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FINAL REPORT

ECOLOGICAL FUNCTIONS OF CONSTRUCTED OYSTER REEFS ALONG AN ENVIRONMENTAL GRADIENT IN CHESAPEAKE BAY

by

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Summary

Oyster reef habitat restoration within the Chesapeake Bay has as its objectives not only the enhancement of the commercially important oyster stocks, but also the restoration of associated assemblages of organisms and, most importantly, the restoration of ecological functions associated with natural reef communities. Despite our efforts to date, many uncertainties still exist with respect to achieving these restoration goals. These include long-term information on the temporal sequence of community development on new reef substrate, evaluating oyster recruitment patterns (a) across restored reef systems and (b) in relation to resident brood stocks.

In this study we sought to characterize the development of resident assemblages on and transient visitors to a variety of constructed reef bases. This study provided a means with which to examine a variety of inter/intra-system processes by coupling the monitoring of resident reef assemblages with characterizations of the transient assemblages (particularly higher trophic levels) in different reef systems. Models of oyster reef community interactions can be generated by synthesizing oyster population data and trophic information over small (system wide) and large (regional) geographic scales.

Replicated small reef bases (ranging from 0.02 to 0.25 acres), constructed at Fisherman's Island, VA in the summer of 1996, were monitored for the development of attached organisms, mobile organisms on the reef surfaces and nekton adjacent to the reefs and in nearby habitats. Year three of this study continued investigations of (*i*) oyster recruitment (from the reeefs and shellstrings), (*ii*) oyster growth and survival (from Fisherman's Island reef), (*iii*) epifaunal assemblages on the reef surface and interstices, (*iv*) comparing oyster recruitment on live oysters versus oyster shell, (*v*) resident finfish and mobile epibenthos, (*vi*) transient finfish and other nekton associated with the reefs and adjacent habitats, and (*vii*) testing an underwater video monitoring system, which will allow us to better characterize utilization of the reefs by mobile species and clarify trophic links. Additionally, much of the samples gathered in previous years were processed from the Fisherman's Island system and the Piankatank River that will be used in the future to model trophic interactions on the reefs and among the different reef systems.

Though development of the assemblages is still underway, several patterns have begun to emerge from these data. These findings serve to reiterate the conclusions of the previous years reports, e.g., there is considerable interannual variation in recruitment density of oysters, which for the past two years has been quite low. Secondly, the handling and production techniques for the surf clam shell and coal ash, respectively, contribute to the inclusion of small particles which fill interstitial spaces on reef bases constructed of these materials. This results in limited habitat availability within the fabric of the reefs constructed with these non-traditional cultch material, poor oyster recruitment and survival, and reduced diversity on these reefs relative to oyster shell reefs. Survival of oysters on the oyster shell reefs has generally been good and multiple year classes are currently present. We have found that important factors relating to successful oyster production to be adequate interstitial space, vertical relief to provide refuge from siltation and predation and the fact that high recruitment numbers may prevail over the limitations of the cultch material.

Over 100 species of invertebrates and finfish have been found associated with or living on the reef surfaces. Results from substrate baskets placed within the reefs further indicate the importance of interstitial space in the development of resident reef assemblages. Fifty-seven mobile, transient species, primarily fishes but also including decapods, mollusks and reptiles, have been collected on and adjacent to the reefs to date. There was a greater number of fish species associated with the Fisherman's Island reefs that with the Piankatank River reefs. This is attributed primarily to the location at Fisherman's Island at the confluence of the bay and the ocean - the probability of capturing species originating from both is greatest.

A conceptual model outling relationship between species and structures and troophic linkages is presented. The primary conclusions from this model is that there are great similarities in relationships derived from both systems. In addition, we have documented a direct link for the oysters some of the top predators that visit the reefs. Based on gut contents was can link oyster larvae to reef fishes (gobies, blennies) which in run can be linked directly to striped bass. Oyster recruitment was found to be greatest associated with oyster shell as opposed to live oysters. A possible reason for this phenomenon was the greater interstitial space associated with the shell.

The results of the studies in both the Fisherman's Island and Piankatank River have progressed the information base upon which reef restoration is founded. The increased emphasis on the construction of three-dimensional reef structures in Virginia for oyster restoration derives from the early signs of success at the Piankatank River and Fisherman's Island.

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Introduction

Restoration of shellfish habitat embodies several different issues and goals, ranging from water quality indicators to fisheries enhancement to restoration of ecological function. Until recently the latter has received minimal attention from researchers and resource managers. There is, however, a growing recognition that in some coastal systems assemblages of molluscan shellfish (e.g., oyster reefs, mussel beds and clam beds) can have significant impact on community and landscape level processes. On some rocky shores mussels can be *keystone species* (sensu Paine 1966), interacting strongly with other species via trophic and habitat links. Numerous examples exist of filtration by dense bivalve populations controlling water column phytoplankton dynamics (e.g, clams in San Francisco Bay: Cloern 1982; cockles and mussels in the Oosterchelde estuary: Smaal and Haas 1997; zebra mussels in the Hudson River: Roditi et al. 1996; oysters in a South Carolina salt marsh: Dame et al. 1986, also see Dame 1996 for a review of shellfish impacts on materials fluxes).

Frequently, shellfish restoration is considered synonymous with fisheries stock enhancement. Wild shellfish stocks in the United States support numerous valuable fisheries (e.g., Atlantic and Gulf coasts: MacKenzie et al. 1997a, Pacific coast: MacKenzie et al. 1997b), most of which are in decline, owing to overfishing, habitat decline and disease pressures (sometimes, see Rothschild et al. 1994). Efforts to sustain these fisheries by developing brood stock sanctuaries, supplementing hard substrate on the bottom, relocating stocks and occasionally supplementing natural populations with hatchery-reared stocks are underway in most coastal states in the U.S. Such efforts have not generally had the broader goal of habitat restoration, but merely fisheries enhancement (reviewed in MacKenzie 1983, 1996a,b).

Both oyster fishery enhancement and ecological restoration generally include the placement of various substrates on the bottom to promote increased oyster recruitment. The most commonly used substrates are fresh and fossil oyster shells, but shortages of these shells in some regions have led to use of other materials, including surf clam, *Spisula solidissima,* shells in Virginia (Wesson et al. 1999), granite, concrete and gypsum in Louisiana (Haywood et al. 1999) and stabilized coal combustion by-products (coal ash pellets) in Virginia (Andrews et al. 1997). While these and other studies have addressed the suitability of alternative materials as cultch for initial oyster settlement, none have fully explored the consequences of using these materials for long-term oyster population and reef community development.

In addition to planting of shell, oyster restoration efforts frequently involve placement of oysters onto to reefs or areas of shelled bottom. Frequently, this is done solely for the purpose of enhancing the short-term abundance of harvestable oysters, as in Connecticut where wild seed oysters are transplanted onto grow-out grounds or Maryland where hatchery-produced oyster spat are seeded onto oyster reefs and later harvested. Alternatively, large oysters may be seeded onto reefs to serve as brood stock for future reef development in areas with low standing stocks and natural recruitment. This approach has been employed over the past several years at a few reef sites in Virginia. First, in 1996 large oysters were transferred from Tangier Sound and planted in high concentrations (~200 m^{-2}) on a constructed reef in the Great Wicomico River. The following year oyster recruitment increased approximately two orders of magnitude on the reef. These results have led to wider interest in the management approach of stocking sanctuary reefs with brood stock oysters in an effort to accelerate oyster population development. Wild brood stock oysters have been added to constructed reefs in the Piankatank River and in the Lynnhaven and Elizabeth Rivers. In Virginia, hatchery-reared oysters have been placed on newly constructed reef bases over the past few years. While increased oyster recruitment has generally been reported from the reefs after such additions, the data are variable and sometimes equivocal. Presumably, the concentration of spawning stock has led to increased larval abundance and hence recruitment. While this is a logical conclusion, the studies to date have failed to distinguish between the effects of enhanced adult oyster abundance on spawning and settlement. From laboratory studies, it is clear that adult oysters enhance the settlement of con-specific larvae through the production of peptides which stimulate larval settlement response (Tamburri et al. 1992; Turner et al. 1994). In the field, on large-scale reef restoration efforts, the effects of concentrations of adult oysters on larval settlement have yet to be determined.

Over the past several years oyster reef restoration has been justified from an ecological perspective, particularly for its habitat value for other organisms (Coen and Luckenbach 1999; Luckenbach et al. 1999). Indeed, it seems reasonable that oyster reefs qualify as *essential fish habitat* under the Manguson-Stevens Act (U.S. Public Law 94-265; Coen et al. 1999). Unfortunately, natural, non-degraded oyster reef habitats no longer exist in this region. Thus, reference sites for establishing natural ecosystem structure and function are not available. Moreover, large-scale replicate experiments characterizing community development on artificial, "restored" reefs have not previously been conducted. Towards that end we have been conducting long-term research projects at Fisherman's Island and the Piankatank River, Virginia, to investigate temporal patterns of species colonization, abundance and growth in reef habitats constructed of various materials and to compare the assemblages on restored reefs to adjacent unmanipulated habitats.

Several studies have reported community profiles for macroinvertebrates and fishes associated with oyster reefs along the south Atlantic and Gulf coasts (Dame 1979; Bahr and Lanier 1981; Stanley and Sellers 1986; Zimmerman et al. 1989), but systematic characterization of community development on oyster reefs in the lower Chesapeake Bay is lacking. Recent monitoring studies have provided some data on oyster distribution in relation to tidal height on constructed reefs in the Piankatank River (Bartol et al., 1999) and on the Eastern Shore (Luckenbach and Wesson, unpublished data). Breitburg (1999) has described utilization of small artificial reefs by larval and juvenile fishes in the upper Bay, but neither spatial nor temporal patterns of finfish utilization have been described for oyster reefs in Virginia waters. Foraging behavior of the American Oystercatcher, *Haematopus palliatus*, on oyster reefs in Virginia was described by Cadman (1980) and in a subsequent study (Tuckwell 1996) was shown to have changed after further decline in oyster abundance.

This research hsa undertaken a suite of experiments and monitoring programs designed to characterize and understand the development of oyster reefs and associated communities on constructed reefs at two locations in Chesapeake Bay—the Piankatank River (a mid-Bay tributary) and Fisherman's Island (near the Bay mouth). The reefs at the two locations have very different origins and designs (see Site Description below); the early studies on each were conducted by different groups (Piankatank: Mann, Harding, Bartol & Southworth; Fisherman's Island: Luckenbach, O'Beirn & Nestlerode) and addressed different specific issues related to reef development. Each detailed the early stages of oyster population growth and community development on these reefs; which has been the subject of our earlier reports and publications (Bartol and Mann 1999; Bartol et al. 1999; Harding and Mann 1999, in review; O'Beirn et al. in review). Additionally, each program focused on some specific issues [e.g, Piankatank: larval production (Harding and Mann in review); Fisherman's Island: alternative substrates (Andrews et al. 1997)]. In this phase of the research, we sought to (*i*) continue monitoring community development on the comparatively younger reefs at Fisherman's Island and investigate factors affecting development of oyster populations, (*ii*) further elucidate of trophic linkages at the two reef systems and (*iii*) make some cross-site comparisons relative to reef development. Though far from complete, we believe that these studies are beginning to clarify how several important features of the design, construction, location and management of reefs contribute to development of oyster populations and associated communities. Furthermore, by beginning to clarify trophic patterns and energy flows through reef communities we are approaching a fuller understanding of how oyster reef restoration can affect system-level ecological processes in the Chesapeake Bay.

Objectives

The long-term goal of our program on oyster reef community restoration is an improved understanding of the ecological functions of restored oyster reefs, related to both to environmental conditions and restoration approaches. Achieving this will require long-term monitoring of successional patterns, experimental manipulations and cross-system comparisons. Our specific objectives in this phase of the work were:

1. to build on our existing databases characterizing community succession on constructed oyster reefs;

2. to relate the development of oyster populations and reef communities to design characteristics of the reefs (i.e., substrate type and elavation);
3. to evaluate the effects of living oysters on intraspecific recruitment to reefs;
4. to characterize trophic linkages within reef communities; and,
5. to synthesize our current information on the structure and function of oyster reef communties over small (individual reef) and large (regional) geographic scales.

Site Descriptions

The major reef systems in this study, the Piankatank and Fisherman's Island systems have been the sites of multi-year studies by the P.I.'s.

Studies were focused on the Palace Bar Reef, Piankatank River and Fisherman's Island, VA (Figure 1). The Palace Bar Reef is an intertidal oyster shell reef constructed in 1993, adjacent to the historic Palace Bar oyster grounds. The entire reef is 1 hectare of which approximately 70% is oyster shell and the remainder is crushed clam shell. The reef is large but unreplicated. Roane Point is a sandflat in the vicinity of the Palace Bar Reef and used as a control site for subsequent assessments of the reef fish communities. In 1997, the Virginia Marine Resources Commission planted brood stock oysters in the vicinity of the Palace Bar Reef.

The study site located near Fisherman's Island, is in the vicinity of the mouth of Chesapeake Bay (Fig. 1). This is a polyhaline site with a tidal amplitude of approximately 1.25 m. Marsh islands, intertidal flats and subtidal bottom within the area are all owned by the Commonwealth of Virginia and the federal government, and are managed by the U.S. Fish & Wildlife Service as part of the Eastern Shore of Virginia National Wildlife Refuge. There are no oyster harvesting activities on or near these reefs.

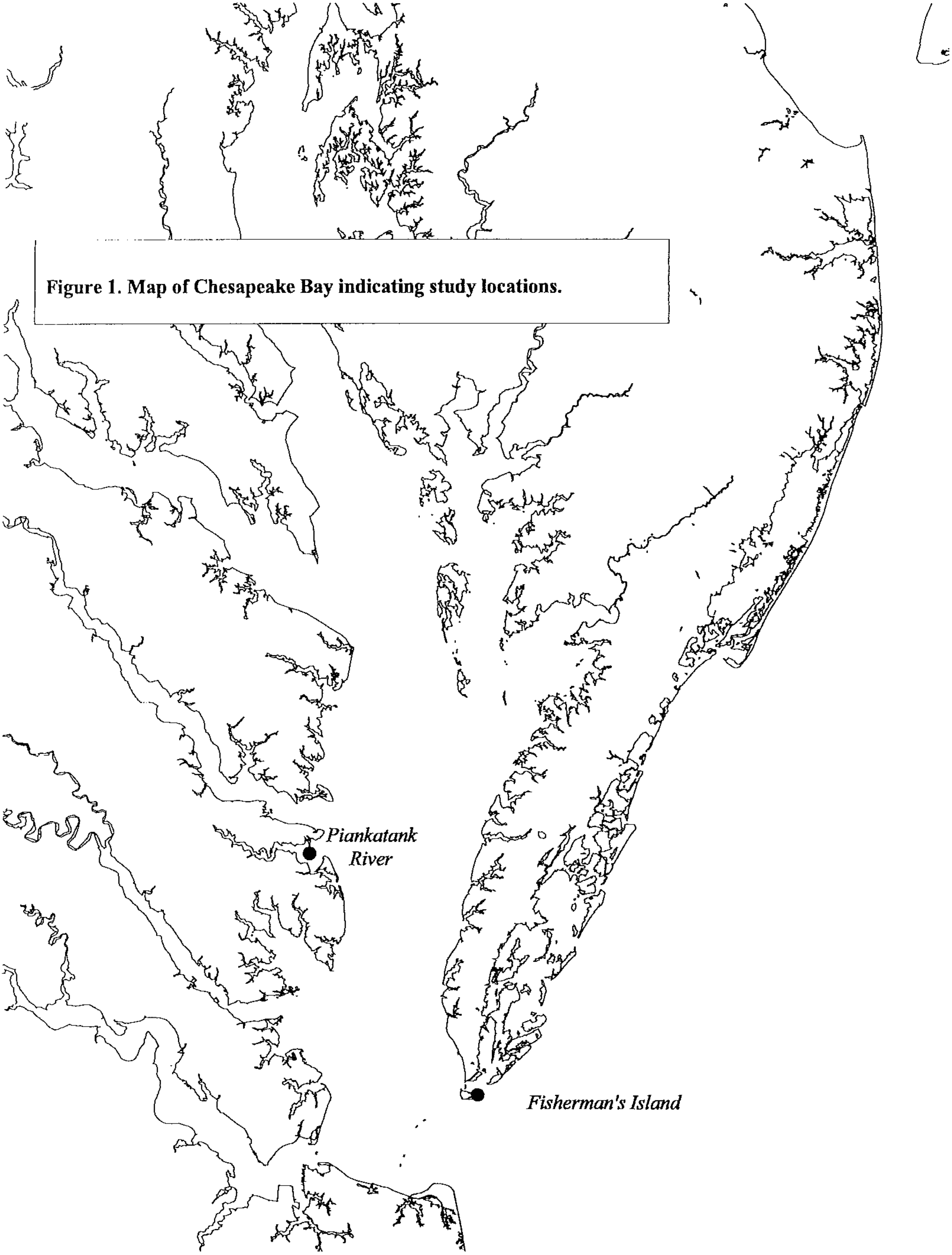
In April 1995 two intertidal reefs, approximately 8,000 m^2 each, were constructed at the site as part of a remediation project funded by the Chesapeake Bay Bridge Tunnel District.

