Trophic studies on constructed “restored” oyster reefs

Roger Mann and Juliana Harding
Dept. of Fisheries Science
Virginia Institute of Marine Science

Trophic studies on constructed "restored" oyster reefs

Roger Mann and Juliana Harding

Department of Fisheries Science
Virginia Institute of Marine Science
Gloucester Point, Virginia

Annual research report submitted to:

Dr. Carin Bisland
Living Resources Coordinator
U.S. Environmental Protection Agency
Chesapeake Bay Program Office

for activity during the period May 1996-May 1997

Grant/Contract No. CB993267-02-1

August 1997

Internet Web Site address: http://www.vims.edu/fish/oyreef/reef_page.html

Table of Contents

Introduction

Historical perspective

Oyster reefs (*Crassostrea virginica*) developed in recent geological time as the current Chesapeake Bay was inundated by rising sea level. Indeed, there is general consensus that oyster reefs were once the dominant feature for much of the Bay. Oysters dominated trophic interactions and enhanced overall system water quality while providing physical structure facilitating the development of complex benthic communities. By early Colonial times, oyster reefs (three dimensional aggregates of oyster shell) had become significant geological and biological features of the Bay and were also major intertidal navigation hazards. Continuing harvest pressure since Colonial times has resulted in the transformation and degradation of the oyster reefs to subtidal "footprints" of former reefs that maintain drastically reduced populations of oysters. Reef degradation has been exacerbated by companion environmental degradation and a historical lack of consideration for water quality and natural resource management. The past three decades have been defined by decline in the fishery production and the oyster resource under the added insult of two protistan parasites, *Perkinsus marinus* ("Dermo") and *Haplosporidium nelsoni* ("MSX"). Since the disease organisms are active throughout most of the growing range of the oyster there have been few sanctuaries in which to plant oysters or in which naturally occurring oysters could be found in appreciable quantities. Indeed, these parasites have effectively eliminated oysters from many sections of the Bay. The native oysters have developed neither tolerance nor absolute resistance to these diseases, and do not exhibit any recovery in disease endemic areas in Virginia. The oyster fishery is in severe decline and there is a recognized and urgent need to restore the oyster resource: not just for the commercial fishery but also to provide the benthic filter feeder that is so pivotal to the ecology of the Bay.

Current status of related oyster reef restoration activities

Oyster reef restoration has begun in the Virginia portion of the Chesapeake Bay as a collaborative effort between the Shellfish Replenishment Program of the Virginia Marine Resources Commission (VMRC) and the Virginia Institute of Marine Science (VIMS). It is timely to examine trophic interactions on restored oyster reefs and use these interactions as an indicator of the success of restoration efforts. Quantitative assessment methods for oyster reef communities are challenging and must incorporate temporal, tidal, and structural attributes of these systems in order to accurately characterize these habitats. We promote the philosophy that current oyster restoration efforts in the Bay may be gauged with respect to the overall demographic and ecological health of existing reef communities. Larval and adult forms of oysters, a suite of other benthic species (ranging from attached filter feeders through detrital feeders to benthic predators such as crabs), intermediate fish species (such as gobies and blennies), and apex predatory species (such as striped bass, weakfish, and spotted sea trout) interact to form the complex trophic structures responsible for creation and maintenance of the stable climax reef community observed historically. Any holistic approach to assessment of restoration must be cognizant of all "the players" in the trophic interactions.

To accurately assess oyster restoration efforts, it is necessary to either establish a "baseline" for comparison or have access to historical data characterizing oyster demographics and ecology. We have access to such a database of oyster information and are currently involved in several monitoring programs which contribute directly to the maintenance of this archive. Restored reef data sets may be compared to extensive historical data sets from productive areas within Virginia waters, most notably the James River. Current and historical maps of oyster aerial densities for all public oyster grounds in Virginia waters are also available. Thus, any data resulting from these restoration efforts can be placed in both historical and geographical context with little difficulty. Integration of these data sets provides context and perspective for oyster reef restoration efforts which, to our knowledge, cannot be duplicated.

To date our activities in reef restoration through active construction and subsequent monitoring and manipulative studies have focused on the Piankatank River (Figure 1). The initial reef, Palace Bar Reef, was constructed in May of 1993 as a joint venture between VMRC and VIMS. Since that time, three more reefs have been constructed in the Piankatank resulting in an available "time series" of reefs with respect to development to a mature standing stock of oysters and associated benthic organisms. It is important to note that these reefs were not initially seeded with oysters. All recruitment is from natural settlement originating from other typical "flat" reefs or rocks in the same river - the location of the Piankatank relative to other known oyster resources strongly suggests this system is isolated with respect to recruitment. These reef restoration projects offer an unparalleled opportunity to document the development of "natural" reef communities on three dimensional structures against a background of typical "flat" reefs or rocks.

The Piankatank River is an excellent site to develop an oyster reef restoration program in that it has not supported a commercial oyster fishery for over a decade; however, it has been the site of a successful seed oyster program, and remains the site of an active blue crab pot fishery and a recreational rod and line fishery. A limited number of typical "flat" oyster rocks in the Piankatank have had applications of shell on a regular basis by VMRC with subsequent harvest of the settled seed after one or two summers of exposure (the summer being the period of oyster settlement) prior to transfer to public oyster bars elsewhere in Virginia. The shell deployment and harvest data are documented by VMRC, the temporal and spatial nature of settlement is documented by a continuing program at VIMS. Oyster spat (juvenile and newly settled oysters) counts of up to 1000 individuals per bushel of shell are commonplace in seed oyster dredging from these maintained and managed areas. The footprints of the former reefs are well documented from both historical sources (Baylor Surveys), recent surveys (Haven and co-workers in the early 1980's, all material on file at both VIMS and VMRC), and continuing work by the VMRC staff. The reefs are not uniform in shape, this is clearly site specific and related to local circulation. The

lack of a continuing commercial presence focused on oysters, the proven history of the site as one of good oyster settlement, the comparatively pristine environment at the site (there is essentially no industrial and very little agricultural development in the Piankatank watershed - even residential density is low), and the strongly supportive attitude of waterfront residents to environmentally sound management (illustrated by the support of the local residents through an environmentally oriented group called S.T.O.P - Save the Old Piankatank) combine to make this a unique and attractive site for continuing study.

Previously, little attention had been given to the trophic interaction of oysters with either fishes or benthic predators such as crabs on restored reefs. The relationship between oyster reefs and small intermediate reef fishes such as gobies and blennies is obvious in that oysters dominate the reef communities, and gobies (*Gobiosoma ginsburgi* and *G. bosci*) and blennies (*Hypsoblennius hentzi* and *Chasmodes bosquianus*), which are some of the most abundant fish species in the Chesapeake Bay, are abundant in reef communities. Gobies and blennies are major food fishes for larger pelagic predatory species (*Morone saxitilis*, *Pomatomus saltatrix*, *Cynoscion_regalis*, *Cynoscion nebulosus*) which potentially use reef communities as both nesting and nursery areas. It is reasonable to suggest a relationship between the developmental stage of a reef (maturity with respect to development of a stable oyster community over time, an index of the success of the restoration/rehabilitation process), the development of a goby population (and other "food" fish populations), and the abundance of major predatory finfishes.

We have examined and continue to examine this relationship through field studies focusing on the oyster (predominantly oyster larvae) - intermediate fish (predominantly larval goby/blenny) relationship as well as the intermediate fish-apex predator fish relationship. A significant portion of this effort has been directed towards water column processes (e.g. predation on oyster veligers by larval intermediate fishes, predation on adult intermediate fishes by apex fish predators), as directly related to the benthic community.

The dependent relationship between oyster reefs and crabs is equally obvious. Crabs, notably the blue crab, *Callinectes sapidus*, are well documented as predators on oysters, especially the smaller size classes. As oyster communities develop to include dense seasonal populations of rapidly growing recent recruits there is an expectancy of intensive blue crab predatory activity. We have examined blue crab abundance and population structure in proximity to the oyster reef over time.

