6-1999

Fish species richness in relation to restored oyster reefs, Piankatank River, Virginia

JM Harding
Virginia Institute of Marine Science

Roger L. Mann
Virginia Institute of Marine Science

BULLETIN OF MARINE SCIENCE, 65(1): 289–300, 1999

NOTES

FISH SPECIES RICHNESS IN RELATION TO RESTORED OYSTER REEFS, PIANKATANK RIVER, VIRGINIA

Juliana M. Harding and Roger Mann

Fish assemblages in relation to "reef" structures in marine habitats have been and continue to be topics for research addressing ecological and management questions. Much effort has been spent describing and defining fish assemblages, or groups of species, associated with tropical coral reefs (e.g., Sale 1991 and chapters therein), temperate hard bottom or rocky reefs (e.g., Sedberry and Van Dolah, 1984; Ambrose and Swarbrick, 1989), tropical lava flows (e.g., Godwin and Kosaki, 1989), and artificial "fishing" reefs (e.g., Chandler et al., 1985; Hueckel and Buckley, 1987; Bohnsack, 1989; Feigenbaum et al., 1989; Rountree, 1989; Stephan and Lindquist, 1989). Temperate oyster reefs, another natural reef type, host diverse finfish assemblages that are just beginning to be described (e.g., Wenner et al. 1996; Mann and Harding, 1997; Luckenbach et al. 1998 and references therein).

Before Eastern oyster (*Crassostrea virginica*) populations were significantly reduced by environmental degradation, fishing pressure, and disease, oyster reefs dominated the intertidal areas of Chesapeake Bay and supported complex ecological communities including many fish species. The living shell matrix created by these predominantly intertidal, estuarine reefs provides structural heterogeneity and vertical relief that attract and sustain fishes from many trophic levels similar to living coral reefs (Roberts and Ormond, 1987; Ebeling and Hixon, 1991; Friedlander and Parrish, 1998). Recreationally and commercially valuable piscivorous finfishes including striped bass (*Morone saxatilis*), bluefish (*Pomatomus saltatrix*), and weakfish (*Cynoscion regalis*) were and are integral components of trophic networks that depend on oyster reefs (Mann and Harding, 1997, 1998). These pelagic finfishes use oyster reefs as both feeding and nursery grounds (e.g., Breitburg, 1998; Mann and Harding, 1997, 1998; J. Harding and R. Mann, unpubl. data).

Current restoration efforts for both oysters and finfishes are realizing the interconnections between these species in the context of intertidal estuarine habitats (Wenner et al. 1996; Breitburg, 1998; Coen et al., 1997; Mann and Harding, 1997, 1998; Nestlerode et al., in preparation). Description of oyster reef fish assemblages and species richness over time provides a direct method to assess the importance of oyster reefs as fish habitat. As reef communities develop at restoration sites, the associated ichthyofauna should increase in species richness, i.e., the number of different species observed at a site. The objectives of this study were to qualitatively describe the ichthyofauna associated with oyster reef restoration sites in the Piankatank River, Virginia along a seasonal gradient and to compare observed fish assemblages and species richness in relation to species richness patterns from similar habitats.

Methods and Results

Study Site.—Field work was conducted at Palace Bar Reef, Piankatank River, Virginia (37°31′41.69″N, 76° 22′25.98″W) during 1996 and 1997 and was expanded to include

