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Recruitment, substrate quality and standing stock monitoring in support of NOAA-ACOA oyster restoration projects in the Great Wicomico, Rappahannock, Piankatank and Lynnhaven River Basins, 2004-2006 : supplementary materials

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Supplemental materials

Recruitment, substrate quality and standing stock monitoring in support of NOAA-ACOE oyster restoration projects in the Great Wicomico, Rappahannock, Piankatank and Lynnhaven River Basins
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INTRODUCTION

Many factors affect the success of oyster restoration efforts. This supplemental report details the VIMS effort under this NOAA-funded program to monitor some of those factors in the Great Wicomico, Rappahannock, Piankatank and Lynnhaven Rivers. Specifically, it details monitoring of (1) oyster settlement at two reefs in each of those tributaries from May to November from 2004 – 2006, along with additional widespread recruitment monitoring in the Lynnhaven River in 2005 & 2006, (2) substrate condition on the same eight reefs during spring, summer and fall of 2004 – 2006, (3) oyster abundance on Shell Bar reef in the Great Wicomico River before and the deployment of hatchery-produced oysters in the spring of 2005, and (4) oyster population distribution, abundance and size in the Lynnhaven River basin during the period from April 2005 – March 2006. The data from each of these monitoring programs are available at the NORM website (www.vims.mollusc/NORM/index.htm) and in a GIS-based product (VIMS-ESL GIS-based Summary of Native Oyster Monitoring, Grant # NA06NMF4570303 by Mark W. Luckenbach and Paige G. Ross) submitted to NOAA on CD on August 26, 2008.

This supplemental report provides greater detail about the methods employed in these monitoring studies and summarizes our findings. The report is divided into three sections; the first details monitoring elements related to recruitment and substrate condition (1 & 2 above), the second reports on our assessment of oysters on Shell Bar reef in the Great Wicomico and the third describes oyster mapping and stock assessment in the Lynnhaven River.

PART 1 – OYSTER SETTLEMENT AND SUBSTRATE CONDITION ON REEFS IN THE GREAT WICOMICO, RAPPAHANNOCK, PIANKATANK AND LYNNHAVEN RIVERS—2004-2006

OBJECTIVES/PROJECT ELEMENTS

Many areas of the Chesapeake Bay and its tributaries have been touted as recruitment limited. However, it is often difficult to tease apart whether the absence of new recruits is a function of low larval abundance, a lack of suitable settlement substrate or a result of high early post-settlement mortality. This portion of the VIMS monitoring program attempted to tease apart the first two of these factors by determining settlement rates on clean substrate placed in four tributaries and by evaluating substrate quality on eight restoration reefs in those tributaries.

Our approach towards monitoring larval settlement was to deploy clean ceramic tiles, remove them within 7-14 days (for enumeration) and deploy new clean tiles throughout the settlement season. The data provide estimates of potential oyster recruitment to a reef if sufficient suitable substrate is available and early post-settlement mortality is low.

There is general consensus that the "condition" of the substrate used to create reefs is important to subsequent success, though the specifics of what constitutes good condition are less well established. Among the factors thought to be important are (1) sediment overburden on the shell substrate, (2) the size and stability of individual shell particles that make up the reef and, (3) the presence of epifauna that compete with oysters for limited resources (i.e. space or food). In the case of the eight reefs monitored in this study sedimentation was not presumed to be a factor since each are relatively high relief reef that do not appear to be experiencing significant siltation. The other two factors, however, were not known for these reefs. Moreover, we would expect these factors to vary temporally, both seasonally (for epifaunal communities) and inter-annually (as unconsolidated reef particles degrade).

STUDY AREA

We monitored oyster recruitment at two reefs in the Great Wicomico, Rappahannock, Piankatank and Lynnhaven Rivers (Figs. 1-4, see also Appendices I & II). Salinities at these reefs generally ranged between 10 and 18 psu in the Great Wicomico, Rappahannock and Piankatank Rivers and between 22 and 32 psu in the Lynnhaven River during this study (Fig. 5). These reefs, which varied in age (Table 1), were constructed by VMRC, often with a core of clam shell covered with clean oyster shell. These reefs were generally built as arrays of shell piles that produce an "upside-down egg carton" appearance (e.g. Fig.6, though at some places these piles blended together over time, see Appendix II-A) and are 3-dimensional in nature (Fig. 7), though the Lynnhaven reefs differed substantially from this. The subtidal reefs were in areas with a seabed depth of 2 to 3 m at Mean Low Water (MLW) and the reef crest depth ranged from intertidal (for portions of the two Lynnhaven River reefs) to 1.8 m at MLW.

Table 1. Summary of reefs monitored for settlement and substrate quality, years constructed and years monitored for settlement.

River	Reef	Year Built	Years Monitored
Great Wicomico	Crane's Creek (CC)	1998	2004-2007
	Shell Bar (SB)	1996	2004-2007
Lynnhaven	Great Neck Point (GN)	?	2005-2006
	Long Creek (LC)	2001	2005-2006
Piankatank	Burton's Point (BP)	1995	2004-2007
	Palace Bar (PB)	1993	2004-2007
Rappahannock	Drumming Ground (DG)	2000	2004-2007
	Parrot's Rock (PR)	2000	2004-2007

Figure 1. Oyster reefs in the Great Wicomico, Rappahannock, Piankatank and Lynnhaven Rivers monitored during this study. (Shading from USGS 1m Digital Elevation Model data).

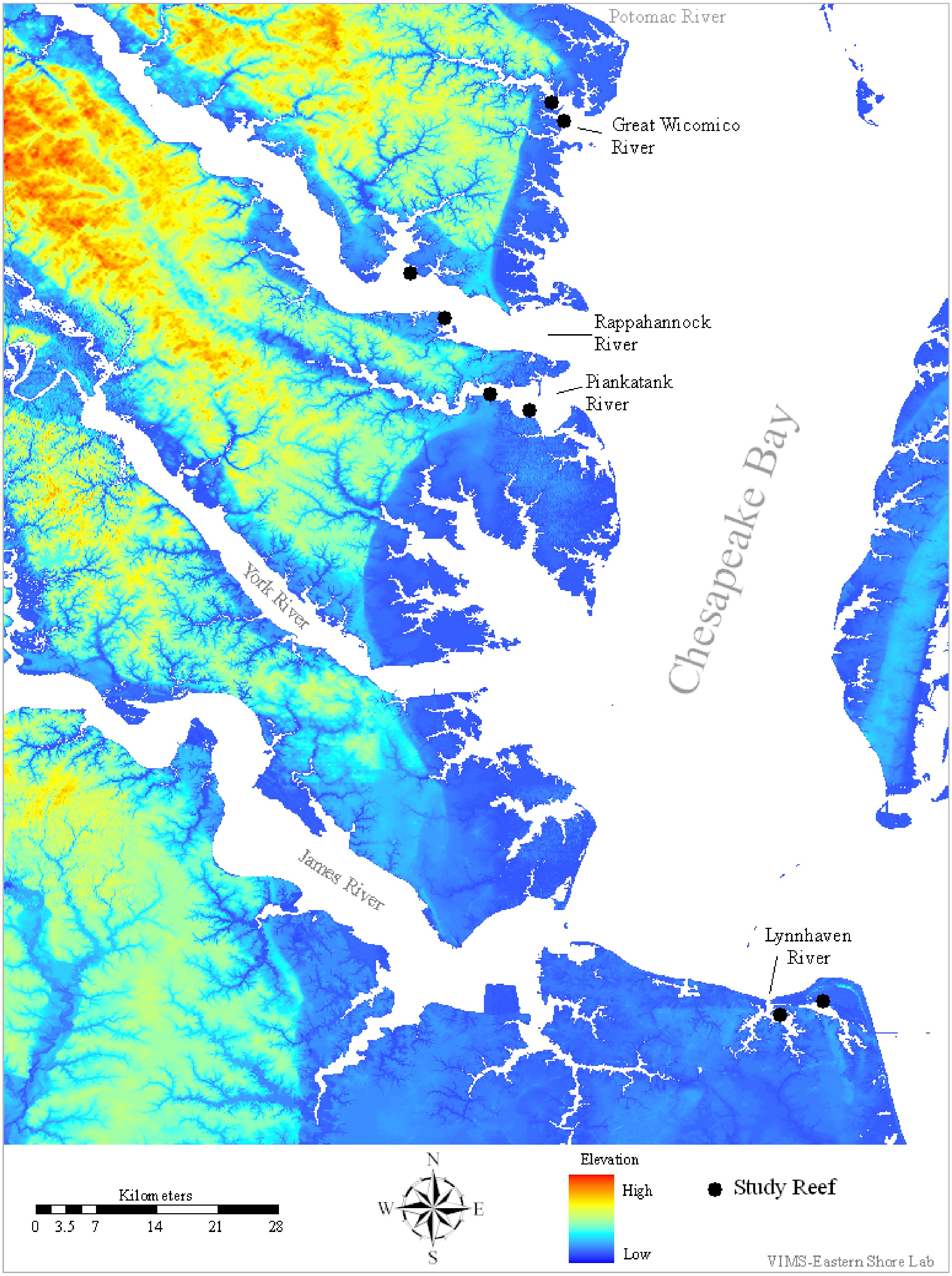


Figure 2. Oyster reefs in the Great Wicomico River monitored during this study. (Shading from USGS 1m Digital Elevation Model data).

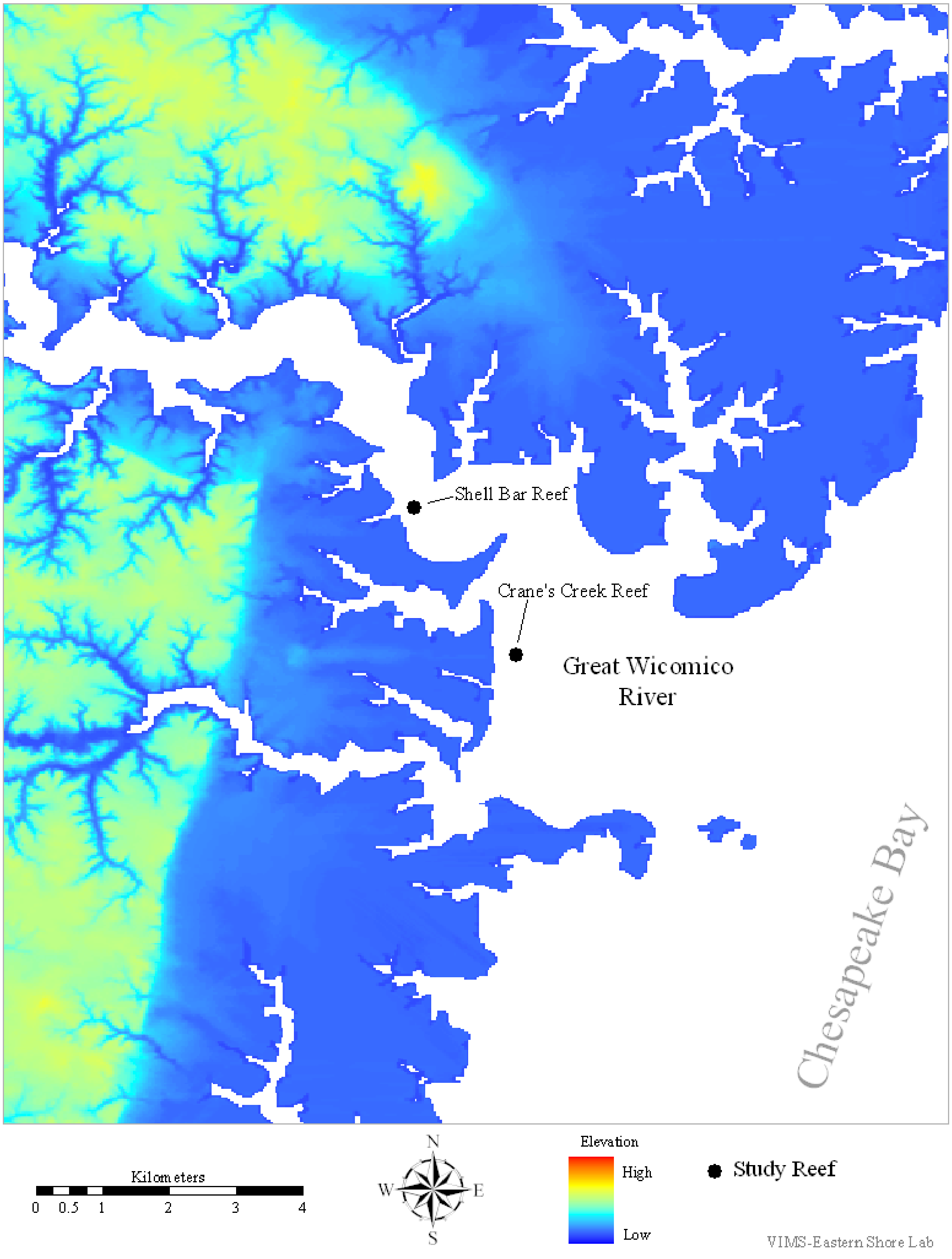


Figure 3. Oyster reefs in the Piankatank and Rappahannock rivers monitored during this study. (Shading from USGS 1m Digital Elevation Model data).

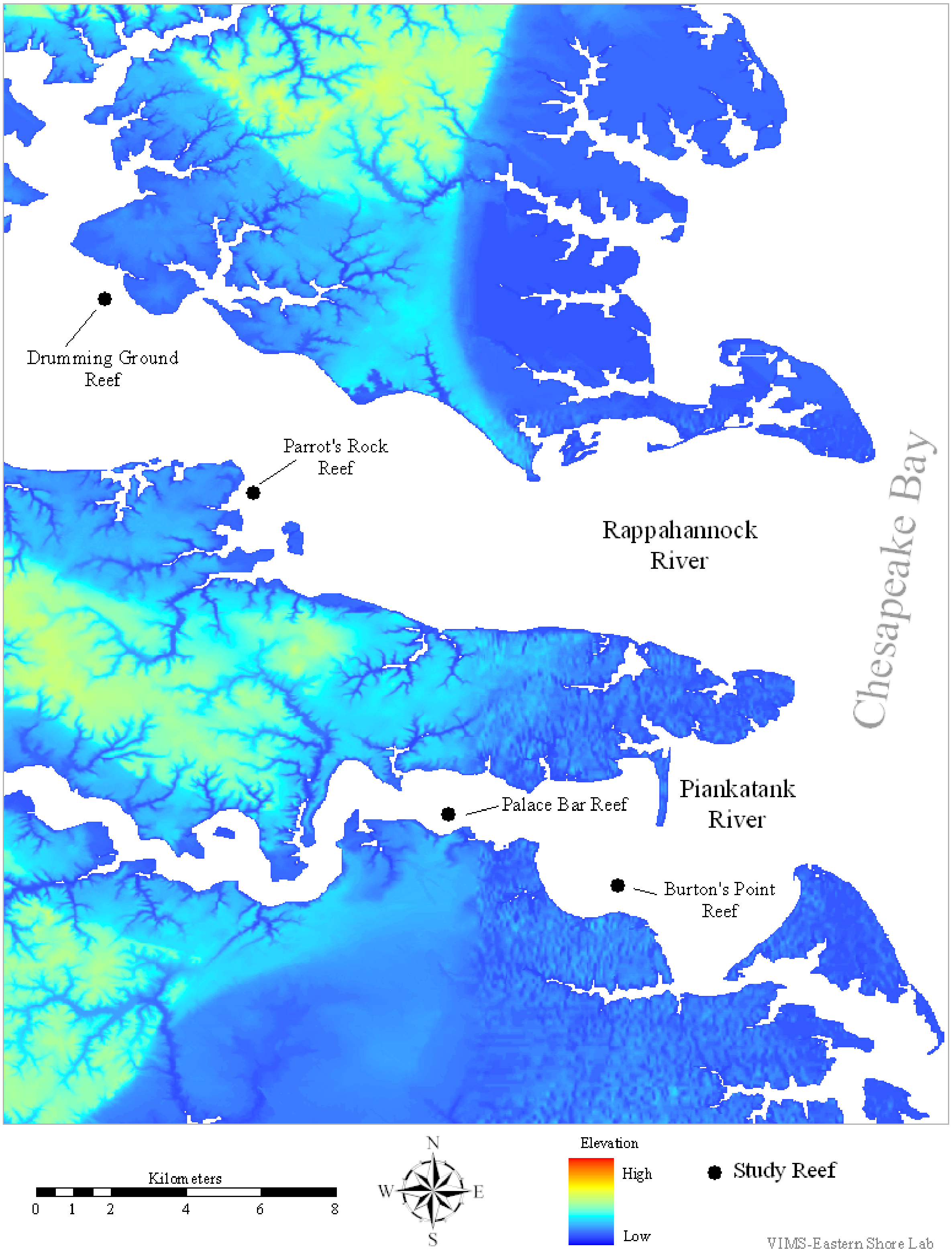


Figure 4. Oyster reefs in the Lynnhaven River monitored during this study. (Shading from USGS 1m Digital Elevation Model data).

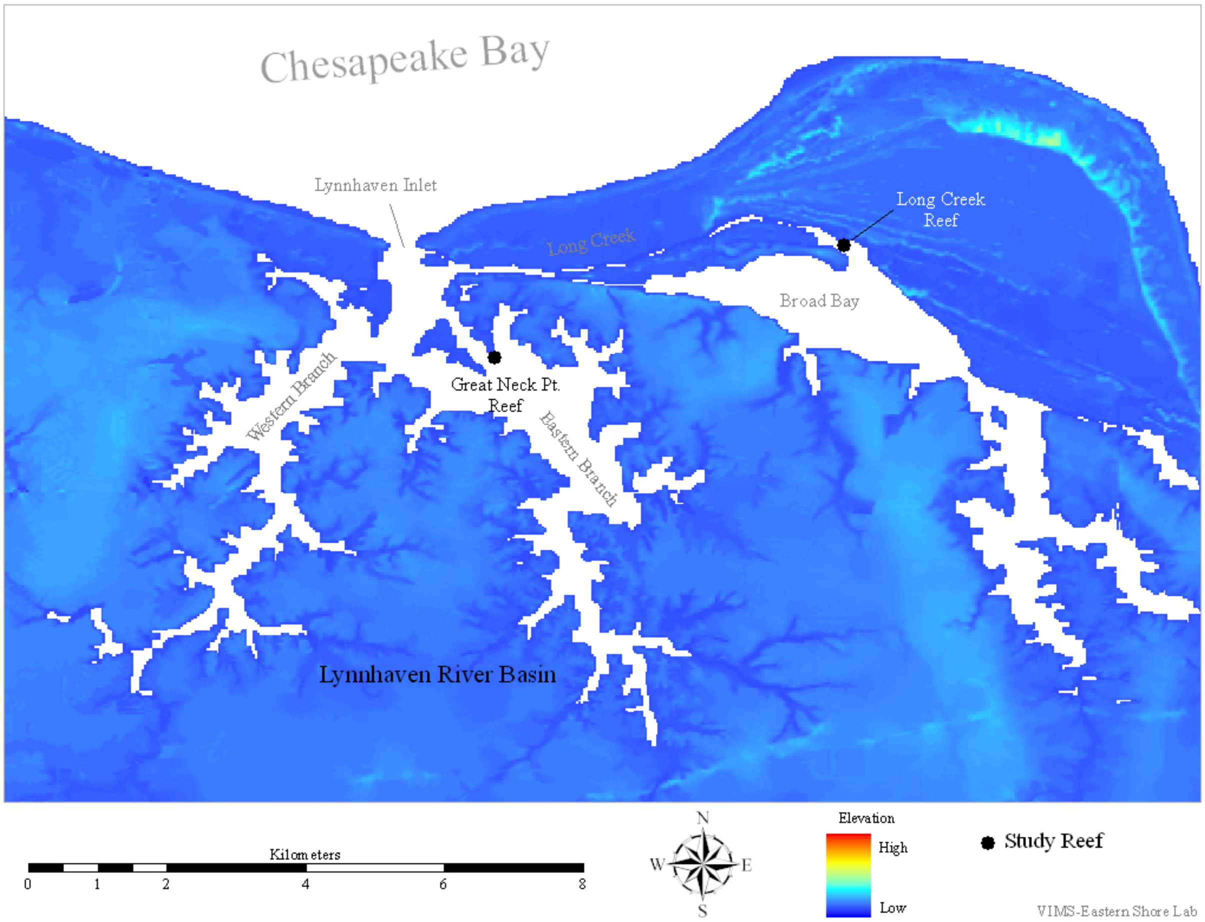


Figure 5. Salinity (psu) at mid-water depth for representative monitoring stations for the four tributaries in this study from 2004-2006. Mean 10-year mid-water column salinity is plotted as a dashed bar for reference (1994-2003). Data were downloaded from the Chesapeake Bay Program website (http://www.chesapeakebay.net/data/index.htm) and correspond to monitoring stations CB5.4W, LE3.4, LE3.7 and CB8.1E for the Great Wicomico, Rappahannock, Piankatank and Lynnhaven Rivers, respectively. Note that the station used for the Lynnhaven River is actually outside of the tributary in the main stem of the Bay.

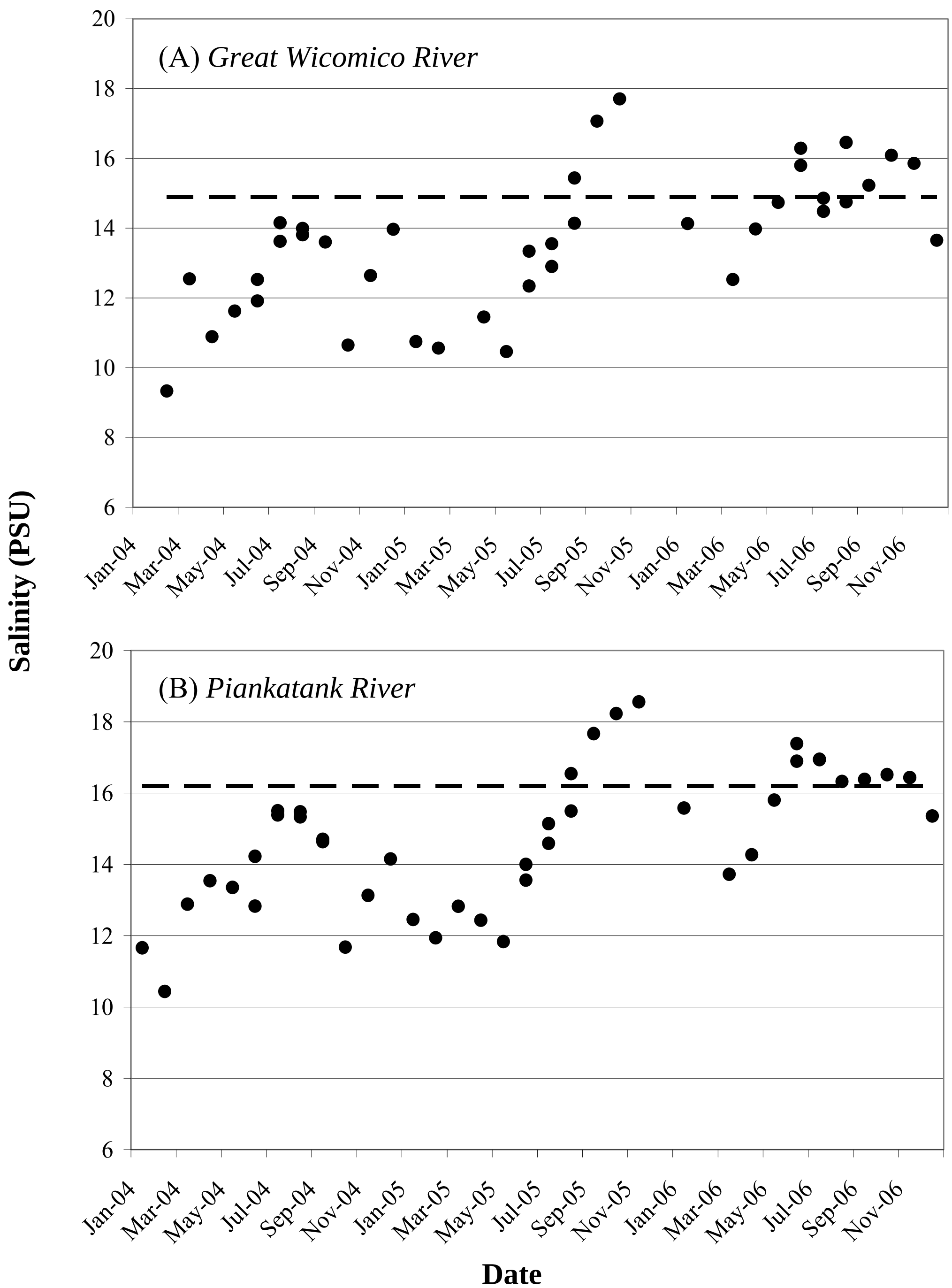


Figure 5 (cont). Salinity (psu) at mid-water depth for representative monitoring stations for the four tributaries in this study from 2004-2006. Mean 10-year mid-water column salinity is plotted as a dashed bar for reference (1994-2003). Data were downloaded from the Chesapeake Bay Program website (http://www.chesapeakebay.net/data/index.htm) and correspond to monitoring stations CB5.4W, LE3.4, LE3.7 and CB8.1E for the Great Wicomico, Rappahannock, Piankatank and Lynnhaven Rivers, respectively. Note that the station used for the Lynnhaven River is actually outside of the tributary in the main stem of the Bay.

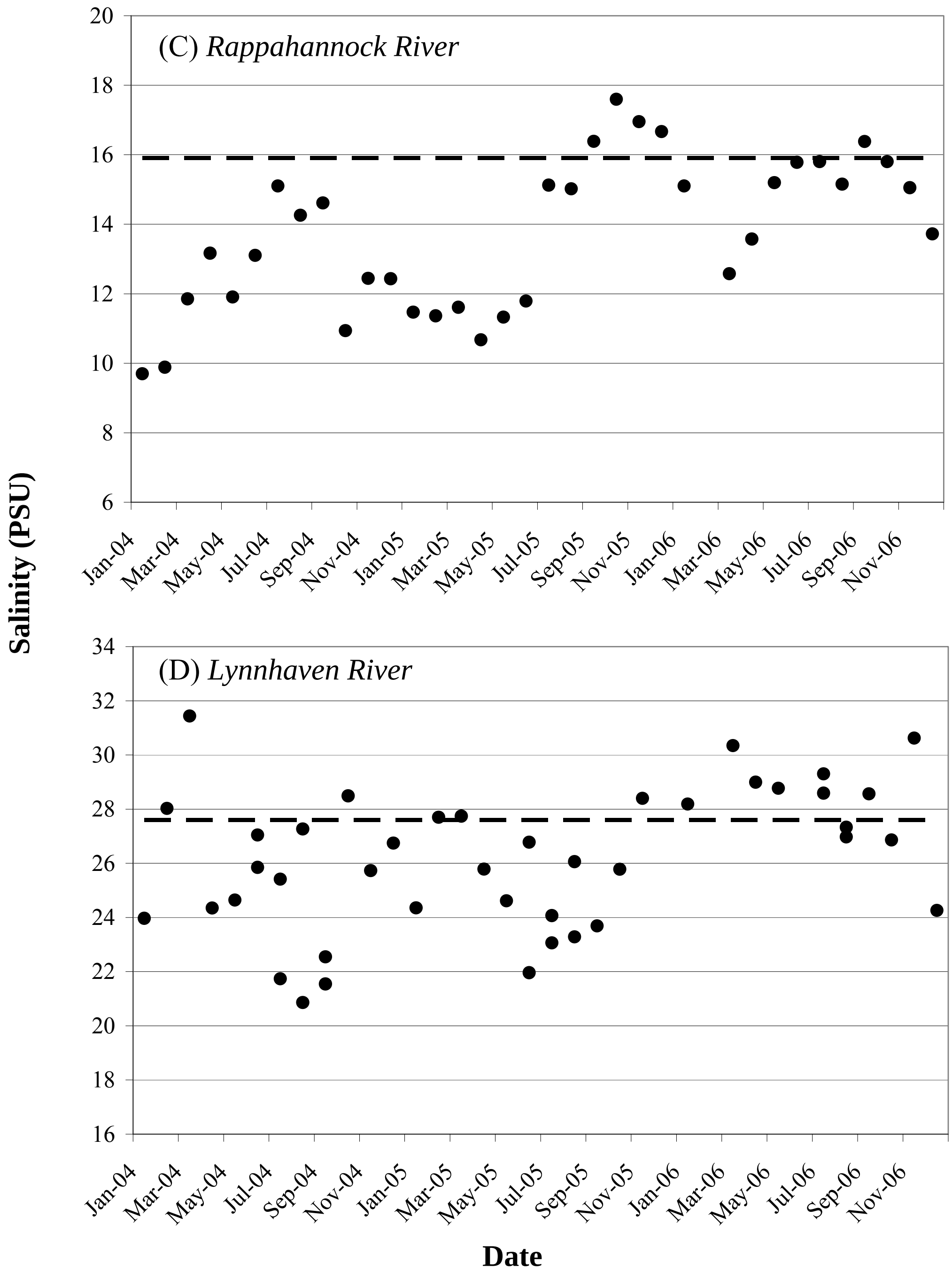


Figure 6. Generalized aerial footprint of a study reef in the Rappahannock River. Each circle represents a mound approximately 10 m diameter. Appendix II contains aerial photographs and schematics for each specific reef.

