Final Report for the program entitled:

Title: Evaluation of oyster settelement and survival on large scale intertidal oyster reefs in Virginia.

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date of report submission: December 16, 1996

This project was funded, in part, by the Virginia Council on the Environment's Coastal Resources Management Program through Grant #NA570Z0560-01 (task #20) of the National Oceanic and Atmospheric Administration, Office of Ocean and Coastal Resource Management Act of 1972 as amended.

Evaluation of oyster settlement and survival on large scale intertidal oyster reefs in Virginia.

Introduction.

The oyster is recognized as both a keystone organism in the ecology of the Chesapeake Bay and the focus of a substantial commercial fishery. Oyster reefs developed in recent geological time as the current Chesapeake Bay was inundated by rising sea level. By early Colonial times oyster reefs had become significant geological and biological features of the Bay - they were also major navigation hazards. Continuing harvest pressure since Colonial times have 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 undoubtedly been exacerbated by companion environmental degradation and an historical lack of consideration for water quality and natural resource management. Statements concerning overfishing by John Mercer Brooks over 100 years ago fell on deaf ears, but are now appreciated, if not entirely heeded. 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. Despite over 30 years of disease activity 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 both the benthic filter feeder that is so pivotal to the ecology of the Bay (see discussion by Newell, 1989; Mann, Burreson and Baker, 1992) and the physical structure which provides habitat for a multitude of species, including many of commercial interest. In the Fall of 1991 a Blue Ribbon Panel developed a comprehensive plan for restoration of the Virginia oyster resource and fishery. Among the recommendations of the panel was a proposal to investigate the construction of oyster reefs identical to those present in the Bay before Colonial settlement.

Since the recommendations of the Blue Ribbon Panel were offered a number of reef systems have been constructed in both the Virginia and Maryland portions of the Bay. An intertidal reef was built at Palace Bar in the Piankatank River in early 1993, predominantly with Commonwealth of Virginia funds. This was followed by two reefs in the James River; a subtidal reef at Wreck Shoal and a more shallow reef off Mulberry Point in 1993 and 1994 respectively. Support for these effort was largely from federal sources. Three more were constructed in the Piankatank in the Spring of 1995: at Burton Point, Bland Point, and Iron Point (the last being close to the natural bar at Cape Tune) Beginning in the summer of 1993 a joint effort was initiated by the current P.I.'s and Dr. F. O. Perkins of the Virginia Institute of Marine Science to examine oyster settlement, growth, and survival, and disease incidence and intensity at the Piankatank site. VCRMP supported this effort from the Fall of 1993 to the Fall of 1995. The quarterly and annual reports from this project, including a substantial M.A. thesis by Ian Bartol of the School of Marine Science, Virginia Institute of Marine Science, College of William and Mary, were provided to VCRMP. From these studies we developed comprehensive methods for collecting quantitative data on the desired subjects, and have noted the importance of spatial refugia in determining micro scale habitats. Animals in the intertidal are offered temporal refuge from predation but exposure to thermal stress (including ice in the winter): however, this is strongly tempered by the ability to settle and grow in the interstices of the reef just below the immediate exposed surface. This tempering provides substantially increased survival and good growth. In subtidal locations the interstitial refugia are important in avoidance of predation loss, a particular problem where predators have no temporal constrictions on their activity.

The Piankatank River is an excellent site to develop a reef 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 managed by the VMRC shellfish replenishment plan, currently under the direction of one of the investigators (Wesson). A limited number of "rocks" have had applications on a regular basis with subsequent harvest of the settled seed after one or two summers of exposure (the summer being the period of oyster settlement). The temporal and spatial nature of settlement is well documented by a continuing program at VIMS under the direction of a second investigator (Mann). 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, and are clearly site specific and related to local circulation. The historical footprints of the reefs are still distinct making reef construction a simpler process. The lack of a continuing commercial presence, the proven history of the site as one of good 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 combine to make this a unique and attractive site for continuing study. By contrast the James River has been the focus of the commercial fishery for decades, and is the only functional commercial fishery for both seed and market oysters remaining in the Virginia section of the Bay.

Project Objectives.

The specific objective of the proposed work is to examine the settlement and survival of juvenile oysters on constructed oyster reefs in the Piankatank and James Rivers in Virginia, in the Spring and Fall of 1996, and from this provide an evaluation of the reefs as tools to develop broodstock sanctuaries. Comparative data to effect this evaluation will be provided from comprehensive stock assessment data from adjacent reefs. The stock assessment program is funded by the Chesapeake Bay Stock Assessment Program of NOAA at no cost to VCRMP. The comparison should provide a valuable data database upon which to make further decisions regarding reef placement and potential.

Project Methods.

