Gulf of Mexico Science

Volume 16
Number 1 *Number 1*

Article 3

1998

Spatial and Temporal Variations in the Species Composition of Bycatch Collected During a Striped Mullet (*Mugil cephalus*) Survey

Daryl J. Pierce
Florida Marine Research Institute

Julie E. Wallin
Florida Marine Research Institute

Behzad Mahmoudi
Florida Marine Research Institute

DOI: 10.18785/goms.1601.03

Gulf of Mexico Science, 1998(1), pp. 15–27

Spatial and Temporal Variations in the Species Composition of Bycatch Collected During a Striped Mullet (*Mugil cephalus*) Survey

DARYL J. PIERCE, JULIE E. WALLIN, AND BEHZAD MAHMOUDI

We examined the variations in species composition of bycatch collected in an annual spawning-season survey of striped mullet, *Mugil cephalus*, in Tampa Bay and Charlotte Harbor, FL. Bycatch was defined as all species captured with the collection gear other than the target species, *M. cephalus*. Variations between habitat types, between months, and between years in the species composition of bycatch captured 1993–96 in this ongoing survey were examined using a nonparametric analysis of variance based on Bray-Curtis similarities. *Mugil cephalus* was the dominant species collected in both study areas, representing 16%–100% of the annual catch. *Lagodon rhomboides* and *Arius felis* were the most abundant bycatch species in Tampa Bay, and *A. felis* and *Mugil curema* were the most abundant bycatch species in Charlotte Harbor. *Archosargus probatocephalus, Sciaenops ocellatus,* and *Cynoscion nebulosus* composed the majority of the remaining bycatch species collected. Bycatch species composition was not significantly different between months, although indices of species richness (Margalef's index, d), species diversity (Shannon index, H'), and evenness (Pielou's index, J') declined from fall to winter in each year. Species composition differed significantly between riverine and bay habitats and between habitats with and without bottom vegetation (seagrass). Samples from seagrass habitats had more *L. rhomboides, A. probatocephalus,* and *S. ocellatus,* and samples from habitats without seagrass had more *A. felis*. Indices of species richness, diversity, and evenness were lowest in 1996 as a result of increased catches of *M. cephalus* and decreased occurrence of bycatch in survey samples. The implementation of the Florida net ban in 1995 may have brought about this increased abundance of *M. cephalus* and concomitant decrease in the percentage of bycatch captured in survey samples in 1996.

Historically, the commercial striped mullet (*Mugil cephalus*) fishery has been the backbone of Florida's commercial fishery. With the passage in 1995 of the constitutional amendment eliminating all entangling nets in Florida's waters, cast and seine nets (limited to less than 500 square feet in size) have replaced the traditional gill net fishery. These gears are fished in a variety of habitats throughout Florida's estuaries. Fishes collected as bycatch may be associated with the target species or may simply be collected on a random basis (Hall 1996). Information on the spatial and temporal distributions of bycatch with *M. cephalus* is necessary for the development of management regulation.

Florida's Department of Environmental Protection (FDEP) Fisheries-Independent Monitoring program conducts intensive sampling for striped mullet each fall and winter to obtain information used in making stock assessments. This survey is conducted in the two largest estuaries on Florida's Gulf coast, Tampa Bay and Charlotte Harbor. Monitoring *M. cephalus* populations in these two estuaries is important because of the historically intense commercial fishing pressure on mullet in these areas; more than 60% of the commercial landings of *M. cephalus* in Florida were made in Tampa Bay and Charlotte Harbor (Mahmoudi 1997). In addition to providing fisheries-independent data to monitor annual fluctuations in the *M. cephalus* population, the survey also provides a unique long-term database on species collected incidental to the target species. Bycatch was defined as all species captured other than *M. cephalus*.

The objectives of this study were to examine the variation in the composition of bycatch species from a directed *M. cephalus* survey from 1993 through 1996 between habitat types, between months (within-season-variation), and between years (between-season variation).

METHODS

This survey was conducted each fall and winter from 1993 to 1996 from two estuaries on the central west coast of Florida in Tampa Bay and Charlotte Harbor (Fig. 1). Each estuary was divided into sampling zones to distribute sampling effort throughout the estuary. Tampa Bay was divided

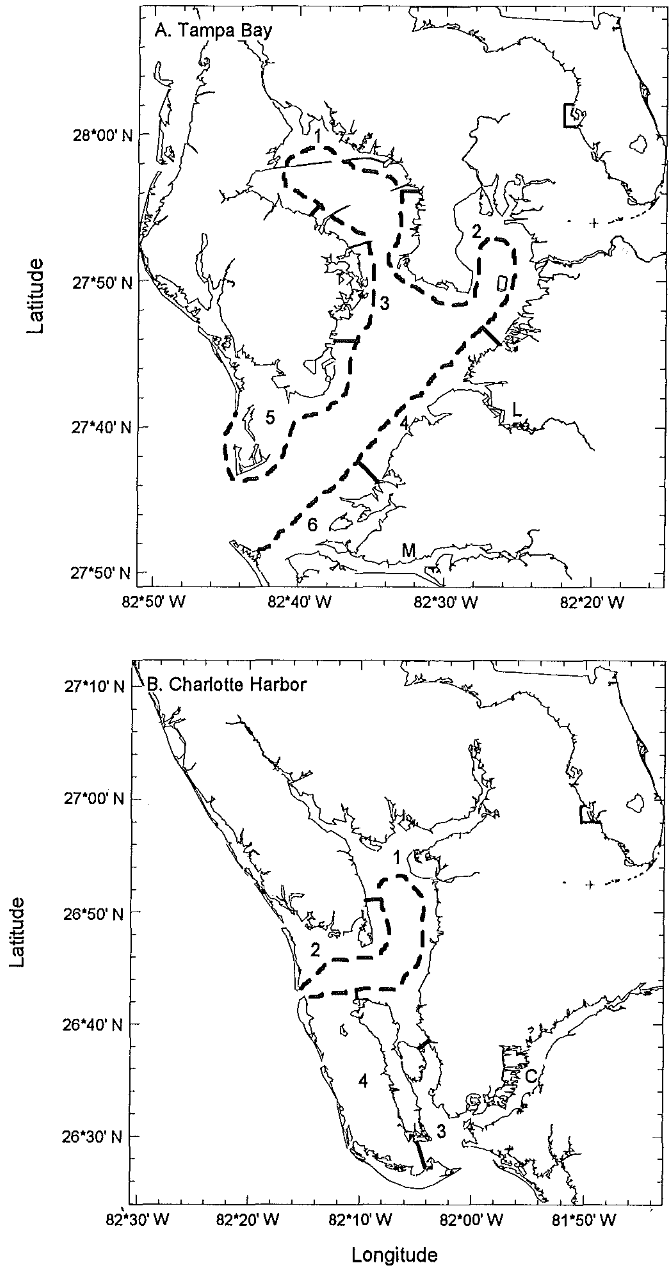

Fig. 1. Survey locations of (A) Tampa Bay and (B) Charlotte Harbor along the central west coast of Florida; Collection zones are denoted by dashed lines. Tampa Bay: (1) Old Tampa Bay; (2) Hillsborough Bay to Apollo Beach; (3) Howard Frankland Bridge to St. Petersburg City Pier; (4) Apollo Beach to Piney Point; (5) St. Petersburg City Pier to Mullet Key; (M) Manatee River; (L) Little Manatee River. Charlotte Harbor: (1) Myakka River to Matlacha Pass; (2) Bull Bay to Boca Grande Pass; (3) Matlacha Pass to York Island (south of Pine Island); (4) Cayo Costa, Pine Island Sound; (C) Caloosahatchee River.