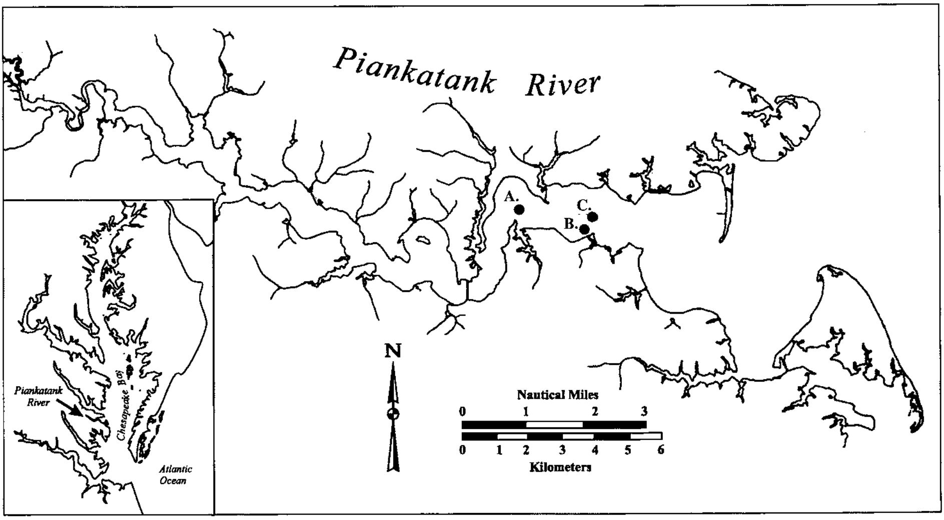

Figure 1. Map of the Piankatank River in relation to the Chesapeake Bay showing sampling locations. Palace Bar Reef (C.) was sampled in 1996 and 1997. Sites at Ginney Point (A.) and Roane Point (B.) were established in 1997 to provide data for non-reef habitats.

two non-reef sites within the Piankatank River during 1997 (Fig. 1). Palace Bar Reef is an intertidal oyster reef (210 × 30 m, reef depth range of 0.5 m above MLW to 3 m below MLW) that was built in July, 1993 adjacent to the historic Palace Bar oyster grounds. Approximately 70% of the reef (0.63 ha) is composed of oyster shell, while the remaining area (0.27 ha) is crushed clam shell (see Bartol and Mann, 1997 for a detailed site description). Since its construction in 1993, Palace Bar Reef has received annual oyster spat settlement (Bartol and Mann, 1997; J. Wesson, unpubl. data) and all oysters on the reef are due to natural settlement and recruitment, i.e., the reef was not initially seeded with oysters. The reef's oyster population is surveyed annually: oysters from multiple (n > 12 annually) 0.25 m quadrats placed randomly on the reef surface are collected by divers and subsequently counted and measured. Annual dredge surveys of the immediately adjacent Palace Bar are part of the VIMS Molluscan Ecology oyster monitoring program. These dredge surveys provide abundance and size class information for a natural oyster population immediately adjacent to Palace Bar Reef (R. Mann, unpubl. data). The first observation of adult or "market" oysters on the reef was during the fall of 1995.

In 1996, a trophic monitoring program was initiated for the reef area to provide baseline upper level trophic data (this study; Mann and Harding, 1997; Mann and Harding, 1998; Harding and Mann, in review). To evaluate reef versus non-reef habitat use by upper level consumers two non-reef sites within the Piankatank River were included in 1997. Data were collected at all sites during the same seasonal, temporal, and tidal scales. The non-reef site at Ginney Point (37° 31′52.78″N, 76°24′08.40″W) is located on a natural oyster shell bar (approximately 400 × 50 m, depth range 2 to 5 m; Fig. 1). The second non-reef site at Roane Point (37°31′37.48″N, 76°22′39.63″W) includes a sand bar south and inshore of Palace Bar Reef (approximately 400 × 15 m; depth range 2–4 m; Fig. 1). Mean tidal range in the Piankatank River is approximately 0.4 m. Water temperature and salinity were recorded once a week in conjunction with other monitoring from May to October during 1996 and 1997 at Ginney Point and Palace Bar Reef (Fig. 2). Water samples were taken