All reefs examined in the current project were surveyed prior to sampling by VMRC personnel and appropriately marked at their boundaries. The reef locations are illustrated in Figures 1 and 2. Reefs in the Piankatank were sampled by divers. Reefs in the James were sampled by patent tong with an opening of one square meter. In both instances support was from the VMRC vessel R/V Baylor. All reefs were exposed for potential recruitment of oysters in the latter part of the summer and early fall of 1995, and the summer and fall of 1996. The first sampling of Palace Bar was completed ion November 13, 1995. Further sampling by divers in the fall of 1995 was curtailed by rapidly falling air and water temperatures. All reefs in the Piankatank were surveyed on June 6 and June 7, 1996 to examine the over winter survivors of the 1995 year class, and on October 7-11, 1996 to examine the cumulative survival to that time including the 1996 year class. The Wreck Shoal and Mulberry Point reefs in the James River were surveyed in August 1996.

For diver surveys three strata were identified on the Piankatank reefs: HIGH being that region exposed or within one meter of the surface at mean low tide, MIDDLE being that region between one and three meters depth, and LOW being the fringing region at the edge of the reef where the reef meets the underlying substrate. Sampling locations on the reef were identified by working from a transect line extending between the two pilings that mark the ends of the reef. Along this transect line up to 10 locations were randomly selected. Secondary lines of sampling extended from the points on the transect at right angles to the transect line. On the secondary lines 3 locations corresponding to HIGH, MIDDLE, and LOW were selected and marked by a surface buoy connected to a wire basket settled on the reef surface. Divers placed a 0.25 sq. m quadrat on the reef surface adjacent to the basket, removed all oyster shell to a depth of approximately 15 cm, and placed it in the basket to facilitate retrieval. This procedure ensured that oysters settling within the substrate matrix as described earlier would be retrieved from counting.

The Wreck Shoal reef was examined at three depth strata as for the Piankatank reefs; however, the Wreck Shoal reef is not exposed at low tide and the sampling strata represent depths above the bottom substrate. The Mulberry Point Reef is in a very shallow location and no depth stratification in sampling was attempted.

Material collected either by patent tong or divers was returned to the R/V Baylor for cleaning, sorting, counting in categories describing live oyster spat (young of the year), live small oysters over one year old but less than the market size of 76mm (3 inches), live market size oysters, and dead oysters (also commonly referred to as boxes). These are standard techniques that we have employed for four years in stock assessment work on "typical" subtidal reefs and rocks of commercial importance. The result is a description of oyster population density by size class. The number of live oysters compared to dead oysters gives an index of mortality. When data on reef area are included in the analysis these population density data can be used to estimate standing stock on the individual reef systems. Direct comparisons can thus be effected with commercially exploited reefs in the upper James River.

Results of Field Sampling.

Palace Bar illustrates the cumulative settlement, growth and mortality of oysters since May 1993 (Table 1). Both spat and small oysters were well represented in Fall 1995 sampling with a limited presence of market size oysters. Although growth of oysters on the reef appears from previous studies to be comparable or greater than on surrounding rocks that lack vertical relief the reefs do not offer protection from disease infections and *Perkinsus* related mortalities have been recorded on the Palace Bar Reef. Market oysters were also observed at Palace Bar in June of 1996 but were absent by October of 1996, probably because of disease mortality. The limited data set describing accumulation of recently dead oysters or "new boxes" in the population support the conclusion of summer mortality. Oyster spat survival over the 1995-1996 winter was good (compare November 1995 and June 1996 data) with spat growing into the small oyster size category by October of 1996. Mean values of spat were not significantly different in the Fall 1995 and 1996 surveys. Although the mean values in isolation for small oysters over the same time period suggest increased number the confidence interval are sufficiently large to make these differences statistically non significant.

Data for the remaining three reefs in the Piankatank River represent the survival of summer 1995 settlement in the June 1996 sampling, and the cumulative settlement and growth of both 1995 and 1996 settlement in the October 1996 sampling. All three reefs exhibited good settlement at all depths. There was considerable variability within samples at one depth (note the ci values in Tables 2 through 4) and in only one case, HIGH sampling at Bland Point in June of 1996, were spat numbers significantly lower than at other reefs, depths and times. By the October sampling all of the "younger" reefs in the Piankatank had similar numbers of oyster spat and small oysters present to that on the "older " community on Palace Bar. In all three instances growth from the spat to small oyster size class on "new" reefs was good and generally accompanied by little mortality (although *Perkinsus* related mortality is not usually observed in smaller size classes and over such a time period, *Perkinsus* tends to result in mortalities over longer time periods) .

Sampling at Mulberry Point in the James River gave highly varying numbers within the 20 samples collected. Thus, data are given in Table 5 for all stations. The volumes of shell collected in each tong collection illustrates that sampling was consistently on the reef surface; however, there were clearly aggregations of very high densities of oyster spat and small oysters (note sample numbers 1, 5, 6, 8, 9, 13, 15 and 20 in Table 5) interspersed with areas with few oysters. There was a notable lack of any dead oysters (boxes) on the entire reef. Mean spat and oyster densities on the reef were comparable to or better than all reefs in the Piankatank River. Although the Mulberry Point reef has only been present for one oyster settlement season, in which there was comparatively good settlement at this site, the prospect for oyster community development at this site is encouraging.