into six sampling zones, two of which contained riverine habitat (Little Manatee and Manatee Rivers; Fig. 1). Charlotte Harbor was initially divided into five sampling zones, but the Caloosahatchee River (sampling zone C) was dropped after 1994 (Fig. 1). Collection periods were defined from the middle of one month to the middle of the next (e.g., mid-Sep. through mid-Oct.) to encompass the prespawning migration of *M. cephalus* from the estuaries to offshore waters during the fall and winter months in Tampa Bay (mid-Sep. through mid-Feb.) and Charlotte Harbor (mid-Oct. through mid-Feb.).

Fish were captured in experimental 366-m-long monofilament trammel nets (308-mm stretch outer mesh, 71-mm stretch inner mesh). Samplers searched shallow (<2 m deep) nearshore areas for aggregations of *M. cephalus*. All fishes collected were identified to species and counted. For each sample, we recorded habitat variables such as bottom type (mud or sand) and bottom vegetation (presence or absence of the seagrasses *Halodule wrighti* and *Thalassia testudinum*) and physical variables such as water temperature and tidal phase.

Margalef's index (d) for species richness, Shannon species diversity index (H'), and Pielou's evenness index (J') were used to evaluate the diversity of the bycatch species composition (Dahlberg and Odum, 1970). These were calculated for samples in each survey year inclusive of all species collected (rare and common) by using the DIVERSE algorithm in the PRIMER (Plymouth Routines in Multivariate Ecological Research, version 4.0) software using $\log_{10}$-transformed data. Kendall's tau correlation was used to evaluate changes in the three indices between collection periods within each survey year (Sokal and Rohlf, 1981). A Kruskal-Wallis test was used to compare the three indices between survey years.

Similarities among samples for each estuary and survey year were described by hierarchical agglomerative cluster analysis using group-average fusion of Bray-Curtis similarity indices (PRIMER's CLUSTER algorithm). To exclude single or rare occurrences, only species that represented >0.5% of the total catch from each collection period were included in the analyses. More samples were collected in Tampa Bay than PRIMER could analyze; therefore, the data set was reduced by averaging samples that were collected on the same day, sampling zone, bottom vegetation, bottom type, and tidal period. Similar reduction was not necessary for Charlotte Harbor, and individual samples were used in the analysis. To reduce emphasis on dominant species, abundance data were $\log_{10}(x + 1)$ transformed.

Analysis of similarity (ANOSIM) was used to compare bycatch species compositions between collection periods, between sampling zones, between bottom vegetation (presence or absence of seagrass), between bottom types (sand or mud), and between tidal phases (flood, ebb, high slack, and low slack) for each estuary and survey year. Each of the categorical variables (collection period, sampling zone, bottom vegetation, bottom type, and tidal phase) were analyzed separately. ANOSIM is a nonparametric analysis of variance based on Bray-Curtis similarities (Clarke, 1993). All comparisons were based on 5,000 permutations by randomly reordering the data to determine a global-R statistic (Clarke and Warwick, 1994). Significant differences between treatments within each categorical variable were determined from pairwise comparisons using ANOSIM; pairwise comparisons were only conducted for treatments with three or more samples. It should be noted that pairwise comparisons do not adjust for multiple tests of the same hypothesis. ANOSIM was also used to compare species compositions between survey years within each estuary. Percentages of individual species contributions to the total average dissimilarity between treatment groups within a categorical variable for each survey year were determined by similarity percentages analysis (SIMPER; Clarke and Warwick, 1994).

RESULTS

In Tampa Bay, the number of trammel net samples collected varied from 51 to 87 per year; these were reduced to 27–57 samples for analysis. In Charlotte Harbor, the number of samples was from 17 to 29 per year. Forty-three species were collected in samples from Tampa Bay, and 30 species were collected in Charlotte Harbor. Ten species accounted for 95% of all individuals collected from both estuaries (Tables 1 and 2). As expected, *M. cephalus* was the most abundant species in all collection periods for both estuaries (16%–100%), because sampling effort was directed at this species (Tables 1 and 2). The most abundant bycatch species in Tampa Bay were *Lagodon rhomboides* (pinfish), *Arius felis* (hardhead catfish), *Mugil curema* (silver mullet), and *Mugil gyrans* (fantailed mullet), which represented 0%–45% of the catch, depending on the collection period. *Arius felis, Archosargus probatocephalus* (sheepshead), and *M. curema* were the most abundant bycatch species in Charlotte Harbor, accounting for 0%–79% of the total catch in each survey year. *Lagodon rhomboides* were not as abundant in Charlotte Harbor as in Tampa Bay and accounted for only 0.4%–25% of the total bycatch in any of the four survey years. *Caranx hippos* (crevalle jack), *Centropomus undecimalis* (common snook), *Sciaenops ocellatus* (red drum), *Cynoscion nebulosus* (spotted seatrout), and *Elops saurus* (ladyfish) composed the ma-

TABLE 1. Partial listing of the bycatch species for each collection period in a particular survey year for Tampa Bay. The percentage of the total catch for each collection period is listed. Those species that occurred more than 0.5% in a collection period within a survey year were included in the analysis. Collection periods are labeled as follows: 1 = Sep./Oct., 2 = Oct./Nov., 3 = Nov./Dec., 4 = Dec./Jan., and 5 = Jan./Feb.

