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Transplanting broodstock oysters, Crassostrea Virginica, onto reconstructed oyster reefs to increase spat recruitment in the Piankatank River

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Abstract

Four oyster reefs were recreated from oyster shells to historical proportions in the Piankatank River from 1993-1995. In December 1997, two of the reconstructed reefs were supplemented with large broodstock oysters from Tangier and Pocomoke Sounds. Since total quantity as well as density of broodstock were believed to be limiting factors for recruitment in this river, adding stock was expected to raise spat recruitment. Methods included dive surveys on the reefs, and dredge and patent tong surveys on the natural oyster bars. The recruitment of spat to both reefs and bars was significantly higher in 1998 ($p<0.001$) than in the previous four years and a positive interaction ($p<0.005$) was seen between the reefs and the year 1998. Based on these data, stock enhancement in the Piankatank River successfully improved recruitment and suggest oyster restoration may be facilitated in other areas of the Chesapeake Bay by strategic enhancement of spawning stocks.

TRANSPLANTING BROODSTOCK OYSTERS, *CRASSOSTREA VIRGINICA*, ONTO RECONSTRUCTED OYSTER REEFS TO INCREASE SPAT RECRUITMENT IN THE PIANKATANK RIVER

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INTRODUCTION

Oyster reefs are important geological and biological structures. The American oyster, *Crassostrea virginica*, inhabits most of the Atlantic and Gulf of Mexico coastal waters, living in shallow, well-mixed estuaries and lagoons that have fluctuating salinities, temperatures, and suspended solids (Cox and Mann, 1992; Kenny et al., 1990; Shumway, 1996; U.S. Army Corps of Engineers, 1986). Oysters are dominant filter feeders that harvest microplankton whose blooms can cause fluctuations in the pH and oxygen levels of the water (Gottlieb and Schweighofer, 1996; Mann et al., 1991) Oysters also aid in cycling nutrients and energy in the ecosystem (Gottlieb and Schweighofer, 1996; Kenny et al., 1990; Mann et al., 1991). Oyster reefs decrease the impact of eutrophication, improve water quality, and provide refuge and attachment sites for many invertebrates. Juvenile and adult fish, crabs, shrimp, and larger predators also use the reefs as habitats (Dame, 1996; Wenner et al., 1996). Furthermore, people enjoy eating oysters. The Virginia oyster industry consists of public and private fisheries which are interwoven with economic, social, political, and natural factors (Hargis and Haven, 1988).

Over the past three centuries, the oyster population has steadily decreased in density. Prior to 1870, oysters were estimated to filter the entire Chesapeake Bay in approximately 3 days, but because of the decreased numbers today, it is estimated to take 325 days for the resident oyster populations to filter the Chesapeake Bay (Mann et al., 1991). Both man-made and natural factors have contributed toward the steady and drastic reduction of oyster population numbers These factors include overharvest (taking without replacing), decreased water quality from pollution, increased sedimentation from dredging and siltation, freshets (large influxes of freshwater which lower the salinity killing oysters), and protozoan epidemics (1959 - present) (Gottlieb and Schweighofer, 1996; Haven et al., 1981; Mann et al., 1991; Rothschild et al., 1994).

HISTORICAL PERSPECTIVES

During the Jamestown colonization era, oyster reefs reached the water surface and were navigational hazards similar to coral reefs. Prior to the 1700's, native Americans harvested the oysters by hand. From the mid-1700's until after the Civil War, oysters were collected by hand tongs. These harvest methods had only minor impacts on the oyster populations because they were slow, inefficient processes and restricted to shallow waters. As technology improved, however, the integrity of the reefs became more and more compromised (Hargis and Haven, 1988).

In the 1800's, watermen began using dredges to harvest the oysters mechanically (in the New England area). Following the Civil War, these technologies spread to the Chesapeake Bay and dredges were dragged over a larger area of the estuary bottom. This dredging technique was used in deeper waters by watermen, removed more oysters, and broke up the oyster reefs. By the late 1870's, there were as many as 700 dredge vessels operating in the Chesapeake Bay. The reefs began to decrease in height because empty shells were not being thrown back after harvesting but instead were being used for building materials, roads, lime, etc. In 1887, hand operated patent tongs, a new device, allowed access to even deeper waters. Oyster densities continued to decrease

Eventually, roads and better transportation methods permitted access to quarries for building material so oyster shells were in less demand and could be returned to the water once again (Hargis and Haven, 1988).

In 1950, the most destructive device, the hydraulic-powered patent tongs, was introduced. It actually penetrated and destroyed the oyster reefs. As the reefs continued to decrease in height, water flow changed, causing increases in silt deposition. Nutrients running into the bay also started increasing and water quality decreased (Hargis and Haven, 1988; Rothschild et al., 1994).

An oyster disease, Dermo, caused by the protozoan *Perkinsus marinus*, was naturally present in the Chesapeake Bay. Around 1959, a new oyster disease, MSX, caused by the protozoan *Haplosporidium nelsoni* and carried over by the Pacific oyster was introduced to the Chesapeake Bay (Gottlieb and Schweighofer, 1996). Both MSX and Dermo attack the digestive gland of adult oysters, generally after the oyster reaches about three years of age (about 3 inches) (Dame, 1996; Haven et al., 1981; Mann et al., 1991; Powell et al., 1994; Rothschild et al., 1994). Both diseases are most prevalent in areas of high salinities (above 15 parts per thousand).

Watermen began harvesting smaller oysters trying to collect them before they became infected with the disease (generally around 3 years of age). Over time, this process allowed large oysters with high fecundity and possible disease resistance to be harvested and consumed by humans. The smaller oysters with lower fecundities and unknown disease resistance were left to maintain the population (Wesson, 1998).

OYSTER RECOVERY

There are four steps to oyster reef recovery: 1) good management, 2) oyster replenishment (placing shells on top of existing areas and transplanting spat), 3) habitat replacement (creating additional reef habitats), and finally, 4) broodstock sanctuaries where harvesting of oysters is prohibited (Rotschild et al. 1994).

After decades of destruction, management steps were taken to attempt to restore the oyster populations. In 1928, the Oyster Repletion Act was passed and planting shells to provide suitable substrate (cultch) to enhance settlement was initiated (Berrigan, 1990; Castanga et al., 1996; Hargis and Haven, 1988; Haven et al., 1981; Mann et al., 1990).

In 1990, Governor Douglas Wilder convened a Blue Ribbon Oyster Panel to develop a plan for restoring the oyster resources and industry. In May of 1992, the plan was adopted by the Virginia Marine Resource Commission (VMRC) with the exception of introducing non-native species. The Commission's two main goals were: "No net loss of existing standing stock of the native oyster over the next five years...[to] and achieve a doubling of the existing standing stock on the native oyster over the next ten years" (Wesson et al., 1998). Recovery was predicted to be slow because of decreased oyster stocks and limited broodstock genetic diversity.

OYSTER MANAGEMENT

Past management practices have included instituting culling laws to protect spat (young of the year), seasonal closing of certain areas, and restrictions on certain types of harvesting gear (Castanga et al., 1996, Hargis and Haven, 1988, Powell et al., 1994). In the mid-1990's a dramatic step was then taken in Virginia by closing most of the lower Chesapeake Bay to harvest and restricting harvest in the remaining areas. Despite the watermen's displeasure, this step was considered necessary to retain the oyster numbers that were left. Management practices also included support for projects involving oyster replenishment, reef creation, and broodstock sanctuaries.

In 1994, Governor George Allen signed the Chesapeake Bay Aquatic Reef Plan and Oyster Fishery Management Plan which "call for the creation of 5000 acres of oyster reef habitat during the next 5 years" (Wesson et al., 1998).

OYSTER REPLENISHMENT

In the past, new oyster bars were created instead of replenishing natural bars. These methods were normally ineffective because oyster bars were expensive to build and maintain; over time many have disappeared (Wesson, 1998). Currently, the VMRC restores cultch on natural bars three ways. Sprinkling clean shells on oyster bars adds to the bars without smothering the oysters already living there. Attempts on the James River bars showed such improvement that it was used in other areas. A second way involves restoring shells on areas with firm bottoms but few remaining oysters, while the third uses a hydraulic excavating machine to turn over sunken shells (Wesson et al., 1998).

Transplanting seed oysters (small oysters) is another method of replenishment. The best spat-producing areas occur in areas with high salinities and disease presence. These oysters, when transplanted, grow best in moderate salinity areas (Wesson, 1998).

HABITAT CREATION

Reef restoration increases spawning success, provides a safe habitat, and increases water filtration which increases water quality. Oyster reefs are three-dimensional structures which are built up from the bottom and have depth while oyster bars are two dimensional structures which are considered to be flat and cover the bottom. Oyster larvae tend to settle on the undersides of oyster shells or in shaded areas (Kennedy, 1996; Michener and Kenny, 1991). This would suggest the use of 3-dimensional reefs which have interstitial spaces between the shells upon which larvae can settle. Because of better water circulation, the spat would be exposed to higher oxygen levels, possibly better food, have less chance of getting covered by sediment, and have more protection from predators on the three-dimensional oyster reefs versus living on the two-dimensional oyster bars (Roegner, 1991; Wesson, 1998). As well as providing habitats for oyster larvae, oyster reefs provide habitat for crabs and fish which in turn attract larger fish. Fisherman are then attracted to the reefs in an attempt to catch these larger fish.

Choosing a site, obtaining funds, and building the reef is not an easy process. There are many abiotic and biotic factors which affect the settlement of oyster larvae and impact reef location (Figure 1). Some of these factors include fluctuations in water quality, food supplies, disease, predation, temperature, salinity, depth, current velocity, and topography (Kenny et al., 1990; Soniat et al., 1991). Pollution and pH can affect oysters and their reefs, but they are not a factor in the Piankatank River because it is has little industrial runoff and is considered to be one of the cleanest rivers in the state of Virginia (pers. comm. with Jim Wesson of VMRC).

The substrate must be firm enough to support the oysters and shells, preventing them from sinking into the bottom and dying from anoxia (Haven et al., 1981). Water current is important because it provides food and removes feces, pseudofeces, and silt that could cover the oyster (U.S. Army Corps of Engineers, 1986). Mature, well-developed bars have strong current flows, but if the current is too strong, it can move the oysters (Rothschild et al., 1994; U.S. Army Corps of Engineers, 1986). The amount of suspended material (turbidity) and sedimentation also affects oysters. Too much suspended material reduces the oyster's pumping rate, resulting in decreased filtration and ingestion of nutrients (Haven et al., 1981; Kenny et al., 1990; Rothschild, 1994; Shumway, 1996; U.S. Army Corps of Engineers, 1986)). Normally, oysters feed most efficiently in clear waters (Shumway, 1996).