The Wreck Shoal reef is located at the southern most end of the extant populations of oysters in the James River in a region subjected to continuous disease pressure even in high river flow, low salinity years. With a limited number of exceptions all collections at all depths indicate poor spat settlement and survival. The exception stations (e.g. HIGH-6, MIDDLE - 7, LOW -7 and LOW -8) exhibited small oyster densities less than the mean value for Mulberry Point stations and more typical of a number of the Piankatank River reefs; however the majority of stations at Wreck Shoal with poor representation in the small oyster size class resulted in low mean values for entire reef. Only the large confidence interval in many of the locations and depths in the Piankatank prevented the Wreck Shoal values from being significantly lower than the Piankatank reefs. The comparison of this reef with others examined in this study must be made with recognition of the fact that the methods of construction of this reef were different (a shell "cap" over a mounded softer substrate) and that data recently collected at the Piankatank sites suggest that the shell covering layer at the Wreck Shoal site may be marginal at best in supporting a developing community of oysters.

Comparison With Extant Oyster Bars

A major question to be addressed in the long term is how will constructed reefs compare with extant oyster bars (the term bar chosen for convenience to distinguish such habitats from constructed reefs in the current text) in terms of populations density and demography?. This question has a time component embedded within it, a time component that can only be distinguished by continuing monitoring. Despite this limitation a comparison of current data with recent stock assessment data, collected by the patent tong apparatus used in the current study, for selected sites in the Piankatank and James Rivers is given in Table 7. Stock assessment data is from surveys effected in November 1995 (1996 surveys are still in progress at the time of writing of this report). For simplicity error bars and confidence intervals have not been included in Table 7.

Within the Piankatank River the reef data compare very favorably with bar data for both spat and small oyster classes indicating that in this location, a region which has suffered historically low spat settlements since 1993 (VIMS weekly oyster spat survey data using shellstrings), the reefs provide enhanced habitat for settlement and/or post settlement survival and growth compared with regions of little or no vertical relief. Indeed, such enhancement is observed even in the "young" reefs which have been exposed for only two summers of oyster settlement.

At Mulberry Point in the James River, a location not historically noted for high oyster spat settlement when compared with other locations in the James, mean spat density is eight fold higher than on adjacent bars, while mean small oyster density is three fold higher. Both comparisons support the argument of improved environment on the reef compared with adjacent bars. Mean values for both spat and small oyster densities are comparable on the reef and bar sites at Wreck Shoal. The comparison within and between the James River locations must also include comparison with locations such as Deep Water Shoal, Horsehead, Moon Rock, V-Rock, Point of Shoals and Cross Rock: regions of consistently highest settlement and survival of oysters in the James River, and other regions (see Table 7) which do not exhibit high settlement. The extant populations of high survival locations have been developed over a considerable time period. Indeed, the category of small oysters probably contains up to three or even four year classes of recruitment at some of these sites. Consequently the comparison of such sites with both Mulberry Point reef and the Piankatank River reefs is potentially confused. The difference among sites does, however, offer a good example of the small scale spatial variability in settlement and growth environment for oysters in rivers like the James, and probably all of the Virginia subestuaries where oysters can still grow, and underscore that in a conducive reef environment populations can thrive. If this observation is superimposed on the comparative data generated thus far for reefs and bars in adjacent locations the temptation to suggest that reefs in optimal locations currently occupied by extant bars could, over reasonable time periods, sustain oyster population densities higher than any that are currently observed anywhere in the Virginia portion of the Chesapeake Bay, and the likes of which have not been encountered in Virginia waters for decades. The implications of such a suggestion for both optimal reproduction, where proximity is crucial to efficient fertilization, and development of a reef structure for habitat for a wide ranging variety of other species, are strongly positive and underscore the need for continued support of reef construction and rehabilitation in the Virginia substuaries of the Chesapeake Bay.

Conclusion

The current limited surveys indicate that in regions of low spat settlement (the Piankatank River 1993-1996) oyster reefs with vertical relief offer enhanced opportunity for settlement and/or survival. In regions of generally higher settlement (Mulberry Point, James River) elevated survival of both spat and small oyster size classes is observed. In marginal regions with respect to disease (Wreck Shoal) no significant enhancement has been observed to this time. When data are compared with stock assessment data from productive extant oyster bars it is evident that development of a stable community on reefs will take a number of years (and year class recruitment's). The limited data available suggest strongly that the locations of reefs in locations that are optimal for continued recruitment could form stable communities with very high oyster densities that are beneficial to both oyster reproduction and reef community development.

Acknowledgements

This project was accomplished with assisatance from a number of colleagues. We are particularly indebted to Reinaldo Morales (VIMS) for his hours spent in organizing field work and data analysis, to John Register and Calvin Smith (VMRC) for vessel operation , and to many pairs of student hands for field and diving assistance.

Literature cited.

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Newell, R. I. E. 1989. Ecological changes in the Chesapeake Bay: Are they the result of overharvesting the American Oyster (Crassostrea virginica)? in: Understanding the Estuary: Advances in Chesapeake Bay Research. Chesapeake Research Consortium Publication No. 129: 536-546.