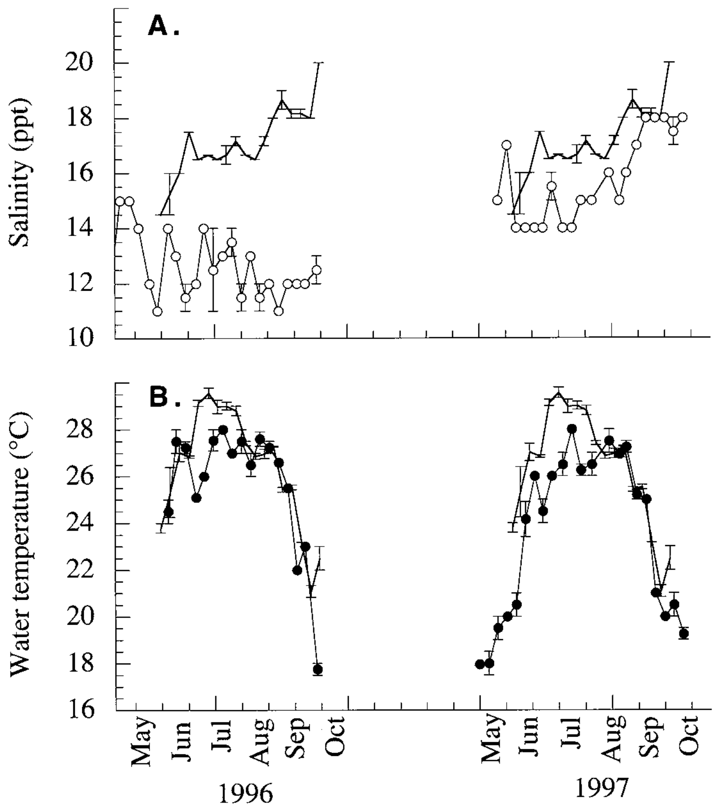

Figure 2. Mean salinity (‰, A.) and water temperature (°C, B.) values (± SE) for Ginney Point and Palace Bar Reef, Piankatank River, Virginia from May to October. Data from these two sites were averaged since there was no siginficant difference in temperature or salinity between sites (ANOVA, $P < 0.05$). Reference mean values for temperature and salinity data from 1993–95 are plotted with a solid line (± SE). Data from 1996 and 1997 are indicated by lines with symbols (± SE).

at the surface and just above the bottom with a Niskin bottle. Temperature was measured immediately with a thermometer and salinity was measured with a refractometer.

Finfish Sampling Periodicity and Methods.—Upper level trophic monitoring efforts focused on the pelagic finfish communities at each site. Fishes were classified based on mobility into one of three groups: resident, semi-resident, and transient. Resident fish species (all life history stages may be found in the habitat; Burchmore et al., 1985) are prey items for larger temporary or semi-resident species (fishes that use the habitat for a portion of their life cycle or on a seasonal basis; Burchmore et al., 1985; Chandler et al. 1985) as well as larger transient species (fishes that are found over a wide range of habitats; Burchmore et al., 1985).

Sampling efforts spanned seasonal, diurnal, and tidal scales. During 1996, regular sampling (gill netting, trawling, crab pot deployment and retrieval, nest substrate deployment and retrieval) was conducted bi-monthly on Palace Bar Reef from May through October during daylight hours and included at least two parts of the tidal cycle. Thirty-six hour sampling stations were conducted on Palace Bar Reef during the full moon in June and August 1996 incorporating tidal, diurnal, and seasonal variation. A total of 42 gill net sets,

Table 1. Family, common, and scientific names with habitat use, life history stages, and species status for all fish species observed in the Piankatank River, Virginia during 1996-97. R denotes resident species, SR for semi-resident, and T for transient per Burchmore et al. (1985). Some semi-residential species may also be considered transient. Life history stages are classified as either adult (A) or juvenile (J) based on length (mm) and coloration. Gear type used to collect fishes include gill nets (G), trawls (T), crab pots (C), and nest substrates (N). Sampling methods and periodicity are detailed in the text
.

Family	Common name	Scientific name	Habitat use	Gear	Life HistoryStage	Recreationally or Commercially valuable species
Anguillidae	American eel	*Anguilla rostrata*	R	C, N, T	A	X
Batrachoididae	Oyster toadfish	*Opsanus tau*	R	C, N, T	A, J	
Blenniidae	Striped blenny	*Chasmodes bosquianus*	R	N, T	A, J	
Bothidae	Summer flounder	*Paralichthys dentatus*	SR	G, T	A, J	X
Clupeidae	Blueback herring	*Alosa aestivalis*	T	G	A	X
	Atlantic menhaden	*Brevoortia tyrannus*	T	G	A, J	X
Cyprinidae	Carp	*Cyprinus carpio*	T	G	A	
Engraulidae	Bay anchovy	*Anchoa mitchilli*	T	T	A	
Ephippidae	Spadefish	*Chaetodipterus faber*	SR	T	J	
Gadidae	Spotted hake	*Urophycis regia*	T	T	J	
Gobiesocidae	Skilletfish	*Gobiesox strumosus*	R	T, N	A, J	
Gobiidae	Naked goby	*Gobiosoma bosc*	R	T, N	A, J	
Haemulidae	Pigfish	*Orthopristis chrysoptera*	T	C, T	A	
Labridae	Tautog	*Tautoga onitis*	SR	N	J	X
Myliobatidae	Cownose ray	*Rhinoptera bonasus*	T	G	A	
Percichthyidae	Striped bass	*Morone saxatilis*	T	G, T	A, J	X
Pomatomidae	Bluefish	*Pomatomus saltatrix*	T	C, G	A	X
Rachycentridae	Cobia	*Rachycentron canadium*	T	G	J	X
Sciaenidae	Atlantic croaker	*Micropogonias undulatus*	T	C, G, T	A, J	X
	Silver perch	*Bairdiella chrysoura*	T	G, T	A, J	
	Speckled trout	*Cynoscion nebulosus*	T	G, T	A, J	X
	Spot	*Leiostomus xanthurus*	T	G, T	A, J	
	Weakfish	*Cynoscion regalis*	T	G, T	A, J	X

Table 1. Continued.