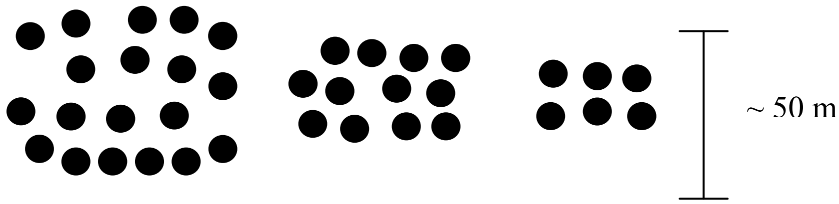
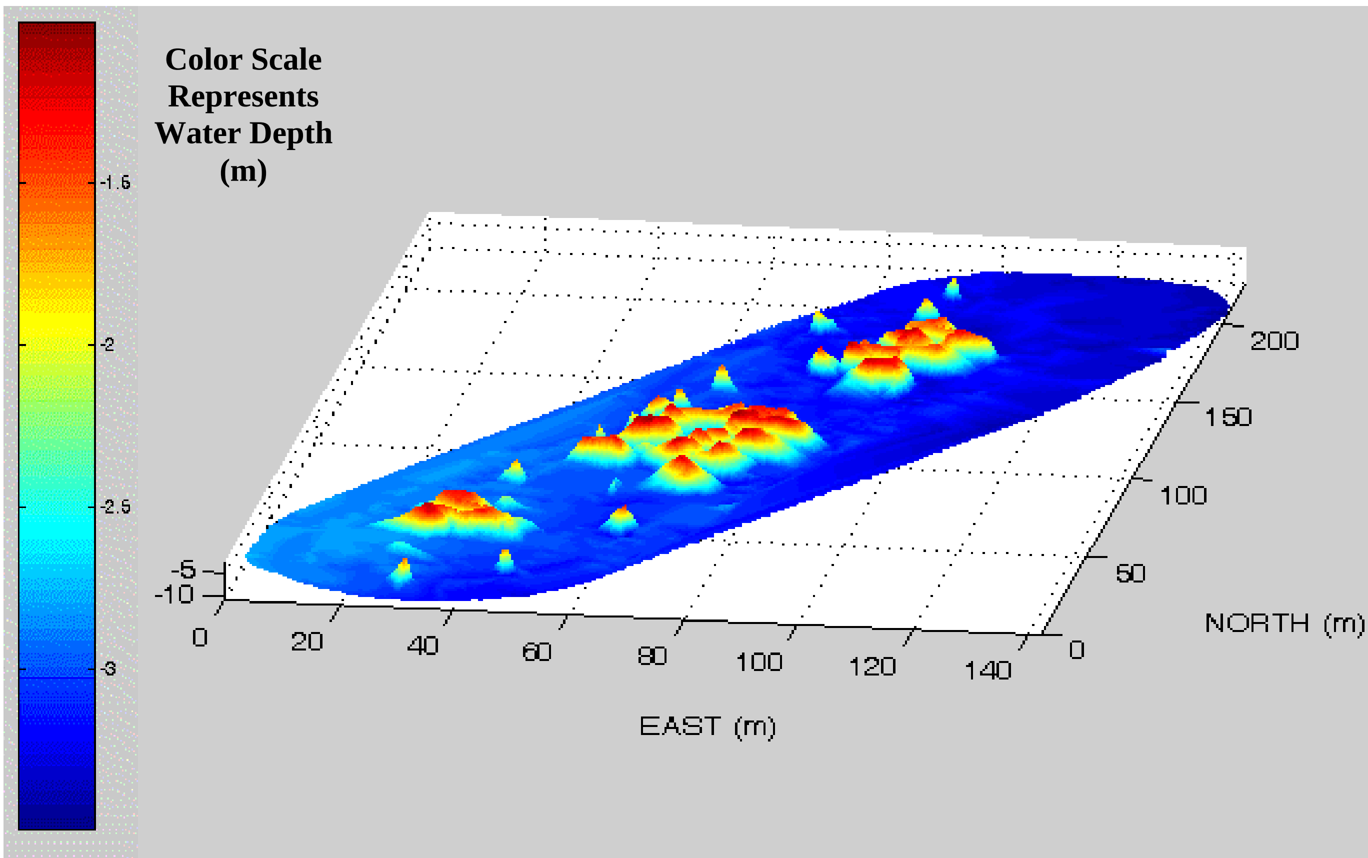


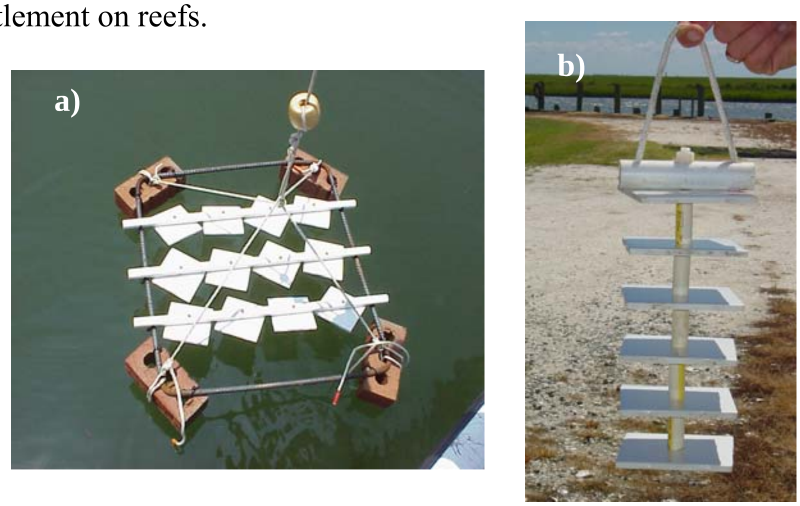
Figure 7. Three dimensional plot of bathymetry data for Parrot's Rock reef in the Rappahannock River from 2002.



METHODS

Oyster Settlement - Replicate settlement collectors consisting of horizontally-oriented arrays of 4" x 4" ceramic tiles (Fig. 8a) were deployed within 10 cm of reef surfaces at all reefs except Shell Bar. Initially in 2004, these arrays were utilized at Shell Bar reef; however, the construction of a net pen to exclude cownose rays from the reef in 2005 reduced our direct access to the reef. Therefore, during 2005 and 2006, we used similar 4" x 4" ceramic tiles oriented vertically (Fig. 8b) in the water column and deployed around the periphery of the net pen. This resulted in tile arrays stationed within 1 m of the seabed and within 10 m of the reef proper. Tiles at all reefs were recovered and replaced with clean ones on a fortnightly or weekly schedule throughout the settlement season. Horizontal arrays were deployed at or near reef crests and bases within each reef. A total of 48 tiles were deployed at each reef, except the two in the Lynnhaven River, where 24 were deployed per reef due to their smaller relative size (see Appendices III - V for the dates and durations of each deployment). Oysters settled on tiles were enumerated under a microscope in the laboratory and were standardized by tile surface area and the # days deployed to estimate a settlement rate (# spat · m^{-2} · $week^{-1}$). We have previously

Figure 8. Two types of arrays of ceramic tiles used to assay oyster settlement on reefs.



used this technique in other studies on oyster reefs and found that it provided a reliable estimate of the rates of recruitment of oysters to the reefs.

In addition to monitoring oyster settlement at designated study reefs, we determined settlement rates at 14 and 20 stations throughout the Lynnhaven Basin during 2005 and 2006, respectively (Figs. 9 & 10). Vertical arrays of six ceramic tiles (Fig. 8b) were deployed in the same manner and schedule as described above for reefs.

Figure 9. Lynnhaven settlement monitoring stations for 2005 (see Appendices VI & VII for reef abbreviations and detailed maps, respectively). Note that LCR & GNR (labeled in blue) are the two study reefs.

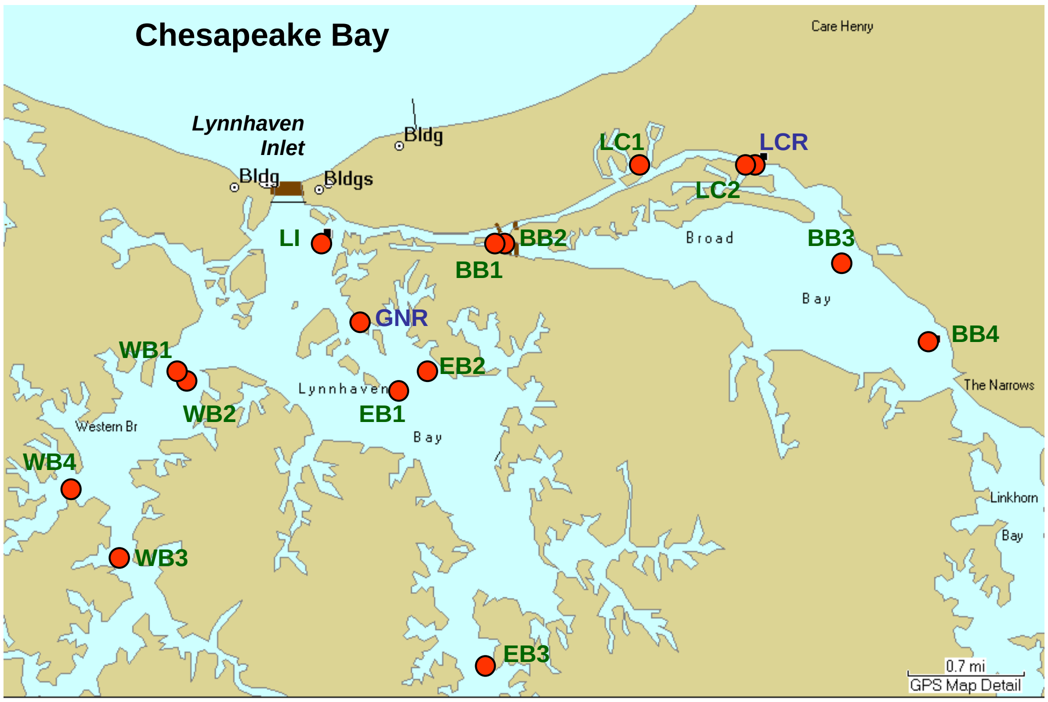
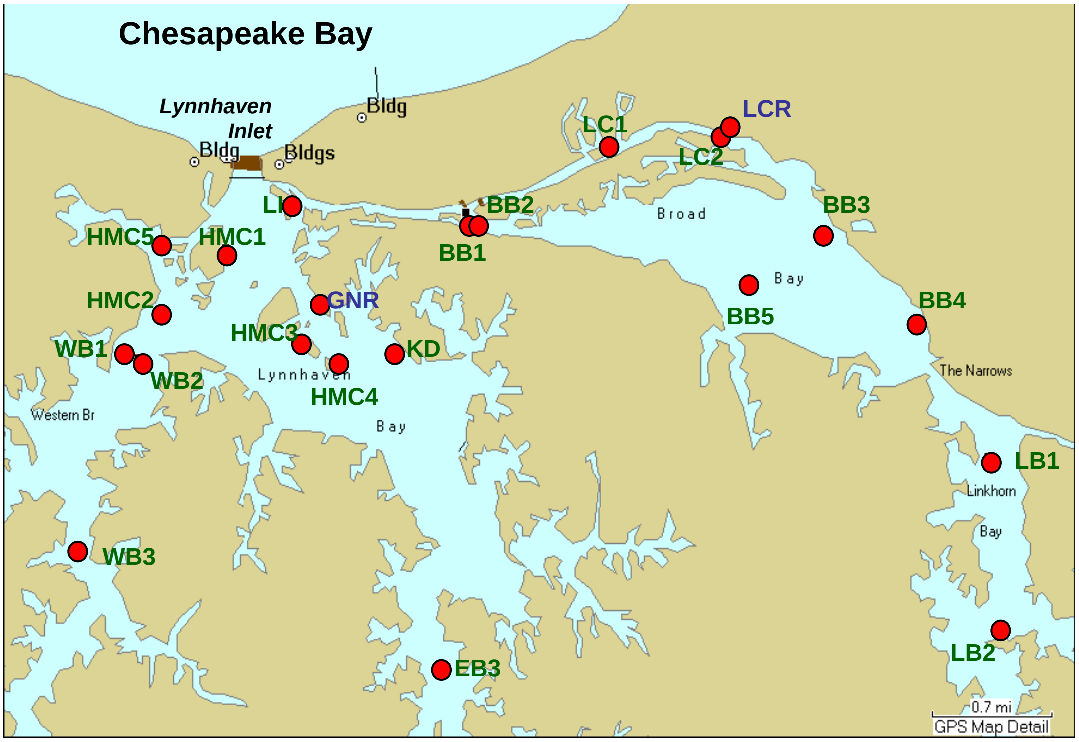


Figure 10. Lynnhaven settlement monitoring stations for 2006 see Appendices VI & VIII for reef abbreviations and detailed maps, respectively). Note that LCR & GNR (labeled in blue) are the two study reefs.



Substrate Condition – During 2004 and 2005, diver-collected quadrate samples of reef material were used to describe epifauna and characterize reef substrate condition. Six replicate quadrates, measuring 25 cm x 25 cm, were haphazardly located within each reef during spring, summer and fall. All reef material with the quadrate was excavated to a depth of 10 cm. Samples included the crest, flank and base portions of reefs in 2004 and 2005. In 2006 we took replicate samples using a dredge lined with 1 mm mesh to collect samples that covered crest, flank and base areas of each reef.

Epifauna were described from samples either in terms of abundance or an estimate of aerial cover (Table 2). Organisms characterized by their aerial cover dominated the epifaunal community, therefore we calculated % Clean Shell as the inverse of the sum of all cover estimates for individual species. Species that were relatively large and uncommon were not used in this evaluation. Therefore, this metric is more an index of the space availability for oysters than competition for other resources.

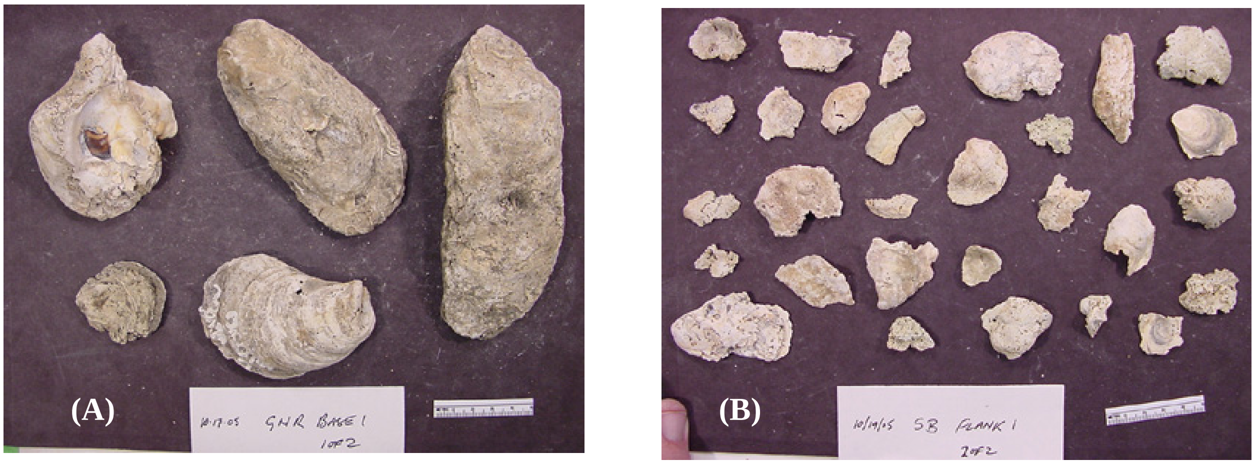
Table 2. Metrics used to quantify abundance of epibenthic organisms of various taxonomic groups enumerated in this study.

Taxonomic Group	Abundance	% Cover[a]
Bivalves	X	
Gastropods	X	
Flatworms	X	
Barnacles		X
Encrusting Bryozoans		X
Calcareous Tube Worms[b]		X
Tunicates		X
Sponges		X
Macroalgae		X
Hydroids		X

[a] % cover estimated subjectively: <1%; 1-10 % in increments of 1%; 10-100% in increments of 5%
[b] % cover of tubes estimated. These are constructed by several polychaete species

A sub-sample of reef particles was then randomly selected for further processing. First, because of its degrading effect (in terms of brittleness), the prevalence of current or previous boring sponge (*Cliona* spp.) damage was documented. Previous boring sponge damage is readily visible as distinct perforations in shells. Second, particles were digitally imaged (e.g. Fig. 11) and Image Pro Plus computer software was utilized to determine the one-sided surface area of individual particles to the nearest mm^2.

Figure 11. Examples of reef particle samples analyzed for shell type, boring sponge evidence and surface area. Images show examples of (A) large oyster shell particles and (B) combination of smaller clam shell particles and highly degraded oyster shell particles. The white scale bar in each image is 150 mm long.



RESULTS

Settlement – Oyster settlement data are reported in two ways: cumulative settlement for an entire season and weekly settlement over time (i.e., rates). Cumulative settlement was normalized by tile surface area (number oysters · m^{-2}). Since there were single arrays for the Lynnhaven settlement stations, missing data occurred if the array was missing. This happened on occasion, especially in 2005 at two locations where either boat interaction or gear tampering occurred. We therefore had to interpolate for missing data in such cases. Most instances had zero settlement before and after missing data. We therefore interpolated zero settlement. In rare cases where settlement was measured before or after a missing date, we simply interpolated using the mean of settlement before and after missing data. Weekly settlement rates were normalized for tile surface area and varying deployment durations and are reported throughout as number oysters · m^{-2} · $week^{-1}$. For Lynnhaven monitoring stations, missing data were treated as such and not plotted. The dates and durations for settlement samples are listed in Appendices III - V. Note that settlement monitoring in the Lynnhaven River system did not begin until 2005.

2004 – Onset of settlement was variable between tributaries, beginning around the middle of September at both Rappahannock reefs, Crane's Creek in the Great Wicomico and Palace Bar in the Piankatank (Table 3). However, settlement was observed much earlier at Shell Bar in the Great Wicomico (early July) and Burton's Point in the Piankatank (late July). Settlement terminated by the end of September at all reefs (Table 3; Figs. 12 & 13).

Weekly settlement rates varied between tributaries and between individual reefs within tributaries and ranged from 0 - 90 oysters $\cdot$ m^{-2} $\cdot$ $week^{-1}$ (Figs. 12 & 13). Oyster settlement in the tributaries that we monitored in 2004 predominantly occurred in one or two discrete events.

Cumulative settlement was virtually nil at Crane's Creek, Drumming Ground and Parrot's Rock (Table 3). Burton's Point in the Piankatank River had the highest settlement (91 oysters $\cdot$ m^{-2}).

2005 – Onset of settlement was variable between tributaries in 2005, beginning in early July at Great Wicomico reefs and late July/early August at Piankatank and Lynnhaven reefs (Table 3). Settlement was minimal in the Rappahannock, with none observed at Parrot's Rock and low levels for one week only (8/24-8/30) at Drumming Ground. Settlement terminated in the latter half of October at all reefs exclusive of those in the Rappahannock (Table 3).

Weekly settlement rates varied between tributaries and between individual reefs within them and ranged from 0 - 366 oysters $\cdot$ m^{-2} $\cdot$ $week^{-1}$ (Fig. 12 & 13). Settlement generally

Table 3. Settlement timing and cumulative oyster settlement ($\# \cdot m^{-2}$) by reef and year for 2004-2007 (see Table 1 for reef abbreviations).

		2004		2005		2006		2007	
River	**Reef**	**Timing[a]**	**Cumulative Settlement**	**Timing[a]**	**Cumulative Settlement**	**Timing[a]**	**Cumulative Settlement**	**Timing[a]**	**Cumulative Settlement**
Great Wicomico	CC	9/14 - 9/27	1	7/6 - 10/19	26	6/21 - 8/30	368	6/18 - 10/10	494
	SB	7/6 - 9/27	43	7/6 - 10/19	17	6/21 - 8/16	1,728	6/18 - 9/25	1,122
Piankatank	BP	7/28 - 9/27	91	7/26 - 10/19	76	7/10 - 9/27	561	7/31 - 10/22	1,291
	PB	9/16 - 9/27	17	7/26 - 10/19	278	6/21 - 9/13	1,455	7/31 - 10/10	3,094
Rappahannock	DG	9/14 - 9/27	5	8/24 - 8/30	2	7/10 - 9/27	66	7/24 - 9/5	194
	PR	9/14 - 9/27	4	none	0	7/17 - 9/13	11	7/10 - 10/10	29
Lynnhaven	GN	n/a	n/a	8/10 - 10/12	1,079	7/5 - 10/16	2,580	n/a	n/a
	LC	n/a	n/a	7/27 - 10/12	292	6/12 - 10/16	1,488	n/a	n/a

[a] Settlement timing indicates that settlement occurred shortly after the first date and terminated for the season shortly before the second date for each reef. Note that this does not imply continuous settlement during this period. See subsequent figures for settlement details.

Figure 12. Area and time standardized mean oyster settlement (oysters • m^{-2} • $week^{-1}$) for study reefs during 2004-2006 in (A) Great Wicomico River and (B) Piankatank River. Note that axis scales are different for 2006 and from portions of Fig. 13 due to extreme differences in settlement.

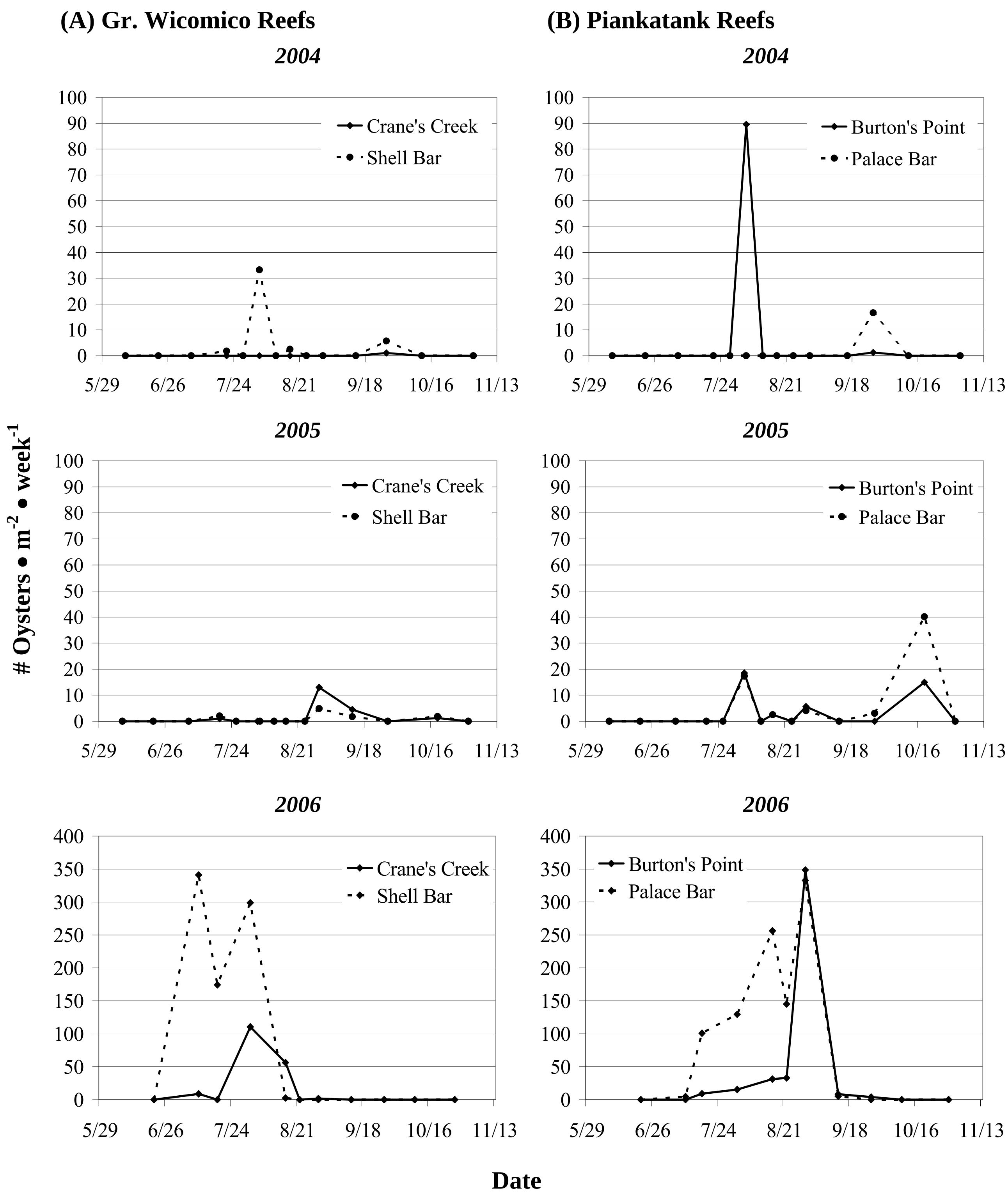
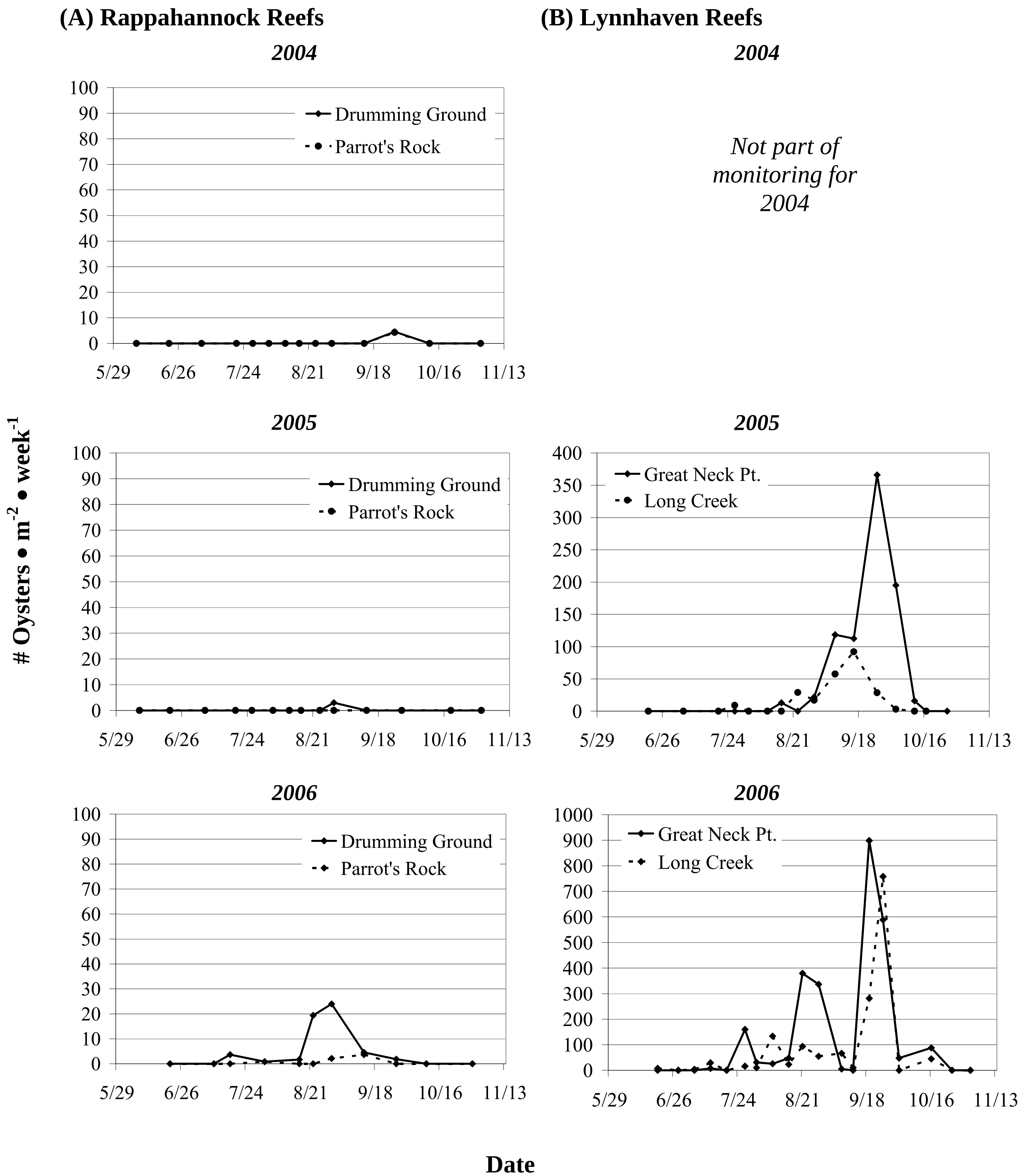


Figure 13. Area and time standardized mean oyster settlement (oysters • m^{-2} • $week^{-1}$) for study reefs during 2004-2006 in (A) Rappahannock River and (B) Lynnhaven River. Note that axis scales are different between these two rivers and from portions of Fig. 12 due to extreme differences in settlement.



occurred in one or two discrete events during 2005, with the exception of the Piankatank and Lynnhaven reefs, where more or less continuous settlement may have occurred during the entire season.

Cumulative settlement was virtually nil at the Rappahannock reefs for the second year in a row (Table 3). Reefs in the Great Wicomico had modest settlement of <30 oysters · m^{-2}, whereas Palace Bar and Burton's Point in the Piankatank River had better settlement (278 and 76 oysters · m^{-2}, respectively). However, settlement at the Lynnhaven reefs was relatively high for Long Creek Reef and very high for Great Neck Point (292 and 1,079 oysters · m^{-2}, respectively).

Initial settlement and termination at Lynnhaven non-reef monitoring stations loosely followed patterns observed at the two study reefs. Weekly rates were variable and ranged from 0 - 205 oysters · m^{-2} · $week^{-1}$ (Fig. 14). Cumulative settlement was highly variable across stations (Fig. 16) and was less than that observed on study reefs (Table 3).

<u>2006</u> - Onset of settlement was again variable between tributaries, beginning in early to mid July at most reefs, with the exceptions of Long Creek in the Lynnhaven (mid June) and Parrot's Rock in the Rappahannock (early August; Table 3). Settlement ended from the middle of August to mid October, depending on the tributary (Table 3).

Weekly settlement rates varied between tributaries and between individual reefs within them and ranged from 0 - 899 oysters · m^{-2} · $week^{-1}$ (Figs. 12 & 13). Oyster settlement in 2006 generally occurred in one or two peak events, with low levels of settlement occurring more or less continuously during the entire season.

Cumulative settlement was the highest observed during this study, sometimes by one to two orders of magnitude (Table 3). Reefs in the Great Wicomico had excellent settlement with

Figure 14. Weekly oyster settlement rates (oysters · m^{-2} · $week^{-1}$) for non-reef monitoring stations in the Lynnhaven River during 2005. Stations are grouped by general geographic location. (see Appendices VI & VII for station abbreviations and locations, respectively.) Note that y-axis range is the same as for 2006 results, Fig. 15, to facilitate comparisons between years.

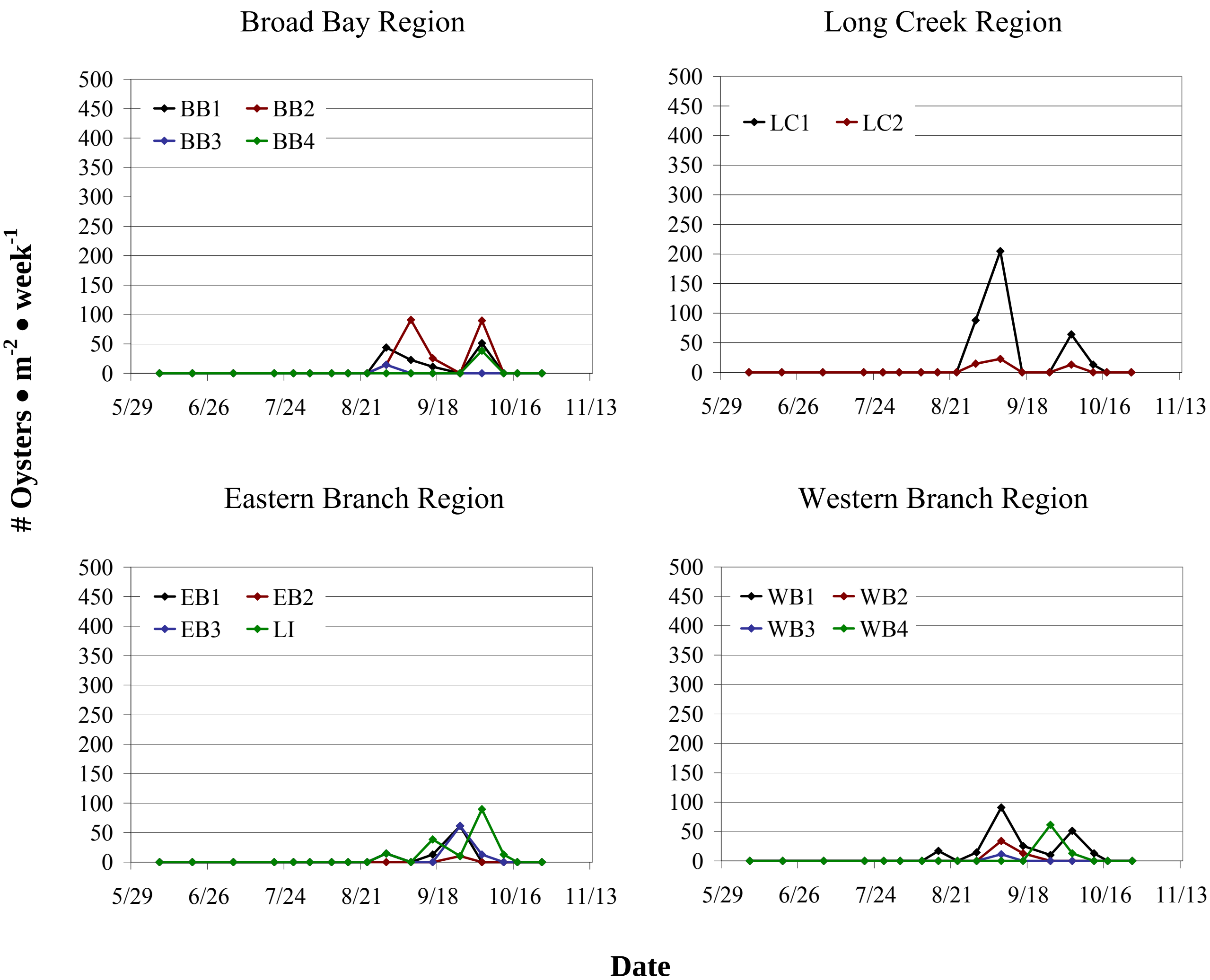


Figure 15. Weekly oyster settlement rates (oysters · m^{-2} · $week^{-1}$) for non-reef monitoring stations in the Lynnhaven River during 2006. Stations are grouped by general geographic location. See Appendices VI and VII for station abbreviations and locations, respectively.