Figure Legends

Figure 1. Reef sampling sites in the Piankatank River, Virginia. A through D are reef sites. A: Palace Bar. B: Bland Point. C: Iron Point. D: Burton Point. Palace Bar and Bland Point were also sampled by patent tong. In addition 1 through 6 are patent tong survey sites (see text and tables for comparative data) 1: Ginney Point. 2: Heron Rock. 3: Stove Point. 4: Cape Tune. 5. Burton Point A. 6: Burton Point B.

Figure 2. Reef sampling sites in the James River, Virginia. The 23 major reef systems in the upper James River are illustrated. A key to reef names is given on the figure. The Mulberry Point reef is in the upper right hand corner of section 12 as viewed in this figure. The Wreck Shoal reef is in the center of section 19. The major productive reefs are in sections 1-13 inclusive.

Figure 1: Piankatank River

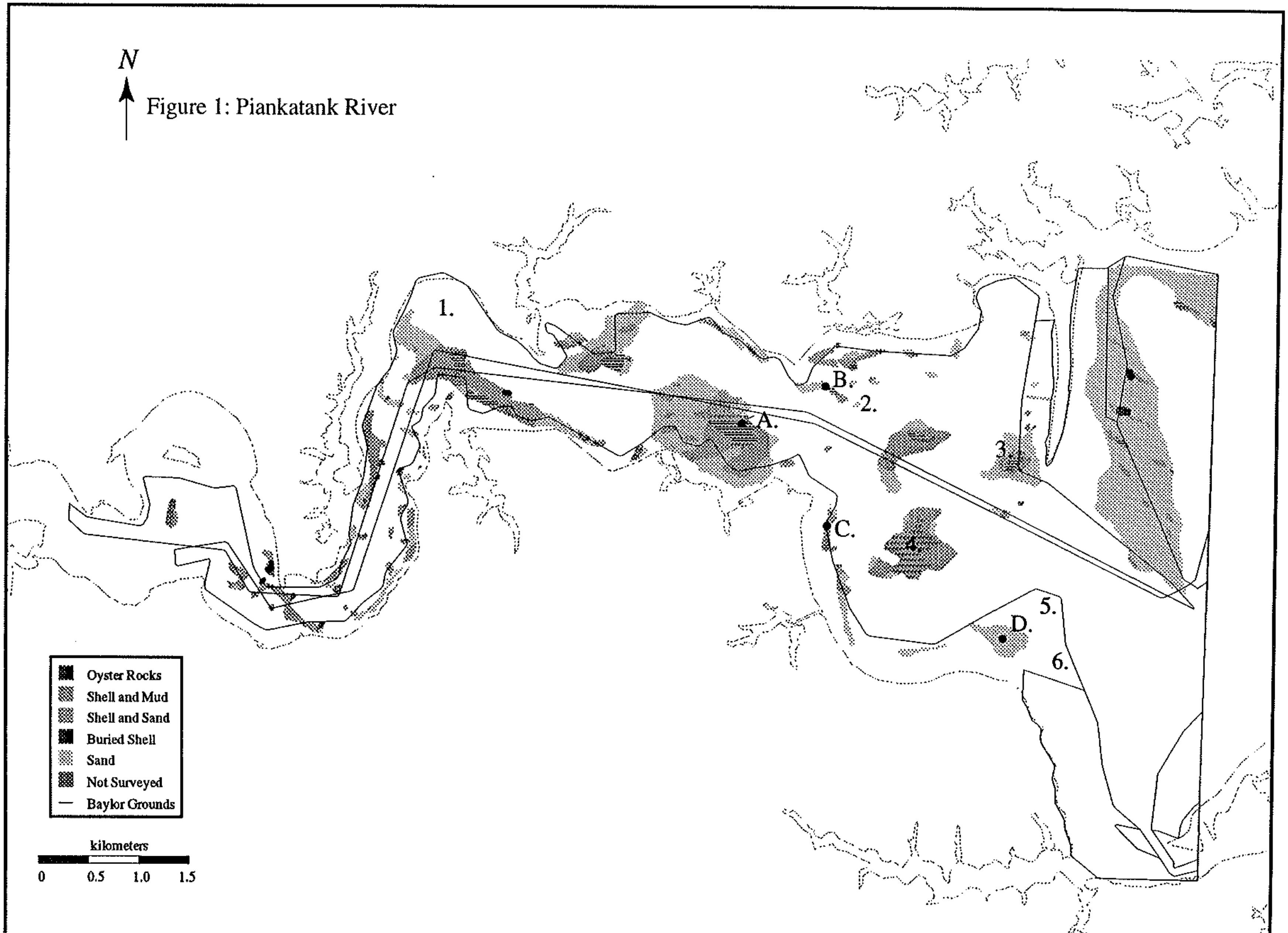

Figure 2: James River

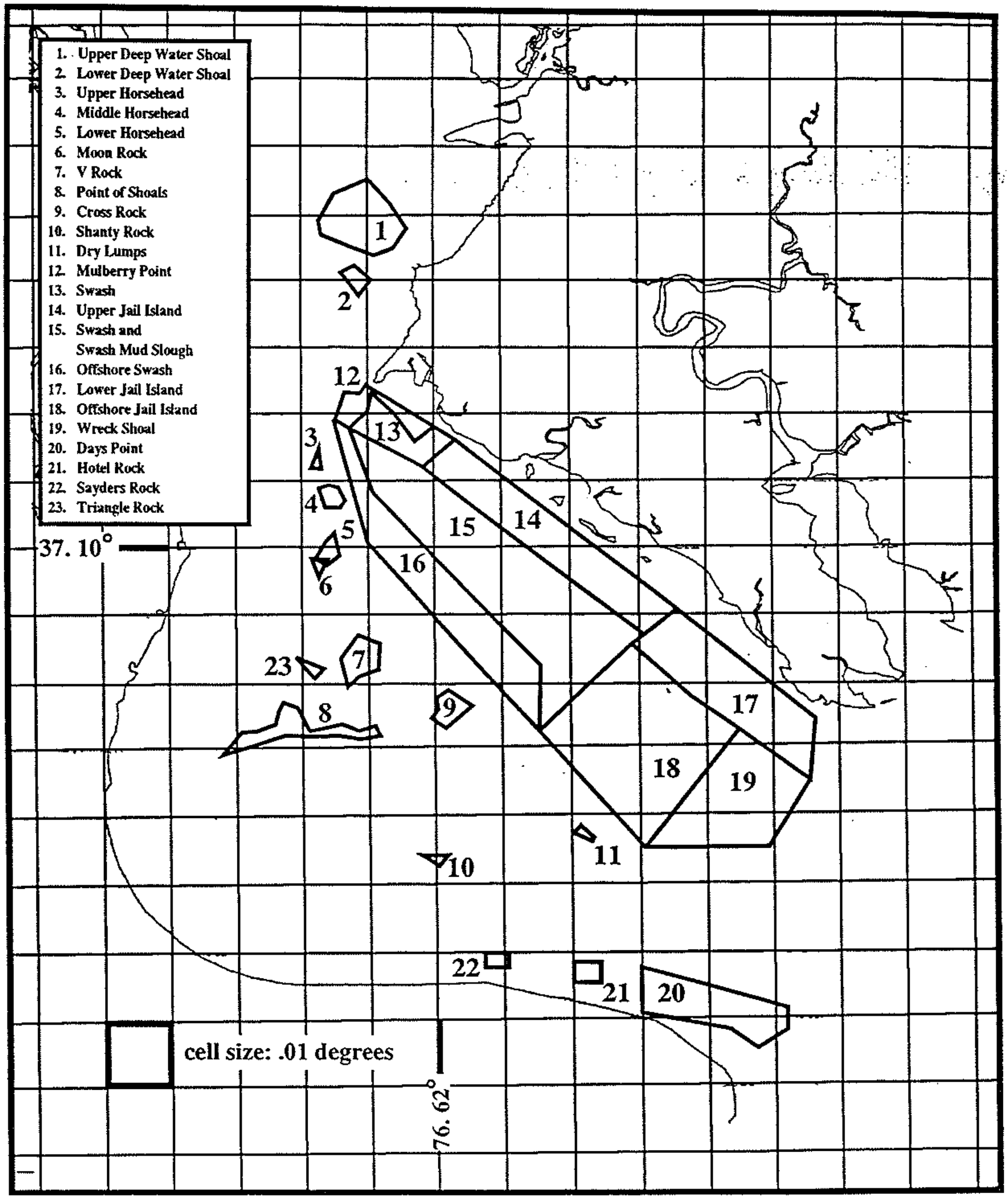

Table 1: Summary of oyster populations by size class at Palace Bar, Piankatank River.
n is the number of samples collected
x is the mean value, +ci and -ci give upper and lower 95% confidence interval

				LIVE OYSTERS				BOXES	
		n		spat	small	market	small+market	old	new
