean use of submerged plant beds in tidal freshwater marsh creeks. Marine Ecology Progress Series 38:101–108.

Serafy, J. E., R. M. Harrell, and J. C. Stevenson. 1988. Quantitative sampling of small fishes in dense vegetation: design and field testing of portable "pop nets." Journal of Applied Ichthyology 4:149–157.

Shireman, J. V., D. E. Colle, and D. F. DuRant. 1981. Efficiency of rotenone sampling with large and small block nets in vegetated and open-water habitats. Transactions of the American Fisheries Society 110:77–80.

Sogard, S. M., and K. W. Able. 1991. A comparison of eelgrass, sea lettuce macroalgae, and marsh creeks as habitats for epibenthic fishes and decapods. Estuarine, Coastal, and Shelf Science 33:501–519.

Sogard, S. M., G. V. N. Powell, and J. G. Holmquist. 1987. Epibenthic fish communities on Florida Bay mudbanks: relations with physical parameters and seagrass cover. Marine Ecology Progress Series 40: 25–39.

Sokal, R. R., and F. J. Rohlf. 1995. Biometry, 3rd edition. Freeman, New York.

Wegener, W., D. Holcomb, and V. Williams. 1974. Sampling shallow water fish populations using the Wegener ring. Proceedings of the Annual Conference Southeast Association of Game and Fish Commissioners 27(1973):663–674.

Wiens, J. A. 1976. Population responses to patchy environments. Annual Review of Ecology and Systematics 7:81–120.

Received December 1, 1996
Accepted April 16, 1997