Family	Common name	Scientific name	Habitat use	Gear	Life HistoryStage	Recreationally or Commercially valuable species
Scombridae	Spanish mackerel	*Scomberomorus maculatus*	T	G	A	X
Serranidae	Black sea bass	*Centropristis striata*	SR	C	A	X
Soleidae	Hog choker	*Trinectes maculatus*	SR	G, T	A	
Sparidae	Pinfish	*Lagodon rhomboides*	SR	C, T	A	
Stromateidae	Butterfish	*Peprilus triacanthus*	T	G, T	A	
	Harvest fish	*Peprilus alepidotus*	T	T	J	
Syngnathidae	Lined seahorse	*Hippocampus erectus*	SR	T	A	
Tetraodontidae	Northern puffer	*Sphoeroides maculatus*	T	T	J	
Triglidae	Northern searobin	*Priontus carolinus*	R	T	A	

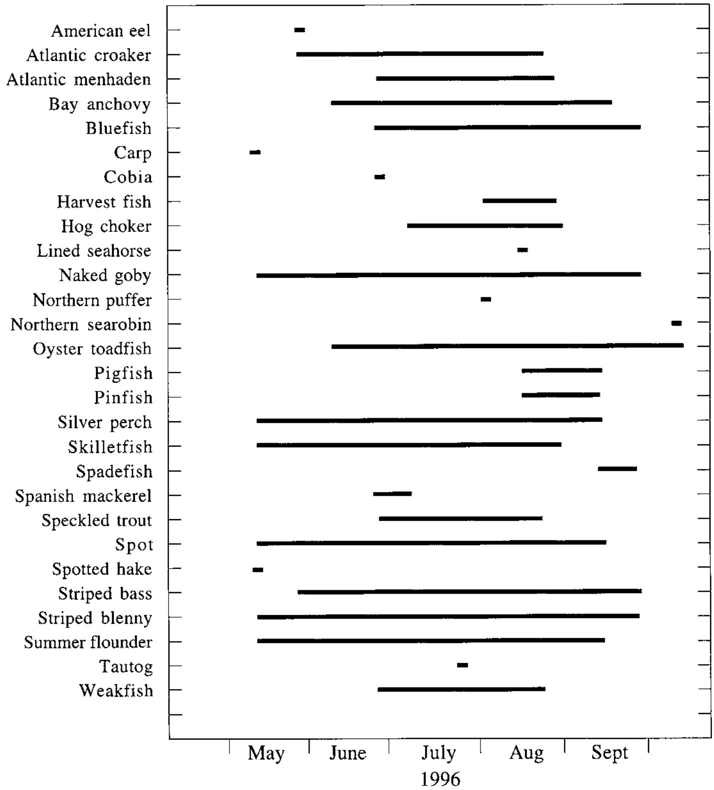

Figure 3. Fish species caught during 1996 with gill nets, otter trawls, crab pots, and nest substrates on Palace Bar Reef, Piankatank River, Virginia. Solid lines span the time interval during which a species was observed.

132 trawls, 120 crab pot sets, and 15 nest substrate deployments were completed during 1996. Sampling during 1997 relied exclusively on nine 36 h stations from May through September on both the new and full moon. On-reef and non-reef sites were sampled at 3 h intervals corresponding to changes in tidal stage. A total of 270 gill net sets, 172 crab pot sets, and 40 nest substrate deployments were completed during 1997.

