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SPATIAL PATTERNS OF ESTUARINE HABITAT TYPE USE AND TEMPORAL PATTERNS IN ABUNDANCE OF JUVENILE PERMIT, *TRACHINOTUS FALCATUS*, IN CHARLOTTE HARBOR, FLORIDA

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ABSTRACT The life history of many marine fishes is a 2-phase cycle: juveniles and adults make up a demersal phase, whereas larvae are planktonic. Determining ontogenetic patterns of habitat type use of the demersal phase has important management and habitat conservation implications for species that use coastal habitat types as juveniles. Juvenile permit, *Trachinotus falcatus*, are presumed to be limited to beaches exposed to open ocean, but few studies have addressed juvenile permit use of estuarine habitat types. Ten years of fisheries-independent monitoring data from a subtropical estuary were analyzed to determine habitat type use patterns and seasonality of juvenile permit. Shallow (< 2 m) habitat types in Charlotte Harbor, Florida, were sampled with 21 m and 183 m seines from 1991 through 2000. Juvenile permit were most abundant along sandy beaches in the lower estuary and were in densities similar to or higher than along exposed coastal beaches reported in other studies. Size of captured permit ranged from 15 to 360 mm standard length. Small juveniles (< 100 mm) were present almost exclusively from June to December. Both small and large (∅ 100 mm) juveniles were most abundant over shallow bottom adjacent to unvegetated beach shorelines. These findings indicate that post-settlement permit recruit seasonally to specific estuarine habitat types. Then, as they grow, they shift to other habitat types, before migrating out of the estuary. Since identification of the suite of juvenile habitat types is prerequisite to determining their nursery value, and many estuarine habitat types are under anthropogenic stress, research on the relative importance of estuarine nurseries for juvenile permit is warranted.

INTRODUCTION

The life history of many marine fishes is a 2-phase cycle: juveniles and adults make up a demersal phase, whereas larvae are planktonic. During and after settlement of larvae, numerous processes act to influence the abundance and distribution of juvenile fishes. These processes include site selection at settlement (Kaufman et al. 1992, Sancho et al. 1997), priority effects (Shulman et al. 1983, Leis and Carson-Ewart 1999), competition (Frederick 1997), predation (Hixon and Beets 1989, 1993, Hixon and Carr 1997), food availability (Stoner 1980, Lenanton 1982), shelter (Hixon and Beets 1989, Tupper and Boutilier 1995, Beets 1997), and physiological requirements (Yamashita et al. 2001). For species that move into different habitat types as adults, the requirements (e.g., food and shelter) and risks (e.g., predation) will change as the fish proceeds through ontogenetic shifts (Vigliola and Harmelin-Vivien 2001). Given that the period of highest mortality for many fishes is during the early life stages (Booth and Brosnan 1995, Sogard 1997), and juveniles of many species use coastal and estuarine habitat types that are vulnerable to anthropogenic impacts (Montague and Ley 1993, Sargent et al. 1995, Tomasko et al. 1996, Rakocinski et al. 1997, Sklar and Browder 1998, Uhrin and Holmquist 2003), it is important to understand the patterns of habitat type use by juvenile fishes to better predict and assess impacts of anthropogenic stress.

Before these habitat-related processes can be examined, however, baseline information must be gathered on spatial and temporal distributions of the target species. In addition, identification of the suite of habitat types used by juveniles is essential to determining which habitat types act as nurseries and contribute to adult populations (Beck et al. 2001). This paper reports patterns of habitat type use by an economically important species and helps lay the foundation for further detailed research.

Permit, Trachinotus falcatus (family Carangidae), inhabit coastal areas of the North Atlantic as far north as Massachusetts and throughout the Gulf of Mexico (GOM) but are commonly found from southern Florida and the Caribbean Sea (Bohlke and Chaplin 1993). Permit are economically important and are an important component of the recreational fishery in Florida (Armstrong et al. 1996) and the Caribbean Sea. Unfortunately, comparative data on habitat type use by juvenile permit are limited, especially for estuarine habitats. Recent information on age and growth (Crabtree et al. 2002) and abundance (C.W. Harnden, Fish and Wildlife Conservation Commission, Melbourne, FL, pers. comm.) were largely based on data collected from the Florida Keys. Most previous research in Florida addressed only surf zones (Springer and Woodburn

1960, Naughton and Saloman 1978, Saloman and Naughton 1979, Peters and Nelson 1987) or did not address patterns of habitat type use (Carr and Adams 1973). Prior to our study, Finucane (1969) provided the only quantitative documentation of habitat type use patterns of permit associated with estuaries.

In this paper we summarize the available data on juvenile permit for Charlotte Harbor, a subtropical estuary of south Florida. Based on 10 years of data collected by the Florida Fish and Wildlife Conservation Commission, Florida Marine Research Institute's Fisheries-Independent Monitoring (FIM) program, we examined catch data of permit in Charlotte Harbor to determine 1) spatial distribution within the estuary, 2) patterns of habitat type use, 3) size distributions, and 4) seasonality of occurrence. Our study will contribute to the management of permit and provide a foundation for future research.

MATERIALS AND METHODS

Study system

Charlotte Harbor is a 700 km^2 coastal plain estuarine system located on the southwest coast of Florida and is one of the largest estuarine systems in the state (Hammett 1990, Figure 1). The Peace, Myakka, and Caloosahatchee rivers, as well as many small creeks throughout the drainage, transport large amounts of fresh water into the harbor. The harbor is connected to the GOM through Boca Grande Pass, San Carlos Bay, and 3 smaller inlets. The climate of Charlotte Harbor is subtropical, mean water temperatures range from 12° to 36 ºC, and freezes are infrequent (Poulakis et al. 2003). Anthropogenic development within the watershed has stressed the estuarine system; however, compared with other Florida estuaries (e.g., Tampa Bay), Charlotte Harbor has remained relatively unspoiled (> 80% of mainland shorelines under protection; R. Repenning, Punta Gorda, FL, Florida Department of Environmental Protection, pers. comm.; Hammett 1990; CHNEP 1999). Seagrass flats (262 km^2, Sargent et al. 1995) and mangrove shorelines (143 km^2, L. Kish, Florida Marine Research Institute, unpubl. data) continue to thrive as the dominant habitat types within the estuary.

Field Methods

Monthly daytime (between 9 AM and 5 PM) sampling was conducted in Charlotte Harbor using 2 different sampling strategies, Fixed-Station (FS) sampling (1991–1995) and Stratified-Random (SR) sampling (1996–2000). At each FS location 3 hauls were completed with a 21 m x 1.8 m center bag seine (3.2 mm stretch mesh, hereafter referred to as the 'small seine'). To collect each sample, the small seine was pulled parallel to the shoreline over a standardized area (330 m^2) and hauled up against the shore. Two FS locations, FS 3 and FS 13, accounted for all juvenile permit collected using this protocol. Fixed-Station 3 has a narrow sandy beach shoreline, with a sand/mud bottom and sparse Halodule wrightii (depth ~ 1.0 m) and is located in the upper harbor near the mouth of the Myakka River. Fixed-Station 13 has a broad, sandy, low-energy beach shoreline, with a sandy bottom and a few small dense patches of Halodule wrightii, Thalassia testudimum, and Syringodium filiforme (depth ~ 1.0 m). This station is located on the northeastern shore of Cayo Costa (barrier island immediately south of Boca Grande Pass) (Figure 1).

Stratified-Random sampling locations were selected based on a randomized design. Charlotte Harbor was subdivided into 1 x 1 nautical mile cartographic grids, and grids with appropriate water depths (< 1.5 m for the small seine, < 2.6 m for the large seine) for seine sampling were selected as the sampling universe. The sampling universe was then subdivided into 4 geographic zones. Monthly sampling grids were randomly selected from within each zone, and within each selected grid a microgrid (one tenth by one tenth of a nautical mile) was also randomly selected. All SR samples were collected inside the estuary using the small seine and a 183 m x 2.5 m center bag seine (37.5 mm stretch mesh, hereafter referred to as the 'large seine'). Twenty-four to 32 small seines and 17 large seines were completed each month, with effort distributed equally among zones. Half of the small seine samples were completed immediately adjacent to the shoreline (shoreline set), and half were completed > 5 m from shore (offshore set). The small seine was pulled over a standardized area (140 m^2) and then collapsed around a pivot pole to force the sample into the bag. The large seine was deployed by boat, set in a standardized rectangular shape (~ 40 m x 103 m) along the shoreline, and hauled up against the shoreline by hand. For all samples, T. falcatus were measured to standard length (SL) and released, and seagrass coverage (%), shoreline percent coverage by mangroves, water temperature (ºC), salinity (psu), and dissolved oxygen (DO, mg/L) concentration were recorded. Seagrass and mangrove coverage were visually estimated by samplers.

Data Analyses

Spatial patterns. We first examined whether juvenile permit abundance was similar throughout Charlotte Harbor. Following Poulakis et al. (2003), 5 zones that encompassed all of the shoreline and shallow water sampled in this study were defined based on hydrological characteristics (Alberts et al. 1969, 1970, Stoker 1992,

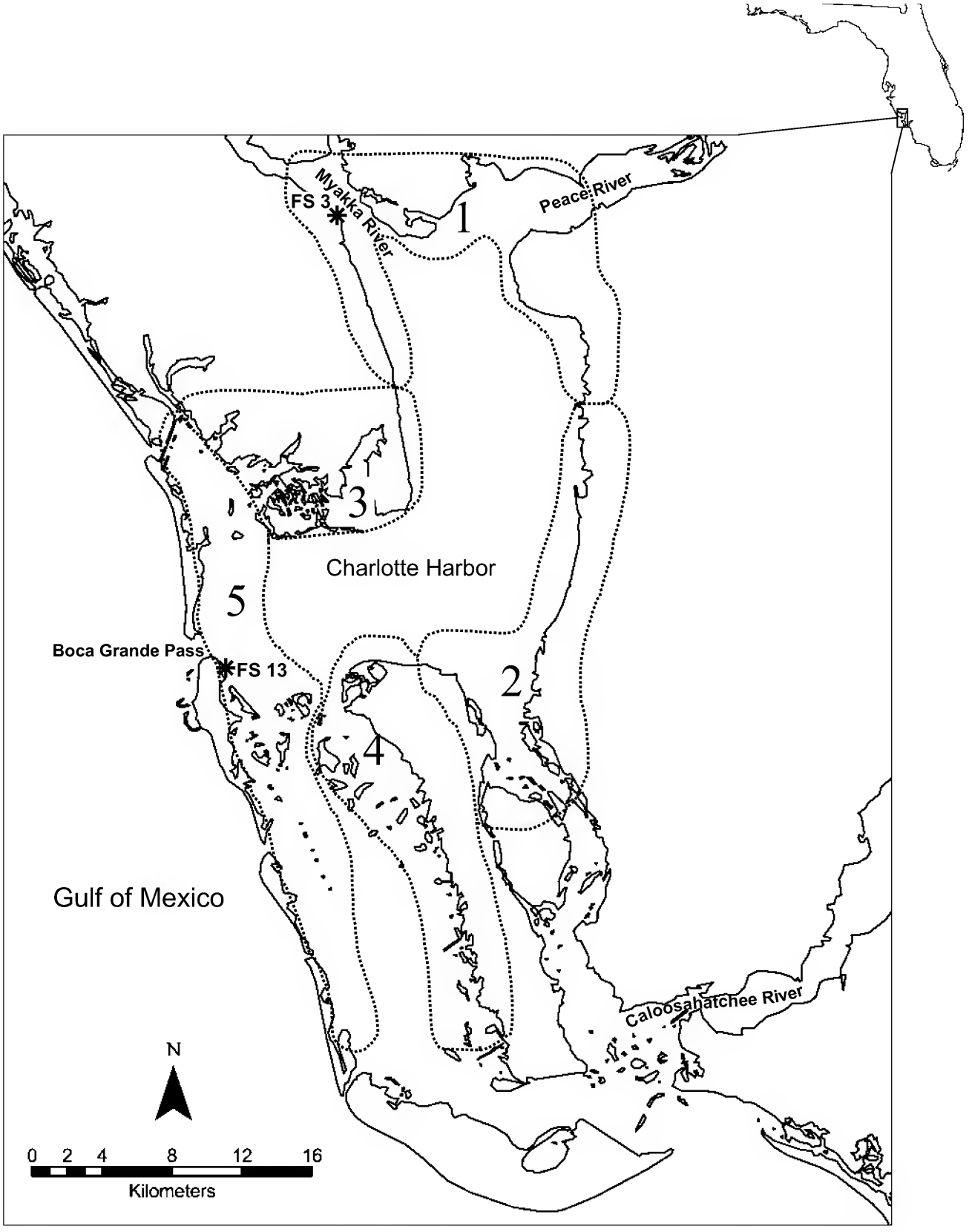

Figure 1. Locations of hydrological zones 1–5 (following Poulakis et al. 2003) and Fixed-Stations (FS) in Charlotte Harbor, Florida.

TABLE 1

Number of permit caught and number of samples by gear type. Fixed-Stations (FS) were sampled from 1991–1995 and Stratified-Random (SR) from 1996–2000. The 21 m seine was deployed immediately adjacent to the shoreline (Shoreline) or > 5 m from shore (Offshore). The 183 m seine was set only along the shoreline.

	21 m seine				183 m seine
	Shoreline (SR)	Offshore (SR)	Shoreline (FS 3)	Shoreline (FS 13)	Shoreline (SR)
Permit (n)	76	1	24	980	162
Samples (n)	787	785	189	165	948

Goodwin 1996) (Figure 1). Stratified-Random data were pooled within each zone, the number of fish per sample (large seine) or the number of fish/100 m^2 (small seine) were calculated, and results were examined graphically. Because only one permit was collected in offshore sets with the small seine (SR), only shoreline sets were used in the analysis. Fixed-Station data were not included in this analysis because only 2 of the 5 zones contained a fixed station that was sampled with a shoreline set. Data were pooled across years and months, because we sought to determine the overall distribution pattern of juvenile permit within the estuary, rather than temporal patterns of variation. We were able to eliminate all but zones 4 and 5 from further consideration with this analysis.

Habitat types were classified according to shoreline and benthic vegetation cover. A shoreline was considered "mangrove" if intertidal vegetation (red mangrove, *Rhizophora mangle*, or black mangrove, *Avicennia germinans*) covered ∅ 40% of the adjacent shoreline, otherwise, the shoreline was considered "beach." Benthic habitat types were classified as "high seagrass" if percent cover of seagrass (*Thalassia testudinum*, *Halodule wrightii*, and *Syringodium filiforme*) was ∅ 40% and as "low seagrass" if < 40% cover. We chose a 40% cutoff based on regional classifications of seagrass coverage and recent Charlotte Harbor research (Adams et al. 2004, B. Robbins, Mote Marine Lab, unpublished summary of seagrass community classification systems in Florida).

To determine patterns of habitat type use by juvenile permit (H_o: abundance of juvenile permit is similar in all habitat types) within zones 4 and 5, SR seine data were analyzed with a Friedman non-parametric test (Zar 1984) with Shoreline (mangrove, beach) and Benthic (high seagrass, low seagrass) as factors. A non-parametric test was used because the data would not meet parametric statistics requirements, despite transformations, because of the high proportion of samples with no juvenile permit. If significant, habitat types were analyzed with a non-parametric post-hoc test similar to the Tukey procedure (Zar 1984).

Data from the small and large seines were analyzed separately. All permit from the small seine were < 100 mm SL. Permit captured in the large seine were divided into 2 size groups (< 100 mm SL = small and ∅ 100 mm SL = large). Within each gear type, data were pooled across years and months. The months of June through December were used for small juveniles (peak recruitment), and all months were used for large juveniles (year round occurrence). A significant result would indicate that numbers of juvenile permit differed among habitat types.

Temporal patterns. Monthly mean abundances of juvenile permit from FS 13 and from SR zones 4 and 5 were plotted to show seasonality of juvenile permit occurrence. Only these data were used because almost all juvenile permit were captured in these areas.

RESULTS

Totals of 1,081 and 162 juvenile permit were captured with the small and large seines, respectively (Table 1). The number of juvenile permit captured by FS sampling totaled 1004 (980 juveniles at FS 13), while 239 juvenile permit were captured in SR sampling. In the SR small seine samples, all but one permit were captured in shoreline sets (vs. offshore sets) (Table 1). Most juvenile permit were captured in zones 4 and 5 (Figure 2). Mean water temperature and DO varied little among the zones, in contrast to variable salinity (Table 2). Salinity differed among zones (ANOVA: $F_{4,1428} = 310.75$, $P < 0.001$), with salty zones 5 > 4 > 3 > 2 > 1 (Bonferroni, all $P < 0.05$).

Habitat type use patterns varied by gear and fish size, but indicate an overall higher use of habitats with lower complexity and habitat types adjacent to beach shoreline. Mean density of small (< 100 mm) juvenile permit caught in small seines was highest in low seagrass adjacent to beach shorelines (Friedman $\chi^2 = 11.74$, $P < 0.01$, df = 3) (Figure 3a). In contrast, abundance of small permit caught with the large seine was higher over high seagrass adjacent to beach shoreline (Friedman c2 = 11.86, $P < 0.01$, df = 3) (Figure 3b). Abundance of large (∅ 100 mm) juveniles

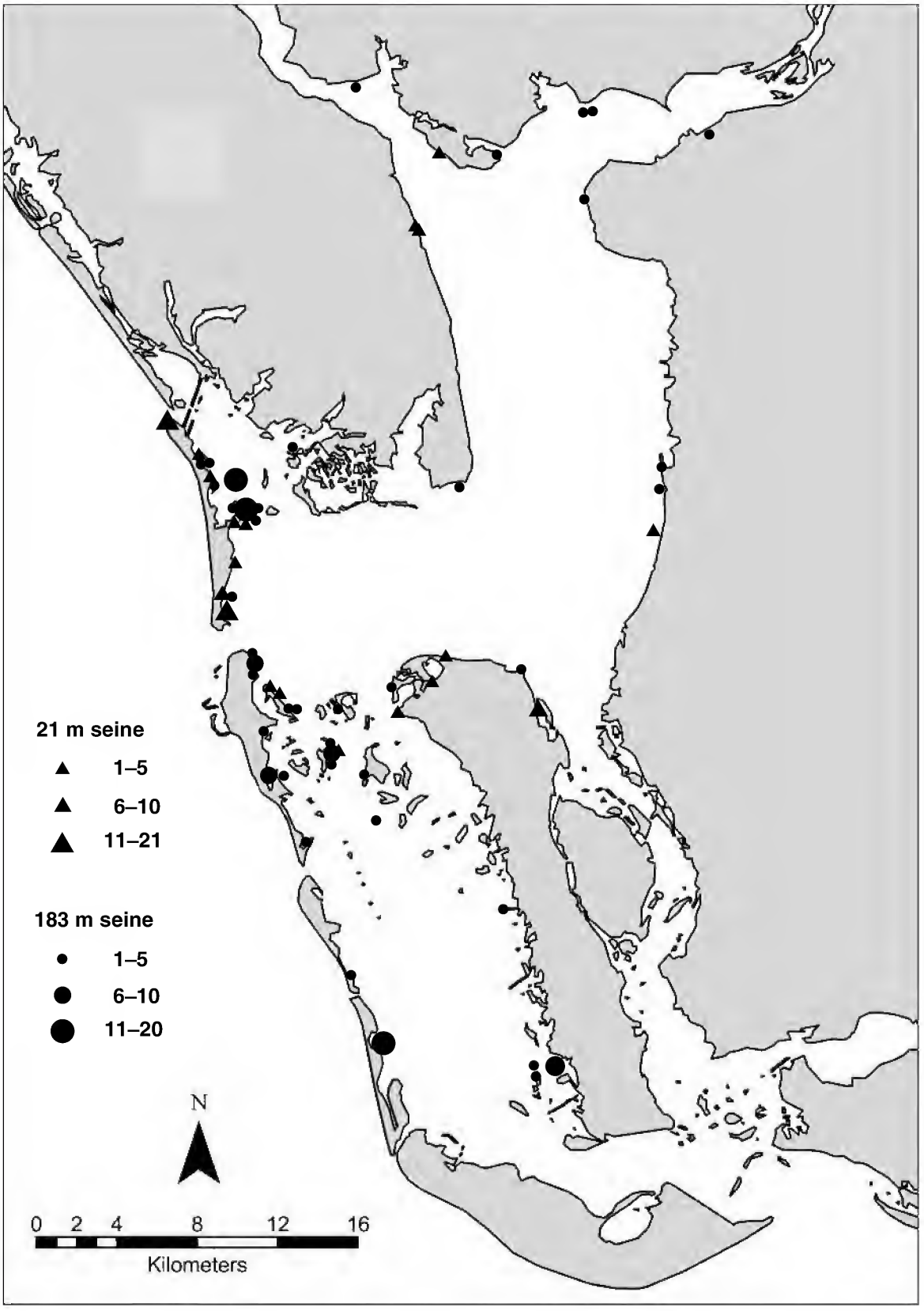

Figure 2. Locations and abundance of permit captured in Charlotte Harbor, Florida using 21 m (triangles) and 183 m (circles) seines.

TABLE 2

Summary statistics for abiotic variables from each zone during June–December, 1996–2000. $s_{\bar{x}}$ = standard error.

	Temperature (°C)			Salinity (psu)			Dissolved oxygen (ppm)		
Zone	Mean	$s_{\bar{x}}$	Range	Mean	$s_{\bar{x}}$	Range	Mean	$s_{\bar{x}}$	Range
1	27.0	0.25	14.8–34.5	18.6	0.39	0.6–33.2	6.5	0.13	0.9–16.2
2	27.7	0.23	14.3–34.4	23.6	0.29	5.2–37.4	6.5	0.12	0.2–12.0
3	27.4	0.29	14.5–36.2	26.5	0.40	6.4–37.9	7.0	0.16	1.0–17.0
4	27.3	0.30	15.8–34.1	31.1	0.24	13.2–39.0	7.0	0.16	0.5–14.1
5	26.7	0.29	15.8–35.0	32.4	0.20	11.7–37.7	7.9	0.13	1.5–16.7

was greater over low seagrass adjacent to beach shorelines, but this difference was not significant (Friedman $\chi^2 = 3.12$, $P > 0.10$, df = 3) (Figure 3c).

Size of permit ranged from 15 to 360 mm SL, with each gear type biased toward different portions of the size range (Figure 4). The SR small and large seines captured juvenile permit from 15–72 mm and 42–360 mm, respectively.

Catches of juvenile permit at FS 13 were consistently higher than catches for estuary-wide SR samples, but temporal trends were similar: densities were greatest from June through December (Figure 5). Monthly length frequencies of small juvenile permit indicate 2 temporally distinct settlement events (May–June and September–October, Figure 6).

DISCUSSION

In contrast to most previously published studies of juvenile permit that report the use of only exposed beaches on outer coasts, our study demonstrates the use of estuarine habitat types in similar densities. Densities of small, juvenile permit in estuarine habitats in lower Charlotte Harbor (June–December) were similar to densities reported from the GOM along the beaches of central Florida (2.93 fish/100 m2, Saloman and Naughton 1979). They were also much higher than densities reported from the northern Florida GOM coast (0.13 fish/100 m2, Naughton and Saloman 1978), compared to overall mean densities of 1.42 fish/100 m2 from SR samples and 2.94 fish/100 m2 from FS samples in this study. Clearly, future studies that address the relative importance of nursery habitats for permit (Beck et al. 2001) should include both estuarine and coastal habitat types.

Within the Charlotte Harbor estuary, juvenile permit are present seasonally and appear to undergo habitat shifts as they grow before vacating shallow estuarine waters. However, the origin of new juveniles and the destination of emigrating juveniles are unknown. Our results suggest that both habitat processes and larval transport patterns play important roles in the distribution of juvenile permit within Charlotte Harbor. The occurrence of juvenile permit in estuarine headwaters indicates that larvae are able to reach well into Charlotte Harbor; however, the majority of juveniles were captured in the lower portions of the estuary. Finucane (1969) also found juvenile permit in an upper estuarine region in Tampa Bay, but only at a single beach location. In contrast, on the GOM coast of northern Florida, juvenile permit were only found at an outer beach location and not in the St. Andrew Bay estuary (Naughton and Saloman, 1978). In our study, juvenile permit were captured in similar habitat types in upper and lower Charlotte Harbor—low seagrass adjacent to sandy beaches. Possible explanations for our results are that fewer larvae reached the upper estuary which limited juvenile abundance, sufficient larvae did reach the upper harbor but quickly reached maximum densities in the few isolated areas with appropriate habitat types, sufficient larvae reached these areas but suffered high mortality, or differences in abiotic factors affected settlement site selection or post-settlement mortality.

The high association of small juvenile permit with low structural-complexity habitat types (low seagrass adjacent to beach shoreline) is counter to conventional wisdom. Small juvenile fishes use structurally complex habitat types as refuges from predation (e.g., Savino and Stein 1989, Sogard and Olla 1993, Jordan et al. 1996, Adams et al. 2004). Once fish reach a size where growth benefits afforded by access to more food outweigh predation risk, juveniles may move into less complex habitat types (e.g., Dahlgren and Eggleston 2000). In our study, small juvenile permit were most abundant in the least complex habitat types sampled and expanded their habitat type use to include more complex habitats as they grew. Whether this is due to low predation, availability of specific required food types, or foraging efficiency is unclear.

Juvenile permit undergo ontogenetic shifts in diet (Carr and Adams 1973). The diet of juveniles 15–20 mm

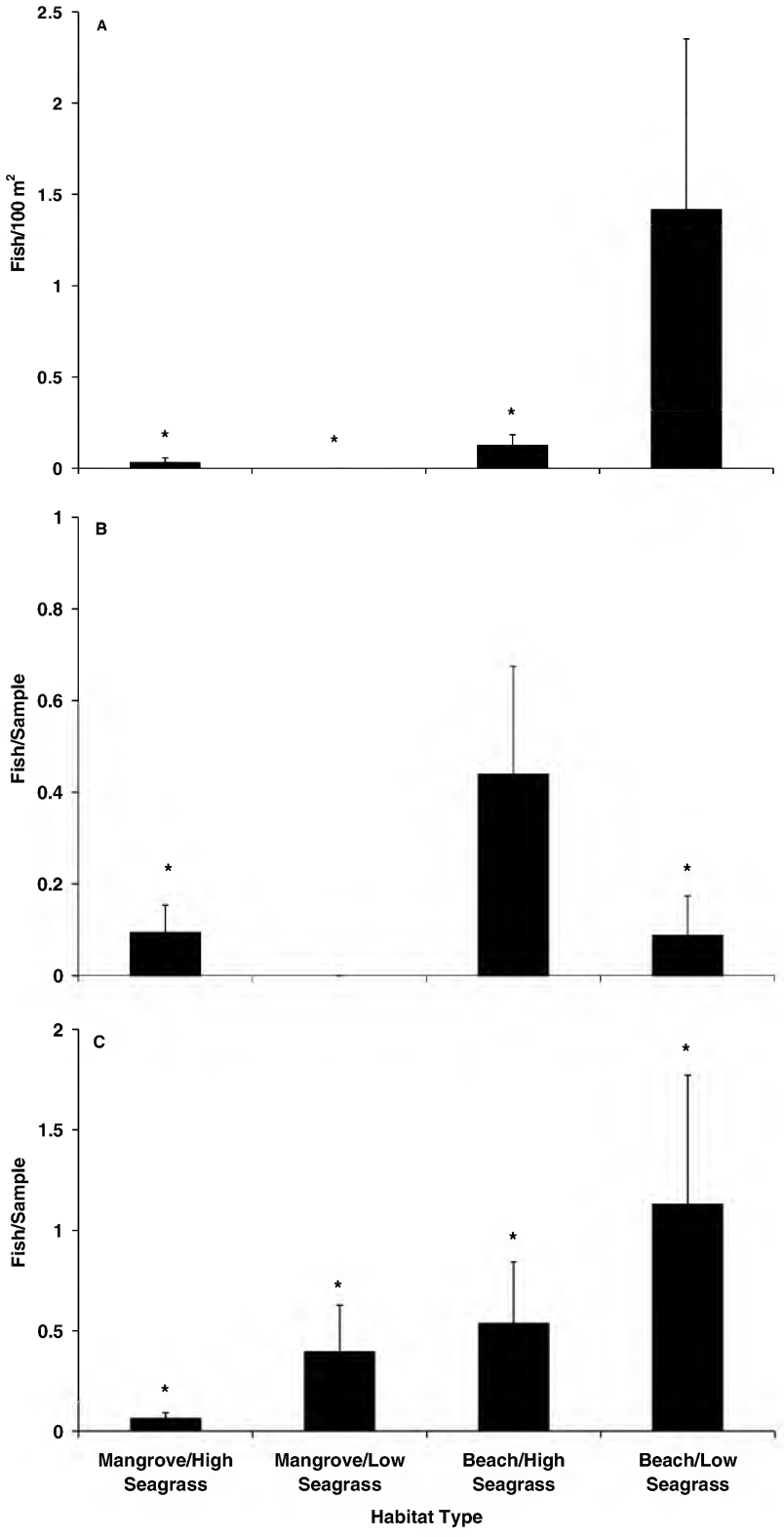

Figure 3. Habitat type use patterns of juvenile permit captured in 21 m and 183 m seines using the Stratified-Random (SR) sampling protocol. Only samples in June through December in zones 4 and 5 were used in this analysis for the 21 m seine; all months, only zones 4 and 5 for the 183 m seine. Values not significantly different among habitat types (Tukey, $P < 0.05$) share an*. (A) Density of juveniles < 100 mm SL caught with the 21 m seine (n = 197 hauls). (B) Number of juvenile permit ≤ 100 mm SL per sample caught with the 183 m seine (n = 339 hauls). (C) Number of juvenile permit > 100 mm SL per sample caught with the 183 m seine (n = 339 hauls). Mean ±1 Standard Error are plotted.

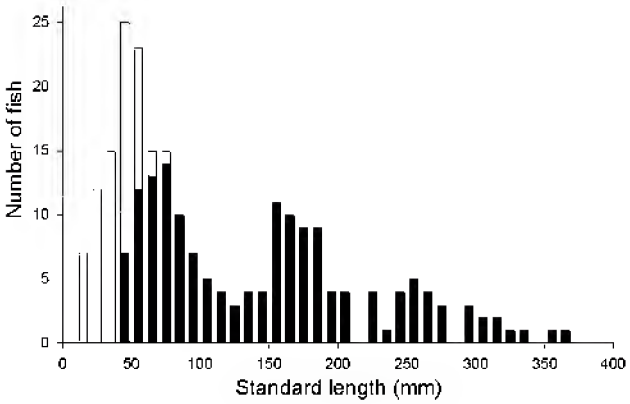

Figure 4. Length frequency distribution of 238 juvenile permit caught by the 21 m seine (open bars) and 183 m seine (black bars) using the Stratified-Random (SR) sampling protocol.

SL is dominated by small fish and mysids. Permit 61–70 mm eat mostly crabs and gastropods (Carr and Adams 1973). Larger crustaceans and mollusks dominate the diet of 50–100 mm permit, and mollusks are the predominant food of permit 100–138 mm (Finucane 1969). These data are insufficient to warrant a food-based explanation to the apparent habitat type shift observed in our study.