PALACE BAR	HIGH	10	x	**17.4**	**26.4**	**1.2**	**27.6**	**34.4**	**9.2**
Nov-95			x+ci	28.5	41.2	2.6	43.3	61.0	18.9
			x-ci	6.3	11.6	-0.2	11.9	7.8	-0.5
	MIDDLE	10	x	**40.0**	**47.6**	**1.2**	**48.8**	**90.8**	**12.8**
			x+ci	61.4	79.1	3.1	81.8	150.4	20.3
			x-ci	18.6	16.1	-0.7	15.8	31.2	5.3
	LOW	10	x	**39.6**	**30.8**	**1.6**	**32.4**	**98.0**	**8.0**
			x+ci	68.8	41.1	5.2	42.4	125.1	16.1
			x-ci	10.4	20.5	-2.0	22.4	70.9	-0.1
PALACE BAR	HIGH	10	x	**40.8**	**27.6**	**4.0**	**31.6**	**39.6**	**3.2**
Jun-96			x+ci	55.9	47.9	7.0	52.9	58.3	5.5
			x-ci	25.7	7.3	1.0	10.3	20.9	0.9
	MIDDLE	10	x	**61.2**	**39.6**	**6.1**	**45.7**	**64.0**	**4.4**
			x+ci	88.4	55.2	11.5	65.1	100.7	7.2
			x-ci	34.0	24.0	0.7	26.3	27.3	1.6
	LOW	10	x	**58.0**	**22.9**	**3.2**	**26.1**	**71.6**	**2.4**
			x+ci	106.8	33.7	7.0	38.5	116.0	5.2
			x-ci	9.2	12.1	-0.6	13.7	27.2	-0.4
PALACE BAR	HIGH	10	x	**32.8**	**47.8**	**0**	**47.8**	**0**	**0.7**
Oct-96			x+ci	46.0	65.7	0	65.7	0	2.1
			x-ci	19.6	29.9	0	29.9	0	-0.8
	MIDDLE	10	x	**22.4**	**53.6**	**0**	**53.6**	**0**	**16.5**
			x+ci	33.0	73.2	0	73.2	0	213.4
			x-ci	11.8	34.0	0	34.0	0	-180.4
	LOW	10	x	**16.8**	**65.6**	**0**	**65.6**	**0**	**60.0**
			x+ci	25.0	73.8	0	73.8	0	212.5
			x-ci	8.6	57.4	0	57.4	0	-92.5