Oysters are generally found in depths less than 25 feet because of low oxygen levels found in deeper waters (Haven et al., 1981; Kenny et al., 1990; Shumway, 1996; U.S. Army Corps of Engineers, 1986). The optimum temperature range for growth is 20° - 30° C with 19° - 24°C being the ideal settlement temperature for oyster larvae. Oysters need a salinity of 5 - 30 parts per thousand (ppt) for survival, with 20 - 35 ppt being the optimum salinity for Virginia oysters (Shumway, 1996, U.S. Army Corps of Engineers, 1986). The highest survival rate, however, is below 15 ppt because of fewer predators.

The lower salinity does cause slower growth in oysters (Cox and Mann, 1992; Dekshenieks et al., 1993; Haven et al., 1981; U.S. Army Corps of Engineers, 1986).

Disease, predation, and competition are major biotic factors affecting oyster reefs. Predators of adult oysters include oyster drills, oyster leaches, blue crabs, mud crabs, gastropods, starfish, and birds. The larvae are eaten by menhaden, shad, herring, comb-jellies, jellyfish, sea nettles, vertebrates, and other invertebrates (Dame, 1996; Haven et al., 1981). Predators have easier access to spat on the 2-dimensional bars because there are fewer areas for larvae to hide in. In both 1996 and 1997, the reef in the Great Wicomico had a higher spat density per meter than the 2-dimensional oyster bars (Wesson, 1998). This suggest that the 3-dimensional structure of the oyster reef reduces predation and increases the oyster survival.

Oysters must also compete for space. Larvae need to settle on a flat, clean surface in order to cement themselves and stay sessile. Such surfaces are also prime spots for mussels, barnacles, algae, tunicates, tube worms, and bryozoans (Haven et al., 1981; Kenny et al., 1990). Oysters can also be found attached to barnacles and mussels.

Between 1993 and 1998, fifteen 3-dimensional oyster reefs were constructed in Virginia's waters (Figure 2). In 1993, the first reef was constructed in the Piankatank River at Palaces Bar. A reef was also built in the James River in 1993 The James River reefs are not surveyed in the dive survey because the currents are too swift for divers to conduct a survey safely and accurately (pers. comm. with Jim Wesson of VMRC).

In 1995, an EPA Chesapeake Bay Program Grant provided funding for three more reefs in the Piankatank River using oyster shells. All three reef locations had old shells, hard bottoms, and depths of 6 - 8 feet at mean low water (Wesson et al., 1998).

In June of 1996, a reef in the Great Wicomico was built (Wesson, 1997a). Reefs were built in the Pungoteague, Lynnhaven, Coan, and Yeocomico Rivers in 1997. In 1998, two more reefs were built, one in the Great Wicomico River at Crane's Creek and the other in the western branch of the Elizabeth River.

After building the reefs, oyster numbers were monitored to measure the success on both the reefs and the surrounding bars. Monitoring included dive surveys, dredge surveys, and patent tong surveys to get a qualitative and quantitative measure. An annual fall dredge survey of the Baylor Survey Grounds (Public Oyster Grounds of Virginia) began in 1947 in Virginia. The dredge survey began in 1971 in the Piankatank River and has continued to the present with the exclusion of 1974 - 1976. It provides information about spatfall and recruitment, mortality, and annual changes in seed and market sized oysters. The dredge survey showed a steady decrease in the oyster population with the lowest being in the last six years (Figure 3). These surveys have also reflected the decreased oyster landing records of watermen as well.

In 1993, the Chesapeake Bay Stock Assessment Committee funded a quantitative stock assessment program in the James and Rappahannock Rivers using a specially built patent tong to give an accurate assessment of the oyster population. More sites were added in 1994 on the Eastern Shore, and in 1995, Virginia's tributaries started being assessed using the patent tong (Wesson et al., 1998). This information has been used by the VMRC in deciding which areas to open and close for harvest as well as to determine restoration success.

The patent tong is used for quantitative comparisons and the dredge for qualitative comparisons because the oyster dredge does not accurately estimate the oyster numbers on the public oyster grounds. The dredge is used, however, as an easy and inexpensive technique for sampling multiple areas. The dredge was found to be only about 10% as accurate as a diver survey, while the patent tong survey had similar results to the dive survey (Chai et al., 1992).

BROODSTOCK SANCTUARIES

The eastern oyster, while being dioecious, is a weakly protandric hermaphrodite. Young adults are mostly male, but as they age, many individuals change sex, making the majority of the larger, older oysters female (Rothschild et al., 1994). The larger the female, the greater number of eggs she will release, ranging from 23 million - 86 million eggs (U.S. Army Corps of Engineers, 1986). Due to the fact that many of older and larger oysters are female, overfishing may remove many of them which decreases the population density, decreasing their fecundity thus reducing their fertilization success (Rothschild et al., 1994).

Oyster reproduce sexually so close proximity of sessile males and females is important. Spawning is initiated by males which trigger the females to release their eggs in a mass spawning. Fertilization normally occurs in the water surrounding the adults.

Eggs hatch about six hours after fertilization and develop into free-swimming larvae. Larvae spend about 20 - 60 days in the water column until settlement occurs; larvae then undergo metamorphosis into their adult form (Baker and Mann, 1997; Dame, 1996; Kennedy, 1996; Keough and Downes, 1982). After oysters survive their first year, most mortality is inflicted by fishing and disease (U.S. Army Corps of Engineers, 1986).

Initially, oyster reefs were built to aid in oyster survival through protection from predation. The idea was that recruitment would occur from the existing oyster bars, so additional broodstock was not needed. While diseases would still be present, the 3-dimensional configuration of the reefs would allow for a faster and safer growth with fewer mortalities than the neighboring 2-dimensional (flat) oyster bars. Sanctuaries would permit disease resistant oysters to grow without being harvested and pass on their genetic resistance. This recruitment has been seen on reefs built in the Coan and Yeocomico Rivers (Figure 2) (Wesson, 1998).

In September 1996, the watermen of Tangier petitioned the VMRC to open Tangier Sound for oyster harvest despite very low densities of oyster and almost no spatset for several years. These oysters were large and old (5 - 7 inches) with high reproductive capability and at least some disease resistance due to their longevity in area of high salinities and presence of disease. Despite protest from oyster scientists and managers, the Commission agreed to the harvest. They later decided that the state would purchase the oysters from the watermen and transplant them to a reef in the Great Wicomico River (Figure 2) In December, 1996, approximately 2,300 bushels of oysters were put on the Great Wicomico reef (Wesson, 1997a; Wesson, 1998). The 1997 dive survey of the oyster reef and the fall dredge survey (Figure 4) in this river both showed a dramatic increase in the oyster spat numbers on oyster bars up to 5 miles away from the reef (Wesson, 1998)

Following the success of the Great Wicomico reef, approximately 1,000 bushels of large Tangier Sound oysters were transplanted to the Bland Point and Iron Point reefs in December 1997 in order to increase spawning. A community effort by the VMRC, Chesapeake Bay Foundation, and Hampton Road students and families resulted in approximately 50,000 live small oysters being grown by citizens and then planted on each of the reefs in the Lynnhaven and the Elizabeth Rivers in late May of 1998.

Historically, the Piankatank River was a valuable oyster production area for public and private oyster industry (Wesson, 1996; Wesson, 1998). Reefs were built in this river because of it being a trap-type tributary and the long presence of both protozoan diseases to which the oysters show some resistance (Wesson, 1996). Trap-type rivers have closed water circulation patterns which cause larvae to stay in the river which increases the chance of colonization. Setting of the larvae (habitat selection) is more intensive and localized (Wesson, 1997b).

Despite being used interchangeably, the terms settlement and recruitment are different. Settlement involves larval stages moving from planktonic to benthic through metamorphosis. Recruitment, however, encompasses both larval and juvenile stages, and implies a passage of time determined by the researcher (Keough and Downes, 1982, Rodriguez et al., 1993; Roegher, 1991). I measured spat recruitment by what could be seen with the naked eye.

My hypothesis was that adding broodstock to two of the reconstructed reefs in the Piankatank River in 1997 would increase the spat recruitment on both the 3-dimensional reconstructed reefs and the natural 2-dimensional oyster bars. I also predicted that the 3-dimensional oysters reefs would have higher spat recruitment than the 2-dimensional oyster bars.

MATERIAL AND METHODS

DESCRIPTION OF STUDY AREA

The Piankatank River (Figure 2) is a small coastal plain sub-estuary of the Chesapeake Bay in Virginia. Spat setting begins in late June and extends into late September with the peak normally being between mid-July and the first week of September (Haven et al., 1984). In recent years, spatsets have remained low suggesting that broodstock levels may be limiting reproductive success. There are four reconstructed oyster reefs located in the Piankatank River: Palaces Bar, Bland Point, Iron Point, and Burton Point (Figure 5).

Palaces Bar

Palaces Bar was the first reconstructed 3-dimensional oyster reef and was built by the VMRC in 1993 (Figure 5). It was constructed into a intertidal reef and made of shucked oyster shells. Shells were loaded onto barges at shucking houses, moved by tugboat to their new location. Using a high pressure water cannon, the shells were offloaded into mounds (piles) which were at the surface at low tide. The reef was constructed on the footprint of an old reef. Water depths were 5 - 8 feet at Mean Low Water (MLW) and oysters shells were visible at the surface at low tide. Approximately, 207,000 bushels of oyster and clamshells were deployed into a reef, 1000 X 100 feet in length and width, 5 - 7 feet high consisting of 22 mounds. No reproductive oysters were added to this reef.

Bland Point

This reef was built in 1995 by the VMRC (Figure 5). The oyster shells were purchased from shucking houses and stockpiled at a loading facility until transported by barge to the Piankatank River. The oyster shell laden barge was held in place by a second crane-operated barge. The shells were pushed off the barge by a front - end loader (Wesson, 1996). Water depths were 6 - 7 feet at MLW and shells were visible at the surface at low tide. Approximately 88,196 bushels of oyster shells were deployed into a reef, 800 X 40 feet in length and width, which consisted of one continuous mound. Approximately 500 bushels of large (3 - 7") oysters were transplanted from Tangier Sound to this reef in December 1997 One bushel of oysters was equivalent to 300 oysters.

Iron Point

This reef was built in 1995 by the VMRC (Figure 5). Reef creation was similar to the Bland Point Reef. This was the deepest reef built with the MLW being 13 - 15 feet Approximately 45,875 bushels of oyster shells were deployed into a reef ,300 X 40 feet in length and width, forming a single line Approximately 500 bushels of large (3 - 7") oysters were transplanted from Tangier Sound to this reef in December 1997. One bushel of oysters was equivalent to 300 oysters.

Burton Point

This reef was built in 1995 by the VMRC (Figure 5). Reef creation was similar to the Bland Point Reef. The MLW was 6 -7 feet. Approximately 119,211 bushels of oyster shells were deployed into a ree,f 900 X 40 feet in length and width, consisting of a single straight line. No reproductive oysters were added to this reef.

SAMPLING

DIVE SURVEY

The dive survey was a quantitative survey which provided information about spatfall and recruitment, mortality, and annual changes in seed and market sized oysters. The reconstructed reef data for the period of 1995-1997 was obtained from the VMRC database. The reconstructed oyster reefs (Figure 5) were sampled via SCUBA by Dr. James Wesson and myself during October and November of 1998.