Adults and juveniles of larger pelagic species were sampled using multi-panel experimental gill nets (one 30.5 × 1.8 m (1996 and 1997) and two 30.5 × 3.0 m (1997 only) nets all with one 7.6 m panel each of stretch square mesh monofilament of 57.2, 63.5, 73.0 and 76.2 mm). Gill nets were deployed such that the entire water column was sampled (e.g., the smallest net at the shallowest site) and were retrieved at 3 h intervals corresponding with changes in tidal stage. A 4.8 m otter trawl (25 mm stretch-mesh body, 7 mm mesh liner) was used in 1996 to sample benthic and smaller pelagic fishes on and immediately above the reef; all trawls were 5 min in duration at similar towing speeds (approximately 1 to 1.5 m s^{-1}) and were made above the reef and around the reef perimeter. Fishes were also collected in crab pots and benthic nest substrates. Nest substrates, benthic trays with potential nest sites (e.g., PVC tubes, paired valves of dead oysters, oyster shell), were deployed and checked bi-monthly throughout both 1996 and 1997 for related studies targeting naked gobies (*Gobiosoma bosc*) and striped blennies (*Chasmodes bosquianus*) (J. Harding, unpubl. data). Fishes were classified as “adult” or “juvenile” at the time of

Table 2. Fishes collected during 1997 with gill nets (G), crab pots (C), and nest substrates (N) in the Piankatank River,Virginia.

Fish species	Gear	Ginney Point	Roane Point	Palace Bar Reef
American eel	N			X
Atlantic croaker	C, G	X	X	X
Atlantic menhaden	G	X	X	X
Black Sea bass	C	X		
Blueback herring	G	X	X	X
Bluefish	C, G	X	X	X
Butterfish	G			X
Carp	G		X	
Cownose ray	G			X
Hogchoker	G	X		X
Naked goby	N			X
Oyster toadfish	N			X
Silver perch	G	X	X	X
Skilletfish	N			X
Speckled trout	G	X	X	X
Spot	G	X	X	X
Striped bass	G	X	X	X
Striped blenny	N			X
Summer flounder	G	X		
Weakfish	G	X	X	X

collection using fork length (mm) (or total length in the absence of fork length) and body coloration.

Sampling efforts during 1996 focused on ichthyofauna observed on and immediately adjacent to Palace Bar Reef. Twenty-eight fish species from 24 families were caught on or immediately adjacent to Palace Bar Reef during 1996 (Table 1, Fig. 3). A total of 20 fish species representing 15 families were collected during 1997 across all three sites (Tables 1,2; Fig. 4). Resident benthic fishes including naked gobies, striped blennies, skilletfish, and oyster toadfish were regularly collected from Palace Bar Reef during both years. Transient fishes including bluefish, striped bass, Atlantic croaker, Atlantic menhaden, and spot were consistently caught on the reef as well as at non-reef locations during 1997 (Table 2; Fig. 3,4).

Data Analyses.—Significance levels for all statistical tests were established at $P = 0.05$ a priori. Bartlett's test for homogeneity of variance and the Ryan-Joiner test for normality were used prior to analyses (Minitab ver. 10.5). The reciprocal transformation was used for all count/abundance data per Zar (1996) prior to analyses to satisfy assumptions of homogeneity of variance and normality.

Abundance of spat, small oysters, and market oysters on Palace Bar and Palace Bar Reef from 1996 and 1997 was compared using a two-factor ANOVA (year × site); data were transformed with the reciprocal transformation (Zar, 1996). Fisher's test was used for post-hoc multiple comparisons. Spat abundance was similar between sites in both years (Table 3; ANOVA, $P > 0.05$). Market oyster abundance was higher on Palace Bar in 1996 (ANOVA, $P < 0.05$) but similar between sites in 1997 (Table 3; ANOVA, $P > 0.05$). Small oyster abundance was greater on Palace Bar during 1996 and greater on Palace