Table 2: Summary of oyster populations by size class at Bland Point, Piankatank River.
n is the number of samples collected
x is the mean value, +ci and -ci give upper and lower 95% confidence interval
n.d. indicates no data collected

				LIVE OYSTERS				BOXES	
		n		spat	small	market	small+market	old	new
BLAND PT.	HIGH	10	x	**5.6**	**0**	**0**	**0**	**0.9**	**0.4**
Jun-96			x+ci	9.5	0	0	0	2.1	1.3
			x-ci	1.7	0	0	0	-0.3	-0.5
	MIDDLE	10	x	**44.8**	**0**	**0**	**0**	**5.6**	**4.8**
			x+ci	74.8	0	0	0	9.0	10.8
			x-ci	14.8	0	0	0	2.2	-1.2
	LOW	10	x	**85.2**	**0**	**0**	**0**	**2.0**	**5.2**
			x+ci	124.9	0	0	0	5.6	10.1
			x-ci	45.5	0	0	0	-1.6	0.3
BLAND PT.	HIGH	10	x	**43.6**	**17.6**	**0**	**17.6**	n.d.	n.d.
Oct-96			x+ci	67.2	21.5	0	21.5	n.d.	n.d.
			x-ci	20.0	13.7	0	13.7	n.d.	n.d.
	MIDDLE	10	x	**38.4**	**22.4**	**0**	**22.4**	n.d.	n.d.
			x+ci	53.5	35.6	0	35.6	n.d.	n.d.
			x-ci	23.3	9.2	0	9.2	n.d.	n.d.
	LOW	10	x	**31.2**	**60.0**	**0**	**60.0**	n.d.	n.d.
			x+ci	37.0	109.5	0	109.5	n.d.	n.d.
			x-ci	25.4	10.5	0	10.5	n.d.	n.d.

Table 3: Summary of oyster populations by size class at Burton Point, Piankatank River.
n is the number of samples collected
x is the mean value, +ci and -ci give upper and lower 95% confidence interval

		n		LIVE OYSTERS spat	small	market	small+market	BOXES old	new
BURTON PT. Jun-96	HIGH	10	x	**19.6**	**0**	**0**	**0**	**1.6**	**0.8**
			x+ci	31.2	0	0	0	4.4	2.0
			x-ci	8.0	0	0	0	-1.2	-0.4
	MIDDLE	10	x	**54.4**	**0**	**0**	**0**	**2.0**	**2.8**
			x+ci	75.4	0	0	0	4.0	5.8
			x-ci	33.4	0	0	0	0	-0.2
	LOW	10	x	**58.8**	**0**	**0**	**0**	**1.6**	**2.4**
			x+ci	76.6	0	0	0	3.6	5.5
			x-ci	41.0	0	0	0	-0.4	-0.7
BURTON PT. Oct-96	HIGH	11	x	**40.4**	**36.4**	**0**	**36.4**	**0**	**0.7**
			x+ci	58.7	56.9	0	56.9	0	1.0
			x-ci	22.0	15.8	0	15.8	0	0.4
	MIDDLE	11	x	**18.2**	**56.4**	**0**	**56.4**	**0.1**	**0.2**
			x+ci	25.1	79.6	0	79.6	0.3	0.5
			x-ci	11.2	33.2	0	33.2	-0.1	-0.1
	LOW	11	x	**21.8**	**56.0**	**0**	**56.0**	**0.1**	**0.2**
			x+ci	29.5	71.1	0	71.1	0.3	0.5
			x-ci	14.1	40.9	0	40.9	-0.1	-0.1