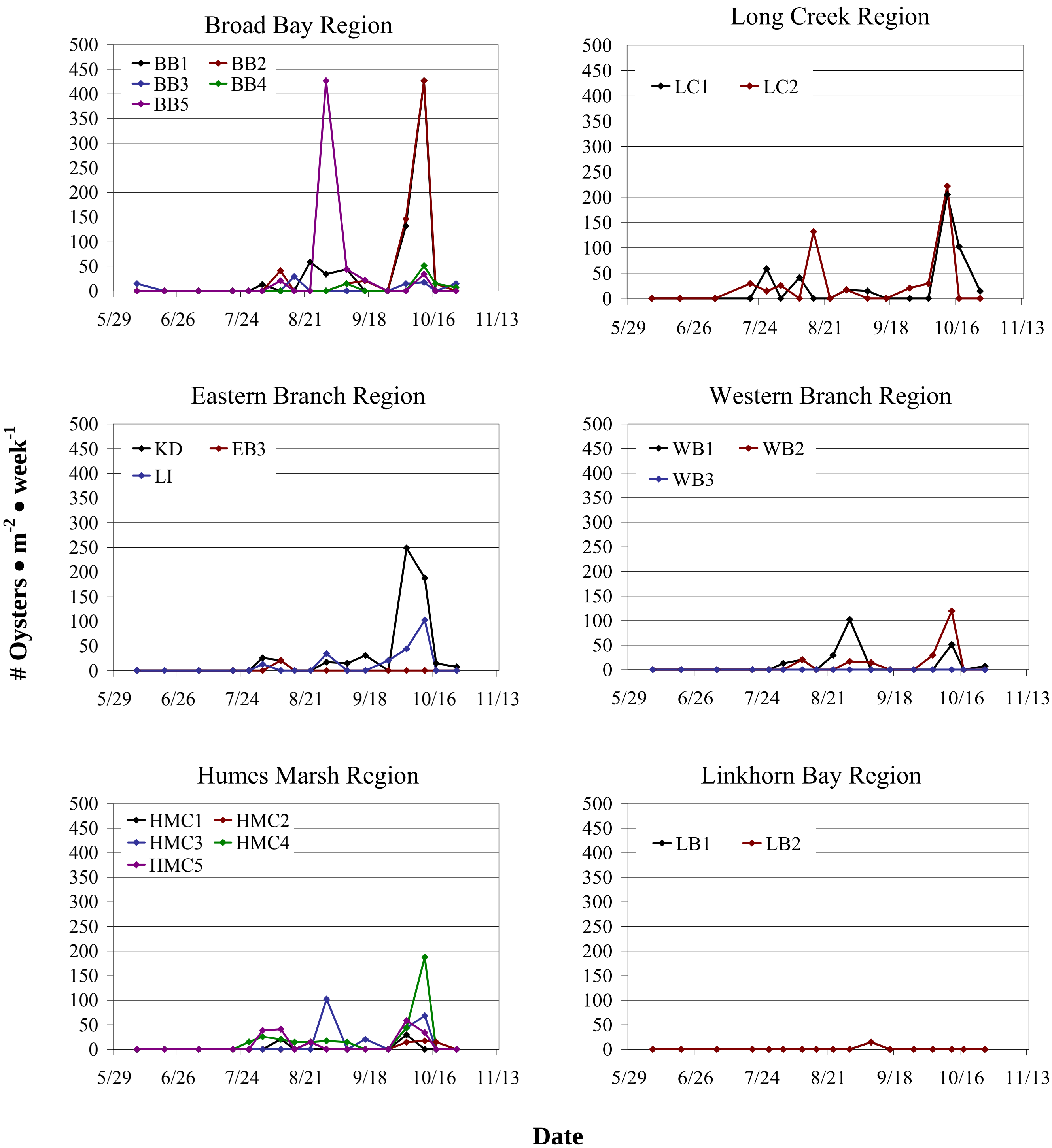
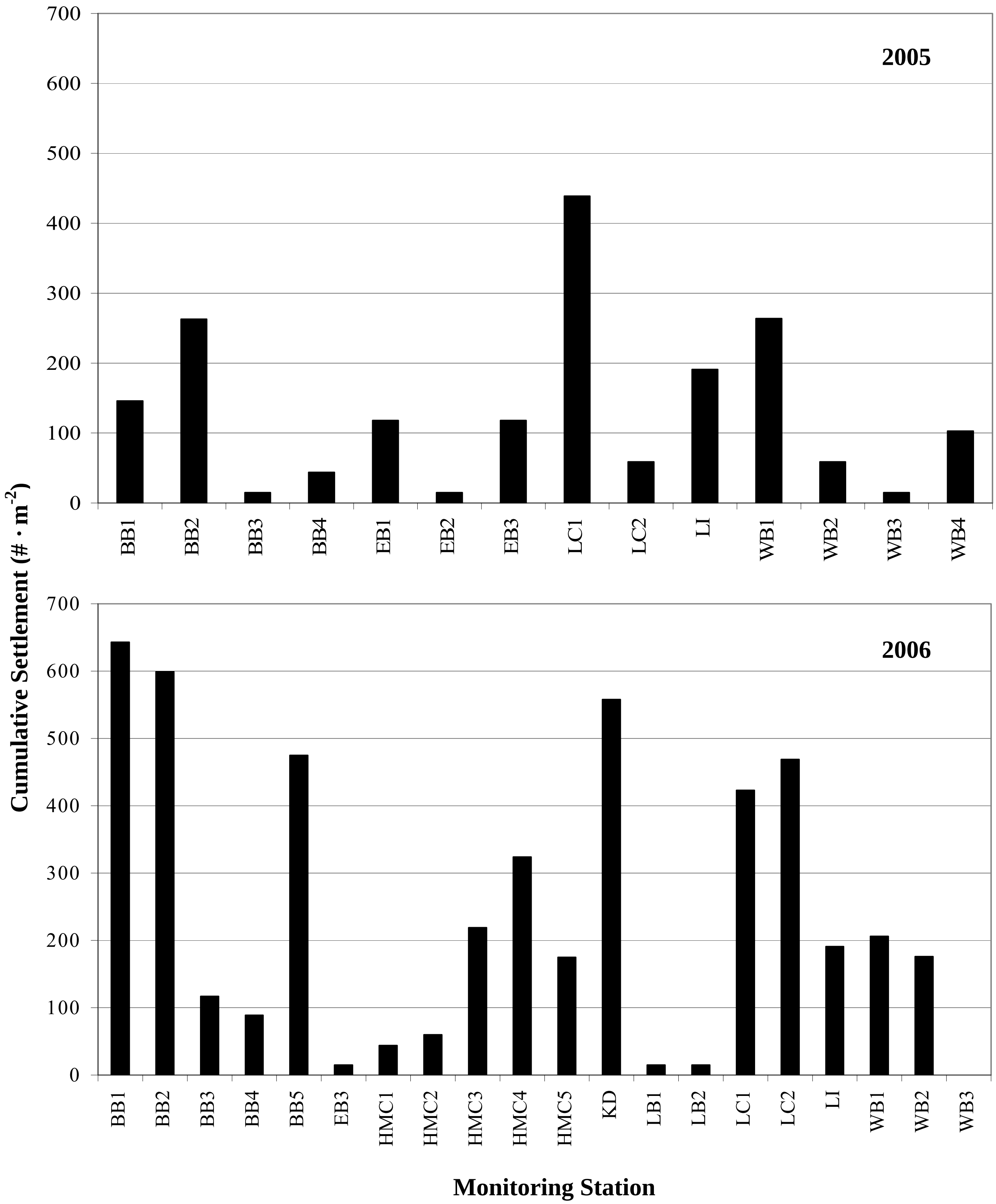


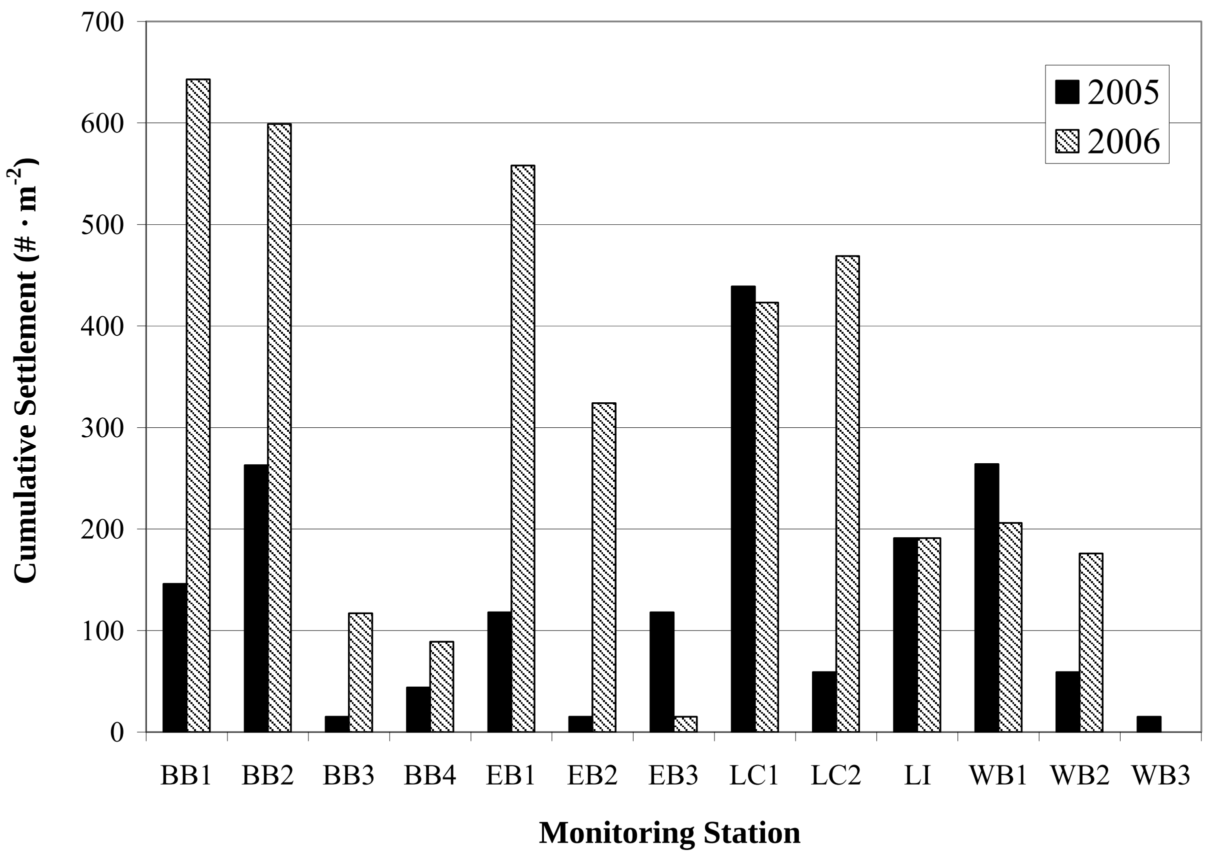
Figure 16. Cumulative oyster settlement (# · m^{-2}) at Lynnhaven monitoring stations during 2005 and 2006 (see Figs. 9 & 10 for station locations and Appendix VI for abbreviations). Note some stations were added and some dropped during 2006 (see Fig. 17 for inter-annual comparison of those stations sampled in both years).



368 - 1,728 oysters · m^{-2}, with Palace Bar and Burton's Point in the Piankatank River having similar settlement (1,455 and 561 oysters · m^{-2}, respectively). However, settlement at the Lynnhaven reefs was once again relatively high for Long Creek Reef and very high for Great Neck Point (1,488 and 2,580 oysters · m^{-2}, respectively).

Initial settlement and termination at Lynnhaven non-reef monitoring stations loosely followed patterns observed at the two study reefs. Weekly rates were variable and ranged from 0 - 426 oysters · m^{-2} · $week^{-1}$ (Fig. 15). Cumulative settlement was subsequently quite variable (Fig. 16) and was less than that observed on study reefs (Table 3), but higher than 2005 (see Fig. 17 for inter-annual settlement comparisons.)

Figure 17. Cumulative oyster settlement (# · m^{-2}) at Lynnhaven monitoring stations deployed during 2005 and 2006 (see Figs. 9 & 10 for station locations and Appendix VI for key to abbreviations). Note some stations were added and some dropped during 2006 and are not included in this graph.



Substrate Condition–Metrics of reef substrate quality reported here are (1) % clean shell (see methods for details), (2) boring sponge (*Cliona* sp.) prevalence and (3) reef particle size. Note that Lynnhaven study reefs were not included in this study until 2005-2006. Twenty-two taxa (mainly species) were identified from samples. Species richness of attached organisms during the entire study ranged from eight at Burton's Point in the Piankatank River to 17 and the Great Neck Point reef in the Lynnhaven (Table 4). The most common taxa were barnacles (*Balanus* spp.) and white crust (*Membranipora tenuis*). Both are potential competitors for space with oysters and were included in % clean shell calculations. Appendices IX and X provide dates and summarized data by date and reef for substrate metrics, respectively.

% Clean Shell – A subset of attached organisms from Table 4 was used to quantify the % clean shell (see Methods for details). Percent clean shell was variable between reefs and over time, and ranged from 29.5 - 91.5 % (Fig. 18). All reefs were observed to have > 50% clean shell with the exception of Crane's Creek during 2006 (29.5%). This was caused by higher than normal colonization by an encrusting bryozoan, *M. tenuis*. Generally decreasing amounts of clean shell (i.e. increased fouling) were observed at Crane's Creek, Parrot's Rock and, possibly, Great Neck Point during the study (Fig. 18).

Cliona Prevalence – Live boring sponge (*Cliona* sp.) was observed at all reefs except Palace Bar in the Piankatank River (Table 9). Mean prevalence of damage (i.e. either live presence or evidence of previous colonization) on individual substrate particles varied between reefs and over time, and ranged from 34.9 - 100% (Figure 19). All reefs exhibited at least 65% prevalence (with many locations and years having >80%) except Drumming Ground in the Rappahannock River (Figure 19).

Table 4. Presence of non-oyster taxa observed in quadrate/dredge samples during 2004-2007 at all study reefs. Absence of taxa is indicated by blank cells. Taxa may not have been present in every sample and every year. Note that GN and LC reefs in the Lynnhaven River were not sampled during 2004. (See Table 1 for reef abbreviations).

Species	CC	SB	BP	PB	DG	PR	GN	LC
Ribbed Mussel, *Geukensia demissa*	X	X	X	X	X	X	X	X
Dwarf Surf Clam, *Mulinia lateralis*	X						X	
Baltic Macoma, *Macoma balthica*					X			
Steamer Clam, *Mya arenaria*					X	X		
Hard Clam, *Mercenaria mercenaria*								X
Blue Mussel, *Mytilus edulis*							X	
Slipper Shell, *Crepidula* spp.				X			X	X
Oyster Drill, *Urosalpinx cinerea*	X			X			X	
Barnacle, *Balanus* spp**.**	X	X	X	X	X	X	X	X
White Crust, *Membranipora tenuis*	X	X	X	X	X	X	X	X
Hydroid, likely *Ectopleura* spp.	X	X		X		X	X	X
Boring Sponge, *Cliona* spp.	X	X	X	X	X	X	X	X
Red Beard Sponge, *Microciona prolifera*	X	X	X	X	X	X	X	X
Fan Worm, *Hydroides dianthus*	X	X	X	X	X	X	X	X
Flat worm, *Stylocus* spp.						X		
Sea Grape, *Molgula manhattensis*	X		X	X	X	X	X	X
Anemone, likely *Haliplanella luciae*				X	X		X	
Red Algae, *Gracilaria* spp.			X	X		X	X	
Red Algae, *Ceramium* spp.	X	X	X	X	X		X	
Red Algae, *Polysiphonia* spp.	X	X	X	X	X		X	X
Green Algae, E*nteromorpha* spp	X	X		X			X	X
Green Algae, *Cladophora* spp.	X						X	
Total Taxa	14	10	10	15	12	11	18	12

Figure 18. Mean % "Clean Shell" (+SE) for study reefs during 2004-2006 (see Table 1 for reef). Samples from spring, summer and fall are pooled for each year (see Appendix X for data reported by individual sample period).

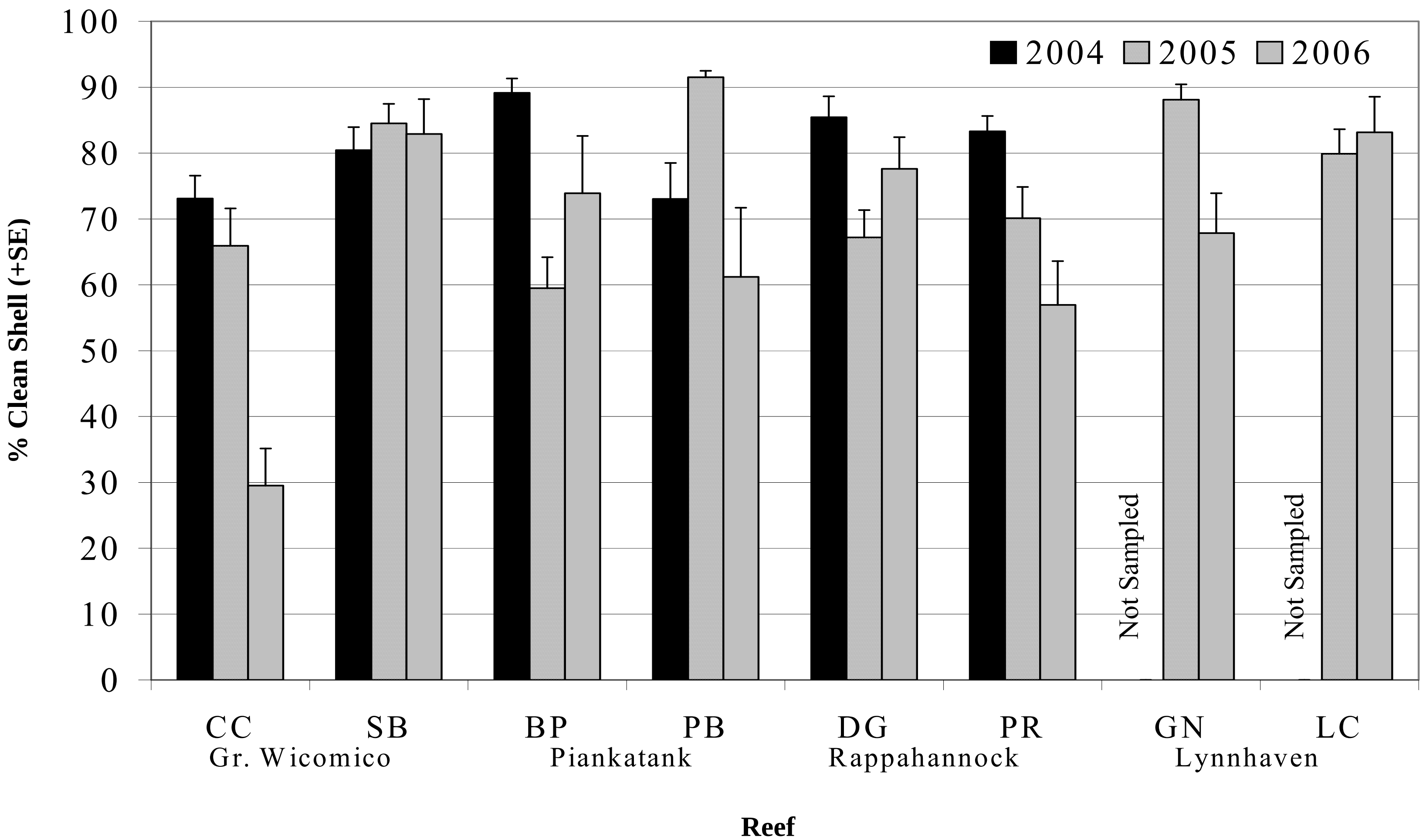


Figure 19. Mean % (+ SE) of individual reef particles with evidence of current or previous boring sponge (*Cliona* spp.) presence during 2004-2006 (see Table 1 for reef abbreviations). Samples from spring, summer and fall are pooled for each year (see Appendix X for data reported by individual sample period)

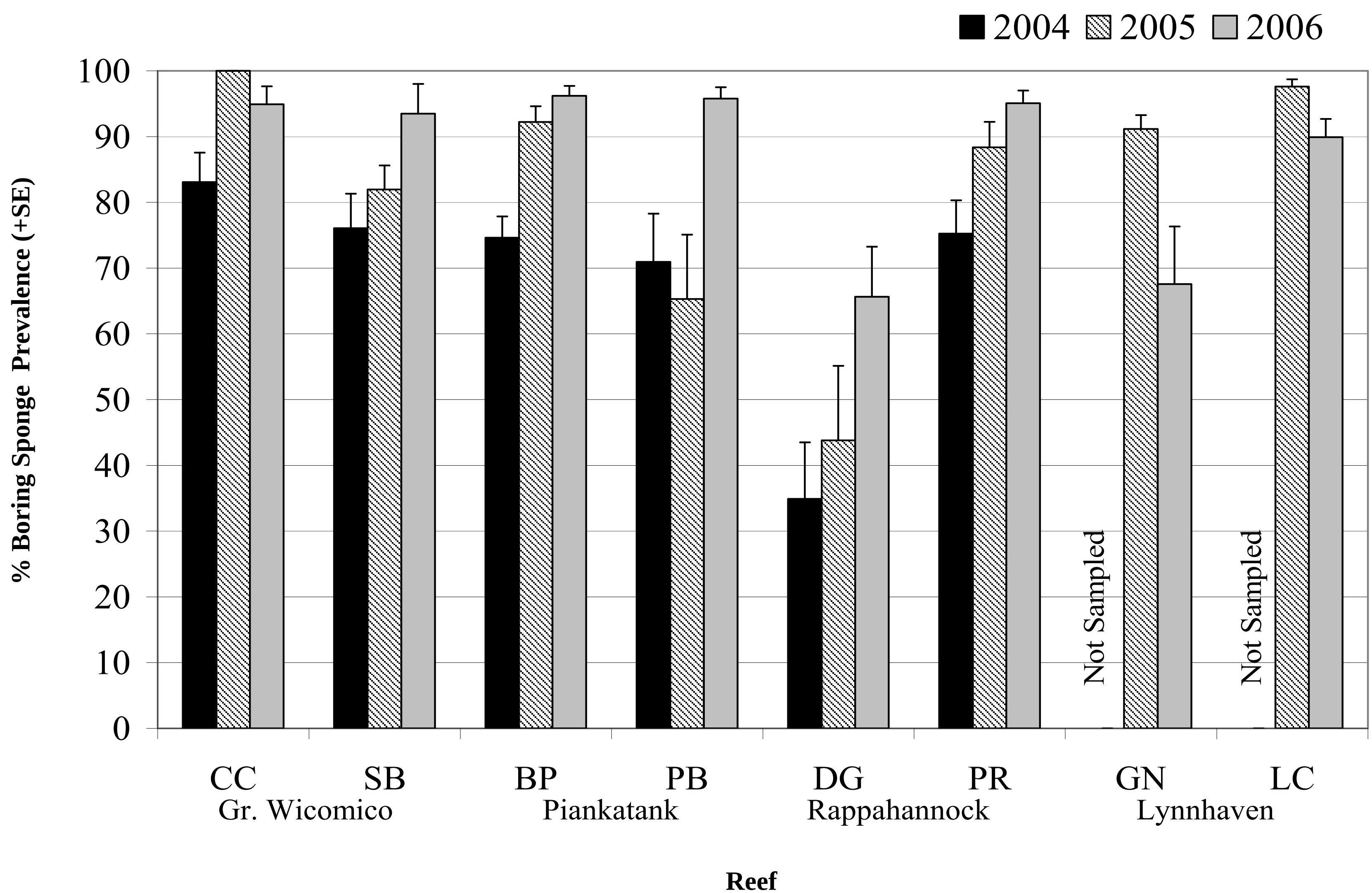
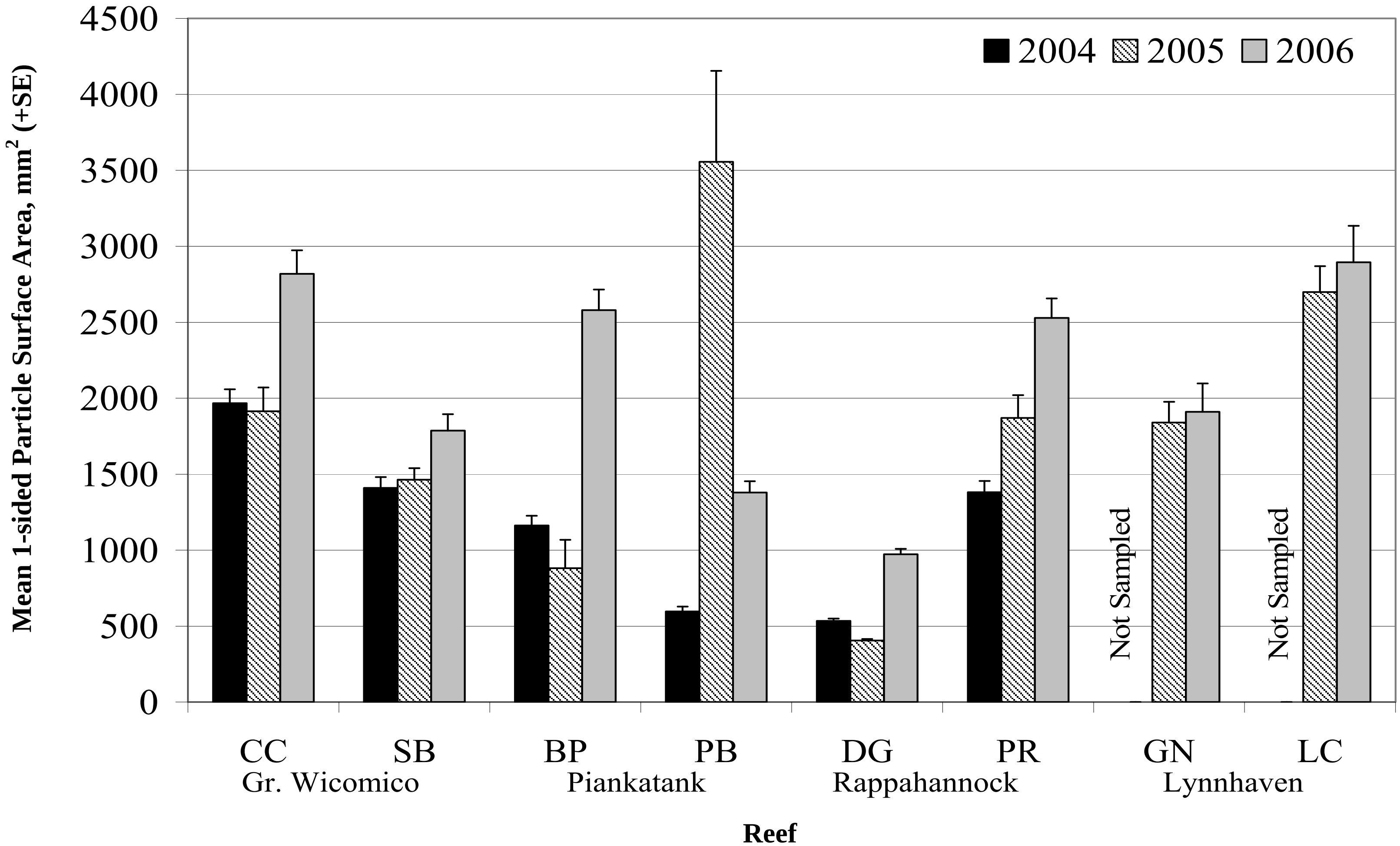
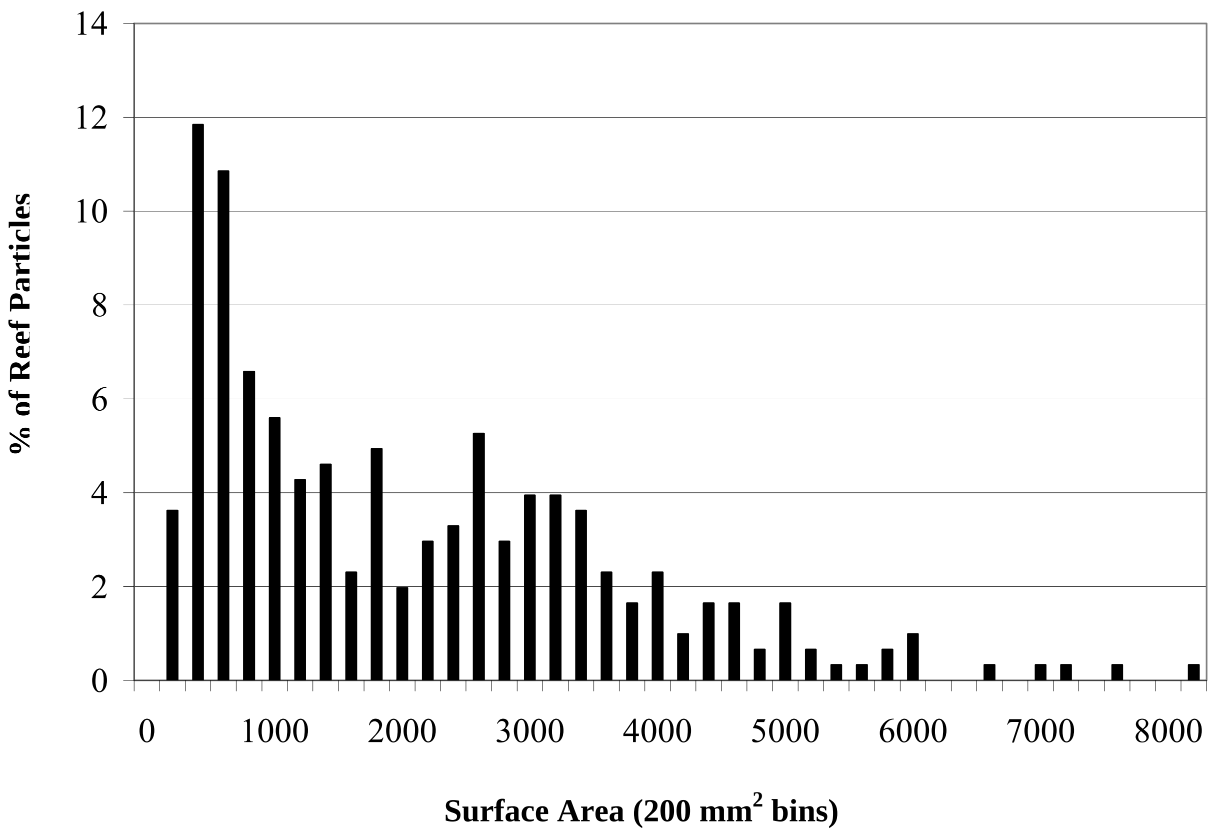


Figure 20. Mean (+ SE) 1-sided surface area (mm^2) of individual reef particles during 2004-2006 (see Table 1 for reef abbreviations). Samples from spring, summer and fall are pooled for each year (see Appendix X for data reported by individual sample period)



Reef Particle Size - The mean one-sided surface area of individual reef particles was highly variable between reefs and years and ranged from 405-3,555 mm^2 (Figure 20). Particle size within samples was also highly variable, with individual particles sizes ranging from <200 mm^2 to > 8,000 mm^2, but were generally skewed towards the lower half of sizes. Figure 21 shows a typical size distribution and Appendix X contains distributions for the latest sampling in fall 2006 for all study reefs.