Approximately by planting approximately 40,000 bushels (~1973 m^3) of surf clam (*Spisula solidissima*) shells were planted on two intertidal mudflats (see A and B in Fig. 1). The reefs extend from ~ 0.5 m below to 0.5 m above MLW; the reef designated A in the figure has a greater extent of surface area at higher tidal elevation than reef B. Irregular patterns of mounds, ridges and furrows exist across the reef surface as a result of the planting technique (deployment from barges by water cannon). Hereafter, the clam shell reefs, constructed in 1995, are designated as 95 Clam reefs.

Eleven additional reefs (Fig. 1) were constructed in 1996 with funding from the Aquatic Reef Habitat Program, Virginia Power Co. and the Virginia Oyster Repletion Program. Five of these reefs were constructed with surf clam shells, two with oyster (*Crassostrea virginica*) shells and four with stabilized coal combustion by-products (fly ash). The latter material, constructed using 88% fly ash stabilized with 12% (w:w) Portland cement, is described in greater detail in Andrews et al. (1997) and has been shown to provide an environmentally suitable substrate for oyster settlement and growth (Alden et al. 1996). Limited availability of oyster shells resulted in the smaller number of reefs (n=2) constructed with that material. A total of 39,920 bushels (1,965 m^3) of surf clam shells, 7,000 bushels (325 m^3) of oyster shell and 20,150 bushels (994 m^3) of coal ash pellets were used to construct the reefs. Two reefs of each substrate type, ranging in size from 162-364 m^2, were selected for monitoring (reefs 1-6 in Figure 1). The reefs were oriented in a North-South direction, with 7 reefs on the east side and 4 reefs to the west of a channel. A channel ranging in width from 10-40 m separates the two rows of reefs. Hereafter, the reefs constructed in 1996 are designated as Oyster, 96 Clam and Ash reefs.

Additional spatfall monitoring and oyster stock assessment were conducted at the James River, Great Wicomico River and Pungoteague River reef sites and additional monitoring sites (e.g., the Coan River and the Lynnhaven) were added dependent upon the activities of the Virginia Marine Resources Commission's restoration efforts.

Figure 1. Map of Chesapeake Bay indicating study locations.



Study Design

Recruitment Monitoring - Spatial and temporal patterns of oyster settlement were examined using "shell strings" as described below. Monitoring was carried out at Fisherman's Island, Pungoteague Creek and the Piankatank River as well as numerous other sites in Virginia. Sampling consists of shell string monitoring at 6 stations along the length of the river for each of the Piankatank and Great Wicomico Rivers, and 13 stations in the James, for a 16 week period from May through September (the spawning and settlement period for oysters in these locations). Two shell string stations were established at Fisherman's Island and one site on Pungoteague. Shell strings consist of twelve oyster shells strung on a metal wire, with all but the top and bottom shell being examined for the presence of newly settled spat and shell scars upon retrieval. They are deployed for periods of one week, the cumulative total of the 16 exposure periods providing both spatial and temporal definition of the settlement at the sites over the reproductive season.

Oyster Abundance Assessment - A hydraulic patent tong (sampling area $1m^2$) was used in the Fall 1998 for quantitative stock assessment of all reefs (with the exception of Fisherman's Island reefs). Upon retrieval the sample was washed on the cull board and processed for counts of live oysters as spat (young of the year), small oysters (less than 3 inches = 76 mm), and market (greater than 3 inches) oysters. In addition, data were collected on dead oysters with paired valves (boxes, indicating recent mortality). The volume of shell retrieved in each tong was also recorded as an index of the quantity of cultch material present at each station.

Sampling of the reefs at Fisherman's Island for determination of oyster abundance and size was carried out on a quarterly basis. On each of the reefs selected for monitoring (two of each substrate type; A,B and 1-6 in Figure 1) quadrat samples (n=3) were collected from each of three tidal heights. The tidal heights were 0.25 m below Mean Low Water (hereafter called Subtidal), at Mean Low Water (hereafter called MLW) and 0.25m above MLW (hereafter, called Intertidal).

Replicate quadrats (0.0625m^2; n=3) were haphazardly placed within each tidal height stratum (Subtidal, MLW and Intertidal) on replicate reefs (n=2) of each reef substrate type (Oyster, 95 Clam, 96 Clam and Ash) to give a maximum of 72 samples per sampling period. All of the reef substrate was retained to a depth of 15 cm within each quadrat sample, but did not include underlying sediments if encountered. All of the samples were transported to the laboratory on ice (if necessary) and were processed live. Processing of the samples involved the enumeration of all live oysters in each sample. In addition, 50 oysters from each tidal height, on each reef sampled, were measured to the nearest 0.1mm.

Recruitment on Live vs. Dead Shell - We evaluated, albeit on a small scale, the impact which live oysters have on oyster recruitment on the reef surface at the Fisherman's Island oyster reefs. Previous efforts have utilized dead clean oyster shell, sampled monthly. This sampling protocol only provides estimates of the initial stages of colonization and does not account for the impact that ever increasing oyster biomass might have on community structure. Therefore, we conducted an experiment to test the hypothesis that oyster recruitment rates would be greater on reefs with adults as a result of attraction to conspecifics (sensu Tamburri et al. 1992; Turner et al. 1994). Specifically, we tested whether oyster recruitment varied over small scales between treatments with live adult oysters and dead oyster shell.

Plastic-coated wire mesh baskets (40cm x 40cm x 8cm) containing live oysters and dead shell were deployed on the two oyster reefs within the system at two tidal heights--high intertidal and subtidal. At each tidal height on each reef, two baskets (of each substrate type) were deployed for a period of one month and replaced with fresh clean substrate. Also, three baskets (of each substrate type) were deployed for a period of six months, commencing in May 1998 and terminating in November 1998. It was hoped that the two sampling regimes would give an estimate of both the short-term and cumulative oyster recruitment and community development, within the sampling baskets. The samples were transported to the laboratory on ice where oysters were identified and enumerated.

Continued Characterization of Assemblages at Fisherman's Island

Because the Fisherman's Island reefs are younger in age than the Palace Bar Reef in the Piankatank and community development has been monitored for a longer period of time on the latter, we continued during the past year to monitor the development of resident and transient assemblages of organisms at the Fisherman's Island reefs. Monthly sampling of all reef types was continued as previously, as were the quarterly samplings of reefs and adjacent waters. Sampling for the Fisherman's Island reefs included: (1) epibenthic macroalgae and invertebrates associated with reef constituent material; (2) infaunal macrobenthos; (3) resident fishes; (4) transient fishes and nektonic invertebrates; and (5) oyster recruitment on reef constituent material.

Methods for characterizing the assemblages at the Fisherman's Island site have been described in detail in previous proposals and reports. Briefly, they included quantitative quadrat and sediment core samples for characterizing epifaunal and infaunal organisms on the reef surfaces and adjacent sedimentary habitats, substrate baskets embedded within the reefs for characterizing recruitment of sessile and motile organisms and, nekton samples using otter trawl, encircling seine (Fig. 3), video monitoring and gill netting.

Epibenthic macroalgae and invertebrates (Fisherman's Island) - We continued to describe the development of the fauna and flora on the reef surfaces from quarterly samples collected during spring low tides when the reefs were fully exposed. Three 0.062-m^2 quadrats were haphazardly located within tidal height strata--High (10-25 cm above MLW), Middle (~MLW) and Low (10-25 cm below MLW)--on each of two replicates of each reef type (oyster shell, clam shell and coal ash). All shell and/or coal ash with attached materials were removed to a depth of 15 cm and placed in a mesh bag. Samples were transported to the laboratory in ice chests and maintained in flow-through seawater tanks until processing. All samples were processed within 4 days of collection. Live and recently dead (still articulated) oysters were enumerated and measured; all other organisms were identified to the lowest practical taxonomic level and appropriate abundance measures for each taxon recorded (e.g., counts for solitary organisms, percent cover for encrusting colonial forms and biomass for macroalgae).

Sampling for transient fishes and mobile macroinvertebrates -It is likely that a large number of species utilize reef habitats only intermittently as temporary feeding grounds or refugia. Quantifying this component of the reef community is difficult and no one approach has proven entirely adequate. Thus, we have employed several methods in this study.

We have relied primarily on three different gears to quantify components of this assemblage, (1) an encircling seine, (2) a 3 m otter trawl and (3) gill nets (100 m) with panels ranging from 1" to 4" mesh size. Each has proven effective in capturing a different component of the nekton. A version of the encircling seine (with 1/4 inch mesh) was tested during the summer of 1997 and the data are reported below. We have since developed a new version with 1/8 mesh and have been using it for quantitative sampling from April – August, 1999. The encircling seine, traps nekton against the reef at mid-tide (see Figure 2). This large (30 m x 1.7 m), heavily weighted seine is remotely deployed and developed to generate a minimal disturbance to the area so as not to scare off wary target organisms prior to capture. Because of strong currents and irregular bottom topography in the sampling area, this seine is designed so that the lead line is sufficiently heavy, flexible, and continuous to avoid the formation of gaps between the net and the substrate. Likewise, the floatation on the top of the net consists of foam-core line to maintain the entire length of the top of the net at the water surface.

Sampling takes place on either a rising or falling tide when the crest of the reef is exposed thus, the emergent portion of the reef itself acts as a barrier. The seine is anchored at one end on the reef and stealthily deployed from the deck of a small boat (1.5 m in length) which is pulled around the sampling area hand over hand using a long rope. The net encircles a measurable area adjacent to and including the submerged portion of the reef. The encircled area is closed in with the seine and trapped nekton are forced into a mesh box trap (1.2 m x 1.2 m x 2.4 m). The trap is then removed from the water and captured specimens are identified, enumerated, and measured. A representative portion of each species was immediately frozen in the field and stored at -80°C for later gut content analysis.

Gear efficiency, or the proportion of target organisms collected from the unit sample area (Rozas and Minello 1997), was measured by mark and recapture of target species during gear deployments. No gear is 100% efficient in capturing estuarine nekton, but by measuring the sample recovery efficiency of the gear, the sampling data may be used to accurately and precisely estimate actual densities and temporal changes in reef nekton populations. Three replicate samples are collected from each of three reef base types (oyster shell, clam shell, and fly ash) each month around the full moon spring tide.

The Otter trawl and gill nets were deployed to compare transient species found in and around the reef areas with those found over a shallow, subtidal mud bottom (control; >100m) away from the reefs.

In addition to the aforementioned sampling techniques, an underwater video monitoring study was initiated to compare fish use of each reef type during high tide when the encircling seine cannot be used. Utilization of three reef area sub-habitats (reef interior, reef edge, and subtidal mudflat approximately 5 meters away from the reef edge) by nekton was monitored using small underwater video cameras (6 cm x 6 cm). The underwater video cameras we used were modified, wide-angle infrared security cameras placed in waterproof plexiglass housings. The cameras were small (6 cm x 9 cm) and the cables leading to recording platforms were maintained above the surface of the water to reduce the amount of introduced structure that may serve to attract fish. Cameras were mounted 20 cm above the substrate and a wood dowel (marked in 1 cm increments) was placed 25 cm in front of the camera. The corresponding substrate surface area of the camera's field of view in front of the dowel is 500 cm^2 and fish abundances could be expressed quantitatively. This dowel served as a reference point for estimating fish abundances (number per square meter of reef) and as a scale bar for estimating fish sizes. Nekton activity was recorded simultaneously at each of the three sub-habitats on either side of high tide (or for the reef interior, for as long as that sub-habitat is submerged). Nekton was identified to the lowest possible taxon and proportional abundances within each sub-habitat were calculated from video footage. Species abundances and size distributions from enclosure trap samples were used in ground-truthing video data.

Development of Trophic Structure Models - We used the data derived from the direct video observations and gut contents to produce a conceptual model of the trophic structure on the Fisherman's Island reefs. For the Palace Bar Reef in the Piankatank, we used the data from field surveys and gut analyses (Luckenbach et al. 1998; Harding and Mann in review a, b) and laboratory feeding studies (Harding 1999). We used these data to construct a general conceptual model of the food web structure and energy flow pathways on the restored reefs. Though we are not able to quantify energy flow between trophic levels, we do have standing stock estimates within trophic level and are able to characterize how the trophic structure changes in the first several years of reef development. Of particular interest were comparisons between food webs on the reef systems within the Piankatank River and those at Fisherman's Island near the Bay mouth. Finfish were categorized as *resident, semi-residents or transients* (sensu Burchmore et al. 1985) and species richness within each group compared across reef system. These classifications of fish species relate primarily to their usage of the reefs and not to their trophic levels. Consequently, the tentative model developed in this study should be classed as a hybrid of trophic levels and reef usage.

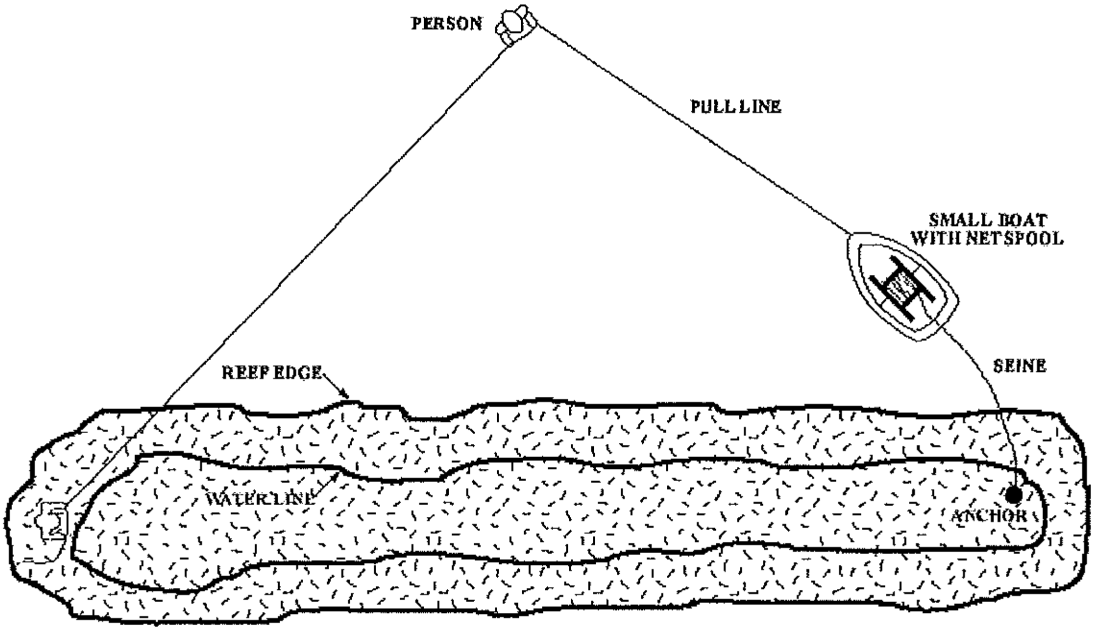
Table 1. Schedule of sampling events at Fisherman's Island.

Sampling Technique	Sampling Dates
Otter Trawl	July 28, Aug. 24, Sept.[1], Nov 2, Nov 30, Dec 21, Jan 28, Feb. 26, Apr. 22 and May 28.
Live vs. Shell baskets	May 29, June 30, July 28 ,Oct 4, Dec 12
Gill Net	June 16, Feb. 24, May 27
Benthic Samples	Aug. 24, Nov. 30, March 16, June 16
Encircling Seine	Sept. 17, 1998
Video monitoring	July 21, 28, August 4, 8, 1998
Substrate baskets	July 28, Oct. 1[2], 1998

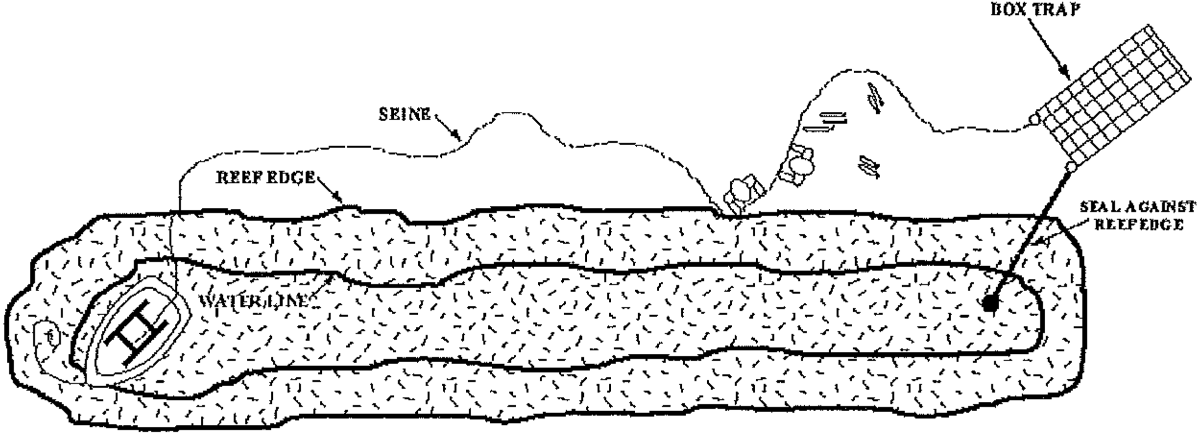
[1] Net damaged, no samples obtained.