Relevance of this project to the Aquatic Reef Restoration Program

Restored oyster reefs are unique sites for examining oyster reef development and parallel development of associated communities within the Chesapeake Bay. The combination of Piankatank reef sites provides an unprecedented opportunity to quantitatively track the chronological development and maturation of "natural" reef sites of differing stages of maturity in a relatively undisturbed setting.

Objectives

The **long term goal** of our oyster reef community restoration program is the understanding of reef function from an ecological community perspective (e.g. food web impacts). In this program we specifically:

1. Build on existing oyster reef restoration database with continued monitoring efforts.
2. Combine monitoring efforts with sampling of upper trophic levels in reef communities.
3. Describe and compare the temporal and spatial changes in abundance of intermediate fishes (gobies and blennies), apex fish predators (e.g. striped bass) and dominant benthic predators (blue crabs) in three dimensional restored reefs.

Study Design

Site Description

Field studies were conducted on Palace Bar Reef, a constructed, restored oyster reef in the Piankatank River, Virginia (see also earlier comments and Figure 1). This reef is constructed on the footprint of ancient reefs, is built exclusively of shell and is located in an area protected from commercial oyster fishing and other perturbations. There is a substantial oyster settlement database and a continuing program of reef study for the Piankatank site to provide supplemental information to the proposed community restoration program.

We have both continuing long-term monitoring programs in the Piankatank River and focused efforts on reef biology. We maintain a program to describe temporal and spatial settlement of oysters (using shellstring substrates deployed for weekly intervals) in the Virginia subestuaries of the Chesapeake Bay, including the Piankatank River, throughout the summer months from June through late September. Dredge surveys are effected in Spring and Fall throughout the Piankatank system. Diver surveys of selected reefs are effected in Spring and Fall, and general patent tong surveys are effected in selected areas in the Fall for quantitative stock assessment.

Methods and Results

Continuing VIMS-sponsored oyster studies have been combined with information on general community structure with the trophic levels directly above the oysters (intermediate fishes (e.g. gobies and blennies) and their pelagic and benthic apex predators (examples are respectively, striped bass, weakfish, bluefish etc., and blue crabs) to provide a more complete picture of oyster reef community function and restoration benefits to the overall ecosystem. The additional community and trophic information has been collected by benthic and pelagic adult fish sampling, plankton surveys, benthic surveys, diver quadrat counts, and crab pot deployments. All diving was done by certified members of the VIMS Scientific Diving team in accordance with appropriate NOAA guidelines.

Sampling schedule

The sampling schedule during 1996 was designed to elucidate seasonal variations in the reef community. Samples were collected based on a two week temporal cycle. Eleven two week sampling sequences were conducted from early May through October 1996. Table 1 provides a complete listing of all sampling days and the protocols completed on each one.

When it became clear that both diurnal and tidal cycles compound seasonal abundance and diversity patterns observed within the reef community, two 36 hour sampling sequences (June 28-9, August 29-30, 1996) were overlaid onto the existing seasonal sampling protocol. Field schedules from each of these stations are included in Appendix A.

Current sample status

A summary of the status of all samples collected with EPA support during the regular 1996 field season is given in Table 2. The zooplankton and bongo samples listed as archived have been preserved and are awaiting processing. These samples will be analyzed and included in the final report for the 1997 proposal which continued and expanded the work described in this final report.

A summary of sample status for samples collected with EPA support during the two 36 hour stations conducted in June and August 1996 is given in Table 3. The zooplankton and bongo samples listed as archived have been preserved and are awaiting processing. These samples will be analyzed and included in the final report for the 1997 proposal which continued and expanded the work described in this final report.

Oyster monitoring data

VIMS maintains an oyster monitoring program which provides data for oyster spat (shellstring program), small, and market-size oyster (annual dredge survey) abundance estimates. An extensive historic data set for both spatfall and adult abundance is available for Palace Bar (site of the primary study reef), Piankatank River. These data provide baseline information regarding the status of the Piankatank oyster populations in relation to Chesapeake Bay oyster populations. The trends observed in both spatfall (Figure 2) and adult abundance (Figure 3) around Palace Bar follow the general decline observed in the Virginia oyster fishery in recent years.

Benthic predators, intermediate fish, and pelagic adult fish surveys:

Surveys of resident fish abundance included both intermediate reef fishes (gobies, blennies) as well as larger pelagic fish found in association with reefs (striped bass, weakfish, speckled trout, etc.).

Surveys of Intermediate fishes

SCUBA observational methods (quadrat counts) were used to quantify intermediate benthic reef fish abundance. The reef area was divided into 32 quadrants. Prior to each day of quadrat counts, twelve quadrants were randomly selected and quadrat counts of adult naked gobies and striped blennies were conducted by diver teams in each quadrant. Depth and substrate composition were also recorded at the time of each count. Figure 4 shows the average numbers of naked gobies and striped blennies (± Standard Error of the Mean) observed per quadrat (0.25 m^2) on Palace Bar Reef from May through October 1996.

Surveys of adult pelagic fishes

Relative abundance and distribution: Otter trawls were used in conjunction with experimental gill nets to collect larger, pelagic fish. It is important to note that the two net formats have been used in combination in that gill nets can provide useful information on fish diversity and abundance over time but trawls provide better specimens for food habits studies in that there is less risk of regurgitation or digestion of prey items when trawling. Trawls were towed immediately adjacent to the reef. All trawls were five minutes in duration, with the tide, with water depth in the tow path ranging from 1.5 to 3.5 m. Experimental gill nets were set for three hour intervals immediately adjacent to the reef oriented parallel to the tide. Preliminary studies indicated that the nets fouled less and fished with similar efficiencies when oriented parallel to the current as opposed to perpendicular. Table 4 presents a complete listing of all fish species collected on and adjacent to Palace Bar Reef during the 1996 field season while Table 5 provides more detail on diurnal patterns of finfish abundance.

The four most abundant species collected on or adjacent to Palace Bar Reef during 1996 are also recreationally and commercially valuable: Atlantic croaker (*Micropogonias undulatus*), bluefish (*Pomatomus saltatrix*), spot (*Leiostomus xanthurus*), and striped bass (*Morone saxatilis*). Abundance patterns of these fishes varied both seasonally and diurnally. Figure 5 illustrates the observed seasonal variability in the distribution of these species around the reef as indicated by gill net collections. Abundance patterns of striped bass adults and juveniles as illustrated by gill net and trawl samples are highlighted in Figure 6.

Diurnal abundance patterns for these species in conjunction with dietary analyses will provide direct evidence for habitat use and segregation based on predator type and prey field. Piscivorous fishes who are top level, visual predators should make the most use of the reef habitat during temporal windows when their prey are foraging or actively moving about. Planktivorous or omnivorous fishes who are not top level predators and are at risk for predation should be most active at dusk or during the night when predation risk from visual predators is reduced. Since the reef's three dimensional structure is accessible to smaller fishes at all times and may provide a buffer or shelter regardless of light levels, the reef itself may modulate expected abundance patterns.

Figure 7 presents the diurnal abundance patterns observed for these species in June (Figure 7a) and August (Figure 7b) around Palace Bar Reef, Piankatank River, Virginia. In June, bluefish (pelagic, piscivorous) are most abundant during the afternoon and evening. Spot (omnivorous, potential prey items) are most abundant during the night when abundance of both striped bass and bluefish is decreased. Atlantic croaker (omnivorous, usually large) are present in low numbers throughout the day. By August, the striped bass are completely absent from the reef community and abundance of croaker seems drastically reduced. Both spot and bluefish are still present, although bluefish abundance patterns have shifted such that bluefish were most abundant during the night.

Dietary analyses: The entire digestive tracts of 338 pelagic fishes including all gut contents were collected and field preserved for subsequent laboratory quantitative gut content analyses. These analyses provide information on multi-species interactions and trophic relationships within and around the reef communities. Dietary analyses are in progress for all species observed but are most complete for the four most abundant fish species observed in proximity to the Palace Bar oyster reef: bluefish (*Pomatomus saltatrix*), Atlantic croaker (*Micropogonias undulatus*), striped bass (*Morone saxatilis*), and spot (*Leiostomus xanthurus*). Table 6 summarizes the major points of the dietary analyses on juvenile fishes (total length < 100 mm) caught during May-October 1996 including the three primary or most abundant prey items and the average percentage of the diet per prey species.