Figure 21. Size frequency distribution of individual reef particles (one-sided surface area, mm^2) from Crane's Creek Reef in the Great Wicomico River during 2004.



PART 2 – OYSTER MONITORING ON SHELL BAR REEF, GREAT WICOMICO RIVER

OBJECTIVES/PROJECT ELEMENTS

The objective of this effort was to provide a post-deployment assessment of cultured oysters placed on Shell Bar reef during 2004 and 2005 aimed at estimating survival of oysters in this stocking activity. Since we had oyster population data for Shell Bar reef beginning in spring 2003, comparing the size structure and abundance of the oyster population before, during and after stocking would aid in evaluating the success this activity. Unfortunately, stocking of the reef did not occur in discrete events but took place over several months in 2004 and 2005. Therefore, we sampled quarterly from summer 2004 – fall 2005 (exclusive of winter).

METHODS

We collected additional samples, beyond those described in the previous section (Part 1), on Shell Bar reef to describe the oyster population prior to, during and after stocking in 2004 and 2005. Since single, cultured oysters were scattered on the reef in a patchy manner, we needed to sample a larger area than we typically have in the past on other reefs. This was a result of both the patchiness of deployed oysters and the likelihood of some portion tumbling down the reef veneer due to currents and wave action acting on the reef crests. Therefore, quadrate samples (25 cm x 25cm x 10 cm deep) were collected every 2 m along 3 replicate transects running from reef crest to base/seabed interface. Live and "box" (dead with valves still articulated) oysters were counted and measured to the nearest 0.1 mm. Transects were chosen haphazardly and length varied depending on the size of the mound(s) chosen to sample. Appendix XI gives details about sampling dates, transect lengths and the number of quadrate samples per transect.

Monitoring for this element was transferred to VMRC beginning in 2006 and results from that time forward are not addressed in this report.

RESULTS

The mean density of live and box oysters increased once stocking was initiated at Shell Bar Reef in the Great Wicomico River during late spring of 2005. Prior to this, in 2004, oyster density was stable to slightly decreasing at approximately $100 \cdot m^{-2}$ (Fig. 22). Although our original sampling plan was to involve a single sampling one month after stocking, this was modified since stocking was not a discrete event, but spread out over most of the summer months. In an effort to capture these effects, we sampled immediately after the initial stocking and then again in late summer and fall 2005. Mean live oyster density increased to $\sim 300 \cdot m^{-2}$ immediately after stocking began and to almost $350 \cdot m^{-2}$ by fall 2005 (Fig. 22). The density of oyster boxes more than doubled during this time frame from $\sim 40 - 100 \cdot m^{-2}$ (Fig. 22).

The size distribution of oysters revealed an increase in oysters in the 35 - 65 mm range during summer 2005 sampling (Fig. 23). This trend continued, to a lesser degree, during summer and fall 2005.

The abundance of oysters along each transect from reef crest to base are shown in Fig. 24. Additional details from these results, including the distance from the reef crest for each quadrate, along with oyster abundance and mean size are given in Appendix XII.

Figure 22. Mean (+ SE) **A)** live and **B)** “box” oyster density ($\# \cdot m^{-2}$) at Shell Bar Reef in the Great Wicomico River during spring 2004 to fall 2005. “Box” refers to recently dead oysters with shell valves still articulated. Dashed line indicates initiation of stocking efforts. See Appendix VIII for individual sample data

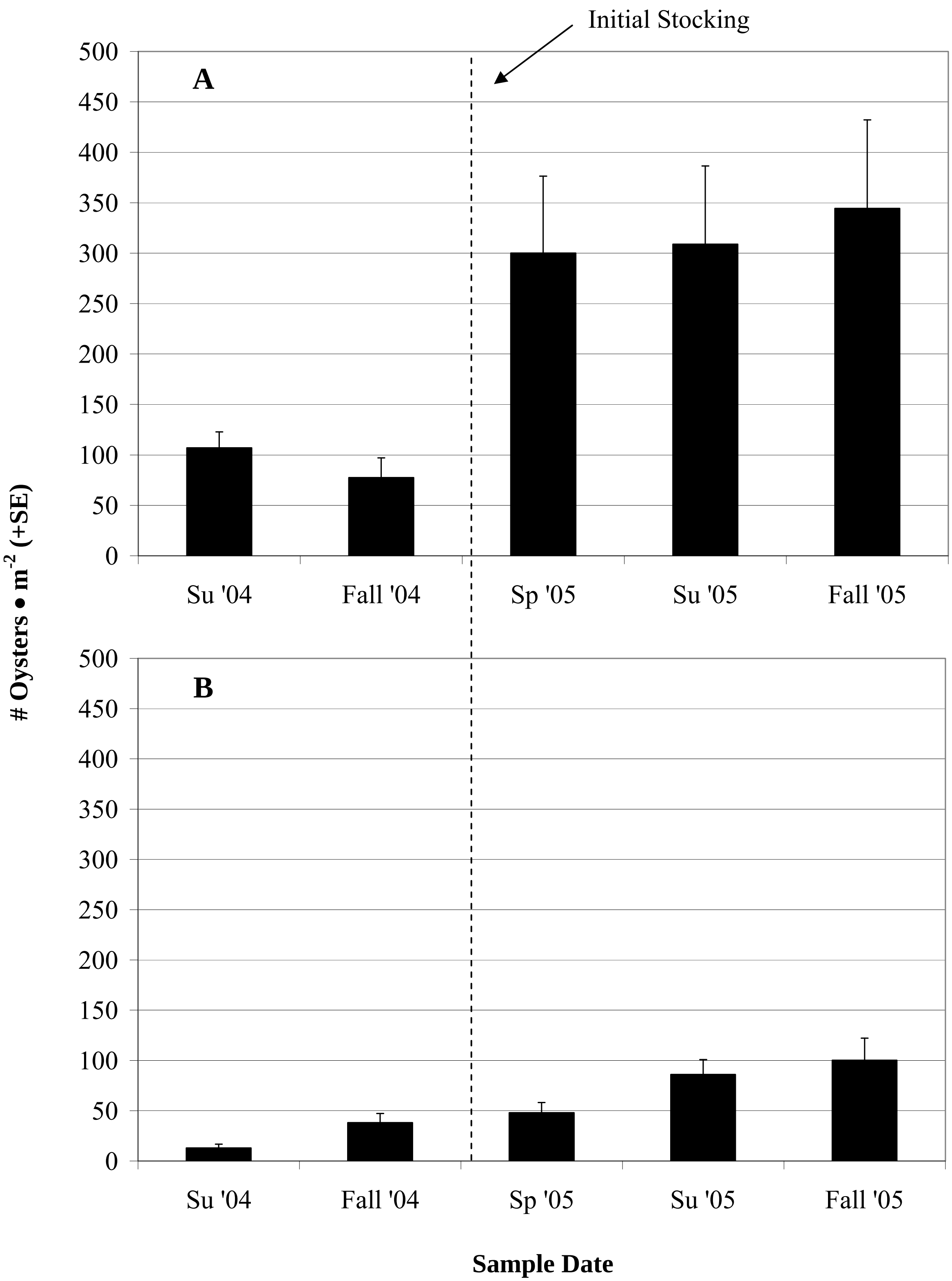


Figure 23. Area standardized size distribution ($\# \cdot m^{-2}$) of live oysters at Shell Bar Reef in the Great Wicomico River during fall 2004 to fall 2005. Shell height is divided into 5 mm bins. Note that oyster stocking efforts began prior to the spring 2005 sampling and continued throughout the summer of 2005.

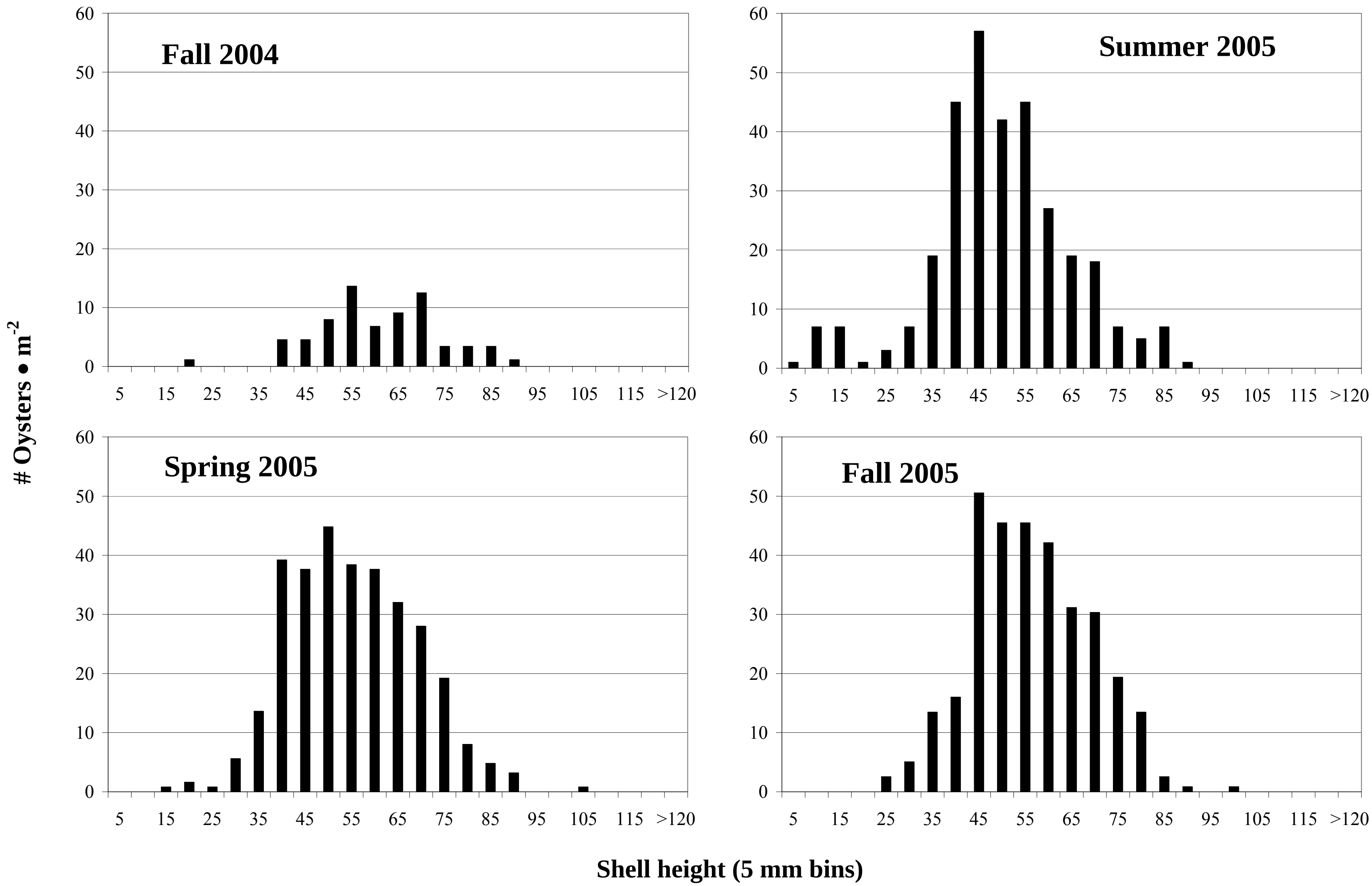
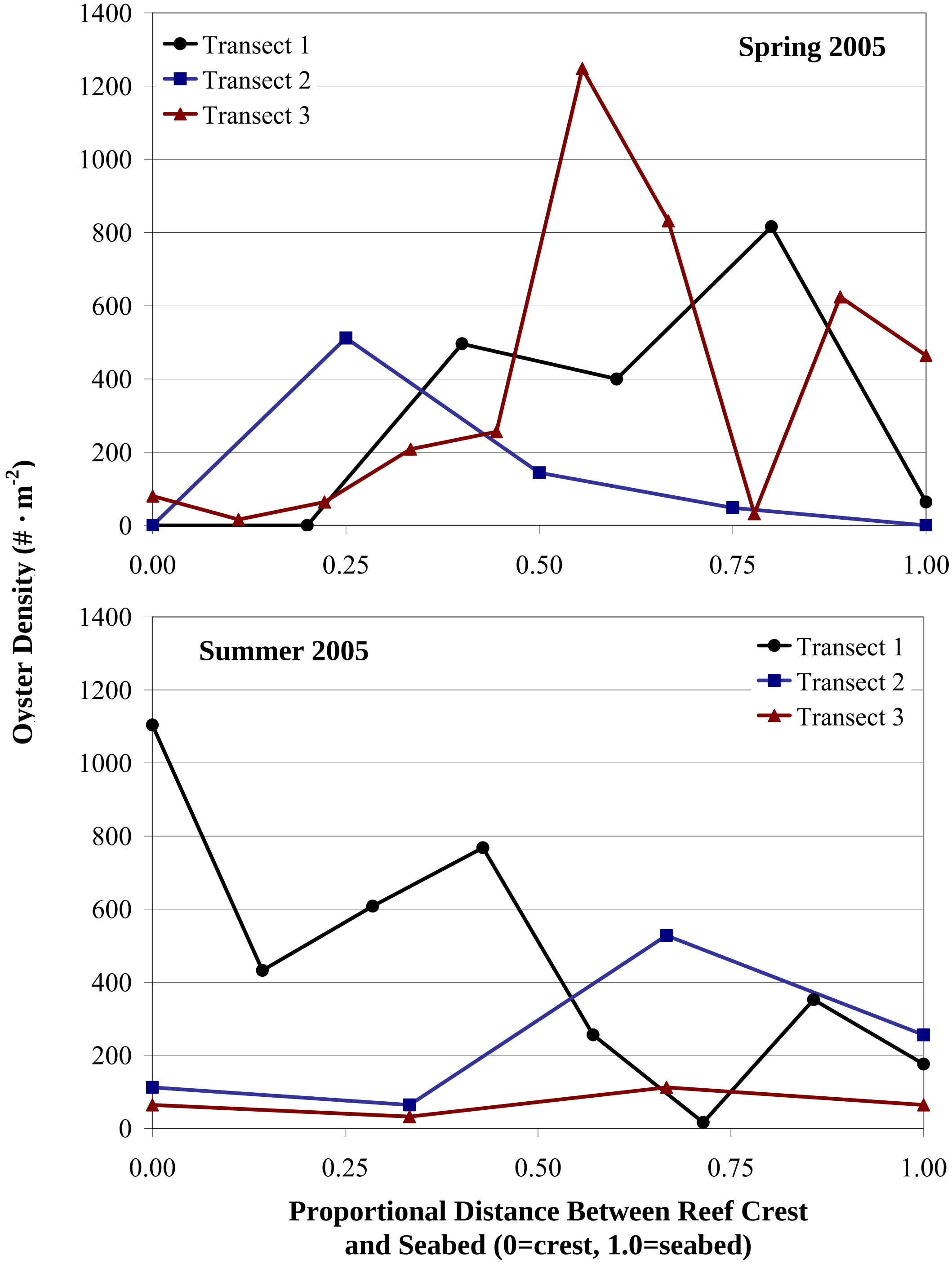


Figure 24. Live oyster density (# · m^{-2}) from individual quadrate samples along three replicate transects at Shell Bar reef in the Great Wicomico River during spring and summer 2005 sampling efforts (see Appendix IX for data for all transects during each season). Length of transects (and therefore the number of samples which were taken every 2 m from the crest to seabead) was variable and dictated by the shape of different portions of the reef. Therefore, locations were standardized as proportional distances between reef crests and the seabed.



PART 3 –SPATIALLY-EXPLICIT STOCK ASSESSMENT IN THE LYNNHAVEN RIVER BASIN

OBJECTIVES/PROJECT ELEMENTS

In advance of the initiation of ACOE oyster restoration in the Lynnhaven River, we undertook a comprehensive survey of oyster habitat and oyster population structure in the basin. Limited stock assessments on restoration reefs had previously been conducted by VMRC and CBF within the baisn. However, qualitative observations suggested that a large portion of the oyster population in this basin was unaccounted for in such surveys. Our focus, therefore, was to include restoration and traditional natural reef structure in addition to areas that have received no attention in stock assessments—marsh habitats and non-traditional manmade habitats such as shoreline armoring structures.

STUDY AREA

The Lynnhaven River is a tidal polyhaline sub-estuary of the Chesapeake Bay. A narrow inlet connects it to the lower Bay (Fig. 25). Like the high salinity coastal bays on the seaside of the Eastern Shore, the oyster population in this basin is largely intertidal. In contrast to the coastal bays, however, the Lynnhaven River is lies in an urban landscape. The basin is virtually surrounded by the City of Virginia Beach with a population of approximately 0.5 million people, with the exception of First Landing State Park.

A large portion of the Lynnhaven River basin was included in this survey (Fig. 26). The upstream limits of the study area were based on a combination of two criteria: the point at which oyster abundance began to diminish noticeably and logistical constraints of time and personnel. This study area was further divided into five geographic regions based on what were perceived functional spatial and ecological groupings (Figure 27).

Figure 25. Map of the Lynnhaven River basin within the lower Chesapeake Bay region (shown in the inset).

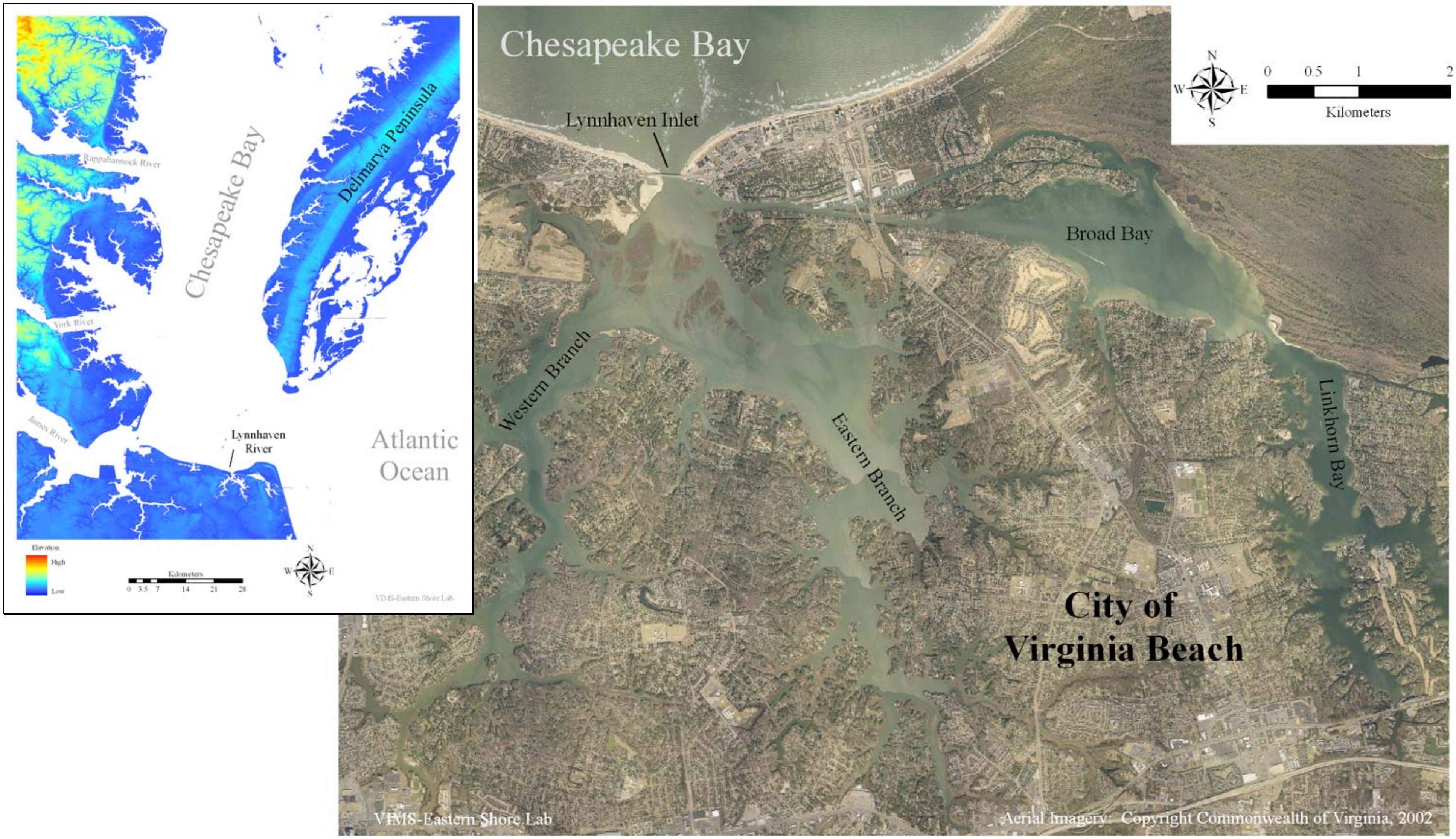


Figure 26. Study area within the Lynnhaven River basin. Shoreline transects and reef polygons that were surveyed are shown in red and green, respectively.

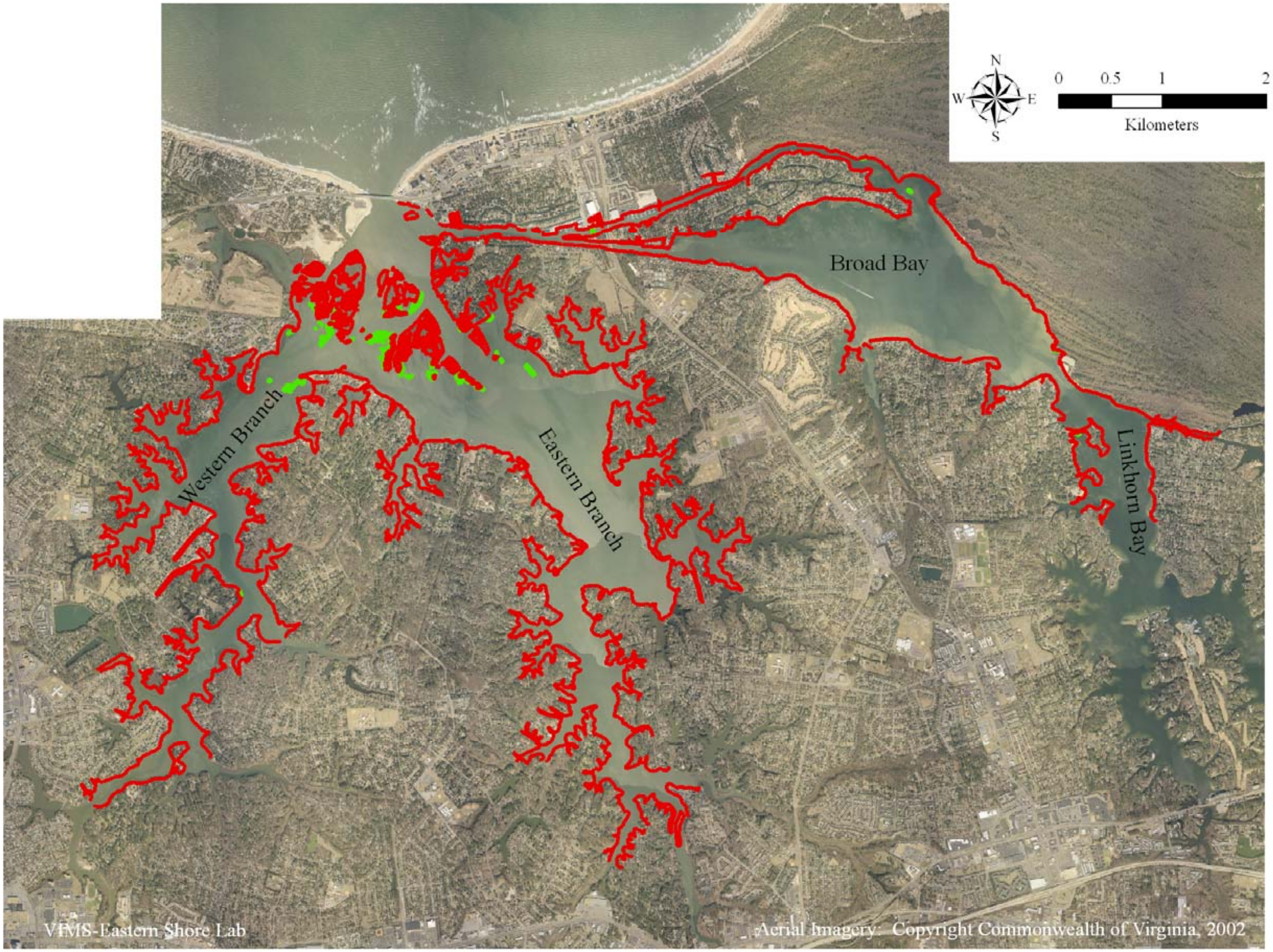
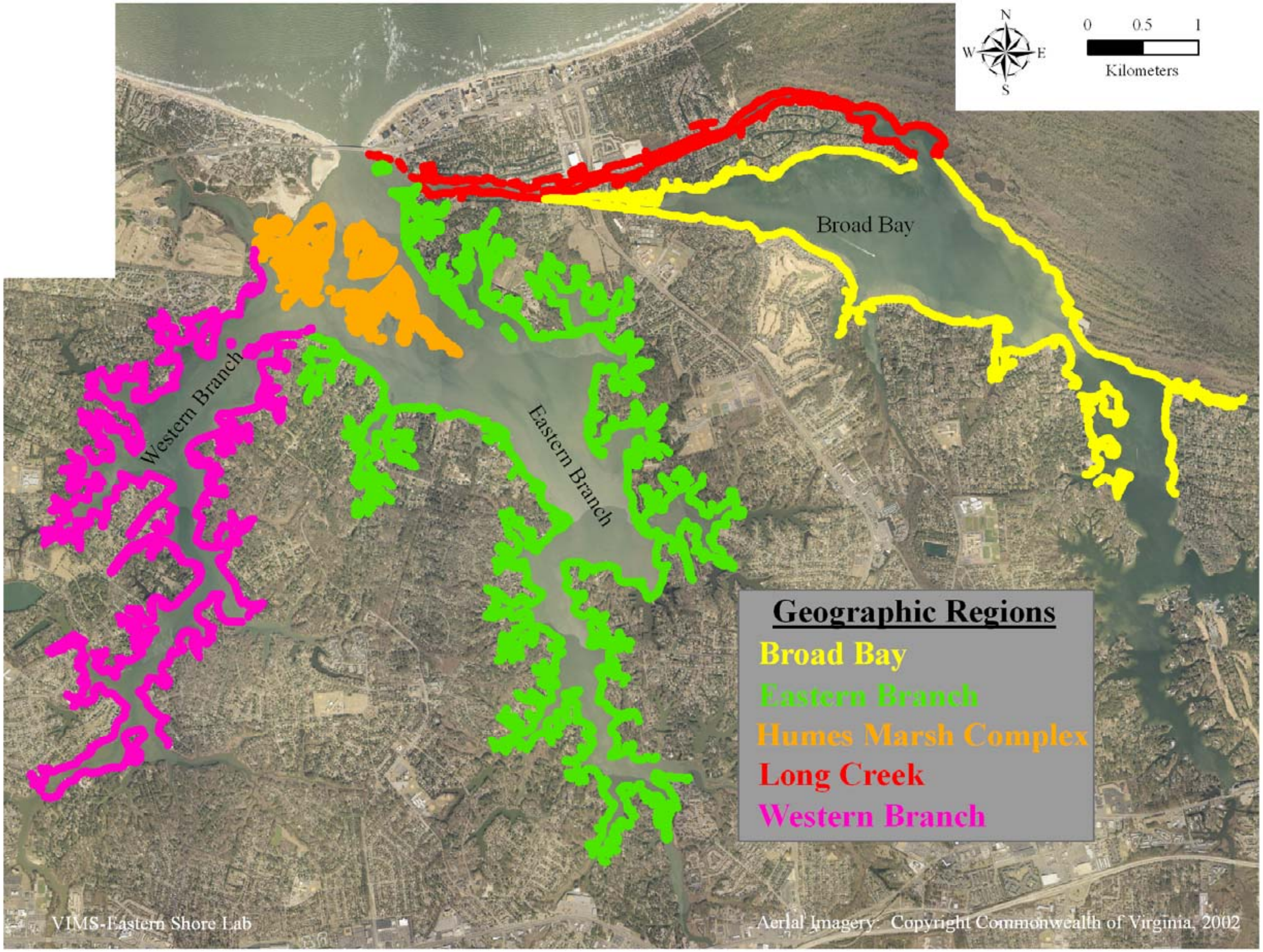


Figure 27. Five geographic regions of the study area within the Lynnhaven River basin.



METHODS

This project was undertaken in three main phases: map oyster habitat, rigorously quantify the oyster population within habitat groupings and combine these two aspects to develop a basin-wide population description in terms of abundance, biomass and size distribution. Results of this study will be summarized in tables and figures; however, the ultimate results were were developed as a Geographic Information System (GIS) product that was previously submitted to NOAA (VIMS-ESL GIS-based Summary of Native Oyster Monitoring, Grant # NA06NMF4570303 by Mark W. Luckenbach and Paige G. Ross, August 26, 2008).

A Global Positioning System (GPS) was used for field mapping. It consisted of a sub-meter accuracy surveying GPS unit and antenna coupled with a field data logger that simultaneously captured position data and user-inputted data. Position data was corrected in real time utilizing a Wide Area Augmentation System (WAAS) signal. This resulted in an on-site horizontal accuracy of 0.4-0.8 m in most instances. Such accuracy was deemed adequate for this study and no further corrections were used. Appendix XIII describes technical specifications for this equipment.

Initial Habitat Mapping – Potential oyster habitats consisting of shorelines and isolated patch reefs were mapped during April 2005 to February 2006. We applied an approach that involved mapping shoreline features and visual estimating % cover of the feature by oysters as a basis for later stratifying our quantitative sampling. Because of the intertidal nature of most of the oyster population in the Lynnhaven Basin, mapping focused on this component. Consultation with several professionals with extensive experience in this river system confirmed our anecdotal observations that there are very limited subtidal oyster stocks in the Lynnhaven.

However, because there are likely some subtidal components that we did not map and, therefore, do not contribute to estimates in this report, these results should be considered conservative.