	1993				1994				1995				1996				
Species	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	5
Ameiurus catus	0	0	0.72	0	0	16.2	0.00	0	0	0	0	0	0	0	0	0	0
Archosargus probatocephalus	1.52	1.07	0.99	2.04	2.68	3.84	2.13	0.80	0.08	5.25	5.26	0	0.56	0.18	2.80	1.74	0
Arius felis	8.64	8.34	10.6	0.58	14.6	10.5	13.9	0.53	17.4	21.2	1.81	0	0.81	0	0.13	0.22	0
Bagre marinus	0.51	0.10	0.08	0	0.06	0	1.39	0	0.08	0	0	0	0	0	0	0	0
Brevoortia smithi	0	0	0	0	0	0	1.81	0	0	0	0	0	0	0	0	0	0
Brevoortia spp.	0.14	0	0	4.13	0	0	0.21	0	0	0	0	0	0.06	0	0	0	0
Carnax hippos	0.23	3.26	2.39	0.10	2.11	0.28	0.32	0.94	0.53	1.18	0.08	0	0.37	0.06	0.57	0	0
Centropomus undecimalis	0.14	0.36	0.32	0	0.70	1.14	0.43	0.13	0.23	0.07	0.78	0	0.31	0.31	0	0	0
Chaetodipterus faber	0.18	0.10	0	0	0.26	0	1.07	0	0	0.26	0	0	0	0	0	0	0
Chilomycterus schoepfi	0.23	0.05	0	0	0	0	0	0	0	0.13	0	0	0.87	0	0.25	0.36	0
Cynoscion nebulosus	0.14	0.31	0.08	0.05	1.15	1.00	0.32	0.94	0.08	0.85	0.31	0	0.81	0.12	0.51	0.36	0
Diapterus plumieri	1.66	0.25	2.74	0	0.38	0.28	1.92	0.53	0.53	0.33	0	0	0.56	0	0	0	0
Elops saurus	0.37	0.15	0.12	0	0.51	0.14	1.81	3.07	0.08	0.46	0.71	0	0	0.06	0.57	0	0
Lagodon rhomboides	18.0	13.0	1.03	0.26	23.3	4.69	0.53	0	19.8	13.5	2.20	0.07	19.8	0.12	0.83	0.14	0
Leiostomus xanthurus	0.65	0	0	0	0.26	0	0	0	0.53	0.46	0	0	2.30	0.06	0	0	0
Lutjanus griseus	1.02	0	0	0	0.06	0	0	0	0	0.00	0	0	0	0	0	0	0
Mugil cephalus	61.2	62.1	80.0	83.1	44.3	48.7	59.5	87.3	54.1	41.5	69.0	99.6	59.2	97.0	90.8	96.1	100
Mugil curema	0.18	2.14	0	8.01	0.77	0.28	10.4	4.81	0.23	0.79	8.63	0	11.8	0.61	1.40	0	0
Mugil gyrans	0.05	3.81	0.04	0.58	6.07	10.6	0.96	0	3.50	11.0	8.08	0	0.06	0	0.13	0	0
Orthopristis chrysoptera	1.02	0.10	0	0	0.51	0.28	0.96	0	0.23	0.26	1.10	0	0.19	0	0	0	0
Pogonias cromis	1.25	1.53	0.24	0.68	0.06	0	0.11	0	0.38	0.07	0.16	0	0.12	0	0.06	0	0
Rhinoptera bonasus	0.51	0.56	0	0	0	0	0.11	0	0.38	0.46	0	0.14	0	0.31	0	0	0
Sciaenops ocellatus	0.14	0.46	0.20	0.37	1.15	0.71	0.53	0.94	0.53	0.26	0.39	0	0.99	0.55	0.51	0.94	0
Tilapia spp.	0.42	0	0.04	0	0	0	0	0	0	0	0	0	0.06	0	0.70	0	0
Number of samples	24	15	9	9	20	9	13	5	12	7	6	2	11	9	13	6	3

TABLE 2. Partial listing of the bycatch species for each collection period in a particular survey year for Charlotte Harbor. The percentage of the total catch for each collection period is listed. Those species that occurred more than 0.5% in a collection period within a survey year were included in the analysis. Collection periods are labeled as follows: 1 = Sep./Oct., 2 = Oct./Nov., 3 = Nov./Dec., 4 = Dec./Jan., and 5 = Jan./Feb.

	1993			1994				1995				1996			
Species	1	2	3	1	2	3	4	1	2	3	5	2	3	4	5
Archosargus probatocephalus	2.72	0.60	3.93	1.30	3.41	1.74	4.50	0.55	0.11	0.85	0	0.35	0.50	0	0
Arius felis	11.5	2.11	10.2	30.4	6.82	0.52	0	46.44	5.78	24.3	0	0	0	0	0
Bairdiella chrysoura	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.83
Carnax hippos	0.34	0.45	0.52	0	0	1.22	0	2.55	2.73	0.43	0.26	3.85	0	0	0
Centropomus undecimalis	0	0.45	1.83	2.61	0	1.04	0.90	0.27	0.11	0	0	0.70	0	0	0
Chilomycterus schoepfi	0	0	0	0	0	0	0	0.18	0.32	0	0	0	0	0	0
Cynoscion arenarius	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.38
Cynoscion nebulosus	0	0	0	0	0	0.35	0	0.27	0.21	4.90	0.26	1.05	1.49	0.55	4.13
Diapterus plumieri	4.76	4.37	1.57	0.43	0	0	0	0	0	0	0	0	0	0	0
Elops saurus	0	0	0	0	0	0.35	0	0.09	0.32	0	0	0	0	0	7.80
Lagodon rhomboides	1.02	0.60	0.52	0.43	0	1.04	0	14.7	25.8	0.43	0	1.05	0	0	0
Leiostomus xanthurus	0	0	0	0	0	0	0	0.18	0	0	0	0	0	0	3.21
Lepisosteus platyrhincus	0	0.45	1.57	0	0	0	0	0	0	0	0	0	0	0	0
Lutjanus griseus	0	0	0	0.87	0	0	0	1.92	0	0	0	0	0	0	0
Mugil cephalus	74.9	84.3	77.4	57.3	80.6	91.8	67.5	29.2	63.1	16.2	59.9	75.8	94.0	98.3	79.8
Mugil curema	0.68	0.15	0	0.00	0	0.87	27.0	0.27	0.32	51.8	38.4	14.3	0	0.37	0
Mugil gyrans	1.70	3.02	0	3.48	0	0	0	0.27	0	0	0	0	0	0	0.46
Sciaenops ocellatus	0	0.15	0.26	0.43	0	0.70	0	0.18	0.21	0.64	0.79	1.75	0.50	0.18	0.46
Tilapis spp.	0	0	0.79	0.43	6.82	0	0	0	0	0	0	0	0	0	0
Number of samples	3	11	9	5	5	5	4	4	5	2	3	6	2	2	3