Table 7 summarizes the dietary analyses to date on adult fishes (> 100 mm) caught during May-October 1996 including the three primary prey items and the average percentage of diet per prey species. “IR fishes” refers to Intermediate Reef fishes such as naked gobies (*Gobiosoma bosci*) and striped blennies (*Chasmodes bosquiannus*). “Teleosts” includes Intermediate Reef fishes as well as Atlantic Silversides (*Menidia menidia*) and menhaden (*Brevoortia tyrannus*) and indistinguishable bony fish remains.

Trophic relationships: Continuing analyses of abundance and distribution patterns in conjunction with gut content analyses will clarify trophic linkages. Because of the volume of data involved, thus far only one such trophic connection has been examined in detail; additional relationships will be extensively explored when the 1997 data set is completed and available for concurrent analyses . Striped bass abundance patterns have been qualitatively compared to naked goby and striped blenny abundance patterns. There seems to be a clear seasonal trend: adult goby and blenny abundance decreases markedly after adult striped bass abundance increases in late June as shown in Figure 8.

Benthic predators: Blue crabs

Abundance: Abundance information for the Palace Bar Reef site has been obtained with baited crab pots (fishery independent data- 2’ x 2’ pots with a 2” cull ring) deployed regularly in proximity to the reef (Figure 10). Generally speaking, crab abundance increases as temperature increases seasonally from May through August as shown in Figure 9 below. The average number of crabs per pot for 12 crab pots baited and left out for 24 hours is shown (± SEM) over time. There is a significant difference in crab abundance over time (ANOVA, $F = 7.915$, $df = 27$, $p < 0.001$). The data were transformed to meet the ANOVA assumptions prior to analyses.

Abundance patterns: males vs. females: A simple plot of male and female blue crab abundance over time indicates a clear difference in habitat use of the reef by the sexes over time (Figure 10). September sampling was complicated by the increased tidal range and wind conditions accompanying Hurricane Fran (September 6-7, 1996). While crab pots were deployed during the hurricane’s presence in the area, these data were considered compromised because of the duration of pot fishing time (four days fished instead of one) and the abnormality of tides and weather in the area and potential confounding effects on crab feeding behavior and density. Logistic regression analyses seems to confirm this trend - males were most abundant at the reef prior to mid-August 1996, females were most abundant after. It is important to note that all of these abundance data are relative and may have been influenced by commercial crabbing in the area which varied in intensity with the seasons e.g. the commercial crabbing presence was most noticeable immediately adjacent to the reef in June and July 1996.

Length-frequency distributions: In addition to estimates of relative total abundance, the crab pots yielded data on length-frequency distributions for this crab population. Each crab's carapace length was measured to the nearest mm. Length frequency diagrams must take into account the gear used to gather the data e.g. 2 " cull rings were in place in all crab pots fished. Given that, the length frequency diagrams for the Piankatank River during May - October 1996 show a steady increase in size throughout the summer, but no clear cohort distinctions (Figure 11).

Plankton surveys:

Plankton surveys have been conducted regularly in and around the restored oyster reefs during 1996 and continuing into 1997 to assess the diversity and density of larval fishes and their prey suite. Bongo tows, zooplankton nets, and larval fish traps have been used to assess the diversity and distribution of the plankton community on and around Palace Bar Reef.

Bongo tows: Paired bongo nets (60 cm diameter, 202 µm mesh) were towed weekly around the reef. Samples were preserved immediately in ethanol or buffered formalin. Analyses will focus on ichthyoplankton abundance, diversity, and prey field quantification in relation to depth, tidal cycle, and season. Relevant selectivity indices will be calculated to quantify predator-prey relationships and potential impacts on recruitment and, ultimately, stock success.

Zooplankton tows: Single zooplankton nets (15 cm diameter, 80 µm mesh) were towed weekly around the reef. Samples were immediately preserved in ethanol. Analyses will focus on veliger abundance and distribution as well as ichthyoplankton abundance, diversity and prey field. Relevant selectivity indices will be calculated to quantify predator-prey relationships and potential impacts on recruitment and, ultimately, stock success.

Fish traps: Passive fish traps were constructed and deployed in the water column directly above the reef weekly to qualitatively assess the plankton community directly above the reef. Traps passively oriented into the current and provide information on presence/absence of veligers and fish larvae along a seasonal gradient.

Current status and connections with continuing research

The combination of the VIMS historic data archives and the abundant trophic data collected at Palace Bar Reef during 1996 with EPA support places us in a unique position: we have the necessary data to establish a baseline of oyster reef community structure. Our 1997 field season (also EPA supported) expanded our focus to include comparisons with local non-reef sites while maintaining monitoring efforts at the Palace Bar Reef site. The end product of the 1996 and 1997 field seasons is two years of intensive reef baseline data coupled with one year of parallel intensive data from a local flat oyster rock and a local sand-bar; an ideal scenario for establishing oyster reef impacts on the local biological landscape. Given the quantity of data involved in this project, our major limiting factors revolve around sample processing and analyses (i.e. time and money to do both properly). Both processing and analyses are currently underway and have been in progress since 1996. When all of these data are processed and analyzed, we will be able to quantitatively and qualitatively describe the development and function of oyster reef trophic structure at an unprecedented level of detail.

Three scales are included in the 1996 sampling design - seasonal, diurnal, and tidal. The combination of these scales and the focus on multiple trophic predator-prey relationships enables a better understanding of community dynamics than has been previously possible. The major benefit of this work is an understanding of the quantitative relationship between oyster reef community food chain levels in an ecological framework dependent upon the oyster (as both a physical habitat and a major prey item) as present on restored oyster reefs and typical "flat" oyster rocks.

Oyster reef restoration for the express purpose of oyster enhancement and water quality improvement may also contribute significantly to provision of habitat for blue crab predation, and to the success of recreational finfish species (probably more so than finfish reef enhancement alone in that oyster reefs provide a viable food chain to support the fishes). Dedicated oyster and finfish reef development will continue in the Bay, probably at accelerated rates in future years. It is fundamental that we understand the processes that dictate the success or failure of these activities, and maximize the benefit of such activities for fisheries enhancement and environmental rehabilitation (that is oyster resource rehabilitation).

Table 1: Piankatank River sampling days with protocols completed on each day during the 1996 field season.

Date	Plankton tows	Bongo tows	Fish traps	Quad counts	Crab pots	Gill net	Trawl	Shell strings
13 May 96						X	X	
16 May 96		X	X					
17 May 96				X	X			
23 May 96	X	X	X					
29 May 96						X	X	
30 May 96	X	X	X					
31 May 96				X	X			
6 June 96	X	X	X					
10 June 96						X	X	
13 June 96	X	X	X					X
14 June 96				X	X			
20 June 96	X	X	X					X
25 June 96						X	X	
27 June 96	X	X	X			X		X
28 June 96	X	X		X	X	X		
5 July 96	X	X	X					X
8 July 96						X	X	
10 July 96	X	X	X					X
11 July 96				X	X			
18 July 96	X	X	X					X
22 July 96						X	X	
25 July 96	X	X	X					X
26 July 96				X	X			
2 Aug 96	X	X	X					X
5 Aug 96						X	X	
8 Aug 96	X	X	X					X
9 Aug 96						X	X	

Table 1 (continued): Piankatank River sampling days with protocols completed on each day during the 1996 field season.

Date	Plankton tows	Bongo tows	Fish traps	Quad counts	Crab pots	Gill net	Trawl	Shell strings
15 Aug 96	X	X	X					X
19 Aug 96						X	X	
22 Aug 96	X	X	X					X
23 Aug 96				X	X			
29 Aug 96	X	X	X			X		X
30 Aug 96	X	X			X	X		
2 Sept 96						X	X	
5 Sept 96	X	X						X
9 Sept 96					X			
12 Sept 96	X	X	X					X
16 Sept 96						X	X	
19 Sept 96	X	X	X					X
20 Sept 96				X	X			
25 Sept 96	X	X	X					X
30 Sept 96						X	X	
3 Oct 96	X	X						X
4 Oct 96					X			
10 Oct 96								X

Table 2: Sample status as of 1 July 1997 for all Piankatank River EPA samples collected during the 1996 field season on regular field days.