A brief note on terminology is appropriate at this point. A "feature" refers to a continuous shoreline or reef habitat that is mapped and described as a single unit. For example, a 50 m section of bulkhead that is continuous and identical in material, oyster community etc. was mapped as a single unit called a feature. If two 50 m sections of wood bulkhead were adjacent, but one was older and had 26-50% oyster coverage while the other section was relatively new had 1-5% oyster coverage, then each section would have been mapped as a separate feature. Individual data collected for each feature are referred to as attributes. For example, "Habitat Type" is an attribute for all features. These two terms are used in this manner in GPS and GIS applications and we use them here for consistency.

Generally, two types of habitat were quantified: shorelines that were mapped as line features and isolated oyster patch reefs that were mapped as polygons (see Fig. 28 for examples of each). Only features >10 m long were included in this inventory. Line features were mapped mainly from a boat which was driven parallel to a feature from its begin to end (Fig. 29) during the period three hours before low tide to three hours after low tide. This allowed us to characterize the intertidal oyster community while it was exposed. Data were collected about each feature using a pre-defined data dictionary in the data logger (see Appendix XIV for GPS and mapping settings), using pull down menus when possible to help standardize technicians. Specific data that were collected along with position coordinates are summarized in Table 5 and will be discussed in detail at the end of this section (See Appendix XV for complete data dictionary of attributes collected). Some of these attributes are directly reported as results, but most were simply used to design a rigorous oyster sampling plan and facilitate field sampling.

Figure 28. Examples of a "line" and a "polygon" feature. The green polygon shown is an intertidal isolated patch reef that was mapped at low tide on foot. The red lines are separate shoreline features mapped from a boat with some post-processing based on aerial images.

Figure 29. Mapping shoreline features from a boat with GPS equipment driven parallel to the shore.

Table 5. Data collected for each feature that was mapped in the Lynnhaven River basin.

Attribute	Categories		Description
Technician	-		Name of person collecting data
Date	-		
Time	-		
Basin Section	Broad Bay		See Figure 3 for map of these regions
	Long Creek		
	Eastern Branch		
	Humes Marsh Complex		
	Western Branch		
Tidal Stage	High		Estimated to the nearest category
	Mid Ebb		
	Low		
	Mid Flood		
Adjacent Water Depth	0 m		Depth of water adjacent to the feature; used to facilitate planning future sampling efforts
	0.1-1 m		
	>1 m		
Habitat Type	Subtidal 2-D Patch Reef	Natural	
		Private Built	
		State Built	
	Subtidal 3-D Patch Reef	Natural	
		Private Built	
		State Built	
	Intertidal Patch Reef	Natural	
		Private Built	
		State Built	
	Fringing Reef	Natural	
		Private Built	
		State Built	
	Marsh/Mud	-	Combo of Marsh with adjacent mud
	Bulkhead	Wood	
		Metal	
		Composite	
	Riprap	Gabion bag	
		Granite-small	
		Granite-large	
		Concrete	
		Other	
	Sand	-	
	Other	-	
Estimated Average Oyster Band Height	5-75cm in 5 cm increments; > 75 cm measured to the nearest 25 cm		Width of oyster "band" containing at least 90% of oysters from lower to upper edge of oyster assemblage

Table 5 (cont.). Data collected for each feature that was mapped in the Lynnhaven River basin. See methodology section for detailed descriptions of each attribute.

Attribute	Categories	Description
% Habitat Directly Shaded	0%	Refers to direct shading by dock, boat lift etc. and not by tree shading
	1-25%	
	26-50%	
	51-75%	
	75-100%	
Oyster % Cover	0%	Subjective visual estimate across an entire feature; variations within a feature were noted along with the percentage of a feature that was represented by each cover category present within a feature.
	1-5%	
	6-25%	
	26-50%	
	51-75%	
	76-95%	
	96-100%	
Notes	-	

The resulting line feature was later imported into Pathfinder Office computer software with an aerial image background for post-processing. Aerial images were 1-m resolution georeferenced Multiresolution Seamless Image Database (MrSID) files produced by the Virginia Base Mapping Project (VBMP; © Commonwealth of Virginia, 2002) during 2002 over flights. Features were either used unaltered, assigned an offset to line up with images or, most commonly, re-digitized based on the field data and aerial image data (i.e. "heads up" digitized). Isolated patch reefs were mapped as polygons on foot at low tide using the same GPS equipment as above by simply walking the reef perimeter. Images were post-processed using the same software, although adjustments were seldom necessary to polygons. This approach, collecting sub-meter accuracy field data and combining it with the recent high resolution aerial imagery to produce accurate maps, resulted in high resolution mapping of features and habitat types.

As noted above, data were collected on several aspects of each feature during the initial mapping phase (Table 5). Most are self-explanatory but several will be covered in detail here. Habitat types included several types of traditional oyster reefs: subtidal and intertidal patch reefs with two and three dimensional designs (i.e., with and without a substantial vertical profile in the water column) and fringing reefs that typically fringe marsh or mudflat and may have both intertidal and subtidal portions. Patch reefs were considered contiguous shell substrate on the seabed and spatially isolated from other habitat types (see Fig. 30a). Fringing reefs were contiguous shell substrate fringing and possibly merging into adjacent marsh or mudflat habitat (see Fig. 30b). Marsh edges containing single oysters or clumps, even if clumps were numerous but not contiguous, were not classified as reefs and were described as marsh/mud habitat (see Fig. 30c).

Figure 30. Examples of (A) patch reef, (B) fringing reef and (C) marsh habitat with interspersed clumps of oysters.

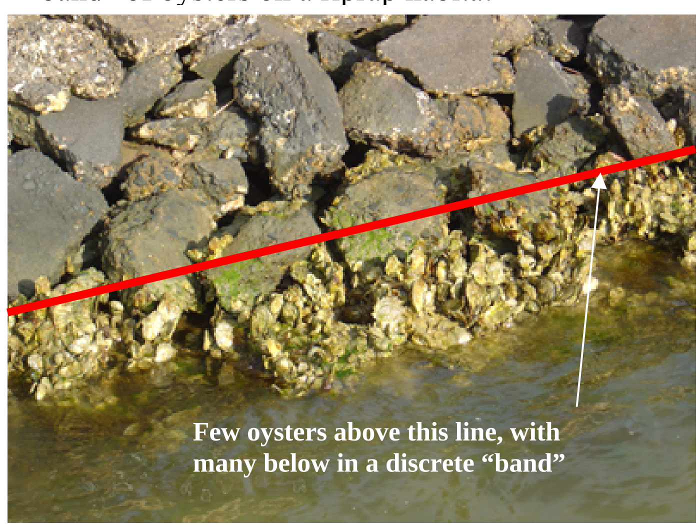
Manmade shoreline armoring structures were divided into two discrete categories: bulkheads and riprap. Bulkheads create vertically-oriented structure (see Fig. 31a). Riprap or revetment is variously graded material (generally granite or concrete particles in the Lynnhaven) placed at varying slopes along the shore and usually extending subtidally to the seabed (see Fig. 31b). Another natural habitat was dominated by bare sand, although marsh grass was often found above the high tide mark or sparsely within the high intertidal zone (Figure 31c). If marsh grass dominated all or part of the intertidal zone, then the feature was considered marsh habitat.

Multiple shoreline types were often found together, such as bulkhead behind a narrow marsh interface. In such cases only the habitat that encompassed the intertidal zone was mapped and attributes refer to them alone. If a bulkhead, as in this example, was placed above the high tide line, then it was certainly not a potential oyster habitat, and was not mapped.

Figure 31. Examples of (A) bulkhead, (B) riprap and (C) sand habitat.

For each shoreline feature mapped, the "Average Oyster Band Height" was estimated. This was the height, or width depending on the shoreline slope and one's perspective, of the band of oysters colonizing a given habitat from their lower limit to the highest vertical limit. In the Lynnhaven River, this band is evident and easily defined for most shorelines (see Fig. 32). It was measured parallel to the landward slope of the shoreline. As the shoreline went from a more vertical (e.g. bulkhead) to a more horizontal (e.g. marsh) interface, this band height increased substantially. We obviously could not determine this extent for every meter of Lynnhaven shoreline in this study. Therefore, we estimated its average within each feature in a way that was useful for later utilizing oyster sampling to extrapolate oyster density to abundance and an overall population estimate. For narrow bands (<75 cm) on the more vertical structure, height was estimated to the nearest 5 cm with a graduated pvc measuring stick. For bands >75 m

Figure 32. Example of a generally discrete "band" of oysters on a riprap habitat



in height, band was estimated to the nearest 0.25 m. These band height measures were used with GPS length measures to estimate an area (m^2) of oyster presence for each feature.

The proportion of a feature that was directly shaded by docks and boat lifts etc. was categorized per Table 5. This did not refer to more indirect or diffuse shading by trees or tall buildings. Although there may be biological significance for this parameter, it was of more interest for subsequent sampling. The complexity of sampling habitats with extra superstructure was higher than more simple structures and we wanted to be able to plan sampling accordingly.

In addition to habitat type and oyster band height, the most important attribute described during the initial sampling phase was % oyster cover. These three attributes were used to calculate oyster abundances for each individual feature and the subsequent overall basin-wide abundance estimates. Percent aerial cover of oysters was estimated visually and subjectively into seven categories described in Table 5. Obvious changes along a feature that did not warrant separation into a new feature were also recorded. Two technicians did all of the mapping and after several days of estimating this together, we were confident that both were calibrated and standardized.

Oyster Density and Size Sampling – Oysters were sampled after settlement concluded from October 2005 to March 2006 in an effort to avoid the confounding effects of sampling across multiple settlement seasons. A rigorous protocol to quantify the oyster population was based on the initial oyster habitat mapping. Specific protocols were developed separately for marsh habitat in the Humes Marsh Complex (HMC), patch reef polygons and all other shoreline features (although differences within this group will be discussed; see Table 6). The HMC marsh, which consisted entirely of *Spartina alternaflora* islands near the inlet, appeared different

Table 6. Summary of protocol for sampling oysters (counts and shell height measurements) within intertidal features. See methods sections for descriptions of feature attributes and sampling details.

Region	Humes Marsh Complex			Broad Bay, Long Creek, Eastern Branch and Western Branch				
Oyster Density Category	0%	>0%		0%	1-5%	>5%		
Habitat Type	All	Marsh	Patch/Fringing Reef	All	All[a]	Marsh	Patch/Fringing Reef	Bulkhead, Riprap, Sand, Other
Sample Technique	none	random quadrate	haphazard quadrate at randomly selected patches	none	"representative" transect at randomly selected features	random transect	haphazard quadrate at randomly selected patches	random quadrate
Sample Dimensions	n/a	0.5m x oyster band height (variable)	0.5m x 0.5m	n/a	0.5m-15m (variable) x oyster band height (variable)	20m x oyster band height (variable)	0.5m x 0.5m	0.5m x oyster band height (variable)
# Samples per Feature	0	20	1-3 (variable based on aerial footprint)	0	1	1-4 (variable based on feature length)	1-5 (variable based on aerial footprint)	1-2 (variable based on feature length)
Total Samples for Study	0	20	30	0	29	30	8	135

[a] There were no patch reefs in these regions that fell into this category

from other marsh habitat throughout the basin with respect to oyster density and distribution and was therefore handled independently.

A digital map of the HMC region was divided into 50 m x 50 m cells. Twenty of these cells were randomly selected and within each a single location along the marsh edge was haphazardly selected on the computer (Fig. 33). Positions were then downloaded to a GPS unit for field sampling. This region was visited around low tide in March 2006 by two teams. Sample locations were located on foot via GPS. A quadrate, centered on the GPS location, was laid out that was 0.5 m parallel to the marsh edge and extended to the lower and upper extent of oysters perpendicular to the marsh edge. The latter dimension was measured to the nearest 0.1 m and varied from 0.8 to 7.5 m depending on the marsh characteristics and allowed for sampling all of the oysters along a linear 0.5 m of shoreline. All live oysters lying at least 50% within the quadrate were counted *in situ*. Shell height (longest lip to hinge distance) of the first 50 haphazardly encountered individual oysters were measured from each of 12 of these quadrates (randomly selected in advance) to the nearest mm (some quadrates had less than 50 oysters in them, therefore all were measured).

All seven VMRC restoration reefs within the study area were sampled via quadrates. Great Neck Point, Long Creek (old and new fringing), Humes Marsh and Broad Bay First Landing State Park Boat Ramp reefs were sampled utilizing multiple haphazardly selected 0.5 m x 0.5 m quadrates with the exception of the new Long Creek fringing reef which used a stratified random protocol. Alanton and Keeling Drain reefs were sampled by VMRC divers using their standard sampling protocols during fall "dive surveys". All live oysters within a quadrate were enumerated and shell height measured to the nearest mm.

Figure 33. Stratified randomly selected sample locations along the marsh edge in the Humes Marsh Complex region of the Lynnhaven River. See Figure 3 for an overview of the location of this region within the basin

Isolated patch reefs were sampled using similar quadrate techniques. Specifically in the HMC region, where patches were numerous, we used a stratified random protocol to develop a group of 20 reefs to sample (Fig. 34). The number of 0.5 m x 0.5 m quadrates haphazardly collected within each patch was approximately proportional to its aerial footprint as follows: <1,250 m^2, 1,250-2,500 m^2 and > 2,500 m^2 had one, two or three samples taken, respectively. Samples were transported back to the lab where all live oysters were counted. Shell heights of the first 50 haphazardly encountered individual oysters were measured to the nearest mm (some quadrates had less than 50 oysters in them, therefore all were measured).

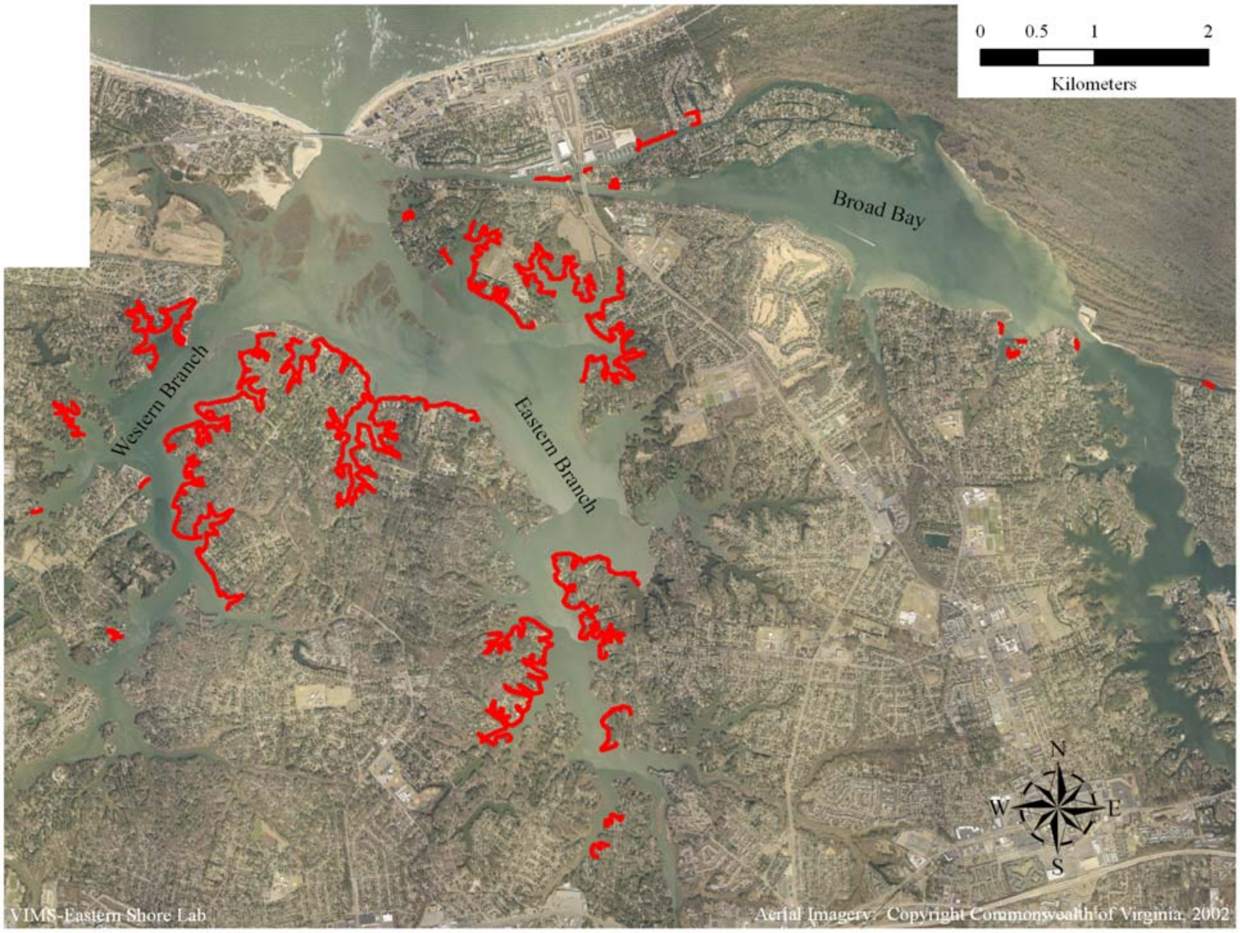
Figure 34. Randomly selected reef patches sampled in the Humes Marsh Complex region of the Lynnhaven River along with two in the Western Branch and one in the Eastern Branch. See Figure 3 for an overview of the location of these regions within the basin. Red polygons indicate sample reefs.

Sampling the remaining shoreline features for oyster density and size was much more complicated. The challenge was to sample, in a random and rigorous manner, enough locations to accurately assess the oyster population, while operating within the logistical constraints of this project. Individual shoreline features were grouped by the following attributes: region (since HMC was covered with more directed sampling as described above, this left Eastern Branch, Western Branch, Broad Bay and Long Creek); broad habitat type (sub groupings such as wood vs. metal bulkhead were combined); and oyster density category. Features to be sampled were then randomly selected from within each of these groupings. Once a feature was selected, specific sampling locations along that feature were randomly selected. We sampled oysters in each habitat and density category by the most appropriate methods, which affected how the data were subsequently applied to the overall population model. Therefore, each sample scheme is discussed separately below. All samples were collected within 2 hr of low tide to ensure complete coverage of the intertidal and high subtidal zones.

Table 6 organizes this complex sampling protocol and can be referred to for clarification throughout the remainder of this section. Across the board, features with different density categories were sampled differently. Features categorized as 0% oysters were assumed to contain a negligible abundance of oysters in the overall scheme of a basin-wide population assessment. Such features may have had no oysters present or very low density widely interspersed single oysters or small and very sporadic clumps. Features in this class were not sampled for oysters.

We initially treated all features with oyster cover categories of 1-5% in the same manner as described above for 0%; assuming that such low density habitats would not be important to an overall population assessment. However, large portions of the study area had habitats in this category and it became obvious that they required enumeration. Because oysters in these low density features were quite patchy in nature, they were sampled as "representative" transects. The location and length of sample transects varied subjectively with the patchiness of the oysters and ranged from 0.5-15m in length. Features for sampling were randomly selected (Fig. 35), then the representative transect was sampled for the entire height of the oyster band which varied considerably between features. Several criteria were used for guidance: a sample transect needed to describe the general oyster population along the entire feature; it should not contain any anomalous clumps or lack of oysters relative to the remainder of the feature; and, the transect

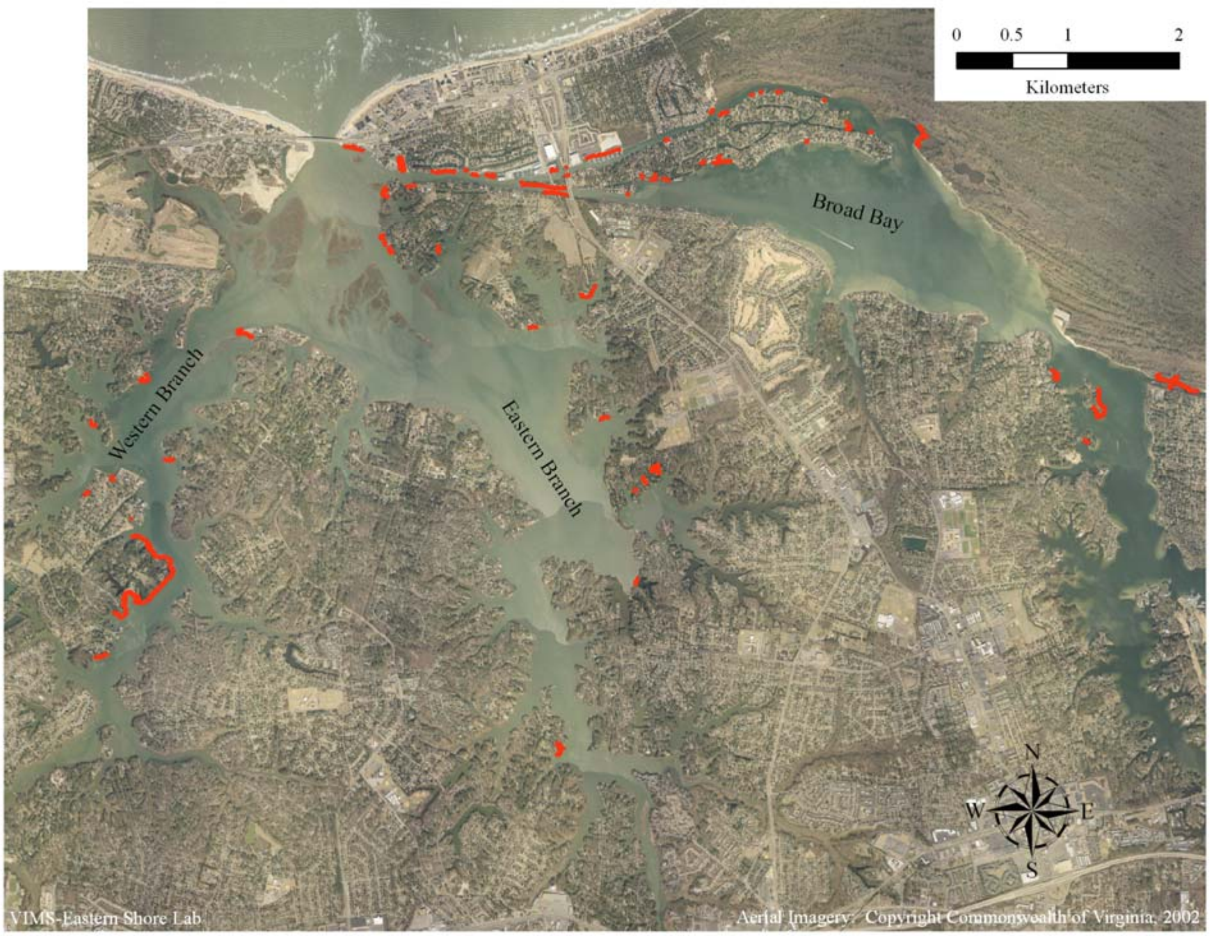
Figure 35. Shoreline features in the 1-5% oyster density category that were randomly selected for oyster sampling.



needed to include the full range of patchiness generally common to the entire feature. For example, if oysters within a feature were sparsely but evenly distributed along its length, then a transect of 0.5 m was deemed appropriate if it encompassed a representative density of oysters. However, a feature with very sparse oyster density that was very patchy in nature may have required a 15 m long transect to be representative of the entire feature and encompass its patchiness. All oysters within transects were counted *in situ* and the representative oyster band height was estimated and measured.

With the exception of marsh habitat, other features with >5% oyster coverage were sampled using quadrate techniques similar to the HMC marsh described earlier. Two randomly selected sample locations were allocated within each randomly selected feature to be sampled (Fig. 36). Sample locations were located by boat or on foot via GPS. Where possible, distance

Figure 36. Shoreline features in >5% oyster density categories that were randomly selected for oyster sampling. The number and locations of specific sample locations within these features can be viewed as a layer in the GIS product accompanying this report. See Fig. 34 for marsh shoreline sample locations in the Humes Marsh Complex Region.



to the center of a quadrate was referenced to a landmark. For example, in ArcGIS a plot of a given random sample point may have been 10 m left of a dock piling. Instructions accompanying field sampling maps and coordinates would include reference to such a landmark to facilitate timely location of these very specific sampling spots. A quadrate, centered on the location, was laid out that was 0.5 m parallel to the feature edge and extended to the lower and upper extent of oysters perpendicular to the feature. The latter dimension was measured to the nearest 0.1 m and varied from ~ 0.2 m to several meter; all of the oysters along a linear 0.5 m of shoreline were sampled. All live oysters lying at least 50% within the quadrate were counted *in situ* when possible to limit sample transport and potential damage to private property. Shell heights of the first 50 haphazardly encountered individual oysters were measured to the nearest mm *in situ* (some quadrates had less than 50 oysters in them, therefore all were measured).

Field crews had the option to reject a randomly selected quadrate sample location if the exact spot differed substantially from the remainder of the feature in some way that was unidentifiable from the aerial images used for planning. For example, if a 67 m bulkhead feature had a 3m section repaired recently and this is where the randomly selected quadrate sample fell, this minor repair was not representative of the feature as a whole. In this example, the discrepancy within the feature was not large enough to warrant separate mapping and would not measurably affect the results. The quadrate sampling location would then be moved directly adjacent to the irregularity. Such on-site adjustments were only made on a few occasions.

Marsh features with >5% oyster coverage were sampled using a transect technique. They were by far the dominant habitat in terms of extent, much of which had relatively low oyster densities, and it seemed impractical to sample these oysters with a large number of small quadrates. Therefore, we sampled randomly selected 20-m transects proportional to the length of the individual feature: features <50 m in length had one 20 m section sampled; those 50-500 m in length had 2 samples; and those >500 m had 2 samples plus one more for each additional 500 m (e.g.; a feature 1,400 m in length would have four 20-m sections sampled). All oysters along these 20-m sections were counted *in situ*. The oyster band height perpendicular to the waterline was measured for each transect. If this varied along transects, then an area of "average" height was chosen and measured. Shell heights of the first 50 haphazardly encountered individual oysters were measured to the nearest mm *in situ*.

Several criteria could result in adjustments the above protocols adaptively based on the situation encountered in the field. If a randomly selected transect or quadrate location was found to be in a position that was deemed unsafe (e.g. unstable section of riprap adjacent to deep water), posed a potential impact to private property (e.g. a boat moored closely to a section of bulkhead) or negatively impacted the standardized collection techniques, field crews could move the sample location to the closest spot directly adjacent to the impediment that could be appropriately and safely sampled. Such situations rarely occurred.

Oyster Biomass Sampling –To obtain biomass estimates we sub-sampled oysters and measured ash-free dry tissue weight. Oysters were collected from five habitats during February to April 2006: bulkhead, riprap, marsh, intertidal patch reefs, and subtidal patch reefs. Sub-samples of several to 30 individuals were haphazardly collected from each of the regions and habitat subtypes for each of the five habitat categories and pooled (see Table 7 for total sample size for each habitat). Oysters representing the bulk of the entire size range of oysters observed within these habitats were collected. Samples kept frozen until processing in the laboratory.

Individual oysters were later removed from the freezer and shell height was immediately measured to the nearest 0.1 mm. Oysters were subsequently thawed and any epiphytes were removed from shells. They were shucked into individually labeled pre-weighed aluminum pans and placed in a 90º C drying oven for at least 48 hrs or until a constant weight was achieved. Tissues were weighed to the nearest 0.001 g, combusted at ~538º C in a muffle furnace for at least 5 hrs, cooled and re-weighed to the nearest 0.001 g.

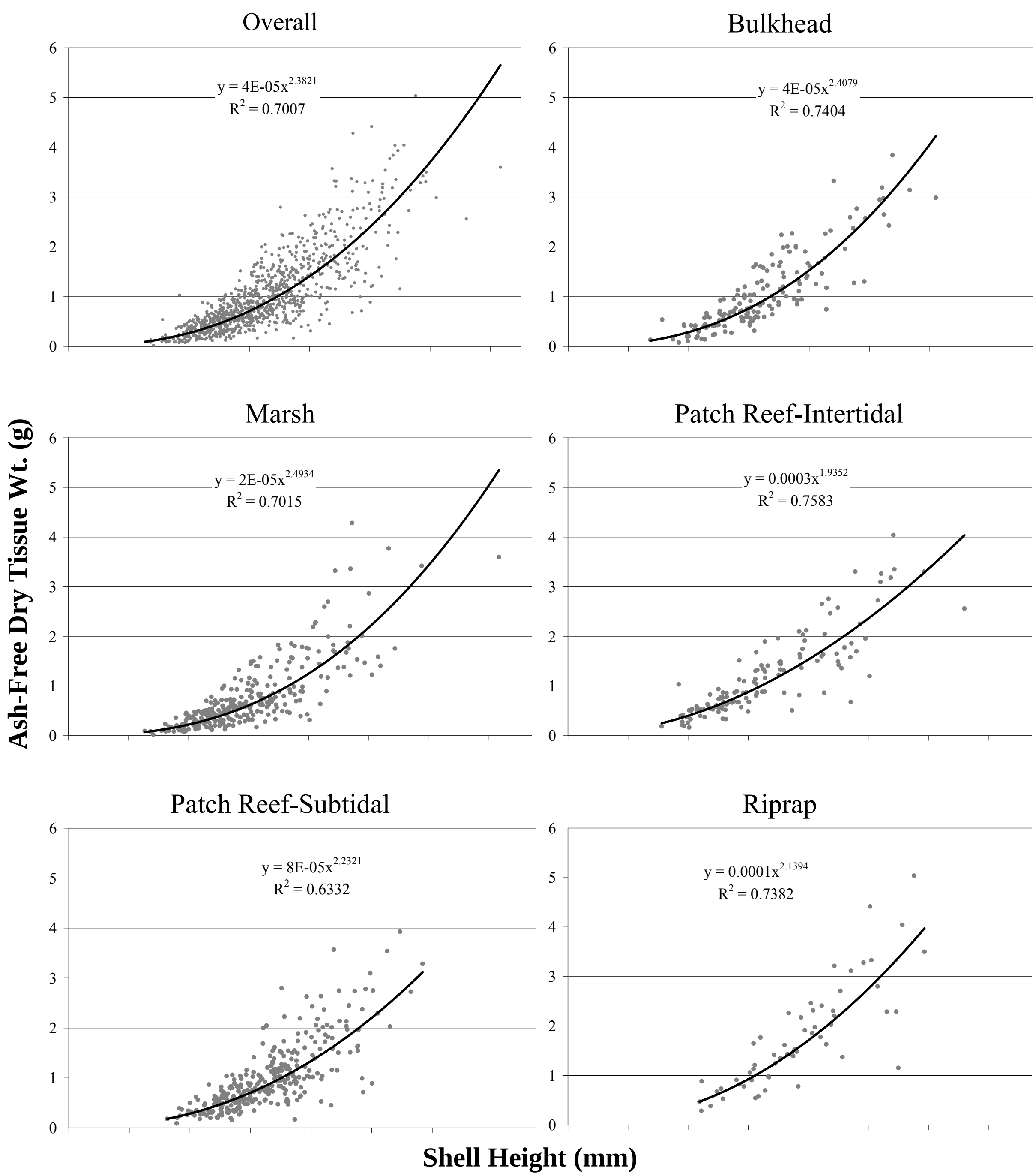
Table 7. Power function relationships between oyster shell height and biomass (as measured by ash-free dry tissue weight) for various habitats within the Lynnhaven study area (see Figure 13 for graphs of habitat specific relationships). Only the first five listed were sampled. Relationships for fringe reefs, sand and other habitats were based on the respective measured relationship noted in the table.