After the boat was anchored, twelve bushel baskets attached to floats were thrown haphazardly toward the reef. Samples were considered to be unbiased since water depth and turbidity prevented sight of the bottom and oyster distribution and densities could not be determined. Samples were taken at the surface (flat top of the reef), in the middle (on the slope of the reef), and at the bottom (about 12 inches up from the sand) Scuba divers located the basket and placed a 0 25 meter metal square onto the reef at the appropriate depth. Oysters, shells, and boxes within the square were picked up and put into the bushel basket until it was full. The basket was returned to the boat where the oysters and shells were counted.

The name of the reef, sample depth, the river location, the water temperature and salinity were recorded on a survey form. Salinity and temperature were measured using an Electrodeless Induction Salinometer (Beckman Industrial, Cedar Grove, NJ). Oysters were counted by size class: spat, small oysters (<3 inches), market oysters (>3 inches), Box I, Box II, and Box III mortalities (Table 1). Spat were oysters that had set during the current setting season; and small oysters were those less than three inches which had set the previous year. Boxes were two oyster shells attached at the hinge. Box II and Box III were normally grouped together because of the difficulty distinguishing between them. After data were collected, the oysters were returned to the reef.

DREDGE SURVEY

This was a qualitative survey which provided information about spatfall and recruitment, mortality, and annual changes in seed and market sized oysters. The fall dredge data were obtained from the VMRC database for the period of 1994 - 1998 and the Virginia Institute of Marine Science (VIMS) database for the period of 1986 - 1993. I assisted the VMRC staff in the collection of the 1997 and 1998 data.

Eight natural, 2-dimensional oyster bars (Figure 5) were located using a combination of GPS, Loran, and depth sounders. A 4-foot dredge with 4-inch teeth was towed behind the 43-foot long VMRC vessel, *J. B. Baylor* The volume collected in the dredge bag was approximately 3 bushels. When it was pulled up, a 10-Liter sample of oyster shells was taken and the rest were returned to the bar. These samples were separated into live oysters, boxes, and empty shells to determine what percentage of shells the oysters were using. The numbers of spat, small, market, Box I, Box II, and Box III (II and III were combined) oysters were counted and recorded.

PATENT TONG SURVEY

This was a qualitative stock assessment survey which provided information about spatfall and recruitment, mortality, and annual changes in seed and market sized oysters. The patent tong stock assessment data were obtained from the VMRC database for the period of 1994 - 1997. I assisted the VMRC and VIMS staff in the patent tong stock assessment survey in 1998.

A patent (hydraulic) tong was used on the 43-foot long VMRC vessel, the *J. B. Baylor*. The patent tong was 1 meter wide and sampled an area of 1 m^2 to a depth of approximately 10 inches into the substrate. Longitude and latitude at sites were randomly generated by the computer prior to sampling. At the site, the patent tong was dropped in the water, a subsample of bottom approximately 1 square meter was taken, and then drawn back up into the boat. Shells on the surface of the samples were scraped off and put in a basket, and the soil was returned to the water. Samples were rinsed and put into 10-L buckets to determine volume. If more than 20-L were present, a subsample was taken. Using a ruler, measurements were made of all live oysters and boxes. They were recorded on a VIMS/VMRC Stock Monitoring sheet and oysters returned to the water Spat measurements were 1 - 45 mm, small measurements were 1 - 75 mm with a cup shape, market measurements were 76 mm and greater, and boxes were divided into Box I and Box II/III.

ANALYSIS

DIVE SURVEY

Spat, small, market, and boxes were multiplied by 4 to give the number of oysters in a square meter and then averaged for depth, size, and reef. The 1998 dive survey data were compared to the previous 2 years.

DREDGE SURVEY

All numbers were multiplied by 5 to determine the numbers for a 50-Liter sample (Virginia bushel). The 1998 dredge survey data were compared to the previous 4 years to compare spat recruitment numbers. Spat trends from the VMRC and VIMS data for the period of 1986 - 1998 were examined for only three of the natural oyster bars in the Piankatank River.

STATISTICS

Spat recruitment (number of spat) on the 3-dimensional oyster reefs was analyzed using an analysis of variance (General Linear Model) (SPSS, v. 8.0) for the factors of depth, reef location, and year All data underwent a square root transformation. Factors were considered to be significant if $p<0.05$. Full ANOVA models included all main factors plus interactions.

Analysis of variance was also performed for spat recruitment on the 2-dimensional oysterbars. This was performed for both the dredge survey and the patent tong survey

All data underwent a square root transformation. Factors were considered significant if $p<0.05$.

RESULTS

DIVE SURVEY

The dive survey conditions of the four reefs showed that spat recruitment increased by more than four - fold in 1998 from previous years (Figure 6 and Figure 7), and small oysters numbers remained stable over the three year period (Figure 6). While market size oysters remained low the first two years on all reefs, 1998 showed an increase on Bland Point Reef and Iron Point Reef, the two reefs transplanted with reproductive oysters (Figure 6). Water temperatures in 1998 ranged from 19.5 °C to 20.1 °C and the salinity for 1997 and 1998 ranged from 16.6 - 18.3 ppt (Table 2).

There were no significant effects of the reefs, depths, or the interactions (reef*depth) on spat recruitment (Table 3). There was a significant difference ($p<0.001$) between the years which was further supported by the interactions of the reef and years ($p<0.005$) and depth and year ($p<0.05$). A positive interaction was seen between the reefs and the year 1998 on spat recruitment. Since depth alone was not significant, and the interaction of depth and year was only marginally significant, it was concluded that the depth and year interaction was a result of the year factor.

DREDGE SURVEY

The dredge survey data (Figure 8) showed the highest spat recruitment for 7 of the 8 oyster bars occurred in 1998. Ginney Point, the most upriver site, had higher numbers in 1995 than in 1998. The highest spat recruitment was recorded at Palaces Bar at 330 spat per bushel. At other oyster bars, spat recruitment ranged from 133 to 311 spat per bushel. The 2-dimensional oyster bars closest to the reefs experienced the highest numbers of spat recruitment (Table 4). Over the past 13 years (1986 - 1998), out of three oyster bars surveyed (Palaces Bar, Ginney Point, and Burtons Point), there was no specific oyster bar with higher or lower spat recruitment (Table 5)

There were no significant differences between the oyster bars. There was a significant difference ($p<0.001$) between the years (Table 3). There is a positive interaction for the year 1998 at all oyster bars where in the previous years, spat recruitment had fluctuated year to year at each location.

PATENT TONG SURVEY

The patent tong survey (Figure 9) showed that the average number of spat per meter in 1998 was similar to 1995 values at 6 of the 8 oyster bars sampled. Two of the oyster bars, Palaces Bar and Deep Rock, showed higher spat recruitments in 1998 than in the previous four years. Table 6 shows the annual stock assessment survey of public oysters for spat, small, and market sized oysters for 1995 - 1998 1997 was not surveyed by patent tong.

There were no significant differences between the oyster bars. There was a significant difference ($p<0.001$) between the years (Table 3).

3-D RECONSTRUCTED OYSTER REEFS vs. 2-D OYSTER BARS

In a comparison of 3-dimensional reconstructed oyster reefs to 2-dimensional (flat) oyster bars (Figure 10), the reefs had higher spat recruitment than the natural oyster bars during the period of 1995 - 1998 with 1998 having the largest difference between spat recruitment on the reconstructed reefs and the natural oyster bars. The Piankatank River was not surveyed via patent tong in 1997 and the Iron Point, Bland Point, and Burton Point Reefs were not sampled in the fall of 1995 due to adverse weather conditions.

DISCUSSION

The Piankatank River is a trap-type estuary so oyster larvae within the tributary remain close to the oyster reefs and bars. In the spring of 1998, VMRC moved 20,000 bushels of seed oysters from the the Great Wicomico River to other areas. Private industry transported about 30,000 bushels of seed oysters to other areas. This abundance was a result of the previous years spatset after broodstock was added in 1996 (Wesson, 1998). One of the goals for the Piankatank River is for the production of seed oysters for transplanting projects.

The limiting factor for spatset in the Piankatank River may be the low broodstock numbers (Haven et al., 1981), so increasing those numbers through stocking should increase the spatset (Figure 1) This is supported by 1994 - 1998 data (Table 4) of eight oyster bars in the Piankatank River in which spat recruitment did increase after the addition of broodstock. Kennedy (1996) stated that seasonal and local recruitment variability exists from year to year due to either poor gamete condition or unknown microscale differences including currents, transport patterns, larval patchiness, or habitat. Roegner (1991) also determined that mortalities during larval settlement and post settlement will affect the abundance of recruits. These variations can cause changes in the population dynamics of the river system (Roegner, 1991). This variation is supported by studies in the Piankatank River beginning in 1936 which show fluctuations in spat numbers continuing through 1976 when the study ended. No area in the river was ever consistently high or low setting area, suggesting that many factors, including abiotic factors, predation, disease, and human activity all impact this area cause fluctuation in spat recruitment (Haven et al., 1981).

Three factors are important for the successful recruitment of spat: availability/supply of larvae, mortality after settlement, and mortality in early life stages (Figure 1) (Kennedy, 1996). The first factor, the supply of larvae is effected by total spawning populations. By adding broodstock, the supply of larvae should increase, increasing the numbers that survive settlement and post-settlement. Barber (1989) stated that the more oysters that are present to reproduce, the greater the recruitment potential will be. In December 1997, large reproductive oysters were transplanted to two reconstructed oyster reefs with the intention of "jump starting" the Piankatank River's low productivity Both the 1998 dive survey data (Figure 7) and the 1998 fall dredge survey data (Figure 8) show a significant increase in spat recruitment in 1998 from the previous few years. This is further supported by the significance of the year factor in the analysis of variance and the positive interaction between the four reefs in 1998 on the estimated spat numbers (Table 3). Stocking efforts in the Lynnhaven River in 1998 of citizen-grown oysters also showed a dramatic increase in the 1998 dive survey as compared to the previous year which further supports stock enhancement on the reconstructed reefs (Table 8).

Historical records show that oysters existed in 3-dimensional reef structures which were exposed at low tide (Hargis and Haven, 1988). Years of harvesting oysters and removing their shells have lowered the elevation of the reefs so that only footprints exist now. Even though the 2-dimensional (flat) oyster bars cover more of the bottom than 3-dimensional oyster reefs, Figure 10 clearly shows higher spat recruitment on all four oyster reefs compared to the natural oyster bars. Three-dimensional oyster reefs should have higher spat recruitment since in the Chesapeake Bay, reefs are the natural substrate for larval development and coordinated spawning (Roegner, 1991). Protection from predation and sedimentation give the spat on the oyster reefs an advantage over their oyster bar counterparts which is seen in the overall numbers of spat on both areas.

Oyster bars closest to the reefs had higher spatsets than areas more than a mile away (Table 4 and Table 6). This demonstrates how 3-dimensional reefs supplemented with broodstock oysters are helping to "jump start" the system by providing a haven for oysters to spawn. The spawning and successful fertilization originate at the reefs so settlement is higher in areas on and around the reef. Due to the trap-type circulation, oyster larvae stay in the Piankatank River and settle on the reefs and the oyster bars.