Permit catches from the small and large seines must be interpreted with regard to each gear's sampling bias. Large juvenile permit were likely able to avoid the small seine, and small permit passed through the mesh of the large seine (Figure 4). This results in size gaps in the comparisons of habitat types between juveniles (15–72 mm SL) collected in the small seine with juveniles (42–360 mm SL) collected in the large seine. In addition, the amount and areas of benthic habitat types sampled differed between the 2 seining operations. The small seine (shoreline set) only sampled the bottom to 15.5 m from shore, whereas the large seine sampled bottom out to 40 m and potentially sampled multiple habitat types per seine haul. Thus, the apparent use of high seagrass adjacent to beach by small juvenile permit caught with the large seine may have been confounded by the gear. The small permit may have been associated with low seagrass near the shoreline, but their habitat was characterized by assessment of habitat type farther offshore. Because small juvenile permit were collected primarily near the shoreline and the small seine sampled a single habitat type, we believe that the small seine data provided more precise information on habitat types where small permit reside (Finucane 1969, Naughton and Saloman 1978, AJA, unpubl. data). This supposition is supported by the near absence of small juvenile permit in offshore small seine samples. Moreover, habitat types adjacent to beaches had higher abundances of small and large juvenile permit than the same habitat types adjacent to mangrove shorelines (Figure 3).

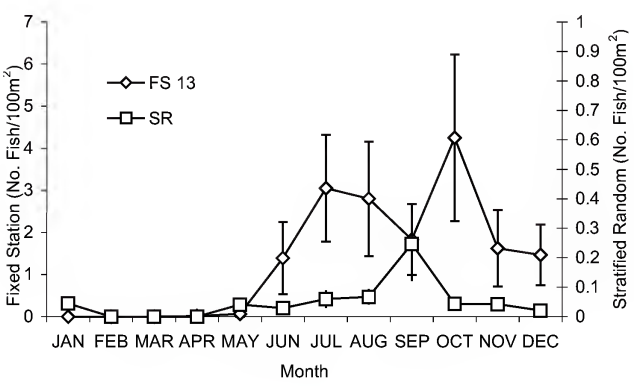

Figure 5. Density of juvenile permit caught in 21 m seines by month from 1991–1995 at Fixed-Station (FS) 13 and from 1996–2000 at Stratified-Random (SR) locations. Mean ±1 Standard Error are plotted.

The distinct seasonality of small juveniles in Charlotte Harbor is similar to findings from other locations in Florida, and support Crabtree et al.'s (2002) conclusion of a spring through summer spawning season. Peak abundance of juveniles in summer or fall also occurred along beaches of the GOM coasts of northern (Naughton and Saloman 1978) and central (Saloman and Naughton 1979) Florida, along the Atlantic coast of central Florida (Peters and Nelson 1987), and in Tampa Bay (Finucane 1969, Crabtree et al. 2002). However, these findings are in contrast to data from St. Croix, US Virgin Islands (I. Mateo, US Virgin Islands Division of Fish and Wildlife, Fredricksted, St. Croix, pers. comm.), Turneffe Atoll, Belize (AJA, unpub. data), and the Florida Keys (C.W. Harnden, Florida Marine Research Institute, Melbourne, FL, pers. comm.), where juvenile permit were captured throughout the year in similar sizes and habitat types as in our study. Numerous, non-exclusive explanations for these differences include 1) differences in spawning seasonality with Charlotte Harbor and other subtropical and warm-temperate locations receive post-settlement stage larvae during much of the year, but conditions become unsuitable for juvenile permit in winter, causing mortality or early emigration from estuarine nursery habitats, and 2) individuals experience highly variable growth rates.

Although seasonality of abundance was similar at FS 13 and for SR samples, the consistent differences in densities between FS 13 and SR samples highlights the tradeoffs of these sampling strategies. The SR strategy provides an overview of temporal and spatial use of Charlotte Harbor, but because all habitat types in all zones are sampled monthly, total catches relative to sampling effort are lower.

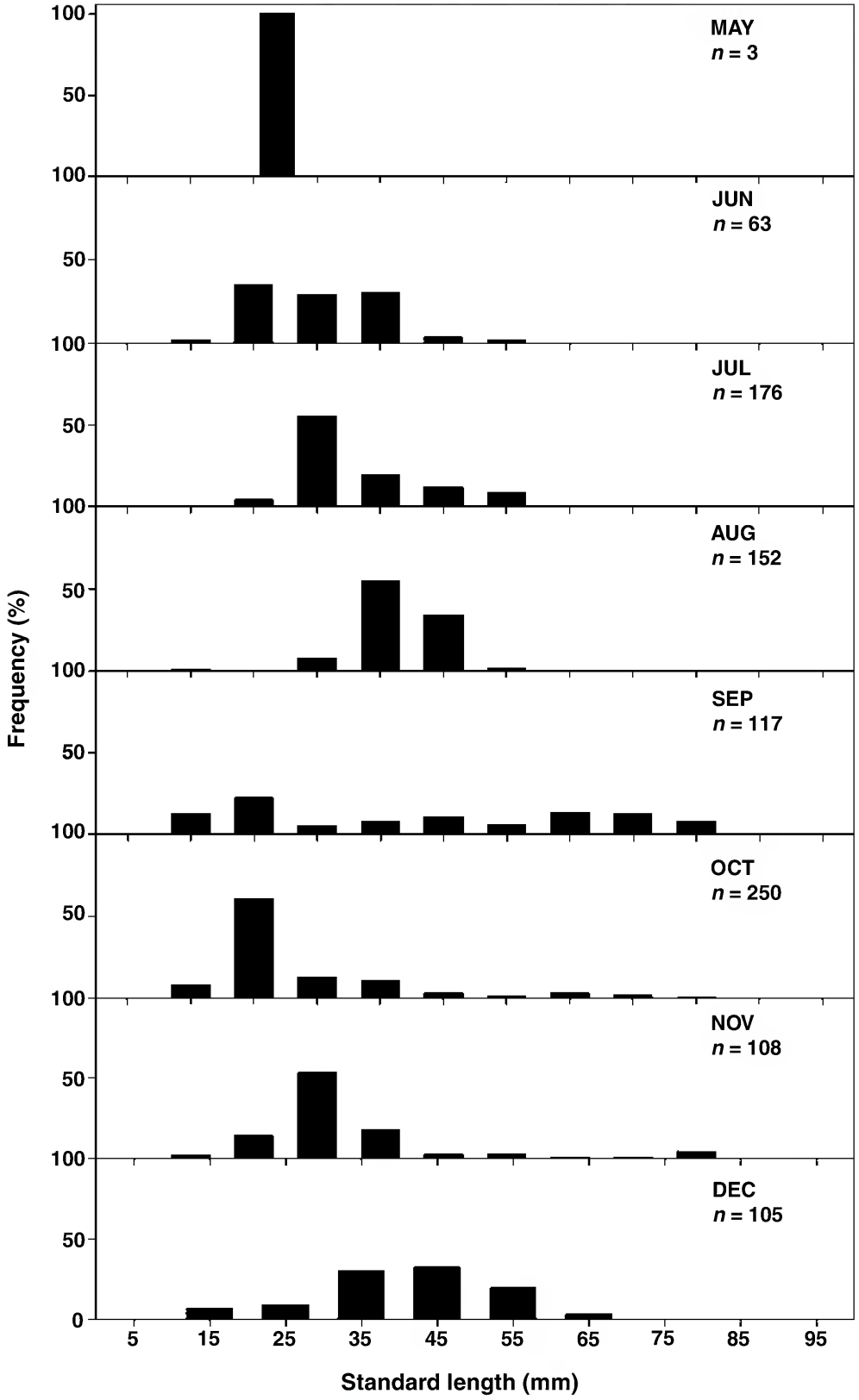

Figure 6. Monthly length frequency of permit caught with the 21 m seine at Fixed-Station (FS) 13. Data pooled over all years (1991–1995).

The SR sampling strategy is well suited for examining patterns of habitat type use within the estuary. The comparative sampling approach of the SR strategy allowed us to incorporate multiple habitat types (shoreline and subtidal benthic) into our examination of habitat type use by juvenile permit. While previous work showed use of habitat types adjacent to beach shorelines by juvenile permit, our study has further described the benthic habitat types adjacent to these shorelines. In contrast, the FS sampling strategy is not as well suited for determining patterns of habitat use, in part because not all habitat types are represented in all zones. When FS locations are found in habitats used by a target species, this is a good strategy for examining temporal trends, and appropriately chosen locations can be used as indexes of recruitment for that species.

The patterns of habitat type use, seasonality, and spatial distribution in Charlotte Harbor raise numerous questions. Are the estuary-wide distribution patterns caused by patterns of larval supply, habitat requirements, or a combination of factors? To what extent are the observed patterns of habitat type use in the lower estuary due to food limitation vs. predation? What are the sources of the juveniles in Charlotte Harbor? To what extent do juveniles found in Charlotte Harbor contribute to adult populations in the region, i.e., to what extent are estuarine juvenile habitat types sources or sinks? Since permit > 350 mm SL do not appear to use shallow shoreline habitat types in Charlotte Harbor, the potential function (i.e., the proportional contribution of permit from these nursery habitats to adult populations (Beck et al. 2001)) of Charlotte Harbor as a nursery should be investigated. Although each question addresses an important ecological and management concern, the last question pertains directly to potential impacts of coastal development, especially if the estuarine nursery habitats are determined to be a population source. Given rates of anthropogenic degradation of these nearshore habitat types, findings from studies that address these questions should have immediate management implications.

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LITERATURE CITED

Adams, A.J., J.V. Locascio, and B.D. Robbins. 2004. Microhabitat use by a post-settlement stage estuarine fish: Evidence from relative abundance and predation among habitats. Journal of Experimental Marine Biology and Ecology 299:17–33.

Alberts, J., A. Hanke, and R. Harriss. 1969. Studies on the geochemistry and hydrography of the Charlotte Harbor Estuary. Charlotte Harbor Estuarine Studies, Mote Marine Laboratory, Sarasota, FL, Progress Report I, 6p.

Alberts, J., A. Hanke, and R. Harriss. 1970. Studies on the geochemistry and hydrography of the Charlotte Harbor Estuary, Florida. Charlotte Harbor Estuarine Studies, Mote Marine Laboratory, Sarasota, FL. Progress Report II, 34 p.

Armstrong, M.P., P.B. Hood, M.D. Murphy, and R.G. Muller. 1996. A stock assessment of permit, *Trachinotus falcatus*, in Florida waters. Florida Department of Environmental Protection, Florida Marine Research Institute IHR 1996-005.

Beck, M.W., K.L. Heck Jr., K.W. Able, D.L. Childers, D.B. Eggleston, B.M. Gillanders, B. Halpern, C.G. Hays, K. Hoshina, T.J. Minello, R.J. Orth, P.F. Sheridan, M.P. Weinstein. 2001. The identification, conservation, and management of estuarine and marine nurseries for fish and invertebrates. BioScience 51:633–641.

Beets, J. 1997. Effects of a predatory fish on the recruitment and abundance of Caribbean coral reef fishes. Marine Ecology Progress Series 148:11–21.

Bohlke, J.E. and C.C.G. Chaplin. 1993. Fishes of the Bahamas and adjacent tropical waters. 2nd Ed. University of Texas Press, Austin, TX, 771 p.

Booth, D.J. and D.M. Brosnan. 1995. The role of recruitment dynamics in rocky shore and coral reef fish communities. Advances in Ecological Research 26:309–385.

Carr, W.E.S. and C.A. Adams. 1973. Food habits of juvenile marine fishes occupying seagrass beds in the estuarine zone near Crystal River, Florida. Transactions of the American Fisheries Society 102:511–540.

Charlotte Harbor National Estuary Program. 1999. Comprehensive Conservation and Management Plan, Volume 1, 250 p.

Crabtree, R.E., P.B. Hood, and D. Snodgrass. 2002. Age, growth, and reproduction of permit (*Trachinotus falcatus*) in Florida waters. Fishery Bulletin, US 100:26–34.

Dahlgren, C.P. and D.B. Eggleston. 2000. Ecological processes underlying ontogenetic habitat shifts in a coral reef fish. Ecology 81:2227–2240.

Finucane, J.H. 1969. Ecology of the pompano (*Trachinotus carolinus*) and the permit (*T. falcatus*) in Florida. Transactions of the American Fisheries Society 98:478–486.

Frederick, J.L. 1997. Post-settlement movement of coral reef fishes and bias in survival estimates. Marine Ecology Progress Series 150:65–74.

Goodwin, C.R. 1996. Simulation of tidal-flow, circulation, and flushing of the Charlotte Harbor estuarine system, Florida. US Geological Survey Water-Resources Investigations Report 93-4153, 92 p.

Hammett, K.M. 1990. Land use, water use, streamflow charateristics, and water-quality characteristics of the Charlotte Harbor inflow area, Florida. US Geological Survey Water-Supply Paper 2359-A, 64 p.

Hixon, M.A. and J.P. Beets. 1989. Shelter characteristics and Caribbean fish assemblages: Experiments with artificial reefs. Bulletin of Marine Science 44:666–680.

Hixon, M.A. and J.P. Beets. 1993. Predation, prey refuges, and the structure of coral-reef fish assemblages. Ecological Monographs 63:77–101.

Hixon, M.A. and M.H. Carr. 1997. Synergistic predation, density dependence, and population regulation in marine fish. Science 277:946–949.

Jordan, F., M. Bartolini, C. Nelson, P.E. Patterson, and H.L. Soulen. 1997. Risk of predation affects habitat selection by the pinfish *Lagodon rhomboides* (Linnaeus). Journal of Experimental Marine Biology and Ecology 208:45–56.

Kaufman, L., J.P. Ebersole, J. Beets, and C.C. McIvor. 1992. A key phase in the recruitment dynamics of coral reef fishes: post-settlement transition. Environmental Biology of Fishes 34:109–118.

Leis, J.M. and B.M. Carson-Ewart. 1999. In situ swimming and settlement behaviour of larvae of an Indo-Pacific coral-reef fish, the coral trout *Plectropomus leopardus* (Pisces: Serranidae). Marine Biology 134:51–64.

Lenanton, R.C.J., A.I. Robertson, and J.A. Hansen. 1982. Nearshore accumulations of detached macrophytes as nursery areas for fish. Marine Ecology Progress Series 9:51–57.

Montague, C.L. and J.A. Ley. 1993. A possible effect of salinity fluctuation on abundance of benthic vegetation and associated fauna in northeastern Florida Bay. Estuaries 16:703–717.

Naughton, S.P. and P.H. Saloman. 1978. Fishes of the nearshore zone of St. Andrew Bay, Florida, and adjacent coast. Northeast Gulf Science 2:43–55.

Peters, D.J. and W.G. Nelson. 1987. The seasonality and spatial patterns of juvenile surf zone fishes of the Florida east coast. Florida Scientist 50:85–99.

Poulakis, G.R., D.A. Blewett, and M.E. Mitchell. 2003. The effects of season and proximity to fringing mangroves on seagrass-associated fish communities in Charlotte Harbor, Florida. Gulf of Mexico Science 21(2):171–184.

Rakocinski, C.F., S.S. Brown, G.R. Gaston, R.W. Heard, W.W. Walker, and J.K. Summers. 1997. Macrobenthic responses to natural and contaminant-related gradients in northern Gulf of Mexico estuaries. Ecological Applications 7:1278–1298.

Saloman, C.H. and S.P. Naughton. 1979. Fishes of the littoral zone, Pinellas County, Florida. Florida Scientist 42:85–93.

Sancho, G., D. Ma, and P.S. Lobel. 1997. Behavioral observations of an upcurrent reef colonization event by larval surgeonfish *Ctenochaetus strigosus* (Acanthuridae). Marine Ecology Progress Series 153:311–315.

Sargent, F.J., T.J. Leary, D.W. Crewz, and C.R. Kruer. 1995. Scarring of Florida's seagrasses: Assessment and management options. FMRI Technical Report TR-1. Florida Marine Research Institute, St. Petersburg, FL, USA, 37 p.

Savino, J.F. and R.A. Stein. 1989. Behavior of fish predators and their prey: Habitat choice between open water and dense vegetation. Environmental Biology of Fishes 24:287–293.

Shulman, M.J., J.C. Ogden, J.P. Ebersole, W.N. McFarland, S.L. Miller, and N.G. Wolf. 1983. Priority effects in the recruitent of juvenile coral reef fishes. Ecology 64:1508–1513.

Sklar, F.H. and J.A. Browder. 1998. Coastal environmental impacts brought about by alterations in freshwater flow in the Gulf of Mexico. Environmental Management 22:547–562.

Sogard, S.M. 1997. Size-selective mortality in the juvenile stage of teleost fishes: a review. Bulletin of Marine Science 60:1129–1157.

Sogard, S.M. and B.L. Olla. 1993. The influence of predator presence on utilization of artificial seagrass habitats by juvenile walleye pollack, *Theragra chalcogramma*. Environmental Biology of Fishes 37:57–65

Springer, V.G. and K.D. Woodburn. 1960. An ecological study of the fishes of the Tampa Bay area. Florida State Board of Conservation. Marine Laboratory Professional Paper Series No. 1, 104 p.

Stoker, Y.E. 1992. Salinity distribution and variation with freshwater inflow and tide, and potential changes in salinity due to altered freshwater inflow in the Charlotte Harbor estuarine system, Florida. US Geological Survey Water-Resources Investigations Report 92-4062, 30 p.

Stoner, A.W. 1980. Feeding ecology of *Lagodon rhomboides* (Pisces: Sparidae): Variation and functional responses. Fishery Bulletin, US 78:337–352.

Tomasko, D.A., C.J. Dawes, and M.O. Hall. 1996. The effects of anthropogenic nutrient enrichment on turtle grass (*Thalassia testudinum*) in Sarasota Bay, Florida. Estuaries 19:448–456.

Tupper, M. and R.G. Boutilier. 1995. Effects of conspecific density on settlement, growth and post-settlement survival of a temperate reef fish. Journal of Experimental Marine Biology and Ecology 191:209–222.

Uhrin, A.V. and J.G. Holmquist. 2003. Effects of propeller scarring on macrofaunal use of the seagrass *Thalassia testudinum*. Marine Ecology Progress Series 250:61–70.

Vigliola, L. and M. Harmelin-Vivien. 2001. Post-settlement ontogeny in three Mediterranean reef fish species of the genus *Diplodus*. Bulletin of Marine Science 68:271–286.

Yamashita, Y., M. Tanaka, and J.M. Miller. 2001. Ecophysiology of juvenile flatfsh in nursery grounds. Journal of Sea Research 45:205–218.

Zar, J.H. 1984. Biostatistical analysis. 2nd ed. Prentice Hall, Inc. Englewood Cliffs, NJ, 718 p.

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Predators and the Distribution and Abundance of Blennies on Offshore Petroleum Platforms

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PREDATORS AND THE DISTRIBUTION AND ABUNDANCE OF BLENNIES ON OFFSHORE PETROLEUM PLATFORMS

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ABSTRACT Predation may be important in structuring fish assemblages but studies of the intensity of predation on marine fish assemblages are uncommon. Predator avoidance behavior was used to identify the predators of an assemblage of blennies found on offshore petroleum platforms in the northern Gulf of Mexico. The distribution of predators was then compared with the distribution of 3 species of blennies to see if predation intensity was related to the vertical zonation of blennies. Predator approaches and blenniid activity were compared in low and high surface current events. Results did not support a hypothesis of predation controlling the distribution and abundance of blennies. Also, predators were less abundant and blennies increased their activity when a surface current was present. 'Enemy free space' created by surface currents may help explain why predation is not important in structuring these blenniid assemblages.

INTRODUCTION

In recent years the role of predation in assemblage regulation has received increased attention (reviewed by Sih et al. 1985, Ebeling and Hixon 1991). Although predation is recognized as an important assemblage structuring process, it has received little attention in marine fish systems (reviewed by Hixon 1991). Studies of predation effects in marine fish assemblages are constrained by design and implementation problems (Hixon 1991, Hixon and Beets 1993).

Blenniid assemblages (Family: Blenniidae) on offshore petroleum platforms in the northern Gulf of Mexico (GOM) are characterized by a distinct bathymetric zonation (Rauch 2003). *Scartella cristata* are found only in the upper few meters of the water column whereas *Parablennius marmoreus* are most abundant at 15 m and do not occur at depths < 5 m. *Hypsoblennius invemar* are found throughout the water column (to depths > 15 m) but are more abundant at shallower depths. The abundance of blennies (all species combined) decreases with increasing depth (at least to 30 m)(Rauch 2003). Although blennies are abundant on offshore platforms, their biomass is small compared to most northern GOM fishes (Gallaway and Lewbel 1982).

If predators are limiting *S. cristata* to depths < 5 m, I should find different predators and abundance at 5 m and 1 m depths. Likewise, if predators are limiting *P. marmoreus* abundance at 10 m, I should find one or more predators at 10 m depths, where the blenny is less abundant, and not find those predators (or find fewer of them) at 15 m depths, where the blenny is twice as abundant. Additionally, if predators reduce the abundance of blennies (all species combined) as depth increases, I should find a greater number of predators at deeper depths. Equal densities of predators at different depths would not be expected if predation were affecting this blenniid distribution.

Surface currents are common but not always present in the northern GOM (Gallaway and Lewbel 1982), and fishes around offshore petroleum platforms often congregate below surface currents (pers. obs.). Stanley and Wilson (1997), using hydroacoustics, noted that fishes ≤ 20 cm were uncommon around offshore platforms during current events. Fishes ≤ 20 cm are within the size range of fishes likely to prey upon blennies, which reach a maximum size of 8 cm (Hoese and Moore 1998). Lima and Dill (1990) suggested that animals assess the risk of predation and behave in a way that reduces this risk. Thus, a surface current may reduce the abundance of fishes likely to be predators of blennies and provide the blennies with 'enemy free space' (Jefferies and Lawton 1984).

Herein I classify fishes as predators/non-predators of blennies and compare the distribution of blenny predators with the distribution of blennies. Additionally, I relate blenniid activity with the abundance of blenniid predators when surface currents are present or absent.

MATERIALS AND METHODS

Observations of fishes (predator/visitors) and blenny behavior were collected between 0830 and 1300 hrs using SCUBA. Blennies chosen for detailed observations were spatially separated by > 5 m, and all focal blennies were located within 0.5 m of one of the depths listed. Observations at 10 and 15 m were conducted every day during the periods of 24–27 July 1996 and 16–24 July 1997 at East Breaks 165A, a platform located 158 km south of Galveston, Texas, in 116 m of water. One and 5 m

observations were conducted on four days between 25 July and 29 August 1998 at or around 7 platforms (South Timbalier 134S, 128R, 151O, 135M, 128X, 151COMP, and 151I) located 50 km south of Fourchon, Louisiana. Platforms are numerous and concentrated within a small area at the Fourchon site (Kasprzak 1998). Depth of these platforms ranged from 30 m (the northernmost platform) to 43 m (the southernmost). Both East Breaks and Fourchon sites have similar blenniid abundance and distribution patterns (Rauch 2003, pers. obs.).

I conducted 10 observations (15 min each) at each of the four depths in 1997 and 1998. Due to logistical constraints, 2 observations in 1997 at the 15 m depth were shortened to 7.8 and 6.4 min. In 1996 a strong surface current limited me to eight observation periods between 10 and 15 m at EB165A.

I used the predator avoidance behavior of blennies, sheltering in barnacle cavities, to classify all fishes larger than adult blennies (those which approached within 1 m of a blenny) as 'predators' or 'non-predators' (Lima and Dill 1990, Hastings 1991). If a blenny retreated into a cavity when a fish approached, the approaching fish was classified as a predator. If a blenny did not retreat into its cavity, the approaching fish was classified as a non-predator. I also categorized the abundance of all fishes which approached within 3 m of the focal blenny as follows: fish species which approached at a rate of between one and four times in a 15 min observation were listed as 'present,' and those that approached at a rate of five or more times were 'numerous.' To avoid errors in identifying damselfishes, all species were grouped as *Stegastes* spp. (Rooker et al. 1997) except for *Abudefduf saxatilis* which could be easily identified by color pattern. Finally, for each depth in 1997 and 1998 I recorded the number of predators/visitors not recorded in a previous observation to ensure adequate sampling.

I used blenniid abundance data from Rauch (2003) for the Fourchon platforms. Blenniid abundance at 5, 10, and 15 m was determined using visual surveys (described in Rauch 2003) in 1997 at East Breaks 165A.

I also classified blenny behavior into one of the following categories: a) in cavity, b) moving outside the cavity, c) feeding, and d) interactions with other blennies. I recorded the activity that the focal blenny was engaged in every five sec throughout each 15 min observation period. I classified water current at the beginning of each observation as follows: a) no current, b) slight current—divers had no trouble swimming against this current, c) strong current—divers had trouble swimming against this current and limited dive time to less than 30 min, and d) very strong current—divers could only swim short distances (< 10 m) against this current and had to be put in the water up-current of the platform and leave the water down-current of the platform.

I used student-*t* tests to compare numbers of blennies at different depths when normality assumptions were satisfied. If the normality assumption was not satisfied, I used a Mann-Whitney (MW) U-test. I grouped blenniid predators by depth and compared their frequency of approach using Chi-square tests of independence (Siegel and Castellan 1988). McNemar's test was used to compare differences in proportions of predator approaches and blenniid behavior (sheltering in cavity or outside of cavity) (Siegel and Castellan 1988).

RESULTS

At the 1 and 5 m depths (Fourchon platforms), 10 species of fishes approached the focal blennies and 4 were considered blenniid predators (Table 1). Blenniid predators outnumbered non-predators in approaches (within 1 m) by 35 to 19.

In 1997, the 10 and 15 m depths (East Breaks platform) were visited by 20 species of fishes, of which 8 were classified as predators (Table 1). Visits (within 1 m) by non-predators of blennies at this site outnumbered predators by 126 to 14. In 1996, predators were so rare during the high current periods that their distribution could not be examined.

In the 1 and 5 m observations combined ($n = 20$), no new species of approaching fishes (both predators and non-predators) were recorded after the 11th observation. In the 10 and 15 m observations (in 1997), no new species of fishes (neither predators nor non-predators) were recorded after the 14th observation. Therefore, there were an adequate number of observation periods.

Blennies were very consistent in their avoidance of predators. In only 2 of 49 cases did a fish categorized as a predator approach within 1 m and not elicit a predator avoidance response by the blenny. In both cases, the predator veered off in another direction before it approached within 0.5 m of the focal blenny.

Species Distribution

No difference was found in the blenniid predator approaches at 1 and 5 m ($\chi^2 = 0.84$, $P = 0.84$) or at 10 and 15 m ($\chi^2 = 6.4$, $P = 0.49$). Because several of the less abundant predators were detected in fewer than five of the observations, these tests lack the desired power (Siegel and Castellan 1988). Therefore, I analyzed each species individually. *Scartella cristata* was more abundant at 1 m ($6.75/m^2$) than at 5 m ($0.16/m^2$)(MW U < 0.001, $P =$

TABLE 1

The number of fishes approaching within 1 m of a focal blenny and number of times the blenny displayed predator avoidance behavior in all observations at the depths listed. Number of 15 min observations (out of 10) that predators/visitors were recorded. Personal observations include observations at these platforms and others that were not part of this project's data collection. Predator/Non-predator classification determined by: *observations at other depths, **stomach content analysis (Randall 1967), ***personal observations.

			Number of times present (numerous in parenthesis)	
	Approaches	**Avoidances**	**Depth 1 m**	**Depth 5 m**
1 and 5 m observations				
(Predators of blennies)				
Lutjanus griseus	25	24	8 (4)	8 (2)
Bodianus rufus	5	4	2	1
Epinephelus adscensionis	2	2	3	5
Caranx fusus	2	2	4	5
(Non-predators of blennies)				
Stegastes sp.	8	0	3 (1)	3
Abudefduf saxatilis	3	0	5	2
Balistes capriscus	1	0	1	1
Kyphosus sectatrix	2	0	2 (10)	0
Chaetodipterus faber	6	0	6	6 (3)
*** *Sphyraena barracuda*	0	0	1	1
10 and 15 m observations				
(Predators of blennies)				
Seriola dumerili	2	2	1	3
Seriola rivoliana	8	8	3 (1)	5 (3)
Bodianus rufus	2	2	3	1
Epinephelus adscensionis	1	1	3	2
Lutjanus griseus	1	1	0	1
* *Caranx fusus*	0	0	5 (3)	6 (4)
** *Caranx latus*	0	0	1	0
** *Caranx lugubris*	0	0	0	2
(Non-predators of blennies)				
Acanthurus coeruleus	45	0	6	8
Stegastes spp.	13	0	4 (2)	2
Paranthias furcifer	52	0	6 (4)	5 (3)
Kyphosus sectatrix	7	0	4 (1)	2
Abudefduf saxatilis	3	0	2 (1)	0
Carcharhinus falciformis	1	0	4	5
Balistes capriscus	1	0	5	1
Thalassoma bifasciatum	2	0	1	1
Canthigaster rostrata	1	0	0	1
Cantherhines pullus	1	0	1	0
*** *Sphyraena barracuda*	0	0	4	4
** *Pomacanthus paru*	0	0	1	0

< 0.0001). *Lutjanus griseus* and *Caranx fusus* had nearly the same abundance at both depths and *Bodianus rufus* was more abundant at the shallower depth. *Epinephelus adscensionis* was slightly more abundant at 5 m but was detected at both depths.

Parablennius marmoreus was more abundant at 15 m ($0.63/m^2$) than at 10 m ($0.29/m^2$)(U = 42.5, $P = 0.029$). Ten and 15 m observations revealed *Seriola dumerili*, *Seriola rivoliana*, *L. griseus*, *C. fusus*, and *Caranx lugubris* were more abundant at 15 m than at 10 m. This distribution is the opposite of that expected if these fishes were limiting the distribution of *P. marmoreus*. *Bodianus rufus* and *E. adscensionis* were present in nearly equal numbers at the two depths. Only *Caranx latus* was found (one time) at 10 m and not at 15 m. This was the only *C. latus* seen around this platform throughout the data collection period (9 days).

Blenniid Abundance

The abundance of blennies dropped from $12.54/m^2$ at 1 m to $7.92/m^2$ at 5 m (student-t = 5.96, $P = < 0.0001$). However, predators (all species combined) did not display an increased frequency of approaches (within 1 m) as depth increased from 1 m (4.88/hr) to 5 m (7.78/hr) (MW U = 29.0, $P = 0.123$).

The abundance of blennies was higher at 10 m ($1.89/m^2$) than at 15 m ($1.32/m^2$)(MW U = 32.0, $P = 0.006$). However, predators (all species combined) did not approach more frequently at 15 m (3.05/hr) than at 10 m (2.75/hr)(MW U = 48.0, $P = 0.912$).

"Enemy free space" and currents

All observation periods ($n = 1089$) in 1996 were classified as 'high current' while all observation periods in 1997 ($n = 3488$) were classified as 'low current.' The proportion of predator approaches (within 1 m) in the 'high current' year (0.18%) was significantly less than the proportion of predator approaches in the 'low current' year (0.40%) (McNemar's test; $x^2 = 1043.8$, $P < 0.0001$).

Blenniid behaviors outside the barnacle cavity included swimming, feeding, patrolling territorial borders, and intra- and interspecific interactions. The focal blennies were outside the barnacle cavity more often in the 'high current' (11.0%) than in the 'low current' (1.7%) events ($x^2 = 3083.4$, $P < 0.0001$). The proportion of observations where blennies were feeding was higher in 'high current' (1.6%) than in 'low current' (0.7%) events ($x^2 = 1003.0$, $P < 0.0001$).