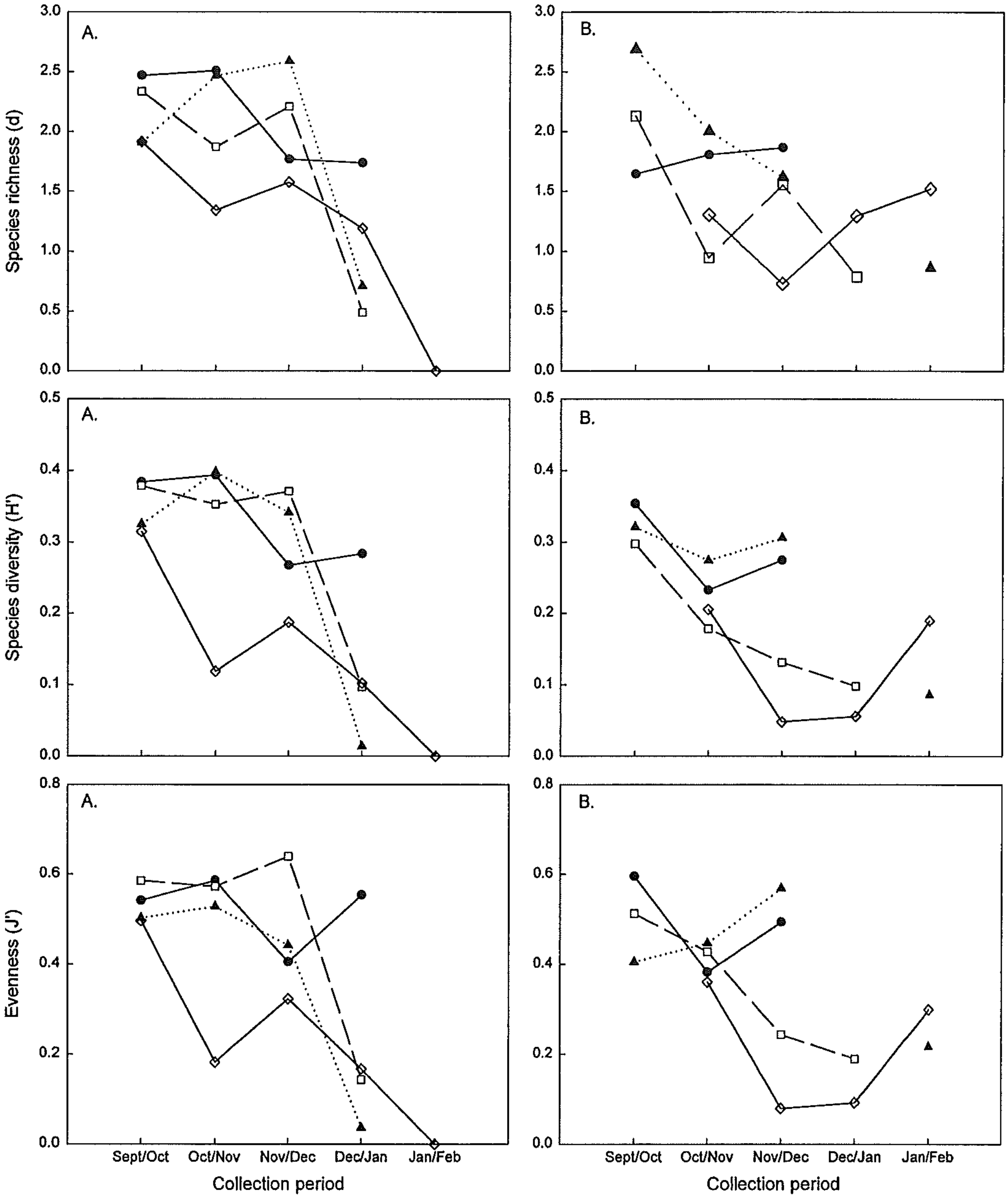

Fig. 2. Mean values of species richness, diversity, and evenness by collection period for (A) Tampa Bay and (B) Charlotte Harbor. (–●–) 1993, (- -□- -) 1994, (···▲···) 1995, and (–◇–) 1996.

jority of the remaining bycatch species in both estuaries.

Species richness (d), species diversity (H'), and evenness (J') were generally greatest in the earliest collection periods (Sep.–Oct.) and decreased in subsequent periods (Fig. 2). In Tampa Bay, species richness in 1993, 1994, and 1996, species diversity in 1993 and 1996, and evenness in 1996 all decreased significantly ($P < 0.05$) from the early fall through the winter collection periods in Tampa Bay (Table 3). In Charlotte Harbor, species diversity and evenness in 1994 decreased significantly ($P < 0.05$) from the fall through the winter collection periods (Table 3). Species diversity and evenness increased during the 1996 Jan./Feb. collection period in Charlotte Harbor, because *M. cephalus* did not dominate the catch in that collec-

TABLE 3. Summary of Kendall's tau correlations (tau) of species richness (*d*), species diversity (*H'*), and evenness (*J'*) between collection periods; analysis of similarities (ANOSIM) global *R* statistics for the five categorical variables (collection period, bottom type, tidal phase, sampling zone, and bottom vegetation); and pairwise comparisons of bycatch species compositions between survey years for Tampa Bay and Charlotte Harbor.

Year	Species richness (*d*) tau	Species diversity (*H'*) tau	Evenness (*J'*) tau	Collection period *R*	Bottom type *R*	Tidal phase *R*	Sampling zone *R*	Bottom vegetation *R*	Pairwise comparisons 1994 *R*	1995 *R*	1996 *R*
Tampa Bay											
1993	−0.190[a]	−0.167[a]	−0.082	−0.012	0.017	0.035	0.142[a]	0.493[a]	−0.01	−0.02	0.35[a]
1994	−0.196[a]	−0.176	−0.059	0.019	−0.033	0.043	0.130[a]	0.259[a]	—	−0.06	0.25[a]
1995	0.112	−0.079	−0.147	0.204[a]	0.003	0.070	0.279[a]	0.269[a]		—	0.34[a]
1996	−0.400[a]	−0.509[a]	−0.526[a]	0.013	0.022	−0.038	−0.008	0.081			—
Charlotte Harbor											
1993	0.014	0.014	−0.004	0.089	0.252[a]	−0.103	0.307[a]	0.292[a]	0.05	0.16[a]	0.17[a]
1994	−0.313	−0.431[a]	−0.471[a]	0.135	−0.001	0.157	0.095	0.076	—	0.04	−0.01
1995	−0.286	−0.360	−0.186	0.127	−0.080	−0.138	0.107	0.459[a]		—	0.09[a]
1996	−0.197	−0.197	−0.198	−0.277	−0.265	0.303	0.004	0.169			—

[a] Denotes a significant correlation, or global *R* statistic ($P < 0.05$).

tion period. The three indices were significantly different between years in Tampa Bay (Kruskal-Wallis, df = 3, $P < 0.001$) but not in Charlotte Harbor (Kruskal-Wallis, df = 3, $P > 0.05$). Both estuarine systems had the lowest values for all three indices in 1996 (Fig. 2).