[2] September sampling attempted on 9/29 & 9/30, but inclement weather force delays until 10/1.

Following Page – Figure 2. Encircling seine used to sample at Fisherman's Island



1. A 30 meter x 1.7 meter heavily weighted seine is laid out in a triangle from the deck of a small boat that is stealthily pulled through the water hand over hand by two people. This is done at the edge of a reef habitat when the water level is slightly below the crest of the reef. A portion of the reef must be exposed out of the water to serve as a barrier to fish movement and facilitate channeling the creatures into a box trap during sample recovery.



2. A 5-sided mesh box trap (1.2 m x 1.2 m x 2.4 m) is installed at one end of the seine and sealed against the reef edge. The seine is closed in from the other end, and the creatures are coerced into the box trap. The box trap is then closed off and lifted entirely out of the water for sample processing.

Results and Discussion

Oyster settlement - Oyster settlement recorded from the shellstring data is outlined in greater detail in Southworth et al. (1999). In summary, oyster settlement in 1998 throughout the Chesapeake Bay and vicinity was variable. Spatfall levels in some areas increased over previous years while others showed no appreciable increase while others still, e.g., the James River system, had the lowest spatfall recorded in the previous ten years. In the Great Wicomico River, oyster settlement was light and considerably lower compared to 1997 levels. This was surprising given the addition of brood stock oyster in the river in 1996 and subsequent increase in oyster settlement in 1997. Increased or similar levels of oyster settlement would be expected in 1998.

The Piankatank system first recorded oyster settlement much earlier (late-June) than the Fisherman's Island system and continued in a sporadic fashion until the end of September. Peak settlement was recorded between the end of August and the end of September. These data represent an increase over the previous three years (Table 2; Southworth et al. 1999). The increase, albeit modest, at the Piankatank River may have been influenced by the addition of brood stock oysters at two locations in the river in 1999.

Oyster settlement at Fisherman's Island was first recorded in mid-July and continued consistently through mid-October. The numbers of spat recorded were comparable with the previous years values and exceeded those values found in 1996. The sustained level of oyster settlement at the Fisherman's Island sites most likely can be attributed to the increase in standing stock of oysters located in the vicinity (see "oyster abundance on reef") and the increased area for settlement that planted shells have provided over the years.

The low settlement levels observed in the mainstem of the Chesapeake Bay have been attributed to a number of factors: 1) Water salinity during the spawning season was low throughout the bay and could have contributed to poor overall conditioning of brood stock and/or larval mortality in the water column. At Fisherman's Island sampling sites (where settlement level remained constant), there was no appreciable decrease in salinity levels throughout 1998 (J. Nestlerode, unpublished data). (2) As the summer progressed, oyster parasite prevalence (Dermo –

Perkinsus marinus) increased and could have further contributed to stress in the adult oysters and resulted in poor spawning potential. This was particularly apparent in the Great Wicomico River.

Table 2. Spatfall levels (cumulative sum of weekly spat/shell) recorded at the Fisherman's Island and Piankatank River systems for the years 1995-1998. FI (N)= Fisherman's Island North, FI(S) = Fisherman's Island South, PR(GP) = Piankatank River, Ginney Point, PR(PB)= Piankatank River, Palace Bar, PR(BP)= Piankatank River, Burton Point.

	SITES				
	FI (N)	*FI(S)*	*PR(GP)*	*PR(PB)*	*PR(BP)*
YEARS					
1995	72.2	8.4	0.5	1.0	1.0
1996	11.7	2.4	1.3	1.6	1.0
1997	29.8	11.9	0.0	0.0	0.7
1998	31.7	11.3	2.2	5.5	1.3

Comparing the two systems, in terms of overall spatfall numbers, it is important to bear in mind differences relating to reef construction material, the addition of brood stock oysters to the Piankatank system and the younger age of the reefs in the Fisherman's Island system. Nevertheless, the use of the same types of spat collectors at each site minimizes some differences between the systems and permits recruitment potential comparisons across systems. There has been an apparent increase in oyster settlement over the last 3 years. At Fisherman's Island in 1995, there was extremely high oyster settlement which was followed by a very low set in 1996 which was also observed in the Piankatank River. In 1997 there was a clear increase in spat set at Fisherman's Island, but a virtual failure of set in the Piankatank River. Following the additions of brood stock oysters to the Palace Bar Reef in the fall and winter of 1997, spatfall increased in 1998 at all three monitoring stations in the Piankatank (Table 2). The increase at Fisherman's Island is a result of natural population development. The increase in oyster settlement on the Piankatank is most likely attributable to brood stock oysters located in the system. However, given the patterns observed in the Great Wicomico River (outlined above) the settlement levels of oysters in future years in the Piankatank should be closely monitored to determine the true efficacy of such an enhancement strategy.

Oyster Abundance – Throughout the Chesapeake Bay, oyster numbers remain low (Southworth et al. 1999). However, in most areas sampled, the numbers of live oysters had increased in 1998 when compared to 1997 data. In some areas (Piankatank, Great Wicomico and the Rappahannock Rivers), these increases have been attributed to brood stock enhancement programs (adult and seed oysters moved from one area to another) which would serve to increase the immediate standing stock and the potential for increased recruitment. Southworth et al. (1999) reported that at the majority of sites sampled, market sized oysters (>76mm) comprised 18% or less of all the live oysters sampled. However, the greatest proportion of market sized oysters were found at lower salinity sites. Presumably, the salinities were such that disease levels at these sites were depressed and resulted in the persistence of older and hence, larger oysters.

Oyster abundances in the Piankatank system, based upon the patent tong survey of the reefs (Southworth et al. 1999), recorded a ten year high in terms of overall numbers of oysters. We attribute this to the location of brood stock oysters within the system and subsequent spawning and settlement on reefs. Areas of highest spatfall were immediately adjacent to the location where brood stock were planted. It is apparent that when standing stock increases, so do the overall spat and recruitment levels. It appears that this factor is important even in light of the vagaries associated with circulation patterns etc. in both systems. Again, the long-term future of the oyster populations must be closely monitored, given the spatfall levels recorded in the Great Wicomico River in 1998 (Southworth et al 1999) and the concerns outlined above (*Oyster Recruitment*).

Oyster abundances at Fisherman's Island were estimated from quarterly quadrat sampling at three tidal heights (high-intertidal, mid-intertidal and mean low water) on each of the three reef types (Clam, Ash and Oyster). Quarterly sampling commenced in August 1998 and continued through May 1999. The high intertidal samples on the oyster reefs (Fig. 3) and '95 clam reefs (Fig.4), for the most part, had the highest abundances of oysters when compared to the other tidal heights and reef types (Figs. 5 & 6). In fact, at all tidal heights oysters were found in greater abundances on the oyster and '95 clam reefs than the '96 clam and ash reefs which had comparable abundances of oysters throughout. At the three tidal heights, oyster abundances tended to fluctuate, with the greatest variability being evident at the low intertidal elevation. This is particularly true for the '95 clam shell (Fig. 5) and ash pellet reefs (Fig. 6). The variation in abundances across tidal height and reef substrate type can be attributed to seasonal factors. As with previous years, this pattern was consistent on all three reef types. The paucity of oysters at the Ash reefs at the intertidal height in November 1998 is most likely a sampling aberration given the patterns observed on the other reef types (Fig. 6) and previously on this reef type. The general trend of greater survival of oysters intertidally is consistent with other studies conducted in mid and southern Atlantic of the U.S. (Roegner and Mann 1995; Kenny et al. 1990; Michener and Kenny 1991; O'Beirn et al. 1995, 1996). These findings serve to highlight the importance of vertical relief when constructing oyster reefs in such environments as Fisherman's Island. Variation in oyster abundance across substrate type was evident at all tidal heights. The trend of greater abundance of oysters on the Oyster reefs compared to the Ash reefs and 96 Clam reefs at this tidal level was evident throughout. Visual comparisons of the reefs are all the more striking. Oyster shell support an uninterrupted layer of live oysters which are not apparent on the other substrates, both of which contain only sporadic clusters of oysters. In addition, the clam shell and ash pellets reefs mostly retained their original bleached white and dark gray colors throughout the study, respectively, indicative of little or no biotic development on the reefs.

We suggest that several factors related to the availability of interstitial space account for the observed differences in oyster abundance across the reefs. First, the reduced interstitial volume in the ash pellets and clam shell relative to oyster shell may have reduced the amount of surface area available for settlement of oysters. Bartol and Mann (1999) have reported oyster settlement onto shells 10 – 15 cm below the surface in a constructed reef in the Piankatank River, VA and J. Nestlerode and F. O'Beirn (unpublished data) have made similar observations in substrate baskets buried in these reefs at Fisherman's Island. The density estimates which we report here include oysters collected to a depth of 15 cm scaled to a flat surface area of the reef and do not account for subsurface area which might be available for oyster attachment. Thus, oyster settlement abundances onto the oyster shell reefs may have exceeded those on the ash and 1996 clam shell reefs. Since recruitment levels were low, however, and attachment surface was not in limited supply, it is unlikely that settlement differences accounted for most of the variation across reef type.

Differential mortality of oysters at the surface and below the surface of the reefs is a likely explanation for the abundance patterns which we observed. Bartol and Mann (1999) have demonstrated the value of interstitial space in aiding the survival of young oysters. The refuge afforded by the interstices protect the young oysters from predation and buffer them from climatic extremes. Considerably lower levels of interstitial space located on the clam shell and ash reefs most likely resulted in increased exposure of the young oysters to potential predators and other detrimental environmental factors (see reviews by White and Wilson 1996 and Shumway 1996).

Figure 3. Oyster abundance (Mean # oysters/m^2) on the Oyster Reefs at the High, Mid and Low intertidal levels

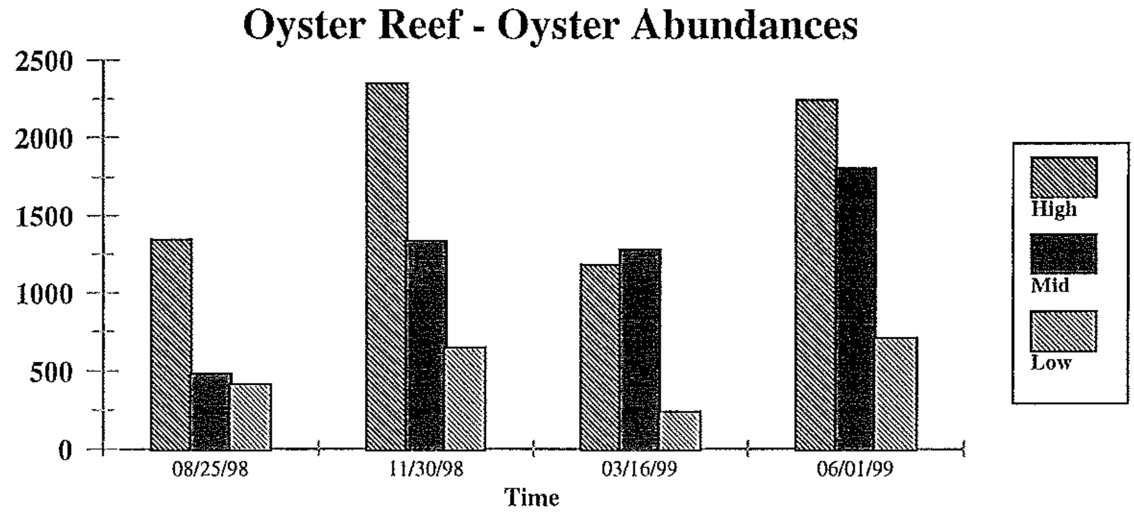


Figure 4. Oyster abundance (Mean # oysters/m^2) on the '95 Clam shell Reefs at the Mid and Low intertidal levels.

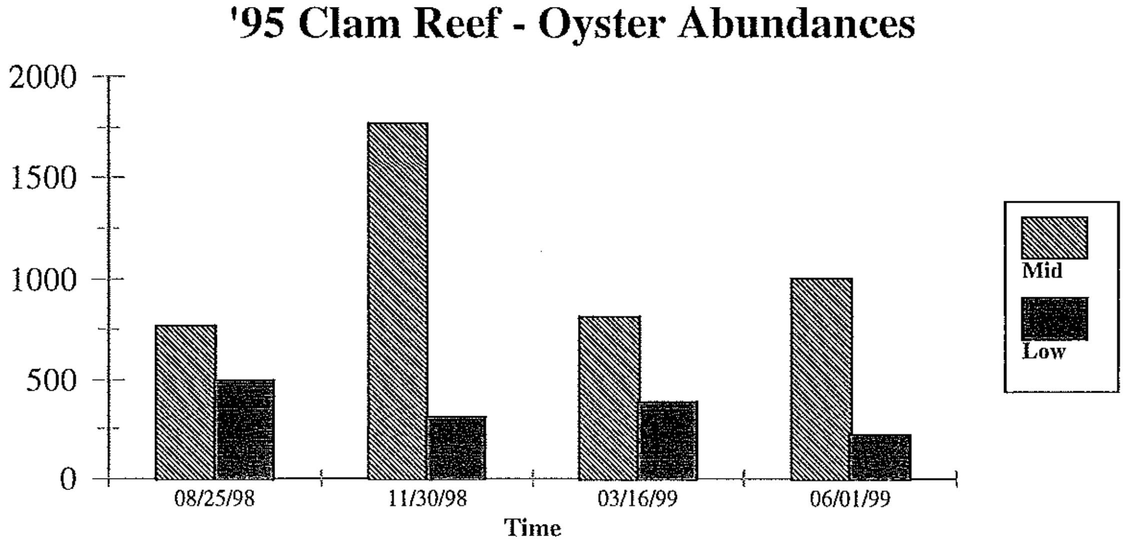


Figure 5. Oyster abundance (Mean # oysters/m^2) on the '96 Clam shell Reefs at the High, Mid and Low intertidal levels.