DISCUSSION

Predator avoidance behavior of blennies was effective in classifying fishes as predators or non-predators, and my classifications were consistent with stomach content analysis (Randall 1967). Additionally, through this research I was able to add species considered blenny predators not recorded by Randall. Fishes recorded around platforms in this study were consistent with the species listed over the last 2 decades (Sonnier et al. 1976, Putt 1982) as well as recently (Bull and Kendall 1994, Rooker et al. 1997, Stanley and Wilson 1997).

The approaches of predators at 1 and 5 m is not consistent with a hypothesis of predators limiting the distribution of *S. cristata* to the upper few meters of the water column. No predators were found at 1 m or 5 m. Observations at 10 and 15 m failed to find any predators with a distribution that could limit the numbers of *P. marmoreus* found at 10 m. Only 2 predators were more common at 15 m, and one, *C. latus*, was observed only once in the 9 d of observations. This lone individual did approach within 3 m of a focal blenny, but rare species are not likely to limit or restrict the distribution of a prey species. Rooker et al. (1997) and Stanley and Wilson (1997, 2000) found that *C. latus* were rare or not present in their observations. *Bodianus rufus* was recorded in three observation periods at 10 m and one at 15 m. Rooker et al. (1997) found *B. rufus* less common at depths < 9 m, a distribution not consistent with the expected distribution if this predator was limiting the distribution of *P. marmoreus*. *Bodianus rufus* are territorial (Hoffman 1983) and additional observations indicated this species consistently frequented parts of the platform that offer some cover (where diagonal and vertical members meet). Such a territorial behavior would limit the potential for this predator to restrict a prey species on areas of the structure that are not a part of its territory. Overall, predation is apparently not important in limiting the distribution of *P. marmoreus*.

The abundance of blennies decreased with increasing depth in both 1 to 5 m and 10 to 15 m observations. However, the number of predators did not increase at these depths. Gallaway and Lewbel (1982) found that the biomass of algae and invertebrates was higher at shallower depths which may limit the numbers of blennies found at greater depths due to lack of prey. Additionally, because blennies shelter and spawn in barnacle cavities, the distribution of barnacle cavities may limit the distribution of blennies (Smith-Vaniz 1980, Rauch 2003).

I found that fishes which produced a predator avoidance response in blennies (predators) were less abundant in observations taken in a current when compared to observa-

tions taken in the absence of a current. These fish abundance patterns are consistent with hydroacoustic measurements taken by Stanley and Wilson (1997). When predators were less abundant, the blennies spent more time outside their cavity. The greater proportion of time spent outside of shelters in a 'high current' suggests that these blennies are able to assess the reduced threat of predation (Lima and Dill 1990). The frequency of sheltering behavior supports the hypothesis of currents producing 'enemy free space' which the blennies exploit by increasing their movement out of shelters.

On offshore petroleum platforms, blennies experience a temporally changing risk of predation and would be expected to minimize their risk of predation by feeding at a greater rate in a 'high current.' I found higher feeding rates when fewer predators were present ('high current' periods). Changes in blenny behavior associated with 'enemy free space' would reduce the opportunities for predators to prey upon blennies and thus reduce the potential for predation to affect the distribution and abundance of these blennies. My observations of the distribution and abundance of blenniid predators failed to support a hypothesis that predation is an important biotic interaction in producing the abundance and distribution patterns of blennies around offshore petroleum platforms. Further research should focus on factors restricting the numbers of blennies with increasing depth.

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LITERATURE CITED

Bull, A.S. and J.J. Kendall Jr. 1994. An indication of the process: Offshore platforms as artificial reefs in the Gulf of Mexico. Bulletin of Marine Science 55:1086–1098.

Ebeling, A.E. and M.A. Hixon. 1991. Tropical and temperate reef fishes: comparison of community structures. In P.F. Sale, ed. The Ecology of Fishes on Coral Reefs. Academic Press, San Diego, CA, USA, p. 509–563.

Gallaway, B.J. and G.S. Lewbel. 1982. The ecology of petroleum platforms in the northwestern Gulf of Mexico: A community profile. FWS/OBS-82/27, 91 p.

Hastings, P.A. 1991. Flexible responses to predators in a marine fish. Ethology Ecology and Evolution 3:177–184.

Hixon, M.A. 1991. Predation as a process structuring coral reef fish communities. In P.F. Sale, ed. The Ecology of Fishes on Coral Reefs. Academic Press, San Diego, CA, USA, p. 475–508.

Hixon, M.A. and J.P. Beets. 1993. Predation, prey refuges, and the structure of coral-reef fish assemblages. Ecological Monographs 63:77–101.

Hoese, H.D. and R.H. Moore. 1998. Fishes of the northwestern Gulf of Mexico, Texas, Louisiana and adjacent waters, 2nd ed. Texas A&M University Press, College Station, TX, USA, 422 p.

Hoffman, S.G. 1983. Sex-related foraging behavior on sequentially hermaphroditic hogfishes (*Bodianus* spp.). Ecology 64:798–808.

Jeffries, M.J. and J.H. Lawton. 1984. Enemy-free space and the structure of ecological communities. Biological Journal of the Linnean Society 23:269–286.

Kasprzak, R.A. 1998. Use of oil and gas platforms as habitat in Louisiana's artificial reef program. Gulf of Mexico Science 16:37–45.

Lima, S.L. and L.M. Dill. 1990. Behavioral decisions made under the risk of predation: A review and prospectus. Canadian Journal of Zoology 68:619–640.

Putt Jr., R.E. 1982. A quantitative study of fish populations associated with a platform within Buccaneer oil field, northwestern Gulf of Mexico. M.S. thesis, Texas A&M University, College Station, TX, USA, 116 p.

Rauch, T.J. 2003. Equilibrial blenniid assemblages on offshore petroleum platforms. Environmental Biology of Fishes 68:301–305.

Randall, J.E. 1967. Food habits of reef fishes of the West Indies. Studies inTropical Oceanography 5:665–847.

Rooker, J.R., Q.R. Dokken, C.V. Pattengill, and G.J. Holt. 1997. Fish assemblages on artificial and natural reefs in the Flower Garden Banks National Marine Sanctuary, USA. Coral Reefs 16:83–92.

Siegel, S. and N.J. Castellan Jr. 1988. Nonparametric Statistics for the Behavioral Sciences, 2nd ed. McGraw Hill, Boston, MA, USA, 399 p.

Sih, A., P. Crowley, M. McPeek, J. Petranka, and K. Strohmeier. 1985. Predation, competition, and prey communities: A review of field experiements. Annual Review of Ecology and Systematics 16:269–311.

Smith-Vaniz, W.F. 1980. Revision of western Atlantic species of the blenniid fish Genus *Hypsoblennius*. Proceedings of the Academy of Natural Sciences of Philadelphia 132:285–305.

Sonnier, F., J. Teerling, and H.D. Hoese. 1976. Observations on the offshore reef and platform fish fauna of Louisiana. Copeia 1976:105–111.

Stanley, D.R. and C.A. Wilson. 1997. Seasonal and spatial variation in the abundance and size distribution of fishes associated with a petroleum platform in the northern Gulf of Mexico. Canadian Journal of Fisheries and Aquatic Sciences 54:1166–1176.

Stanley, D.R. and C.A. Wilson. 2000. Variation in the density and species composition of fishes associated with three petroleum platforms using dual beam hydroacoustics. Fisheries Research 47:161–172.

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Studies on the Crustacea of the Turks and Caicos Islands, British West Indies. V. Records of Mysids from Pine Cay, Fort George Cay, Water Cay, and Adjacent Waters

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STUDIES ON THE CRUSTACEA OF THE TURKS AND CAICOS ISLANDS, BRITISH WEST INDIES. V. RECORDS OF MYSIDS FROM PINE CAY, FORT GEORGE CAY, WATER CAY, AND ADJACENT WATERS

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ABSTRACT Only 2 species of mysids, *Heteromysis spottei* and *Stygiomysis clarkei,* have been previously reported from the Turks and Caicos Islands. Between 1988 and 1990, 21 species of mysids were collected from reef (to 38 m) and shallow non-reef habitats surrounding Pine Cay, Fort George Cay, and Water Cay, Turks and Caicos Islands. One species collected, *Anchialina typica*, is distributed throughout tropical and subtropical seas. Twelve species (*Bowmaniella johnsoni, Dioptromysis paucispinosa, Heteromysis bermudensis, H. guitarti, H. mayana, Mysidium columbiae, M. gracile, M. integrum, Mysidopsis bispinulata, M. brattstromei, Parvimysis bahamensis, and Siriella chierchiae*) are widely distributed throughout the subtropical and tropical waters of the Northwest Atlantic. Five species (*Amathimysis serrata, A. torleivi, Heteromysis coralina, Mysidopsis mathewsoni, and Siriella chessi*) are reported for only the second or third time. Three undescribed species are recognized: 2 species of *Amathimysis* associated with either gorgonians on reefs or grass beds and a species of *Heteromysis* collected from sponges on deeper reefs.

INTRODUCTION

The Turks and Caicos Islands are the northernmost islands in the British West Indies and are located about 175 km north of Hispaniola and 250 km northeast of Cuba. This archipelago of inhabited and uninhabitated islands is geologically part of the southeastern Bahamas (Schotte et al. 1991).

This report represents the fifth in a series devoted to the crustacean fauna of the Turks and Caicos Islands. The first 4 contributions dealt with marine isopods (Kensley and Heard 1991, Schotte and Heard 1991, Schotte et al. 1991) and a mysid species (Price and Heard 2000). In addition, another series of 5 publications addressed the taxonomy, distribution, and ecology of commensal palaemonid shrimps (Heard and Spotte 1991, Heard et al. 1993, Spotte, et al. 1994, Spotte and Bubucis 1996, Heard and Spotte 1997).

To date, documentation of the mysid fauna of the Turks and Caicos Islands includes only 2 species; *Stygiomysis clarkei* Bowman, Iliffe, and Yager, 1984 and *Heteromysis spottei* Price and Heard, 2000 were described from an anchialine cave on Middle Caicos Island (Bowman et al. 1984) and from live bottom (calcareous algae, sponges, anthozoans) off Pine Cay (Price and Heard 2000), respectively. The purpose of this study is to document the marine mysid fauna from the reef (to 38 m) and shallow non-reef habitats surrounding Pine Cay, Fort George Cay, and Water Cay, Turks and Caicos Islands (Figure 1).

MATERIALS AND METHODS

Mysids were collected from subtidal habitats in the vicinity of Pine Cay, St. George Cay, and Water Cay in the northeastern Turks and Caicos Islands (Figure 1) between April 1988 and June 1990. Collecting methods included the use of fine mesh kicknets (0.5 and 1.0 mm), an epibenthic sled (0.33 mm), plankton nets (mouth dia. 33 cm, 0.33 mm mesh size), yabby pumps, and plankton (light) traps. Algal-sponge-rock substrata were gently washed in a weak formalin-seawater solution and specimens were captured on a 0.5 mm sieve. SCUBA was used to collect subtidal organisms. The slimy sea plume *Pseudopterogorgia americana* (Gmelin, 1791) and other gorgonian species were sampled for crustacean associates utilizing hand nets, kicknets, and plastic bags placed over the gorgonians from the Turks and Caicos Islands. Additional samples were collected with a kicknet by the second author from Tobago in 1993 and during a study by Spotte et al. 1995 from Guana Island, British Virgin Islands in 1995 in which plastic bags were used. The plastic bagging procedure is described in detail by Spotte et al. 1995 and Spotte and Bubucis 1996. Samples were preserved in 10% formalin-seawater. Measurements of total length of mysids were determined as the distance from the anterior dorsal margin of the carapace to the posterior margin of the telson, excluding spiniform setae. Brood size was determined from counts of young removed from full marsupia of ovigerous females. Larval development was categorized into 3 phases according to Wittmann (1981): 1) embryonic—embryo spherical

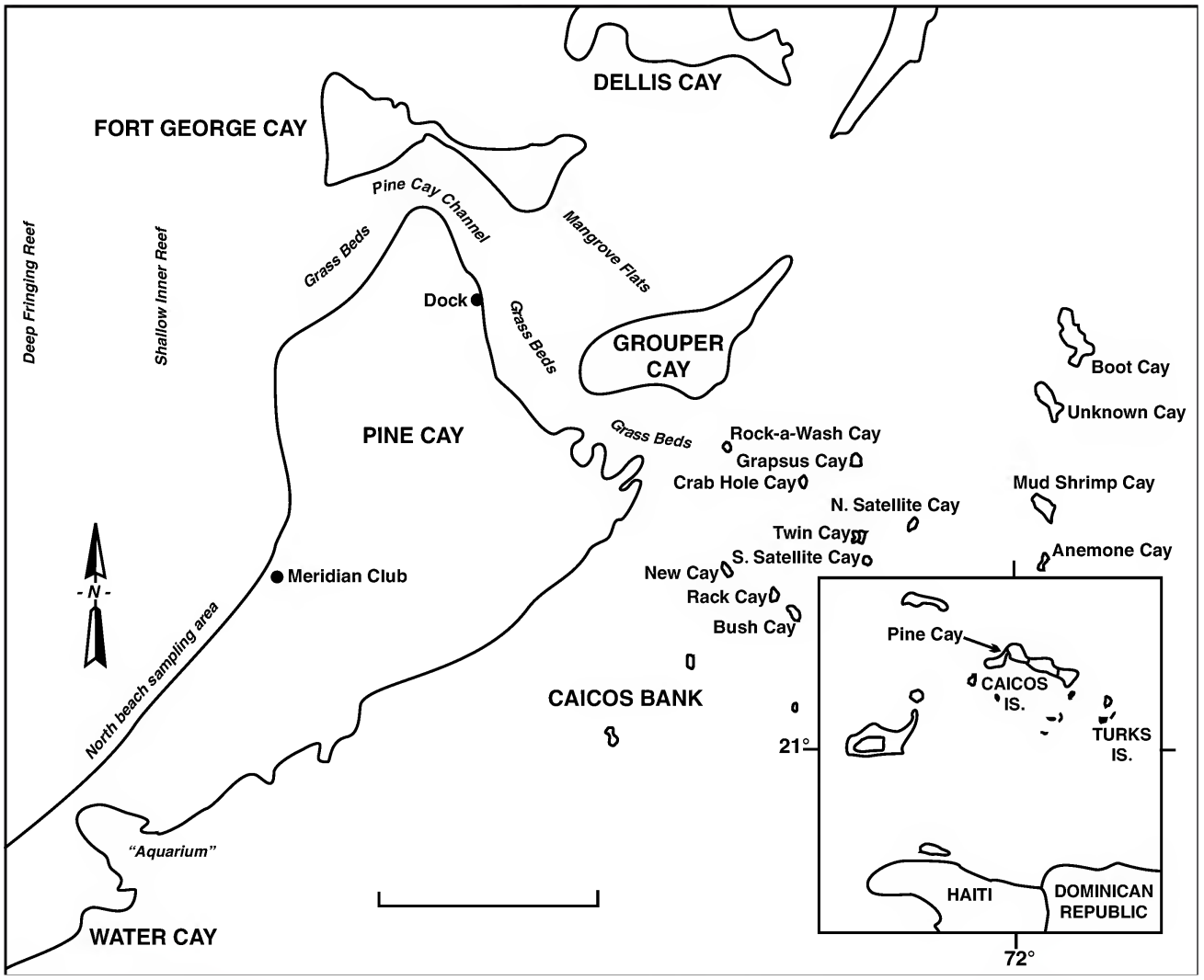

Figure 1. Map showing collecting sites in waters adjacent to Pine Cay, Turks and Caicos Islands, British West Indies. Scale=1km.

and surrounded by an egg membrane; 2) nauplioid—larva elongate, but enclosed in naupliar cuticle; 3) postnauplioid—all appendages and eyestalks free following molt of cuticle. Representative specimens of each described species are deposited in the National Museum of Natural History, Smithsonian Institution, Washington, DC, and the Gulf Coast Research Laboratory Museum.

RESULTS

Eighteen described and 3 undescribed species of mysids were identified from more than 1500 specimens collected from subtidal habitats surrounding Pine Cay. Occurrence, distribution, ecological information, and, at times, systematic remarks are presented for each species. Synonymies, type localities, and detailed ecological remarks are given only for species not treated in Price et al. (2002). For an illustrated key to most species included in this study, see Price et al. 2002. Refer to figure 2 for the general morphological features of the family Mysidae.

ORDER MYSIDA
Family Mysidae
Sub-family Siriellinae
Siriella chessi Murano, 1986
(Figure 3B)

Material. (males-2, ovigerous females-0, immature females-6, juveniles-0), Pine Cay, Aquarium, plankton trap, night, 12 Oct 1989.—(0-0-1-1), Pine Cay, North beach, sand, epibenthic sled, night, 12 April 1989.

Distribution. Virgin Islands (Murano 1986); Cayman Islands (Price et al. 2002); Turks and Caicos Islands (present study).

Ecological remarks. Collections of *Siriella chessi* in the Turks and Caicos represent the third report for this

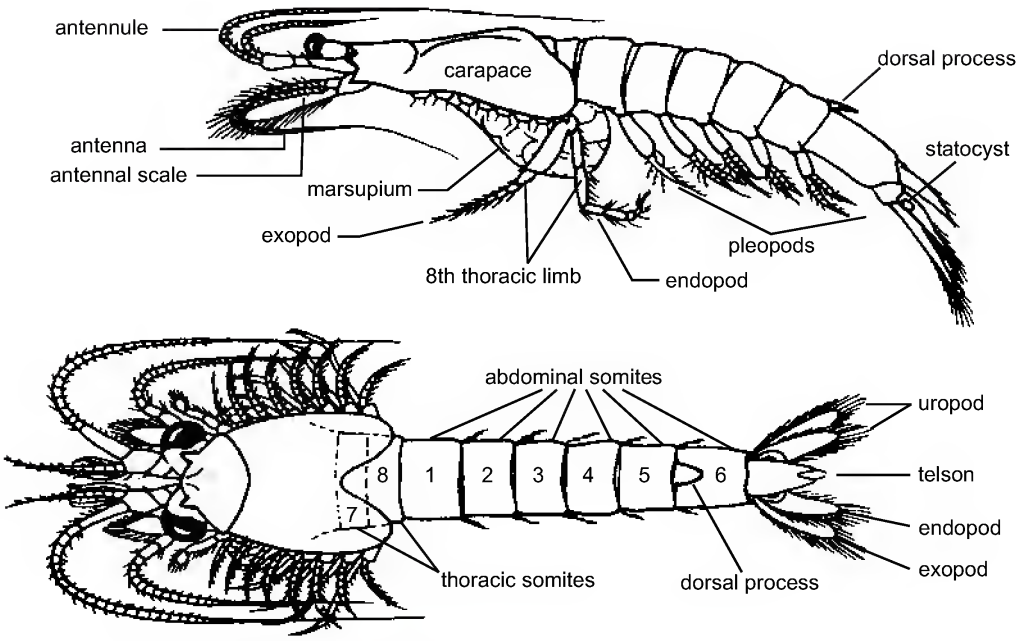

Figure 2. Morphological features typical of the Mysidae.

species. Specimens were collected only in the water column at night. Similar to other oceanic and neritic species of *Siriella*, this species probably undergoes vertical migration and remains near the bottom during the day.

Systematic remarks. See remarks for *Siriella chierchiae.*

Siriella chierchiae Coifmann, 1937 (Figure 3A)

Material. (males-1, ovigerous females-0, immature females-0, juveniles-0), Pine Cay, deep fringing reef, sand/silt, 34-38 m, hand net, 4 Nov 1988.—(1-0-1-0), Pine Cay, deep fringing reef, yellow sponge, 34–38 m, 10 Nov 1988.—(0-0-1-0), Water Cay, algae at reef top, 3–4 m, algae washings, 18 Apr 1988.—(0-1-0-0), South Satellite Cay, 1–2 m, 11 Nov 1988.—(0-1-0-0), Crab Hole Cay, 1 m, 2 Nov 1988.—(0-1-0-0), Rock-a-Wash Cay, sand, 1 m, kicknet, 11 Apr 1988.—(4-0-1-0), Rock-a-Wash Cay, *Neogoniolithon* washings, 0.5 m, 16 Apr 1988.

Distribution. Caribbean Sea, coastal waters of western Atlantic to Brazil (Coifmann 1937, W.M. Tattersall 1951, Brattegard 1970a, b, 1973, 1974a, b, 1975, Băcescu and Ortiz 1984, Modlin 1987a, Markham et al. 1990, Price et al. 2002), Key West, Florida (Tattersall 1951), Gulf of Mexico (Modlin 1984, Escobar-Briones and Soto 1988).

Ecological remarks. This species was associated with a variety of benthic substrata during daytime sampling.

Systematic Remarks. Mature specimens of this widely distributed western Atlantic species exhibited greater morphological variation than previously reported. A 6 mm ovigerous female has 30 spiniform setae on the uropodal endopod and 7 spiniform setae on the outer margin of the proximal article of the uropodal exopod. These numbers are smaller than previously reported (see Price et al. 2002) and overlap with setal counts for *Siriella chessi.* Differences in setation of the posterior two-thirds of the lateral telson margins appear to be the only reliable characteristic separating these 2 species. *Siriella chessi* has a row of subequal spiniform setae (Figure 3B); whereas, *S. chierchiae* has a series of spiniform setae in which larger ones are separated by groups of 2–6 smaller ones (Figure 3A).

Sub-family Gastrosaccinae
Anchialina typica (Kroyer, 1861) (Figure 3D)

Material. (male-1, ovigerous female-1, immature female-1, juvenile-0), Pine Cay, deep fringing reef, sand/silt, 34–38 m, 4 Nov 1988.—(0-0-0-1), Pine Cay, shallow inner reef, sand-pebble, 4 m, 5 Nov 1988.—(0-1-0-3), Pine Cay, North beach, sand, 3–4 m, epibenthic sled, night, 9 Nov 1988.—(0-0-0-1), Pine Cay, Aquarium, plankton trap, night, 12 Sept 1989.

Distribution. Widely distributed in the tropical and sub-tropical regions of the Atlantic, Indian and Pacific oceans (W.M. Tattersall 1951, Ii 1964, Brattegard 1970a, 1973, 1975, Băcescu and Ortiz 1984, Price et al. 2002), waters off Nova Scotia (Nouvel 1943), South Carolina

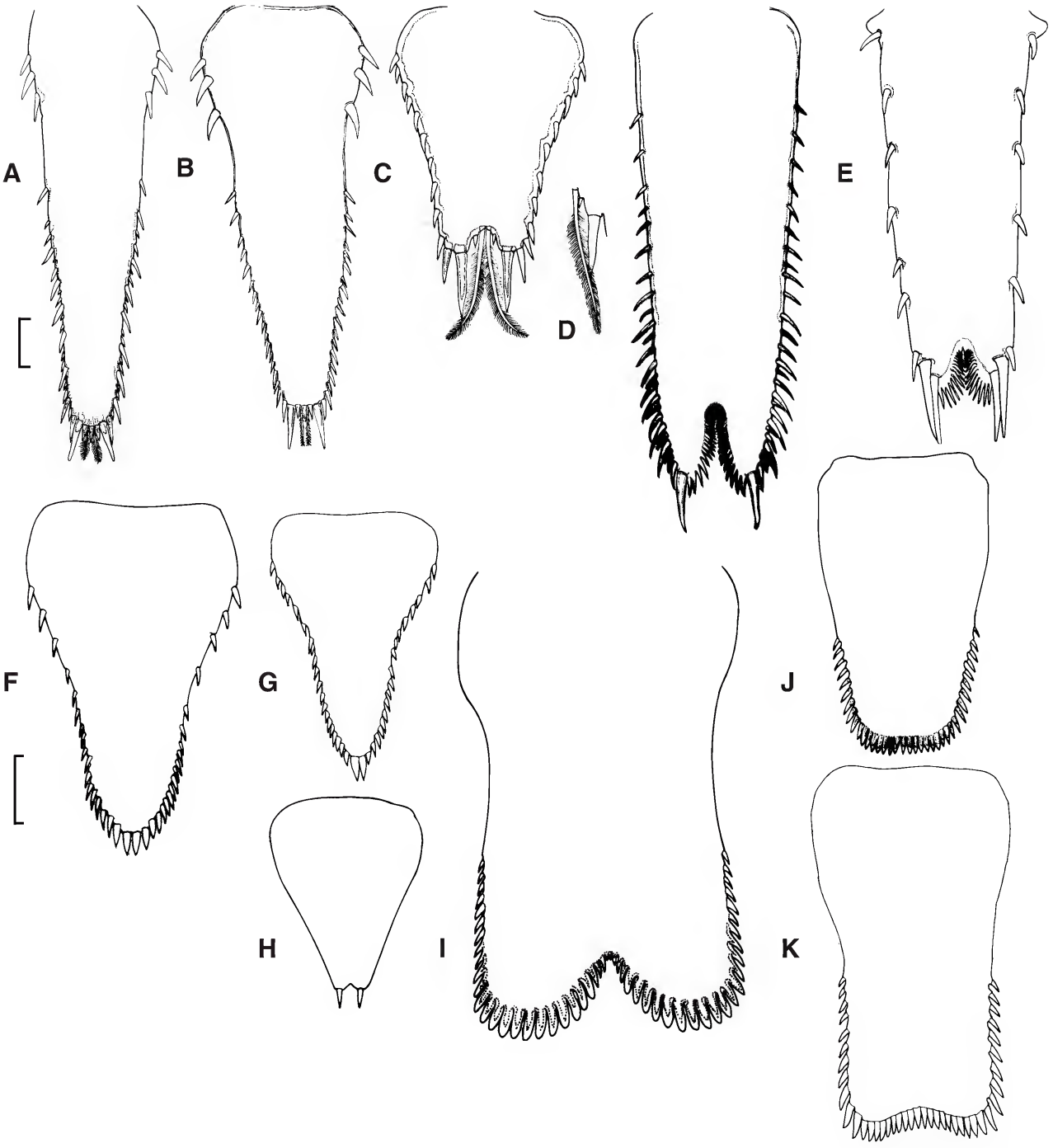

Figure 3. Telsons, dorsal view. A, *Siriella chierchiae*; B, *Siriella chessi*; C, *Dioptromysis paucispinosa* entire, closeup of apex D, *Anchialina typica*; E, *Bowmaniella johnsoni*; F, *Mysidopsis brattstroemi*; G, *Mysidopsis mathewsoni*; H, *Mysidopsis bispinulata*; I, *Mysidium colombiae*; J, *Mysidium integrum*; K, *Mysidium gracile*. Scales = 0.1 mm.

(Wigley and Burns 1971), Gulf of Mexico (Hopkins 1966, Stuck et al. 1979a, b, Modlin 1984, Price et al. 1986).

Ecological remarks. This widely distributed species was collected on/over sand bottoms during the day and in the water column at night.

Systematic Remarks. None.

Bowmaniella johnsoni (W.M. Tattersall, 1937) (Figure 3E)

Material. (males-0, ovigerous-0, immature females-1, juveniles-0), Pine Cay, seagrass beds, 2 m, epibenthic sled, night, 8 Nov 1988.—(6-6-5-0), Pine Cay, North beach, 1.0–1.5 m, sand, kicknet, 4 Nov 1988.—(10-7-29-

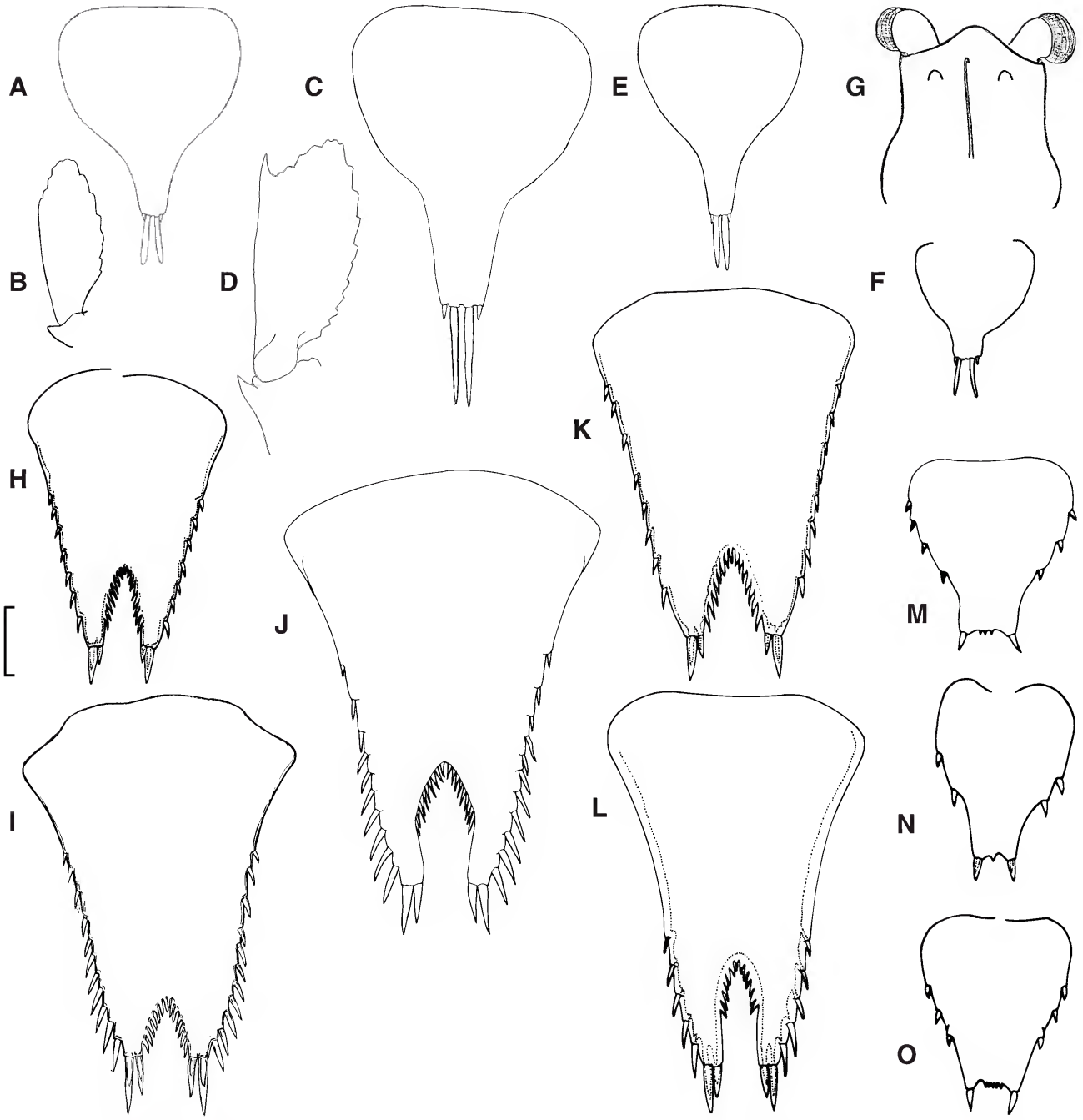

Figure 4. A, *Amathimysis torleivi*, telson; B, *A. torleivi* , antennal scale; C, *A. serrata*, telson; D, *A. serrata*, antennal scale; E, *Amathimysis* sp. A, telson; F, *Amathimysis* sp. B, telson; G, *Amathimysis* sp. B, carapace (dorsal view); H, *Heteromysis mayana*, telson; I, *Heteromysis* sp. A, telson; J, *H. coralina*, telson; K, *H. guitarti*, telson; L, *H. bermudensis*, telson; M–O, *Parvimysis bahamensis*, showing variation in telson morphology. Scale = 0.1 mm.