Trophic level	Type of sample	# of samples	Processing status
Oysters-Intermediate fishes	Zooplankton tows	264	In progress
Oysters-Intermediate fishes	Bongo tows	54	Archived
Intermediate fishes	Quadrat counts	132	Completed
Benthic predators	Crap pot deployment	132	Completed
Apex predators	Gill net deployment	22 sets	Completed
Apex predators	Otter trawls	132	Completed

Table 3: Sample status for Piankatank River 36-hour station samples from June and August 1996.

Trophic level	Type of sample	# of samples	Processing status
Oysters-Intermediate fishes	Zooplankton tows	120	Archived
Oysters-Intermediate fishes	Bongo tows	60	Archived
Apex predators	Gill net deployment	20 sets	Completed

Table 4: Summary of finfishes collected on and immediately adjacent to Palace Bar Reef, Piankatank River, Virginia during May-September 1996. Data from both gill netting (G) and trawling (T) are presented for both seasonal (regular) and diurnal (36 hour) sampling.

Common name	***Scientific name***	**Gear**	**Sampling method**
Atlantic croaker	*Micropogonias undulatus*	G, T	Seasonal and diurnal
Atlantic menhaden	*Brevoortia tyrannus*	G	Diurnal
Bay anchovy	*Anchoa mitchilli*	T	Seasonal
Bluefish	*Pomatomus saltatrix*	G	Seasonal
Carp	*Cyprinus carpio*	T	Seasonal
Cobia	*Rachycentron canadium*	G	Diurnal
Harvestfish	*Peprilus alepidotus*	T	Seasonal
Hogchoker	*Trinectes maculatus*	T	Seasonal
Lined seahorse	*Hippocampus erectus*	T	Seasonal
Naked goby	*Gobiosoma bosci*	T	Seasonal
Northern puffer	*Sphoeroides maculatus*	T	Seasonal
Northern searobin	*Prionotus carolinus*	T	Seasonal
Oyster toadfish	*Opsanus tau*	G, T	Seasonal
Pigfish	*Orthopristis chrysoptera*	G, T	Seasonal
Pinfish	*Lagodon rhomboides*	T	Seasonal
Silver perch	*Bairdiella chrysoura*	G, T	Seasonal and diurnal
Skilletfish	*Gobieosox strumosus*	T	Seasonal
Spadefish	*Chaetodipterus faber*	T	Seasonal
Spanish mackerel	*Scomberomorus maculatus*	G	Seasonal
Speckled trout	*Cynoscion nebulosus*	G	Diurnal
Spot	*Leiostomus xanthurus*	G, T	Seasonal and diurnal
Spotted hake	*Urophycis regia*	T	Seasonal
Striped bass	*Morone saxatilis*	G, T	Seasonal and diurnal
Striped blenny	*Chasmodes bosquianus*	T	Seasonal
Summer flounder	*Paralichthys dentatus*	T	Seasonal
Weakfish	*Cynoscion regalis*	G	Diurnal

Table 5: Summary of all pelagic fishes collected by gill netting during 36-hour sampling stations at Palace Bar Reef, Piankatank River, Virginia in June and August 1996.

Common name	***Scientific name***	**Daylight collection**	**Night collection**
Atlantic croaker	*Micropogonias undulatus*	June, August	June, August
Atlantic menhaden	*Brevoortia tyrannus*	None	June, August
Bluefish	*Pomatomus saltatrix*	June, August	June, August
Cobia	*Rachycentron canadium*	None	June
Silver perch	*Bairdiella chrysoura*	June	June, August
Speckled trout	*Cynoscion nebulosus*	None	June
Spot	*Leiostomus xanthurus*	June	June, August
Striped bass	*Morone saxatilis*	June	June
Weakfish	*Cynoscion regalis*	None	June, August

Table 6: Summary of the major diet items for juveniles (TL < 100 mm) of the four main pelagic fish species caught at Palace Bar Reef, Piankatank River, Virginia during May-October 1996,.

Species	**n**	**1° prey**	**% of diet**	**2° prey**	**% of diet**	**3° prey**	**% of diet**
Leiostomus xanthurus	9	Copepods	85	Ostracods	5	Gastropods	5
Micropogonias undulatus	2	Oligochaetes	35	Polychaetes	28	Copepods	16
Morone saxatilis	29	Mysids	91	Amphipods	7	Polychaetes	2
Pomatomus saltatrix	0	-	-	-	-	-	-

Table 7: Summary of the major diet items for adults (TL > 100 mm) of the four main pelagic fish species caught at Palace Bar Reef, Piankatank River, Virginia during May-October 1996.

Species	**n**	**1°prey**	**% of diet**	**2° prey**	**% of diet**	**3° prey**	**% of diet**
Leiostomus xanthurus	60	Gastropods	31	Ostracods	28	Mysids	22
Micropogonias undulatus	25	Mysids	67	Gastropods	17	Polychaetes	6
Morone saxatilis	15	Mysids	50	IR fishes	17	Polychaetes	4
Pomatomus saltatrix	41	Teleosts	82	Mysids	11	Portunids	2

Figure 1: Map of the Piankatank River, Virginia indicating the field site for this project: Palace Bar oyster reef.

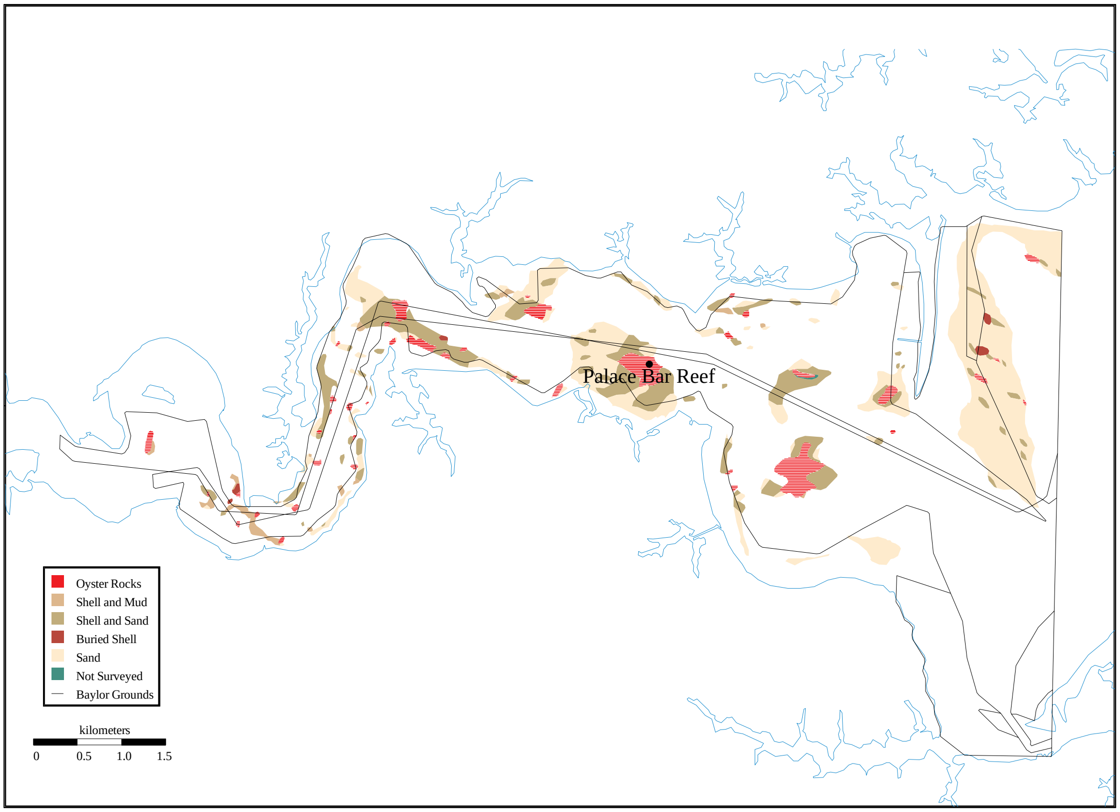


Figure 2: Average annual spatfall for 1967-96 (± Standard error of the mean) recorded at Palace Bar, Piankatank River, Virginia. Data provided courtesy of the VIMS Molluscan Ecology program.