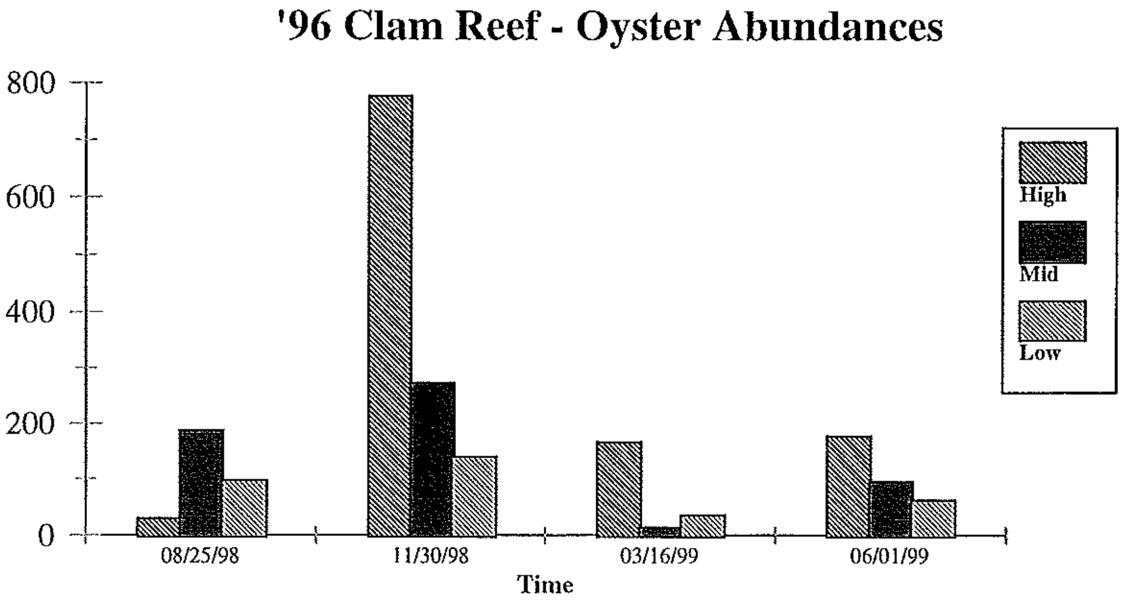
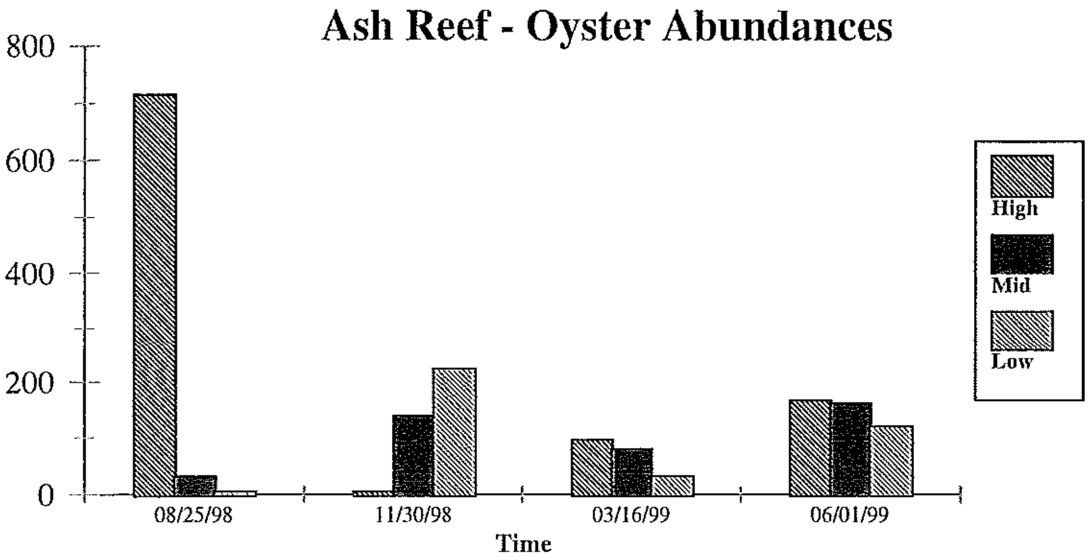


Figure 6. Oyster abundance (Mean # oysters/m^2) on the Ash Pellet Reefs at the High, Mid and Low intertidal levels.



Oyster Growth - Oyster sizes (from Fisherman's Island only) at the three tidal heights were pooled for each reef type and reported as frequency distributions within each sampling period (Figs. 7-10). The oyster size distributions observed from the reefs were consistent with those patterns observed in previous years. The suitability of the oyster shell substrate was further emphasized when examining the size data of oysters from each of the substrate types. Both the Ash and '96 Clam substrates were dominated by smaller oysters throughout the entire monitoring period. There was no persistence of larger (i.e., older) oysters in either of these reef types. The '95 Clam reefs and the Oyster shell reefs had relatively greater proportions of larger oysters representing multiple year classes. When viewed in conjunction with the abundance values from each of these reef types, this represents a substantial number of larger oysters which could contribute considerably to future reproductive events (Cox and Mann 1992) and, therefore, realize a primary goal of restoration efforts. In addition, the higher density of oysters resulted in a reef matrix that is likely to ensure the maintenance and stability of the valuable interstices.

Figure 7. Size frequency of oysters on the various substrate types in Summer 1998.

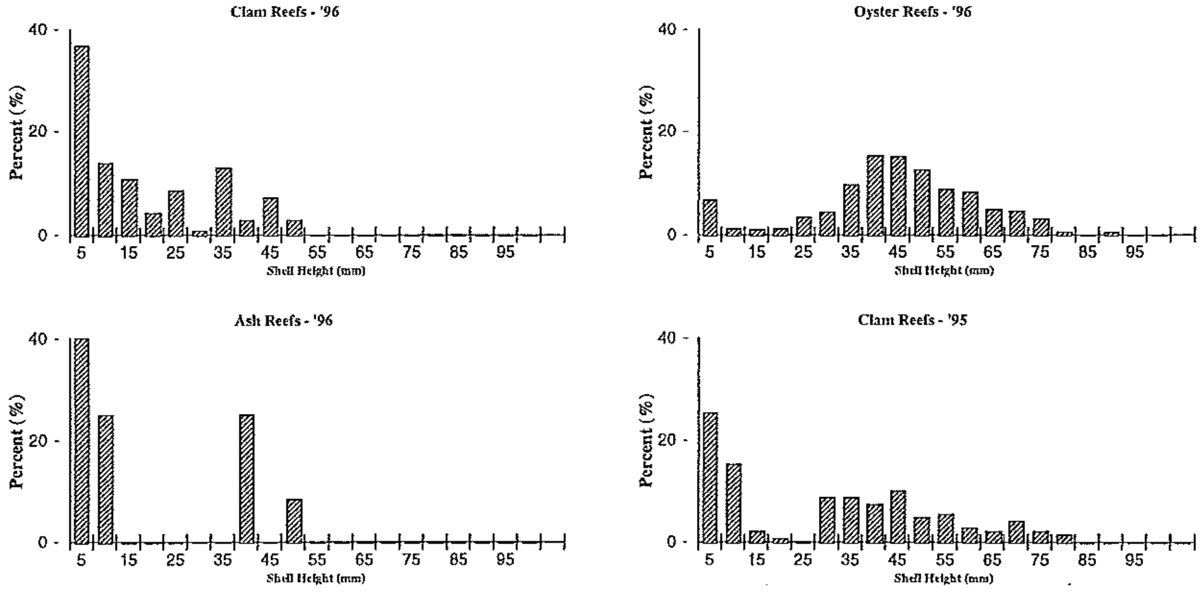


Figure 8. Size frequency of oysters on the various substrate types in Fall 1998.

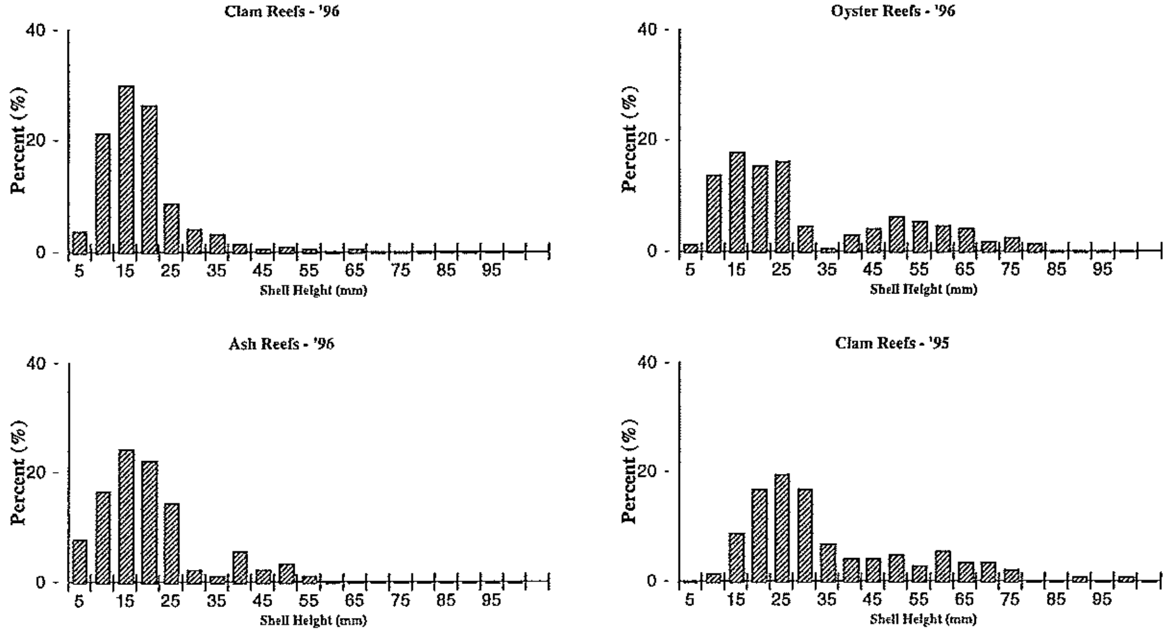


Figure 9. Size frequency of oysters on the various substrate types in Winter 1999.

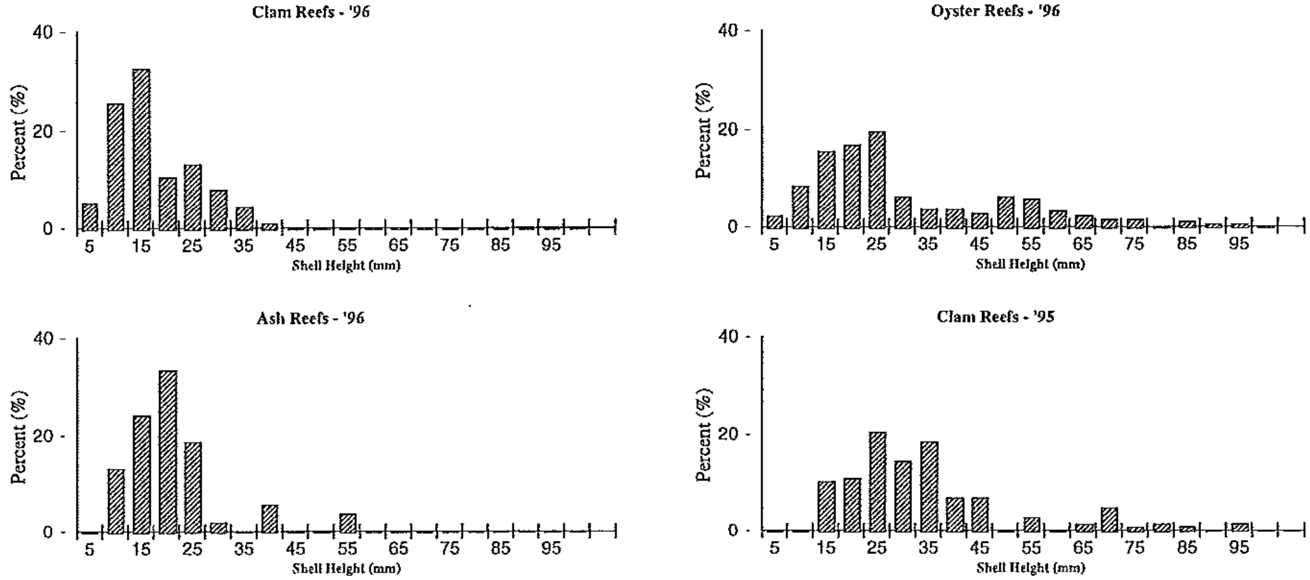
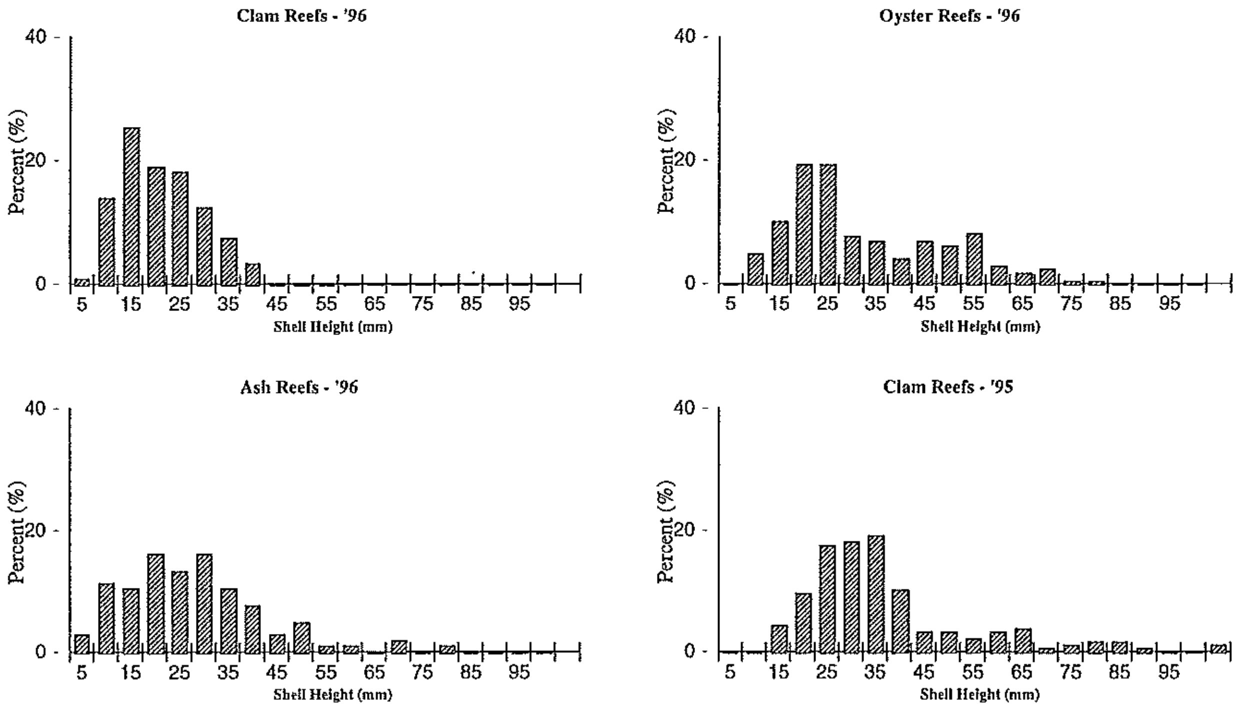


Figure 10. Size frequency of oysters on the various substrate types in Spring 1999.



Clam Reefs - '96

Oyster Reefs - '96

Ash Reefs - '96

Clam Reefs - '95

Recruitment on Live vs Dead Shell - In 1996, large brood stock oysters were added to constructed oyster reefs in the Great Wicomico River. Subsequent recruitment evaluation in the region for 1997, revealed the highest levels recorded ever for the area. Most likely, this large recruitment event is attributable to the transplanted oysters. The addition of high densities of brood stock oysters to the Great Wicomico reef in 1996 has spawned much interest in Virginia in the efficacy of stocking sanctuary reefs with spawning stocks. While our spatfall monitoring efforts are addressing the issue of larval supply to these and other reefs, the impact of high densities of adults on the recruitment of oysters to reefs remains in question. Analysis of the recruitment data in the live oysters vs. oyster shell study are presented (Figure 11). It is obvious that the major peak in recruitment occurred between July and September. No oyster spat were recorded prior to September. The September data (Figure 11A) reveal two interesting trends. One is that the highest recruitment occurs intertidally. This is not unusual, as spat lower down would be exposed to greater

Figure 11A.
September 1998

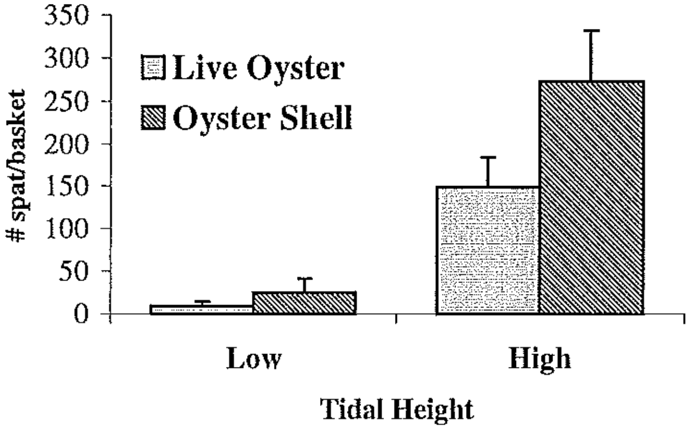
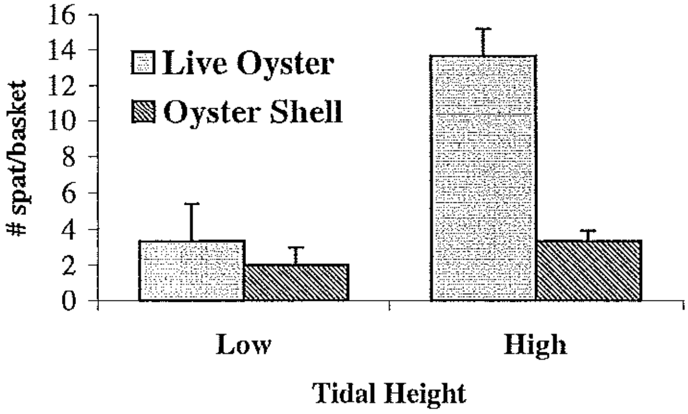