0), Pine Cay, North beach, 1.0–1.5 m, sand, plankton net, night, 30 Nov 1988.—(11-5-13-0), Pine Cay, North beach, sand, 3–4 m, epibenthic sled, night, 9 Nov 1988.—(7-32-4-0), Pine Cay, North beach, sand, 1 m, kicknet, 12 Apr 1989.—(10-78-7-3), Pine Cay, North beach, sand, epibenthic sled, night, 12 Apr 1989.

Distribution. Puerto Rico, Virgin Islands (W.M. Tattersall 1937); Lesser Antilles (Brattegard 1975); Cayman Islands (Price et al. 2002).

Ecological remarks. Specimens were associated exclusively with sand substrata on or near the bottom during the day and in the water column at night.

Systematic Remarks. None.

Sub-family MYSINAE
Tribe Erythropini
***Amathimysis serrata* Murano, 1986**
(Figures 4 C, D)

Amathimysis serrata.—Murano 1986:141, Figures 5–6.

Material. (males-0, ovigerous females-0, immature females-1, juveniles-0), Pine Cay, seagrass, 2 m, epibenthic sled, night, 8 Nov 1988.—(1-0-0-0), Rack Cay, sponge washings, 1 m, 31 Oct 1988.—(0-2-0-0), Mud Shrimp Cay, sand, 1 m, kicknet, 8 Apr 1988.—(1-1-3-0), Mud Shrimp Cay, algal washings, 0.5–1.0 m, 14 Apr 1988.—(1-0-0-0), Pine Cay, seagrass, epibenthic sled, night, 7 Apr 1989.

Type Locality. St. Croix, US Virgin Islands

Distribution. St. Croix, US Virgin Islands (Murano 1986); Turks and Caicos Islands (present study).

Ecological remarks. This species was collected from a variety of habitats including seagrass, sand, and sponge/algal washings. Murano (1986) reported specimens taken by divers outside a barrier reef in Tague Bay, US Virgin Islands in depths of 8–10 m.

Ovigerous females were 2.7–2.9 mm in length.

Systematic remarks. Specimens from this second record of *Amathimysis serrata* agree with Murano's (1986) original description but appear to exhibit sexual dimorphism in reference to the median dorsal keel anterior to the cervical sulcus of the carapace. The 3 males examined have higher, more pronounced keels than females. Males and females of *Amathimysis cherados* Brattegard, 1974 from Grand Cayman Island showed similar sexual dimorphism (Price et al. 2002). The carapace median keel of *A. serrata* may superficially resemble that of *A. cherados* and *A. gibba* Brattegard, 1969, but these latter species have much larger keeled humps than the former.

***Amathimysis torleivi* Ortiz, Lalana and Sánchez-Diaz, 2000**
(Figures 4 A, B)

Amathimysis torleivi.—Ortiz, Lalana and Sánchez-Díaz 2000:55, Figures 1–4.

Material. TURKS AND CAICOS ISLANDS. Shallow inner reef northwest of Pine Cay, on gorgonians, (males-19, ovigerous females-8, immature females-7, juveniles-0), 9 m, 12 Apr 1989.—(5-0-0-0), 9–11 m, 12 Apr 1989.—(11-2-1-0), Pine Cay, 8–9 m, 10 Feb 1990.—(4-0-2-0), Pine Cay, 9–11 m, hand net, 9 Feb 1990.—(2-3-0-1), Pine Cay, 18 Nov 1989.—(2-0-0-0), Pine Cay, 6.5–8.0 m, 18 Feb 1990.—(1-1-0-0), 5 m, 30 June 1990. TOBAGO. Goat Island, on gorgonians, (9-20-2-1), 4 m, 14 Jan 1993.—BRITISH VIRGIN ISLANDS, GUANA ISLAND, White Bay, off Iguana Head, on *Pseudopterogorgia americana*, (2-0-0-0), 4.5 m, July 1992.

Type Locality. Ciudad de La Habana, Cuba.

Distribution. Cuba (Ortiz et al. 2000); Turks and Caicos Islands, Guana Island, British Virgin Islands, Tobago (present study).

Ecological remarks. *Amathimysis torleivi* as well as an undescribed species, *Amathimysis* sp A, were collected on the slimy sea plume *Pseudopterogorgia americana* and other gorgonians (Figure 3). Both species were never taken on the same host and each occurred in a different bathymetric zone of the reef habitat. While *A. torleivi* was found on shallow inner reefs (11 m), *A.* sp. A was collected on outer fringing reefs, generally in depths of 20 m or more. In addition, *A. torleivi* was collected from gorgonians in shallow waters surrounding Tobago and Guana Island, British Virgin Islands.

Ortiz et al. (2000) reported *Amathimysis torleivi* from the sponge *Callyspongia vaginalis* (Lamarck, 1814) at a depth of 8 m along the north coast of the province of Ciudad de La Habana, Cuba. Sponge washings from the Turks and Caicos yielded only species of *Heteromysis*; *A. torleivi* and *A.* sp A were collected only in association with gorgonians. It appears that at least *A. torleivi* is somewhat of a generalist in its association with sessile invertebrate hosts.

Members of the genus *Amathimysis* are not generally known to live in association with gorgonians or other invertebrates, although *A. gibba* was taken from a scaly soft coral on the Florida Middle Ground (Modlin 1984) and *A. polita* Brattegard, 1974 was collected at the base of hard and soft corals and from a sponge in Belize (Modlin 1987a).

Ovigerous females of *Amathimysis torleivi* ranged from 2.1–3.3 mm in length and carried 3–4 larvae per brood. Embryonic phase diameter 0.34–0.36 mm.

Systematic remarks. *Amathimysis torleivi* can be easily distinguished from its congeners by the absence of a distolateral tooth on the antennal scale (Figure 3 B). In addition, the inner pair of apical telson spiniform setae is relatively short (0.25 or less telson length) and blunt (Figure 4A), characteristics shared only with *Amathimysis* sp. A (Figure 4 E). All other members of this genus have a longer (0.3–0.5 telson length), acute inner pair of spiniform setae on the apex of the telson.

Specimens of *Amathimysis torleivi* from the Turks and Caicos, Guana Island, and Tobago differ slightly in a number of morphological characteristics when compared to the

Figure 5. Photograph of *Amathimysis* sp. A on the gorgonian *Pseudopterogorgia americana*.

description of Ortiz et al. (2000). The width/length ratio of the base of the telson varies from 0.8–1.1 as compared to 1.0; the inner pair of spine-setae on the telson apex is 4.0–5.5 rather than 3–4 times as long as the outer pair. Ortiz et al. (2000) illustrate a faint distal suture on the antennal scale; a suture was present on a minority of specimens from the Turks and Caicos material. Ortiz et al. (2000) report a sub-distal setose "prominencia" on article 2 of the mandibular palp, but no such structure is found on our specimens. In the original description, the dactylus of thoracic endopod 2 is described and illustrated as truncate distally; our material has a dactylus that terminates in a slightly curved claw, similar to all other known species of *Amathimysis*. Male pleopod 1 of our material has 1 terminal seta on the endopod and 5 plumose setae on the pseudobranchial lobe, rather than 1 medial seta and 2 setae, respectively. Our specimens have 7-articulated endopods and exopods on male pleopods 2–5, with coarse plumation on the distal ends of subterminal and terminal setae of the endopod of pleopod 5. Ortiz et al. (2000) report 6-articulated endopods and exopods for pleopods 2–5 with the exception of 7 articles for the exopod of pleopod 3. No mention is made of coarse plumation of pleopod 5.

Amathimysis sp. A
(Figures 4E; 5)

Material. Deep fringing reef northwest of Pine Cay, on gorgonians, (males-4, ovigerous females-5, immature females-5, juveniles-3), 19 m, 26 June 1990.—(1-7-0-0), 18 m, 29 June, 1990.—(4-11-1-0), 21 m, 29 June 1990.—(5-5-1-0), 23 m, 29 June 1990.—(8-10-11-0), 25–32 m, 10 Feb 1990.

Ecological remarks. See remarks for *Amathimysis torleivi*.

Systematic remarks. *Amathimysis* sp. A is morphologically similar to *Amathimysis torleivi* but has a distolateral tooth on the antennal scale.

Amathimysis sp B
(Figure 4F, G)

Material. (males-0, ovigerous females-0, immature females-1, juveniles-1), Pine Cay, 0.5–2.0 km N of Meridian Club, seagrass, algae, 9 m, epibenthic sled, 14 Apr 1989.

Ecological remarks. None.

Systematic remarks. The 2 damaged specimens differ from all known species of *Amathimysis* in the dorsal ornamentation of the carapace anterior to the cervical sulcus. They have a median keel flanked by a tubercle on either side (Figure 4 G). The specimens most closely resemble *A. trigibba* Murano and Chess, 1987, known from coastal waters of California. *Amathimysis trigibba* has a median and 2 lateral tubercles on the carapace. Description awaits the availability of more specimens for study.

Tribe Leptomysini
Dioptromysis paucispinosa Brattegard, 1969
(Figure 3 C)

Material. (males-6, ovigerous females-2, immature females-3, juveniles-0), Twin Cay, sand, 1 m, epibenthic sled, night, 1 Nov 1988.—(1-0-0-0), Rock-a-Wash Cay, sand, 1 m, kicknet, 11 Apr 1988.—(1-1-0-0), Mud Shrimp Cay, sand 1 m, kicknet, 8 Apr 1988.—(0-1-0-0), Pine Cay, 2 km N of Meridian Club, seagrass/algae, 9 m, epibenthic sled, 14 Apr 1989.

Distribution. Bahamas (Brattegard 1969); Belize (Modlin 1987a); Grand Cayman Island (Price et al. 2002).

Ecological remarks. This rare species was collected from sand or seagrass/algae habitats with kicknets and epibenthic sleds.

Systematic remarks. This species is more widely distributed throughout the Caribbean than its only western Atlantic congener, *Dioptromysis spinosa* Brattegard, 1969, which has been collected in the Bahamas and Florida Keys (Brattegard 1969). The 2 species are similar morphologically but may be distinguished most readily by differences in numbers of spiniform setae on the uropodal endopod (2–6 for *D. paucispinosa*; 13–20 for *D. spinosa*).

Mysidopsis bispinulata Brattegard, 1974 (Figure 3 H)

Material. (males-0, ovigerous females-2, immature females-1, juveniles-0), Pine Cay, seagrass beds, 2 m, epibenthic sled, night, 8 Nov 1988.—(29-17-12-0), Pine Cay, North beach, sand, 3–4 m, epibenthic sled, night, 9 Nov 1988.—(5-2-3-11), Pine Cay, North beach, sand, 10–15 m, epibenthic sled, 14 Apr 1989.—(8-24-3-8), Pine Cay, North beach, sand, epibenthic sled, night, 12 Apr 1989.

Distribution. Caribbean coasts of Colombia (Brattegard 1973, 1974a) and Panama (Brattegard 1974b); Grand Cayman Island (Price et al. 2002); Turks and Caicos Islands (present study).

Ecological remarks. *Mysidopsis bispinulata* is reported for the first time from the Bahamas and its range is extended into the northern Caribbean Sea. This species was taken in fairly large numbers from sand and seagrass habitats.

Systematic remarks. None.

Mysidopsis brattstroemi Brattegard, 1969 (Figure 3 F)

Material. (males-1, ovigerous females-1, immature females-0, juveniles-0), Pine Cay, seagrass beds, 1–3 m, epibenthic sled, night, 30 Oct 1988.—(3-1-2-0) Pine Cay, North beach, sand, 3–4 m, epibenthic sled, night, 9 Nov 1988.

Distribution. Bahama Islands and southern Florida (Brattegard 1969); Caribbean coast of Panama (Brattegard 1974b); Little Cayman Island (Price et al. 2002).

Ecological remarks. This species was collected in small numbers from sand and seagrass habitats.

Systematic remarks. None.

Mysidopsis mathewsoni Brattegard, 1969 (Figure 3 G)

Material. (males-0, ovigerous females-0, immature females-1, juveniles-0), Pine Cay, seagrass beds, 2 m, epibenthic sled, night, 8 Nov 1988.—(0-1-1-0), Pine Cay, shallow inner reef, sand, rubble, 4–5 m, yabby pump, 10 Nov 1989.

Distribution. Bahamas Islands (Brattegard 1969); Grand Cayman Island (Price et al. 2002).

Ecological remarks. This rare species is reported for only the third time. It was taken over sand bottoms and seagrass beds.

Systematic remarks. None.

Tribe Mysini

Mysidium columbiae (Zimmer, 1915) (Figure 3 I)

Material. (males-12, ovigerous females-16, immature females-9, juveniles-4), Pine Cay, deep fringing reef, 30 m, 4 Nov 1988.—(1-0-8-5), Pine Cay shallow inner reef, sand, 4 m, 3 Nov 1988.—(58-57-10-0), Pine Cay, shallow inner reef, 2–3 m, kicknet, 5 Nov 1988.—(2-2-15-1), Pine Cay, North beach, sand/seagrass, 15–20 m, epibenthic sled, night, 14 Apr 1989.—(0-1-0-0), Rock-a-Wash Cay, *Neogoniolithon* washings, 1 m, 16 Apr 1988.

Distribution. Coastal areas throughout the Caribbean Sea and southern Gulf of Mexico (Zimmer 1915, W.M. Tattersall 1951, Steven 1961, Goodbody 1965, Emery 1968, Brattegard 1969, 1970b, 1973, 1974a, b, 1975, Băcescu and Ortiz 1984, Murano 1986, Modlin 1987a, Markham et al. 1990, Price et al. 2002).

Ecological remarks. Most specimens were collected near shallow and deep coral reefs as well as seagrass/sand habitats.

Systematic remarks. *Mysidium columbiae* from the Turks and Caicos show greater morphological variation than previously reported for the 3-articulated exopod of male pleopod 4. The ratio of the length of article 1 to articles 2 and 3 combined is greater than 2.0 for both our material (2.1–2.9) and Brattegard's specimens from the Bahamas and south Florida (Brattegard 1969). Zimmer (1915) and Price et al. (2002) recorded ratios that are generally less than 2.0 for specimens from Colombia and the Cayman Islands, respectively.

Mysidium gracile (Dana, 1852) (Figure 3 K)

Material. (males-26, ovigerous females-31, immature females-9, juveniles-0), Pine Cay, shallow inner reef, 3 m, 18 Apr 1988.

Distribution. Bermuda (Jander 1962), Florida Keys (Randall et al. 1964, Emery 1968, Brattegard 1969, 1970b), coastal areas throughout the Caribbean Sea (W.M. Tattersall 1951, Randall et al. 1964, Berrill 1968, Emery 1968, Brattegard 1974b, 1975, Price et al. 2002), coast of Brazil (Dana 1852, Zimmer 1918, Costa 1964).

Ecological remarks. Although *Mysidium gracile* has been reported throughout the Caribbean Sea, this collection is the first from the Bahamian archipelago.

Systematic remarks. Investigators have noted variation in the morphology of the antennal scale, telson, and male pleopod 4 for *Mysidium gracile* from the western Atlantic. The length-width ratio of the antennal scale for our material as well as Brattegard's (1969) specimens from south Florida ranges from 4–5. This is similar to Zimmer's (1918) description (~ 4) but contrasts with a ratio of 5–6 for specimens from the Cayman Islands (Price et al. 2002). Only pointed spiniform setae on the telson are reported by Price et al. 2002 and illustrated by Zimmer (text: Figure 44); however, *M. gracile* from the present study and from south Florida (Brattegard 1969) exhibit pointed spiniform setae on the lateral margins that grade into blunt spiniform setae apically. The specimens in our study have unequal distal articles (2 > 3 > 4) for the exopod of male pleopod 4. This agrees with Zimmer (1918) and Price et al. 2002, but Brattegard found articles 2–4 to be subequal.

Mysidium integrum W.M. Tattersall, 1951 (Figure 3 J)

Material. (males-5, ovigerous females-16, immature females-8, juveniles-0), Pine Cay, deep fringing reef, 30 m, 4 Nov 1988.—(4-8-1-2), Pine Cay, deep fringing reef, 17 m, 9 Feb 1989.—(5-9-1-0), Pine Cay, shallow inner reef, sand, 4 m, 3 Nov 1988.—(3-4-2-6), Pine Cay, shallow inner reef, 2–3 m, kicknet, 5 Nov 1988.—(1-1-7-0), Pine Cay, North beach, sand-seagrass, 15–20 m, epibenthic sled, 14 Apr 1989.—(42-58-2-0), Ft. George Cay, sand, 1 m, 5 Feb 1989.

Distribution. Coastal areas throughout the Caribbean Sea (W.M. Tattersall 1951, Brattegard 1969, 1970b, 1973, 1974a, b, 1975, Modlin 1987a, Price et al. 2002), Bermuda (Brattegard 1973), southern Florida (Emery 1968, Brattegard 1969), Gulf of Mexico (W.M. Tattersall 1951, Modlin 1984).

Ecological remarks. This species was often taken with *M. columbiae* in coral reef and seagrass/sand habitats.

Systematic remarks. Our specimens differ in some respects from the descriptions of W.M. Tattersall (1951) and Brattegard (1969, 1970b), but the morphological variations are similar to those found for specimens from the Cayman Islands (Price et al. 2002).

Some confusion exists concerning the articulation of the exopod of male pleopod 4 of *Mysidium integrum*. In the original description, Tattersall (1951) states that the exopod is 4-articulated and that article 1 is equal in length to the distal 3 articles combined. No mention is made of the relative lengths of articles 2 and 3. However, his Figure 96E shows only 3 articles, with article 1 longer than the distal 2 articles combined, and article 2 shorter than article 3. Subsequent examination of specimens from southern Florida, Bahamas, Antigua, Cayman Islands, and the present study show male pleopod 4 to be 4-articulated with article 1 longer than the distal articles combined, and article 2 > 3 > 4. A lot of more than 100 specimens of *M. integrum* collected at the same location, Cruz Bay, St. John, Virgin Islands, and the same time as the type lot was examined. Male pleopod 4 of mature males in the sample exhibits a 4-articulate exopod in which article 1 is 1.2–1.5 times longer than articles 2–4 combined. In addition, articles 2–4 decrease in length. It appears that Brattegard's illustration of male pleopod 4 (Figure 26D, 1969) is correct, but Tattersall's Figure 96E lacks an article 4 and has the lengths of articles 2 and 3 reversed. Tattersall's description is correct with the exception of the statement about the length of article 1 of male pleopod 4.

Parvimysis bahamensis Brattegard, 1969 (Figures 4 M–0)

Material. (males-5, ovigerous females-0, immature females-1, juveniles-0), Pine Cay, deep fringing reef, sand, 30 m, 2 Nov 1988.—(1-2-0-0), Pine Cay, deep fringing reef, sand/silt, 34–38 m, 4 Nov 1988.—(0-1-0-0), Pine Cay, seagrass beds, 2 m, epibenthic sled, night, 8 Nov 1988.—(23-27-19-0), Twin Cay, sand, 1 m, epibenthic sled, 1 Nov 1988.—(2-5-0-0), algal washings, 1 m, 14 Apr 1988.

Distribution. Coastal waters throughout the Caribbean Sea (Brattegard 1969, 1970b, 1973, 1974a, b, 1975, Modlin 1987a, Ortiz and Lalana 1993, Price et al. 2002, Florida Keys (Brattegard 1973).

Ecological remarks. The largest collection of this species was made in a shallow water sand habitat, but small numbers were taken near deep fringing reefs and in algal washings.

Systematic remarks. Morphological variation of this species is similar to that found for material from the Cayman Islands (Price et al. 2002).

Tribe Heteromysini

Heteromysis (Olivemysis) bermudensis G.O. Sars, 1885 (Figure 4 L)

Material. (males-2, ovigerous females-2, immature females-3, juveniles-1), Rack Cay, sponge washings, 1 m, 12 Apr 1988.—(14-8-6-3) South Satellite Cay, 1–2 m, 11 Nov 1988.—(0-2-1-0), Twin Cay, algal washings, 1 m, 1 Nov 1988.—(1-2-0-1), Rock-a-Wash Cay, *Neogoniolithon*-sponge washings, 1 m, 30 Oct 1988.—(0-1-0-1), Mud Shrimp Cay, sponge washings, 17 Apr 1988.—(0-0-2-0), Ft. George Cay, *Neogoniolithon* washings, 1 m, 18 Apr 1988.

Distribution. Bermuda (G.O. Sars 1885, Verrill 1923, Clarke 1955, Bowman 1981, Băcescu and Iliffe 1986), Turks and Caicos Islands (present study), Cuba (Băcescu 1968), Grand Cayman (Price et al. 2002), Belize (Modlin 1987a), Caribbean coast of Colombia (Brattegard 1973), Saba Bank, Lesser Antilles (Brattegard 1980).

Ecological remarks. Species of *Heteromysis* collected in the Turks and Caicos were associated with a variety of algae and sessile invertebrates. Unfortunately, in most cases, collecting methods involved sampling multiple host groups simultaneously, and it was impossible to determine if a heteromysid was associated with a specific host. *Heteromysis bermudensis* was extracted from washings of sponges, algae, and *Neogonolithion*.

Systematic remarks. As discussed by Price et al. 2002, this species is represented by 2 nominal subspecies: *Heteromysis b. bermudensis* G.O. Sars, 1885 and *Heteromysis b. cesari* Băcescu, 1968. Our material from the Turks and Caicos appears closest to *H. b. bermudensis* sensu Bowman (1981) with respect to eye and male pleopod characters. The details of earlier descriptions of this species agree with our material with minor exceptions. We found a short distal article on the antennal scale of all specimens examined. This article is noted by G.O. Sars (1885) and Bowman (1981) but not by Băcescu (1968) and Brattegard (1973). The distal margin of male pleopod 4 is armed with 27–47 flagellated spiniform setae; to date, this represents the greatest variation in this character reported from one geographical location.

Heteromysis (Olivemysis) coralina Modlin, 1987 (Figure 4J)

Material. (males-0, ovigerous females-0, immature females-1, juveniles-0), Rack Cay, sponge washings, 1 m, 12 Apr 1988.—(8-3-5-4), Rack Cay, sponge washings, 1 m, 31 Oct 1988.—(3-2-1-1), males, Rack Cay, sponge washings, 1 m, 13 Apr 1988.—(24-6-4-0), South Satellite Cay, 1–2 m, 11 Nov 1988.—(11-10-3-10), Twin Cay, algal washings, 1 m, 1 Nov 1988.—(3-4-5-3), Crab Hole Cay, algal-coral washings, 1 m, 5 Nov 1988.—(9-9-7-2), Crab Hole Cay, algal-coral washings, 1 m, 2 Nov 1988.

Distribution. Florida Keys (Modlin 1987c); Cayman Islands (Price et al. 2002); Turks and Caicos Islands (present study).

Ecological remarks. This species was collected from sponge, algal, and algal/coral washings. Ovigerous females were 3.6–4.9 mm in length and carried 3–4 larvae per brood. Diameter of embryonic phase 0.36–0.42 mm; longest postnauplioid larva 1.1 mm.

Systematic remarks. This third report of *Heteromysis coralina* extends its range eastward to the Bahamian archipelago. The morphology of our material agrees with Modlin (1987c) and Price et al. (2002) with one minor exception. The lateral margins of the telson are armed with 9–13 spiniform setae (including apical setae), rather than 7–10.

Heteromysis (Olivemysis) guitarti Băcescu, 1968 (Figure 4K)

Heteromysis guitarti.—Băcescu 1968:226, Figure 3.—Brattegard 1970:134, Figure 9.—Brattegard 1975:113.—Modlin 1984:283.—Băcescu and Iliffe 1986:102, Figure 1 K–P.—Modlin 1987b:301.

Material. (males-13, ovigerous females-5, immature females-6, juveniles-3), Rock-a-Wash Cay, sponge washings, 1 m 31 Oct 1988.—(9-5-4-0), Rack Cay, sponge washings, 1 m, 31 Oct 1988.—(1-0-2-0), Rack Cay, sponge washings, 1 m, 12 Apr 1988.—(10-7-9-5), Rock-a-Wash Cay, sponge washings, 13 Apr 1989.

Type Locality. Havana, Cuba.

Distribution. Cuba (Băcescu 1968), Bahama Islands (Brattegard 1970b, Modlin 1987b), Margarita, Lesser Antilles (Brattegard 1975), eastern Gulf of Mexico (Modlin 1984), Bermuda (Băcescu and Illife 1986).

Ecological remarks. All collections of *Heteromysis guitarti* are from sponges, strengthening the suggestion of Modlin (1984) that this species has a close commensal relationship with sponges, specifically the genus *Ircinia*. In all but one previous report (Brattegard 1975), *H. guitarti*

has been taken with sponges (Băcescu 1968; Brattegard 1970b; Modlin 1984, 1987b; Băcescu and Illife 1986).

Lengths of ovigerous females were 3.5–4.1 mm.

Systematic remarks. In most respects, our material agrees with previous descriptions (Băcescu, 1968, Brattegard, 1970b, Băcescu and Illife 1986), but exhibits more variation. For the Turks and Caicos specimens, the lateral margins of the telson have 9–14 spiniform setae (including apical setae) rather than 11–14; the telsonal cleft is lined with 13–20 spinules rather than 16–27; the carpopropodus of thoracic endopod 3 is armed with 7–10 flagellated spiniform setae, rather than 7; and the distal margins of male pleopods 3 and 4 have 5–10 and 9–17 flagellated spiniform setae, respectively, rather than 2–5 and 8–13.

Heteromysis (Olivemysis) mayana Brattegard, 1970 (Figure 4 H)

Material. (males-0, ovigerous females-0, immature females-0, juveniles-1), Rack Cay, sponge washings, 1 m, 12 Apr 1988.—(1-1-0-0), Rock-a-Wash Cay, *Neogoniolithon*-sponge washings, 1 m 30 Oct 1988.

Distribution. Quintana Roo, Mexico (Brattegard 1970b, Markham et al. 1990), Belize (Modlin 1987a), Caribbean coast of Colombia (Brattegard 1973, 1974a), tentatively from the Virgin Islands (Brattegard 1975), Grand Cayman Island (Price et al. 2002), Turks and Caicos Islands (present study).

Ecological remarks. Only 3 specimens were collected from sponge and *Neogonolithion*/sponge washings.

Systematic remarks. Minor morphological differences exist between our Turks and Caicos specimens and the original description (Brattegard 1970b) and Cayman material (Price et al. 2002). The lateral telson margin is armed with 7–9 spiniform setae, rather than 6–8 reported by Brattegard. There appears to be considerable variability in the length ratio of the outer and inner spiniform setae on the apical lobes of the telson. Brattegard's illustration (Figure 13E) shows an outer: inner ratio of 3:1, whereas Price et al. report a ratio of < 2:1. For our material, the ratio is 2.3:1.

Heteromysis sp. A (Figure 4 I)

Material. (males-3, ovigerous females-2, immature females-0, juveniles-0), Pine Cay, fringing reef, hard sponge, 24–27 m, 17 Nov 1989.—(2-0-0-1), Pine Cay, fringing reef, large yellow tube sponge, 21 m, 13 Nov 1989.—(1-2-0-0), Pine Cay, fringing reef, sponge, 24–27 m, 17 Nov 1989.

Ecological remarks. Specimens were associated with sponges from fringing reefs at depths of 21–27 m.

Systematic remarks. This undescribed species of *Heteromysis* appears to be spongicolous and is most closely related to *H. gomezi* Băcescu 1970 and *H. mayana*. It differs from these species in the form of the telson and the setation of thoracic endopod 3, male pleopods 3 and 4 and telson. Our specimens have a telsonal cleft 1/6 the length of the telson, 8–9 flagellated spiniform setae on the carpopropodus of thoracic endopod 3, male pleopods 3 and 4 without modified spiniform setae, and the telsonal outer apical spiniform seta 1.6 times the length of the inner seta.

DISCUSSION

Three of the mysid species reported in this study, *Amathimysis* spp. A, B, and *Heteromysis* sp. A, are currently known only from the Turks and Caicos Islands, and another 5, *A. serrata*, *A. torleivi*, *H. coralina*, *Mysidopsis mathewsoni*, and *Siriella chessi* are recorded for only the second or third times. The other 13 species have, at least, fairly widespread distributions in the tropical western North Atlantic; however, this is the first report for 5 of these species, *Bowmaniella johnsoni*, *Heteromysis bermudensis*, *H. mayana*, *Mysidium gracile*, and *Mysidopsis bispinulata* from the Bahamian archipelago.

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LITERATURE CITED

Băcescu, M. 1968. Heteromysini nouveaux des eaux Cubaines: trois especes nouvelles de *Heteromysis* et *Heteromysoides spongicola* n. g. n. sp. Revue Roumaine de Biologie, Serie de Zoologie 13:221–237.

Băcescu, M. 1970. New spongicolous *Heteromysis* of the Caribbean Sea (*H. gomezi* n.sp. and *H. mariani* n.sp.). Revue Roumaine de Biologie, Serie de Zoologie 15:11–16.

Băcescu, M. and T.M. Iliffe. 1986. *Bermudamysis* g. n., *Platyops* g. n. and other mysids from Bermudian caves. Stygologia 2:93–104.

Băcescu, M. and M.T. Ortiz. 1984. Contribution to the knowledge of the Mysidacea of the Cuban insular shelf waters. Travaux du Museum d'Histoire naturelle "Grigore Antipa" 26:15–23.

Berrill, M. 1968. The schooling and antipredatory behavior of mysid shrimp. Ph.D. thesis. Princeton University, Princeton, NJ, USA, 50 p.

Bowman, T.E. 1981. First description of the male opposum shrimp, *Heteromysis bermudensis bermudensis* (Crustacea: Mysidacea). Proceedings of the Biological Society of Washington 94:458–461.

Bowman, T.E., T.M. Iliffe, and J. Yager 1984. New records of the troglobitic mysid genus *Stygiomysis*: *S. clarkei*, new species, from the Caicos Islands, and *S. holthuisi* (Gordon) from Grand Bahama Island (Crustacea: Mysidacea). Proceedings of the Biological Society of Washington 97:637–644.

Brattegard, T. 1969. Marine biological investigations in the Bahamas. 10. Mysidacea from shallow water in the Bahamas and southern Florida. Part 1. Sarsia 39:17–106.

Brattegard, T. 1970a. Marine biological investigations in the Bahamas. 11. Mysidacea from shallow water in the Bahamas and southern Florida. Part 2. Sarsia 41:1–35.

Brattegard, T. 1970b. Mysidacea from shallow water in the Caribbean Sea. Sarsia 43:111–154.

Brattegard, T. 1973. Mysidacea from shallow water on the Caribbean coast of Colombia. Sarsia 54:1–65.

Brattegard, T. 1974a. Additional Mysidacea from shallow water on the Caribbean coast of Colombia. Sarsia 57:47– 86.

Brattegard, T. 1974b. Mysidacea from shallow water on the Caribbean coast of Panama. Sarsia 57:87–108.

Brattegard, T. 1975. Shallow-water Mysidacea from the Lesser Antilles and other Caribbean regions. Studies on the Fauna of Curacao and other Caribbean Islands 47(157):102–115.

Brattegard, T. 1980. *Platymysis facilis* gen. et sp. nov. (Crustacea: Mysidacea: Heteromysini) from the Saba Bank, Caribbean Sea. Sarsia 65:49–52.

Coifmann, I. 1937. Misidacei raccolti dalla *R. corvetta* "*Vettor Pisani*" negli anni 1882–85. Annuario del Museo Zoologico della R. Università di Napoli, n.s. 7:1–14.