When compared to the Great Wicomico broodstock transplanting in 1997, the Piankatank River did not show as large of an increase in 1998. There are three possible explanations for the lower spat recruitment in the Piankatank River. Any one of the reasons could explain the differences, but I believe that it was a combination of the possible explanations.

In December of 1996, 2,300 bushels of large oysters were transplanted to the Great Wicomico Reef. In December 1998, only 1,000 bushels of large oysters were transplanted to the Piankatank River and they were divided between two reefs. This lower number of broodstock that was added to the reefs could be reason why spat recruitment was not as high as in the Great Wicomico. A second explanation may be the conditions in the rivers themselves. Every river has different conditions (size, water current, topography, etc.) which effect population dynamics within that system.

The third explanation is weather related. Since temperature and salinity play a role in gamete production, larval development, and larval settlement (Dame, 1996; Shumway, 1996; U.S. Army Corps of Engineers, 1986), high rainfall during the summer of 1998 may have lowered the salinity and possibly assisted in lowering the water temperatures in the Piankatank River. This may have caused a late spawn, resulting in spat not showing up in the river until late September - mid-October. A lower salinity may also have caused a longer metamorphosis period allowing larvae to spend more time being transported in the river's water. The increased time in the water column may have resulted in higher mortalities of larvae prior to settlement which may have lowered spat recruitment.

Over centuries of misuse, the oyster reefs in the Piankatank River and other tributaries of the bay have steadily been reduced to mere "footprints." Disease decimated the populations even more bringing their numbers to their lowest in the mid-1990s (Figure 3). With good management, oyster replenishment, habitat creation, and broodstock sanctuaries, the oyster population is increasing. Spat recruitment in the Piankatank River in 1998 was the most substantial increase since 1990 (Figure 3) suggesting that the broodstock sanctuaries aided in the increase. The 1990 increase was a result of extensive shellplanting in the Piankatank River and the higher numbers of native stock at the time. Possibly if more oysters had been added, there would have been a greater increase in spat recruitment.

Although this first year was a success, further stocking is still needed to continue to rebuild the depleted population in the Piankatank River. Long-term monitoring of these reefs is also necessary because the oyster lives in a dynamic system and is impacted by many factors, all of which cause fluctuation in spat numbers and mortalities. Based on data collected, stock enhancement in the Piankatank River successfully improved recruitment and suggest oyster restoration may be facilitated in other areas of the Chesapeake Bay by the strategic enhancement of spawning stocks.

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TABLE 1. Classification of oysters and mortalities by size classes and characteristics for measurement.

TYPE	SIZE	CHARACTERISTICS
Spat	Young of the year	Live
Small	> 3 inches	Live
Market	< 3 inches	Live
Box I (NEW)	any size	Mortality of less than 2 weeks Inside shell is clean
Box II & III (OLD)	any size	Mortality of greater than 2 weeks Inside shell is brown with biofouling

TABLE 2. Mean number per meter of spat, small oysters (< 3 in), and market size oysters (> 3 in) sampled during October dive surveys on the reconstructed reefs in the Piankatank River over the period of 1996 through 1998.

	PALACES BAR REEF			BLAND PT REEF			BURTONS PT REEF			IRON PT REEF		
YEAR	SPAT	SMALL	MARKET	SPAT	SMALL	MARKET	SPAT	SMALL	MARKET	SPAT	SMALL	MARKET
1995	32	35	1	-	-	-	-	-	-	-	-	-
1996	24	56	0	38	33	0	27	50	0	27	47	0
1997	5	44	2	4	69	0	8	52	2	3	53	2
1998	169	31	5	131	47	37	279	31	3	158	32	65

TABLE 3 Analysis of variance of spat settlement on four reconstructed reefs in the Piankatank River from 1996 to 1998 and on eight natural oyster bars from 1994 to 1998 (dredge survey) and on eight natural oyster bars from 1995 to 1998 (patent tong; 1997 not sampled). Data underwent a square root transformation. Factors are significant if $p < 0.05$.

Source	df	Sum of Squares	Mean Square	F-value	P-value
Reef	3	18.043	6.014	1.155	0.415
Depth	2	1.817	0.909	0.322	0.749
Year	2	840.069	420.034	51.936	0.000
Reef*Depth	6	2.696	0.449	0.47	0.818
Reef *Year	6	34.287	5.715	5.978	0.004
Depth*Year	4	13.316	3.329	3.482	0.041
Oysterbar (dredge)	7	83.672	11.953	1.439	0.23
Year (dredge)	4	625.339	156.335	18.815	0.000
Oysterbar (tong)	7	28.394	4.056	2.509	0.068
Year (tong)	2	45.798	22.899	14.164	0.000

TABLE 4 Annual fall dredge survey data reported as the average number of spat, small oysters (< 3 in), and market size oysters (> 3 in) per bushel on natural bottom collected at oyster bars on the Piankatank River between 1994 and 1998.

YEAR	PALACES BAR (41 ACRES)					BLANDS PT (26 ACRES)					BURTONS PT (37 ACRES)					CAPE TOONE (42 ACRES)				
	ppt	°C	SPAT	SMALL	MKT	ppt	°C	SPAT	SMALL	MKT	ppt	°C	SPAT	SMALL	MKT	ppt	°C	SPAT	SMALL	MKT
1994	15.3	16.5	15	0	0	16.4	16.6	40	325	0	15.9	15.2	10	310	0	16.8	14.5	25	450	0
1995	19.8	19	80	0	0	19.7	20.4	125	15	0	22	18.2	5	40	5	20.4	19.1	50	15	5
1996	10.1	16.3	65	130	10	-	-	35	325	5	12.1	16.2	18	144	5	-	-	60	35	0
1997	18.3	19.4	19	77	4	18.2	19.3	16	128	12	18.8	18.7	23	35	3	18.5	18.8	10	46	2
1998	17	17.8	330	96	8	17.2	17.9	256	138	23	17.5	18.2	311	57	12	17.2	18	278	40	1

YEAR	GINNEY PT (6 ACRES)					STOVE PT (6 ACRES)					HERON ROCK (12 ACRES)					3 BRANCHES				
	ppt	°C	SPAT	SMALL	MKT	ppt	°C	SPAT	SMALL	MKT	ppt	°C	SPAT	SMALL	MKT	ppt	°C	SPAT	SMALL	MKT
1994	15.4	16.6	0	45	0	15.8	15.5	125	0	0	15.7	15.7	130	0	0	-	-	-	-	-
1995	19.5	18.9	155	20	0	20.8	18.2	80	0	0	19.7	20.4	65	25	0	20.3	19.2	15	5	5
1996	11.4	16.3	105	10	0	-	-	120	270	5	-	-	45	230	0	-	-	65	80	20
1997	17.7	19.4	18	29	4	18.5	18.7	10	112	0	18.4	19.2	18	60	2	18.9	18.7	34	28	4
1998	16.7	17.9	133	70	8	17.5	18.2	162	59	4	17.3	18.2	240	47	8	17	NS	196	30	4

TABLE 5. Annual fall dredge survey data reported as the average number of spat, small oysters (< 3 in), and market size oysters (> 3 in) per bushel on natural bottom collected at three oyster bars (Ginney Point, Palaces Bar, and Burton Point) on the Piankatank River between 1986 and 1998.

YEAR	Ginney Point					Palaces Bar					Burton Point				
	°C	ppt	Spat	Small	Market	°C	ppt	Spat	Small	Market	°C	ppt	Spat	Small	Market
1986	22.2	20	121	230	36	NS	20.3	481	210	30	23	20.6	238	168	11
1987	16.2	18.9	65	83	5.5	15.2	19.2	202	104	4	18	19.3	152	3	0
1988	20.8	18.7	281	43	0	20.8	18.9	307	80	1	20.2	19.3	119	3	0
1989	21	14.4	230	120	1	20.9	14.4	147	83	2	19.8	15.4	893	13	1
1990	21.5	16	661	87	0	21	16	629	87	0	20.2	16.5	1222	157	0
1991	21.7	19	813	194	0	21.7	19	841	95	0	21.9	20	622	126	0
1992	19	15	27	69	0	-	-	-	-	-	18	16	83	83	0
1993	23.4	19	55	45	0	-	-	-	-	-	23.2	19	55	101	0
1994	16.6	15.4	0	45	0	16.5	15.3	15	0	0	15.2	15.9	10	310	0
1995	18.9	19.5	155	20	0	19	19.8	80	0	0	18.2	22	5	40	5
1996	16.3	11.4	105	10	6	16.3	10.1	65	130	10	16.2	12.1	18	144	5
1997	19.4	17.7	18	29	4	19.4	18.3	19	77	4	18.7	18.8	23	35	3
1998	17.9	16.7	133	70	8	17.8	17	330	96	8	18.2	17.5	311	57	12

TABLE 6. Annual stock assessment survey data reported as the average number of spat, small oysters (< 3 in), and market size oysters (> 3 in), per meter on natural bottom collected at oyster bars on the Piankatank River between 1995 and 1998 using a patent tong. The Piankatank River was not surveyed by patent tong in 1997.

YEAR	PALACES BAR (41 ACRES)			BLAND PT (25 ACRES)			BURTON PT A (37 ACRES)			CAPE TOONE (42 ACRES)		
	SPAT	SMALL	MARKET	SPAT	SMALL	MARKET	SPAT	SMALL	MARKET	SPAT	SMALL	MARKET
1995	18	5	0	31	5	0	11	5	0	11	8	0
1996	4	33	0	2	56	0	2	18	0	1	13	0
1997	-	-	-	-	-	-	-	-	-	-	-	-
1998	82	28	2	38	20	2	10	6	0	11	4	0

YEAR	GINNEY PT (6 ACRES)			STOVE PT (5 ACRES)			HERON ROCK (12 ACRES)			DEEP ROCK		
	SPAT	SMALL	MARKET	SPAT	SMALL	MARKET	SPAT	SMALL	MARKET	SPAT	SMALL	MARKET
1995	16	2	0	25	2	0	16	4	0	NS	NS	NS
1996	2	28	1	3	26	0	2	28	0	1	4	0
1997	-	-	-	-	-	-	-	-	-	-	-	-
1998	11	6	0	32	15	1	13	7	1	13	4	2

TABLE 7. Comparison of spat recruitment on the 3-dimensional reconstructed reef structures versus the 2-dimensional natural oyster bars sampled during the October dive surveys on the reconstructed reefs and the fall stock assessment survey on the natural bottom collected at oyster bars in the Piankatank River over the period of 1995 through 1998. (Patent tong was not completed in the Piankatank River in 1997.)