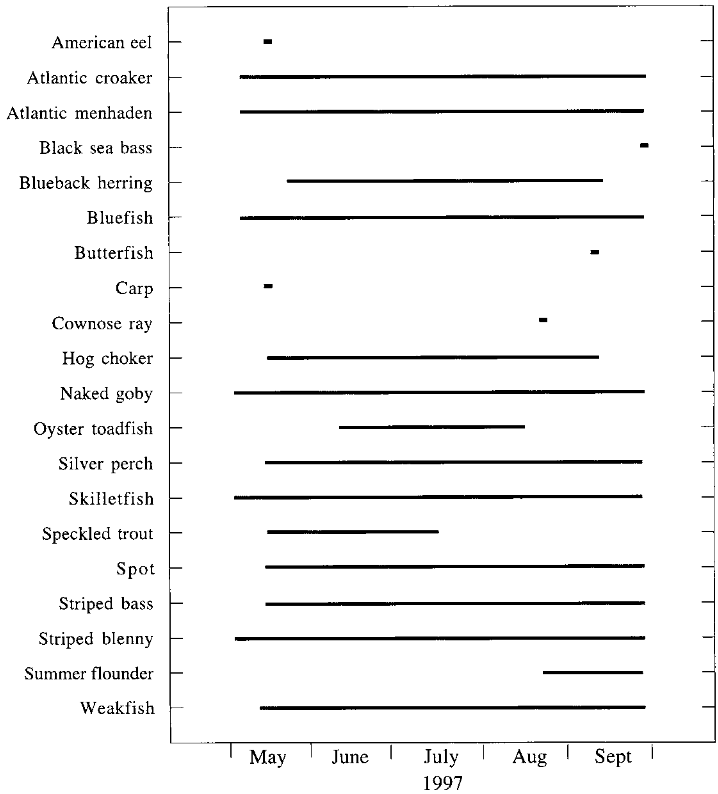

Figure 4. Fish species caught during 1997 with gill nets, crab pots, and nest substrates from Ginney Point, Roane Point, and Palace Bar Reef, Piankatank River, Virginia. Solid lines span the time interval during which a species was observed.

Bar Reef in 1997 (Table 3).

Water temperature and salinity data were transformed (natural logarithm) prior to analyses and satisfied assumptions of both homogeneity of variance and normality. Neither water temperatures nor salinity values were significantly different between depths (surface or near-bottom) or sampling sites (ANOVA, $P < 0.05$). Salinities, but not water temperatures, were significantly different between years: 1996 and 1997 (ANOVA, $P < 0.05$). Recorded weekly water temperatures during 1996 and 1997 were similar to those observed weekly at the same sites during 1993–95 (Fig. 2, R. Mann, unpubl. data). Salinities observed during 1996 were the lowest observed at these sites from 1993–97.

Total number of fish species collected with gill nets at Palace Bar Reef were compared between 1996 and 1997 using an ANOVA to assess potential interannual variation at the reef site. Data were transformed (reciprocal transformation, per Zar, 1996) prior to analyses and satisfied assumptions of both homogeneity of variance and normality. There was no significant difference between numbers of species caught in gill nets at Palace Bar Reef between years (ANOVA, $P > 0.05$).

Numbers of fish species caught with gill nets during the 1997 36-h sampling stations were compared between sites and across seasons using an ANOVA with site and day of the year as factors. The reciprocal transformation (Zar, 1996) was used and data satisfied assumptions of both homogeneity of variance and normality. Neither site nor season (as

Table 3. Comparision of oyster abundance on Palace Bar and Palace Bar Reef, Piankatank River, Viginia during 1996 and 1997. Average counts of spat, small, and market oysters m^{-2} are presented with standard error (SE); n refers to the number of samples collected. "Spat" refers to young-of-the-year oysters; "small" oysters are less than 7.6 cm (maximum dimension) while "market" oysters are greater than 7.6 cm (maximum dimension). Sampling methods are detailed in the text. Vertical lines are to the right of samples that are statistically similar at the P = 0.05 level (ANOVA).

Year	Site	n	Average No. market oysters m^{-2} (± SE)	Average No. small oysters m^{-2} (± SE)	Average No. spat m^{-2} (± SE)
1996	Palace Bar	4	2.0 (1.4)	165.0 (30.4)	22.5 (2.6)
	Palace Bar Reef	30	0 (0)	55.7 (4.2)	24.0 (2.9)
1997	Palace Bar	4	3.5 (2.1)	19.0 (6.2)	77.5 (23.0)
	Palace Bar Reef	12	1.8 (1.0)	43.6 (5.0)	4.9 (1.5)

indicated by day of the year) significantly affected the numbers of fish species caught with gill nets (ANOVA, P > 0.05).

Discussion

Palace Bar Reef, Piankatank River, Virginia supports a diverse fish fauna; 32 species of finfishes representing 26 families were observed on or in proximity to Palace Bar Reef during 1996–97. Differences in sampling gear, gear efficiency, and sampling effort between years may account for differences in fish species richness (20 species vs 28) between years. Many of the fish species observed in relation to Palace Bar Reef during 1996 but not 1997 were captured with trawls, e.g., bay anchovies, northern searobins, spadefish, spotted hake. Presence of benthic and midwater species smaller than gill net meshes at Roane Point and Ginney Point are unknown since these sites were sampled with gill nets only. Gill netting data showed no differences between these three sites, but it is possible that there would be differences between sites in benthic and midwater fish species because of the absence of relief (both Ginney Point and Roane Point) and substrate heterogeneity due to shells (Roane Point). Further study is needed to clarify habitat use patterns by these fishes.