Clarke, W.D. 1955. A new species of *Heteromysis* (Crustacea, Mysidacea) from the Bahama Islands, commensal with a sea-anemone. American Museum Novitates 1716:1–13.

Costa, R.H. Da, 1964. Notas sobre os Mysidacea da Costa Brasileira. Boletim Museu National, Rio de Janeiro Zoologia n.s. 147:1–9.

Dana, J.D. 1852. United States Exploring Expedition during the years 1838, 1839, 1840, 1841, 1842, under the command of Charles Wilkes, U.S.N., 13. Crustacea, pt. 1, C. Sherman, Philadelphia, PN, USA, 685p.

Emery, A.R. 1968. Preliminary observations on coral reef plankton. Limnology and Oceanography 13:293–303.

Escobar-Briones, E. and L.A. Soto. 1988. Mysidacea from Términos Lagoon, southern Gulf of Mexico, and description of a new species of *Taphromysis*. Journal of Crustacean Biology 8:639–655.

Gmelin, J.F. 1791. Caroli a Linné Systema Naturae per regna tria naturae, secundum classes, ordines, genera, species, cum characteribus, differentiis, synomymis, locis. Editio decima tertia, aucta, reformata. Lipsiae 1:3021–4120.

Goodbody, I. 1965. Continuous breeding in populations of two tropical crustaceans, *Mysidium columbiae* (Zimmer) and *Emerita portoricensis* Schmidt. Ecology 46:195–197.

Heard, R.W. and S. Spotte. 1991. Pontoniine shrimps (Decapoda: Caridea: Palaemonidae) of the northwest Atlantic. II. *Periclimenes patae*, new species, a gorgonian associate from shallow reef areas off the Turks and Caicos Islands and Florida Keys. Proceedings of the Biological Society of Washington 104:40–48.

Heard, R.W. and S. Spotte. 1997. Pontoniine shrimps (Decapoda: Caridea: Palaemonidae) of the northwest Atlantic. V. *Periclimenes mclellandi*, new species, a gorgonian associate from Pine Cay, Turks and Caicos Islands. Proceedings of the Biological Society of Washington 110:39–48.

Heard, R.W., S Spotte, and P.M. Bubucis. 1993. Pontoniine shrimps (Decapoda: Caridea:Palaemonidae) of the northwest Atlantic. III. *Neopericlimenes thornei*, new genus, new species, from Pine Cay, Turks and Caicos Islands, British West Indies. Journal of Crustacean Biology 13:793–800.

Hopkins, T.L. 1966. The plankton of the St. Andrew Bay System, Florida. Publication Institute of Marine Science Texas 11:12–64.

Ii, N. 1964. Mysidae (Crustacea). Fauna Japonica. Biogeographical Society of Japan. Tokyo, Japan, 610 p.

Jander, R. 1962. The swimming plane of the crustacean *Mysidium gracile* (Dana). Biological Bulletin 122:380–390.

Kensley, B. and R.W. Heard. 1991. Studies on the Crustacea of the Turks and Caicos Islands, British West Indies. I. Four new marine isopod crustaceans from the vicinity of Pine Cay. Gulf Research Reports 8:237–246.

Kröyer, H.N. 1861. Et bidrag til Kundskab om Krebsdyrfamilien Mysidae. Naturhistorisk Tidsskrift, Copenhagen, Ser. 3. 1:1–75.

Lamarck, J. 1814. Sur les polypiers empâtés. Annales du Muséum d'histoire naturelle Paris 20:432–458.

Markham, J.C., F.E. Donath-Hernandez, J.L. Villalobos-Hiriart, and A.C. Diaz-Barriga. 1990. Notes on the shallow-water marine Crustacea of the Caribbean coast of Quintana Roo, Mexico. Anales del Instituto de Biologia Universidad Nacional Autonoma de Mexico, Serie Zoologia 61:405–446.

Modlin, R.F. 1984. Mysidacea from the Florida middle ground, northeast Gulf of Mexico with descriptions of three new species of *Heteromysis* and a key to the Heteromysini of the western Atlantic. Journal of Crustacean Biology 4:278–297.

Modlin, R.F. 1987a. Mysidacea from shallow waters in the vicinity of Carrie Bow Cay, Belize. Central America, with descriptions of two new species. Journal of Crustacean Biology 7:106–121.

Modlin, R.F. 1987b. Heteromysini from Grand Bahama Island: Description of *Heteromysis agelas*, new species, first description of male *H. floridensis*, and notes on *H. guitarti* (Crustacea: Mysidacea). Proceedings of the Biological Society of Washington 100:296–301.

Modlin, R.F. 1987c. *Heteromysis kensleyi* and *H. coralina*, new species from the shallow waters off Looe Key, Florida (Mysidacea: Heteromysini. Proceedings of the Biological Society of Washington 100:653–658.

Murano. M. 1986. Three new species of Mysidacea from Saint Croix, Virgin Islands. Crustaceana 50:133–145.

Murano, M. and J.R. Chess 1987. Four new mysids from Californian coastal waters. Journal of Crustacean Biology 7:182–197.

Nouvel, H. 1943. Mysicacés provenant des Campagne du Prince Albert Ier de Monaco. Résultats des Campagnes Scientifiques accomplies sur son Yacht par Prince Albert Ier de Monaco 105:1–128.

Ortiz, M. and R.R. Lalana. 1993. *Mysidopsis cojimarensis*, una nueva especie de misidáceo marino (Crustacea, Mysidacea) de Cuba. Caribbean Journal of Science 29:50–53.

Ortiz, M., R. Lalana, and A. Sánchez-Díaz. 2000. Una nueva especie de misidáceo marino del género *Amathimysis* Brattegard, 1969 (Mysidacea, Mysidae), de aguas cubanas. Avicennia 12/13:55–62.

Price, W.W. and R.H. Heard. 2000. Studies on the Crustacea of the Turks and Caicos Islands, British West Indies. IV. *Heteromysis* (*Heteromysis*) *spottei*, a new species (Peracarida: Mysidacea: Mysidae) from Pine Cay. Proceedings of the Biological Society of Washington 113:88–94.

Price, W.W., R.W. Heard, J.T. Harris, and C.M.R. McCoy. 2002. Crustacea of the Cayman Islands, British West Indies. I. Records of mysids from shallow water non-reef habitats. Gulf and Caribbean Research 14:35–52.

Price, W.W., A.P. McAllister, R.M. Towsley, and M. DelRe. 1986. Mysidacea from continental shelf waters of the Northwestern Gulf of Mexico. Contributions in Marine Science 29:45–58.

Randall, J.E., R.E. Schroeder, and W.A. Stark, II. 1964. Notes on the biology of the echinoid *Diadema antillarum*. Caribbean Journal of Science 4:421–433.

Sars, G.O. 1885. Report on the Schizopoda collected by H.M.S. "Challenger" during the years 1873–1876. Challenger Reports 13:1–228.

Schotte, M. and R.W. Heard. 1991. Studies on the Crustacea of the Turks and Caicos Islands, British West Indies. II. *Armadilloniscus stepus*, n. sp. (Isopoda: Oniscidea: Scyphacidae) from Pine Cay. Gulf Research Reports 8:247–250.

Schotte, M., R.W. Heard, and B. Kensley. 1991. Studies on the Crustacea of the Turks and Caicos Islands, British West Indies. III. Records of marine Isopoda from Pine Cay, Fort George Cay, Water Cay, and adjacent waters. Gulf Research Reports 8:251–257.

Spotte, S. and P.M. Bubucis. 1996. Diversity and abundance of caridean shrimps associated with the slimy sea plume (*Pseudopterogorgia americana*) at Pine Cay, Turks and Caicos Islands, British West Indies. Marine Ecology Progress Series 133:229–302.

Spotte, S., P.M. Bubucis, and R.M. Overstreet. 1995. Caridean shrimps associated with the slimy sea plume (*Pseudopterogorgia americana*) in midsummer at Guana Island, British Virgin Islands, West Indies. Journal of Crustacean Biology 15:291–300.

Spotte, S., R.W. Heard, and P.M. Bubucis. 1994. Pontoniine shrimps (Decapoda: Caridea: Palaemonidae) of the northwest Atlantic. IV. *Periclimenes antipathophilus* new species, a black coral associate from the Turks and Caicos Islands and Eastern Honduras. Bulletin of Marine Science 55:212–227.

Steven, D.M. 1961. Shoaling behaviour in a mysid. Nature 192:280–281.

Stuck, K.C., H.M. Perry, and R.W. Heard. 1979a. An annotated key to the Mysidacea of the north central Gulf of Mexico. Gulf Research Reports 6:225–238.

Stuck, K.C., H.M. Perry, and R. W. Heard. 1979b. Records and range extensions of Mysidacea from coastal and shelf waters of the eastern Gulf of Mexico. Gulf Research Reports 6:239–248.

Tattersall, W.M. 1937. New species of mysidacid crustaceans. Smithsonian Miscellaneous Collections 91(26):1–18.

Tattersall, W.M. 1951. A review of the Mysidacea of the United States National Museum. Bulletin of the United States National Museum 201:1–292.

Wigley, R.L. and B.R. Burns. 1971. Distribution and biology of mysids (Crustacea, Mysidacea) from the Atlantic Coast of the United States in the NMFS Woods Hole collection. Fishery Bulletin, US 69:717–746.

Wittmann, K.J. 1981. Comparative biology and morphology of marsupial development in *Leptomysis* and other Mediterranean Mysidacea (Crustacea). Journal of Experimental Marine Biology and Ecology 52:243–270.

Verrill, A.E. 1923. Crustacea of Bermuda. Schizopoda, Cumacea, Stomatopoda and Phyllocarida. Transactions of the Connecticut Academy of Arts and Sciences 26:181–211.

Zimmer, C. 1915. Schizopoden des Hamburger Naturhistorischen (Zoologischen) Museums. Mitteilungen aus dem Zoologischen Museum in Hamburg 32:159–182.

Zimmer, C. 1918. Neue und wenig bekannte Mysidaceen des Berliner Zoologischen Museums. Mitteilungen aus dem Zoologischen Museum in Berlin 9:13–26.

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Range Extensions and Review of the Caprellid Amphipods (Crustacea: Amphipoda: Caprellidae) from the Shallow, Coastal Waters from the Suwanee River, Florida, to Port Aransas, Texas, with an Illustrated Key

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RANGE EXTENSIONS AND REVIEW OF THE CAPRELLID AMPHIPODS (CRUSTACEA: AMPHIPODA: CAPRELLIDAE) FROM THE SHALLOW, COASTAL WATERS FROM THE SUWANNEE RIVER, FLORIDA, TO PORT ARANSAS, TEXAS, WITH AN ILLUSTRATED KEY

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ABSTRACT Eight species of the amphipod family Caprellidae *sensu* Myers and Lowry, 2003 are currently known to occur in the shallow, near shore waters of the northern Gulf of Mexico (GOM), from the Suwannee River, Florida, to Port Aransas, Texas, and to depths of 10 m. They include: *Phtisica marina, Hemiaegina minuta, Paracaprella pusilla, Paracaprella tenuis, Deutella incerta, Caprella equilibra, Caprella penantis,* and *Caprella scaura*. Another species, *Caprella andreae*, is also suspected to occur in this region due to its close association with sea turtles, which nest on the sand beaches of the northern GOM. The occurrence of these 9 species in the northern GOM is discussed; known distributions, new records, synonymies, diagnoses, and remarks on life history and ecology are also presented. In addition, new northern GOM records for 7 of these species are provided along with a simplified identification key.

INTRODUCTION

There are published records for 8 species of caprellid amphipods from the shallow, coastal waters of the northern Gulf of Mexico (see Pearse 1908, 1912; Hedgpeth 1950, 1953; Menzel 1956; Steinberg and Dougherty 1957; Pequegnat 1966; McCain 1968; Foster et al. 2004). This report presents additional records and an updated key to the shallow water amphipods of the family Caprellidae *sensu* Myers and Lowry, 2003, currently known from the northern Gulf of Mexico (GOM) limited by the Suwannee River (Florida) in the east, by Port Aransas (Texas) in the west, and by a depth of 10 m.

Steinberg and Dougherty (1957) reviewed the early literature for the caprellid amphipods known from the Gulf of Mexico. In 1968, McCain provided a comprehensive taxonomic study of the northwestern Atlantic caprellids. Laubitz (1993) revised the suborder Caprellidea *sensu* Leach, 1814, to accommodate 3 additional families: the Phtisicidae Vassilenko, 1968, Caprellinoididae Laubitz, 1993, and Pariambidae Laubitz, 1993. The higher taxonomy of the Caprellidea was also reviewed, and 8 families within the suborder were recognized: Paracercopidae Vassilenko, 1972, Phtisicidae; Caprellinoididae; Cyamidae White, 1847, Caprogam-maridae Kudrjaschov and Vassilenko, 1966, Caprellidae Leach, 1814, Pariambidae; and Protellidae McCain, 1970. Myers and Lowry (2003) reviewed the classification of the Corophiidea Leach, 1814, and placed the infraorder Caprellida within the suborder Corophiidea. In addition, they expanded the superfamily Caprelloidea to include Caprellidae, Caprogammaridae, Cyamidae, Dulichiidae Dana, 1849, and Podoceridae Leach, 1814. This study focuses on the family Caprellidae *sensu* Myers and Lowry, 2003. Only the subfamilies Caprellinae and Phtisicinae are represented in the shallow, near shore waters of the northern GOM.

An artificial key to the caprellid amphipods known from the northern GOM is provided along with an annotated listing of the species with a brief synopsis of distribution data, diagnoses, synonymies, new records, and ecological information. Synonymies given are since McCain's 1968 monograph. Table 1 presents a systematic list of the 9 species known or suspected to occur in the shallow, near shore waters of the northern GOM. Figure 1 provides a generalized caprellid body plan for use with the key.

ARTIFICIAL KEY TO THE FAMILY CAPRELLIDAE (CRUSTACEA: AMPHIPODA) KNOWN FROM THE COASTAL WATERS OF THE NORTHERN GULF OF MEXICO

1. Pereopods 3 and 4 well-developed, attenuated, with 6 articles (Figure 2a,e) . . . . . *Phtisca marina*

Pereopods 3 and 4 absent, reduced, or vestigial, when present having no more than 2 articles (Figures 3a,c; 4a,e,h; 5a,d; 6a,g; 7a,d; 8a,d; 9a,d; 10a,d) 2

2. Pereonites hexagonal in dorsal view; pereopods 3 and 4 minute, composed of 1 article (Figure 3a,c) . . . . . *Hemiaegina minuta*

Pereonites not hexagonal in dorsal view; pereopods 3 and 4 absent or minute, consisting of 2 articles (Figures 4a,e,h; 5a,d; 6a,g; 7a,d; 8a,d; 9a,d; 10a,d). 3

3. Antenna 2 with sparse, short, setae ventrally; pereopods 3 and 4 minute, composed of 2 articles (Figures 4a,e,h; 5a,d; 6a,g) 4

Antenna 2 with dense row of long setae ventrally; pereopods 3 and 4 absent (Figures 7a,d; 8a,d; 9a,d; 10a,d)(*Caprella*) 6

4. Pereopod 5 inserted near middle of pereonite 5 (Figure 4a,e,h); dorsal pair of spines present on cephalon (head) and second thoracic somite (Figure 4a,e). . . . . *Deutella incerta*

Pereopod 5 inserted in posterior 1/4 of pereonite 5; cephalon and second thoracic somite without dorsal spines (Figures 5a,d; 6a,g). 5

5. Basis of male gnathopod 2 with proximal knob on posterior margin (Figure 5a), that of female relatively short (Figure 5d); mandibular palp vestigial, represented by single seta (Figure 5e); anterolateral margin of pereonite 2 with large triangular projection in males, similar in females, projection smaller (Figure 5a,d) . . . . . *Paracaprella pusilla*

Basis of male gnathopod 2 lacking proximal knob on posterior margin (Figure 6a), that of female relatively long (Figure 6g); mandibular palp minute, composed of 2 small segments (Figure 6e,f); anterolateral margin of pereonite 2 with small triangular projection in males (Figure 6a), absent in females (Figure 6g). . . . . *Paracaprella tenuis*

6. Cephalon lacking anterodorsally directed spine or process; ventral spine between insertions of gnathopod 2 in both sexes (Figure 7a,d) . . . . . *Caprella equilibra*

Cephalon with anterodorsally directed process or projection, blunt or sharp; no ventral spine between insertions of gnathopod 2 (Figures 8a,d; 9a,d; 10a,d) 7

7. Cephalon with sharp, acutely tipped, anterodorsally directed spine (Figure 8a,d); body of adult male attenuated; male with gnathopod 2 inserted in posterior 1/5 of pereonite 2 (Figure 8a). . . . . *Caprella scaura*

Cephalon with blunt anterodorsally directed process; body of males, like females, compressed, not attenuated (Figures 9a,d; 10a,d).; male with gnathopod 2 inserted in middle of pereonite 2 (Figures 9a; 10a). 8

8. Pereopods 5–7 with palm of propodus convex (Figure 9c) Caprella andreae Pereopods 5–7 with palm of propodus concave (Figure 10e). . . . . *Caprella penantis*

Pereopods 5–7 with palm of propodus concave (Figure 10e) . . . . . *Caprella penantis*

TABLE 1

Taxonomic listing of the amphipods of the family Caprellidae presently known from the shallow coastal waters of the northern Gulf of Mexico.

Order Amphipoda
Suborder Corophiidea
Infraorder Caprellida
Family Caprellidae Leach, 1814
Subfamily Caprellinae Leach, 1814
Genus *Caprella* Lamarck, 1801
Caprella equilibra Say, 1818
Caprella scaura Templeton, 1836
Caprella andreae Mayer, 1890
Caprella penantis Leach, 1814
Genus *Deutella* Mayer, 1890 [=*Luconacia* Mayer, 1903]
Deutella (= *Luconacia*) *incerta* (Mayer, 1903)
Genus *Hemiaegina* Mayer, 1903
Hemiaegina minuta Mayer, 1890
Genus *Paracaprella* Mayer, 1890
Paracaprella pusilla Mayer, 1890
Paracaprella tenuis Mayer, 1903
Subfamily Phtisicinae Vassilenko, 1968
Genus *Phtisica* Slabber, 1769
Phtisica marina Slabber, 1769

Phtisica marina Slabber, 1769

(Figure 2a–g)

Diagnosis. Mandible with 3-segmented palp; carpus of gnathopod 2 shorter than merus, with greatest width proximally; abdomen of male with 2 pairs of biarticulate appendages and 1 pair of pyriform appendages, females with 2 pairs of biarticulate appendages and 1 pair of lobes; pereopods 3 and 4, 6-segmented; pereopod 5, 5-segmented; pereopod 6, 6-segmented.

Synonymies. McCain 1968: 91–97, Figures 46–47; Pequegnat and Pequegnat 1968: 24, 33; Krapp-Schickel 1969: 279, 346–347, 391, 413; McCain and Steinberg 1970: 65; Gosner 1971: 508–510; Griffiths 1973: 304; Griffiths 1974a: 205; Griffiths 1974b: 258; Griffiths 1974c: 333; Griffiths 1975: 177; Vassilenko 1974: 94–96, Figure 47; Arimoto 1980: 96–101, Figure 2; Vadon 1984: 553; Laubitz 1995: 83; Camp et al.1998: 132; Serejo 1998: 381; Ortiz et al. 2002: Figure 40; Guerra-García and Takeuchi 2002: 705.

Known distribution. Northeastern Atlantic; British Isles; Norway; Mediterranean Sea; Black Sea; West Africa; South Africa; Brazil; Gulf of Mexico; Caribbean.

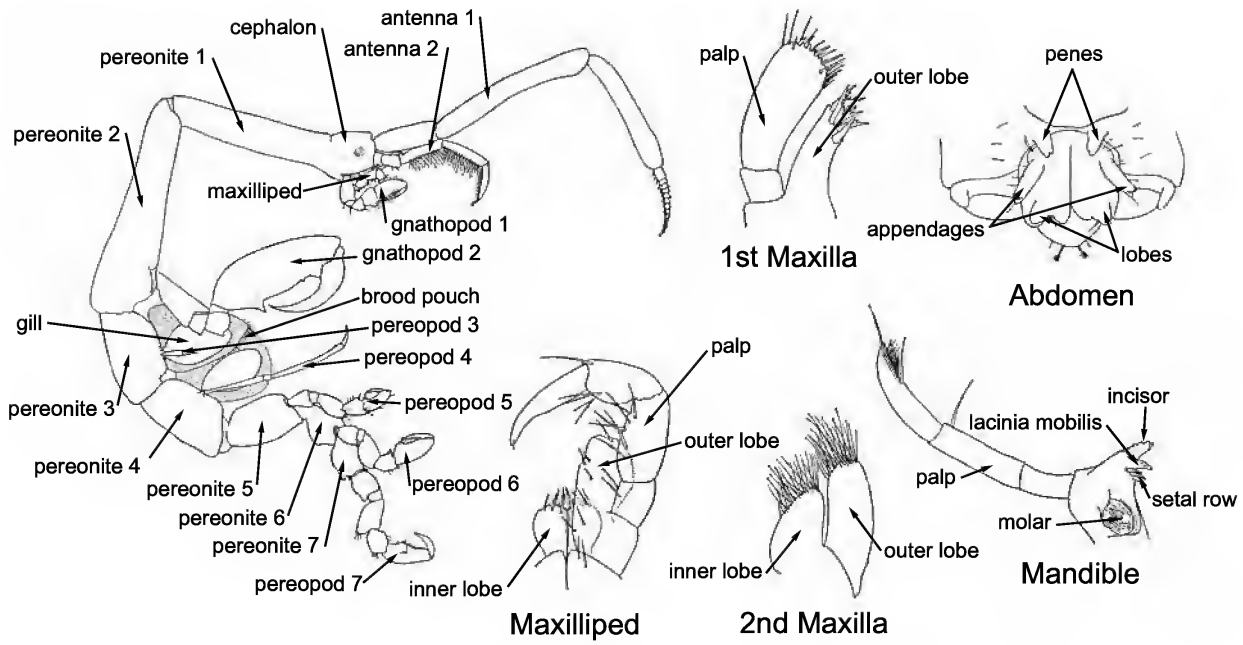

Figure 1. Generalized caprellid body plan. (From McCain 1968: Figure 1).

Known Gulf of Mexico records. McCain (1968) reports this species along the east coast of the GOM from Tortugas northward to Panama City, Florida.

New records. No new GOM records.

Remarks. Habitat consists of various algae, hydroids, seagrasses, sponges, and bryozoans (ectoprocts). Wirtz (1998) also recorded *P. marina* as an associate of the holothurian *Holothuria tubulosa* in the Azores. McCain (1968) reported *P. marina* as a component of the planktonic community in the Western Atlantic Ocean.

Specimens assignable to this species have been collected by Texas A&M University on the continental slope of the GOM at depths of 200–300 m (Foster, pers. obs.).

Hemiaegina minuta Mayer, 1890
(Figure 3a–f)

Diagnosis. Peduncle of antenna 1 not inflated in males, flagellum of antenna 2 biarticulate, swimming setae absent; mandible without palp; outer lobe of maxilliped larger than inner lobe; pereonites with hexagonal shape in dorsal view; propodus of gnathopod 1 with large proximal knob covered with setae; pereopods 3 and 4 1-segmented, pereopod 5 6-segmented; abdomen of male and female with a pair of biarticulate appendages.

Synonymies. McCain 1968: 61–64, Figures 29–30; Utinomi 1969: 297–299, Figure 2; Arimoto 1970: 15; McCain and Steinberg 1970: 51; Gosner 1971: 508–510; Laubitz 1972: 59–60, Figure 15; Griffiths 1973: 303; Griffiths 1974c: 332; Griffiths 1975: 175; Arimoto 1976: 58–60, 62, Figures 26–28; Arimoto and Kikuchi 1977: 95–96, Figure 41; Gable and Lazo-Wasem 1987: 637; Aoki and Asakura 1995: 192; Takeuchi 1995: 196–197, Figures 21; Serejo 1997: 630–632; Camp et al. 1998: 132; Ortiz et al. 2002: Figure 32.

Known distribution. Cosmopolitan (Japan, Indonesia, Australia, Hawaii, South Africa, Caribbean Sea) (McCain 1968).

Known Gulf of Mexico records. Port Aransas, Texas; off Pensacola, Tortugas at Loggerhead Key, Florida (McCain 1968).

New records. 2 adult males, 1 adult female, St. Joseph Bay, Florida, 29 May 2000, less than 1.0 m depth, *Sargassum* wash, coll. J.M. Foster, id. by J.M. Foster, GCRL 2065.

Remarks. Monotypic genus. Remarkable due to the hexagonal outline of the pereonites. McCain (1968) reports this species taken in plankton samples associated with *Sargassum.*

Deutella (= *Luconacia*) *incerta* (Mayer, 1903)
(Figure 4a–j)

Diagnosis. Cephalon and pereonite 2 having dorsal surface with anteriorly projecting spines; anterolateral margin of pereonite 2 with anterolateral spine or projection; mandibular palp 3-segmented; propodus of gnathopod 1 triangular, grasping margins of dactylus and propodus serrate; gnathopod 2 having propodus with proximal grasping spine and well developed tooth at mid-margin

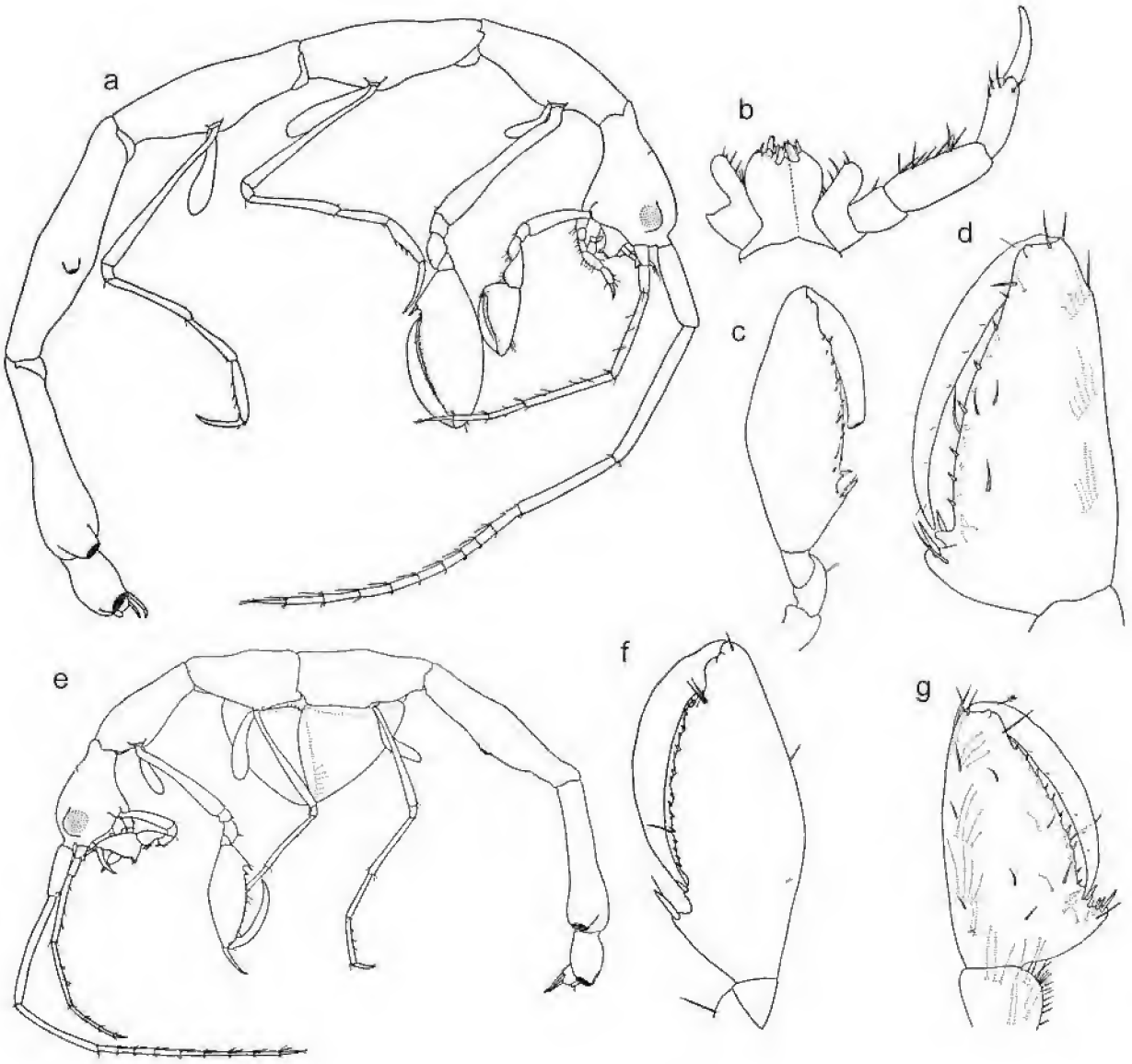

Figure 2. ***Phtisica marina*** **Slabber, 1769, a–d, male, e–g, female; a, lateral view; b, maxilliped; c, gnathopod 2; d, gnathopod 1; e, lateral view; f, gnathopod 2; g, gnathopod 1.(a–d, from McCain 1968: Figure 46; e–g, from McCain 1968: Figure 47).**

creating an excavate posterior margin; pereopod 5 inserted near midlength of pereonite 5, pereopod 5 six-segmented.

Synonymies. McCain 1968: 68–72, Figures 33–35; Pequegnat and Pequegnat 1968: 24, 33–34, 66; McCain and Steinberg 1970: 53; Gosner 1971: 508–510; Laubitz 1972: 61; Caine 1974: 81–96, Figures 4, 7, 10, 13, 16, 19, 23, 24, 28, 29, 33, 34, 36; Lewis and Stoner, 1983: 298, 301; Johnson 1986: 381, Figure 125; Sterrer 1986: 379, 381; Gable and Lazo-Wasem 1987: 635–636, Figure 4; Camp et al.1998: 132; Ortiz et al. 2002: Figure 29; Guerra García 2003a: 1062–1065, Figure 3.

Known distribution. Atlantic coast of United States; Caribbean Sea; GOM.

Known Gulf of Mexico records. Mobile Bay, Alabama; Port Isabel, Texas; Horn Island, Mississippi; and Cedar Key, Florida (McCain 1968).

New records. 1 male, 1 female, St. Andrew Bay, Florida, City Marina, 5 February 2000, wash of *Sargassum* and *Ectocarpus*, coll. J.M. Foster, id. by J.M. Foster, GCRL 2070; 1 male, 1 female, St. Joseph Bay, Florida, 6 January 2001, epifaunal on unidentified sponge, intertidal, coll. J.M. Foster, id. by J.M. Foster, GCRL 2071.

Remarks. Widespread in western Atlantic, occurring on seagrass, hydroids, sponges, alcyonarians, and ascidians.