Habitat	Size-Biomass Equation*	R^2	Sample Size
Bulkhead	$y=0.00004x^{2.4079}$	0.74	162
Marsh	$y=0.00002x^{2.4934}$	0.70	285
Patch Reef-Intertidal	$y=0.0003x^{1.9352}$	0.76	130
Patch Reef-Subtidal	$y=0.0001x^{2.1394}$	0.74	58
Riprap	$y=0.00008x^{2.2321}$	0.63	316
Overall	$y=0.00004x^{2.3821}$	0.70	951
Fringe Reef	based on Patch Reef-Intertidal	-	-
Sand	based on Riprap	-	-
Other	based on Riprap	-	-

* y=ash-free dry tissue wt. (g) and x=shell ht. (mm)

Since this procedure could only be performed on a limited number of individuals, due to obvious logistics, we developed separate shell height to biomass (ash-free dry tissue weight) relationships for each of the five habitat categories sampled (Fig. 37 & Table 7). Best-fit power functions were applied to the data and the resulting equations were used to estimate biomass based on shell height. The dry tissue biomass of all oysters measured during the study could then be estimated individually and, based on relative size distributions, we could estimate dry tissue biomass within and across several study parameters and overall for the entire oyster population described in this study. This process will be detailed in the next section.

Figure 37. Best-fit power function relationships between oyster size (shell height, mm) and biomass (ash-free dry tissue wt., g) overall and for five different habitats sampled in the Lynnhaven River



Basin-wide Population Estimate – Oyster densities observed in the above detailed sampling were applied to each individual feature mapped to estimate oyster abundance in the entire Lynnhaven Basin study area. Feature-level abundance was estimated based on feature area (# oysters · m^{-2}) or feature linear length (# oysters · linear m^{-1}). These two different models were needed to accommodate the various habitats and density of oysters encountered. Generally, all habitats categorized as 1-5% oyster cover and some marsh and sand habitats with higher cover used a linear model (Table 8). This was also true for marsh and sand habitats with >5% estimated oyster cover that had quite variable oyster band heights. Marsh habitats with >5% estimated oyster cover had relatively static oyster band height and we thus used the area model. These decisions were based on the reality that estimating oyster band height accurately, but quickly enough to complete the study in a timely manner, was very difficult for marsh and sand habitats with varying band widths and for low oyster density habitats (i.e. 1-5% cover category). Rather than break some of these features into large numbers of very short features based on band height, we decided that applying the linear model fit the overall of objectives of the study while remaining logistically feasible and still providing acceptable feature-specific oyster data.

In the linear model, we calculated the total number of oysters for a given feature (Oys_f) by multiplying the total length (L_f) of that feature by the mean number of oysters · linear m^{-1} based on the sampling described above: $Oys_f = L_f$ * (mean number of oysters · linear m^{-1}). For example, based on oyster sampling, it was observed that bulkheads in Broad Bay that were categorized as 1-5% oyster cover had 4.7 oysters · linear m^{-1}, on average. Therefore, a 50-m bulkhead fitting this description in Broad Bay was calculated to have 235 oysters within its entire extent: $Oys_f = 50 * 4.7 = 235$.

Table 8. Oyster density models (linear vs. area) used to estimate feature specific oyster abundance by region, habitat type and density category[a].

Region	Habitat	Density Category	Model
All	Restoration Reefs	ALL	Area
Broad Bay	Bulkhead	1-5%	Linear
		6-25%	Area
		26-50%	Area
		51-75%	Area
	Marsh	1-5%	Linear
		6-25%	Area
	Riprap	1-5%	Linear
		6-25%	Area
		26-50%	Area
		51-75%	Area
	Sand	1-5%	Linear
		26-50%	Linear
Eastern Branch	Bulkhead	1-5%	Linear
		6-25%	Area
	Riprap	6-25%	Area
		26-50%	Area
		51-75%	Area
		76-95%	Area
	Marsh	1-5%	Linear
		6-25%	Linear
		26-50%	Linear
	Patch reef (intertidal)	26-50%	Area
Long Creek	Bulkhead	1-5%	Linear
		6-25%	Area
		26-50%	Area
		51-75%	Area
	Marsh	1-5%	Linear
		6-25%	Area
	Other	26-50%	Area
		51-75%	Area
Long Creek (cont.)	Riprap	6-25%	Area
		26-50%	Area
		51-75%	Area
		76-95%	Area
	Sand	1-5%	Linear
Western Branch	Bulkhead	1-5%	Linear
		6-25%	Area
		26-50%	Area
	Marsh	1-5%	Linear
		6-25%	Area
		26-50%	Linear
	Other	26-50%	Linear
	Patch reef (intertidal)	1-5%	Area
		26-50%	Area
	Patch reef (subtidal)	.	Area
	Riprap	1-5%	Linear
		6-25%	Area
		26-50%	Area
		51-75%	Area
		76-95%	Area
Humes Marsh	Patch reef (intertidal)	1-25%	Area
		26-75%	Area
	Marsh	ALL	Linear

[a] Not all combinations of habitat and density categories were present within regions. Only those present were included in this table.

In the area model, we calculated the total number of oysters for a given feature (Oys_f) by multiplying the total length (L_f) of that feature by the estimated band height (H_f) and the mean number of oysters · m^{-2} based on the sampling described above: $Oys_f = L_f * H_f$ * (mean number of oysters · m^{-2}). For example, based on oyster sampling, it was observed that bulkheads in Broad Bay that were categorized as 26-50% oyster cover had 76.7 oysters · m^{-2}, on average. Therefore, a 50-m bulkhead fitting this description in Broad Bay and having an estimated oyster band height of 0.35 m was calculated to have 1,342 oysters within its entire extent: $Oys_f = 50 * 0.35 * 76.7 = 1,342$.

Table 8 details which model was utilized for specific habitats and density categories. Once oyster abundance was estimated for each feature, they were summed to estimate the oyster population abundance for different groupings and the entire basin overall: $Oys_{total} = \sum Oys_f$.

Basin-wide total biomass was calculated differently than abundance. Since individual oyster shell height was used to calculate individual oyster biomass, we had to extrapolate total biomass for the entire population, or within various useful groupings, based on size distributions and abundance estimates. An overall size distribution was developed and was divided into 2 mm shell height "bins". Individual oyster biomass was then estimated for the midpoint of each bin using the overall size-biomass relationship in Fig. 37. These estimates were then multiplied by the total estimated number of oysters in that size bin. Total bin biomass estimates were summed to estimate total biomass. This technique could be used for any grouping of oysters, such as by habitat type and region, etc.

GIS Product Development – Raw field mapping data were uploaded to Pathfinder Pro mapping software. Feature lines and polygons were applied to a background of georeferenced 1m resolution aerial images of the Lynnhaven basin. Minor adjustments or offsets were applied in this software. In some cases, features were completely re-digitized based on the field mapping and the aerial image backgrounds. This was often necessary for the marsh features, since following the exact contour of the shoreline by boat was difficult at best.

Files were subsequently exported as ESRI shapefiles, including feature lengths and areas as calculated in the Pathfinder Pro software. Another option would have been to calculate these geometric dimensions in GIS. However, the results were needed immediately to design and implement the oyster sampling protocols. Therefore, these parameters followed each feature into the GIS format in the attributes table from Pathfinder Pro.

Once mapped features were in GIS formats, they were added to an ArcGIS project. Feature-specific oyster abundance data, based on oyster population samples, were then added to the attribute tables. Other separate data layers were later added to describe the study area, sample locations and oyster settlement data. We initially set the symbology for each layer in a manner we felt was appropriate to graphically organizing and presenting the data. These aesthetic parameters can be easily changed by any end user.

A general description of the format of the GIS product follows in Table 9. More specific information can be found in the metadata that were formatted to meet NOAA criteria (see hardcopy in Appendices XV and XVI.

Table 9. General description of GIS final product format. See metadata for product details (hardcopy in Appendix XVI).

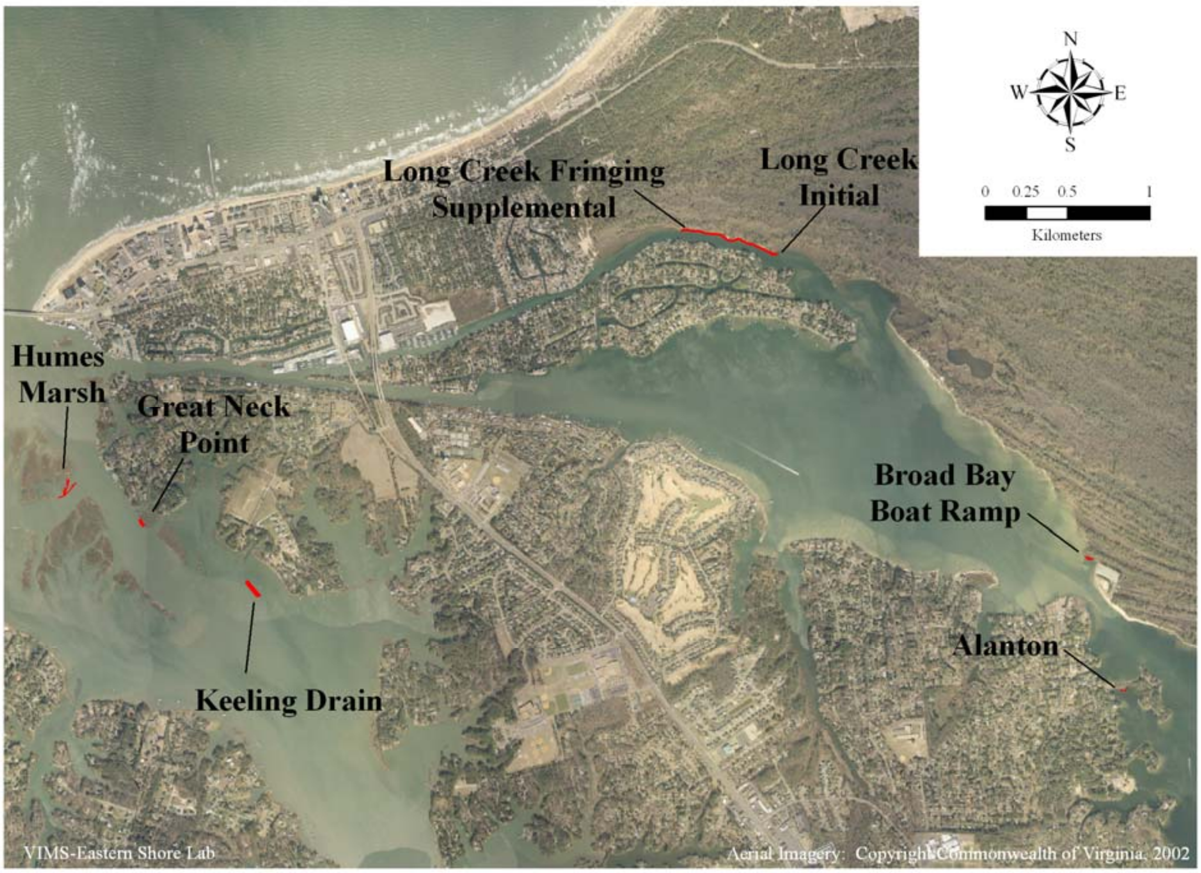
Parameter	Value/Format
Software	ESRI ArcGIS, v. 9.1
Coordinate System	US State Plane (Feet) NAD 1983 Virginia South FIPS 4502
Data layers:	
Aerial background images[a]	paired *.sid & *.sdw files (raster)
Shoreline features	polyline shapefile
Patch reefs	polygon shapefile
Shoreline features where oysters were sampled	polyline shapefiles (x2)
Patch reefs where oysters were sampled	polygon shapefile
Specific oyster sample points	point shapefile
Oyster settlement (2005 & 2006 separate files)	point shapefiles (x2)

[a] Copyright Commonwealth of Virginia, 2002

RESULTS & DISCUSSION

Initial Habitat Mapping – Overall, 634 individual features encompassing 195 km of shoreline and 63 patch and fringing reefs totaling 49,100 m^2 were mapped during the course of this study. Seven state created restoration reefs were included in this mapping: Humes Marsh (fringing), Great Neck Point (fringing), Keeling Drain (isolated subtidal patch), Broad Bay Boat Ramp (fringing), Long Creek (initial plant; fringing), Long Creek (supplemental plant; fringing) and Alanton (isolated subtidal patch). Figure 38 shows the location of restoration reefs. Shoreline features and patch/fringing reefs will be treated separately throughout this section since they were mapped differently as lines and polygons, respectively. The following mapping results are meant to be summary in nature. Specific spatial relationships can be seen in the GIS product and interpreted by the end user.

Figure 38. Seven restoration reefs included in the mapping and oyster population estimates for the Lynnhaven River



<u>Shoreline Features</u>-Within the specified study area (Fig. 26), Eastern Branch (see Fig. 27 for region delineations) had the most shoreline while Long Creek had the least (Table 10). Overall, marsh was the dominant shoreline habitat (Table 11) and was the only shoreline feature in the Humes Marsh Complex. Even though the Lynnhaven River basin is situated in an urban landscape, much of the intertidal-upland interface is composed of marsh. In some cases, marsh buffers are very narrow and include shoreline stabilization structures immediately above them. In other cases, marsh habitat is wider and lies adjacent to natural wetland-upland transitional

habitats. Marsh habitat is less prevalent along the more commercially developed and narrow Long Creek region until the border of First Landing State Park..

Table 10. Intertidal shoreline mapped in study regions of the Lynnhaven River. See Figure 27 for map of regions.

Region	# Features Mapped	Total Linear Distance Mapped (m)	Relative Proportion (%)
All Combined	634	194,525	n/a
Broad Bay	150	22,645	11.6
Eastern Branch	115	75,437	38.8
Humes Marsh Complex	129	40,036	20.6
Long Creek	129	13,237	6.8
Western Branch	111	43,170	22.2

Table 11. Intertidal shoreline mapped in the Lynnhaven River study area by habitat category.

Habitat Category	# Features Mapped	Total Linear Distance Mapped (m)	Relative Proportion (%)
Marsh	290	152,419	78.4
Bulkhead	177	21,735	11.2
Riprap	123	11,403	5.9
Sand	40	8,685	4.5
Other	4	283	0.1

Overall, 53.2 % of shoreline habitats were classified as having 1-5% oyster cover and oyster cover was heavily skewed towards the lower oyster cover categories (Table 12). This suggests that oysters are virtually ubiquitous throughout the study area at generally low densities, with small, yet dense concentrations in localized areas. This is further illustrated in the GIS product.

Table 12. Intertidal shoreline mapped in the Lynnhaven River study area by oyster density category.

Oyster Density Category	# Features Mapped	Total Linear Distance Mapped (m)	Relative Proportion (%)
0%	114	22,317	11.5
1-5%	211	103,492	53.2
6-25%	206	54,522	28.0
26-50%	64	9,678	5.0
51-75%	32	4,070	2.1
76-95%	7	445	0.2
96-100%	0	0	0.0

When further analyzing the three dominant shoreline habitat types (i.e. bulkhead, marsh and riprap), several patterns emerge with respect to the oyster population. Bulkheads are dominated by features with <6% oyster cover (Table 13). In fact, 36.4% of bulkheaded shoreline had no oysters present. When marsh is encountered, there are typically oysters present as well, although mainly at relatively low densities (Table 13). Conversely, riprap habitats had oysters present with aerial coverage >26% over half of the time (Table 13).

It is important to note that the cause for such differences is hard to address based on the data collected in this study. One possibility is the inherent architectural and biological impacts of the individual habitats. For example, one habitat might provide a more suitable substrate for oyster settlement or promote post-settlement survival, both of which have been shown to be very

Table 13. Intertidal shoreline mapped in the Lynnhaven River study area by oyster density category within the three dominant shoreline habitat categories.

Habitat Cat.	C.v. Density Category	# Features Mapped	Total Linear Distance Mapped (m)	Relative Proportion within Habitat (%)	Relative Proportion Overall (%)
Bulkhead	0%	55	7,905	36.4	4.1
	1-5%	67	8,554	39.4	4.4
	6-25%	31	2,618	12.0	1.3
	26-50%	17	1,471	6.8	0.8
	51-75%	7	1,187	5.5	0.6
	76-95%	0	0	0.0	0.0
	96-100%	0	0	0.0	0.0
Marsh	0%	15	5,694	3.7	2.9
	1-5%	127	93,480	61.3	48.1
	6-25%	144	49,008	32.2	25.2
	26-50%	4	4,237	2.8	2.2
	51-75%	0	0	0.0	0.0
	76-95%	0	0	0.0	0.0
	96-100%	0	0	0.0	0.0
Riprap	0%	11	756	6.6	0.4
	1-5%	11	815	7.1	0.4
	6-25%	31	2,896	25.4	1.5
	26-50%	39	3,648	32.0	1.9
	51-75%	24	2,842	24.9	1.5
	76-95%	7	445	3.9	0.2
	96-100%	0	0	0.0	0.0

important factors in oyster community development. However, the trends might also be artifacts of spatial relationships. For example, more riprap is found in downstream portions of the regions, mainly due to the higher erosive forces and increased need for shoreline stabilization in these areas. Downstream reaches of the Lynnhaven River may have better water quality parameters that can impact oysters (e.g. lower salinity variability due to proximity to the Lynnhaven Inlet). Experiments will be required to address habitat-specific factors affecting oyster abundance.

Oyster band height varied with shoreline habitat architecture. More or less vertical structures such as bulkhead had narrower oyster bands than did more sloping habitats such as marsh (Table 14). This result is purely a function of the inundation of variously sloped intertidal zones.

Table 14. Mean (± SE) oyster "band height" (cm) within intertidal shoreline habitats in the Lynnhaven River study area.

Habitat Category	# Features Mapped	Mean (cm)	SE (cm)
Bulkhead	122	34	1.3
Riprap	112	46	2.3
Other	4	66	22.2
Sand	7	72	38.1
Marsh	275	131	2.7

Patch/Fringing Reef Features - Most shell-based reefs were isolated intertidal patch reefs that accounted for 84.2% of the features that were mapped (Table 15). The majority of these were located in the Humes Marsh Complex region (Table 16). This area is mainly “natural”, although many of the patch reefs were likely either created and/or managed intensively in the recent past. The remaining reefs of this type were mainly found in downstream adjacent areas of the Eastern and Western Branch regions.

Table 15. Fringing reef and intertidal and subtidal patch reefs (all with a shell base) mapped the Lynnhaven River study area by habitat category. See Table 11 for similar data for intertidal shoreline.

Habitat Category	# Features Mapped	Total Area Mapped (m^2)	Relative Proportion (%)
Patch Reef Intertidal	55	41,323	84.2
Patch Reef Subtidal	4	4,500	9.2
Fringing Reef	4	3,277	6.7

Table 16. Fringing reef and intertidal and subtidal patch reefs (all with a shell base) mapped in study regions of the Lynnhaven River. See Fig. 27 for map of regions.

Region	# Features Mapped	Total Area Mapped (m^2)	Relative Proportion (%)
All Combined	63	49,100	n/a
Broad Bay	2	1,088	2.2
Eastern Branch	5	5,843	11.9
Humes Marsh Complex	51	33,041	67.3
Long Creek	2	2,995	6.1
Western Branch	3	6,133	12.5

All intertidal patch reefs had oysters present, with 71.7% being categorized with 26-50% oyster coverage (Table 17). In comparison, fringing reefs often had very few or no oysters present, although 70% were categorized with 6-25% oyster coverage. It is important to note that two restoration reefs are included in this category: Humes Marsh and Long Creek supplemental plant. The other intertidal reefs were classified as intertidal patch reefs. This is a bit arbitrary, since those reefs are basically hybrids based on our classification system. They all fringe marsh and have a portion of the reef that is intertidal and resembles a fringing reef. They also typically have a more dominant subtidal portion adjacent the fringing band. This characteristic is an artifact of restoration reef design and is not typical of natural fringing reefs observed in this region. These reefs could have a classification all their own, but we made the decision to lump them in with the intertidal patch reefs because the oyster populations appeared to be similar and similar sampling protocols were used later in the study.

Table 17. Fringing reef and intertidal patch reefs (all with a shell base) mapped in the Lynnhaven River study area by oyster density category.

Habitat Category	C.v. Density Category	# Features Mapped	Total Area Mapped (m^2)	Relative proportion within Habitat (%)	Relative proportion Overall (%)
Patch Reef- Intertidal	0%	0	0	0.0	0.0
	1-5%	1	1,403	3.4	3.1
	6-25%	11	3,299	8.0	7.4
	26-50%	35	29,637	71.7	66.4
	51-75%	8	6,984	16.9	15.7
	76-95%	0	0	0.0	0.0
	96-100%	0	0	0.0	0.0
Fringing Reef	0%	2	905	27.6	2.0
	1-5%	1	78	2.4	0.2
	6-25%	1	2,294	70.0	5.1
	26-50%	0	0	0.0	0.0
	51-75%	0	0	0.0	0.0
	76-95%	0	0	0.0	0.0
	96-100%	0	0	0.0	0.0

Oyster Density and Size – Mean oyster density for intertidal and subtidal habitats were calculated from 252 and four samples, respectively, collected throughout the study area. The four "samples" for subtidal habitats were developed from multiple quadrate sub samples at four locations. Samples from the two VMRC reefs in this category were collected using previously established VMRC and VIMS-ESL protocols. Since the number of sub-samples based on these protocols was not proportional to each feature's size, we simply averaged the sub-samples to produce each "sample" value. Had we not done this, the sub-samples from restoration reefs would have skewed the results for this habitat category.

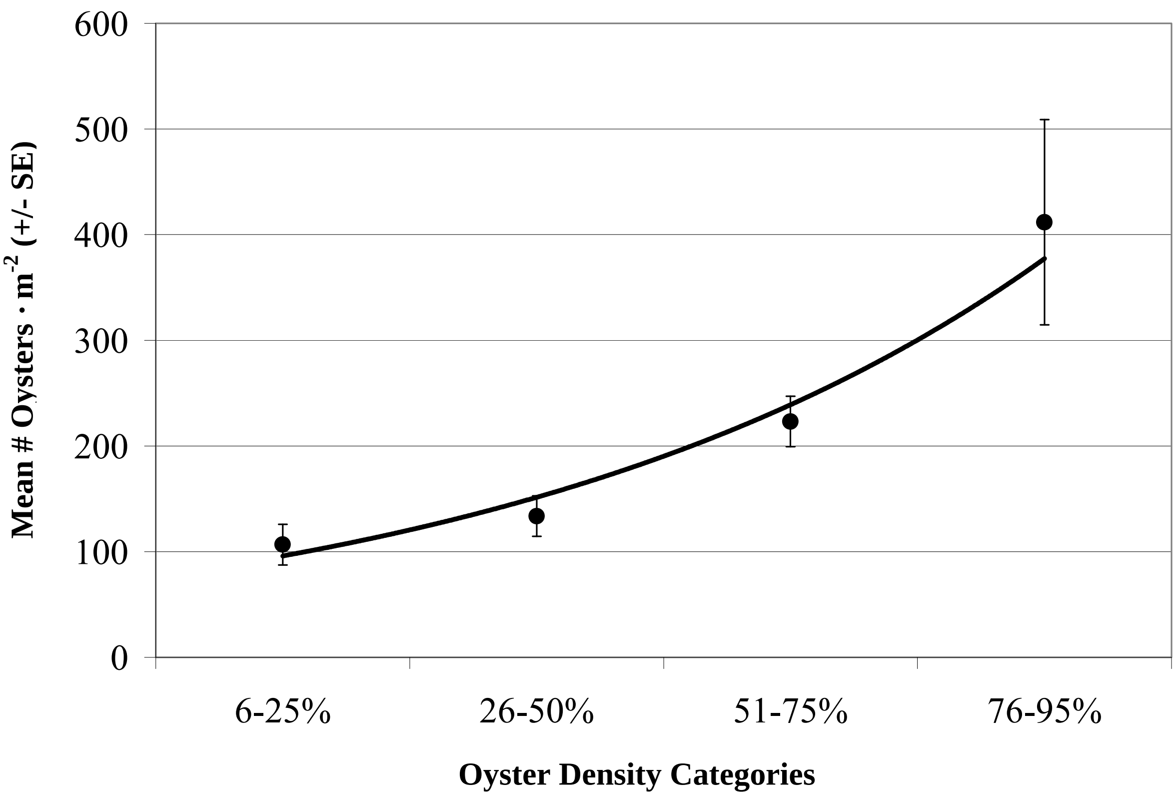
We used the oyster population sampling to evaluate our initial classification of individual features by density categories. We specifically looked at pooled samples from bulkhead, riprap and marsh (those from areas other than Humes Marsh Complex) that were categorized with > 5% oyster cover. These were the dominant habitats that substantially influenced the design of oyster sampling protocols and subsequently impacted population estimates. Overall, oyster density increased as density categories increased (Table 18). Variability increased substantially for the higher density categories and was likely a function of decreasing sample size (Table 18) and the inherent variability in oyster density in highly populated habitats. Although these density categories were quite broad (25%), a very strong exponential relationship (R^2=0.96) was observed with the actual mean oyster density from samples (Fig. 39). Since our density categorizations were a two dimensional parameter (i.e. % aerial cover of oysters), it is not surprising that an

Table 18. Mean (± SE) oyster density ($\# \cdot m^{-2}$) measured within bulkhead, riprap and marsh features (from regions other than Humes Marsh Complex) initially classified in several oyster density categories >5% during habitat mapping.

Density Category	n	Mean	SE
6-25%	60	107	19
26-50%	41	134	19
51-75%	36	223	24
76-95%	10	412	97

exponential relationship was seen with actual measured oyster densities. As actual density increases, oysters are found in three dimensions within the two dimensional aerial footprint on the surface of habitats and the additional dimension on each other vertically relative to the habitat. This occurs well before 100% aerial coverage occurs. This suggests that the density categories we initially chose were appropriate and that features were accurately categorized during the mapping phase.

Figure 39. Relationship between measured mean oyster density (# oysters · m^{-2}) and visually estimated oyster cover categories from initial mapping (% cover) for categories >5%. Points are mean oyster density (+/- SE) and the curve is the exponential trendline (R^2=0.96).



Overall, when oysters were present, mean live oyster density within habitat categories ranged from <1-227 oysters · m^2 (Table 19). It should be emphasized that these means do not include features that had no oysters present. Oyster density at restoration reefs ranged from 24-202 oysters · m^2 (Table 20). We do not include the Humes Marsh reef in this range or grouping. It was mapped along with the more natural intertidal patch reef adjacent to it, which contained most of the oysters represented in these samples. We classified the entire patch as an intertidal patch reef for all other analyses. Although no specific statistical comparisons between habitats were planned, we did compare higher density habitats *a posteriori* because of discussions and interest

Table 19. Mean (± SE) oyster density (# · m^{-2}) for various habitats[a] sampled in the Lynnhaven River.

Habitat Category	n	Mean	SE
Riprap	83	227.4	21.9
Patch Reef-Intertidal	53	217.7	20.4
Fringing Reef	5	144.0	55.4
Patch Reef-Subtidal	4	114.8	41.4
Bulkhead	58	89.2	9.6
Marsh	52	17.9	5.4

[a] Density estimates are only calculated for shoreline features having >1% aerial coverage of oysters and are only provided for habitats making up at least 1% of the oyster population.

Table 20. Mean (± SE) oyster density (# · m^{-2}) for seven VMRC restoration reefs in the Lynnhaven River.

Restoration Reef	n	Mean	SE
Great Neck Point	6	202.7	85.0
Long Creek (Initial)	6	146.7	31.3
Long Creek (Supplement)	6	144.0	55.4
Keeling Drain	12	65.7	8.2
Broad Bay Boat Ramp	3	32.0	24.4
Alanton	9	23.6	10.9
Humes Marsh[a]	3	392.0	139.8

[a] This reef is classified as a restoration reef here, although it is composed of a restoration plant portion and a more natural patch reef portion where the majority of the oysters were found. Elsewhere it is classified as an intertidal patch reef.

during the course of the project. Riprap and intertidal patch reefs had significantly higher oyster densities than did bulkhead and marsh, but were similar to fringing and subtidal patch reefs (Fig. 40; ANOVA & Tukey's Multiple Comparison, $p<0.0001$). Additionally, several types of patch/fringing reefs were compared to riprap (Fig. 41). "Natural" intertidal patch reefs had significantly higher oyster densities than did restoration reefs (both those that were intertidal/subtidal and solely subtidal in nature), but was similar to riprap (Fig. 41; ANOVA, $p<0.0001$; Tukey's Multiple Comparison). This appears to be a trend of increasing oyster density with intertidal exposure among the hard substrate habitats (i.e. marsh excluded). Throughout the Lynnhaven Basin, the oyster population tends to inhabit the intertidal zone with distinct zonation at the low intertidal/subtidal interface. While several parameters may contribute to this pattern, we suspect that predation is likely an important factor.

Figure 40. Mean (+SE) oyster density for dominant habitats. Means with different letters were significantly different (ANOVA and Tukey's Multiple Comparison, $p<0.01$).

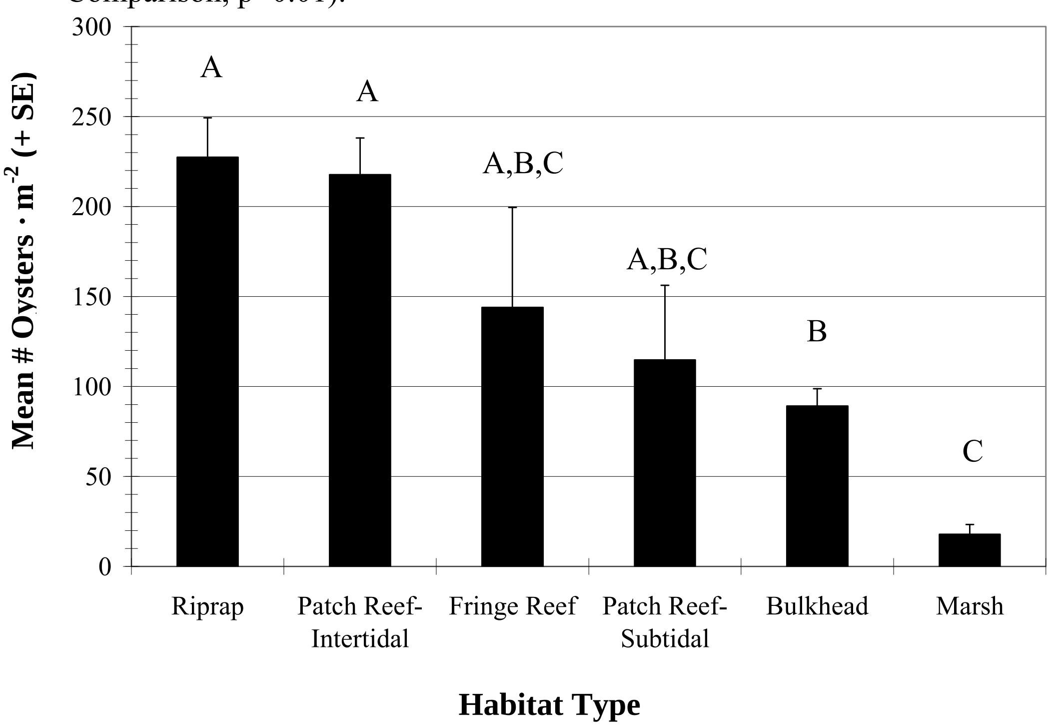
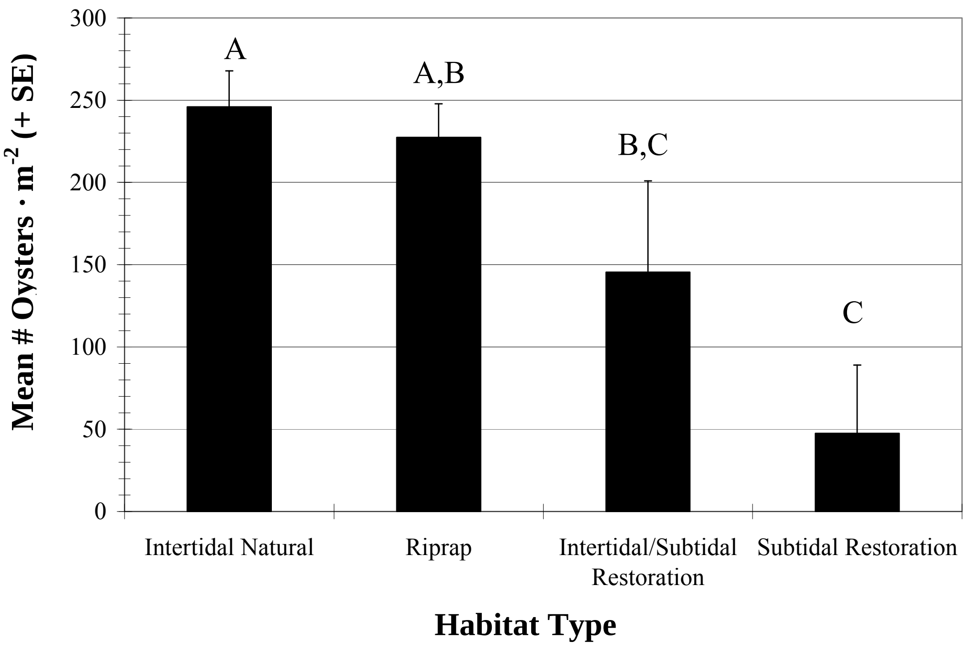


Figure 41. Mean (+SE) oyster density for several types of patch/fringing reefs and shoreline riprap. Means with different letters were significantly different (ANOVA and Tukey's Multiple Comparison, p<0.01).