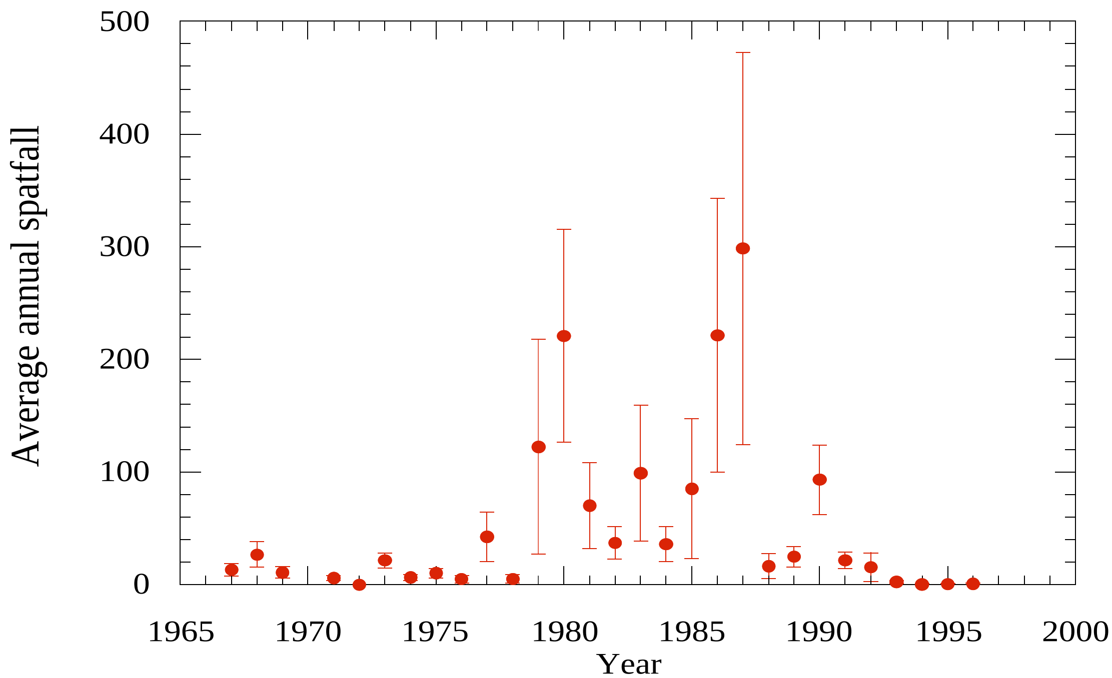


Figure 3: Average annual oyster abundance (1946-96) recorded through dredge surveys of Palace Bar, Piankatank River, Virginia. Data for both small and market oysters are presented courtesy of the VIMS Molluscan Ecology program.

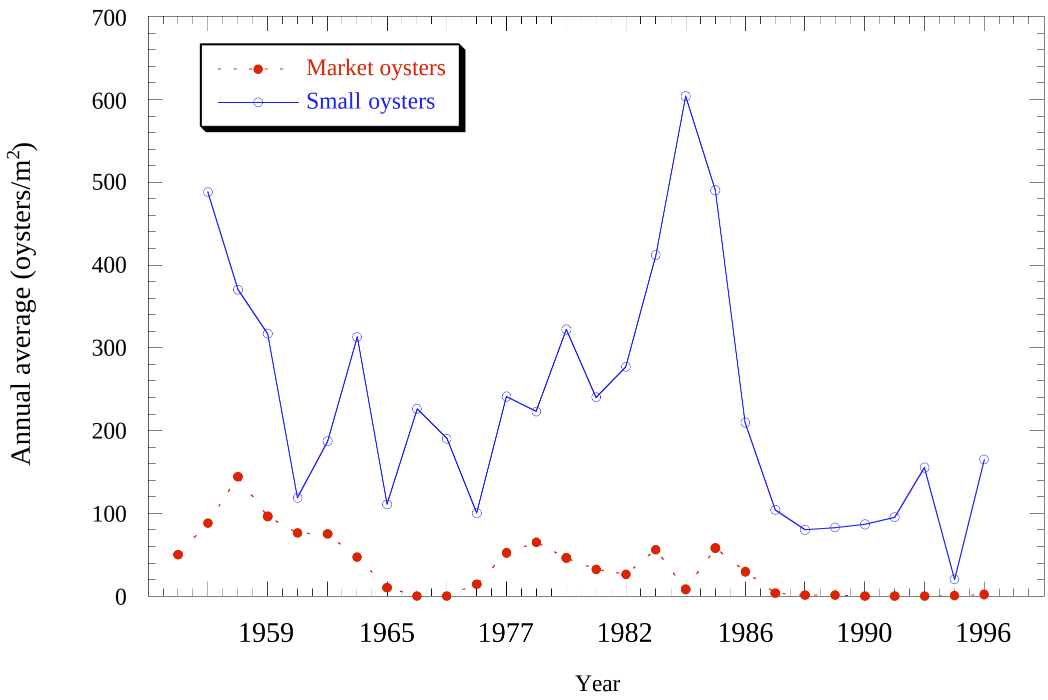


Figure 4: Average abundance of naked gobies and striped blennies (± Standard error of the mean) observed per quadrat (0.25 m^2) on Palace Bar Reef, Piankatank River, Virginia from May through October 1996.

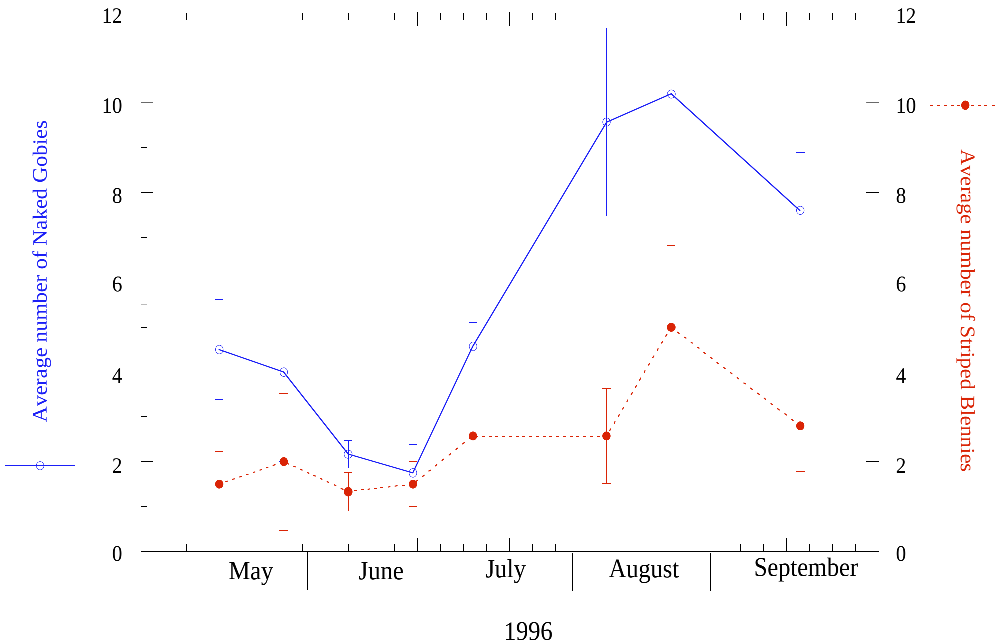


Figure 5: Abundance patterns of the four most common finfish species observed on Palace Bar Reef, Piankatank River, Virginia from May through October 1996. Data for bluefish, Atlantic croaker, striped bass, and spot are from both gill net and trawl collections.