Bycatch species composition was generally not significantly different between collection periods, between bottom types, or between tidal phases in Tampa Bay or Charlotte Harbor (Table 3). However, in 1995, bycatch species composition did differ significantly between collection periods in Tampa Bay ($R = 0.204$, $P = 1.4\%$) (Table 3). Pairwise comparisons of the collection periods showed that the Sep./Oct. collection period was significantly different from the Nov./Dec. period ($R = 0.390$, $P = 0.2\%$). *Mugil cephalus* (representing 54.0% of total catch), *L. rhomboides* (19.8%), and *A. felis* (17.4%) accounted for the majority of the catch in the Sep./Oct. collection period, and *M. cephalus* (69.0%), *M. curema* (8.6%), *M. gyrans* (8.0%), and *A. probatocephalus* (5.2%) accounted for the majority of the catch in the Nov./Dec. collection period. Bycatch species composition was significantly different between bottom types in Charlotte Harbor in 1993 ($R = 0.252$, $P = 4.3\%$) (Table 3). Individual species contributions indicated that *M. cephalus* (72.0%), *A. felis* (11.2%), *Diapterus plumeri* (striped mojarra) (9.9%), *C. undecimalis* (3.0%), and *A. probatocephalus* (1.5%) were collected over mud bottoms, whereas only *M. cephalus* (95.4%) and *A. probatocephalus* (2.6%) were typically collected over sand bottoms.

Bycatch species compositions were significantly different between sampling zones within each survey year in Tampa Bay except 1996 (Table 3). Bycatch species compositions of riverine sampling zones were different from those of estuarine sampling zones (3 vs L, 3 vs M, 5 vs L, 5 vs M, 6 vs L, and 6 vs M in 1993; 3 and 5 vs M in 1994; and 2, 3, and 5 vs M in 1995; See Figure 1 for locations of numbered and lettered zones). Bycatch species compositions also differed between some sampling zones within the open bay of the estuary (zones 3 vs 5 in 1993 and 1994 and zones 1 vs 3, 1 vs 6, and 2 vs 5 in 1995). Although many of the same species were collected in most or all of the sampling zones, only a few species were responsible for the discrimination of the sampling zones. *Arius felis, A. probatocephalus,* and *L. rhomboides* contributed the most to differences in bycatch species composition between sampling zones. Riverine sampling zones were distinguished from estuarine samples by higher abundances of *A. felis, D. plumieri,* and

Pogonias cromis (black drum) and lower abundances of *A. probatocephalus* and *L. rhomboides* (Table 4). Within the open bay of the estuary, differences in bycatch species composition between sampling zones were generally attributed to differences in abundances of *A. probatocephalus, L. rhomboides, A. felis,* and *Mugil* species in the different sampling zones (Table 4). In Charlotte Harbor, bycatch species compositions were significantly different between sampling zones only for the 1993 survey year (Table 3). As in Tampa Bay, several species characterized many sampling zones, and bycatch species composition in the riverine sampling zone (C) differed from that in the estuarine zone (Table 4). The riverine sampling zone (C) had higher abundances of *A. felis* and lower abundances of *D. plumieri, A. probatocephalus,* and *L. rhomboides* than did the estuarine sampling zone (3) (Table 4).

Bycatch species composition was significantly different between the presence or absence of bottom vegetation in every survey year in both estuaries except 1996 in Tampa Bay and 1994 and 1996 in Charlotte Harbor (Table 3). *Arius felis* and *L. rhomboides* were primarily responsible for the dissimilarity between bottom vegetations. In Tampa Bay, bycatch species composition was distinguished by higher abundances of *L. rhomboides* and *A. probatocephalus* in seagrass bottom vegetations and higher abundances of *A. felis* in non-seagrass bottom vegetation (Table 5). In Charlotte Harbor, similar bycatch species compositions characterized bottom types with and without seagrass, as they did in Tampa Bay, although the contributions of *L. rhomboides* were smaller in Charlotte Harbor than in Tampa Bay for the 1993 survey year (Table 5). Differences in bycatch species composition in both 1993 and 1995 between bottom vegetation types was due to higher abundances of *A. felis* in nonvegetated habitats (1993) and higher abundances of *D. plumieri* (1993) and *L. rhomboides* (1995) in grass habitats (Table 5). The unusually high abundance of *A. felis* in the bycatch of samples collected over grass in 1995 was heavily influenced by a single large catch of *A. felis* in a grass habitat.

Bycatch species compositions were significantly different between survey years in both estuaries (ANOSIM, Tampa Bay: $R = 0.166$, $P < 0.0\%$; Charlotte Harbor: $R = 0.085$, $P < 0.9\%$). In Tampa Bay, species compositions in 1993, 1994, and 1995 were significantly different from species compositions in 1996 (Table 3). Bycatch species compositions in 1996 were distinguished by much larger catches of *M. cephalus* and lower catches of *L. rhomboides* and *A. felis* than in previous years (Table 6). In Charlotte Harbor, the bycatch species composition in 1993 was significantly different from those in 1995 and 1996, and the bycatch species composition in 1995 was significantly different from that in 1996 (Table 3). The significant difference between bycatch species composition in 1993 and 1995 was attributed to the single large catch of *A. felis* in 1995. As in Tampa Bay, *M. cephalus* were more abundant in 1996 samples, and *A. felis* were less common. Also, *M. curema* and *C. nebulosus* occurred more frequently as bycatch catch than in previous years (Table 6).

Discussion

Although *M. cephalus* dominated the trammel net samples, species diversity was fairly high each year, and other species were consistently collected with *M. cephalus. Lagodon rhomboides* and *A. felis* composed the majority of the bycatch in all years except 1996, when the percentage of occurrence of *A. felis* declined sharply in both Tampa Bay and Charlotte Harbor. This decline may have been due to a large adult *A. felis* mortality event associated with a virus epidemic in the fall of 1995 (Jan Landsberg, Florida Marine Research Institute, pers. comm., Dec. 1997).

Species compositions did not statistically differ between collection periods, indicating that bycatch species compositions did not change within survey years (i.e., the same bycatch species were caught from early fall through winter). However, indices of species richness, species diversity, and evenness declined within each year from the fall through the winter collection periods as a result of increased dominance of *M. cephalus* and reduced occurrences of bycatch species as the sampling season progressed. With the onset of winter and increasing occurrences of climatic cold fronts, *M. cephalus* congregate in prespawning migratory schools that are easy to detect and encircle with a trammel net, thus increasing their susceptibility to the sampling gear. In addition, many of the other species commonly collected in early fall tend to migrate out of shallow water to deeper, warmer waters because of seasonally cooling water temperatures or winter spawning activity (Springer and Woodburn, 1960; Wang and Raney, 1971; Fraser, 1997; Pattillo et al. 1997), thus potentially reducing their susceptibility to the gear as the sampling season progresses.

Differences between habitats in the open bay and riverine sampling zones resulted in dif-

TABLE 4. Mean abundances of bycatch species for significantly different sampling zones from the pairwise comparisons (ANOSIM) for each estuary. A dash indicates no individual species contribution. Sampling zones are labeled as defined in Figure 1.