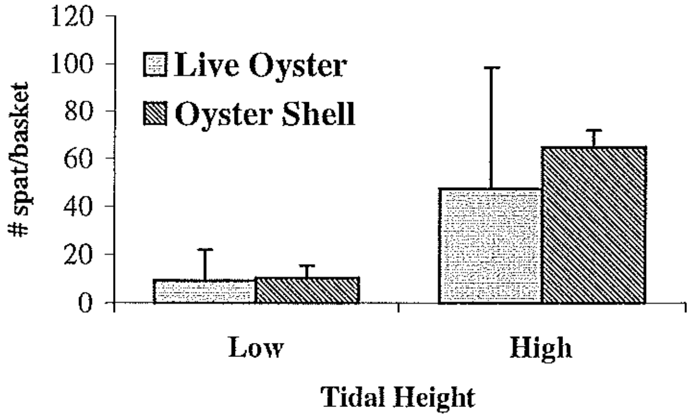
Figure 11B.
December 1998



threats of predation as well as siltation. The cumulative recruitment of oysters higher up the intertidal zone results in greater numbers intertidally than subtidally. The other trend suggests that greater numbers of spat are present in the baskets with dead shell as opposed to live oysters. This particular trend was reversed in the December samples (Figure 11B). The "Live oyster" baskets had greater numbers of spat than the oyster shell baskets. However, it must be considered that the overall oyster spat numbers in December were considerably lower than September. Therefore, this trend might be an artifact of the low sample numbers. The estimates of mortality of live oysters in the baskets are high – subtidal = 64.2% and intertidal = 53.8% . This is a further confounding aspect, by virtue of the fact that the majority of the spat recorded in the "live oyster" baskets would have been counted on dead shell. This might account for the observed patterns in the Seasonal baskets (Figure 12). Here again the numbers of oysters found intertidally were higher than those found subtidally in both basket types. However, the difference between the treatments is less pronounced. Also, the cumulative nature of discrete bimonthly samples is considerably greater that the values realized in the seasonal samples. Given the nature of oyster population biology this phenomenon is not surprising. The interstitial space of the substrates differed according to the substrate type used (Table 3). It is apparent that the Oyster shell substrate used in this portion of the study and the Oyster reef estimates taken from the existing reef matrix have the greatest interstitial volumes. There appears to be a concomitant decrease in the oyster recruitment and interstitial volume. We have discussed possible benefits the increased interstices

Figure 12

Seasonal-1998



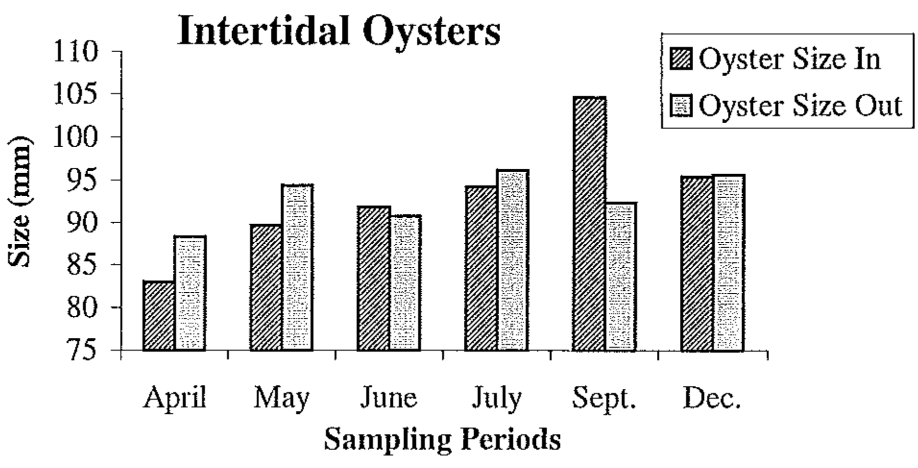
would confer on the oysters previously. The mortality experienced in both sets of oysters in this study is most likely attributed to siltation. The high levels of sediment in the baskets allied with the anoxic condition of the shells led to this conclusion. However, some dead animals located on the surface of the intertidal baskets had scarring consistent with predation induced mortality. The potential predators are numerous – however, the most likely suspects are blue crab (*Callinectes sapidus*) and oyster catchers (*Haemotopus palliatus*).

Table 3. Mean interstitial volume estimates from the substrate type used throughout the entire study related to oyster recruitment levels. Interstitial volumes are based on a 6 litre total container volume.

Substrate	Oyster Recruitment	Mean Volume
- Live Oyster	*Moderate*	3.8L
- Oyster Shell	*High*	4.6L
- Oyster Reef	*High*	4.0L
- Clam Reef	*Low/Moderate*	2.9L
- Ash Reef^	*Low/Moderate*	3.4L

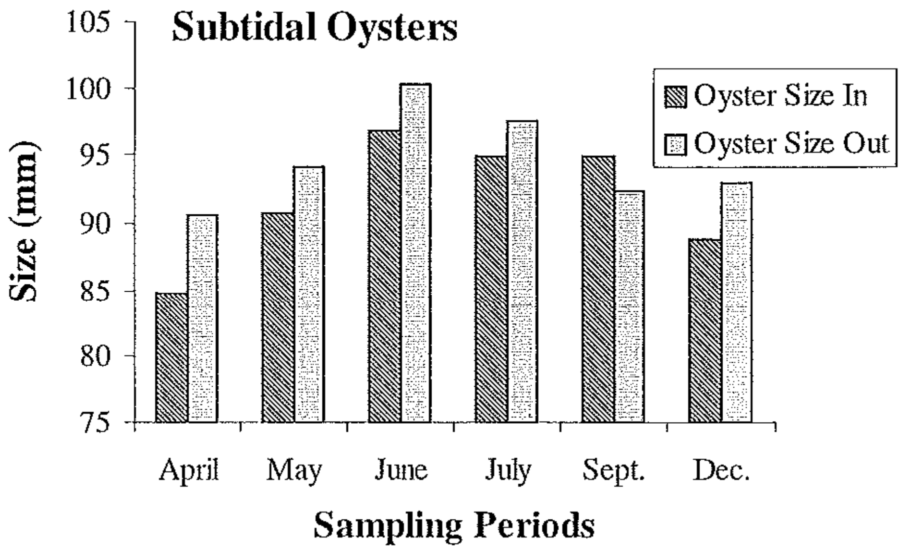
The live oysters used in this study were measured before and after their deployment in the baskets on the reefs. Obviously there were fewer animals measured upon retrieval due to the aforementioned high mortality levels. This precluded any valid statistical comparisons. However, certain trends were evident that appear to contradict the findings of others who have examined oyster growth in relation to elevation on three dimensional reef structures. For the intertidal oysters, the increase noted in the April, May and July oysters is what one would expect (Fig. 13). The apparent decrease in size is most likely due to mortality of larger animals. However, even allowing for mortality in the subtidal oysters (which was higher than intertidal levels) the oysters consistently displayed an

Fig.13 Sizes of intertidal oysters before and after deployment.



increase in sizes upon return to the laboratory. These findings appear to conflict with the findings of Lenihan (1996) who found that oysters located on the crest of submerged reefs have greater growth rates that those located nearer the base of the reefs. These faster growth rates appear to be related to higher water flow rates found there. The intertidal and exposed nature of the oysters on the crest of the Fisherman's Island reefs seem to counter the benefits of being located on the reef crest. The implications of these findings relate to the strategy of location of brood stock oysters on similar intertidal reefs. Where does one locate the oysters on the reefs so as to maximize both survival and growth and hence reproductive potential (Cox and Mann, 1992)?

Fig14. Sizes of subtidal oysters before and after deployment.



Epibenthic Taxa (Fisherman's Island) - A total of 24 taxa (mostly species) were collected from the reef surface samples over the course of this year (Tables 4-7). We have reported the abundances of macroalgae as dry weight biomass/m^2, encrusting and colonial forms (Bryozoa and Porifera) as presence/absence and all others as numbers of individuals/m^2. Of interest was that after year 1, we noted that greater numbers of hard clams, *Mercenaria mercenaria*, were collected from the clam and ash reefs as compared to the oyster reefs. That trend was not consistent throughout the second year, with hard clams sometimes being more abundant on the oyster reef. However, in the third year the hard clams were once again more abundant on the clam shell reefs. The sizes of the clams (not reported) were consistent with young-of-the-year or last year's recruited animals.

In August 1998, there were no detectable levels of macroalgae found on any of the reef types (Table 4). This is in contrast with the previous quarter (May 1998; not reported) and the previous August. Macroalgae are susceptible to large die-offs resulting in their almost complete removal from the substrate of attachment (I. Anderson, Virginia Institute of Marine Science, personal communication). A major macroalgal crash was witnessed prior to the Summer sampling and resulted in almost complete denudation of the reefs, such that, sampling revealed no detectable weights of macroalgae. By Fall 1998 (November), algae had re-established itself on the reefs. However, the levels are predictably low at that time of year (Table 5). In March 1999, algae had accumulated on the reefs in modest levels, particularly on the oyster reefs. This trend was continued in the Spring samples. Of note was the difference in macroalgal abundance and richness among the three reef substrate types. The oyster reef had 12 species of algae in March 1999 compared with 3 and 5 species for the clam and ash reefs, respectively (Table 6). The difference was even more dramatic in the June samples (Table 7). Oyster reefs contained 8 species of macroalgae while both the clam and ash reefs only had one species (*Gracialaria verrucosa*).

The abundance of epifauna and macroalgae appear to be lower than corresponding sampling periods in previous years (Table 8). This is particularly evident in the spring 1999 sampling. We attribute this discrepancy to the unusually cool spring water temperatures experienced on the eastern shore of Virginia this year. However, it appears that the oyster reefs have consistently higher numbers of organisms and greater abundances associated with them than the other substrate types. This further serves to underscore the advantages oyster shell substrate has over the other substrate types.

Table 4. Abundance and standard deviation measures of epibenthic taxa on each reef type during Summer 1998. (Measures are scaled to 1 square meter and reported as dry weight for macroalgae, +/- for encrusting forms as well as colonial organism and # of individuals for solitary organisms). Note: macroalgae were not found in appreciable amounts during this sampling event.

		Substrate					
		Oyster		**Clam**		**Ash**	
Species	**Common name**	**Mean**	**S.D.**	**Mean**	**S.D.**	**Mean**	**S.D.**
No Macro Algae							
				number or % coverage			
Anomia simplex	common jingle	3.20	8.67	6.22	12.15	1.33	4.42
Balanus eburneus	barnacle	43.73	37.62	6.22	17.89	128.00	151.79
Crassostrea virginica	eastern oyster	627.20	522.83	104.00	122.38	189.33	380.08
Crepidula fornicata	slipper shell	3.20	8.67	2.67	9.52	0.00	0.00
Geukensia demissa	ribbed mussel	0.00	0.00	0.89	0.00	1.33	4.42
Mercenaria mercenaria	hard clam	1.07	3.99	3.56	5.96	4.00	6.93
Mytilus edulis	blue mussel	0.00	0.00	13.33	66.33	0.00	0.00
Molgula manhattensis	sea squirt	3.20	8.67	0.89	4.42	0.00	0.00
Sclerodactyla briareus	brown sea cucumber	5.33	9.54	0.00	0.00	0.00	0.00
Hydroides dianthus	tube-building polychaete	647.47	493.39	47.11	114.14	158.67	157.51
Cnidaria sp.	sea anemone	4.27	10.88	0.00	0.00	0.00	0.00
Membranipora tenuis	encrusting bryozoan	+		+		+	
Cliona celata	boring sponge	+		-		-	

Table 5. **Abundance and standard deviation measures of epibenthic taxa on each reef type during Fall 1998. (Measures are scaled to 1 square meter and reported as in Table 4)**

		Substrate					
		Oyster		**Clam**		**Ash**	
Species	**Common name**	**Mean**	**S.D.**	**Mean**	**S.D.**	**Mean**	**S.D.**
				grams			
Ceramium fastigiatum	red algae	0.00	0.00	0.00	0.00	0.39	1.30
Ceramium rubrum	red algae	0.03	0.11	0.00	0.00	0.01	0.02
Cladophora albida	green algae	0.00	0.00	0.00	0.00	0.08	0.19
Enteromorpha linza	green algae	0.00	0.00	0.00	0.00	0.00	0.01
Enteromorpha plumosa	green algae	0.00	0.00	0.00	0.00	0.04	0.09
Gracilaria verrucosa	red algae	6.27	18.24	1.73	3.95	17.79	27.25
Spyridia filamentosa	red algae	4.94	5.61	0.13	0.39	3.73	11.32
Ulva curvata	green algae	0.03	0.11	0.00	0.00	0.08	0.26
				number			
Balanus eburneus	barnacle	28.80	34.66	5.33	9.98	58.67	83.99
Crassostrea virginica	eastern oyster	1261.87	797.35	395.56	336.09	148.00	223.44
Geukensia demissa	ribbed mussel	4.27	12.35	0.89	4.42	0.00	0.00
Mercenaria mercenaria	hard clam	0.00	0.00	12.44	10.33	4.00	9.52
Molgula manhattensis	sea squirt	7.47	15.31	0.89	4.42	0.00	0.00
Sclerodactyla briareus	brown sea cucumber	5.33	16.18	0.00	0.00	0.00	0.00
Hydroides dianthus	tube-building polychaete	505.60	477.64	25.78	38.55	104.00	187.45
Sabella micropthalma	tube-building polychaete	32.00	51.93	4.44	7.54	22.67	44.04
Tellinidae sp.	surf clam	1.07	3.99	0.89	4.42	0.00	0.00
Cnidaria sp.	sea anemone	3.20	8.67	0.00	0.00	0.00	0.00
Cliona celata	boring sponge	+		-		-	

Table 6. Abundance and standard deviation measures of epibenthic taxa on each reef type during Winter 1999. (Measures are scaled to 1 square meter and reported as in Table 4)

		Substrate					
		Oyster		Clam		Ash	
Species	Common name	Mean	S.D.	Mean	S.D.	Mean	S.D.
				grams			
Ceramium strictum	red algae	0.07	0.16	0.00	0.00	0.00	0.00
Cladophora albida	green algae	6.21	20.49	0.00	0.00	14.24	29.81
Codium sp.	green algae	30.41	45.56	0.00	0.00	0.00	0.00
Ectocarpus confervoides	green algae	0.03	0.12	0.00	0.00	0.00	0.00
Enteromorpha intestinalis	green algae	0.04	0.16	0.04	0.16	0.00	0.00
Enteromorpha linza	green algae	19.66	38.52	0.32	1.31	0.23	0.45
Enteromorpha minima	green algae	1.52	3.58	0.00	0.00	0.00	0.00
Enteromorpha plumosa	green algae	16.91	47.27	0.00	0.00	0.05	0.11
Fucus vesiculosus	brown algae	0.10	0.29	0.00	0.00	0.00	0.00
Gracilaria verrucosa	red algae	9.21	29.46	0.71	2.04	20.86	22.01
Petalonia fascia	brown algae	18.20	39.46	0.00	0.00	0.00	0.00
Ulva curvata	green algae	0.09	0.35	0.00	0.00	0.03	0.10
				number			
Anomia simplex	common jingle	3.20	8.67	0.00	0.00	1.33	4.42
Balanus eburneus	barnacle	10.67	17.20	0.89	0.00	4.00	9.52
Crassostrea virginica	Eastern oyster	841.60	687.29	71.11	98.63	58.67	54.78
Geukensia demissa	mud mussel	1.07	3.99	1.78	4.42	0.00	0.00
Mercenaria mercenaria	hard clam	0.00	0.00	8.00	13.79	12.00	14.79
Mya arenaria	soft-shelled clam	0.00	0.00	0.89	0.00	0.00	0.00
Molgula manhattensis	sea squirt	17.07	15.96	0.00	0.00	2.67	5.96
Sclerodactyla briareus	brown sea cucumber	2.13	5.44	0.00	0.00	0.00	0.00
Hydroides dianthus	tube-building polychaete	545.07	484.69	16.89	21.12	122.67	208.14
Sabella micropthalma	tube-building polychaete	32.00	67.63	7.11	5.96	5.33	9.98
Tellinidae sp.	surf clam	0.00	0.00	0.00	0.00	1.33	4.42
Membranipora tenuis	encrusting bryozoan	+		+		+	
Cliona celata	boring sponge	+		-		-	

Table 7. Abundance and standard deviation measures of epibenthic taxa on each reef type during Spring 1999. (Measures are scaled to 1 square meter and reported as in Table 4)

		Substrate					
		Oyster		Clam		Ash	
Species	Common name	Mean	S.D.	Mean	S.D.	Mean	S.D.
Ceramium rubrum	red algae	0.02	0.07	0.00	0.00	0.00	0.00
Enteromorpha intestinalis	green algae	0.01	0.02	0.00	0.00	0.00	0.00
Enteromorpha linza	green algae	8.79	18.46	0.00	0.00	0.00	0.00
Enteromorpha minima	green algae	0.03	0.11	0.00	0.00	0.00	0.00
Gracilaria foliifera	red algae	1.39	5.20	0.00	0.00	0.00	0.00
Gracilaria verrucosa	red algae	30.57	85.46	1.45	5.57	31.70	52.52
Petalonia fascia	brown algae	4.19	12.52	0.00	0.00	0.00	0.00
Ulva curvata	sea lettuce	1.08	3.46	0.00	0.00	0.00	0.00
				number			
Anadara ovalis	blood ark	0.00	0.00	0.00	0.00	1.33	4.42
Balanus balanoides	barnacle	81.07	95.19	3.56	7.54	17.33	24.84
Crassostrea virginica	eastern oyster	1452.80	801.11	110.22	115.35	141.33	126.29
Crepidula fornicata	slipper shell	1.07	3.99	0.00	0.00	0.00	0.00
Geukensia demissa	ribbed mussel	1.07	3.99	4.44	13.79	60.00	199.00
Mercenaria mercenaria	hard clam	0.00	0.00	34.67	26.50	24.00	29.57
Mytilus edulis	blue mussel	23.47	75.47	16.00	31.21	293.33	534.44
Molgula manhattensis	sea squirt	55.47	207.54	0.00	0.00	0.00	0.00
Petricola pholadiformis	false angel wing	0.00	0.00	0.00	0.00	1.33	4.42
Sclerodactyla briareus	brown sea cucumber	1.07	3.99	0.00	0.00	0.00	0.00
Hydroides dianthus	tube-building polychaete	1048.53	674.35	22.22	41.83	80.00	81.06
Sabella micropthalma	tube-building polychaete	195.20	178.47	4.44	13.79	9.33	15.26
Tellinidae sp.	surf clam	0.00	0.00	0.00	0.00	10.67	21.00
Cnidaria sp.	sea anemone	30.93	70.46	0.00	0.00	1.33	4.42
Stylochus sp.	flat worm	1.07	3.99	0.00	0.00	0.00	0.00
Membranipora tenuis	encrusting bryozoan	+		-		+	
Cliona celata	boring sponge	+		-		-	

Table 8. Species richness of epibenthic taxa by reef type and season. Values are total numbers of species collected from the reef surfaces.