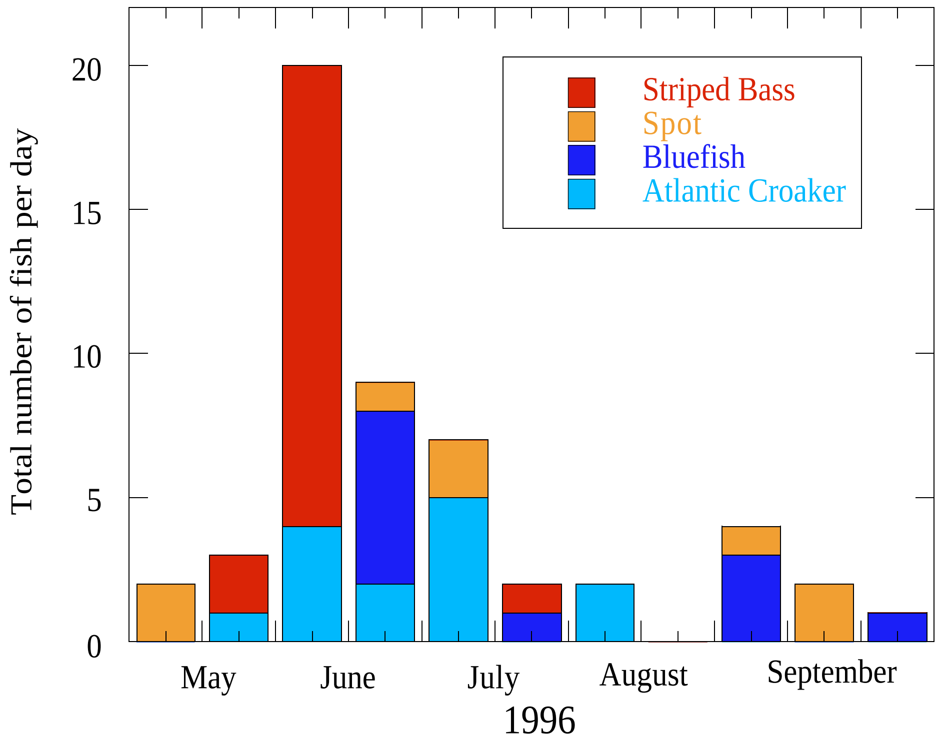


Figure 6: Abundance patterns of striped bass caught near Palace Bar Reef, Piankatank River, Virginia from May through October 1996 in relation to total length (mm). Data are from both gill net and trawl collections.

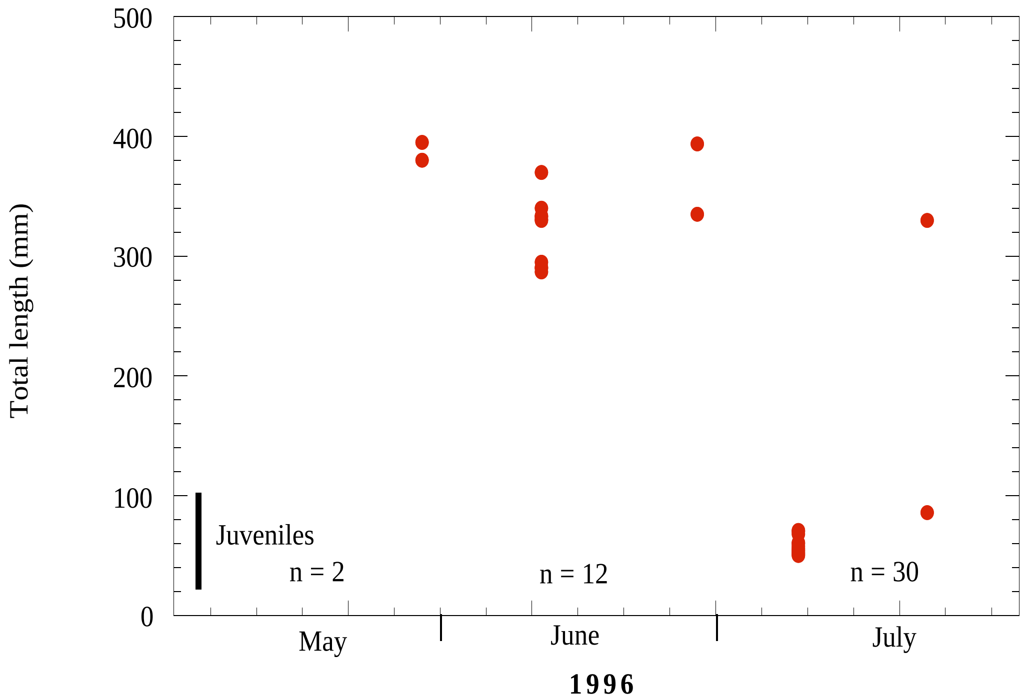


Figure 7: Diurnal abundance patterns for the four most common finfish species observed near Palace Bar Reef, Piankatank River, Virginia. Data are from 36 hour gill netting stations conducted in June (a) and August (b) 1996.

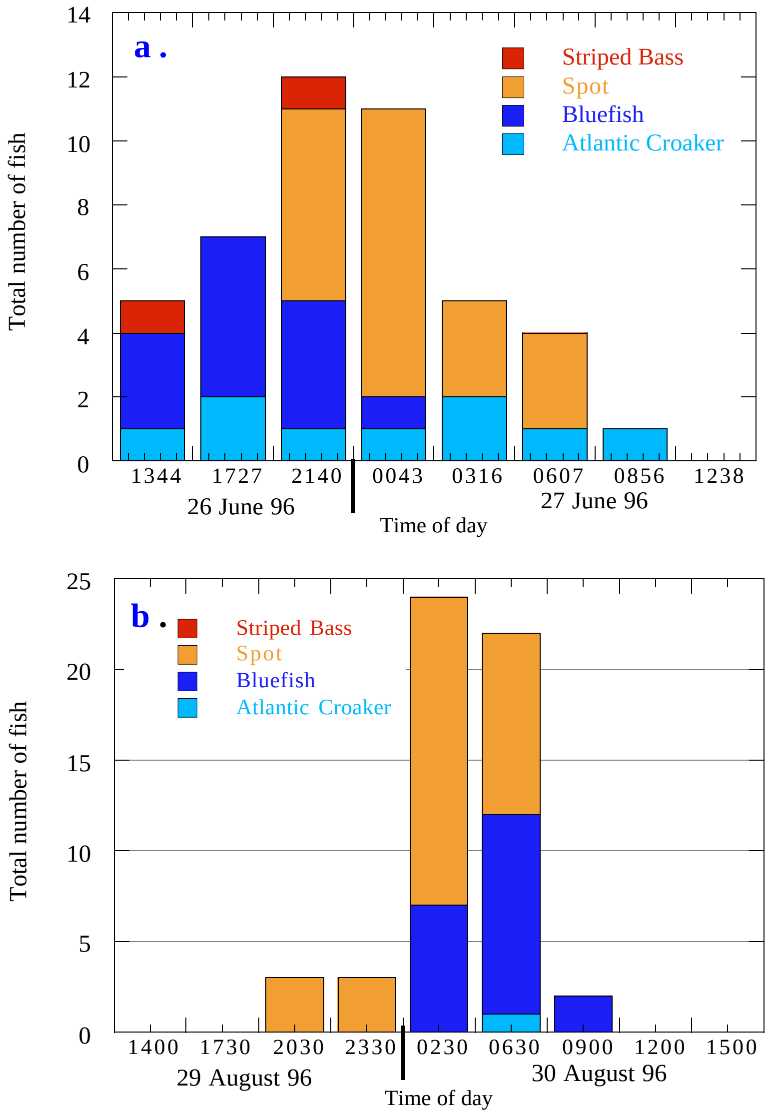


Figure 8: Average seasonal abundance patterns of naked gobies and striped blennies (± Standard error of the mean) in relation to total striped bass abundance on Palace Bar Reef, Piankatank River, Virginia.