	PALACES BAR REEF		BLAND PT REEF		BURTONS PT REEF		IRON PT REEF	
YEAR	REEF	BOTTOM	REEF	BOTTOM	REEF	BOTTOM	REEF	BOTTOM
1995	32	18	-	31	-	11	-	11
1996	24	4	38	2	27	2	27	1
1997	5	-	4	-	8	-	3	-
1998	169	82	131	38	279	10	158	11

TABLE 8 Reef name, number of spat, small oysters (< 3 in), market size oysters (> 3 in), new boxes, and old boxes in square meter samples taken in the 1997 and 1998 dive survey on the reconstructed oyster reefs in Virginia.

	Date of Construction	Year Sampled	Salinity	Spat	Small	Market	Box I	Box II/III
PIANKATANK RIVER	93	97	17.9	5	44	2	2	4
PALACES BAR		98	16.6	169	31	5	1	10
PIANKATANK RIVER	95	97	17.5	4	69	0	3	1
BLAND POINT		98	16.8	131	47	37	7	29
PIANKATANK RIVER	95	97	17.5	3	53	2	1	1
IRON POINT		98	16.6	158	32	65	4	28
PIANKATANK RIVER	95	97	18.3	8	52	2	0	1
BURTON POINT		98	17.3	279	31	3	1	5
GREAT WICOMICO	96	97	16.8	856	72	36	18	25
SHELL BAR		98	16.5	34	560	19		
COAN RIVER	97	97	13.8	338	0	0	3	0
		98	13.1	8	150	11	13	20
YEOCOMICO RIVER	97	97	13.5	362	0	0	4	0
		98	13.4	1	179	8	18	30
LYNNHAVEN RIVER	97	97	25	8	0	0	0	0
		98	22.5	181	11	0	1	2
ELIZABETH RIVER								
	98	98	20	100	5	0	4	4
GREAT WICOMICO								
CRANES CREEK	98	98	17.4	74	0	0	1	0

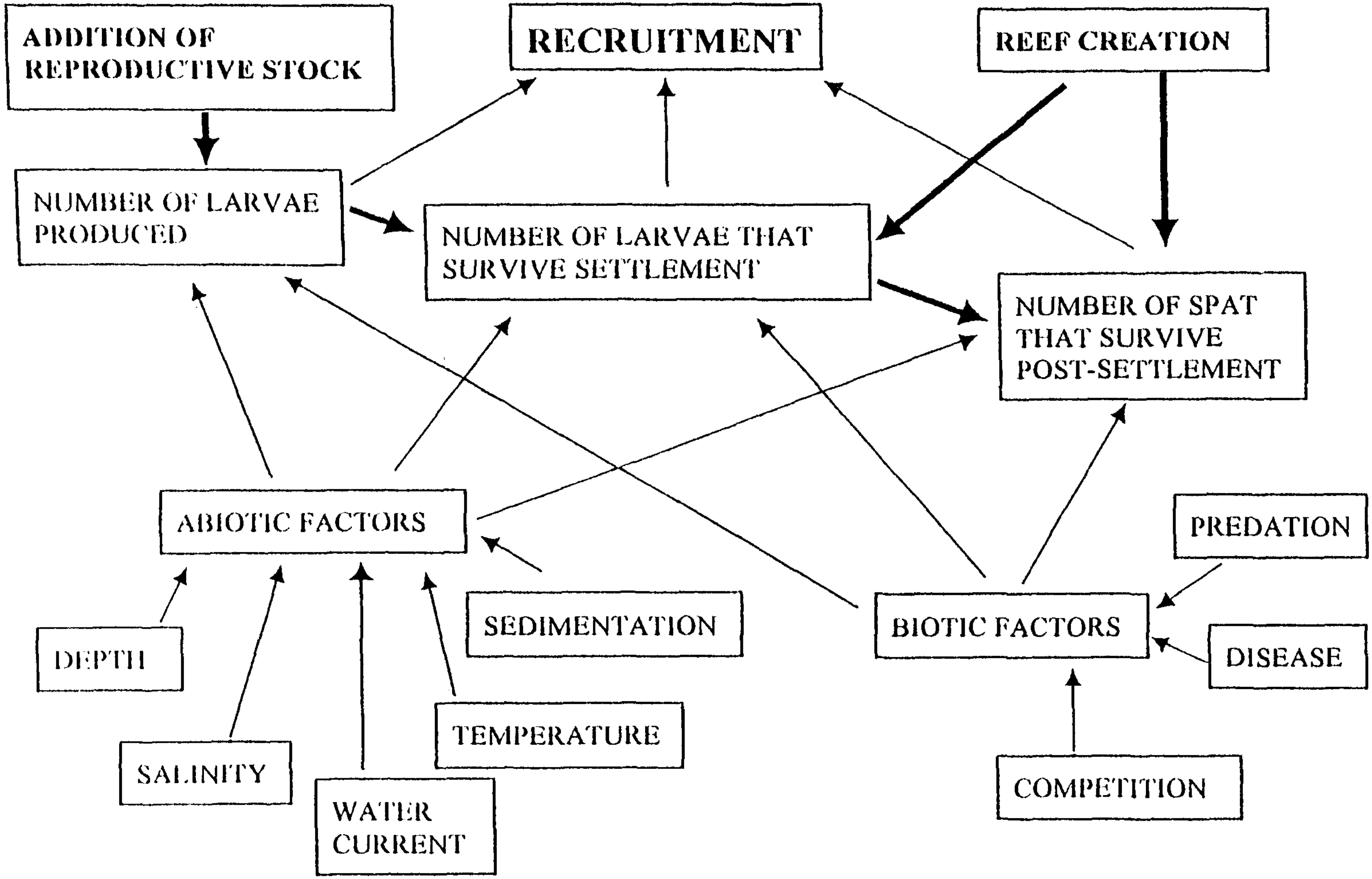

FIGURE 1. Recruitment flow chart showing interactions of abiotic and biotic factors on the three mechanisms of recruitment. Reef creation and addition of reproductive stock positively influence recruitment.

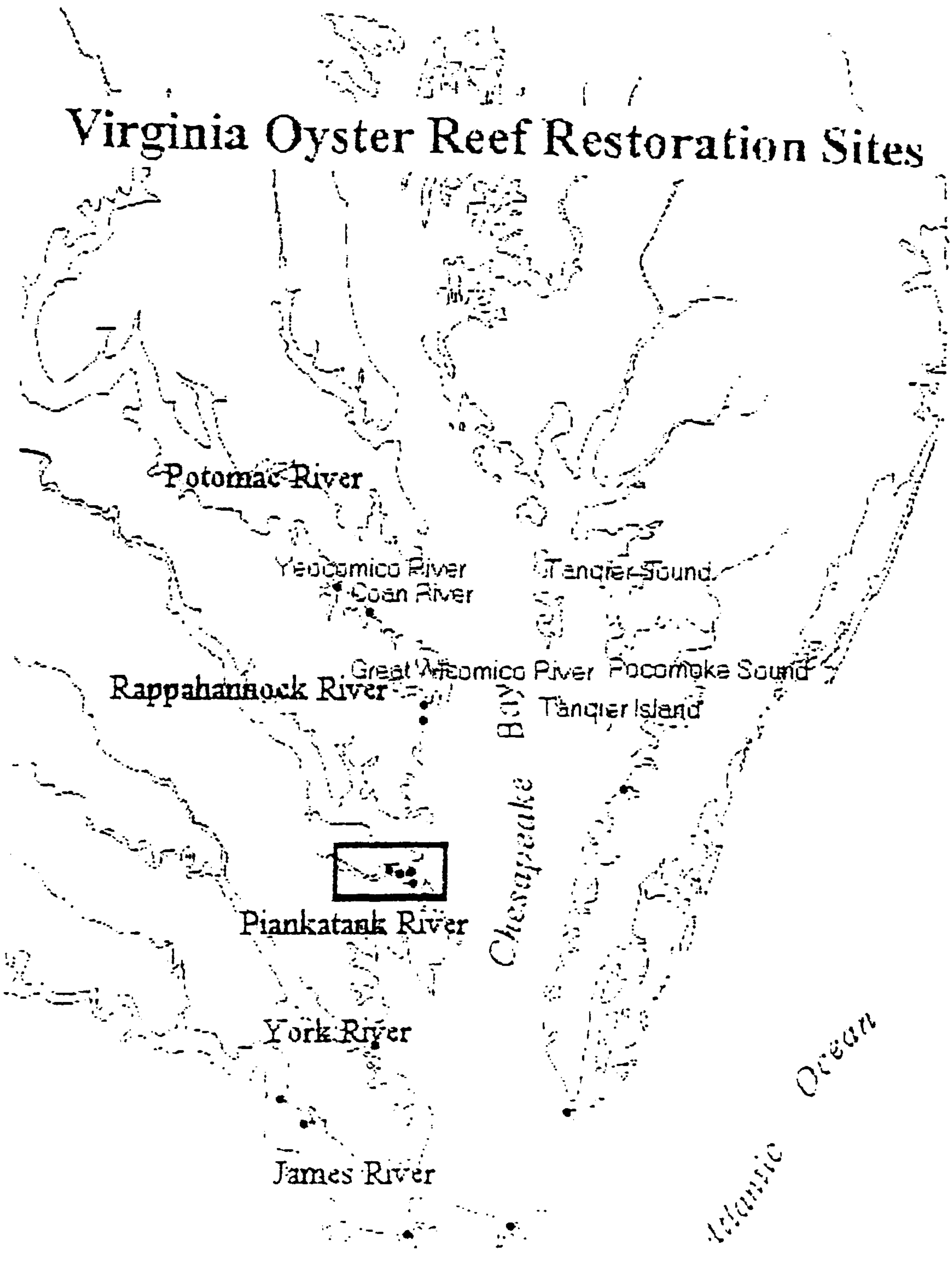

FIGURE 2. Map of the Chesapeake Bay indicating the locations of the Virginia oyster reef restoration sites as of 1998.