	Tampa Bay														Charlotte Harbor 1993	
	1993					1994			1995							
Species	3	5	6	L	M	3	5	M	1	2	3	5	6	M	3	C
Arius felis	2.3	2.8	4.1	22.7	8.7	7.9	3.3	10.6	14.2	38.6	5.3	10.7	0.0	8.7	1.6	3.1
Archosargus probatocephalus	2.0	1.3	0.6	0.0	1.0	1.2	2.6	7.3	0.0	0.0	4.3	5.9	22.5	0.0	1.8	1.1
Bagre marinus	0.0	0.09	0.0	1.1	0.2	0.0	0.0	0.7	—	—	—	—	—	—	—	—
Brevoortia spp.	0.0	3.8	0.0	0.0	0.0	0.8	0.8	0.0	—	—	—	—	—	—	—	—
Carnax hippos	0.1	0.0	0.3	0.1	0.4	0.6	0.0	0.4	0.4	0.0	0.3	0.3	0.0	0.5	0.7	0.2
Centropomus undecimalis	—	—	—	—	—	0.3	0.1	0.3	—	—	—	—	—	—	0.5	0.4
Diapterus plumieri	0.3	0.0	0.0	1.0	3.3	0.2	0.0	1.6	0.0	0.0	0.0	0.0	0.0	1.7	4.1	1.7
Elops saurus	—	—	—	—	—	0.1	0.2	2.0	1.6	0.0	2.6	0.0	0.0	0.0	—	—
Lutjanus griseus	0.4	0.6	0.3	0.0	0.0	—	—	—	—	—	—	—	—	—	—	—
Lagodon rhomboides	5.5	15.8	33.5	0.0	0.0	3.2	15.0	0.0	0.0	0.0	2.3	25.1	1.5	0.0	1.1	0.0
Leiostomus xanthurus	0.0	0.1	1.8	0.0	0.0	—	—	—	0.0	0.0	0.0	0.8	0.0	0.0	—	—
Mugil cephalus	91.5	37.1	55.3	51.4	117.7	53.4	11.7	42.7	74.2	23.0	59.0	206.1	97.5	33.0	51.1	39.8
Mugil curema	0.6	1.5	13.0	0.4	1.9	0.4	1.7	6.9	0.6	0.0	1.3	0.1	5.0	2.7	0.1	0.0
Mugil gyrans	2.1	0.0	0.0	0.1	0.3	0.8	6.9	0.09	0.0	10.6	1.0	0.1	13.0	0.0	3.3	0.0
Orthopristis chrysoptera	0.0	0.9	1.6	0.0	0.0	0.0	0.9	0.0	0.0	0.0	0.0	0.3	1.0	0.0	—	—
Pogonias cromis	0.0	0.2	0.0	0.1	3.5	—	—	—	—	—	—	—	—	—	—	—
Rhinoptera bonasus	1	0.0	0.0	0.3	0.1	—	—	—	—	—	—	—	—	—	—	—
Sciaenops ocellatus	—	—	—	—	—	0.6	0.6	0.4	0.6	1.3	0.0	0.2	2.0	0.0	—	—

TABLE 5. Mean abundances of bycatch species for significantly different bottom vegetation types from the pairwise comparisons (ANOSIM) for each estuary. A dash indicates no individual species contribution. G = sea grass bottom vegetation, N = no seagrass bottom vegetation.

Species	Tampa Bay						Charlotte Harbor			
	1993		1994		1995		1993		1995	
	G	N	G	N	G	N	G	N	G	N
Arius felis	4.6	5.1	7.8	7.3	11.4	15.5	2.8	24.2	80.8	1.1
Archosargus probatocephalus	1.6	0.5	2.8	0.1	5.6	0.5	0.7	2.6	0.6	0.1
Carnax hippos	0.1	0.1	0.2	0.3	0.4	0.2	0.2	0.0	4.3	0.1
Centropomus undecimalis	—	—	—	—	—	—	0.5	0.0	—	—
Diapterus plumieri	0.1	1.1	0.2	2.2	0.0	0.2	2.5	0.0	—	—
Elops saurus	—	—	0.1	0.3	0.0	1.1	0.8	0.0	—	—
Lutjanus griseus	0.9	0.0	—	—	—	—	—	—	2.8	0.0
Lagodon rhomboides	25.6	0.1	12.2	0.8	27.1	0.5	0.4	0.0	32.3	5.1
Mugil cephalus	49.4	54.8	24.2	105.2	217.4	61.2	42.4	56.6	51.6	114.5
Mugil curema	1.0	3.8	0.6	6.5	0.7	0.4	0.1	0.4	0.8	1.5
Mugil gyrans	0.0	0.0	0.5	0.5	2.6	2.3	1.0	1.0	—	—
Pogonias cromis	0.1	1.0	—	—	—	—	—	—	—	—
Sciaenops ocellatus	—	—	1.0	0.3	0.6	0.5	—	—	1.0	0.3

ferent bycatch species compositions, particularly in Tampa Bay. The open-bay sampling zones in Tampa Bay and Charlotte Harbor are characterized by seagrass beds interspersed with mud or sand patches, whereas the riverine sampling zones are characterized by unvegetated silt and mud bottom types. Riverine sampling zones had higher abundances of *A. felis*, *D. plumieri*, and *P. cromis*, which are typically associated with mud bottom types (Table 5). There were no differences in bycatch species compositions between sampling zones in Charlotte Harbor in 1994–96, but riverine sampling zones were not sampled in 1995 or 1996. In 1993, however, when there was more intensive sampling in the lower Caloosahatchee River sampling zone (C), there were significant differences in species composition between the open-bay and riverine sampling zones.

The presence or absence of bottom vegetation (seagrasses) appeared to have the strongest influence on bycatch collected in the mul-

TABLE 6. Mean abundances of bycatch species for significantly different survey years from the pairwise comparisons (ANOSIM) for each estuary. A dash indicates no individual species contribution.

Species	Tampa Bay				Charlotte Harbor			
	1993	1994	1995	1996	1993	1994	1995	1996
Arius felis	7.2	6.7	11.2	0.1	7.9	3.5	35.2	0.0
Archosargus probatocephalus	1.4	1.2	5.2	1.3	1.1	0.9	0.3	0.1
Bagre marinus	0.1	0.1	0.1	0.0	—	—	—	—
Brevoortia spp.	0.9	0.0	0.0	0.0	0.0	0.0	0.1	0.1
Carnax hippos	0.3	0.4	0.6	0.4	0.2	0.1	1.9	0.8
Centropomus undecimalis	0.2	0.1	0.2	0.2	0.4	0.6	0.1	0.1
Cynoscion nebulosus	0.1	0.3	0.2	0.4	0.0	0.1	0.2	1.3
Diapterus plumieri	0.9	0.8	0.3	0.3	2.0	0.1	0.0	0.0
Elops saurus	0.1	0.6	0.6	0.2	0.1	0.0	0.2	1.3
Lutjanus griseus	0.2	0.0	0.0	0.0	0.0	0.1	1.2	0.0
Lagodon rhomboides	8.4	4.5	17.8	3.5	0.3	0.3	16.7	0.2
Lepisosteus platyrhincus	—	—	—	—	0.3	0.0	0.0	0.0
Mugil cephalus	65.4	50.8	93.8	118.5	45.4	40.0	87.5	86.0
Mugil curema	3.3	3.3	2.4	3.3	0.1	1.7	1.2	3.3
Mugil gyrans	0.7	2.2	6.8	0.1	1.0	0.4	0.1	0.1
Orthopristis chrysoptera	0.2	0.2	0.4	0.0	—	—	—	—
Pogonias cromis	0.7	0.0	0.2	0.1	—	—	—	—
Sciaenops ocellatus	0.4	0.7	0.4	0.7	0.8	0.2	0.6	0.2