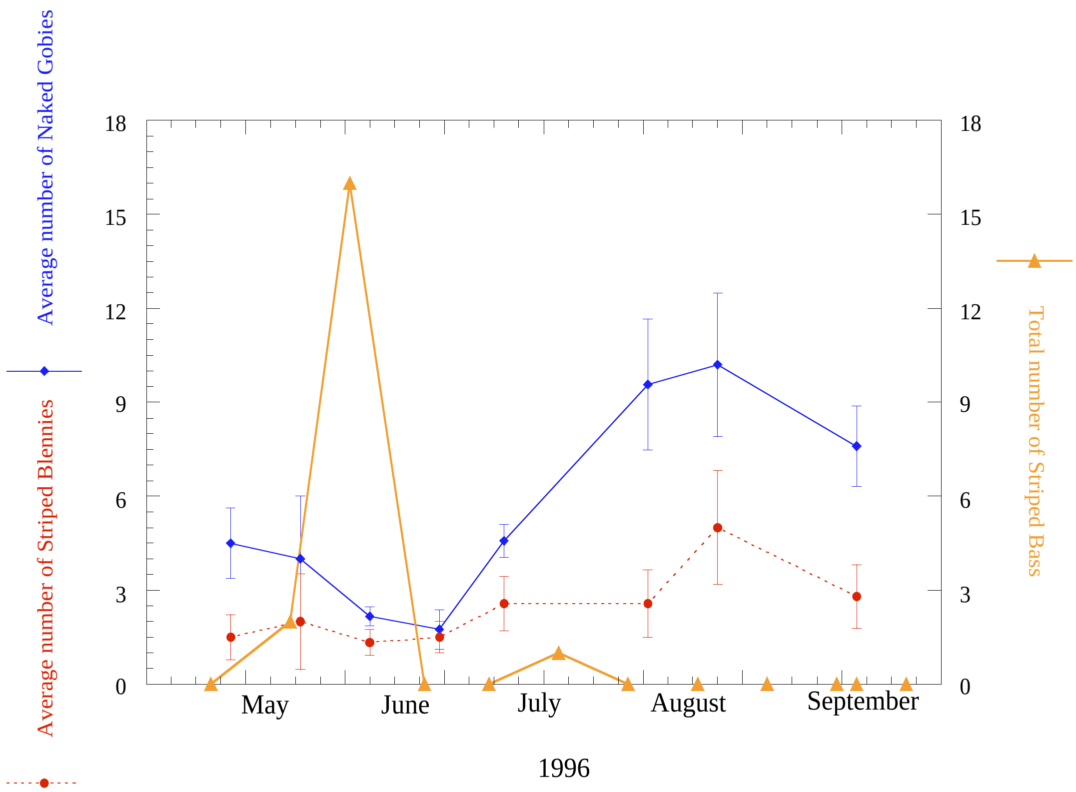


Figure 9: Average blue crab abundance (± Standard error of the mean) on Palace Bar Reef, Piankatank River, Virginia, in relation to water temperature (° C) from May through September 1996.

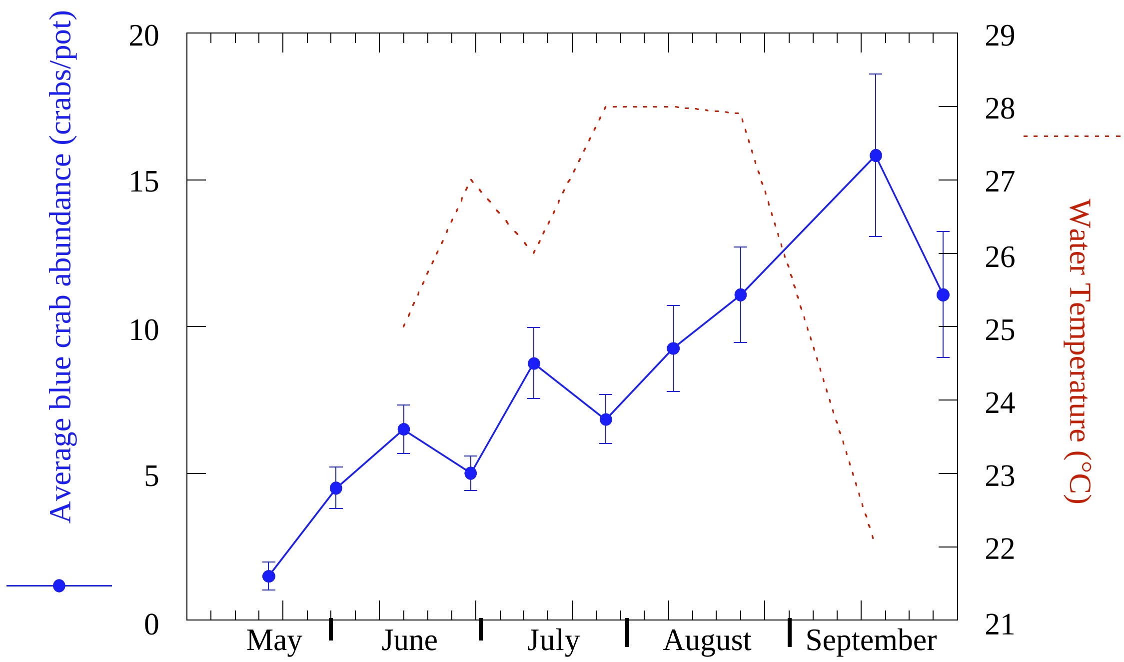


Figure 10: Total blue crab seasonal abundance by sex on Palace Bar Reef, Piankatank River, Virginia from May through September 1996.