	Reef Type		
Season	Oyster shell	Clam Shell	Coal Ash
Summer 1998	11	10	7
Fall 1998	14	10	12
Winter 1999	22	11	14
Spring 1999	21	8	13

Transient finfish and other nekton (Fisherman's Island) - Characterizing the transient assemblages of fishes and invertebrates using the reefs has been a challenging aspect of this work. The variety of gear employed captured components of this assemblage with differing efficiencies. A cumulative species list of all animals collected by these various gear throughout the project is shown in Table 9.

Otter trawl samples from June 1998 to May 1999 collected a total of 11,985 individuals comprising 28 species from all habitats throughout the year and clear seasonal patterns are evident in the data (Table 10). In general the numbers of species found were considerably reduced when compared with previous years, while the abundance was greater. This increase in abundance can be attributed to the large number (7723) of rough silversides (*Membranus marinica*) sampled in June 1998. The lowest numbers of species and individuals were recorded in February 1999 with a single glass eel (*Anguilla rostrata)* caught in the mudflat trawl (Table 10). Fish abundance and species richness began to increase again and by May 1999 there were six, three and six species recorded in each of the reef, channel and mudflat areas, respectively.

Differences in richness were also apparent when the data is examined according to location. Although species richness was consistently greatest on the mud flats, the greatest abundance was observed in the vicinity of the reef areas (see above for explanation). Of note was the fact that the rough silversides were found primarily on the reef and channel areas; the majority of bay anchovys (*Anchoa mitchilli*) were located on the mudflats. As with the epifaunal samples, the most likely explanation for the overall reduction in species and abundance is the relatively low water temperatures experienced in spring of this year.

Two new species were recorded in the trawl samples within this sampling year. A single naked goby (*Gobistoma bosci*) was retained in a reef trawl in May 1999. The individual probably was dislodged from the refuge of the reefs. In addition, a northern sennet (*Sphyraena borealis*) was retained on the mudflats in June 1998.

Table 9. Species collected to date using trawl, seine, drop ring, gill net, long line and hook and line techniques in reef, intertidal mudflat, and subtidal bare-mud bottom areas. "Reef" represents the area on or immediately adjacent to the reef; "Mudflat" represents the intertidal mudflat area sampled at a distance of at least 100 meters away from the edge of a reef; "Channel" represents subtidal, bare mud habitat at a distance of at least 100 m from the reef edge; "+" indicates presence in samples collected from corresponding habitat.

	REEF	MUDFLAT	CHANNEL
FISHES:			
Alosa acstivalis			+
Anchoa hepsetus	+	+	+
Anchoa mitchelli	+	+	+
Anguilla rostrata		+	+
Brevoortia tyrannus		+	+
Opsanus tau	+		
Gobiesox strumosus	+		+
Cyprinodon variegatus		+	
Fundulus heteroclitus	+	+	+
Fundulus majalis		+	
Lucania parva		+	
Membras martinica	+	+	+
Syngnathus fuscus	+	+	+
Hippocampus erectus	+	+	+
Morone americanus	+		
Morone saxatilis	+		+
Centropristis striata	+	+	+
Pomatomus saltatrix	+	+	+
Selene vomer	+		
Trinectes maculatus			+
Bairdiella chrysoura	+	+	+
Pogonias cromis	+		
Leiostomus xanthurus	+	+	+
Cynoscion regalis	+	+	+
Mugil sp.	+	+	
Chasmodes bosquianus	+	+	
Gobiosoma ginsburgi	+		+
Paralichthys dentatus	+	+	+
Prionotus sp.	+		+
Symphurus plagiusa	+		
Sphoeroides maculatus		+	+
Stenotomus chrysops		+	
Chilomycterus shoepfi		+	+
Urophycis regia	+	+	+
Congridae	+		
Gastrosteus aculeatus	+		
Orthopristis chrysoptera	+	+	+

	REEF	MUDFLAT	CHANNEL
Menidia menidia			+
Tautoga onitis		+	
Micropogonias undulatus	+		+
Eucinostomus sp.	+	+	+
Gobiostoma bosci	+		
Sphyraena borealis		+	
Clupeidae	+		+
Chaetodon ocellatus	+		
Synodontidae			+
Gymnura micrura			+
Sparidae		+	
Tylosurus crocodilus		+	
Peprilus alepidotus			+
Mycteroperca microlepis			+
Etropus microstomus	+	+	
Opisthonema oglinum		+	
Scomberomorus maculatus	+		
Archosargus probatocephalus	+		+
Cyprinodon variegatus			+
Pleuronectes americanus	+	+	+
Menticirrhus saxatilis		+	
Sciaenops ocellatus			+
Urophycis regia			+
DECAPOD CRUSTACEANS			
Palaeomontes sp.	+	+	
Callinectes sapidus	+	+	+
Callinectes similis	+	+	+
Panaeus aztecus	+		+
Alpheus heterochelis	+		
Libinia emarginata	+	+	
Xanthidae	+	+	
Pagurus sp.	+	+	
Ovalipes ocellatus			+
Cancer irroratus			+
OTHER:			
Lolliguncula brevis	+	+	+
Malaclemys terrapin	+	+	+

Following Page - Table 10. Abundance and size of species caught in trawl samples throughout the sampling year. (Location designations are as Table 9; size measures are standard length for finfish, carapace width for crustaceans, total length for reptiles and mantle length for cephalopods.)

Throughout the year four gill net sets were deployed – one per season. Gill nets were set parallel to the reefs and the channel, such that they were presumed to have caught fish moving across the reefs into the channel (or vice versa); others were set similarly with respect to unmanipulated subtidal mudflat habitat. Few fish were caught in gill nets at either location during year 1 of the study, owing we believe to net fouling due to drifting macroalgae. In year 2 we modified our procedures to include more frequent fishing of the nets (3 hours as opposed to 12 hours in Year 1) and this resulted in more consistent catches of fish. However, net fouling was still a major problem, given in part to the heavy growth of macroalgae in the vicinity of the reefs early in 1998. Throughout the third year of this study, the variety and abundances of fish species captured by the gill net were low in both habitats (Tables 9-12). There were no clear patterns in these data with respect the species richness or abundances across the two habitats. However, these samples did collect large predatory species of fish (bluefish and striped bass) in the vicinity of the reefs.

Table 11. Species and abundances caught in gill net samples during Summer 1998.

Location	Species	Common name	# Caught
Reef/Channel	*Bairdiella chrysoura*	silver perch	13
	Paralicthys dentatus	summer flounder	1
Mudflat/	*Bairdiella chrysoura*	silver perch	12
Channel	*Micropogonias undulatus*	croaker	6
	Cynoscion regalis	weakfish	2
	Orthopristis chrysoptera	pigfish	1

Table 12 . Species and abundances caught in gill net samples during Fall 1998.

Location	Species	Common name	# Caught
Reef/ Channel	no fish caught*		
Mudflat/ Channel	no fish caught*		

* Very heavy macroalgal fouling of the nets was experienced at both deployment locations.

Table 13. Species and abundances caught in gill net samples during Winter 1999.

Location	Species	Common name	# Caught
Reef/ Channel	no fish caught		
Mudflat/ Channel	no fish caught		

Table 14. Species and abundances caught in gill net samples during Spring 1999.

Location	Species	Common name	# Caught
Reef/ Channel	*Carcharhinus* sp.	sandbar/dusky shark	1
	Sciaenops ocellatus	red drum	1
Mudflat/ Channel	*Pomatomus saltatrix*	bluefish	1
	Leistomus xanthurus	spot	1
	Rhinoptera bonasus	cownose ray	1
	Cynoscion regalis	grey trout	3
	Bairdiella chrysoura	silver perch	11

Encircling seine sampling continued through Spring and Summer 1999 and will continue into the fall of 1999. These data have not yet been analyzed or tabulated. However, the encircling seine captured many more species and individuals than previously collected with the beach seine. Further, this sampling device permits us to sample through a longer portion of the tidal cycle and in a more quantitative manner than the conventional beach seine—mid ebb through mid flood tide for the former as opposed to low tide for the latter. A cursory examination of the data obtained to date reveals that the reef areas are being used by juveniles of a large number of commercially and recreationally important finfish (flounder, striped bass) and shellfish (blue crabs). These data serve to further highlight the importance of oyster reefs and add credence to their designation as essential fish habitat.

Video observation (Fisherman's Island) - Evaluating the role of oyster reefs as essential fish habitat for both commercially and ecologically valuable fishes and crustaceans is a crucial element in their restoration. Because of the nature of reef systems, these habitats are difficult to sample by conventional fisheries methods. To quantify the use of reef habitats and to evaluate the success of constructed reef systems, we use underwater video to compare fish use of the reef in relation to tidal stage at Fisherman's Island, Virginia. Utilization of three reef area sub-habitats (reef interior, reef edge, and subtidal mudflat 5 meters away from the reef edge) by nekton was monitored simultaneously over an entire daylight tidal cycle. Reference points were established within the camera's field of view so that a known area is sampled. Quantitative measurements of nekton assemblages associated with the reef with respect to time and tidal stage were derived from this video footage.

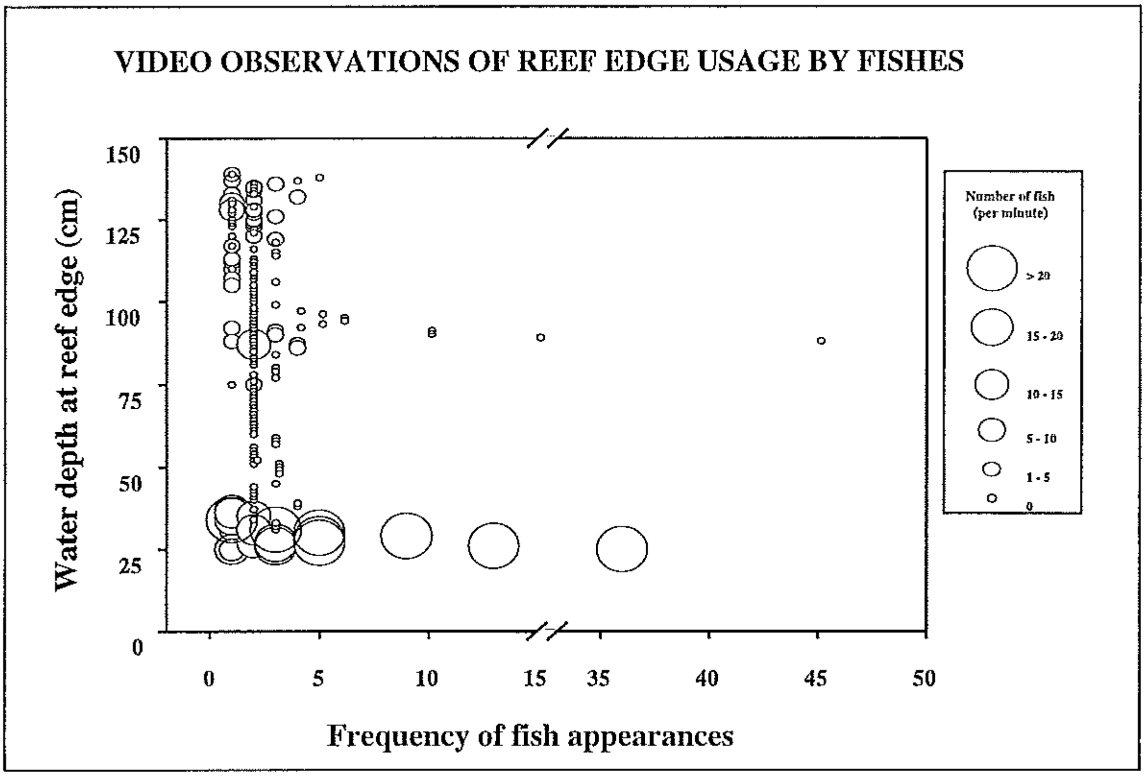


Figure 15. Abundance of fishes observed at reef edges in one minute increments over an entire tidal cycle (see text for explanation of patterns).

Video tapes were analyzed in 1-minute increments to examine tidal shifts in the fish assemblage at the reef edge habitat. The number of fish visible in front of the reference dowel each minute at a particular water depth was recorded. At high tide, individuals and small groups of fish (e.g., spot, silver perch, black sea bass, pigfish and mojarra) were occasional visitors to the reef edge. As the tide fell, larger groups of fishes (e.g., schools of mummichogs and silversides) moved in to the camera's field of view and remained for many minutes. Since less water column is available at low tide the pattern may be a result of tidal habitat compression. We are continuing to evaluate the sources of this tidal variation.

Preliminary observations suggest that nekton are more abundant at all tidal stages in the reef habitat compared with the subtidal mudflat habitat. Transient nekton (silversides, killifish, and juvenile silver perch) are present around the reef at all tidal stages, but appear to be most abundant around the reef at lower stages of the tide. We anticipate additional video monitoring work to reveal relationships between tidal stage and temporal use of the constructed reef habitat as refuge and foraging areas by juvenile and adult finfish species

Comparison of Finfish Species Richness between Fisherman's Island and the Piankatank River – We were able to compare data collected in 1996 and 1997 only for the comparison of finfish species collected from the two systems examined. This was due to the fact that sampling was only carried out on the Piankatank River system in these two years. Table 15 outlines the species richness of fish species sampled in 1996 and 1997. It is apparent that the reef structures consistently retained greater numbers of species than the off-reef/control sites. Of note is that in the Piankatank River in 1996 the numbers of species sampled on the reefs (28) greatly exceeded that number in 1997 (17), while at the Fisherman's Island system the reverse was the case – 21 species in 1996 vs. 34 species in 1997. At Fisherman's Island we attribute the rise in species numbers to the increased frequency of sampling effort undertaken at this site in 1997. The reverse appears to be the case for the Piankatank system, where in 1997 there were no otter trawls carried out (Harding and Mann 1999).

	LOCATION			
	PR(PBR)	*PR(RP)*	*FI(R)*	*FI(M)*
Year				
1996	**28**	**-**	**21**	**13**
1997	**17**	**10**	**34**	**28**

Table 15. Number of fish species captured at the reefs and control locations within the Piankatank River (PR) and Fisherman's Island (FI) during 1996 and 1997. Sampling occurred on the constructed reefs – Palace Bar Reef PR(PBR) and reef FI(R) as well as the control sites Roane Point PR(RP) and mudflat FI (M).