Given that the Piankatank River is a small Chesapeake Bay subestuary, high levels of species richness might be surprising unless placed in context or associated with living oyster reefs. Other studies on natural or restored oyster reefs within Chesapeake Bay have observed similarly high numbers of finfish species. Breitburg (1998) describes 17 fish species representing 14 families at Flag Pond oyster reef, near the Patuxent River, Maryland (salinity range 10 to 17‰, water temperature range 19 to 29°C) . Nestlerode et al. (in prep.) reports 34 fish species from 24 families on restored oyster reefs near Fisherman's Island, Virginia (salinity range 33–35 ‰, water temperature range 15–28°C). Natural and restored oyster reefs within Chesapeake Bay support diverse fish assemblages along a gradient of physical conditions. By comparison, Feigenbaum et al. (1989) report nine fish species in relation to an artificial "fishing" reef near Gwynn's Island (approximately 12 km east of Palace Bar Reef in the mainstem of Chesapeake Bay).

Differences in sampling regimes among sites and studies make quantitative comparisons between species assemblages difficult; standardization of sampling methods and effort would reduce both seasonal and gear biases. However, on the basis of available presence/ absence data, natural oyster reefs within Chesapeake Bay support high numbers of fish species. Species richness in and of itself may be an indicator of relative community rehabilitation or trophic health. Transient species are unlikely to be consistently present within a habitat, especially a small subestuary, unless they are deriving some benefit. In this case, many of the transient species observed on and around Palace Bar Reef were foraging on the reef (Mann and Harding, 1997; Harding and Mann, in review; J. Harding, unpubl. data). Interannual species-specific diet and abundance patterns by site, season, and tidal stage for transient fishes caught in the Piankatank River by site are currently under investigation (J. Harding and R. Mann, unpubl. data).

Increased levels of fish species richness associated with oyster reefs is not surprising in light of the trophic interconnections between the oysters themselves and resident, semi-resident, and transient fishes. Success of lower trophic levels enhances production at the upper levels; living reefs host a strong trophic network and have high potential for long term productivity because the resources necessary for trophic enhancement are inherent in the habitat. As reef restoration efforts continue in estuarine habitats, the trophic impacts of reef restoration have ramifications for recreationally and commercially valuable finfish communities.

Acknowledgments

Support for this project was provided by the U.S. Environmental Protection Agency Chesapeake Bay Program (CB993267-02-1 and CB993267-03-1) and the Department of Fisheries Science, Virginia Institute of Marine Science. The following individuals graciously donated their time to assist with field sampling: F. Arazyus, I. Bartol, R. Boger, S. Brooke, J. Brust, N. Clark, V. Clark, C. Conrath, S. Drake, J. Duggan, K. Farnsworth, C. Fennessy, J. Goins, S. Goodbred, A. Hayes, E. Hinchey, K. Hovel, D. Kerstetter, T. Lewis, K. Murray, J. Nestlerode, S. Neubauer, J. Newton, J. Oliver, C. Robertson, V. Roggero, W. Rose, H. Simpkins, M. Southworth, C. Squyars, M. Thompson, B. Trainum, M. Wagner, K. Walker, J. Walter, G. White, and H. Yarnall. J. Duggan provided valuable assistance designing and building the gill net reel used to store and deploy nets. This paper is contribution No. 2183 from the Virginia Institute of Marine Science.

Literature Cited

Ambrose, R. F. and S. L. Swarbrick. 1989. Comparison of fish assemblages on artificial and natural reefs off the coast of southern California. Bull. Mar. Sci. 44: 718–733.

Bartol, I. and R. Mann. 1997. Small-scale settlement patterns of the oyster, *Crassostrea virginica*, on a constructed intertidal reef. Bull. Mar. Sci. 61: 881–897.

Bohnsack, J. A. 1989. Are high densities of fishes at artificial reefs the result of habitat limitation or behavioral preferences? Bull. Mar. Sci. 44: 631–645.

Breitburg, D. 1998. Are three dimensional structure and healthy oyster populations the keys to an ecologically interesting and important fish community. *In* M. W. Luckenbach, R. Mann, and J. A. Wesson, eds. Oyster reef habitat restoration. A synopsis and synthesis of approaches. Virginia Institute of Marine Science Press. In press.