Table 4: Summary of oyster populations by size class at Iron Point, Piankatank River.
n is the number of samples collected
x is the mean value, +ci and -ci give upper and lower 95% confidence interval

		n		LIVE OYSTERS spat	small	market	small+market	BOXES old	new
IRON POINT Jun-96	HIGH	7	x	**50.3**	**0**	**0**	**0**	**0**	**0.6**
			x+ci	78.2	0	0	0	0	2.0
			x-ci	22.4	0	0	0	0	-0.8
	MIDDLE	7	x	**60.0**	**0**	**0**	**0**	**0**	**2.3**
			x+ci	90.8	0	0	0	0	4.3
			x-ci	29.2	0	0	0	0	0.3
	LOW	7	x	**76.0**	**0**	**0**	**0**	**0**	**2.3**
			x+ci	108.9	0	0	0	0	5.9
			x-ci	43.1	0	0	0	0	-1.3
IRON POINT Oct-96	HIGH	10	x	**32.9**	**28.4**	**0**	**28.4**	**0.1**	**0.4**
			x+ci	41.8	53.8	0	53.8	0.4	1.0
			x-ci	24.0	3.1	0	3.1	-0.1	-0.1
	MIDDLE	10	x	**23.1**	**47.6**	**0**	**47.6**	**0.0**	**0.9**
			x+ci	31.6	74.3	0	74.3	0.0	1.9
			x-ci	14.6	20.8	0	20.8	0.0	-0.1
	LOW	10	x	**26.0**	**66.0**	**0**	**66.0**	**0.2**	**1.8**
			x+ci	42.1	102.5	0	102.5	0.6	5.1
			x-ci	9.9	29.5	0	29.5	-0.3	-1.4

Table 5: Summary of oyster populations by size class at Mulberry Point, James River.
Date of sampling: August 16, 1996
x is the mean value, +ci and -ci give 95% confidence interval
All values are oysters / sq. m

sample number	live spat	live small	live market	boxes spat	boxs small	boxes market	shell volume L
1	224	19	1	2	0	0	1
2	18	0	0	0	1	0	7
3	76	1	0	0	0	0	9
4	5	0	0	0	0	0	6
5	220	225	0	0	2	0	12
6	165	95	0	0	0	0	12
7	1	0	0	0	0	0	12
8	319	417	0	0	0	1	11
9	106	41	0	0	2	6	12
10	91	10	0	1	0	0	22
11	21	34	0	0	0	0	9
12	24	10	0	0	0	0	15
13	199	50	0	1	0	0	10
14	20	39	0	0	0	0	8
15	93	60	0	0	0	0	9
16	5	1	0	0	0	0	9
17	3	0	0	0	0	0	4
18	0	1	0	2	0	0	9
19	82	40	0	0	2	0	18
20	218	271	1	0	2	0	7
x	**94.5**	**65.7**	**0.1**	**0.3**	**0.5**	**0.4**	**10.1**
max	0.0	0.0	0.0	0.0	0.0	0.0	1.0
min	319.0	417.0	1.0	2.0	2.0	6.0	22.0
x + ci	139.9	117.6	0.2	0.6	0.8	1.0	12.3
x - ci	49.1	13.8	0.0	0.0	0.1	-0.3	7.9

Table 6: Summary of oyster populations by size class at Wreck Shoal, James River.
Date of sampling: August 15, 1996
x is the mean value, +ci and -ci give 95% confidence interval
All values are oysters / sq. m

	live spat	live small	live market	boxes spat	boxes small	boxes market	shell volume L
HIGH-1	0	7	0	0	4	0	9
HIGH-2	0	1	0	0	0	0	4
HIGH-3	0	0	0	0	0	0	11
HIGH-4	0	0	0	0	0	0	9
HIGH-5	7	11	3	1	2	0	10
HIGH-6	1	2	0	0	0	0	15
HIGH-7	8	30	0	3	1	2	20
HIGH-8	1	12	0	1	0	0	9
HIGH-9	0	1	0	0	1	0	7
HIGH-10	0	0	0	0	0	0	6
x	**1.7**	**6.4**	**0.3**	**0.5**	**0.8**	**0.2**	**10.0**
max	0.0	0.0	0.0	0.0	0.0	0.0	4.0
min	8.0	30.0	3.0	3.0	4.0	2.0	20.0
x + ci	3.9	13.2	1.0	1.2	1.7	0.7	13.3
x - ci	-0.5	-0.4	-0.4	-0.2	-0.1	-0.3	6.7
MIDDLE-1	1	0	0	0	0	1	12
MIDDLE-2	5	10	0	1	1	0	10
MIDDLE-3	0	2	0	0	0	0	3
MIDDLE-4	0	0	0	0	0	0	0
MIDDLE-5	0	1	1	0	0	0	0.5
MIDDLE-6	0	0	0	0	0	0	10
MIDDLE-7	9	40	1	1	2	2	20
MIDDLE-8	0	1	0	0	0	0	11
MIDDLE-9	2	3	1	0	0	1	11
MIDDLE-10	2	2	1	0	0	0	8
x	**1.9**	**5.9**	**0.4**	**0.2**	**0.3**	**0.4**	**8.6**
max	0.0	0.0	0.0	0.0	0.0	0.0	0.0
min	9.0	40.0	1.0	1.0	2.0	2.0	20.0
x + ci	4.0	14.7	0.8	0.5	0.8	0.9	12.9
x - ci	-0.2	-2.9	0.0	-0.1	-0.2	-0.1	4.2
LOW-1	0	3	0	0	0	1	4
LOW-2	0	0	0	0	0	0	10
LOW-3	0	1	0	0	0	0	3
LOW-4	1	8	2	0	2	0	11
LOW-5	2	1	0	0	0	0	5
LOW-6	3	4	0	0	0	1	14
LOW-7	4	39	5	1	1	1	11
LOW-8	2	33	1	1	7	2	10
LOW-9	3	1	0	0	0	1	3
LOW-10	0	2	0	0	0	0	4
x	**1.5**	**9.2**	**0.8**	**0.2**	**1.0**	**0.6**	**7.5**
max	0.0	0.0	0.0	0.0	0.0	0.0	3.0
min	4.0	39.0	5.0	1.0	7.0	2.0	14.0
x + ci	2.6	19.5	2.0	0.5	2.6	1.1	10.4
x - ci	0.4	-1.1	-0.4	-0.1	-0.6	0.1	4.6