DOI: 10.18785/goms.1601.03

let survey samples. Generally, more bycatch species were collected along with *M. cephalus* over sea grass habitats. Bycatch species typically collected in grass habitats included *L. rhomboides, A. probatocephalus, Orthopristis chrysoptera* (pigfish), and *S. ocellatus* (Table 5). Habitats without bottom vegetation tended to have higher numbers of *A. felis*. Bottom vegetation was apparently responsible for the differences between collection periods in 1995 in Tampa Bay. During that year, the early collections (Sep./Oct.) were typically from habitats without vegetation, resulting in large catches of *M. cephalus* and *A. felis*. Later in the season, more samples were collected in habitats with seagrass and were composed of *M. cephalus, L. rhomboides, A. probatocephalus,* and *A. felis*.

The percentage of bycatch collected with *M. cephalus* decreased during the sampling years and was lowest in 1996. This may have been the result of fishery management regulations including weekend closures and gear limitations and/or the implementation of the Florida net ban in July 1995, which severely restricted commercial catches of *M. cephalus* by eliminating the use of entangling nets within 1.6 km of the east coast and within 4.8 km of the west coast. Mahmoudi (1997) reported a significant proportional increase in the abundance of larger, older *M. cephalus* after the net ban to an 80% reduction of statewide commercial mullet landings. The lower species diversity and evenness values for 1996 reflect an increase in the dominance of *M. cephalus* in the catches from that year.

Other faunal studies indicated that the bycatch species from our study were common in both Tampa Bay and Charlotte Harbor estuaries (Springer and Woodburn, 1960; Gunter and Hall, 1965; Finucane, 1966; Wang and Raney, 1971; Fraser, 1997). *Anchoa mitchilli, L. rhomboides, Bairdella chrysura* (silver perch), *O. chrysopterus,* and *Eucinostomus* spp. were commonly reported residential species collected throughout both estuaries. Wang and Raney (1971) also noted greater occurrences of *D. plumieri* at the mouths of the Myakka and Peace Rivers, Charlotte Harbor. However, many of the listed residential species, including some of the more abundant species (*A. mitchilli, Leiostomus xanthurus* (spot), *B. chrysura*) either were not collected or were rare occurrences of bycatch with *M. cephalus* due to the larger mesh size of this study's experimental trammel net. Adult *M. cephalus* were also most likely underrepresented due to gear limitations (Springer and Woodburn, 1960; Wang and Raney, 1971) although Springer and Woodburn (1960) and Gunter and Hall (1965) reported collections of young-of-the-year (YOY) *M. cephalus* (<80 mm Standard Length (SL)) from all sampling habitats year round in Tampa Bay and YOY *M. cephalus* (16–133 mm total length) from the Caloosahatchee River, respectively.

Hueter (1994), using large-mesh (75-, 100-, 116-, and 125-mm stretch mesh) gill nets for an elasmobranch (adult sharks) survey, reported that adult *B. marinus* (23.2%), *A. felis* (22.6%), *B. smithi* (14.1%), *S. maculatus* (5.9%), *C. faber* (4.1%), *E. saurus* (4.0%), and *C. hippos* (2.6%) dominated the bony fish bycatch in both Tampa Bay and Charlotte Harbor for all combined gear mesh sizes. However, due to the extremely large mesh sizes, *M. cephalus* were rarely caught (less than 17 fish from 782 samples). The author also surveyed a few commercial striped mullet gill net catches from November 1991 through August 1993 in both Tampa Bay (13 sets) and Charlotte Harbor (9 sets). In Tampa Bay, *M. cephalus* (80.8%) dominated the catches, with *A. felis* (5.7%), *A. probatocephalus* (4.2%), *M. curema* (3.0%), and *B. smithi* (3.0%) as the most abundant bycatch species (Table 7). In Charlotte Harbor, *M. cephalus* (50.1%), *E. saurus* (27.8%), *C. faber* (7.2%), and *C. hippos* (6.9%) dominated the catch (Table 7). The commercial bycatch reported by Hueter (1994) was similar that of this study, especially for Tampa Bay; however, a larger percentage of *E. saurus* and *C. faber* occurred in the Charlotte Harbor commercial fishery than in this study. Other common bycatch species from this study, including *L. rhomboides, M. curema,* and *M. gyrans,* were rare in the commercial catches, most likely due to the larger mesh sizes (75–113-mm stretch mesh) for the commercial gill nets.

Motta (1993) reported bycatch species of the traditional striped mullet gill net fishery from Jan. to Dec. 1992 in Tampa Bay. *Mugil cephalus* (56.1%), *Brevoortia* spp. (8.8%), *A. felis* (7.5%), *C. hippos* (6.3%), *A. probatocephalus* (4.4%), *L. rhomboides* (4.2%), *C. nebulosus* (3.1%), *L. xanthurus* (1.3%), *O. chrysurus* (1.2%), and *D. plumieri* (1.1%) were the 10 most abundant fish caught from 80 commercial catches surveyed throughout Tampa Bay. However, the percentages of bycatch species reported by Motta (1993) from the third and fourth quarters (Sep.–Dec. 1992) were dominated by *M. cephalus, Brevoortia* spp., *A. felis,* and *L. rhomboides,* which corresponded to this study's species composition from collection periods 1, 2, and 3 (Table 7). Motta (1993) also reported lowest species richness (22 species) in

TABLE 7. Total percentages of bycatch species composition reported by Motta (1993) and Hueter (1994) from the traditional *Mugil cephalus* gill net fisheries from Tampa Bay and Charlotte Harbor. A dash indicates species was not collected. Collection period: 1 = Sep./Oct.; 2 = Oct./Nov., 3 = Nov./Dec. Total = percent total catch from Nov. 1991 to Aug. 1993.