Burchmore, J. J., D. A. Pollard, J. D. Bell, M. J. Middleton, B. C. Pease and J. Matthews. 1985. An ecologcial comparison of artificial and natural rock reef fish communities in Botany Bay, New South Wales, Australia. Bull. Mar. Sci. 37: 70–85.

Chandler, C. R., R. M. Sanders, Jr. and A. M. Landry, Jr. 1985. Effects of three substrate variables on two artificial reef fish communities. Bull. Mar. Sci. 37: 129–142.

Coen, L., E. Wenner, D. Knott, B. Stender, N. Hadley, M. Bobo, D. Richardson, M. Thompson, and R. Giotta. 1997. Intertidal oyster reef habitat assessment and restoration: evaluating habitat use, development and function. J. Shellfish Res. 16: 262.

Ebeling, A. W. and M. A. Hixon. 1991. Tropical and temperate reef fishes: comparison of community structures. Pages 509–301 *in* P. F. Sale, ed. The ecology of fishes on coral reefs. Academic Press, Inc., San Diego, California.

Feigenbaum, D., M. Bushing, J. Woodward and A. Friedlander. 1989. Artificial reefs in Chesapeake Bay and nearby coastal waters. Bull. Mar. Sci. 44: 734–742.

Friedlander, A. and J. Parrish. 1998. Habitat characteristics affecting fish assemblages on a Hawaiian coral reef. J. Exp. Mar. Biol. Ecol. 224: 1–30.

Godwin, J. R. and R. K. Kosaki. 1989. Reef fish assemblages on submerged lava flows of three different ages. Pacific Sci. 43: 289–301.

Hueckel, G. J. and R. M. Buckley. 1987. The influence of prey communities on fish species assemblages on artificial reefs in Puget Sound, Washington. Environ. Biol. Fishes 19: 195–214.

Luckenbach, M., R. Mann, and J. A. Wesson. 1998. Oyster reef habitat restoration. A synopsis and synthesis of approaches. Virginia Institute of Marine Science Press. In press.

Mann, R. and J. Harding. 1997. Trophic studies on “restored” oyster reefs. Annual report submitted to U.S. EPA Chesapeake Bay Program, Annapolis, Maryland 21043.

_______ and _________. 1998. Continuing trophic studies on “restored” oyster reefs. Annual report submitted to U.S. EPA Chesapeake Bay Program, Annapolis, Maryland 21043.

Minitab 10.5. 1995. Minitab 10Xtra user’s guide. Minitab Inc., State College, Pennsylvania. 298 p.

Nestlerode, J., M. Luckenbach, F. O’Biern and G. Coates. In preparation. Comparisons of resident assemblages associated with constructed oyster reef habitats.

Roberts, C. M. and R. F. Ormond. 1987. Habitat complexity and coral reef fish diversity and abundance on Red Sea fringing reefs. Mar. Ecol. Prog. Ser. 41: 1–8.

Rountree, R. A. 1989. Association of fishes with fish aggregation devices: effects of structure size on fish abundance. Bull. Mar. Sci. 44: 960–972.

Sale, P.F. 1991. The ecology of fishes on coral reefs. Academic Press, Inc., San Diego, California.

Sedberry, G. R. and R. F. Van Dolah. 1984. Demersal fish assemblages associated with hard bottom habitat in the South Atlantic Bight of the U.S.A. Environ. Biol. Fishes 11: 241–258.

Stephan, C. D. and D. G. Lindquist. 1989. A comparative analysis of the fish assemblages associated with old and new shipwrecks and fish aggregating devices in Onslow Bay, North Carolina. Bull. Mar. Sci. 44: 698–717.

Wenner, E., H. Beatty and L. Coen. 1996. A method for quantitatively sampling nekton on intertidal oyster reefs. J. Shellfish Res. 15: 769–775.

Zar, J. H. 1996. Biostatistical analysis, 3rd ed. Prentice Hall, New Jersey. 662 p.

Date Submitted: May 6, 1998. Date Accepted: November 23, 1998.

Addresses: *Department of Fisheries Science, Virginia Institute of Marine Science, P.O. Box 1346, Gloucester Point, Virginia 23062.* (J.M.H.) *jharding@vims.edu;* (R.M.) *mann@vims.edu.*