As previously described in the Methods section, mean oyster density (as described by # oysters · m^2 and # oysters · linear m) for groupings of features by region, habitat and density category were used to develop the overall Lynnhaven Basin oyster population estimate. Mean oyster density for the "area model" groupings ranged from 0.5-538 oysters · m^2 and for the "linear model" groupings ranged from <0.1-108 oysters · linear m^{-1} (Table 21). In some cases live oyster density was actually found to be higher in habitats classified as 50-75% oyster cover than those classified as 76-95% oyster cover, especially on riprap (see Table 21). This apparent discrepancy was likely due to the presence of many dead "box" oysters scattered among live oysters. At the highest densities, it was very difficult to tell live vs. box oysters during the initial mapping. They were only enumerated during actual quadrate sampling.

Table 21. Oyster densities used to estimate feature specific oyster abundance by region, habitat type and density category.

Region	Habitat	Density Cat.	Model	Oyster Density Estimate
Broad Bay	Bulkhead	1-5%	Linear	4.7
		6-25%	Area	70.0
		26-50%	Area	76.7
		51-75%	Area	140.4
	Marsh	1-5%	Linear	26.9
		6-25%	Area	0.5
	Riprap	1-5%	Linear	27.2
		6-25%	Area	61.0
		26-50%	Area	113.8
		51-75%	Area	260.8
	Sand	1-5%	Linear	0.0
		26-50%	Linear	25.0
Eastern Branch	Bulkhead	1-5%	Linear	2.5
		6-25%	Area	89.5
	Riprap	6-25%	Area	43.4
		26-50%	Area	44.7
		51-75%	Area	294.1
		76-95%	Area	250.5
	Marsh	1-5%	Linear	6.7
		6-25%	Linear	30.7
		26-50%	Linear	108.0
	Patch reef (intertidal)	26-50%	Area	168.0
Long Creek	Bulkhead	1-5%	Linear	22.2
		6-25%	Area	76.0
		26-50%	Area	58.8
		51-75%	Area	119.9
	Marsh	1-5%	Linear	39.4
		6-25%	Area	67.3
	Other	26-50%	Area	58.8
		51-75%	Area	119.9
Long Creek (cont.)	Riprap	6-25%	Area	450.6
		26-50%	Area	236.9
		51-75%	Area	246.8
		76-95%	Area	538.0
	Sand	1-5%	Linear	0.0
Western Branch	Bulkhead	1-5%	Linear	6.6
		6-25%	Area	138.9
		26-50%	Area	149.3
	Marsh	1-5%	Linear	24.6
		6-25%	Area	12.5
		26-50%	Linear	181.8
	Other	26-50%	Linear	1.5
	Patch reef (intertidal)	1-5%	Area	12.0
		26-50%	Area	202.4
	Patch reef (subtidal)	.	Area	185.0
	Riprap	1-5%	Linear	66.0
		6-25%	Area	156.8
		26-50%	Area	231.8
		51-75%	Area	284.2
		76-95%	Area	194.3
Humes Marsh	Patch reef (intertidal)	1-25%	Area	105.6
		26-75%	Area	282.8
	Marsh	ALL	Linear	84.0

Mean oyster shell height ranged from 40.6-58.1 mm across the dominant habitat categories that were sampled (Table 22). Size frequency distributions are reported in Fig. 42 for several habitats. Multiple size classes are seen for all habitats, suggesting that multiple oyster age classes are present within each habitat type. However, an obvious grouping of small oysters 5-25 mm was seen for intertidal patch reefs and marshes, but not for riprap and bulkhead (Fig. 42). This size class represents newly recruited oysters from the previous settlement season. The lower relative abundance of oysters <25 mm for riprap and bulkhead may reflect recruitment or survival differences that have important consequences for the population. In the case of riprap, however, this may reflect sampling error due to difficulties enumerating small oysters in the interstices of complex riprap structures.

Table 22. Mean (± SE) oyster shell height (mm) for oysters sampled from the dominant non-restoration reef habitats in the Lynnhaven River.

Habitat	# Oysters Measured	Mean	SE
Bulkhead	999	54.0	0.6
Marsh	1,282	48.5	0.7
Patch Reef-Intertidal	1,586	40.6	0.7
Patch Reef-Subtidal	213	56.1	2.1
Riprap	3,183	58.1	1.6

Oyster Biomass – Based on shell height-biomass relationships calculated from oyster samples (see Fig. 37 and Table 7) and size distributions (see Fig. 42), we estimated biomass densities for habitats (Table 23). The relative ranking of habitats based on biomass compared to the density of oyster (see Table 19) changes, reflecting different size distributions across habitat.

Figure 42. Oyster shell height (mm) distribution (%) for bulkhead, marsh, patch/fringing reefs and riprap. Shell height is plotted by 5 mm bins.

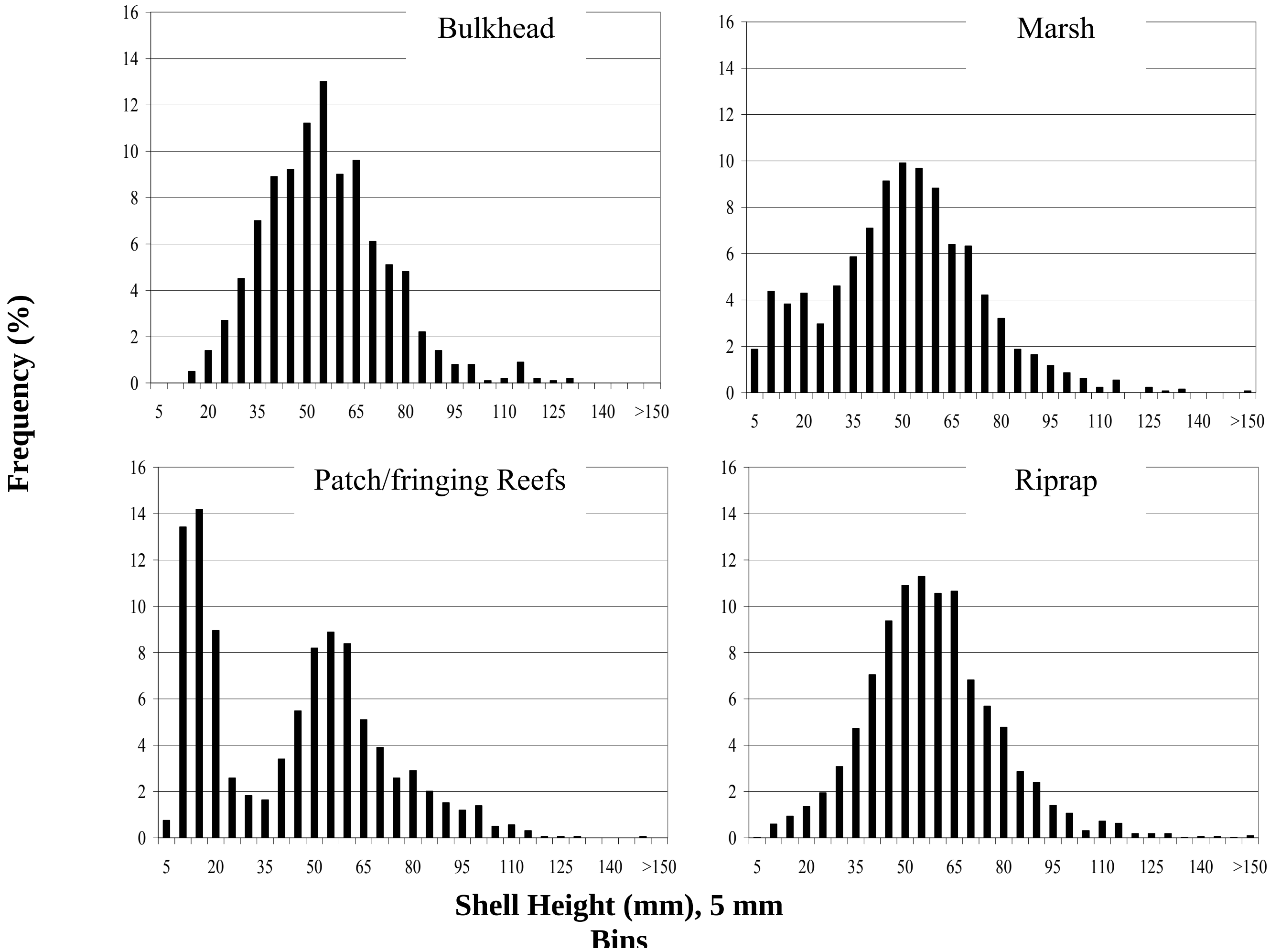


Table 23. Estimated oyster biomass (i.e. ash-free dry tissue weight) density (g · m^{-2}) for the dominant habitats[a] sampled in the Lynnhaven River.

Habitat Category	Oyster Biomass Density
Fringe Reef	152.5
Riprap	136.6
Patch Reef-Intertidal	127.3
Patch Reef-Subtidal	61.1
Bulkhead	43.7
Marsh	13.4

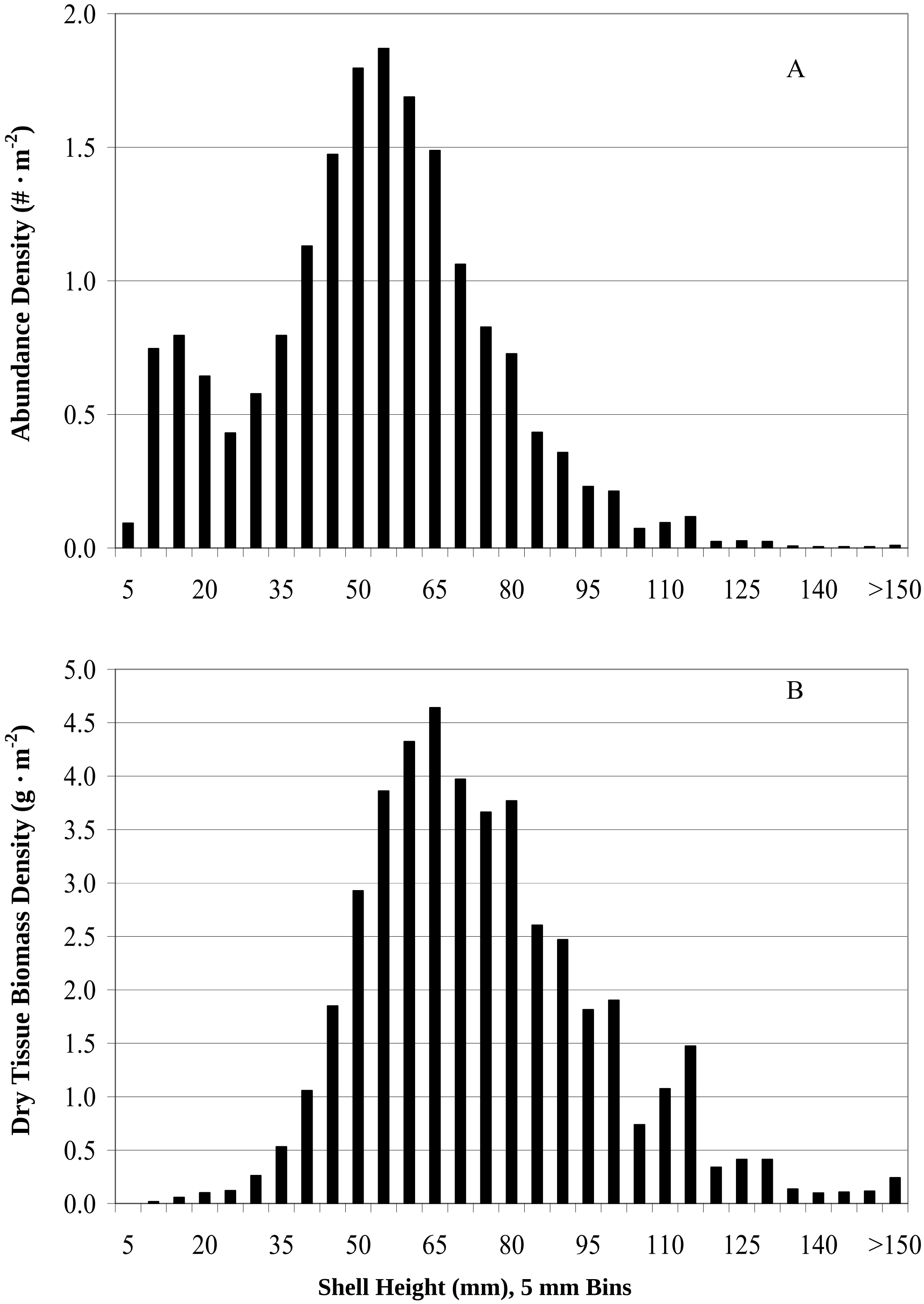
[a] Density estimates are only calculated for shoreline features having >1% aerial coverage of oysters and are only provided for habitats making up at least 1% of the oyster population.

It is important to note how oyster biomass density was derived. To estimate the mean # oysters · m^{-2}, as reported above, we analyzed region, habitat and density category-specific densities. However, we only measured a maximum of 50 individuals for each feature sampled. We assumed that those 50 individuals were sampled in a manner that provided a representative size distribution and we applied the size-density relationship to the entire total estimated number of oysters for each habitat type based on the size distribution and divided it by the total area of each habitat. While this gave a coarser estimate of biomass density than using feature-specific data, it was the best option available and still provided a metric for comparing habitats.

When all data were pooled, the distribution of the density of individuals (i.e. # oysters · m^{-2}) in various size classes was more or less tri-modal, with distinct structure seen for oysters <25 mm, 25-100 mm and >100 mm (Fig. 43a). However, the distribution of the density of biomass (i.e. g oysters · m^{-2}) showed a substantial shift to the right and became basically bi-modal (Fig. 43b). This illustrates the higher contributions of larger, and presumably older, individuals to oyster biomass within this system. This concept is important for discussing oyster population parameters such as fecundity and for evaluating the ecological services of the oyster populations such as filtration potential.

Basin-wide Population Estimate – As described in detail in the Methods section, measured oyster densities for specific groupings were applied to individual features and summed to develop an overall, basin-wide population estimate for the Lynnhaven River study area. Total oyster abundance and biomass was estimated to be 17.8 million oysters and 9,300 kg of dry tissue, respectively. Intertidal patch reefs and marsh habitats contributed almost 90% of the oysters and over 80% of the oyster biomass, making them the most important oyster habitats by far (Table 24). While marsh habitat had relatively low oyster density (see Table 19), it was the

Figure 43. Oyster abundance density (# oysters · m^{-2}) and dry tissue biomass density (g · m^{-2}) by oyster shell height (mm) overall for oysters in the Lynnhaven River. Shell height is plotted by 5 mm bins.



most widely distributed habitat (see Table 11). Additionally, high oyster densities on a relatively large aerial footprint of intertidal patch reefs resulted in a large contribution to this population estimate.

It is likely that these overall population estimates are conservative for several reasons. We did not intensively sample subtidal habitats. As discussed above, although the prevalence of contiguous subtidal reefs was low, we still sampled two natural and two restoration reefs. However, we observed scattered live oysters throughout the high to mid subtidal zone, primarily adjacent to shoreline habitats containing live oysters. Some of our sampling included very small portions of these areas directly adjacent individual features. However, it was not logistically feasible to thoroughly sample these regions within the context of this study.

Additionally, it is possible that we underestimated oyster densities on some habitats given the difficult nature of enumerating large numbers of oysters in the field. We discussed above the possibility that, in the case of riprap, a low incidence of <25 mm oyster may reflect sampling error due to difficulties enumerating small oysters in the interstices of complex riprap structures.

The population estimates provided here are based on mapping from 2004-2005 and the oyster population as quantified during the winter and early spring of 2005-2006. The oyster population is obviously dynamic over time; recruitment and mortality vary temporally, thus impacting population demographics. Habitats are also dynamic over time. We documented at least four shoreline features that changed during a six month period from our mapping and sampling phases, representing more than 100 m of habitat changing from riprap with fairly high oyster densities to new and bare bulkhead. Additionally, many shoreline features that were new and bare during the 2005 mapping are now seasoned habitat with up to four years of oyster settlement. While such changes may generally offset each other and remain somewhat constant over time, we saw extensive marine construction during 2005-2006 (and even during 2007) due to damage from Hurricane Isabel (2003) and several recent Nor'easters.

GIS Product - The final GIS product consisted of an ArcMap project and the data layers outlined in Table 9. Actual feature attribute tables for polyline and polygon layers are provided in Appendices XIV and XV, respectively. There are many ways to organize and analyze these data in the GIS framework. The relative locations and extents of various habitat types can be useful for planning future monitoring and to other ongoing research within the Lynnhaven Basin examining habitat-specific questions (e.g., Fig. 44). Additionally, graphically mapping oyster densities on individual portions of shorelines and reef patches will be integral to planning restoration activities and developing ecological models (e.g., Figs. 45 & 46). Such mapping can be significantly enhanced by elaborating multiple layers, such as settlement data (Fig. 47). The advantage of a fully interactive GIS final product is that all possible facets and combinations can be manipulated by different end users to suit their specific requirements.

Metadata conforming to the Federal Geographic Data Committee's Content Standards for Digital Geospatial Metadata (FGDC-STD-001-1998) should be consulted for layer-specific information (see Appendix XVI for hardcopy example of this documentation). Note that the aerial image backgrounds were simply provided to enhance the presentation and interpretation of oyster data. They are copyrighted by the Commonwealth of Virginia (2002) and should not be reproduced for publication without proper licensing. A static text hardcopy of the metadata for this dataset is provided in Appendix XVII. Digital metadata for the layers produced by the Eastern Shore Lab accompany the data product (VIMS-ESL GIS-based Summary of Native Oyster Monitoring, by Mark W. Luckenbach and Paige G. Ross, August 26, 2008).

Figure 44. Example of GIS analysis showing shoreline and patch reef features by habitat type (see legend for details). This image shows a portion of Long Creek and the Humes Marsh Complex in the Lynnhaven River (see footnote bar for dates).

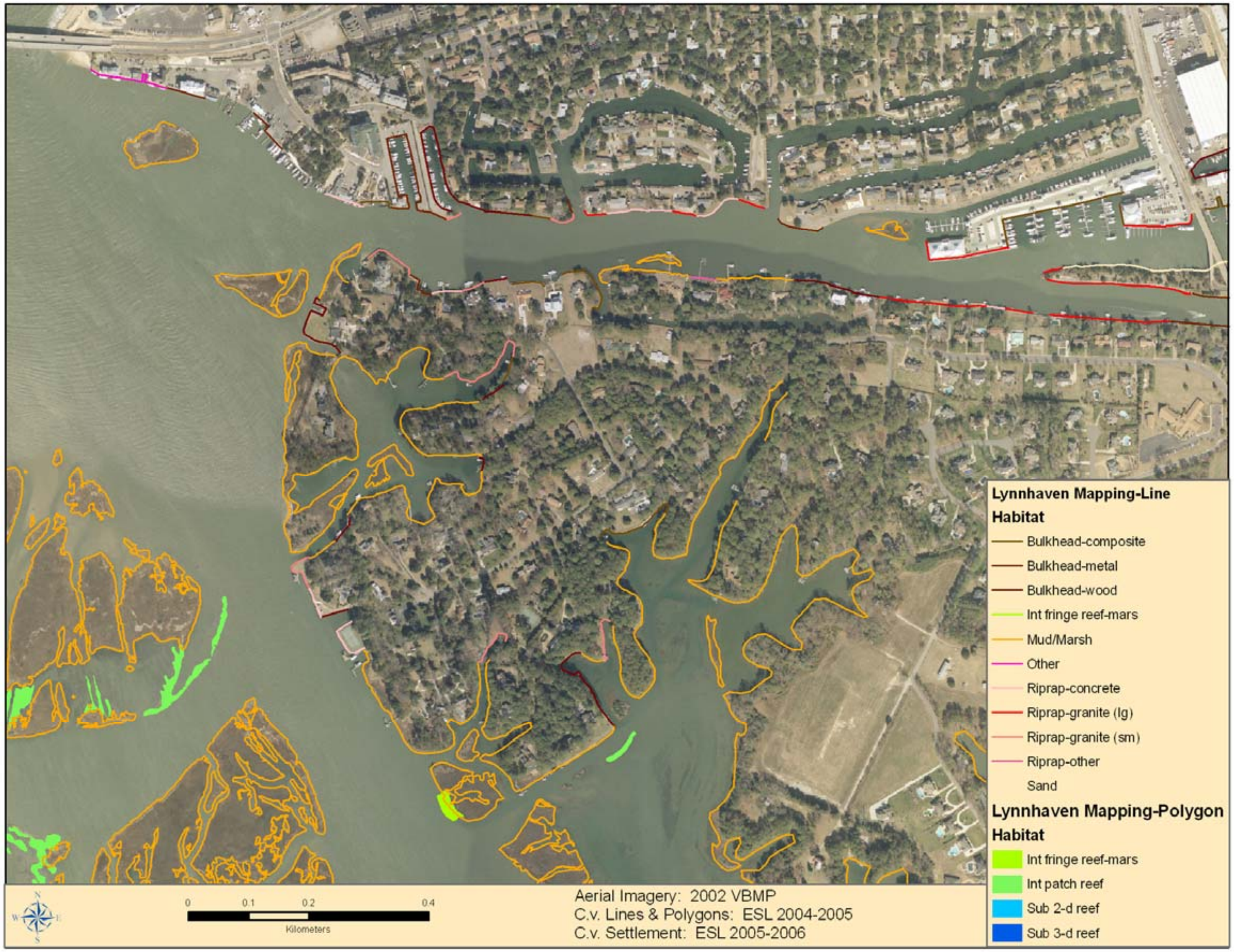


Figure 45. Example of GIS analysis showing shoreline and patch reef features by oyster density (# · m^2; see legend for details). This image shows a portion of the Humes Marsh Complex in the Lynnhaven River.

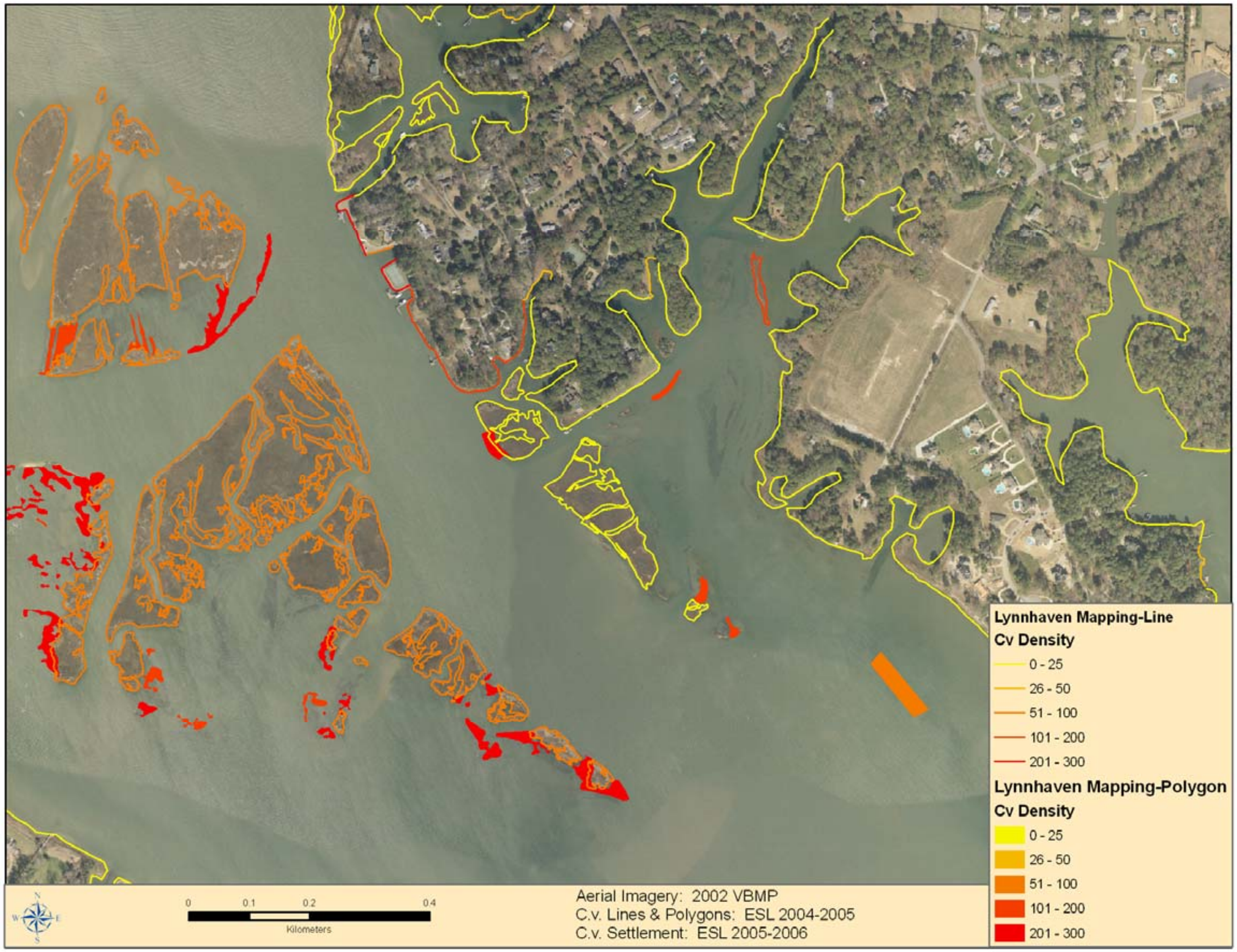


Figure 46. Example of GIS analysis showing shoreline and patch reef features by oyster density ($\# \cdot m^2$; see legend for details). This image shows a portion of Long Creek in the Lynnhaven River

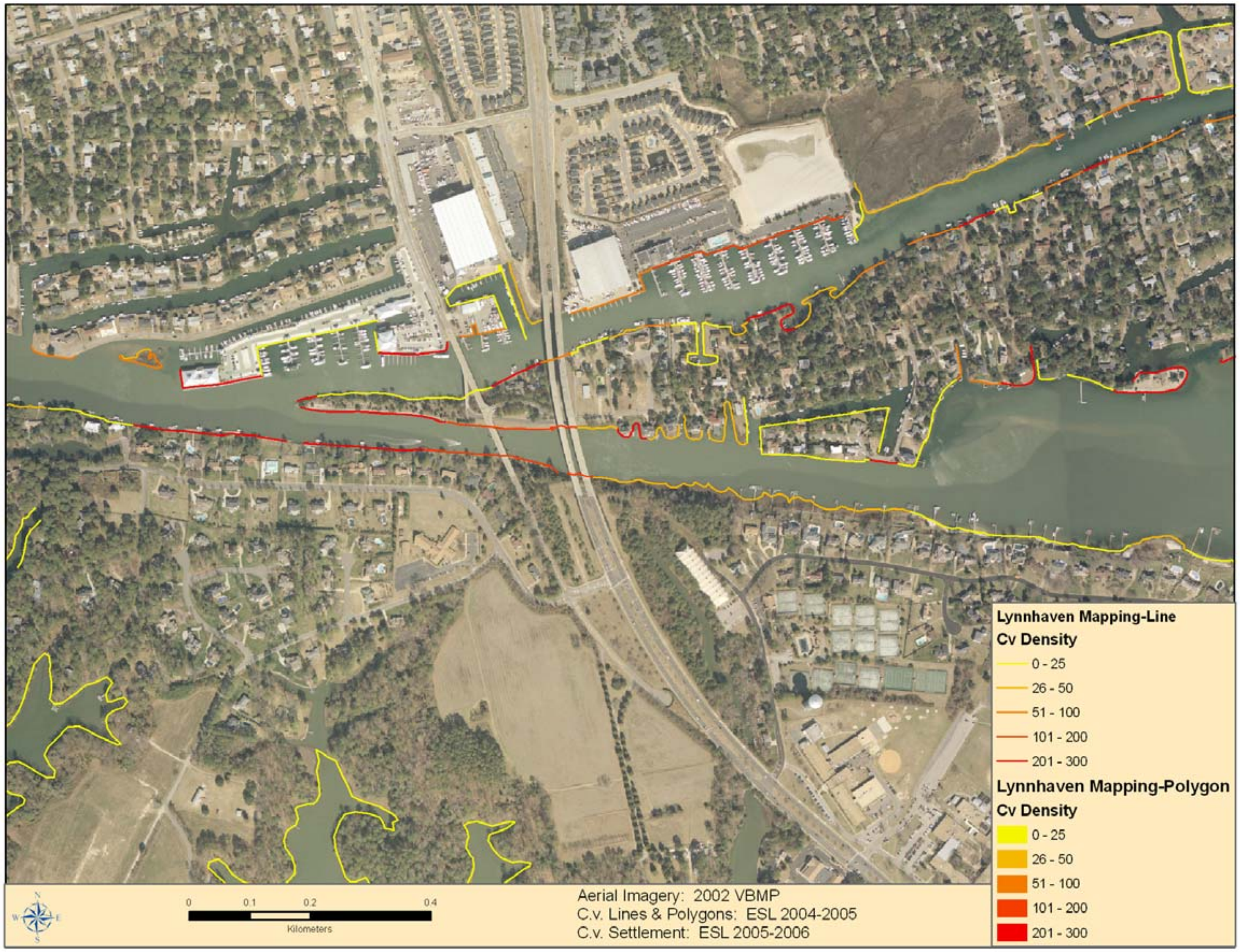
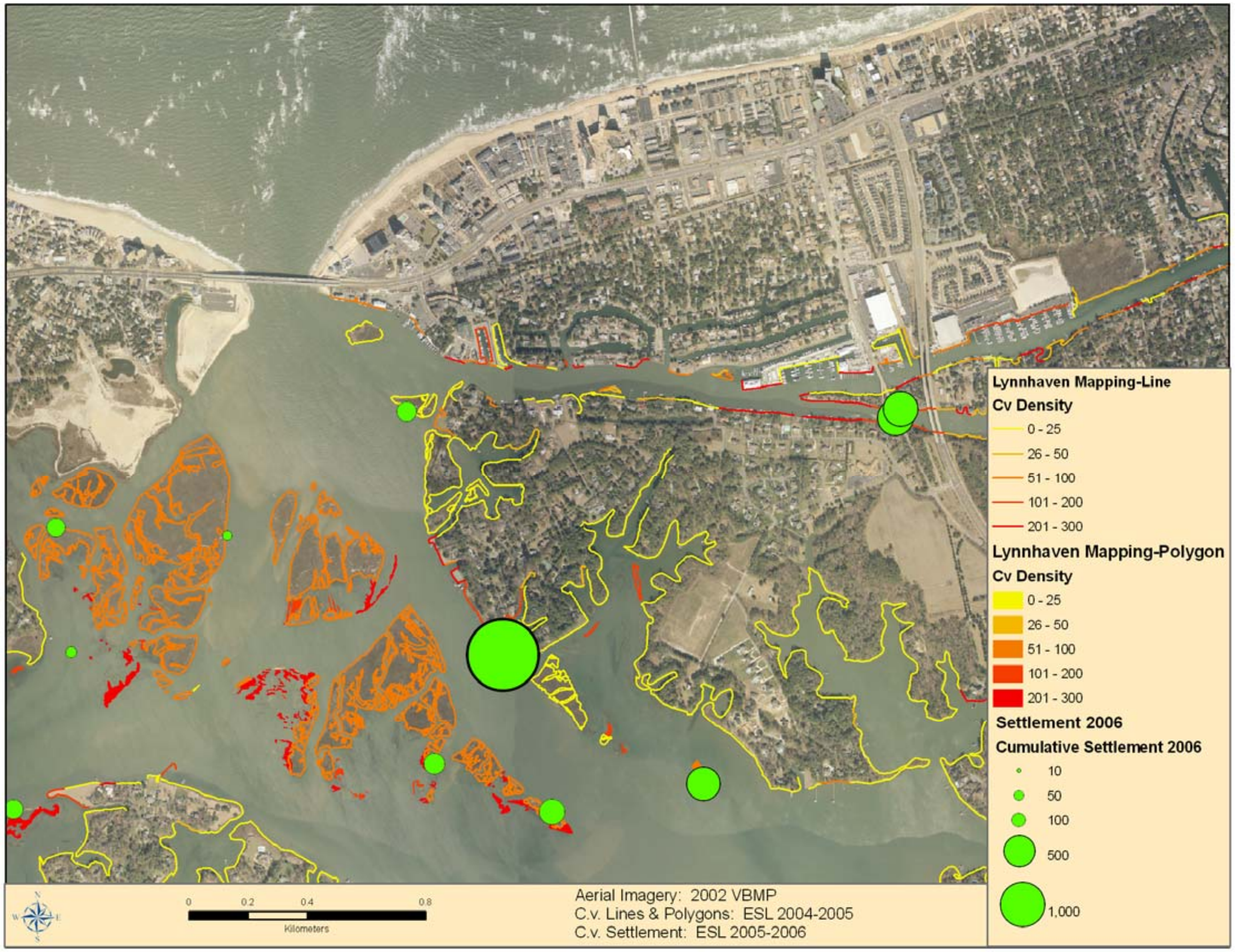


Figure 47. Example of GIS analysis showing shoreline and patch reef features by oyster density (# · m^2) and cumulative oyster settlement for 2006 (# · m^2; see legend for details). This image shows a portion of the Humes Marsh Complex in the Lynnhaven River.