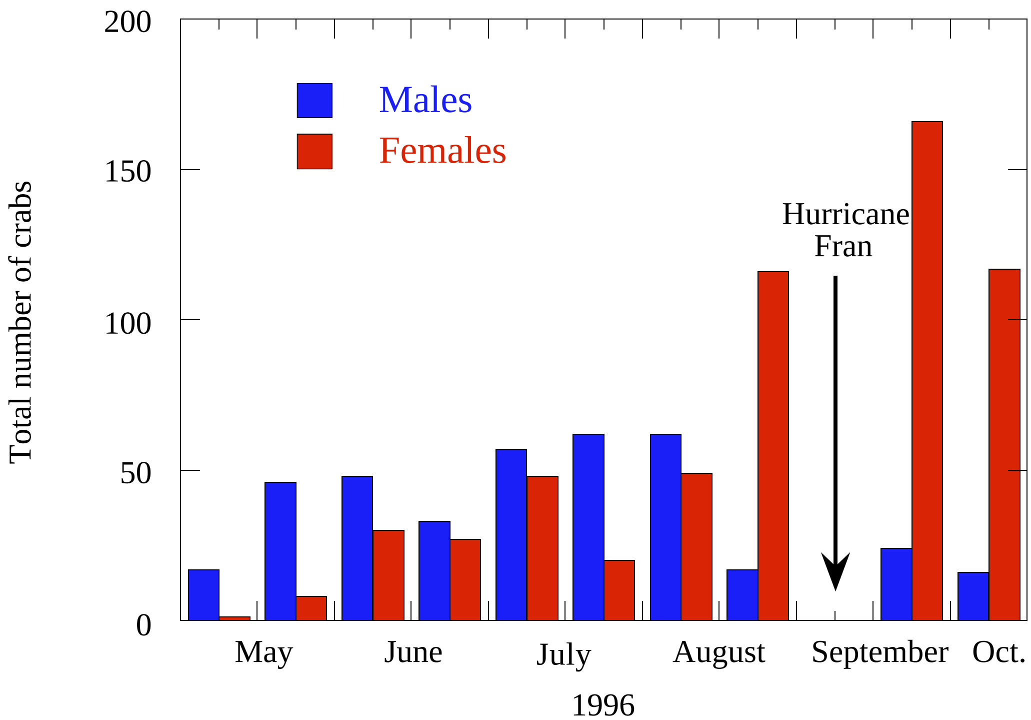
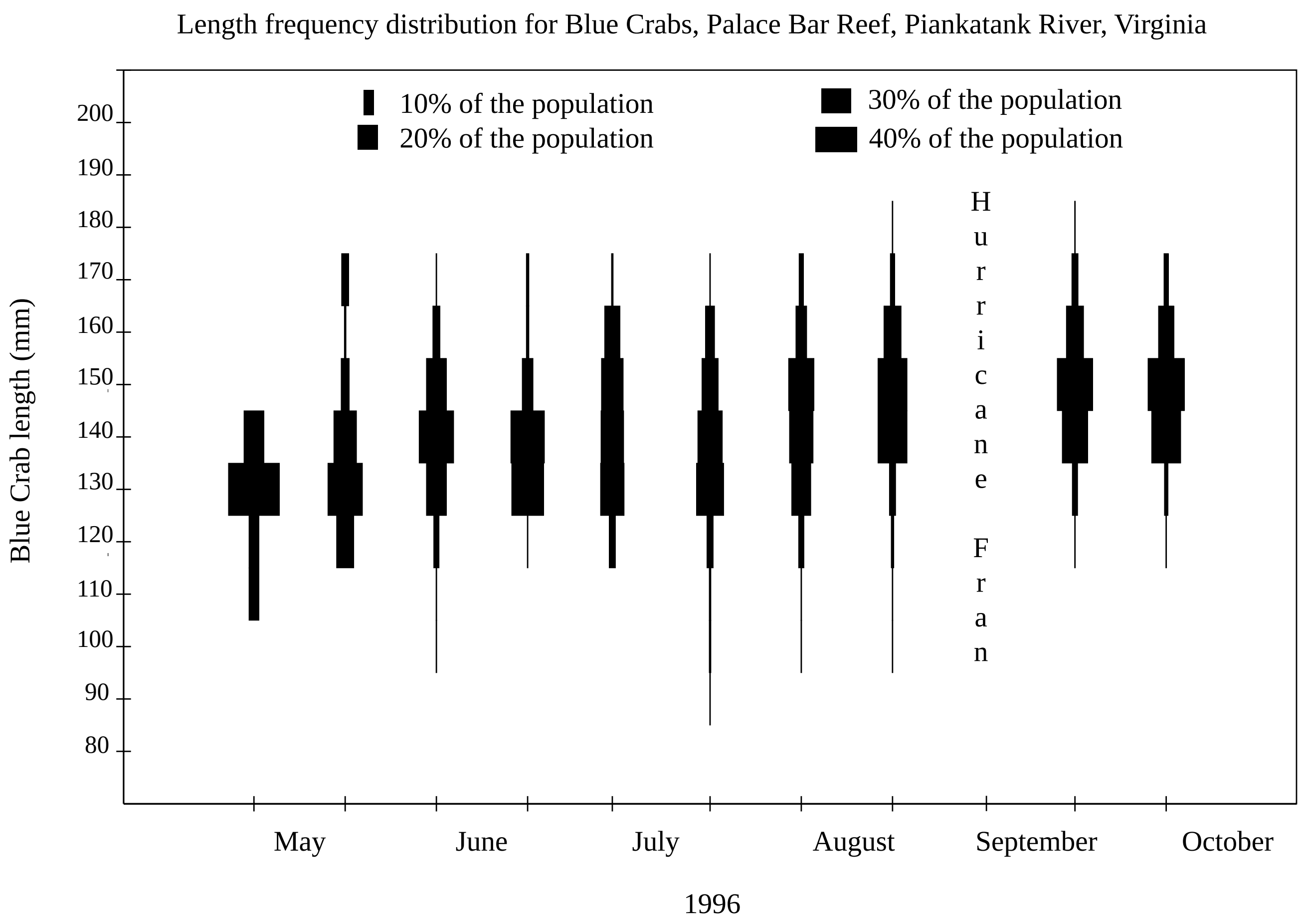


Figure 11: Length - frequency distribution for blue crabs (both males and females) caught in proximity to Palace Bar Reef, Piankatank River, Virginia from May through September, 1996.



Appendix 1

Field sampling schedules for 1996 Piankatank River

36 hour sampling stations

27-28 June 1996

29-30 August 1996

24 Hour Sampling Schedule
Piankatank River: Palace Bar Reef
27-28 June 1996

	Time	Tidal Stage	Event
Thursday	0730		Crew 1 leaves VIMS
	0830		Pick up crab pots
	0845		Launch
	0900		Reef
	0900-1000		Crab pot deployment
	1000-1100		Fish trap set #1
	1100	**Slack before Ebb**	**Gill net set #1**
	1130		Bongo #1
	1200		Lunch
	1230-1400		Trap set #2/ZP#1
	1400	**Max ebb**	**Gill net check #1/Set #2**
	1430		Bongo #2
	1500		Trap retrieval/ ZP #2
	1600		Leave reef for crew change
			Crew 2 leaves VIMS
	1700		Back on reef
	1730	**Sl before Flood**	**Gill net check #2/Set #3**
	1800		Bongo #3
	1830		ZP #3
	2000		Pizza @ Roger's dock/water refill
	2130	**Max Flood**	**GNC #3/ Set #4**
	2200		Bongo #4
	2300		Visit Roger's dock if needed
	2330		ZP #4
Friday	**0045**	**Sl before Ebb**	**GNC #4/ Set #5**
	0115		Bongo #5
	0145		ZP #5
	0300	**Max Ebb**	**GNC #5/ Set #6**
	0330		Bongo #6
	0400		ZP #6
	0545		Visit Roger's dock if needed
	0620	**Sl before Flood**	**GNC #6/ Set #7**
	0650		Bongo #7
	0720		ZP #7
	0730		Crew #3 leaves VIMS
	0800		Leave reef for crew change
	0830		Crew change
	0940	**Max Flood**	**GNC #7/ Set #8**
	1010		Bongo #8
	1040		ZP #8
	1110		Lunch
	1200	**Sl before Ebb**	**GNC #8**
	1230		Bongo #9
	1300		ZP #9
	1330		Diver quad counts
	1530		Crab pot retrieval
	1630		Pull boat
	1730		Return VIMS

36 Hour Sampling Schedule
Piankatank River
August 29-30 1996

	Time	Tidal Stage	Event
Thursday	0715		Crew 1 gathers at VIMS
	0745		Crew 1 Leaves VIMS
	0845		Launch at Deep Point, Harcum
	0910		Arrive Palace Bar Reef
	1010		Finish Shell strings
	1015		***Begin Trap Deployment #1***
	1100	Max Flood	**Gill net set #1, Sampling Round 1 begins**
	1300		Lunch
	1320		***Trap Recovery #1 and Set #2***
	1400	Slack	**Gill net check #1/ Set #2/ SR #2**
	1600		***Trap Recovery #2***
	1615		Crew #2 Leaves VIMS
	1630		Leave Palace Bar Reef for crew change
	1700		Crew Change
	1720		Back on Reef
	1730	Max Ebb	**Gill net check #2/Set #3/ SR #3**
	1915		Glo stick deployment on buoys and gear
	1945		Pizza at Roger's Dock, water refill
	2000		Back on Reef
	2030	Slack	**Gill net check #3/Set #4/ SR #4**
	2330	Max Flood	**Gill net check #4/Set #5/ SR #5**
Friday	**0230**	Slack	**Gill net check #5/Set #6/ SR #6**
	0500		Visit Roger's Dock if needed
	0600	Max Ebb	**Gill net check #6/Set #7/ SR #7**
	0730		Crew #3 leaves VIMS
	0745		Leave Reef for Crew Change at dock
	0815		Crew Change
	0840		Pick Roger up at his dock
	0900	Slack	**Gill net check #7/Set #8/ SR #8**
	1100		Go to Ginney Point Marina and get gas
	1200	Max Flood	**Gill net check #8/ Set #9/ SR #9**
	1400		Lunch
	1500	Slack	**Gill net check #9 and recovery/ SR #10**
	1630		Trailer leaves VIMS for dock
	1700		Boat Recovery @ Launch
	1800		Return VIMS