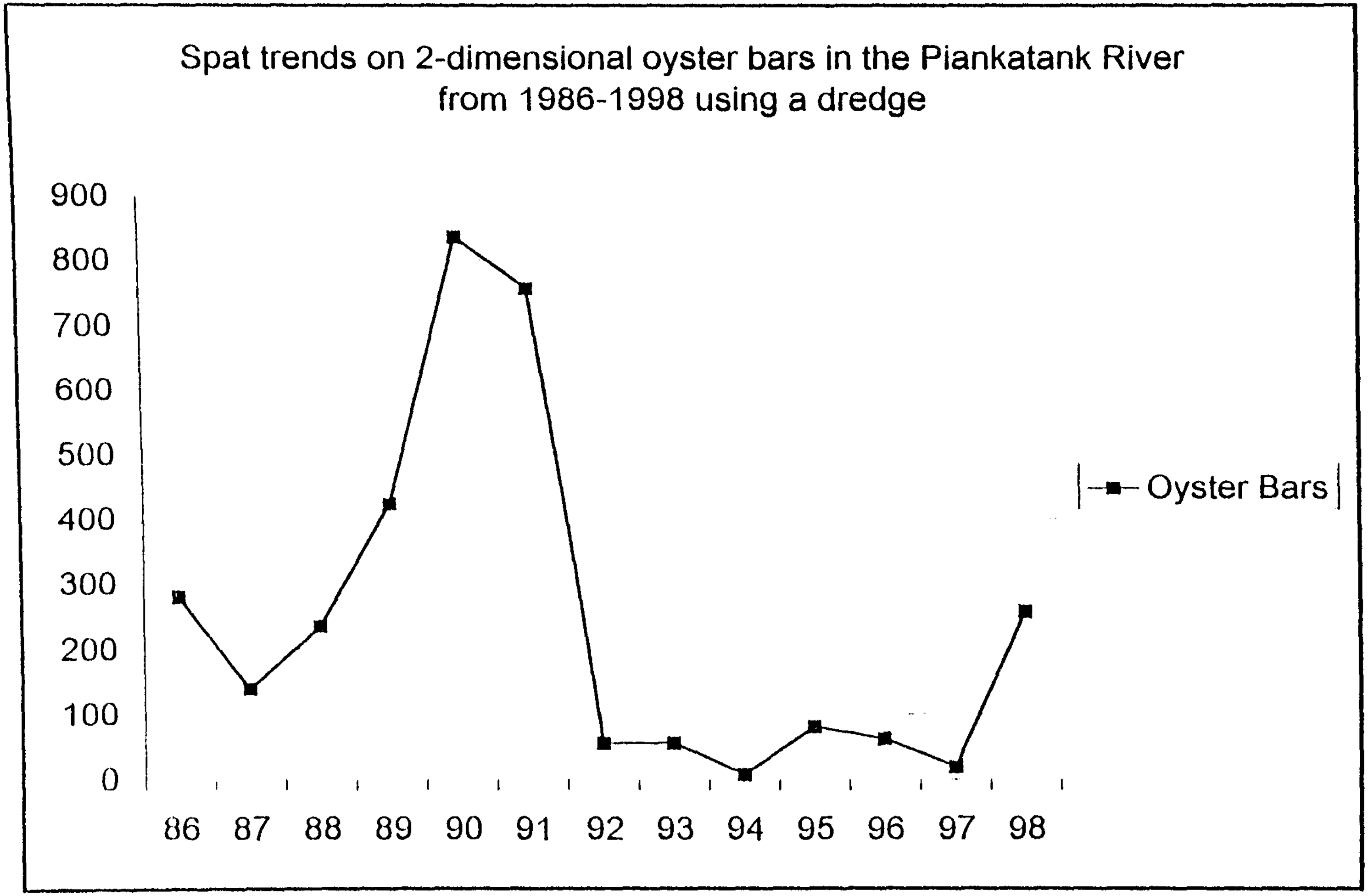

FIGURE 3 Trend in the abundance of oyster spat at Ginney Point, Palaces Bar, and Burton Point in the Piankatank River collected in the annual fall dredge surveys by VIMS and VMRC for the period of 1986 - 1998. Palaces Bar was not sampled 1992 - 1993. Data was averaged.

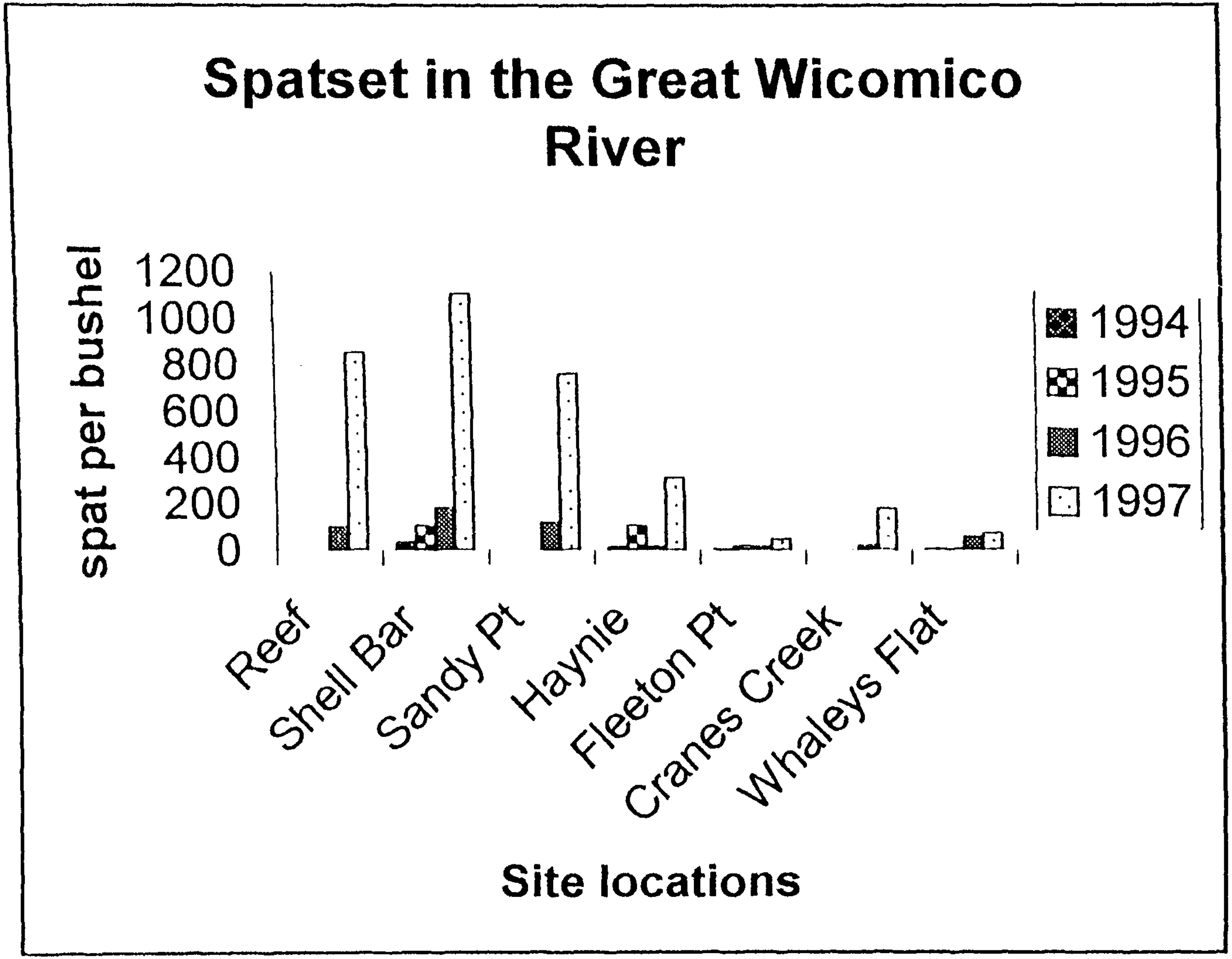

FIGURE 4. 1997 dive survey and dredge survey on the Great Wicomico River. Oyster bars increase in distance as they move away from the reef.

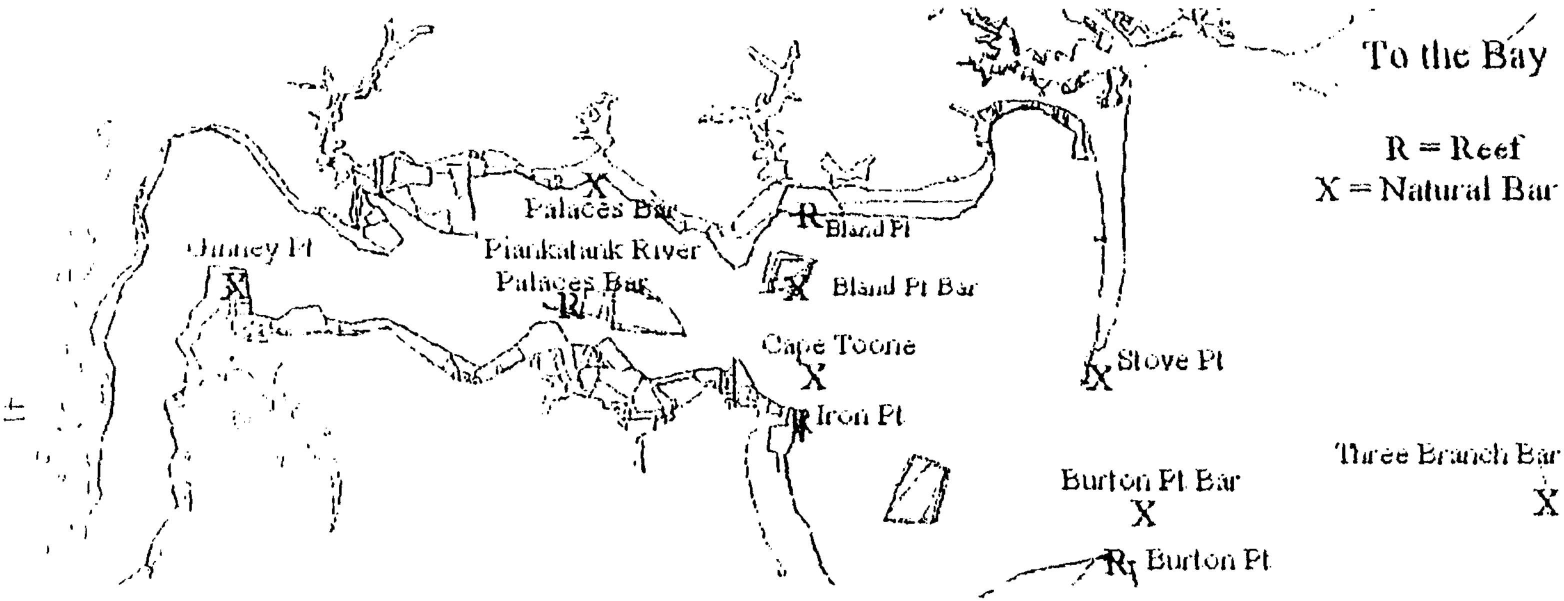

FIGURE 5 Map of the Piankatank River indicating with an R the locations of the constructed oyster reefs and with an X for the natural oyster bars.