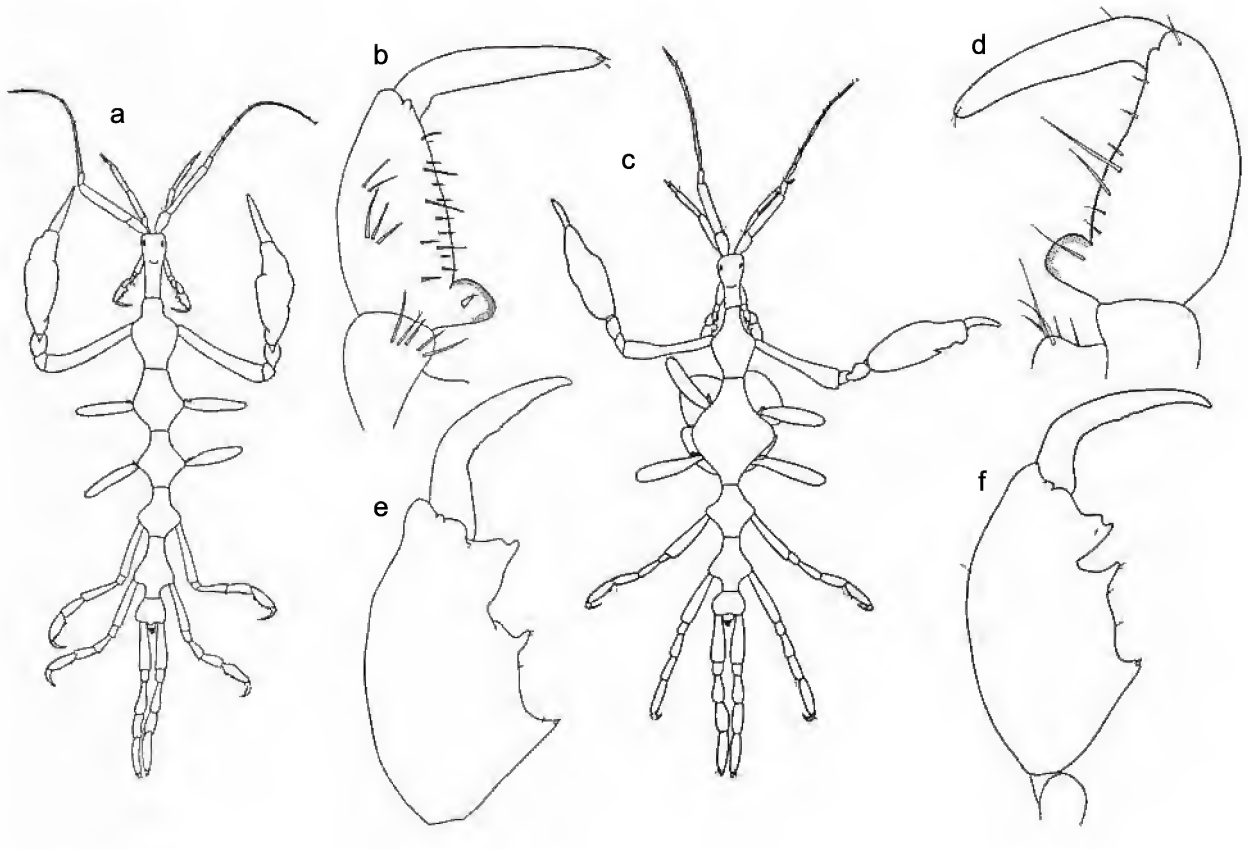

Figure 3. ***Hemiaegina minuta*** **Mayer, 1890, a–b, e, male, c–d, f, female; a, dorsal view; b, gnathopod 1; c, dorsal view; d, gnathopod 1; e, gnathopod 2; f, gnathopod 2. (a–b, e, from McCain 1968: Figure 29; c–d, f, from McCain 1968: Figure 30).**

Paracaprella pusilla Mayer, 1890
(Figure 5a–f)

Diagnosis. Males with large triangular projection on anteroventeral margin of pereonite 2; mandible without palp except for simple seta; basis of gnathopod 2 short and expanded with proximal knob on posterior margin, propodus with shallow rounded notch at midlength; pereopod 5 inserted near posterior part of pereonite 5.

Synonymies. McCain 1968: 82–86, Figures 32a–b, 41–42; Griffiths 1974b: 257; Camp et al. 1998: 132; Serejo 1998: 381; Guerra-García and Thiel 2001: 880, Figure 8; Ortiz et al. 2002: Figure 37; Escobar-Briones and Winfield 2003: 38.

Known distribution. Cosmopolitan. (East and South Africa; Hawaii; Japan; China; South America; Western Atlantic; Caribbean Sea) (McCain 1968).

Known Gulf of Mexico records. Sarasota Bay, St. Andrew Bay, Florida; Grand Isle, Louisiana; Port Isabel, Texas (McCain 1968).

New records. Adult female, Alabama/Mississippi Rapid Assessment Team (AMRAT) Station # M-098, navigational buoy, Horn Island pass, Mississippi Sound, Mississippi, 30 August 2004, collected at 1.0 m depth, scraping, coll. P. Felts and D. Landi, id. by S.E. LeCroy, GCRL 2255; 2 adult females, 3 adult males, 4 juveniles, AMRAT Station # M-099, navigational buoy, Horn Island pass, Mississippi Sound, Mississippi, 30 August 2004, collected at 6.0 m depth, scraping, coll. P. Felts and D. Landi, id. by S.E. LeCroy, GCRL 2256; 2 adult females, 1 adult male, 1 subadult male, AMRAT Station # M-103, navigational buoy #38, Horn Island pass, Mississippi Sound, Mississippi, 30 August 2004, collected at 10.0 m depth, scraping, coll. D. Hataway and K. Berry, id. by S.E. LeCroy, GCRL 2257; 1 adult male, AMRAT Station # M-196, navigational buoy, Dog Keys pass, Mississippi Sound, Mississippi, 31 August 2004, collected at 9.5 m depth, scraping, coll. P. Felts and D. Landi, id. by S.E. LeCroy, GCRL 2258.

Remarks. Found in mangrove habitats, seagrass, on hydroids and ascidians. Martin and Bortone (1997) recovered this species from artificial reefs at the mouth of Choctawhatchee Bay, Florida.

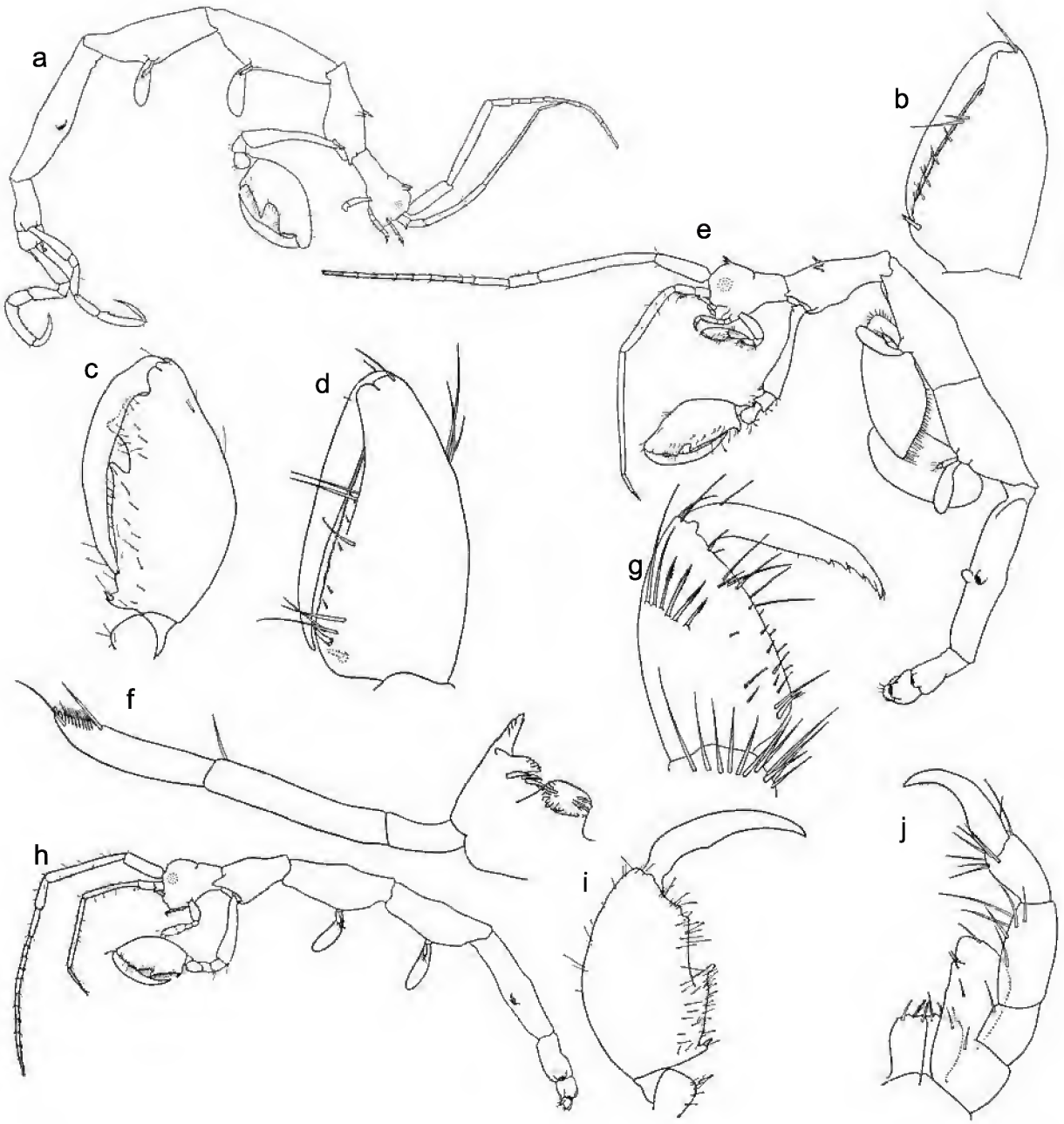

Figure 4. ***Deutella*** **(=*Luconacia*) *incerta* (Mayer, 1903), a–b, adult male, c–f, female, g–j juvenile male; a, lateral view; b, gnathopod 1; c, gnathopod 2; d, gnathopod 1; e, lateral view; f, left mandible; g, gnathopod 1; h, lateral view; i, gnathopod 2; j, maxilliped. (a–b, from McCain 1968: Figure 33; c–f, from McCain 1968: Figure 34; g–j, from McCain 1968: Figure 35).**

Paracaprella tenuis Mayer, 1903

(Figure 6a–h)

Diagnosis. Males with small triangular projection on anterolateral margin of pereonite 2; mandible with minute 0-3 segmented palp, including terminal seta; basis of gnathopod not expanded and without a proximinal knob on posterior margin, palm of propodus with a large angular notch at midlength.

Synonymies. McCain 1968: 86–89, Figures 43–44; Arimoto 1970: 14; Arimoto 1971c: 61–63, Figures 11–12; Gosner 1971: 508–510; Laubitz 1972: 67–68, Figure 18; Wass 1972: 151; Watling and Maurer 1972: 255–256, 258, 259, 263; Caine 1974: 81–96, Figures 2, 3, 6, 9, 12, 15, 18, 21, 22, 26, 27, 31, 35; Stoner, 1980: 542; Arimoto 1976: 55-58, Figure 24–25; Caine 1986: 20; Rupert and Fox 1988: 239, 403; Camp et al. 1998: 132; Guerra-García 2002: 225–227, Figures 9–12; Ortiz et al. 2002: Figure 38.

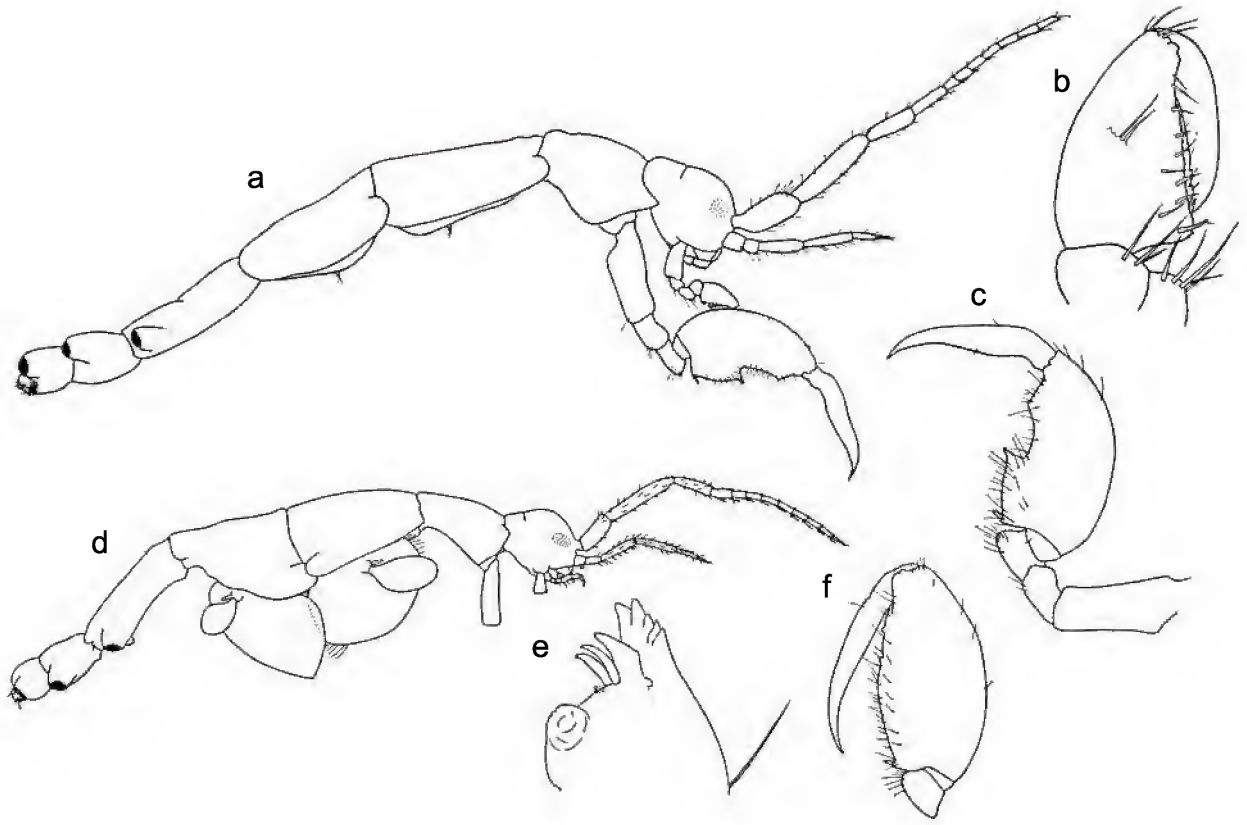

Figure 5. ***Paracaprella pusilla*** **Mayer, 1890, a–c, male d–f, female; a, lateral view; b, gnathopod 1; c, gnathopod 2; d, lateral view; e, right mandible; f, gnathopod 2. (a–c, from McCain 1968: Figure 41; d–f, from McCain 1968: Figure 42).**

Known distribution. Western Atlantic Ocean (Gulf of St. Lawrence; Maine; Massachusetts; Chesapeake Bay; New Jersey; Sapelo Island, Georgia)(McCain 1968); Japan (Takeuchi 1999).

Known Gulf of Mexico records. Alligator Harbor, Tampa Bay, and Pensacola Bay, Florida; Galveston Bay, Port Isabel, and Corpus Christi Bay, Texas (Menzel 1956; Steinberg and Dougherty 1957; McCain 1968).

New records. Adult female, St. Joseph Bay, Florida, 5 May 1990, less than 1.0 m depth, algae wash, coll. S.E. LeCroy, id. by S.E. LeCroy, GCRL 2064; 3 males, 6 females, St. Andrew Bay, Florida, Long Point, 2 January 2003, less than 1.0 m depth, kick net over *Thalassia,* coll. J.M. Foster, id. by J.M. Foster, GCRL 2072.

Remarks. Found with red and brown algae attached to hard substrates, seagrasses, sponges, hydroids, alcyonarians, and bryozoans (ectoprocts). Caine (1998) observed a mutualistic relationship between *P. tenuis* and the hydrozoan *Bougainvillia rugosa. Paracaprella tenuis* was observed defending the hydroid's tentacles from predation by the nudibranch *Tenellia pallida. Paracaprella tenuis* apparently uses the hydroid as a substratum to which it clings and grazes on diatoms. Caine's observations documented for the first time a mutualistic relationship between a caprellid amphipod and a hydrozoan.

Caprella equilibra **Say, 1818**

(Figure 7a–g)

Diagnosis. Cephalon smooth, without dorsal process; mandible without palp; peduncle of antenna 1 not inflated in males; basis of gnathopod 2 less than one-half the length of pereonite 2; pereopod 2 usually with spine between the insertions of gnathopods 2; pereonites elongated in large males; pereopods 3 and 4 absent, pereopods 5–7 without grasping spines.

Synonymies. McCain 1968: 25–30, Figures 12–13; Pequegnat and Pequegnat 1968: 24, 33–34, 53-54, 60–62, 67; Ricketts et al. 1968: 102, 491; McCain 1969: 287–288, Figure 1; Keith 1969: 119–124; Krapp-Schickel 1969: 284, 349; McCain and Steinberg 1970: 19; Laubitz 1970: 55–58, Figure 17; McCain and Gray 1971: 113–114, Figure 3; Arimoto 1971a: 15–16; Arimoto 1971b: 30–35, Figures 1–4; Arimoto 1971d: 1–8, Figures 1–4; Gosner 1971: 508–510; Laubitz 1972: 34; Wass 1972: 151; Watling and Maurer 1972: 255, 256, 263; Griffiths 1973:

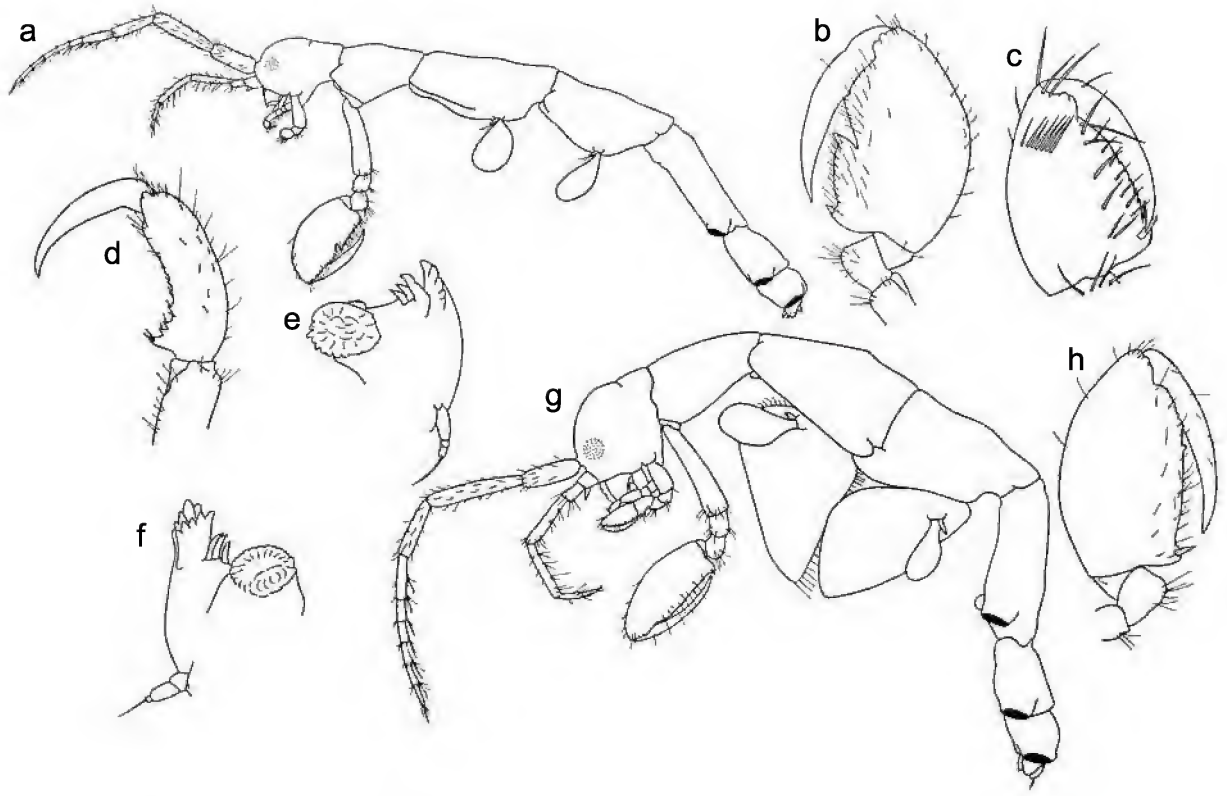

Figure 6. ***Paracaprella tenuis*** **Mayer, 1903, a–f, male, g–h, female; a, lateral view; b, gnathopod 2; c, gnathopod 1; d, pereopod 7; e, right mandible; f, left mandible; g, lateral view; h, gnathopod 2. (a–f, from McCain 1968: Figure 43; g–h, from McCain 1968: Figure 44).**

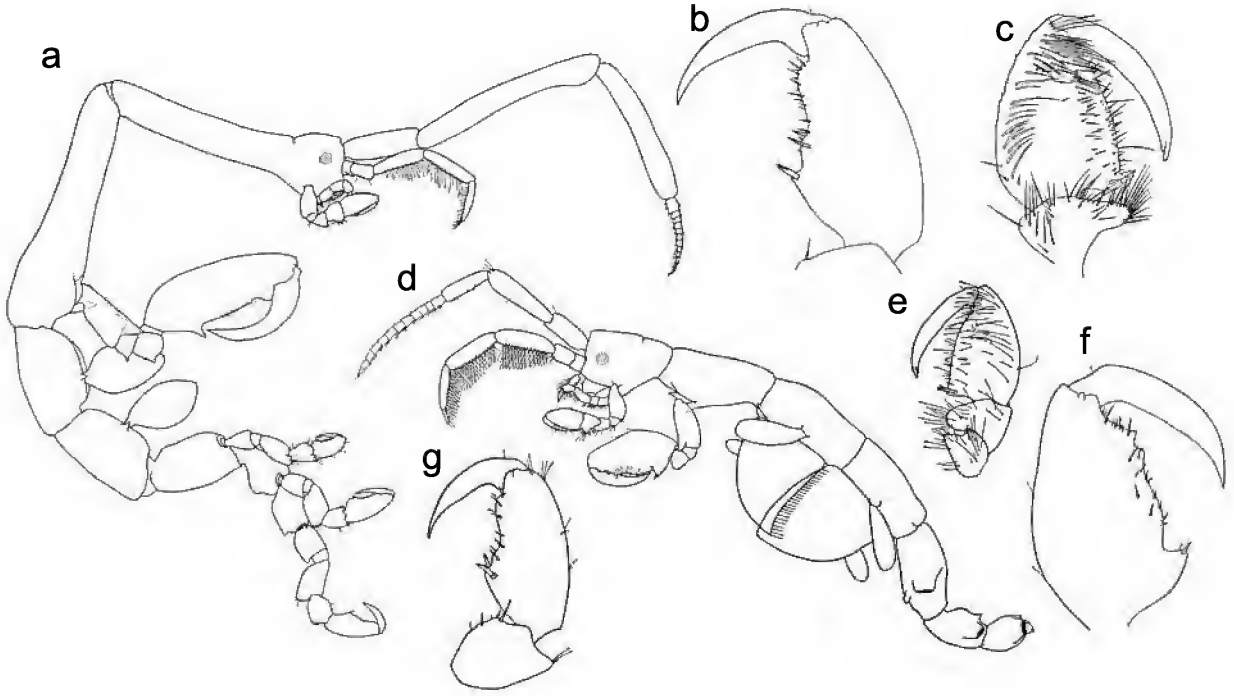

Figure 7. ***Caprella equilibra*** **Say, 1818, a–c, male, d–g, female; a, lateral view; b, pereopod 5; c, gnathopod 1; d, lateral view; e, gnathopod 1; f, gnathopod 2; g, pereopod 6; (a–c, from McCain 1968: Figure 12; d–g, from McCain 1968: Figure 13).**

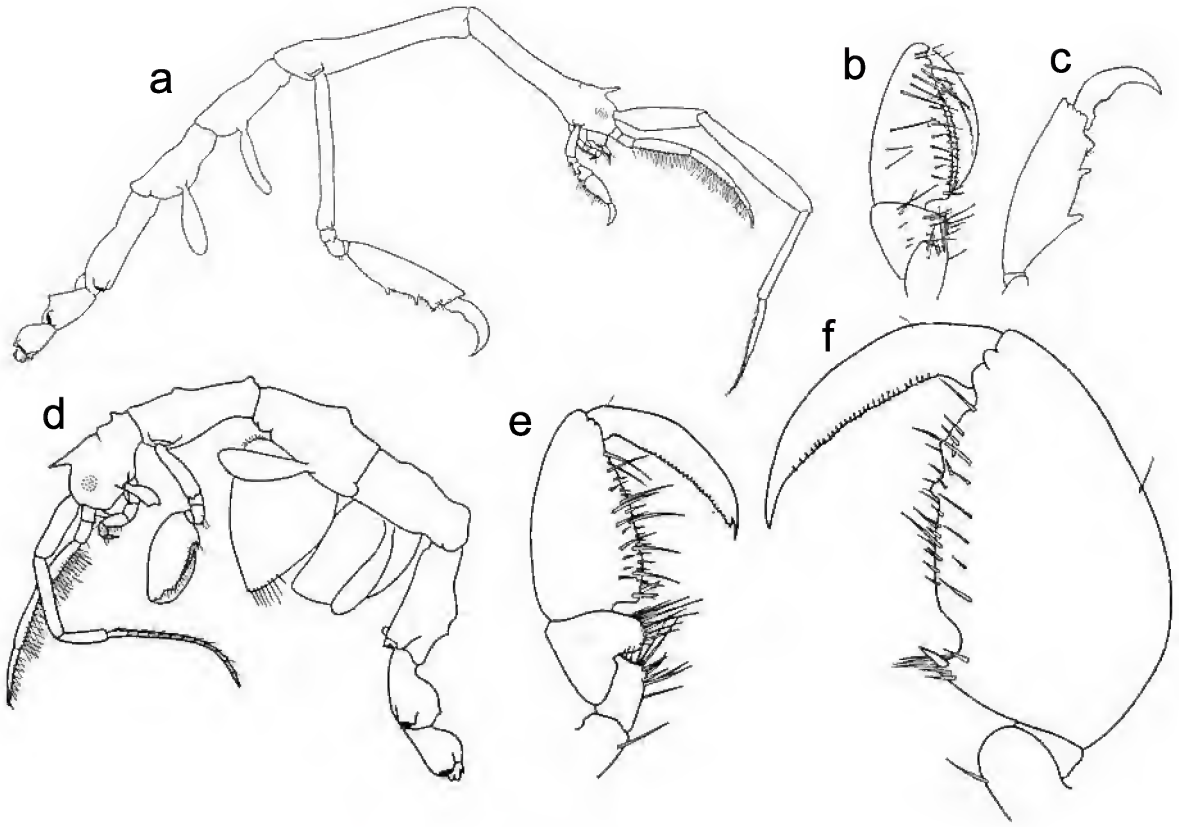

Figure 8. ***Caprella scaura*** **Templeton, 1836, a–c, male, d–f, female; a, lateral view; b, gnathopod 1; c, gnathopod 2; d, lateral view; e, gnathopod 1; f, gnathopod 2. (a–c, from McCain 1968: Figure 17; d–f, from McCain 1968: Figure 18)(Note: In McCain 1968, page 42, Figure 17e represents gnathopod 2, but is incorrectly labeled as gnathopod 1).**

303; Utinomi 1973: 33; Griffiths 1974a: 205; Griffiths 1974b: 255; Griffiths 1974c: 331; Griffiths 1975: 175; Cavedini 1982: 500; Arimoto 1976: 195–205, Figures 106–108; Arimota and Kikuchi 1977: 93, Figure 9D; Caine 1986: 20; Johnson 1986: 381, Figure 125; Sterrer 1986: 379, 381; Cockman and Albone 1987: 163; Lazo-Wasem and Gable 1987: 335–336 (as *Caprella bermudia*); Gable and Lazo-Wasem 1987: 637; Rupert and Fox 1988: 239, 351, 403; Krapp-Schickel 1993: 782–783, Figure 533; Lee and Lee 1993: 358; Aoki and Asakura 1995: 192; Laubitz 1995: 93; Camp et al. 1998: 132; Serejo 1998: 380; Guerra-García and Thiel 2001: 878–879, Figure 6; Ortiz et al. 2002: Figure 21; Escobar-Briones and Winfield 2003: 38; Guerra-García 2003b: 181, Figure 4; Guerra-García and Takeuchi 2004: 1013, Figure 34.

Known distribution. Nearly cosmopolitan.

Known Gulf of Mexico records. Panama City, Florida; Grand Isle, Louisiana; Galveston, Port Isabel, and Port Aransas, Texas (McCain 1968).

New Records. Juvenile female, West Pass jetties, St. Andrew Bay, Florida, 21 June 1984, 1.0 m depth, *Sargassum* wash, coll. J.M. Foster, id. by J.M. Foster, GCRL 2067; 28 males, 13 females, floating fish cage near Chevron Rig 999, 29°27.9'N, 88°36.3'W, off coast of Mississippi, 1 February 2003, fouling on mesh and riggings of floating cage, coll. C. Bridger, id. by S.E. LeCroy, GCRL 2068.

Remarks. *Caprella equilibra* was originally described by Say (1818) from Sullivan's Island near Charleston, South Carolina, in association with salt marshes. Sconfietti and Luparia (1995) collected this species from wooden pilings near Venice, Italy, in the North Adriatic Sea, where they observed peak breeding activity in April and September with a decrease in the summer and no breeding activity shown in the winter.

Guerra-García and Takeuchi (2002) described the new species, *Caprella ceutae* Guerra-García and Takeuchi, 2002, which is morphologically similar to *C. equilibra* from the Mediterranean Sea on the coast of North Africa. *Caprella ceutae* can be distinguished from *C. equilibra* based primarily upon the prominent ventral spine between the bases of the second gnathopods of *C. equilibra*, which is lacking in *C. ceutae*. In addition, the inferior margin of the third peduncular article of the first antenna is densely setose in *C. ceutae* but is naked or nearly so in *C. equilibra*.