Table 7: Comparison of oyster populations by size class on constructed reefs and natural bars in the Piankatank River and James River. n is the number of samples collected. Reef samples collected as described in text. Bar samples collected by patent tong. H, M and L denote HIGH, MEDIUM and LOW samples respectively as described in text

		date	n	spat	small	market	small+market
Piankatank River - Reefs							
Palace Bar	H	Nov-95	10	17.4	26.4	1.2	27.6
	M		10	40	47.6	1.2	48.8
	L		10	39.6	30.8	1.6	32.4
Palace Bar	H	Jun-96	10	40.8	27.6	4	31.6
	M		10	61.2	39.6	6.1	45.7
	L		10	58	22.9	3.2	26.1
Palace Bar	H	Oct-96	10	32.8	47.8	0	47.8
	M		10	22.4	53.6	0	53.6
	L		10	16.8	65.6	0	65.6
Bland Point	H	Jun-96	10	5.6	0	0	0
	M		10	44.8	0	0	0
	L		10	85.2	0	0	0
Bland Point	H	Oct-96	10	43.6	17.6	0	17.6
	M		10	38.4	22.4	0	22.4
	L		10	31.2	60	0	60
Burton Point	H	Jun-96	10	19.6	0	0	0
	M		10	54.4	0	0	0
	L		10	58.8	0	0	0
Burton Point	H	Oct-96	11	40.4	36.4	0	36.4
	M		11	18.2	56.4	0	56.4
	L		11	21.8	56.0	0	56.0
Iron Point	H	Jun-96	7	50.3	0	0	0
	M		7	60.0	0	0	0
	L		7	76.0	0	0	0
Iron Point	H	Oct-96	10	32.9	28.4	0	28.4
	M		10	23.1	47.6	0	47.6
	L		10	26.0	66.0	0	66.0
Piankatank River -Bars		Nov-95					
Bland Point			7	31.4	5.3	0.1	5.4
Burton Point A			9	11.1	5.0	0.3	5.3
Cape Tune			9	11.4	7.6	0.0	7.6
Ginney Point			7	15.7	1.7	0.0	1.7
Palace Bar			9	17.7	5.2	0.1	5.3
Stove Point			7	25.4	2.4	0.1	2.6
Heron Rock			7	16.0	3.9	0.0	3.9
Burton Point B			7	15.0	3.3	0.4	3.7

		date	n	spat	small	market	small+market
James River - Reefs		Aug-95					
Mulberry			20	94.5	65.7	0.1	65.2
Wreck Shoal	H		10	1.7	6.4	0.3	6.7
Wreck Shoal	M		10	1.9	5.9	0.4	6.3
Wreck Shoal	L		10	1.5	9.2	0.8	10
James River - Bars		Nov-95					
Upper Deep Water Shoal			72	194.1	7.2	1.6	8.8
Lower Deep Water Shoal			8	17.6	0.8	0.3	1.0
Upper Horsehead			7	68.4	253.0	15.0	268.0
Middle Horsehead			10	116.7	346.6	12.1	358.7
Lower Horsehead			12	110.2	273.3	9.3	282.7
Moon Rock			8	118.0	263.4	13.3	276.6
V-Rock			21	73.3	198.1	8.7	206.8
Point of Shoals			33	78.4	200.2	14.0	214.2
Cross Rock			21	13.1	182.8	3.7	186.5
Shanty Rock			7	8.9	78.7	2.9	81.6
Dry Lumps			7	4.7	22.1	0.4	22.6
Mulberry Point			31	12.8	22.2	2.9	25.1
Swash			22	5.7	10.9	1.6	12.5
Upper Jail Island			65	0.7	8.6	1.6	10.2
Swash Mud Slough			125	2.1	20.5	2.5	23.0
Offshore Swash			101	3.2	38.3	2.0	40.3
Lower Jail Island			62	0.5	9.7	3.3	13.0
Offshore Jail Island			102	1.3	6.8	0.7	7.4
Wreck Shoal			50	0.8	6.6	0.3	7.0