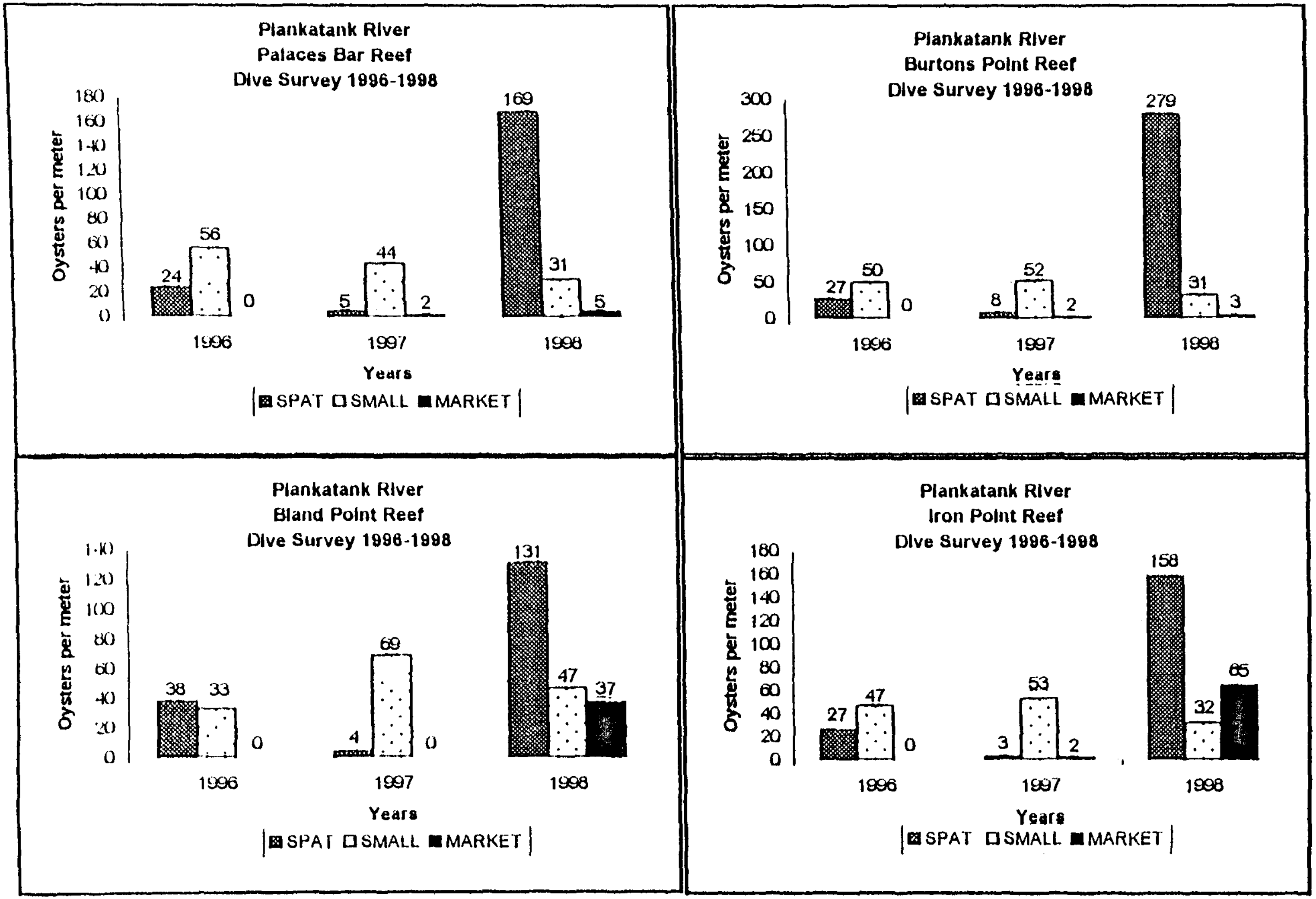

FIGURE 6 Fall dive survey on the constructed oyster reefs in the Plankatank River for the period of 1996 through 1998. *Graphs show size classes of spat, small oysters (< 3 in), and market size oysters (> 3 in) for each reef.*

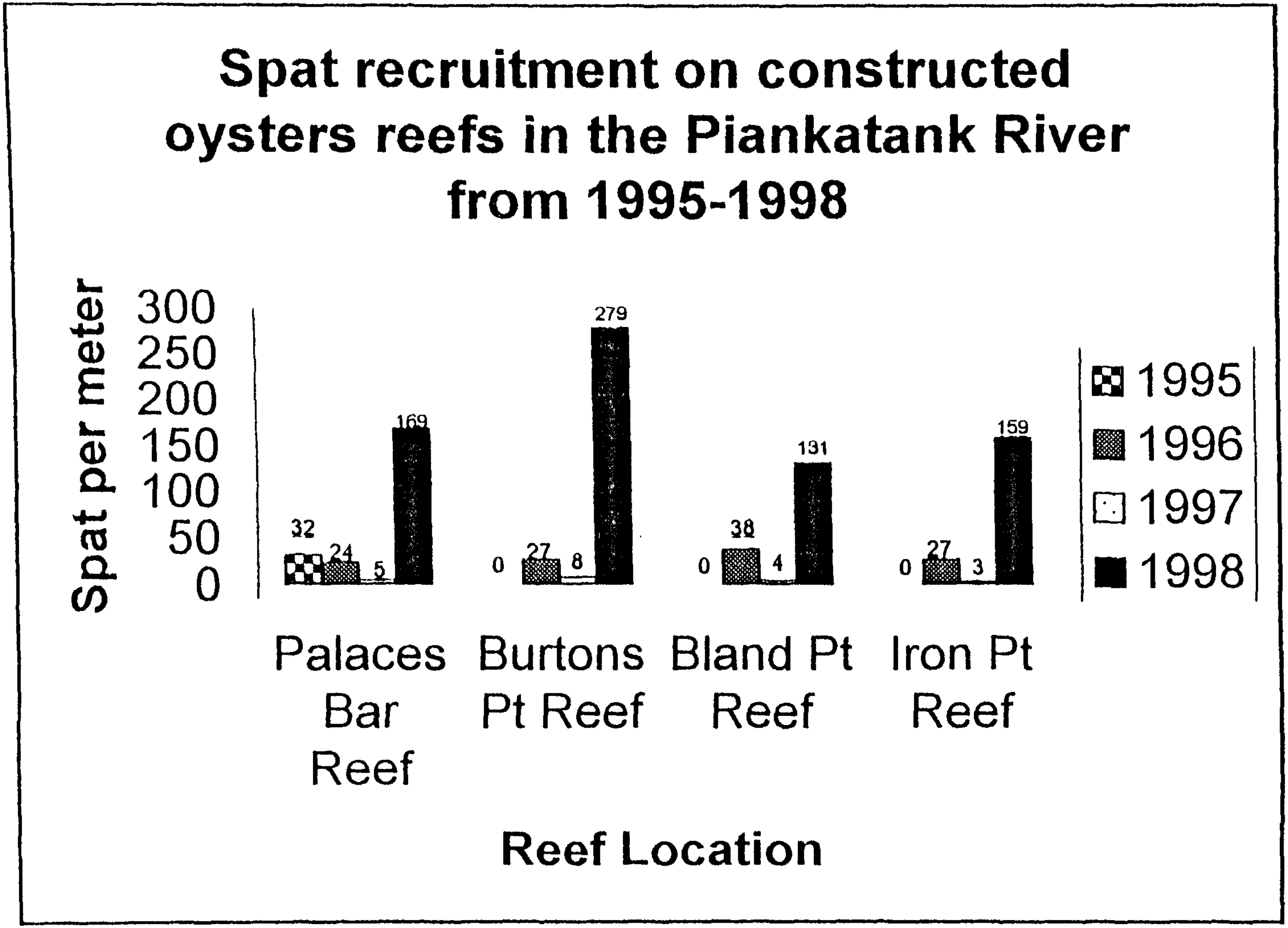

FIGURE 7 Spat recruitment on constructed oyster reefs in the Piankatank River from 1995 - 1998.

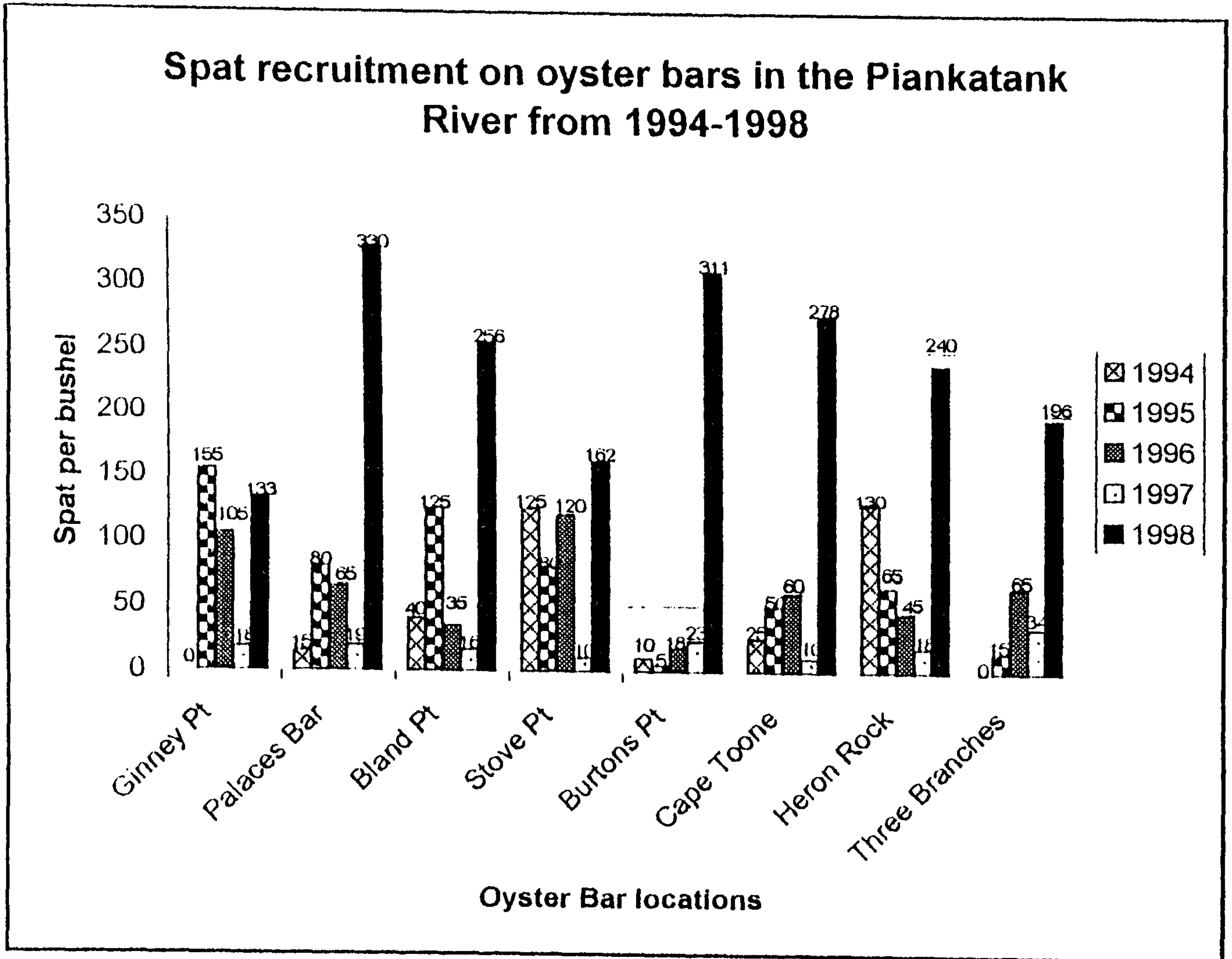

FIGURE 8. Spat recruitment on oyster bars in the Piankatank River from 1994 - 1998 collected in the annual fall dredge survey of the natural bottom.