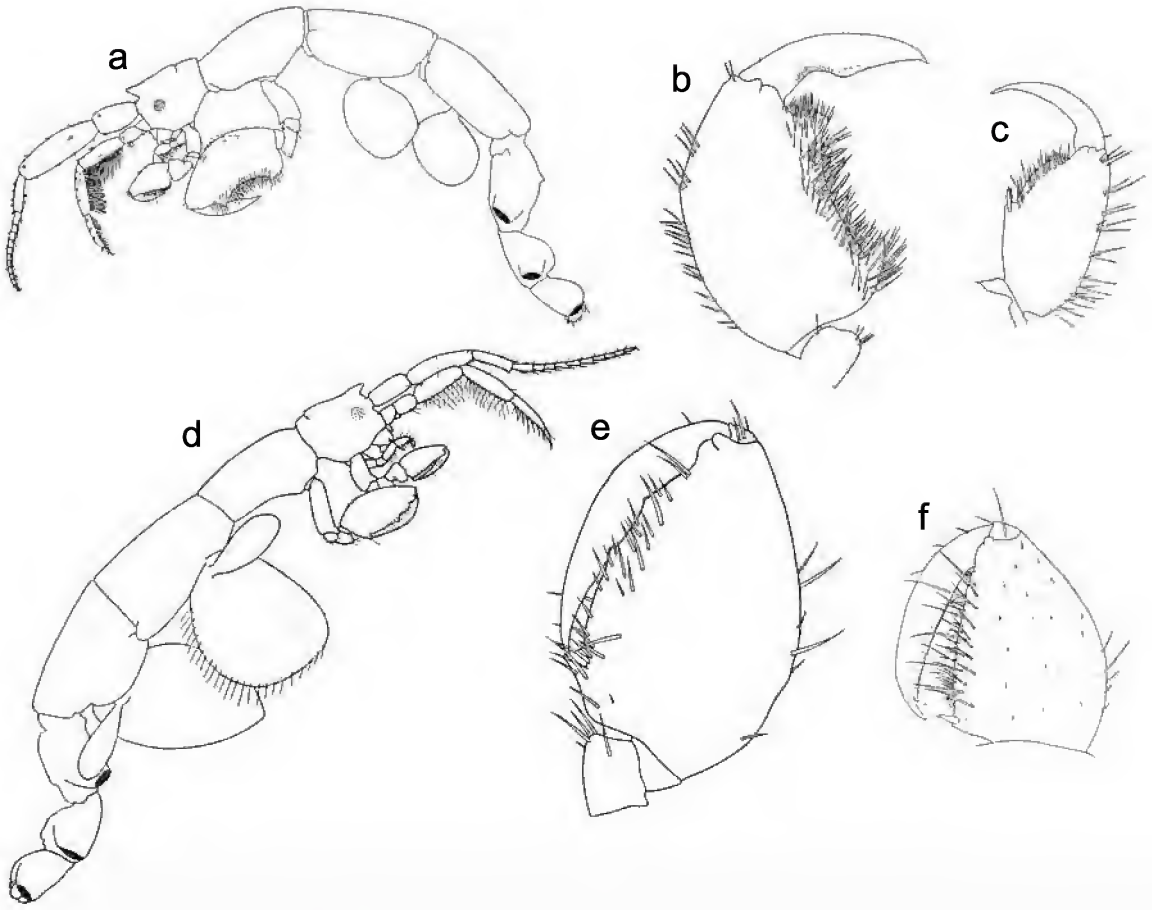

Figure 9. ***Caprella andreae*** **Mayer, 1890, a–c male, d–f, female; a, lateral view; b, gnathopod 2; c, pereopod 6; d, lateral view; e, gnathopod 2; f, gnathopod 1. (a–c, from McCain 1968: Figure 8; d–f, from McCain 1968: Figure 9).**

Caprella scaura Templeton, 1836
(Figure 8a–f)

Diagnosis. Cephalon with anteriorly directed spine, acutely tipped; mandible without palp; peduncle of antenna 1 not inflated in males; pereonites 1–2 elongate in males; basis of gnathopod 2 approximately the length of pereonite 2; propodus of pereopods 5–7 with proximal grasping spines.

Synonymies. McCain 1968: 40–44, Figures 17–18; Utinomi 1969: 304; McCain and Steinberg 1970: 37; Arimoto 1971b: 42–48, Figures 10–14; Arimoto 1971c: 44–45; Griffiths 1973: 303; Utinomi 1973; 35; Griffiths 1974a: 205; Griffiths 1974b: 256; Griffiths 1974c: 332; Griffiths 1975: 175; Arimoto 1976: 146–148, Figure 78; Arimoto and Kikuchi 1977: 94–95, Figure 3G; Arimoto and Hirayama 1979: 50; Arimoto 1980: 109–110, Figure 10; Marelli 1981: 660, Figure 2A; Lim and Alexander 1986: 217–230, Figures 1–6; Cockman and Albone 1987: 163; Lee and Lee 1993: 364; Laubitz 1995: 98; Takeuchi 1995: 198, Figures 180; Aoki 1997: 447, 451–456; Camp et al. 1998: 132; Serejo 1998: 380; Guerra-García and Thiel 2001: 877–878, Figure 5; Ortiz et al. 2002: Figure 24; Guerra-García and Takeuchi 2003: 161–163, Figure 7; Foster et al. 2004: 65–69, Figures 1–2; Guerra-Garcia and Takeuchi 2004: 1016–1017, Figure 36.

Known distribution. Nearly cosmopolitan.

Known Gulf of Mexico records. St. Andrew Bay, Panama City, Florida. (Foster et al. 2004).

New records. Adult female, Panama City Marina, St. Andrew Bay, Florida, 24 December 2003, less than 1.0 m depth, *Padina* wash, coll. J.M. Foster, id. by J.M. Foster, GCRL 2066; gravid female, Long Point, St. Andrew Bay, Florida, 2 January 2003, kick net over *Thalassia* with *Bugula* and oyster shells, coll. J.M. Foster, id. by J.M. Foster, GCRL 2073.

Remarks. This is a large species that is widely distributed in temperate and tropical seas of both hemispheres. The collections published by Foster et al. (2004) represent a range extension from the Caribbean Sea (McCain 1968).

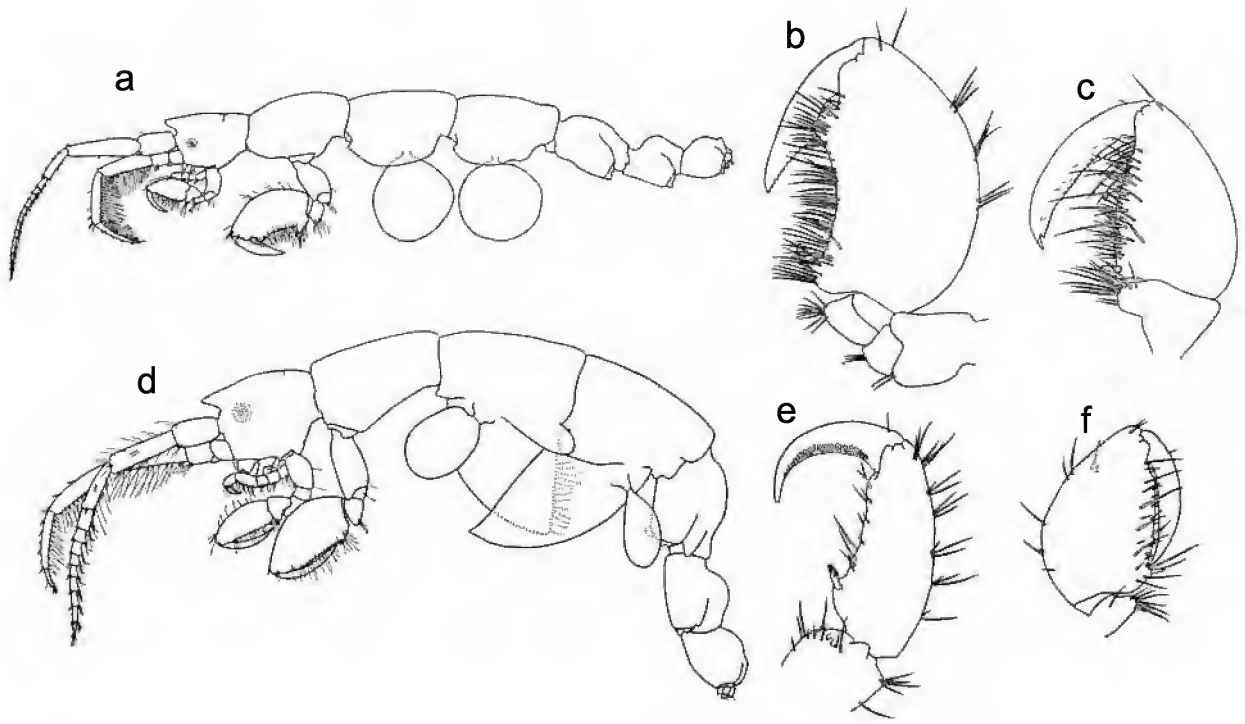

Figure 10. ***Caprella penantis*** **Leach, 1814, a–c, male, d–f, female; a, lateral view; b, gnathopod 2; c, gnathopod 1; d, lateral view; e, pereopod 7; f, gnathopod 2. (a–c, from McCain 1968: Figure 15; d–f, from McCain 1968: Figure 16).**

Caprella andreae **Mayer, 1890**
(Figure 9a–f)

Diagnosis. Cephalon with anteriorly directed triangular projection, blunt, not acutely tipped; peduncle of antenna 1 inflated in males; mandible without palp; pereopods 3 and 4 absent; palm of propodus of pereopods 5–7 convex with medial grasping spines.

Synonymies. McCain 1968: 19–22, Figures 8–9; Gosner 1971: 508–510; Laubitz 1972: 26; Watling and Maurer 1972: 256, 263; Caine 1986: 20; Minchin and Holmes 1993: 285–286; Krapp-Schickel 1993: 777, Figure 530; Aoki and Kikuchi 1995: 54–58, Figures 1–2; Camp et al. 1998: 132; Ortiz et al. 2002: Figure 18.

Known distribution. Northeastern Atlantic; Mediterranean Sea; Hawaii; Sea of Japan; Atlantic coast of United States; Key West, Florida; Cuba (McCain 1968).

Known Gulf of Mexico records. Key West, Florida (McCain 1968)

New records. No new GOM records.

Remarks. McCain (1968) remarks that *C. andreae* appears to be ecologically isolated from other members of the genus by its habit of attaching to floating driftwood, buoys, plants, and the algal incrustations on the backs of sea turtles collected off Cuba and Key West, Florida. Caine (1986) reported *C. andreae* on the carapaces of nesting loggerhead sea turtles on the Florida Atlantic coast. Watling and Maurer (1972) reported *C. andreae* from incrustations on the back of a loggerhead turtle caught on a fish line south of the Mispillion River in Delaware Bay. Other confirmed co-occurrences of this species with sea turtles were reported by Aoki and Kikuchi (1995).

Although the presence of *C. andreae* has not been confirmed in the northern GOM, its occurrence on carapaces of nesting sea turtles throughout the world indicates a likely presence. Collections of epibionts on the carapaces of sea turtles in the northern GOM should be made to clarify the role of sea turtles in the distribution of this cosmopolitan caprellid species.

Caprella penantis **Leach, 1814**
(Figure 10a–f)

Diagnosis. Cephalon with anteriorly directed triangular projection, blunt, not acutely tipped; mandible without palp; peduncle of antenna 1 not inflated in males; basis of gnathopod 2 shorter than pereonite 2; pereopods 3 and 4 absent, pereopods concave, grasping spines proximal.

Synonymies. McCain 1968: 33–40, Figures 15–16; Bieri and Tokioka 1968: 383; Ricketts et al. 1968: 102, 491; Pequegnat and Pequegnat 1968: 24, 33; Utinomi 1968: 287–288; Utinomi 1969: 302; McCain and Steinberg 1970: 33; Arimoto 1971a: 19–20; Arimoto 1971b: 36–41, Figures 5–9; Gosner 1971: 508–510;

Laubitz 1972: 41; Watling and Maurer 1972: 255, 256, 259, 262, 263; Caine 1974: 81–96, Figures 1, 5, 8, 11, 14, 17, 20, 25, 30; Griffiths 1974a: 205; Griffiths 1974b: 256; Griffiths 1974c: 332; Griffiths 1975: 175; Arimoto 1976: 209-220, Figure 113–114; Arimoto and Kikuchi 1977: 93–95, Figure 2E; Arimoto and Hirayama 1979: 51; Cavedini 1982: 508; Wass 1972: 151; Rupert and Fox 1988: 238, 239, Figure 222, 403; Krapp-Schickel 1993: 791–793; Aoki and Asakura 1995: 192; Takeuchi 1995: 202–203, Figure 189; Aoki 1997: 449; Camp et al. 1998: 132; Cházaro-Olvera et al. 2002: 5; Ortiz et al. 2002: Figure 23; Guerra-Garcia and Takeuchi 2002: 692–693, Figure 12; Guerra-Garcia and Takeuchi 2004: 1013, Figure 35.

Known distribution. Nearly cosmopolitan. (Northeast Atlantic, Nova Scotia to Georgia; GOM; Caribbean Sea; California; South Africa; Hawaiian Islands; Sea of Japan; New Zealand; New South Wales, Australia) (McCain 1968).

Known Gulf of Mexico records. Alligator Harbor, Panama City, St. Andrew Bay, and Destin, Florida (McCain 1968).

New records. Ocean Springs, Mississippi (S.E. LeCroy, pers. comm., The University of Southern Mississippi, Gulf Coast Research Laboratory.)

Remarks. Habitat preference is nonspecific, occurring on various algae, seagrasses, sponges, hydroids, tunicates, bryozoans (ectoprocts), and echinoids (*Arbacia*) (McCain 1968). Bynum (1978) examined the reproductive biology of this species in North Carolina and noted that it apparently breeds year round with a peak in the spring and a lesser peak in late summer or early fall. In 1980, Bynum explored the morphological variation within *C. penantis* and noted 2 trends, one apparently related to the degree of wave action and the second trend based upon seasonal variation between summer and winter. Caine (1983) reported *C. penantis* on the sea whip *Leptogorgia virgulata* in *Thalassia testudinum* meadows in northwestern Florida. Valério-Berardo and Flynn (2002) noted that *C. penantis* comprised 23.77% of the total amphipod fauna associated with the red algae *Bryocladia trysigera* at a study site in southeastern Brazil. *Caprella penantis* appears to be the most common caprellid found as epibionts on the carapaces of loggerhead sea turtles *Caretta caretta* on the east coast of the United States (Mike Frick, pers. comm., *Caretta* Research Project, Savannah, Georgia.)

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LITERATURE CITED

Aoki, M. 1997. Comparative study of mother-young association in caprellid amphipods: is material care effective? Journal of Crustacean Biology 17:447–458.

Aoki, M. and A. Asakura. 1995. Caprellids (Crustacea: Amphipoda: Caprellidae) collected from the Ogasawara (Bonin) Islands. Journal of the Natural History Museum and Institute of Chiba 3(2):191–194.

Aoki, M. and T. Kikuchi. 1995. Notes on *Caprella andreae* Mayer, 1890 (Crustacea: Amphipoda) from the carapace of loggerhead sea turtles in the East China Sea and in Kyushu, Japan. Proceedings of the Japanese Society for Systematic Zoology 53:54–61.

Arimoto, I. 1970. List of Caprellid Amphipoda in Japan with record of new localities. Bulletin of the Biogeographical Society of Japan 25(3):13–15.

Arimoto, I. 1971a. List of Caprellidae (Amphipoda) in Japan with record of new localities. Bulletin of the Biogeographical Society of Japan 26(3):13–20.

Arimoto, I. 1971b. The Caprellidae (Crustacea: Amphipoda) of Lake Kamo-ko and Ryotsu Bay, Sado Island. Annual Report of the Sado Marine Biological Station Niigata University 1:29–50.

Arimoto, I. 1971c. Caprellidae of Japan. Bulletin of the Biogeographical Society of Japan 27:59–65.

Arimoto, I. 1971d. Morphological change due to growth found in *Caprella equilibra* Say. Research on Crustacea 4,5:1–8.

Arimoto, I. 1976. Taxonomic studies of caprellids (Crustacea, Amphipoda, Caprellidae) found in the Japanese and adjacent waters. Special Publications from the Seto Marine Biological Laboratory, Series 3, 229 p.

Arimoto, I. 1980. Supplements to the Japanese caprellid fauna. I. Caprellids from the Korean Straits and adjacent waters. Publications of the Seto Marine Biology Laboratory 25:95–113.

Arimoto, I. and A. Hirayama. 1979. A list of Caprellidea (Amphipoda) in Oshika Peninsula, Tohoku District, with description of a new species and some new record to Japan. Bulletin of the Biogeographical Society of Japan 33(5):43–53.

Arimoto, I. and T. Kikuchi. 1977. Caprellids obtained in the vicinity of the Amakusa Island West Kyushu. Publications of the Amak USA Marine Biological Laboratory 4(2):91–98.

Bieri, R. and T. Tokioka. 1968. Dragonet II, an opening-closing quantitative trawl for the study of microvertical distribution of zooplankton and the meio-epibenthos. Publications of the Seto Marine Biology Laboratory 15:373–390.

Bynum, K.H. 1978. Reproductive biology of *Caprella penantis* Leach, 1814 (Amphipoda: Caprellidae) in North Carolina, U.S.A. Estuarine and Coastal Marine Science 7:473–485.

Bynum, K.H. 1980. Multivariate assessment of morphological variation in *Caprella penantis* Leach, 1814 (Amphipoda: Caprellidae). Estuarine and Coastal Marine Science 10:225–237.

Caine, E.A. 1974. Comparative functional morphology of feeding in three species of caprellids (Crustacea, Amphipoda) from the northwestern Florida gulf coast. Journal of Experimental Marine Biology and Ecology 15:81–96.

Caine, E.A. 1983. Community interactions of *Caprella penantis* Leach (Crustacea: Amphipoda) on sea whips. Journal of Crustacean Biology 3:497–504.

Caine, E.A. 1986. Carapace epibionts of nesting loggerhead sea turtles: Atlantic coast of U.S.A. Journal of Experimental Marine Biology and Ecology 95:15–26.

Caine, E.A. 1998. First case of caprellid amphipod-hydrozoan mutualism. Journal of Crustacean Biology 18:317–320.

Camp, D.K., W.G. Lyons, and T.H. Perkins. 1998. Checklists of selected shallow-water marine invertebrates of Florida. Florida Marine Research Institute Technical Report TR-3:1–238.

Cavedini, P. 1982. Contributo alla conoscenza dei Caprellidi del Mediterraneo (Crustacea, Amphipoda). Bollettino del Museo civico di storia naturale di Verona 8:491–531.

Cházaro-Olvera, S., I. Winfield, M. Ortiz, and F. Álvarez. 2002. Peracarid crustaceans from three inlets in the southwestern Gulf of Mexico: new records and range extensions. Zootaxa 123:1–16.

Cockman, B. and P. Albone. 1987. Caprellidae of the Swan River Estuary. Curtin University Environmental Studies Group Report No. 1:163–177.

Escobar-Briones, E. and I. Winfield. 2003. Checklist of the benthic Gammaridea and Caprellidea (Crustacea: Peracarida: Amphipoda) from the Gulf of Mexico continental shelf and slope. Belgian Journal of Zoology 133:37–44.

Foster, J.M., R.W. Heard, and D.M. Knott. 2004. Northern range extensions for *Caprella scaura* Templeton, 1836 (Crustacea: Amphipoda: Caprellidae) on the Florida Gulf coast and in South Carolina. Gulf and Caribbean Research 16:65–69.

Gable, M.F. and E.A. Lazo-Wasem. 1987. The Caprellids (Amphipoda: Caprellidae) of Bermuda: A survey of specimens collected from 1876–1987, including cave inhabitants, and the description of *Deutella aspiducha*, new species. Proceedings of the Biological Society of Washington 100:629–639.

Gosner, K.L. 1971. Guide to the Identification of Marine and Estuarine Invertebrates: Cape Hatteras to the Bay of Fundy. Wiley-Interscience, New York, NY, USA, 693 p.

Griffiths, C.L. 1973. The Amphipoda of Southern Africa. Part 1. The Gammaridea and Caprellidea of southern Moçambique. Annals of the South African Museum 60:265–306.

Griffiths, C.L. 1974a. The Amphipoda of southern Africa, Part 2. The Gammaridea and Caprellidea of South West Africa south of 20ºS. Annals of the South African Museum 62:169–208.

Griffiths, C.L. 1974b. The Amphipoda of southern Africa, Part 3. The Gammaridea and Caprellidea of Natal. Annals of the South African Museum 62:209–264.

Griffiths, C.L. 1974c. The Amphipoda of southern Africa, Part 4. The Gammaridea and Caprellidea of the Cape Province east of Cape Agulhas. Annals of the South African Museum 65:251–336.

Griffiths, C.L. 1975. The Amphipoda of southern Africa, Part 5. The Gammaridea and Caprellidea of the Cape province west of Cape Agulhas. Annals of the South African Museum 67(5):91–181.

Guerra-García, J.M. 2002. Redescription of five rare caprellids (Crustacea: Amphipoda: Caprellidea) collected from Tanzanian coasts. Helgoland Marine Research 55:221–231.

Guerra-García, J.M. 2003a. Revision of the genus *Deutella* (Crustacea: Amphipoda: Caprellidea) with description of a new species, redescription of *Deutella venenosa* Mayer, 1890 and a key to the species of *Deutella*. Journal of Natural History 37:1059–1084.

Guerra-García, J.M. 2003b. The caprellidean Amphipoda from the subantarctic islands of New Zealand and Australia with the description of a new genus and two new species. Scientia Marina. 67:177–194.

Guerra-García, J.M. and I. Takeuchi. 2002. The Caprellidea (Crustacea: Amphipoda) from Ceuta, North Africa, with the description of three species of *Caprella*, a key to the species of *Caprella*, and biogeographical discussion. Journal of Natural History 36:675–713.

Guerra-García, J.M. and I. Takeuchi. 2003. The Caprellidea (Malacostraca: Amphipoda) from Mirs Bay, Hong Kong, with the description of a new genus and two new species. Journal of Crustacean Biology 23:154–168.

Guerra-García, J.M. and I. Takeuchi. 2004. The Caprellidea (Crustacea: Amphipoda) from Tasmania. Journal of Natural History 38:967–1044.

Guerra-García, J.M. and M. Thiel. 2001. La fauna de caprelidos (Crustacea: Amphipoda: Caprellidea) de la costa de Coquimbo, centro-norte de Chile, con una clave taxonomica para la identificacion de las especies. The caprellid fauna (Crustacea: Amphipoda: Caprellidea) from the coast of Coquimbo, Northern-central Chile, with a taxonomic key for species identification. Revista Chilena de Historia Natural 74:873–883.

Hedgpeth, J.W., H.L. Whitten, and H.F. Rosene. 1950. Annotated list of certain marine invertebrates found on Texas jeties. Appendix V. The invertebrate fauna of Texas coast jetties: A preliminary survey. Publications of the Institute of Marine Science of the University of Texas 1(2):53–87.

Hedgpeth, J.W. 1953. An introduction to the zoogeography of the northwestern Gulf of Mexico with reference to the invertebrate fauna. Publications of the Institute of Marine Science of the University of Texas 3:107–224.

Johnson, S.E. 1986. Order Amphipoda. In: W. Sterrer, ed., Marine Fauna and Flora of Bermuda. John Wiley & Sons, New York, NY USA, p. 372–381.

Keith, D.E. 1969. Aspects of feeding in *Caprella californica* Stimpson and *Caprella equilibra* Say (Amphipoda). Crustaceana 16:119–124.

Krapp-Schickel, G. 1969. Zur Ökologie der Amphipoden aus dem Phytal der Nordadria. Zoologische Jahrbuecher Systematik 96:264–448.

Krapp-Schickel, G. 1993. Suborder Caprellidea. In: S. Ruffo, ed. The Amphipoda of the Mediterranean. Part 3. Gammaridea (Melphidippidae to Talitridae), Ingolfiellidea, Caprellidea. Mémoires de l'Institut océanographique, Monaco 13:773–813.

Laubitz, D.R. 1970. Studies on the Caprellidae (Crustacea, Amphipoda) of the American North Pacific. National Museum of Natural Sciences (Ottawa), Publications in Biological Oceanography 1:1–89.

Laubitz, D.R. 1972. The Caprellidae (Crustacea, Amphipoda) of Atlantic and Artic Canada. National Museum of Natural Sciences (Ottawa), Publications in Biological Oceanography 4:1–82.

Laubitz, D.R. 1993. Caprellidea (Crustacea: Amphipoda): towards a new synthesis. Journal of Natural History 27(4):965–976.

Laubitz, D.R. 1995. Caprellidea (Crustacea: Amphipoda) from the southern and western Indian Ocean. Mesogee 54:81–100.

Lazo-Wasem, E.A. and M.F. Gable. 1987. A review of recently discovered type specimens of Bermuda Amphipoda (Crustacea: Peracarida) described by B.W. Kunkel (1882–1969). Proceedings of the Biological Society of Washington 100:321–336.

Lee, K.S. and C.M. Lee. 1993. Caprellids (Amphipoda, Caprellidae) from the East Sea in Korea. Korean Journal of Zoology 36:353–366.

Lewis, F.G. III and A.W. Stoner. 1983. Distribution of macrofauna within seagrass beds: An explanation for patterns of abundance. Bulletin of Marine Science 33:296–304.

Lim, S.T.A. and C.G. Alexander. 1986. Reproductive behaviour of the caprellid amphipod, *Caprella scaura typica,* Mayer 1980. Marine Behavior and Physiology 12:217–230.

Marelli, D.C. 1981. New records for Caprellidae in California, and notes on a morphological variant of *Caprella verrucosa* Boeck, 1871. Proceedings of the Biological Society of Washington 94:654–662.

Martin, T.R. and S.A. Bortone. 1997. Development of an epifaunal assemblage on an estuarine artificial reef. Gulf of Mexico Science 1997(2):55–70.

McCain, J.C. 1968. The Caprellidae (Crustacea: Amphipoda) of the Western North Atlantic. Bulletin of the United States National Museum No. 278:1–147.

McCain, J.C. 1969. New Zealand Caprellidae (Crustacea: Amphipoda). New Zealand Journal of Marine and Freshwater Research 3:286–295.

McCain, J.C. and W.S. Gray Jr. 1971. Antarctic and subantarctic Caprellidae (Crustacea: Amphipoda). Biology of the Antarctic Sea 4:111–139.

McCain, J.C. and J.E. Steinberg. 1970. Caprellidae I. Family Caprellidae. In: H.-E. Gruner and L.B. Holthius, eds. Crustaceorum Catalogus. Amphipoda I, part 2. Dr. W. Junk Publishers, The Hague, The Netherlands, p. 1–78.

Menzel, R.W. 1956. Annotated check-list of the marine fauna and flora of the St. George's Sound—Apalachee Bay region, Florida Gulf coast. Florida State University Oceanographic Contribution No. 61:1–78.

Minchin, D. and J.M.C. Holmes. 1993. A skeleton shrimp *Caprella andreae* Mayer (Crustacea: Amphipoda) new to Ireland, and other strandings in September 1991. Irish Naturalist's Journal 24:285–286.

Myers, A.A. and J.K. Lowry. 2003. A phylogeny and a new classification of the Corophiidea Leach, 1814 (Amphipoda). Journal of Crustacean Biology 23:443–485.

Ortiz, M., F. Álvarez, and I. Winfield. 2002. Caprellid amphipods (Amphipoda: Caprellidea): Illustrated key for the genera and species from the Gulf of Mexico and Caribbean Sea. Universidad Nacional Autónoma de México, Facultad de Estudios Superiores Iztacala, Mexico. 83 p.

Pearse, A.S. 1908. Descriptions of four new species of amphipodous Crustacea from the Gulf of Mexico. Proceedings of the US National Museum 34:27–32.

Pearse, A.S. 1912. Notes on certain amphipods from the Gulf of Mexico, with descriptions of new genera and new species. Proceedings of the US National Museum 43:369–379.

Pequegnat, W.E. 1966. Biofouling studies off Panama City, Florida. I. Research Report, Office of Naval Research, Texas A&M University, Department of Oceanography, Reference 66-17T, 33 p.

Pequegnat, W.E. and L.H. Pequegnat. 1968. Ecological aspects of marine fouling in the northeastern Gulf of Mexico. Texas A&M University, Department of Oceanography, Reference 68-22T, College Station, TX, USA, 80 p.

Ricketts, E.F., J. Calvin, and J.W. Hedgpeth. 1968. Between Pacific tides. 4th ed. Stanford University Press. Stanford, CA, USA, 614 p.

Rupert, E.E. and R.S. Fox. 1988. Seashore Animals of the Southeast: A Guide to Common Shallow-Water Invertebrates of the Southeastern Atlantic Coast. University of South Carolina Press, Columbia, SC, USA, 429 p.

Say, T. 1818. An account of the Crustacea of the United States. Journal of the Academy of Natural Sciences of Philadelphia 1:374–401.

Sconfietti, R. and P. Luparia. 1995. Population ecology of the amphipod *Caprella equilibra* Say in a lagoon estuary (northern Adriatic Sea, Italy). Marine Ecology 16:1–11.

Serejo, C.S. 1997. *Hemiaegina costai* Quitete, 1972 a synonym of *Hemiaegina minuta* Mayer, 1890 (Amphipoda, Caprellidae). Crustaceana 70:630–632.

Serejo, C.S. 1998. Gammaridean and caprellidean fauna (Crustacea) associated with the sponge *Dysidea fragilis* Johnston at Arraial do Cabo, Rio de Janeiro, Brazil. Bulletin of Marine Science 63:363–385.

Steinberg, J.E. and E.C. Dougherty. 1957. The skeleton shrimps (Crustacea: Caprellidae) of the Gulf of Mexico. Tulane Studies in Zoology 5:267–288.

Sterrer, W. and C. Schoepfer-Sterrer, eds. 1986. Marine Fauna and Flora of Bermuda: A Systematic Guide to the Identification of Marine Organisms. John Wiley and Sons, New York, NY, USA, 742 p.

Stoner, A.W. 1980. The role of seagrass biomass in the organization of benthic macrofaunal assemblages. Bulletin of Marine Science 30:537–551.

Takeuchi, I. 1995. Suborder Caprellidea. In: S. Nishimura ed. Guide to seashore animals of Japan with color pictures and keys. Vol. 2. Hoikusha, Osaka, Japan. p. 193–205 (in Japanese).

Takeuchi, I. 1999. Checklist and bibliography of the Caprellidea (Crustacea: Amphipoda) from Japanese waters. Otsuchi Marine Science 24:5–17.

Utinomi, H. 1968. Epibenthic or planktonic caprellids from the environs of Tanabe Bay (Amphipoda: Caprellidae). Publication of the Seto Marine Biological Laboratory 16:281–289.

Utinomi, H. 1969. Caprellids from Kamaé Bay, northeastern Kyusyu (Amphipoda; Caprellidae). Publications of the Seto Marine Biological Laboratory 16:295–306.

Utinomi, H. 1973. Additional records of the Caprellidae (Amphipoda) from Japan. Bulletin of the Biogeographical Society of Japan 29:29–38.

Vadon, C. 1984. La faune carcinologique associée à l'actinie *Anemonia sulcata* (Pennant) sur les côtes françaises de Méditerranée. Océanis 10:551–555.

Valério-Berardo, M.T. and M.N. Flynn. 2002. Composition and seasonality of an amphipod community associated to the algae *Bryocladia trysigera*. Brazilian Journal of Biology 62:735–742.

Vassilenko, S.V. 1974. Caprellids (marine shrimps) of the seas of the USSR and neighboring waters. Order Amphipoda (Families Paraceropidae, Phtisicidae, Caprellidae). Opredeliteli po Faune SSSR 107:1–288 [in Russian].

Wass, M.L. 1972. A check list of the biota of lower Chesapeake Bay: With inclusions from the upper bay and the Virginian Sea. Virginia Institute of Marine Science, Special Scientific Report No. 65:1–290.

Watling, L. and D. Maurer. 1972. Marine shallow water amphipods of the Delaware Bay area, U.S.A. Crustaceana, Studies on Peracarida (Isopoda, Tanaidacea, Amphipoda, Mysidacae, Cumacea). Supplement 3:251–266.

Wirtz, P. 1998. Caprellid (Crustacea)—holothurian (Echinodermata) associations in the Azores. Arquipélago Boletim da Universidade dos Acores Ciencias Biologicas e Marinhas 16:53–55 [In English with Portuguese summary].