Table 16 list the species found at the sites within the Piankatank River. When compared with Table 9 it is clear that considerably more species were found at Fisherman's Island (n=61) than within the Piankatank River system (n=28). A number of species that occurred at one site did not occur at the other. For example, seven species were found on the Piankatank that were not found at Fisherman's Island. These species are marked with as asterisk in Table 16. All of these species are typically found in the lower Chesapeake Bay and, therefore, are not unusual visitors to the Piankatank River. A single carp (*Cyprinus carpio)* was found at the Piankatank Reef; it is typically a freshwater fish and probably an escapee from an upriver freshwater pond. The pinfish (*Lagodon rhomboides)* is typically tolerant of lower salinities (Murdy et al. 1997) and was also found at the Palace Bar Reef. The greater number of species sampled at the Fisherman's Island site are probably attributable to a number of reasons. The site is at the confluence of the Chesapeake Bay and the Atlantic Ocean - therefore there is an increased probability of capturing a variety of oceanic species in addition to those typically found in the Chesapeake Bay. Despite its broad geographic location near the Bay mouth, locally the reefs are in an area narrowly constrained between marsh and islands. Therefore, sampling of the area will be more inclusive and the chances of escape are considerably lower than at the other locations. Finally, the sampling at Fisherman's Island occurred on a seasonal basis and therefore was more inclusive than the Piankatank where sampling efforts were focused from May through September. This last factor may not be as important as it may seem, because the numbers of species and abundances typically decline in the fall and winter months at the Fisherman's Island location (Table 10).

The one consistent facet of the fish data obtained from the two systems is that structured habitats in the form of the three dimensional oyster reefs have more species associated with them than the non-reef control sites. This highlights the importance of structure in attracting fish to a particular area either for refuge, nesting location or predation.

Table 16. Species collected to date using trawl, gill net, crab pots and nest substrates. Palace Bar reef is the reconstructed oyster reef. Roane Point (from 1997 only) is a sand bar that acted as a control site through the study.

	Palace Bar Reef	Roane Point
Alosa acstivalis	+	+
Anchoa mitchelli	+	
Anguilla rostrata	+	
Bairdiella chryosoura	+	+
Brevoortia tyrannus	+	+
Opsanus tau	+	
Gobiesox strumosus	+	
Hippocampus erectus	+	
Morone saxatilis	+	+
Centropristis striata		+
Pomatomus saltatrix	+	+
Trinectes maculatus	+	
Leiostomus xanthurus	+	+
Cynoscion regalis	+	+
Chasmodes bosquianus	+	
Paralichthys dentatus	+	
Sphoeroides maculatus	+	
**Rancycentron canadium*	+	
Tautoga onitis	+	
Gobiostoma bosc	+	
Scomberomorus maculatus	+	
Cynoscion nebulosa	+	+
**Cyprinus carpio*	+	+
Rhinoptera bonasus	+	
**Lagodon rhomboides*	+	
**Peprilus triacanthus*	+	
**Peprilus alepidotus*	+	
**Priontus carolinus*	+	
**Chaetodipterus faber*	+	

Development of Trophic Models- As an additional means of classifying the ecological function of oyster reefs, gut contents of fish species captured on or near reefs were analyzed in an attempt to determine the trophic structures of the two systems examined (Piankatank River and Fisherman's Island). Information is limited, but we can assign some fish species to trophic levels. To date we have processed the gut contents from 83 individuals comprising 12 species (Table 17) that were captured using the encircling seine. Of the 83 individuals, 11 had empty guts. In total, 13 food categories were identified (Table 17). Among the species classified as resident species (striped and feather blenny and oyster toadfish) there was considerable variation in diet, including plant material, amphipods, crabs and shrimp. Other species listed in Table 17 are primarily classed as semi-residents and only one (sheepshead) was found to contain algal or plant material in their guts; all others had animals derived material in their guts. Only silver perch were shown to be piscivorous.

In addition to the data generated from the encircling seine returns, we also have gut contents from fishes captured adjacent to the reefs at Fisherman's Island using gill nets. These data are presented in Table 18. Given that we only have qualitative estimates of food items from the fish guts, we report them in terms of the proportion of the individual species that had that item in their stomach. It is obvious from the gill net returns that there was a greater proportion of piscivorous fishes captured than with the encircling seine. None of the guts of the species captured with the gill nets contained any plant material. The striped bass had the greatest variety of food items. They were shown to have spotfin mojarra, mummichogs, silversides, blue crabs and grass shrimp in their guts. The relatively large proportion of fishes with empty guts is probably an artifact of the sampling whereby the fishes when stressed will disgorge gut contents if not retrieved in a timely manner. Also, individuals that were approaching the reefs to feed may have been intercepted prior to foraging.

Gut contents analysis from four species of fishes (croaker, striped bass, bluefish and spot) in the Piankatank River have been completed and are reported according to adult (>100mm) and juvenile (<100mm) composition for each species in Table 19. We do have quantitative estimates of prey items from the gut contents and the data are reported as the proportion of total food items sampled. Only the three most abundant prey items are reported (Table 19). As with the Fisherman's Island system none of these species had algal/plant material in their guts. Both the bluefish and the striped bass had fish in their guts.

Table 17. Summary of gut contents of representative specimens of species collected by encircling seine gear. The number under each species name represents the number of guts examined. The frequency of empty guts or the presence each prey item type appears in the gut of a given species is expressed as percent occurrence (calculated from the number of guts containing that prey item divided by the total number of guts examined).

	sheepshead (n=23)	silver perch (n=20)	black sea bass (n=1)	spotfin butterflyfish (n=2)	striped blenny (n=2)	mummichog (n=7)	halfbeak (n=1)	feather blenny (n=1)	gray snapper (n=5)	oyster toadfish (n=5)	pigfish (n=23)	tautog (n=3)
Empty Guts:	13.04	5	0	0	50	0	0	0	0	20	17.39	33.33
Percent occurrence of (prey item):												
Algae/Plant material	78.26					100		100				
Polychaete	43.5											
Bivalve											43.5	
Copepod											60.87	
Ostracod												33.33
Isopod		4.35	5									
Amphipod	8.7	25	100		50				20	40	8.7	66.67
Caridea (shrimp)	4.35	60								40	8.7	
Brachyura (true crabs)		20	100							40		33.33
Pagurus sp.		5										
Fish (Fundulus sp.)		10										
Fish (unknown spp.)		10										
Unidentifiable digested material				100							8.7	

Table 18. Summary of gut contents from fishes captured by gill nets at Fisherman's Island. Given are the species, the number of individuals and the proportion of that number that had a particular food item in their gut.

Species	bluefish *n=3*	silver perch *n=15*	Spanish mackeral *n=1*	weakfish *n=1*	spot *n=18*	mullet *n=2*	striped bass *n=1*	summer flounder *n=16*	red drum *n=1*	croaker *n=1*
Empty Guts	66	13	0	0	100	66	12.5	50	0	100
Algal/plant										
Oligochaetes							31.25			
Amphipods							6.25		100	
Shrimp (Caridea)		53.3		100			18.75	100		
Crabs (Brachyura)							25		100	
Teleosts	100	6.7	100				68.75			
Unidentified				100						

Table 19. Piankatank River fish gut analysis. Given are the species of fish analysed, their ontogenic grouping, the number of individuals sampled and the proportion of the prey item found in the guts.

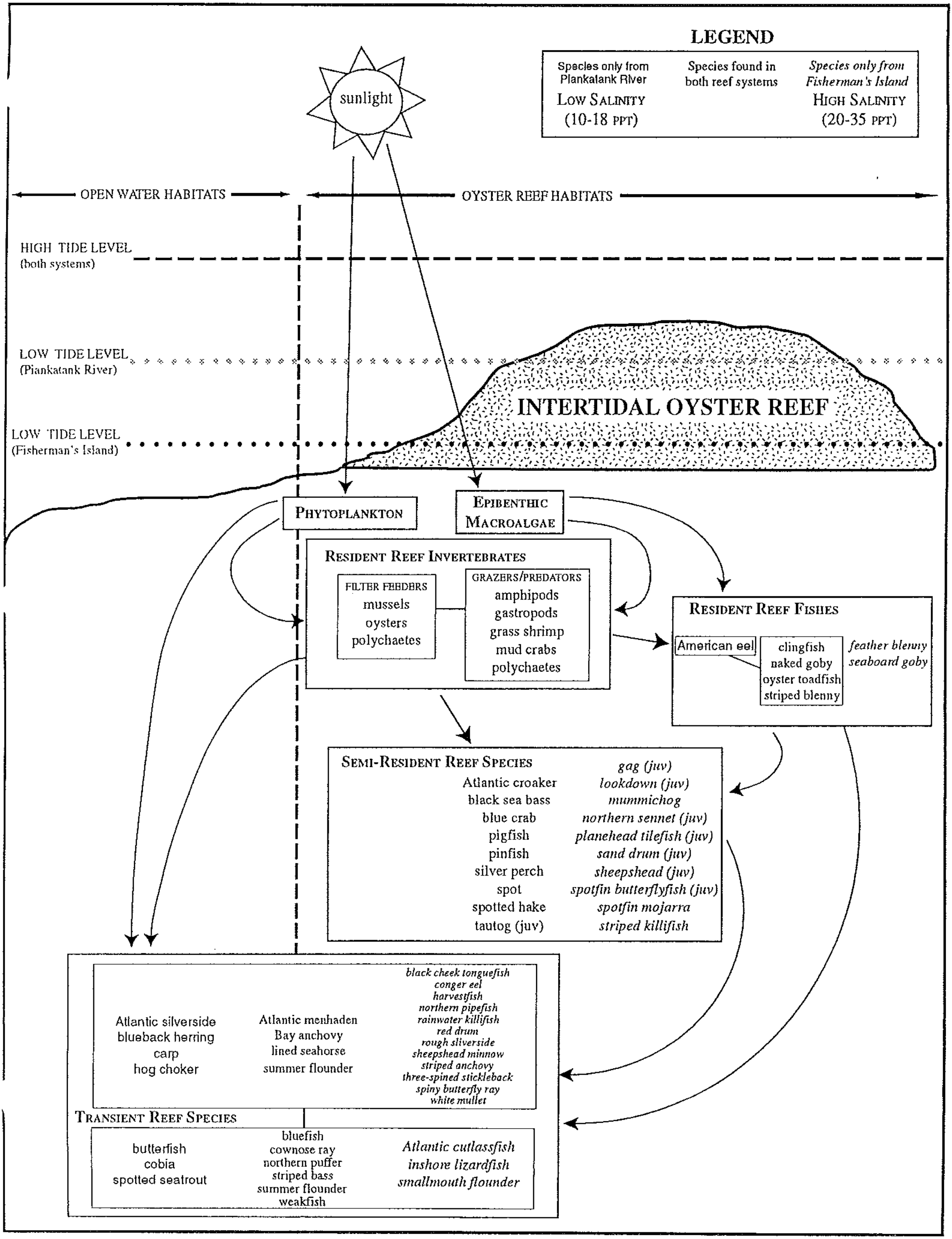
Species	spot		striped bass		bluefish		croaker	
	adult	*juv.*	*adult*	*juv.*	*adult*	*juv.*	*adult*	*juv.*
	n=60	*n=9*	*n=15*	*n=29*	*n=41*	*n=0*	*n=25*	*n=2*
Oligocheates								35
Polychaetes			6	2			4	28
Ostracods	28	5						
Mysids	22		50	91	11		67	
Copepods		85						16
Amphipods				7				
Portunids					2			
Gastropods	31	5					17	
Teleosts					82			
Reef fishes			17					

We have constructed a preliminary conceptual model which classifies all fish species found in both systems according to their perceived relationships to reef structures and their trophic status (Figure 16). The species list was derived from the gamut of sampling techniques outlined in previous sections of this report. To date, we have been able to assign all species to single categories in this tentative model, regardless of reef system. It is possible that with time and more information we may need to move some species between categories or place some in more than one category. However, the similar use of reefs by these species in different geographic locations, highlight important general features of the reef systems in the Chesapeake Bay.

The scheme we present is a hybrid model which uses relationship to structure as its basis and infers trophic relationships among the organisms listed. For example, we are not precluding the predation of semi-resident fish species on other piscivorous species classed in the same group. This is borne out by the revelation from preliminary findings that gut contents of silver perch was shown to contain mummichogs [*Fundulus* sp. (Table 17)]. Both of these species are classed as semi-residents of restored reef structures. Gill nets deployed at Fisherman's Island also provided data comprising semi-resident and transient species and thus reveal links among different classifications of reef users. Specifically, we provide a link from resident reef invertebrates (amphipods, polychaetes) to semi-residents (silver perch, blue crab) to transient species (striped bass). Also based on the Piankatank River data, we are able to conclusively link some of the reef user groups. For example, striped bass were shown to have naked gobies and striped blennies in their guts. In addition, Mann and Harding (1997) also report that there was a seasonal trend in relation to goby and blenny abundances on the oyster reefs. The numbers of these species were shown to decrease markedly when striped bass abundances increased. Other fishes were shown to have consumed invertebrate species (amphipods, portunids) that are considered reef residents (Table 19). Additionally, Harding (1999) has shown that resident species of fishes (striped blenny, naked goby and feather blenny) as larvae prey effectively upon bivalve veliger larvae. In fact, naked goby larvae showed a preference for bivalve larvae over other invertebrate prey choices.

All of the relationships described provide evidence relating to some of the interactions on or near the oyster reefs. They conclusively highlight the fact that a variety of species actually visit reef structures to forage (striped bass). These data show that these prey items (blennies and gobies) are important consumers of food items (amphipods and algae) which are considered lower on a trophic scale but are also found on the reefs. We hope that future studies on these and other reefs will help us further detail trophic linkages and add to or remove the tentative links we provide in Figure 16.

Following Page - Figure 16. Tentative trophic web combining species from the Piankatank River and Fisherman's Island. Classifications are based upon fish species relationship to the reef structure. Legend refers to the Resident Reef fishes the semi-Resident Reef fishes and the Transient Species only.


LEGEND
Species only from Piankatank River
LOW SALINITY (10-18 PPT)
Species found in both reef systems
Species only from Fisherman's Island
HIGH SALINITY (20-35 PPT)
sunlight
OPEN WATER HABITATS
OYSTER REEF HABITATS
HIGH TIDE LEVEL (both systems)
LOW TIDE LEVEL (Piankatank River)
LOW TIDE LEVEL (Fisherman's Island)
INTERTIDAL OYSTER REEF
PHYTOPLANKTON
EPIBENTHIC MACROALGAE
RESIDENT REEF INVERTEBRATES
FILTER FEEDERS
mussels
oysters
polychaetes
GRAZERS/PREDATORS
amphipods
gastropods
grass shrimp
mud crabs
polychaetes
RESIDENT REEF FISHES
American eel
clingfish
naked goby
oyster toadfish
striped blenny
feather blenny
seaboard goby
SEMI-RESIDENT REEF SPECIES
Atlantic croaker
black sea bass
blue crab
pigfish
pinfish
silver perch
spot
spotted hake
tautog (juv)
gag (juv)
lookdown (juv)
mummichog
northern sennet (juv)
planehead tilefish (juv)
sand drum (juv)
sheepshead (juv)
spotfin butterflyfish (juv)
spotfin mojarra
striped killifish
Atlantic silverside
blueback herring
carp
hog choker
Atlantic menhaden
Bay anchovy
lined seahorse
summer flounder
black cheek tonguefish
conger eel
harvestfish
northern pipefish
rainwater killifish
red drum
rough silverside
sheepshead minnow
striped anchovy
three-spined stickleback
spiny butterfly ray
white mullet
TRANSIENT REEF SPECIES
butterfish
cobia
spotted seatrout
bluefish
cownose ray
northern puffer
striped bass
summer flounder
weakfish
Atlantic cutlassfish
inshore lizardfish
smallmouth flounder

Conclusions

The full development of restored oyster reefs will most likely require more than the 3-5 years time span over which these reefs have been studied. To conclusively state that these structures have been restored to fully functioning oyster reefs will be difficult as we have little in terms of background information to base any success upon. However, it is appreciated that an important facet will be the establishment of a population comprising multiple year classes of oysters. The persistence of older oysters on these reefs allied with the recruitment of younger classes is essential. The reefs at Fisherman's Island have developed 2-3 year classes of oysters – this is encouraging. The development of abundant and diverse epibenthic communities on these reefs will contribute to their ecological functioning and add to structural complexity of the system. As yet, it is uncertain whether the communities established within this system are stable and robust enough to withstand the biological vagaries of poor recruitment and/or epizootic outbreaks or environmental fluctuations (e.g., ice scour or storms). The oyster reefs in the Piankatank River have multiple year classes of oysters as attested by the presence of market sized oysters (2-3 years old). However, the numbers of larger animals are extremely low and it's questionable whether there are sufficient numbers to influence spawning and subsequent settlement events.