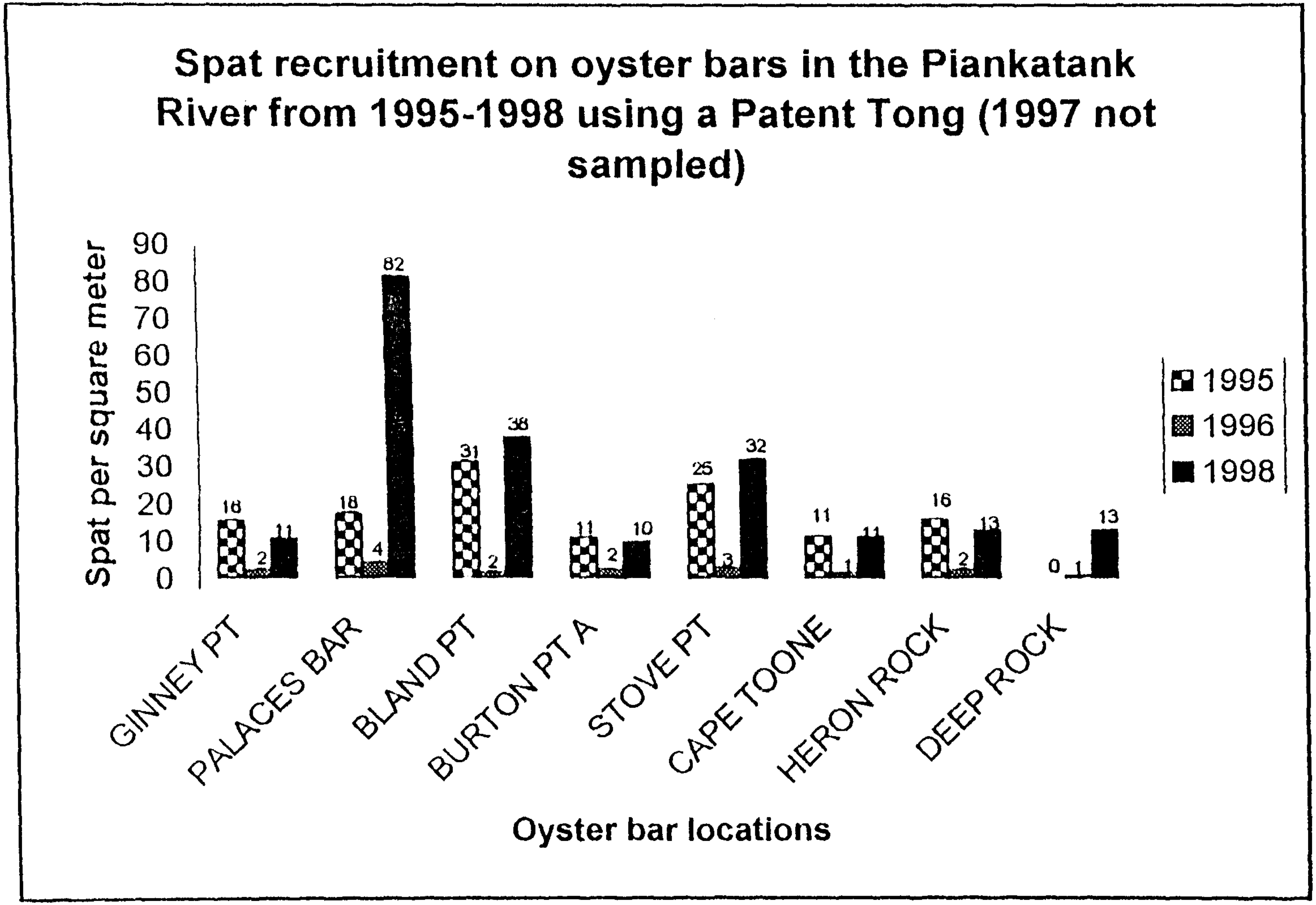

FIGURE 9 Spat recruitment on oyster bars in the Piankatank River from 1995 - 1998 collected by patent tong in the stock assessment survey of natural bottom. The stock assessment survey was not completed in 1997.

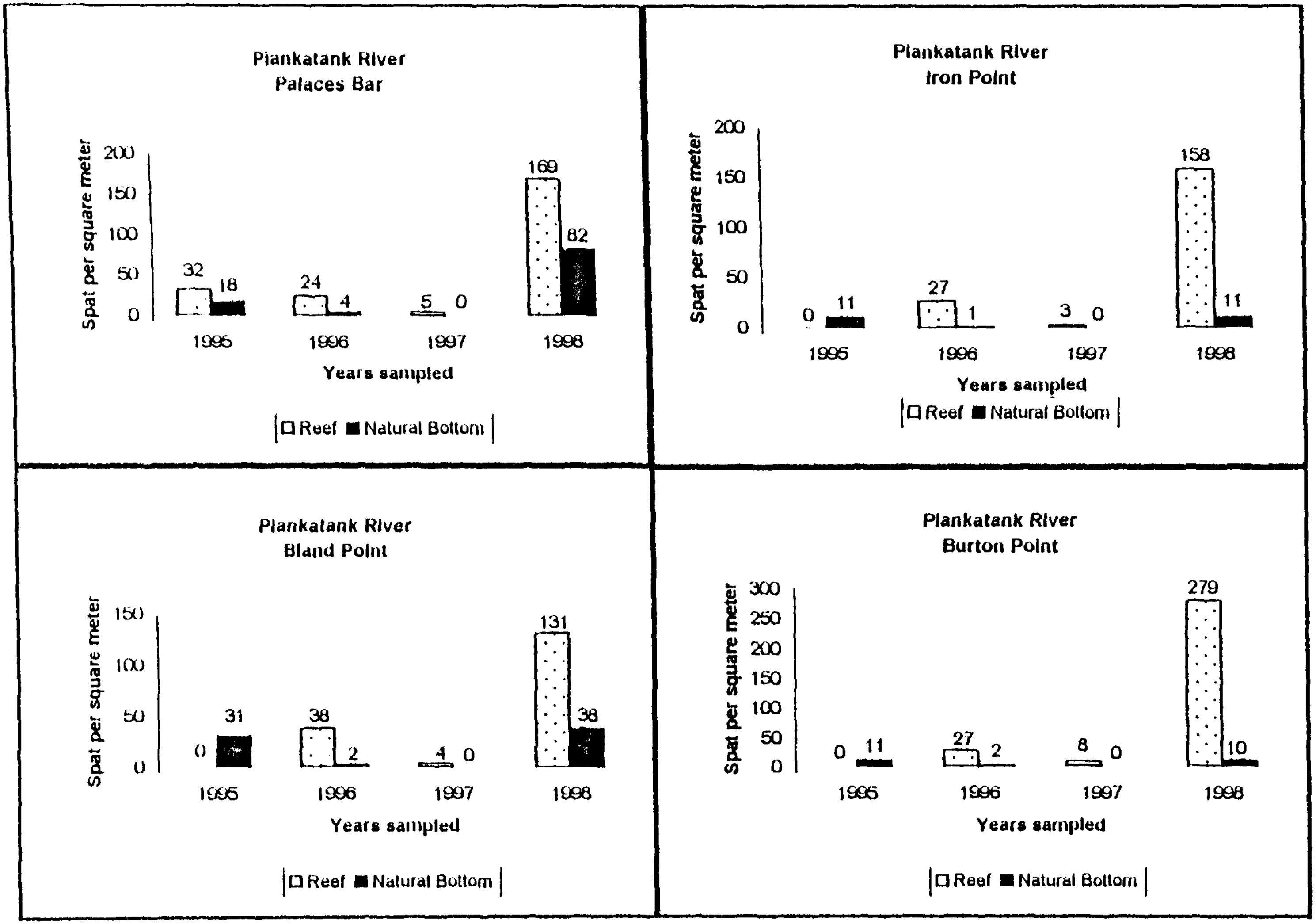

FIGURE 10. A comparison of spat per square meter on 3-dimensional constructed reefs versus the 2-dimensional (flat) oyster bars over the period of 1995 - 1998.

Appendix. Reef name, sample location by depth, number of spat, small oysters (< 3 inches), market size oysters (> 3 inches), new boxes, and old boxes in a 0.025 meter sample taken in the fall 1998 dive survey on the four reconstructed oyster reefs in the Piankatank River

Reef	Spat	Small	Market	New Boxes	Old Boxes
Piankatank (Bland)					
Top	8	7	18	2	7
Top	22	7	1	0	0
Top	26	20	11	3	5
Top	30	5	0	0	0
Average (Top)	86	39	30	5	12
Middle	54	13	1	0	2
Middle	34	11	9	1	12
Middle	16	10	21	3	23
Middle	31	7	0	0	0
Average (Middle)	135	41	31	9	49
Bottom	19	17	11	2	10
Bottom	48	14	18	4	13
Bottom	45	16	8	0	4
Bottom	61	15	12	2	9
Average (Bottom)	173	62	49	8	26
Total Oyster/Meter	131	47	37	7	29

Reef	Spat	Small	Market	New Boxes	Old Boxes
Piankatank (Burton)					
Top	91	3	0	0	0
Top	43	5	0	0	1
Top	47	9	1	0	2
Top	49	9	0	0	0
Average (Top)	230	26	1	0	3
Middle	85	4	0	0	0
Middle	67	7	0	2	3
Middle	61	3	0	0	0
Middle	81	15	2	0	3
Average (Middle)	294	29	2	2	6
Bottom	74	11	4	0	1
Bottom	64	6	1	0	0
Bottom	108	3	0	0	1
Bottom	68	18	1	1	3
Average (Bottom)	314	38	6	1	5
Total Oyster/Meter	279	31	3	1	5

Reef	Spat	Small	Market	New Boxes	Old Boxes
Piankatank (Iron)					
Top	31	9	1	1	1
Top	37	11	15	0	6
Top	30	4	36	4	11
Top	40	7	23	0	4
Average (Top)	138	31	75	5	22
Middle	29	9	29	4	20
Middle	62	0	12	0	5
Middle	31	12	17	1	12
Middle	30	6	4	0	2
Average (Middle)	152	27	62	5	39
Bottom	61	17	18	0	4
Bottom	57	4	5	1	6
Bottom	39	8	3	0	4
Bottom	28	8	31	2	10
Average (Bottom)	185	37	57	3	24
Total Oyster/Meter	158	32	65	4	28

	Spat	Small	Market	New Boxes	Old Boxes
Piankatank (Palace)					
Top	27	6	0	0	0
Top	54	4	0	0	0
Top	36	1	1	0	0
Top	45	4	0	0	0
Average (Top)	162	14	1	0	0
Middle	27	8	0	0	0
Middle	37	5	0	0	0
Middle	53	9	1	1	4
Middle	49	4	1	1	1
Average (Middle)	165	26	2	2	5
Bottom	52	15	2	1	8
Bottom	26	16	5	0	6
Bottom	45	12	1	0	6
Bottom	56	7	4	1	5
Average (Bottom)	179	50	12	2	25
Total Oysters/Meter	169	31	5	1	10

Vitae

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