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A Characterization of the Shallow-Water Coral Reefs and Associated Habitats of Puerto Rico

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A CHARACTERIZATION OF THE SHALLOW-WATER CORAL REEFS AND ASSOCIATED HABITATS OF PUERTO RICO

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ABSTRACT We mapped bottom types and shelf zones of 1600 km^2 or about one fourth of Puerto Rico's insular shelf from the shoreline to the shelf edge. Overall map accuracy for these bottom types is estimated as 93.6% correct. Maps were produced through visual interpretation of benthic features using orthorectified aerial photographs within a Geographic Information System with customizable software. The maps are one component of an integrated mapping and monitoring program underway by NOAA and its partners in the US Coral Reef Task Force to assess all US reef ecosystems. Maps are currently being used to enhance coastal research and management activities in Puerto Rico such as fisheries assessments and designation of important fish habitats.

INTRODUCTION

Coral reef ecosystems present spatial challenges for research and management. The broad scales of ecosystem processes and complex connections among diverse components including seagrass beds, mangroves, algal plains, coral reefs, and other hard bottom substrates are often best understood and managed using ecosystem maps as a spatial framework. The ability to properly stratify sampling programs for research, make informed decisions on defining fish habitats, and place ecologically relevant boundaries for marine protected areas is necessarily limited without accurate benthic maps created using an appropriate classification framework. The National Action Plan for US Coral Reef Protection endorsed by the US Coral Reef Task Force (USCRTF) identified mapping of all US coral reefs as one of the highest priorities for understanding and protecting these important ecosystems (USCRTF 2000, Monaco et al. 2001).

To meet this goal in the US Caribbean (Puerto Rico and the US Virgin Islands), visual interpretation of aerial photography was identified as the most effective approach given the size of the region to be mapped, the well documented and successful applications of photo-interpretation, the desired thematic and spatial resolution of map products, and the desired accuracy of map attributes. The alternatives and tradeoffs among various mapping technologies have been discussed elsewhere in detail (e.g., Holden and LeDrew 1998, Green et al. 2000) and are beyond the scope of this assessment. Furthermore, the specific methods used to create the map products are documented in detail in Kendall et al. (2001), Kendall et al. (in press), and Warner et al. (in review), and so will only be provided in general form here. Rather, the present focus is on the results of a photography-based characterization of reef ecosystems in Puerto Rico.

Previous assessments of marine ecosystems in Puerto Rico have been patchy, focused on single ecosystem characteristics or components (e.g., geology, coral reefs, or mangrove forests respectively), have too coarse a resolution to support most research and management applications, or are simply out of date given the frequency of hurricanes, pace of coastal development, and other vectors of habitat change in the region (e.g., Rodriguez et al. 1977, Morelock 1978, Goenaga and Cintron 1979, Beach and Trumbull 1981, Grove 1983, Pilkey et al. 1987, Trias 1991, Rodriguez et al. 1992, Morelock et al. 1994, Kruer 1995, Reid and Kruer 1998). These historical assessments provide valuable perspective on a subset of ecosystem components, but do not provide the island-wide characterization of the reef ecosystem called for by the USCRTF.

Building on the recently created benthic maps for the Florida Keys (Florida Marine Research Institute 1998) and the US Virgin Islands (Kendall et al. 2001, Kendall et al. in press), the objective of this project was to produce a spatial characterization of the shallow water coral reefs and associated habitats in Puerto Rico, specifically to: 1) map seabed features visible in aerial photography using a hierarchical classification scheme and a minimum mapping unit (MMU; smallest feature mapped) of 4048 m^2 (1 acre); 2) map seabed features with a minimum thematic accuracy of 90% correct for map categories including coral reefs/hard bottom, unconsolidated sediment, and submerged vegetation; 3) identify areas not able to be mapped

with this approach to focus future assessments using alternative technologies; 4) quantify the coverage and distribution of mapped features; 5) provide digital habitat maps, images, and other data products to support research and management of coral reef ecosystems.

MATERIALS AND METHODS

Location Description

Puerto Rico is located at the intersection of the greater and lesser Antilles on the northern edge of the Caribbean Plate. It shares a volcanic island platform at the edge of the Puerto Rican Trench with several of the US and British Virgin Islands, but has a much larger land area and consequently has a more significant river drainage than the smaller Virgin Islands. The north coast is characterized by a narrow shelf and large amounts of river discharge. The south, southwest, and east coasts of the island have less river output and much broader shelf area. The large area and variable geomorphology of these coastal regions, plus the unique formations of the smaller Puerto Rican islands of Culebra, Vieques, Desecheo, and Mona make comprehensive mapping of benthic resources challenging.

Mapping Methods

Color aerial photographs were acquired in 1999 by NOAA's Aircraft Operation Center and National Geodetic Survey. These 1:48,000 scale photos (except for Desecheo at 1:20,000 and Mona at 1:28,000) were scanned at a resolution of 500 dots per inch resulting in digital images with 2.4 m pixels (Desecheo 1.0 m and Mona 1.5 m). The best images for benthic mapping (least clouds, sun glint, and turbidity) were selected and orthorectified by the NOAA National Geophysical Data Center using ground control points, flightline kinematics, and other image parameters uploaded into Socet Set version 4.2.1 (Warner et al. in review). The coastal regions described above and the individual small islands were batch processed such that 7 separate, orthorectified mosaics were created (Table 1). The positional accuracy of each mosaic was measured using independent ground control points collected with differential GPS. Additional detail on the acquisition parameters and orthorectification process are available in Kendall et al. (2001) and Warner et al. (in review).

Coral reefs and associated benthic habitats such as hard bottom, mangroves, seagrass beds, sand, and algal plains were mapped using GIS software and a hierarchical classification system developed in consultation with local experts and the many schemes classifying Caribbean benthos (e.g., Shepard et al. 1998, Mumby and Harborne 1999). The 3 main habitat categories in the scheme were: coral reef and hard bottom, unconsolidated sediment, and submerged vegetation which encompassed a total of 26 mutually exclusive subcategories. In addition to these bottom types, mapped features were also assigned a location attribute, or zone, to denote their position on the insular shelf. The following zones were identified: shoreline/intertidal, lagoon, backreef, forereef, reef crest, bank/shelf, bank/shelf escarpment, or dredged ("dredged" is included here since this activity eliminates natural zonation). Detailed descriptions as well as under water and aerial imagery for each bottom type and zone are available in Kendall et al. (2001).

Benthic features defined in the classification scheme were visually identified in the orthorectified mosaics and digitized by tracing around their edges using the Habitat Digitizer extension for ArcView 3.2 (Kendall et al. 2001). This software allows users to customize a classification scheme, set a MMU and mapping scale, and facilitates assignment of polygon attributes. Polygons were delineated at a mapping scale of 1:6000 on the computer monitor, which maximized the ability to identify bottom types given the scale and scan resolution of the original imagery. A MMU of 4048 m^2 (1 acre) was selected to meet the spatial

TABLE 1

Mosaic specifications for each island or coastal segment. Positional accuracy is in meters +/- standard deviation.

Location	Photo scale	Pixel width (m)	No. of photos	Mean spatial accuracy (m) latitude	Mean spatial accuracy (m) longitude
Culebra	1:48000	2.4	14	5.51 +/- 20.1	7.04 +/- 18.2
Mona	1:28000	1.5	14	2.76 +/- 9.1	4.06 +/- 4.5
Desecheo	1:20000	1.0	3	4.26 +/- 30.0	9.47 +/- 36.4
Puerto Rico: South	1:48000	2.4	72	0.06 +/- 3.0	0.89 +/- 4.4
Puerto Rico: East	1:48000	2.4	55	0.85 +/- 9.5	2.59 +/- 7.8
Puerto Rico: West	1:48000	2.4	34	1.65 +/- 5.1	1.04 +/- 6.7
Puerto Rico: North	1:48000	2.4	51	4.88 +/- 9.6	4.06 +/- 5.3

resolution requested by the USCRTF and by local natural resource managers. Field surveys conducted with local experts and previous studies of Puerto Rico's benthic habitats were used to guide polygon delineation and labeling whenever possible. Previous studies consulted included geological maps (Beach and Trumbull 1981, Grove 1983, Morelock 1978, Morelock et al. 1994, Pilkey et al. 1987, Rodriguez et al. 1977, Rodriguez et al. 1992, Trias 1991), biological characterizations (Goenaga and Cintron 1979, Kruer 1995, Reid and Kruer 1998), and those that integrate multiple data types (NOAA et al. 2000). Specific field sites that were examined included those with difficult to interpret spectral and textural signatures in the orthorectified mosaics and sites with signatures that were representative of different combinations of bottom type, depth, zone, and water clarity. Draft maps were reviewed by local researchers and managers and further refined.

Thematic accuracy of the final benthic maps was measured through intensive field sampling within a small but representative region of the project area due to the logistical constraints of collecting a widespread accuracy assessment dataset around all of the islands mapped. For this purpose, the La Parguera area in southwestern Puerto Rico was chosen because of the wide variety of water depth, turbidity, and habitat types present at this site. The accuracy measured at La Parguera is assumed to be similar to the accuracy of maps elsewhere in the project area. Data for accuracy assessment were collected from 200 sites. Sites were selected using a random stratified approach based on the 3 main habitat types in the classification scheme and 2 depth strata (0–15 and 15–30 m). This ensured that comparison points were spread throughout the assessment area and that estimated accuracy would be representative of the wide variety of habitat types and water depths present. Bottom type was recorded at each field site and then compared to the attributes assigned to that location in the habitat map. An error matrix that displays errors of inclusion and exclusion for only the 3 main habitat categories was produced due to the logistical constraints of collecting the recommended minimum range of 20–50 accuracy check points for each of the 26 classifications at the detailed level of the hierarchy (Congalton 1991).

RESULTS

Positional accuracy for orthorectified mosaics varied depending on the data available for georeferencing and the quality of the imagery (Table 1). In general, pixel position in the mosaics was estimated to be within a few pixel widths (~ 10 m) of their true location. An exception to this was the mosaic of Desecheo Island, northwest of Puerto Rico, which was not as accurately geopositioned as the other islands due to the difficulty in identifying coordinates of corresponding land and image features on its barren landscape. Because benthic habitats were digitized directly in a GIS using the georeferenced imagery, the positional accuracy of the habitat maps for each island or island segment is assumed to be the same as that reported for the mosaiced photography (Table 1).

Thematic accuracy of the general level of habitat classification in the La Parguera area was determined to be 93.6 percent overall (Table 2). Maps were 100 percent accurate for the unconsolidated sediment category and 99 percent for the submerged vegetation category. A small

TABLE 2

Error matrix for habitat classification at La Parguera. Numbers in the matrix indicate class coincidence, (I) indicates accuracy based on inclusion errors, and (E) indicates accuracy based on exclusion errors calculated from analysis of 200 ground truth points.

	Actual habitat type		
	Coral reef/ hardbottom	**Submerged vegetation**	**Unconsolidated sediment**
Mapped habitat type			
Coral Reef/Hardbottom	76 91.6% (I) 98.7% (E)	7	0
Submerged Vegetation	1	92 98.9% (I) 92.9% (E)	0
Unconsolidated Sediment	0	0	24 100% (I) 100% (E)

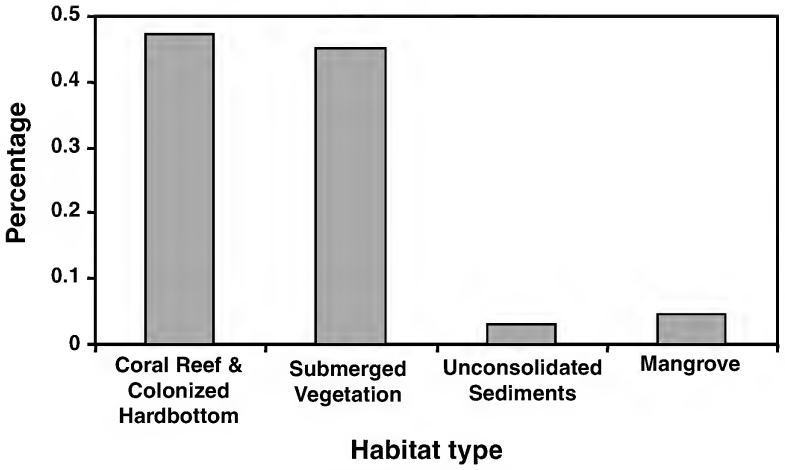

Figure 1: Mapped habitat types in Puerto Rico near shore waters (percent of area excluding polygons with "unknown" bottom type). Only the 3 most general classification categories plus mangroves are displayed.

percentage of coral reef/hardbottom sites were misclassified as submerged vegetation.

About 1600 km^2 of benthic features were mapped. The habitat type with the largest area, excluding areas labeled unknown due to water depth or turbidity, was coral reef/hardbottom which accounted for nearly half of the mapped area (Figure 1). Submerged aquatic vegetation accounted for over 40 percent of the area mapped although this includes patchy seagrass and algae which may include considerable areas of bare sand. Mangrove forests covered about 5 percent of the area mapped. The bank/shelf zone included 85% of the area mapped (Figure 2). Combinations of habitat and zone that covered large areas included seagrass and colonized pavement with sand channels on the bank shelf which together accounted for more than half of the total area mapped (Table 3). Notable sites with extensive coverage of seagrass include the region between Vieques and the east end of Puerto Rico (240 km^2) and the southwestern corner of Puerto Rico around Cabo Rojo (80 km^2) (Figure 3). A large, continuous mangrove forest was mapped east of San Juan (15.5 km^2). Areas with discontinuous mangrove forests that covered large areas included the eastern tip of Puerto Rico around Roosevelt Roads Naval Base (9.1 km^2) and the Parguera area (4.1 km^2) (Figure 3). The largest reef areas mapped were located primarily along the southern and southwestern edge of the island where the shelf is broad and flat.

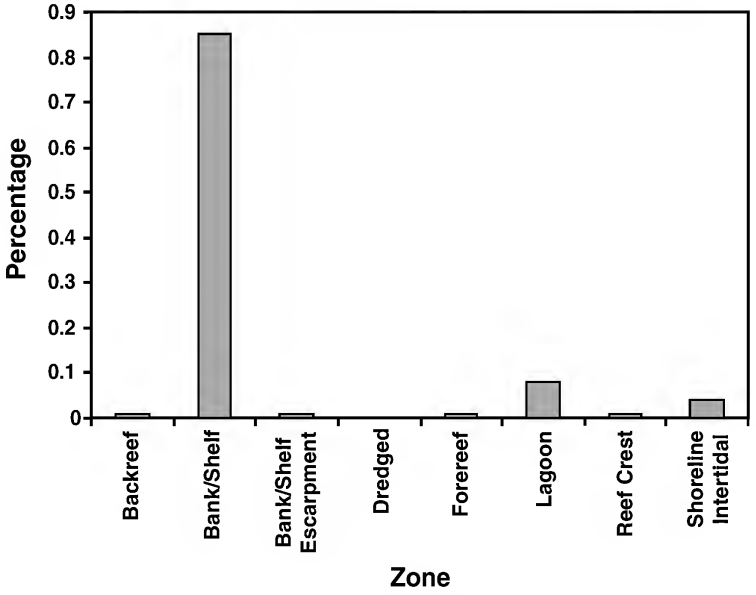

Figure 2: Mapped geomorphic zones in Puerto Rico near shore waters (percent of area excluding polygons with "unknown" zone).

TABLE 3

Matrix of area and percent of total area mapped the unique zone/habitat combinations. Some of the very similar habitat subcategories were grouped to save journal space (such as all 8 categories of seagrass and macroalgal patchiness). Polygons with either zone or habitat type labeled as "unknown" were excluded (this results in small differences between row and column totals between this table and values in Figures 1 and 2). The upper value in each cell denotes the area mapped in km^2 for each zone/habitat combination. The lower value in each cell is the percentage of the total area mapped that is covered by each zone/habitat combination. Blank cells indicate that no polygons were mapped that met those zone and habitat criteria. All table values are rounded to 2 decimal places and therefore may result in some zero values for very small features as well as slight apparent discrepancies in presentation of row and column totals.

General habitat types	Detailed habitat types	Shoreline intertidal	Lagoon backreef	Reef crest	Forereef	Bank/Shelf	Bank/Shelf	Escarpment	Dredged	ROW TOTALS
Unconsolidated sediment	Mud	11.5	6.2				4.0			21.7
		1.0	0.0			0.0				1.0
	Sand	0.3	2.2	0.1		24.5	0.0			27.1
		0.0	0.0	0.0		2.0	0.0			2.0
Coral reef and hardbottom	Colonized Bedrock	0.9	2.0	0.1	0.2	0.0	23.7			26.9
		0.0	0.0	0.0	0.0	0.0	1.0			2.0
	Colonized Pavement	0.1	1.7	0.1	0.0	0.7	176.3	3.5		182.4
		0.0	0.0	0.0	0.0	0.0	11.0	0.0		11.0
	Colonized Pavement with Sand Channels		2.8	0.7		1.0	305.9	5.8		316.2
			0.0	0.0		0.0	19.0	0.0		20.0
	Linear Reef	0.1	1.1	1.0	19.6	14.3	33.2	5.7		75.0
		0.0	0.0	0.0	1.0	1.0	2.0	0.0		5.0
	Patch Reef (Aggregated)		3.5	0.1			63.2			66.8
			0.0	0.0			4.0			4.0
	Patch Reef (Individual)	0.0	0.3	0.1	0.1	0.1	14.1			14.7
		0.0	0.0	0.0	0.0	0.0	1.0			1.0
	Reef Rubble			0.1	0.3		0.2			0.6
				0.0	0.0		0.0			0.0
	Scattered Coral/Rock in Unconsolidated Sed.		9.0	0.5	1.3	0.1	61.3	0.1		72.4
			1.0	0.0	0.0	0.0	4.0	0.0		5.0
	Spur and Groove Reef					0.1	1.8	0.1		1.9
						0.0	0.0	0.0		0.0
	Uncolonized Bedrock	0.1								
		0.0								
Submerged vegetation	Macroalgae (continuous and patchy)	1.0	6.8	0.2			88.4	0.2	0.0	96.7
		0.0	0.0	0.0			6.0	0.0	0.0	6.0
	Seagrass (continuous and patchy)	3.4	51.9	16.9	1.8	0.3	550.0			624.3
		0.0	3.0	1.0	0.0	0.0	34.0			39.0
Other	Mangrove	72.4			0.2					72.6
		5.0			0.0					5.0
	Artificial						0.1			0.1
							0.0			0.0
	COLUMN TOTALS	90.0	87.0	20.0	24.0	16.0	1347.0	15.0	0.0	1599.0
		6.0	5.0	1.0	1.0	1.0	84.0	1.0	0.0	100.0

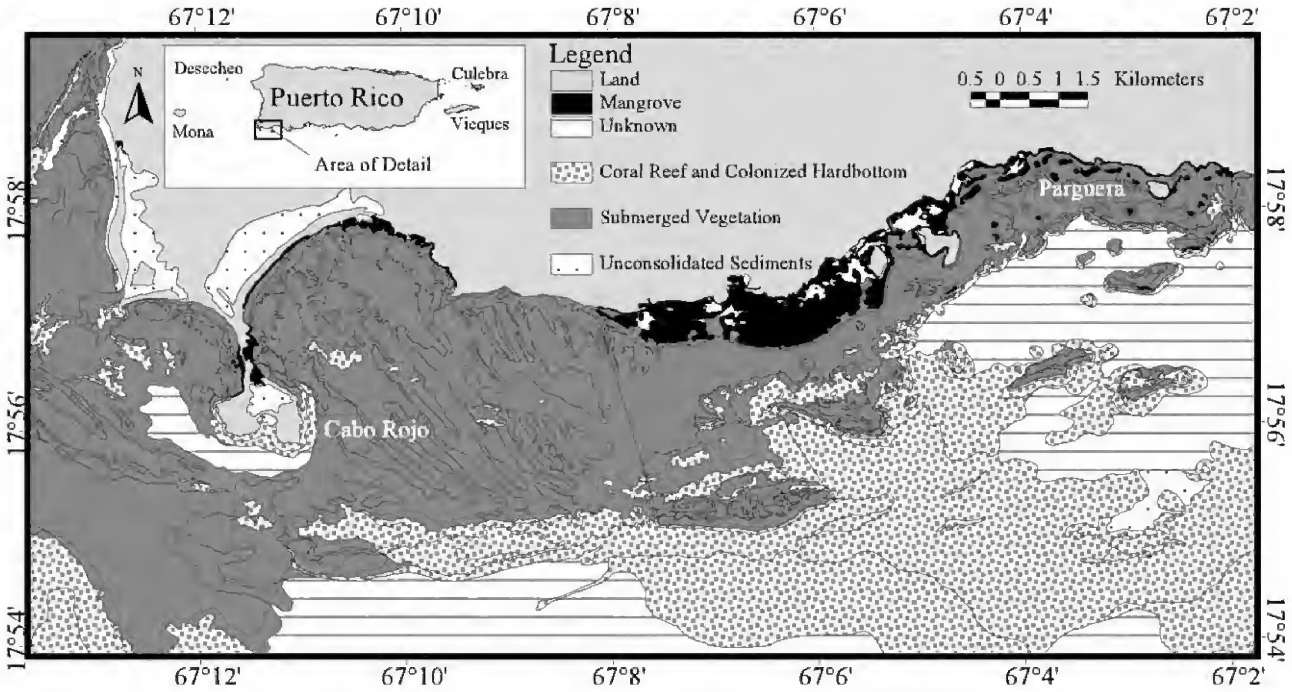

Figure 3: Benthic map of southwestern Puerto Rico from Cabo Rojo to Parguera. To simplify this example map, only "land", "mangrove", "unknown", "coral reef and hardbottom", "submerged vegetation", and "unconsolidated sediments" are shown rather than all of the more detailed thematic classifications.

DISCUSSION

The baseline inventory of Puerto Rico's coral reefs, seagrass beds, mangroves, and associated habitats provided by this assessment offer diverse opportunities for research and management of this ecosystem. Uses of these map products already include a wide range of research, monitoring, and management applications. The GIS data provides a spatial framework within which to stratify sampling for fisheries and habitat research (Christensen et al. 2003). The maps are one component of an integrated monitoring and assessment program underway by NOAA and its partners in the USCRTF to assess reef condition and health trends (Monaco et al. 2001). The spatially articulated inventory of coral reefs and associated habitats is required for identifying Essential Fish Habitat (Rosenberg et al. 2000), identifying locations and appropriate sizes for marine protected areas (National Research Council 2001), and providing coastal management agencies with basic information to conduct change detection following natural or anthropogenic disturbance events.

The large area mapped, small MMU, and large number of detailed classifications prevent inclusion of all but an example map in journal format (Figure 3; only 4 map classes shown). Furthermore, the real value of this assessment goes well beyond the summary statistics of habitat areas reported above. An atlas containing 211 printable maps, digital map data (ArcGIS shapefiles), orthorectified mosaics of aerial photos, unrectified scans of all aerial photographs, ground control points, accuracy assessment points, the Habitat Digitizer extension to ArcView 3.x, and other project components are all freely available from the authors' website (http://biogeo.nos.noaa.gov).

It is important to note that the summary statistics reported above do not include the large area of insular shelf that could not be mapped in this assessment. Due to discharge of turbid rivers, suspended sediment from wave action, water depth, clouds, and other factors that prevent benthic features from being visible, 75% of the Puerto Rican insular shelf (area between the shoreline and the 30 m isobath or shelf edge) could not be mapped using the available aerial photography. Much of the north coast of Puerto Rico could not be mapped due to turbidity associated with the many rivers and heavy surf conditions that characterize this region. The central portion of the west coast had shelf features obscured by sediment laden river discharge from Rio Guanajibo and Rio Grande de Anasco. The very small island of Monito was not photographed. A large area between the islands of Vieques and Culebra extending eastward along the shelf platform to the territorial boundary of the US Virgin Islands was not mapped because bottom depth was beyond the limit of detection by aerial photography (~ 20 m). A widening variety of remote sensing technologies including satellites, airborne hyper-

spectral scanners, lidar, and shipboard multibeam sonar are rapidly improving and providing ever more detailed, accurate, and cost effective alternatives for benthic mapping in range of depths and water conditions. A combination of these aerial, satellite, and in water technologies will be required to comprehensively and cost effectively map all US reef ecosystems (USCRTF 2000) such as those portions of the Puerto Rican shelf mapped as "unknown" in this assessment.

Thematic accuracy measured in the Parguera area was well within acceptable levels for maps of this type. Since the variety of water conditions and habitats in Parguera are representative of most of Puerto Rico, the entire project area is assumed to be mapped with similar success. Areas with poorer water conditions were labeled as unknown. It is important to note, however, that the accuracy assessment applies only to the highest level in the classification hierarchy. This was identified by the local scientific and management groups consulted during map production as the most important level in the scheme to be evaluated using the limited funds and logistical support available for field activities. While categories at this hierarchical level encompass the more detailed classifications, thematic accuracy of the more detailed categories was not quantified and is likely to be lower than the overall accuracy and values for the 3 main categories (Table 2).

Our modifications to an established and proven approach to coral ecosystem mapping have been used in Puerto Rico, the US Virgin Islands (Kendall et al. in press), portions of the Hawaiian Islands (Coyne et al. 2003), and are being further modified to incorporate new technologies for mapping US coral ecosystems elsewhere in the world. The maps and associated products made by this assessment provide a needed characterization of Puerto Rico's benthic habitats, direct future assessments toward unmapped areas, and enhance coastal research and management capabilities in the region.

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LITERATURE CITED

Beach, D.K. and J.V.A. Trumbull. 1981. Marine Geologic map of the Puerto Rico insular shelf, Isla Caja de Muertos area. Miscellaneous Investigations Series I-1265. US Geological Survey, Washington, DC, USA.

Christensen, J.C., C.F.G. Jeffrey, C. Caldow, M.E. Monaco, M.S. Kendall, and R.S. Appeldoorn. 2003. Cross-shelf habitat utilization patterns of reef fishes in southwestern Puerto Rico. Gulf and Caribbean Research 14:9–28.

Congalton, R.G. 1991. A review of assessing the accuracy of classifications of remotely sensed data. Remote Sensing of the Environment 37:35–46.

Coyne, M.S., T.A. Battista, M. Anderson, J. Waddell, W. Smith, P. Jokiel, M.S. Kendall, and M.E. Monaco. 2003. Benthic Habitats of the Main Hawaiian Islands. NOAA NOS NCCOS CCMA Technical Memorandum (On-line). URL: http://biogeo.nos.noaa.gov/projects/mapping/pacific/. Silver Spring, MD, USA.

Florida Marine Research Institute. 1998. Benthic habitats of the Florida Keys. FMRI Technical Report TR-4, St. Petersburg, FL, USA.

Goenaga, C. and G. Cintron. 1979. Inventory of the Puerto Rican coral reefs. Report submitted to the Coastal Zone Management, Department of Natural Resources, San Juan, PR, USA, p. 123–159.

Green, E.P., P.J. Mumby, A.J. Edwards, and C.D. Clark. 2000. Remote Sensing Handbook for Tropical Coastal Management.UNESCO Publishing, Fontenoy, Paris, France, 316 p.

Grove, K.A. 1983. Marine geologic map of the Puerto Rico insular shelf, Northwestern area: Rio Grande de Anasco to Rio Camuy. Miscellaneous Investigations Series, I-1418. US Geological Survey, Washington, DC, USA.

Holden, H. and E. LeDrew. 1998. The scientific issues surrounding remote detection of submerged coral ecosystems. Progress in Physical Geography 22:190–221.

Kendall, M.S., C.R. Kruer, K.R. Buja, J.D. Christensen, M. Finkbeiner, R.A. Warner, and M.E. Monaco. 2001. Methods used to map the benthic habitats of Puerto Rico and the US Virgin Islands. NOAA NOS NCCOS CCMA Technical Report 152. Silver Spring, MD, USA, 45 p.

Kendall, M.S., K.R. Buja, J.D. Christensen, C.R. Kruer, and M.E. Monaco. in press. The seascape approach to coral ecosystem mapping: an integral component of understanding the habitat utilization patterns of reef fish. Bulletin of Marine Science.

Kruer, C.R. 1995. Mapping and characterizing seagrass areas important to manatees in Puerto Rico—Benthic communities mapping and assessment. Report prepared for US Department of Interior, National Biological Survey, Sirenia Project, Order No. 83023-5-0161, 14 p.

Monaco, M.E., J.D. Christensen, and S.O. Rohmann. 2001. Mapping and monitoring of US coral reef ecosystems. Earth System Monitor 12:1–7.

Morelock, J. 1978. Shoreline of Puerto Rico. Coastal Zone Management Program, Department of Natural Resources, San Juan, PR, USA, 45 p.

Morelock, J., E. Winget, and C. Goenaga. 1994. Marine geology of the Parguera-Guanica quadrangles, Puerto Rico. USGS Miscellaneous Investigations Series. US Geological Survey, Washington, DC, USA.

Mumby, P.J. and A.R. Harborne. 1999. Development of a systematic classification scheme of marine habitats to facilitate regional management and mapping of Caribbean coral reefs. Biological Conservation 88:155–163.

NOAA, US Environmental Protection Agency, US Coast Guard, Puerto Rico Departmento de Recursos Naturales y Ambientales, and Department of Interior. 2000. Sensitivity of Coastal and Inland Resources to Spilled Oil—Puerto Rico Atlas. Hazardous Materials Response Division of NOAA. Seattle, WA, USA.

National Research Council. 2001. Marine Protected Areas: Tools for Sustaining Ocean Ecosystems. National Academy Press, Washington, DC, USA, 272 p.

Pilkey, O.H., D.M. Bush, and R.W. Rodriguez. 1987. Bottom sediment types of the northern insular shelf of Puerto Rico: Punta Penon to Punta Salinas. Miscellaneous Investigations Series I-1861. US Geological Survey, Washington, DC, USA.

Sheppard, C.R., K. Matheson, J.C. Bythel, P.Murphy, C.B.Myers, and B.Blake. 1998. Habitat mapping in the Caribbean for management and conservation: Use and Assessment of Aerial Photography. Aquatic Conservation 5:277–298.

Reid, J.P. and C.R. Kruer. 1998. Mapping and characterization of nearshore benthic habitats around Vieques Island, Puerto Rico. Report to US Navy. US Geological Survey/BRD, Sirenia Project, Gainesville, FL, USA, 8 p.

Rodriguez, R.W., J.V.A. Trumbull, and W.P. Dillon. 1977. Marine geologic map of Isla de Mona area, Puerto Rico. Miscellaneous Investigations Series I-1063. US Geological Survey, Washington, DC, USA.

Rodriguez, R.W., R.M.T. Webb, D.M. Bush, and K.M. Scanlon. 1992. Marine geologic map of the north insular shelf of Puerto Rico- Rio de Bayamon to Rio Grande de Loiza. Miscellaneous Investigations Series I-2207. US Geological Survey, Washington, DC, USA.

Rosenberg, A., T.E. Bigford, S. Leathery, R.L. Hill, and K. Bickers. 2000. Ecosystem approaches to fishery management through essential fish habitat. Bulletin of Marine Science 66:535–542.

Trias, J.L. 1991. Marine geologic map of the Puerto Rico insular shelf- Guanica to Ponce area. Miscellaneous Investigations Map I-2263. US Geological Survey, Washington, DC, USA.

USCRTF. 2000. The National Action Plan to Conserve Coral Reefs. (http://coralreef.gov/) Washington, DC, USA, 8 p.

Warner, R.A., J. Dietz, M.S. Kendall, G. Goddard, and C. Elvidge. in review. Operational photogrammetric method used for mapping US Caribbean shallow water coral reefs. Photogrammetric Engineering and Remote Sensing.