Species	Motta (1993) Tampa Bay collection period			Hueter (1994)	
	1	2	3	Tampa Bay total	Charlotte Harbor total
Archosargus probatocephalus	0.8	0.2	1.0	—	1.6
Arius felis	4.1	2.2	0.1	5.7	—
Bagre marinus	0.0	0.0	0.0	—	0.2
Bairdiella chrysoura	—	—	—	—	0.5
Brevoortia smithi	—	—	—	3.0	—
Brevoortia spp.	23.1	43.7	0.0	—	—
Carnax hippos	0.0	16.6	0.0	—	6.9
Centropomus undecimalis	—	—	—	0.3	—
Chaetodipterus faber	0.0	0.1	0.0	—	7.2
Chilomycterus schoepfi	0.0	0.3	0.0	—	0.2
Cynoscion arenarius	—	—	—	0.3	—
Cynoscion nebulosus	0.0	1.1	0.1	0.1	—
Dasyatis sabina	—	—	—	0.6	2.2
Diapterus plumieri	15.7	0.0	0.1	—	—
Elops saurus	0.0	0.7	0.0	—	27.8
Eucinostomus harengulus	0.8	0.0	0.0	—	—
Lactophrys quadricornis	0.0	0.1	0.0	—	—
Lagodon rhomboides	1.7	4.4	0.0	—	—
Leiostomus xanthurus	0.0	2.8	0.0	0.1	—
Lutjanus griseus	—	—	—	—	0.5
Mugil cephalus	51.2	24.4	98.4	80.8	50.1
Mugil curema	—	—	—	3.0	—
Negaprion brevirostris	—	—	—	0.1	—
Orthopristis chrysoptera	0.0	1.7	0.0	—	1.1
Paralichthys albigutta	0.8	0.1	0.0	0.1	—
Pogonias cromis	0.0	0.1	0.1	0.1	1.1
Rhinoptera bonasus	0.8	0.0	0.1	—	—
Sciaenops ocellatus	0.0	0.8	0.2	0.6	—
Sphyrna tiburo	0.8	0.0	0.0	—	—
Synodus foetens	0.0	0.1	0.0	—	—
Trachinotus falcatus	0.0	0.4	0.0	—	—
Number of sets surveyed	4	6	11	13	9

the fourth quarter (Oct., Nov., and Dec.) compared with the previous three quarters (24, 27, and 31 species for quarters 1, 2 and 3, respectively). Motta (1993) indicated that this was partially attributable to a change in management regulations in the fourth quarter and selective fishing for *M. cephalus.* The large numbers of *Brevoortia* spp. and *C. hippos* reported in Motta (1993) compared with those reported in Hueter (1994) or this study are due to a small number of sampled sets (n = 3) when the these fish were targeted instead of *M. cephalus.*

The gear characteristics in the striped mullet fishery changed with the 1995 net ban referendum. Cast and seine nets (69-mm stretch mesh) have replaced the traditional large-mesh gill nets. There is no information concerning the bycatch species compositions of cast and seine nets used in the existing fishery; however, the mesh sizes of the gear used in the existing fishery are similar to that of the experimental trammel net used in this study. Comparison of Motta's (1993) and Hueter's (1994) reported percentages and numbers of bycatch species caught in the traditional gill net fishery with those of species caught in our experimental trammel net gear shows differences in bycatch species compositions; thus, the selectivity patterns of bycatch species composition may have altered. (Tables 1, 2, and 7)

In conclusion, bycatch collected in the annual *M. cephalus* survey on Florida's west coast was sporadic and tended to decline in abundance from the fall through the winter collection periods. Species richness, species diversity, and evenness did not significantly decline with collection period; however, all three indices decreased from the fall through the winter, indicating a slight reduction in the abundance of bycatch species. Bycatch species composition differed between samples collected in the open bay and samples from riverine habitats and depending on the presence or absence of seagrass at sample sites. The lowest values of species richness and diversity occurred in 1996 after the implementation of the Florida net ban, possibly due to greater susceptibility of *M. cephalus* and a concomitant decrease in the percentage of bycatch captured.

Acknowledgments

We thank field personnel from the FLDEP Fisheries-Independent Monitoring Program. We also thank Robert McMichael, Richard McBride, Gary Nelson, Dana Winkelman, Jim Quinn, Lynn French, and Judy Leiby for their helpful comments on the manuscript. This work was supported in part under funding from the Department of the Interior, U.S. Fish and Wildlife Service, Federal Aid for Sportfish Restoration Project Number F-43 and by funds from Florida Saltwater Fishing License sales.

Literature Cited

Clarke, K. R. 1993. Non-parametric multivariate analyses of changes in community structure. Aust. J. Ecol. 18:117–143.

———, and R. M. Warwick. 1994. Change in marine communities: an approach to statistical analysis and interpretation. Natural Environment Research Council, Plymouth Marine Laboratory, Plymouth, U.K.

Dahlberg, M. D., and E. P. Odum. 1970. Annual cycles of species occurrence, abundance, and diversity in Georgia estuarine fish populations. Am. Midl. Nat. 83:382–392.

Finucane, J. H. 1966. Faunal production project. U.S. Fish. Wildl. Serv. Circ. 242:18–20.

Fraser, T. H. 1997. Abundance, seasonality, community indices, trends and relationships with physicochemical factors of trawled fish in upper Charlotte Harbor, Florida. Bull. Mar. Sci. 60:739–763.

Gunter, G., and G. E. Hall. 1965. A biological investigation of the Caloosahatchee estuary of Florida. Gulf Res. Rep. 2:1–17.

Hall, M. A. 1996. On bycatches. Rev. Fish Biol. Fish. 6:319–352.

Hueter, R. E. 1994. Bycatch and catch-release mortality of small sharks and associated fishes in the estuarine nursery grounds of Tampa Bay and Charlotte Harbor. Final Report FDEP Grant Agreement C7237/C7849. Mote Marine Laboratory, Sarasota, FL.

Mahmoudi, B. 1997. Status and trends in the Florida mullet fishery and an update on stock assessment. Florida Department of Environmental Protection, Florida Marine Research Institute, St. Petersburg, FL.

Motta, P. 1993. Tampa Bay gill net fishing study–final report. Contract No. C-7498. Florida Department of Natural Resources, Florida Marine Research Institute, St. Petersburg, FL.

Pattillo, M. E., T. E. Czapla, D. M. Nelson, and M. E. Monaco. 1997. Distribution and abundance of fishes and invertebrates in Gulf of Mexico estuaries, volume 2: Species life history summaries. ELMR Rep. No. 11. NOAA/NOS Strategic Environmental Assessments Division, Silver Spring, MD.

Springer, V. G., and K. D. Woodburn. 1960. An ecological study of the fishes in Tampa Bay area. Prof. Pap. Ser. No. 1. Fla. Board Cons. Mar. Lab., St. Petersburg, FL.

Sokal, R. R., and F. J. Rohlf. 1981. Biometry. 2d ed. W. H. Freeman, New York.

Wang, J. C. S., and E. C. Raney. 1971. Distribution and fluctuations in the fish fauna of the Charlotte Harbor estuary, Florida. Charlotte Harbor Estuarine Studies, Mote Marine Lab., FL.

Florida Department of Environmental Protection, Florida Marine Research Institute, 100 8th Avenue SE, St. Petersburg, Florida 33701. Date accepted: October 15, 1998.