The principal reef systems studied by our research groups differ in a number of important ways: construction date, scale, morphology and material. Additionally, the Piankatank River and the tidal marsh environment at Fisherman's Island near the mouth of the Chesapeake Bay represent very different habitats. The reefs at both locations were not constructed in a manner to facilitate comparative testing in a meaningful way. Nevertheless, simple comparisons of the development of the oyster populations and associated assemblages at each location provide a means of understanding some of the factors affecting oyster reef development.

Oyster settlement varied spatially and temporally throughout the lower Bay during the years we have studied the development of the reefs. Overall, it appears that oyster reefs at Fisherman's Island experienced high recruitment despite variable settlement levels. Consequently, a large oyster population has developed on the reefs in this system. It appears that development of the oyster population on the reefs in the Piankatank River was retarded when compared with Fisherman's Island. This is most likely due to overall lower numbers of settlers and low recruitment in the system, perhaps due to the low numbers of resident brood stock oysters and the mesohaline environment. Unfortunately, we have no background estimates of adult oyster abundance from either system prior to the construction of the reefs to effect a comparison.

There appears to be a positive relationship between recruitment and the presence of live animals on the reefs, as borne out by the data between 1996 and 1998 at Fisherman's Island. The brood stock at Fishermans's Island developed naturally on the reefs and may contribute to both spawning and recruitment. However, a longer time series of analysis is necessary to confirm this contention. The effects brood stock addition (in 1997) had on spatfall in the Piankatank River is less clear. While an increase in overall levels of settlers was observed in 1998, it was not at such a magnitude to suggest a real effect. Again, further evaluation will have to be carried out to determine the true efficacy of brood stock additions to the reefs. To this end, we evaluated whether the presence of live oysters would influence settlement of oysters to the reef surface. We found that oysters did indeed settle on adult animals, however, in much fewer numbers than on control substrate which was just shell material (Figure 11A). We attribute the recruitment discrepancy between the two substrates to the benefit afforded by the greater interstitial space among the shell material (Table 3). Another consideration is that all of the brood stock plantings (Great Wicomico and Piankatank Rivers, "Live vs. Dead shell" at Fisherman's Island) have been carried out using large single oysters. The animals would be prone to redistribution on the reef by hydrodynamic forces, thus potentially dislodging new recruits. In addition, these animals would be oriented in a horizontal fashion as opposed to naturally occurring reef oysters that are (for the most part) oriented vertically and protrude into the water column. Consequently, it would seem single brood stock animals would be subject to greater mortality (due to predation, disease, low dissolved oxygen and siltation) as well as provide less interstitial space than naturally formed reef clusters as witnessed at Fisherman's Island. One avenue for further research would be a comparison of brood stock enhancement techniques, whereby the performance of single oysters was compared with that of clustered oysters.

Further, we have concluded that if the initial settlement and survival of oysters is of an appropriate magnitude (in part because of factors above), living oysters come to dominate the surface features of the reef and contribute to further interstitial space. In effect, the oysters themselves provide a refuge in numbers. Additionally, the presence of large numbers of resident oysters in subsequent years may enhance settlement through the release of water-soluble settlement inducing peptides (Tamburri et al. 1992; Turner et al. 1994). For instance, the abundances of oysters and spatial complexity of the oyster shell reefs have been increasing since their planting in 1996. These reefs have developed abundant oyster densities with multiple year classes present and the reef surfaces are dominated by living oysters. In contrast, the Ash reefs and the Clam shell reefs have failed to develop abundant oyster populations and generally only support small size classes which diminish in abundance after recruitment events. Our "live vs. dead shell" study may seem to contradict these findings. However as stated above, the dead shell provided a somewhat similar environment as the naturally recruited oysters – a stable matrix of shell with adequate interstitial space. Moreover, the oysters in the study were large single oysters - with reduced interstitial space, as opposed to the typically fused 'reef oysters' that would occur naturally.

Interstital space is clearly important to survival of oysters on these reefs systems. This is borne out by the work of Bartol and Mann (1999) on the Piankatank River reefs and confirmed by findings at Fisherman's Island presented here (Table 3). Given that the substrates used (clam shell and ash pellets) have been shown to promote oyster settlement, we conclude post-settlement mortality is the cause of difference among the substrates. A variety of alternative substrates for oyster settlement have been tested in other studies including slate (Haven et al. 1987), expanded shale, shredded tires (Mann et al. 1990), gypsum, *Rangia cuneata* shells, limestone, concrete and gravel (Soniat et al. 1991; Haywood and Soniat 1992; Haywood et al. 1999) with varying degrees of suitability observed for different substrate types. In North Carolina, limestone marle is a routinely used settlement substrate in a fishery enhancement program (Marshall et al. in press). The applicability of these substrates for large scale endeavors may have to be re-evaluated in light of the findings presented in this study, particularly as they relate to substrate stability and interstitial volume.

In this study, we have observed a major interaction between oyster recruitment and intertidal location, leading us to conclude that vertical relief is essential for adequate oyster population development. Oysters survived in greater numbers at Fisherman's Island reefs in the intertidal zone than lower down. We attribute this phenomenon to the greater degree of predation and siltation that oysters would be exposed to lower in the intertidal zone. These findings confirm the findings of Bartol and Mann (1999) who tested specific hypotheses relating to tidal location and oyster performance. They determined that oyster performance increased with tidal height. Lenihan (1996) found that oyster performance was greatest on structures with a high degree of vertical relief – presumably they avoided hypoxic/anoxic events lower down. The similarity of our conclusions between the systems highlight the importance of vertical relief in ensuring oyster population development.

Of the information gathered to date, one important conclusion is that multiple year classes are essential to the successful development of oyster populations. The persistence of older and larger oysters are essential to enhancing the reproductive potential of a population (Cox and Mann, 1992). Older animals on a reef can facilitate future recruitment by contributing to spawning events and subsequently providing habitat. The survival and persistence of older and larger oysters on a reef also increase the probability of introducing disease resistance into future populations. The primary goal of many restoration efforts has been to enhance a fishery. However, the findings of our investigations seem to suggest that certain areas should remain closed to fishing such that they can function as brood stock sanctuaries and provide propagules for recruitment to areas where fishing is allowed. Removal of larger market-sized oysters may greatly reduce the spawning potential of that population as well as remove potentially disease resistant animals. In addition, the usual method of harvest (dredging, tonging) results in destruction of the shell matrix on the reefs and negatively impact the habitat that oysters provided for themselves and other organisms.

The assemblages associated with experimental reefs at Fisherman's Island have maintained a high degree of species diversity and abundance, primarily on the oyster shell reefs. It is on these reefs that the majority of live oysters are found. We assume that the high species richness and abundance associated with these reefs are due in no small part to the persistence of live oysters on these reefs, even allowing for seasonal variations. In contrast, the diversity and abundance of organisms on ash and clam shell reefs tend to fluctuate greatly. The factors that have resulted in the persistence of oysters on the oyster shell reefs (vertical relief, interstitial space) may also influence the persistence and development of epibenthic assemblages. The development of an oyster reef community is an important factor in restoring the ecological function of a particular system. The robustness of a system is a function of its biodiversity. The greater species diversity a system displays (e.g., oyster shell reefs in our studies), its resilience stability, i.e., the ability of the ecosystem to recover rapidly in the face of disturbance, is potentially increased (Odum, 1989).

At the Fisherman's Island system there has been a distinct difference among reef substrate types in terms of macroalgal abundance and diversity. It is clear from three years of monitoring that oyster reefs have consistently had greater abundance of macro algae than the clam shell and ash pellet reefs. Accounting for this phenomenon is more complex than accounting for faunal differences among the substrate types. Given that macro algae utilize ammonia as a nitrogen source and that invertebrates' primary excretory material is ammonia, we hypothesize that the higher macro algal abundances are due to higher species abundance on the oyster shell reefs. However, defining this link is not easy. We propose, in future studies, to examine the relationship between algal biomass and the levels of ammonia found in and around the reefs. The implication of this proposed work is that it may provide a direct link to species abundance in the reefs and the amount of algae on the reef. Consequently, if this link is confirmed we may be able to use algal cover as a means of evaluating success of any particular restoration effort. The use of macroalgae as an indicator of success of a restoration project or health of the reef system may have some advantages. Assuming elevated numbers of macroalgae species and biomass can be equated to the rich and abundant assemblage of species on the reef type, the measurement of algae on the reefs may replace the more laborious, involved and time consuming epifaunal benthic sampling. However, a caveat is that our results to date can only be applied to polyhaline environment where the reefs are typically intertidal in nature. Application of this technique to the reefs located in mesohaline environments (Piankatank River) may not be entirely appropriate, unless a similar relationship can be demonstrated.

In addition to epibenthic assemblages that have developed on the oyster reefs, we have documented a considerable number of motile species associated with the reefs. These species include crustaceans, teleosts, reptiles and avian users of the reefs. Given the differences between the two systems outlined above, we have been as comprehensive as possible in terms of sampling fishes on the reefs. This has meant utilizing as many different sampling gears as possible thus allowing meaningful comparisons between systems. In total, we have documented 61 and 28 species of finfish associated with the reefs at Fisherman's Island and the Piankatank River, respectively. The reasons for the differences in species number between systems most likely relates to the fact that Fisherman's Island is at the confluence of the Bay and the ocean and the potential for species common to both systems to occur there is greater. Another possible reason relates to number of sampling events carried out at Fisherman's Island, which greatly exceed those on the Piankatank River.

The fishes captured have been classed according to their perceived use of the reef structure (Figure 16). There were seven species of fishes classed as resident fish species between the two reef systems. Oysters and the structure they provide are extremely important to these fishes. Breitburg (1999) outlined the importance of oysters as nesting sites for a number of fishes. Their structural complexity also provides a predation refuge (Posey et al. 1999). We have outlined potential linkages among different reef constituents. Harding (1999) demonstrated that juvenile and larval gobies and blennies will prey upon bivalve (oyster) larvae and Breitburg (1999) reported that juvenile gobies are fed upon by striped bass. We have reported that resident reef fishes are also preyed upon by striped bass. Also, we have shown that transient species of fishes will prey upon semi-transient fish species. It is clear that there are similarities among the systems analyzed in terms of trophic groupings despite the broad scale geographic range. What remains to be determined, however, are the complete linkages among different trophic groups and the degree of energy transfer among the different levels.

The increased emphasis on the construction of three-dimensional reef structures in Virginia for oyster restoration derives from the early signs of success at the Piankatank River and

Fisherman's Island. However, agreement as to the best means to effect restoration is not universal For example, the State of Maryland is pursuing a strategy of low relief shell planting as a means to maximize oyster production and harvest. The success of our approach in Virginia will depend in part, upon our definition and the importance attached to the ecological function of reef systems. It is clear that oyster populations will have to continue to develop to maintain viable reefs. Continued monitoring of established and newly constructed reef systems throughout the lower bay is recommended to judge success of different approaches and to facilitate adaptive management strategies.

The results of the studies in both the Fisherman's Island and Piankatank River have progressed the information base upon which reef restoration is founded. The products of this research have produced tangible results in the form of presentations and peer reviewed publications (Appendix 1). We will continue to submit the body of our work for publication in the hope that the work carried out in Virginia and funded by the EPA Chesapeake Bay Program will be applied by the resource managers that control resources in the Bay and vicinity.

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Appendix 1

Publications - Throughout the year a number of publications have been submitted and presentations made relating to the reef restoration work being carried out at the various sites. Two papers (listed below) have been published and are included as Appendix 2 and 3.

Harding, J. M. 1999. Selective feeding behavior of larval naked gobies (*Gobiosoma bosc*) and blennies (*Chasmodes bosquianus* and *Hypsoblennius hentzi*): preferences for bivalve veligers. *Marine Ecology Progress Series.* 179:145-153

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Coen, L.D., M.W. Luckenbach, D.L. Brietburg. The role of oyster reefs as essential fish habitat; A review of current knowledge and some new perspectives. Amer. Fisheries Soc. Symposium (in press)

Coen, L.D. and M.W. Luckenbach. Developing success criteria and goals for evaluating shellfish habitat restoration: ecological function of resource exploitation. Ecological Engineering (in press)

A number of other manuscripts have been submitted for publication and are currently in review:

Harding, J. M. and Mann, R. Diet and habitat use by bluefish (*Pomatomus saltatrix*) in a Chesapeake Bay estuary. In review at *Copeia.*

Harding, J. M. and Mann, R. Estimates of naked goby (*Gobiosoma bosc*), striped blenny (*Chasmodes bosquianus*) and eastern oyster (*Crassostrea virginica*) larval production around restored Chesapeake Bay oyster reefs. In review at *Bulletin of Marine Science.*

Harding, J. M. and Mann, R. Striped bass (*Morone saxatilis*) diet and habitat use in a Chesapeake Bay Estuary. In review *Transactions of the American Fisheries Society.*

Mann, R. Restoring the oyster reef communities in the Chesapeake Bay: A commentary. Journal of Shellfish Research.

O'Beirn, F.X., M.W. Luckenbach and J.A. Nestlerode. Oyster recruitment as a function of substrate type and tidal height. (Journal of Shellfish Research)

Harding, J.M., R. Mann and J. Duggan. Design of a semi-portable gill-net reel for sequential sampling at multiple estuarine sites. (Journal of Fish Biology)

Brietburg, D., L.D. Coen, M.W. Luckenbach, R. Mann, M. Posey and J. Wesson. Oyster reef restoration: Convergence of harvest and conservation strategies. (Journal of Shellfish Research)

Presentations

We presented four talks and a poster derived from the work supported by the Chesapeake Bay Program at the International Conference on Shellfish Restoration in Hilton Head, S.C. from Nov. 18-21, 1998. One of the presentations was a plenary address given by Roger Mann. In addition, Mark Luckenbach was a co-moderator of the "Oyster Reef Habitat, Development and Restoration" contributed session, a panel member of the "Essential fish habitat and environmentally sound aquaculture" panel session and co-moderator of the "Oyster Habitat/Resource Panel – Similarities and Differences for Restoration of Shellfish Communities among Sites and Systems" panel session. The abstracts from these presentations will be published in the Journal of Shellfish Research. The titles and authorships are listed below.

Harding, J.M. and R. Mann. Oyster reef restoration as a habitat enhancement tool for recreationally valuable shellfish.
Mann, R. Restoring oyster reef communities in the Chesapeake Bay.
Nestlerode, J.A., M.W. Luckenbach and F.X. O'Beirn. Trends in early community development and trophic links on constructed oyster reefs.
Nestlerode, J.A., M.W. Luckenbach and F.X. O'Beirn. Use of underwater video to monitor and quantify use of constructed oyster reef habitats by mobile commercially and ecologically important species.
O'Beirn, F.X., M.W. Luckenbach and J.A. Nestlerode. Oyster recruitment as a function of substrate type and tidal height.

There were also several invited presentations related to this project given during this quarter.

Luckenbach, M.W. "Oyster reef restoration in Virginia." New York State Dept. of Environmental Conservation, Stonybrook, NY. Jan 4, 1999.
Luckenbach, M.W. Approaches to oyster reeef restoration in the mid- and south- Atlantic." The Baykeepers, New York, NY. Jan 5, 1999.
Luckenbach, M.W. "The role of oyster reefs as essential fish habitat." Washington State Shellfish Growers Association, Olympia, WA. Feb 15, 1999
O'Beirn, F.X. – Invited to attend and participate in a press conference relating to the shell plant (overseen by the Bay Keepers) at Liberty Island, New York Harbour, June 24, 1999.

A number of presentations are scheduled to be given the Estuarine Research Federation Meeting in New Orleans (September 1999) and the International Conference on Shellfish Restoration in Cork, Ireland (October 1999) relating to the reef restoration work..

Oyster Reef Restoration in Virginia, USA: Rehabilitating habitats and restoring ecological functions
Luckenbach, M. W., Harding, J., Mann, R., Nestlerode, J., O'Beirn, F. X., and Wesson, J. A. – ICSR '99

Evaluating spatial and temporal trends in the restoration of oyster reef assemblages: The interactive effects of design criteria and recruitment levels. O'Beirn, F. X., J. A. Nestlerode and M. W. Luckenbach – ICSR '99

Oyster Reef Habitat Restoration And Enhancement: Optimizing Utilization By Resident And Transient Species. Coen, Luckenbach and Breitburg - ERF '99

Quantitative sampling appraoches for characterizing resident and transient assemblages on restored oyster reefs. A. Nestlerode, M. W. Luckenbach and F.X. O'Beirn – ERF '99