APPENDICES

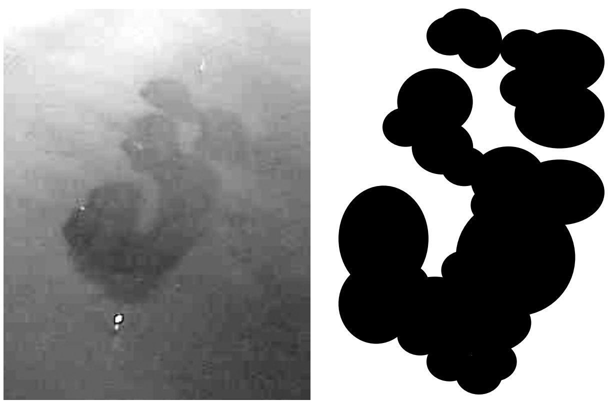
Appendix I. Latitude and longitude for study reefs.

Tributary	Reef	Lat. – Long.
Great Wicomico River	**Crane's Creek**	N 37° 48.521' W 076° 18.198'
	Shell Bar	N 37° 49.739' W 076° 19.102'
Lynnhaven River	**Great Neck Point**	N 36° 53.753' W 076° 05.016'
	Long Creek	N 36° 54.591' W 076° 02.381'
Piankatank River	**Burton's Point**	N 37° 30.690' W 076° 19.936'
	Palace Bar	N 37° 31.693' W 076° 22.433'
Rappahannock River	**Drumming Ground**	N 37° 39.248' W 076° 27.648'
	Parrots Rock	N 37° 36.443' W 076° 25.412'

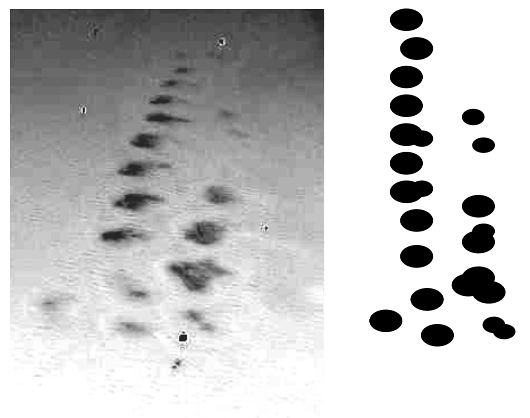
Appendix II. Digitally enhanced aerial photographs paired with aerial footprint schematics of individual shell mounds for each reef in this study.

A) Reefs in Great Wicomico River

<u>Crane's Creek Reef</u>

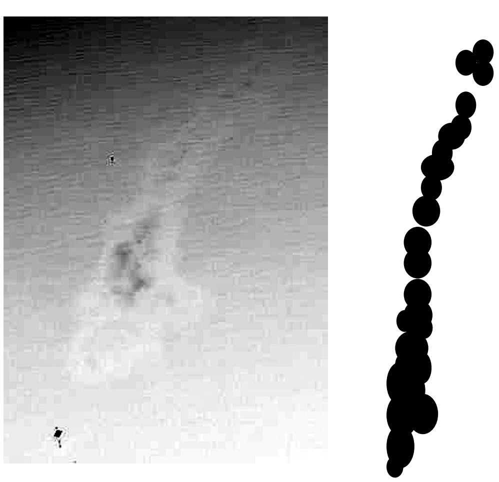


<u>Shell Bar Reef</u>

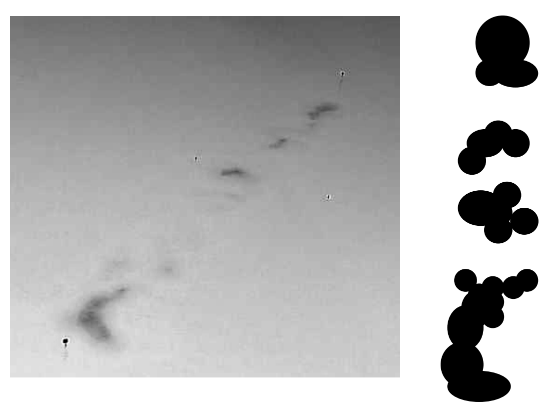


B) Reefs in Piankatank River

<u>Burton's Point Reef</u>



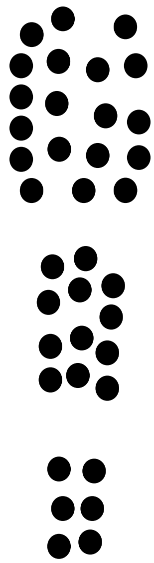
<u>Palace Bar Reef</u>



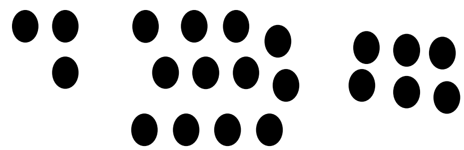
Appendix II (cont.). Digitally enhanced aerial photographs paired with aerial footprint schematics of individual shell mounds for each reef in this study.

C) Reefs in Rappahannock River

Drumming Ground Reef



Parrot's Rock Reef



D) Reefs in Lynnhaven River

Great Neck Point Reef

Long Creek Reef

Appendix III. Dates and durations for deployment of tile arrays for oyster settlement during 2004 for (A) Great Wicomico reefs, (B) Piankatank reefs and (C) Rappahannock reefs.

A) Great Wicomico reefs
- Total number of tiles deployed=1,248

Deployment #	Date Deployed	Date Retrieved	# Days in Field
1	5/24	6/8	14
2	6/8	6/22	13
3	6/22	7/6	13
4	7/6	7/21	14
5	7/21	7/28	6
6	7/28	8/4	6
7	8/4	8/11	6
8	8/11	8/17	5
9	8/17	8/24	6
10	8/24	8/31	6
11	8/31	9/14	13
12	9/14	9/27	12
13	10/5	10/12	6

B) Piankatank reefs
- Total number of tiles deployed=1,248

Deployment #	Date Deployed	Date Retrieved	# Days in Field
1	5/24	6/8	14
2	6/8	6/22	13
3	6/22	7/6	13
4	7/6	7/21	14
5	7/21	7/28	6
6	7/28	8/4	6
7	8/4	8/11	6
8	8/11	8/17	5
9	8/17	8/24	6
10	8/24	8/31	6
11	8/31	9/16	15
12	9/16	9/27	10
13	10/4	10/12	7

Appendix III (cont). Dates and durations for deployment of tile arrays for oyster settlement during 2004 for (A) Great Wicomico reefs, (B) Piankatank reefs and (C) Rappahannock reefs.

C) Rappahannock reefs
- Total number of tiles deployed=1,248

Deployment #	Date Deployed	Date Retrieved	# Days in Field
1[a]	5/24	6/8	14
2	6/8	6/22	13
3	6/22	7/6	13
4	7/6	7/21	14
5	7/21	7/28	6
6	7/28	8/4	6
7	8/4	8/11	6
8	8/11	8/17	5
9	8/17	8/24	6
10	8/24	8/31	6
11	8/31	9/14	13
12	9/14	9/27	12
13	10/4	10/12	7

[a] Drumming Ground deployed 5/25 for 13 days afield

Appendix IV. Dates and durations for deployment of tile arrays for oyster settlement during 2005 for (A) Great Wicomico reefs, (B) Piankatank reefs, (C) Rappahannock reefs and (D) Lynnhaven reefs and monitoring stations.

A) Great Wicomico reefs
- Total number of tiles deployed=1,344

Deployment #	Date Deployed	Date Retrieved	# Days in Field
1	5/25	6/8	14
2	6/8	6/21	13
3	6/21	7/6	15
4	7/6	7/19	13
5	7/19	7/26	7
6	7/26	8/5	10
7	8/5	8/11	6
8	8/11	8/16	5
9	8/16	8/24	8
10	8/24	8/30	6
11	8/30	9/13	14
12	9/13	9/28	15
13	9/28	10/19	21
14	10/19	11/1	13

B) Piankatank reefs
- Total number of tiles deployed=1,344

Deployment #	Date Deployed	Date Retrieved	# Days in Field
1	5/25	6/8	14
2	6/8	6/21	13
3	6/21	7/6	15
4	7/6	7/19	13
5	7/19	7/26	7
6	7/26	8/4	9
7	8/4	8/11	7
8	8/11	8/16	5
9	8/16	8/24	8
10	8/24	8/30	6
11	8/30	9/13	14
12	9/13	9/28	15
13	9/28	10/19	21
14	10/19	11/1	13

Appendix IV (cont). Dates and durations for deployment of tile arrays for oyster settlement during 2005 for (A) Great Wicomico reefs, (B) Piankatank reefs, (C) Rappahannock reefs and (D) Lynnhaven reefs and monitoring stations.

C) Rappahannock reefs
- Total number of tiles deployed=1,344

Deployment #	Date Deployed	Date Retrieved	# Days in Field
1	5/25	6/8	14
2	6/8	6/21	13
3	6/21	7/6	15
4	7/6	7/19	13
5	7/19	7/26	7
6	7/26	8/4	9
7	8/4	8/11	7
8	8/11	8/16	5
9	8/16	8/24	8
10	8/24	8/30	6
11	8/30	9/13	14
12	9/13	9/28	15
13	9/28	10/19	21
14	10/19	11/1	13

D) Lynnhaven reefs
- Total number of tiles deployed=2,244

Deployment #	Date Deployed	Date Retrieved	# Days in Field
1	5/25	6/8	14
2	6/8	6/20	12
3	6/20	7/5	15
4	7/5	7/20	15
5	7/20	7/27	7
6	7/27	8/2	6
7	8/2	8/10	8
8	8/10	8/16	6
9	8/16	8/23	7
10	8/23	8/30	7
11	8/30	9/8	9
12	9/8	9/16	8
13	9/16	9/26	10
14	9/26	10/4	8
15	10/4	10/12	8
16	10/12	10/17	5
17	10/17	10/26	9

Appendix V. Dates and durations for deployment of tile arrays for oyster settlement during 2006 for (A) Great Wicomico reefs, (B) Piankatank reefs, (C) Rappahannock reefs and (D) Lynnhaven reefs and monitoring stations.

A) Great Wicomico reefs
- Total number of tiles deployed=1,056

Deployment #	Date Deployed	Date Retrieved	# Days in Field
1	6/9	6/21	12
2	6/21	7/10	19
3	7/10	7/18	8
4	7/18	8/1	14
5	8/1	8/16	15
6	8/16	8/22	6
7	8/22	8/30	8
8	8/30	9/13	14
9	9/13	9/27	14
10	9/27	10/10	13
11	10/10	10/27	17

B) Piankatank reefs
- Total number of tiles deployed=1,056

Deployment #	Date Deployed	Date Retrieved	# Days in Field
1	6/9	6/21	12
2	6/21	7/10	19
3	7/10	7/18	8
4	7/17	8/1	15
5	8/1	8/16	15
6	8/16	8/22	6
7	8/22	8/30	8
8	8/30	9/13	14
9	9/13	9/27	14
10	9/27	10/10	13
11	10/10	1030	20

Appendix V (cont). Dates and durations for deployment of tile arrays for oyster settlement during 2006 for (A) Great Wicomico reefs, (B) Piankatank reefs (C) Rappahannock reefs, and (D) Lynnhaven reefs and monitoring stations.

C) Rappahannock reefs
- Total number of tiles deployed=1,056

Deployment #	Date Deployed	Date Retrieved	# Days in Field
1	6/9	6/21	12
2	6/21	7/10	19
3	7/10	7/18	8
4	7/17	8/1	15
5	8/1	8/16	15
6	8/16	8/22	6
7	8/22	8/30	8
8	8/30	9/13	14
9	9/13	9/27	14
10	9/27	10/10	13
11	10/10	1030	20

Appendix V (cont). Dates and durations for deployment of tile arrays for oyster settlement during 2006 for (A) Great Wicomico reefs, (B) Piankatank reefs (C) Rappahannock reefs, and (D) Lynnhaven reefs and monitoring stations.

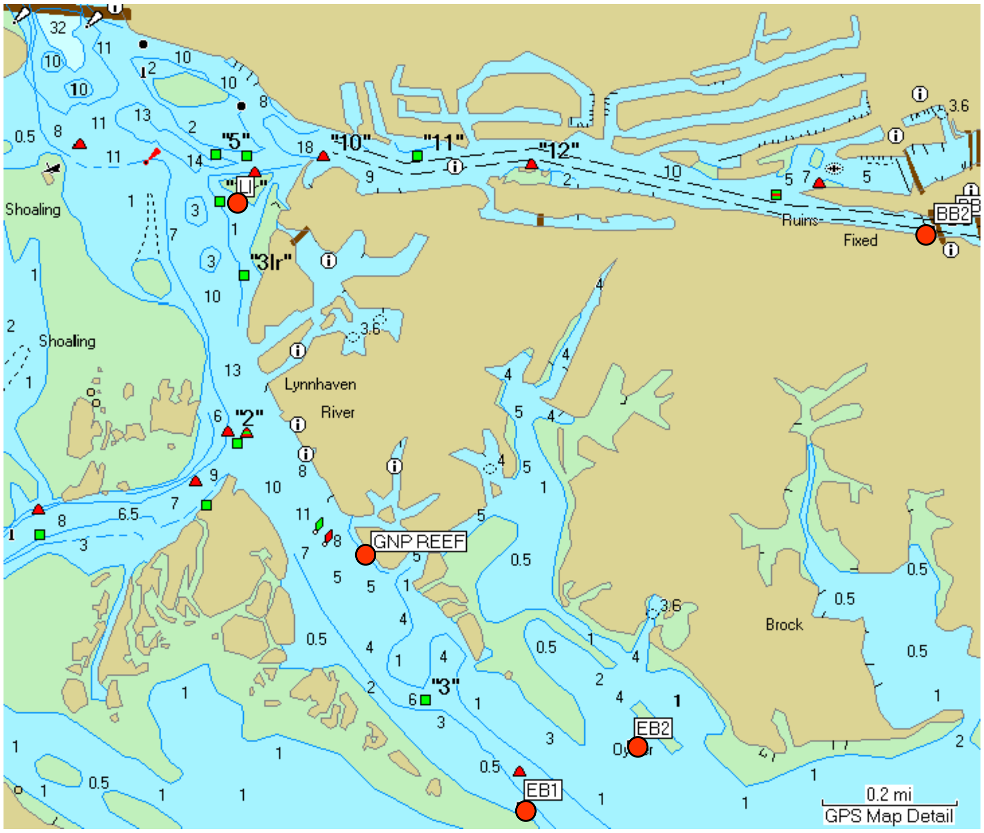
D) Lynnhaven reefs & monitoring stations
- Total number of tiles deployed=3,192

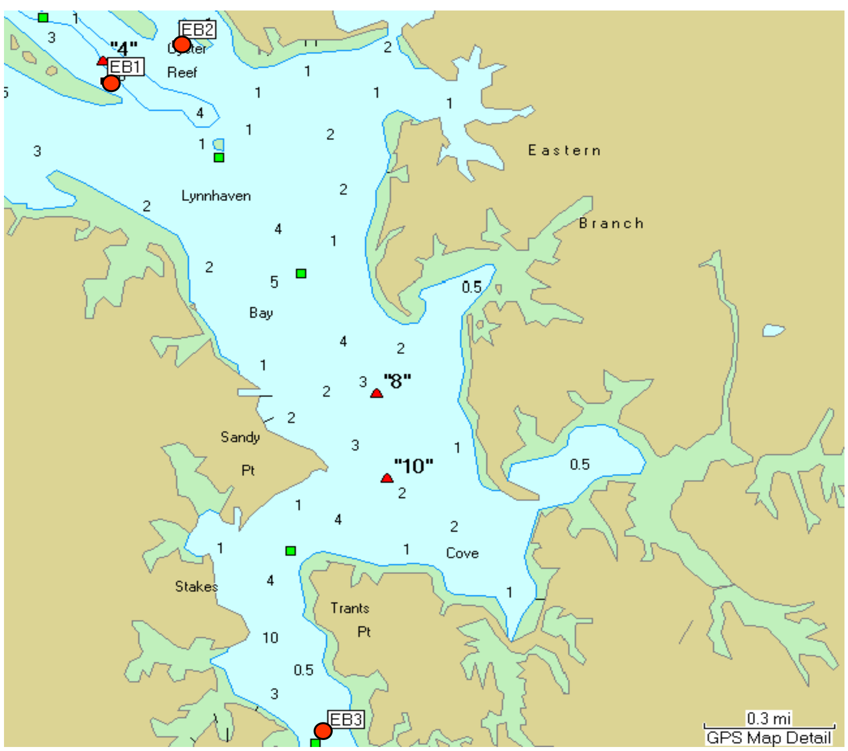
Deployment #	Date Deployed	Date Retrieved	# Days in Field
1	6/5	6/19	14
2	6/19	6/28	9
3	6/28	7/5	7
4	7/5	7/12	7
5	7/12	7/19	7
6	7/19	7/27	8
7	7/27	8/1	5
8	8/1	8/8	7
9	8/8	8/15	7
10	8/15	8/21	6
11	8/21	8/28	7
12	8/28	9/7	10
13	9/7	9/12	5
14	9/12	9/19	7
15	9/19	9/25	6
16	9/25	10/2	7
17	10/2	10/16	14
18	10/16	10/25	9
19	10/25	11/2	8

Appendix VI. Abbreviations for settlement monitoring stations in the Lynnhaven River.

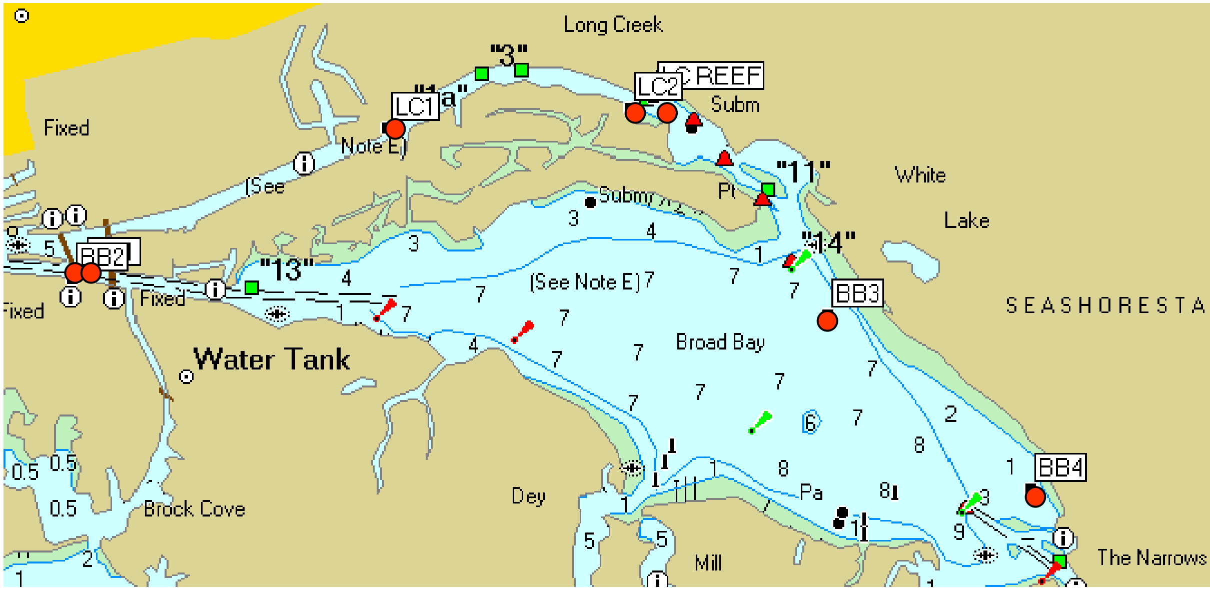
Station Abbrviation	Station Name
BB1	Broad Bay 1
BB2	Broad Bay 2
BB3	Broad Bay 3
BB4	Broad Bay 4
EB1	Eastern Branch 1
EB2 (KD FOR 2006)	Eastern Branch 2 (2005); Keeling Drain reef (2006)
EB3	Eastern Branch 3
LC1	Long Creek 1
LC2	Long Creek 2
LI	Lynnhaven Inlet
WB1	Western Branch 1
WB2	Western Branch 2
WB3	Western Branch 3
WB4	Western Branch 4
BB5	Broad Bay 5
HMC1	Humes Marsh Complex 1
HMC2	Humes Marsh Complex 2
HMC3	Humes Marsh Complex 3
HMC4	Humes Marsh Complex 4
HMC5	Humes Marsh Complex 5
LB1	Linkhorn Bay 1
LB2	Linkhorn Bay 2

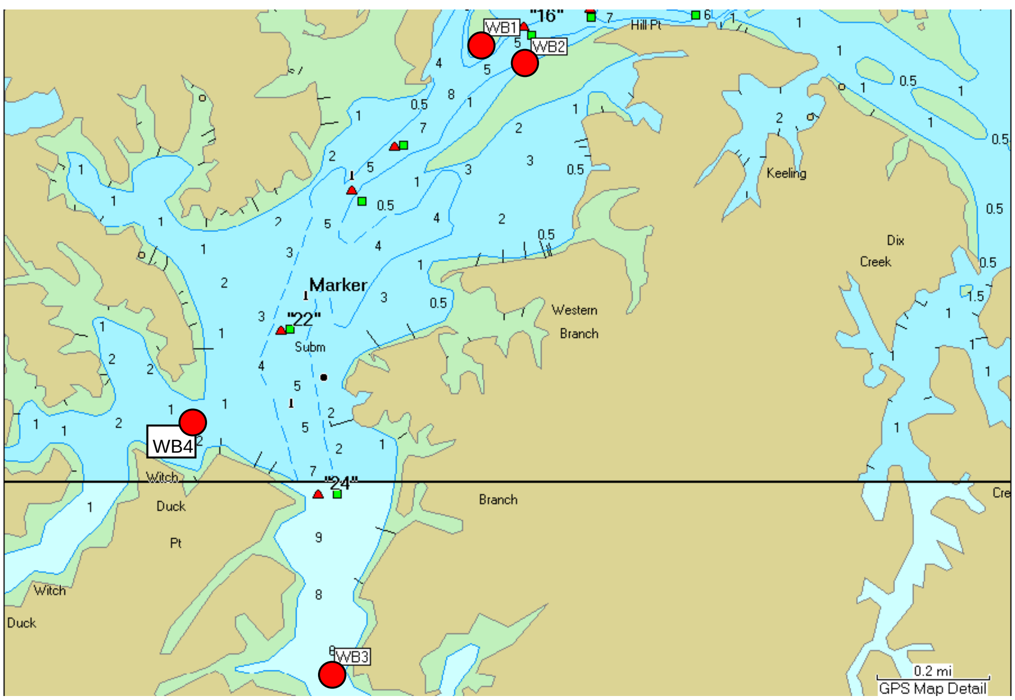
Appendix VII. Specific Lynnhaven settlement tile locations for 2005 (note that several sites appear on more than one close-up; see Figure 9 for overall map).



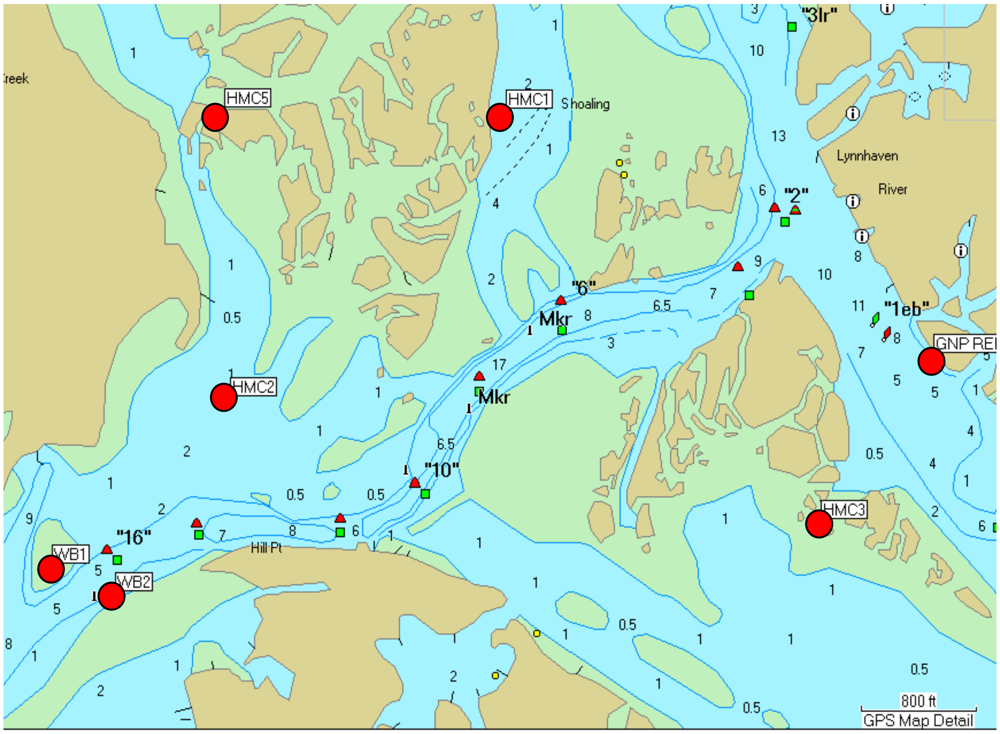


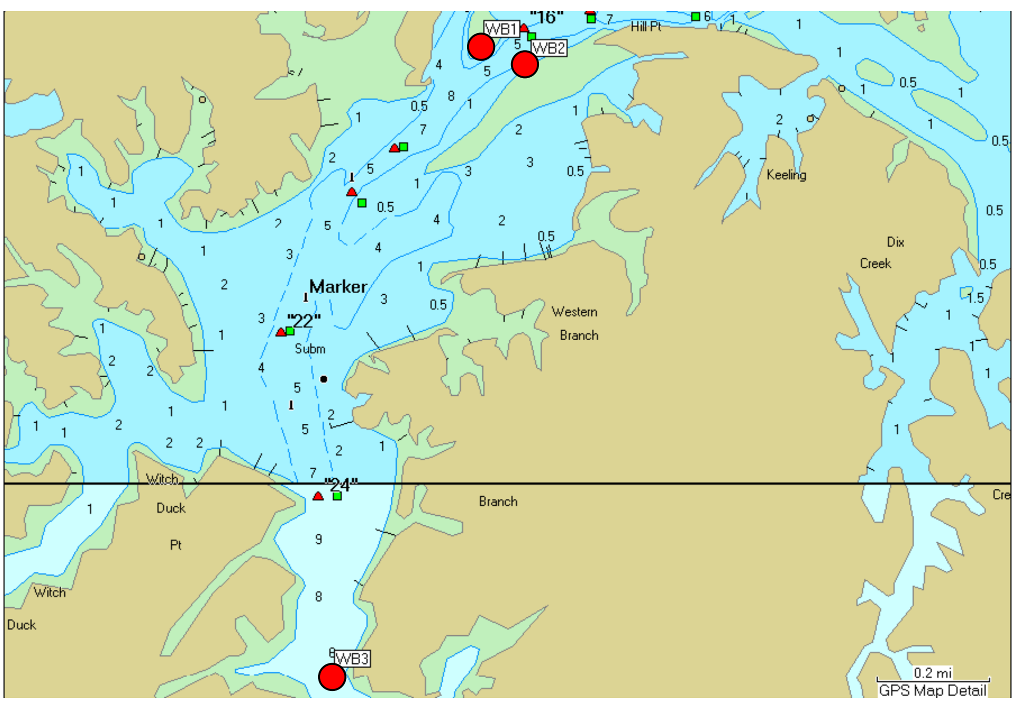
Appendix VII (cont.). Specific Lynnhaven settlement tile locations for 2005 (note that several sites appear on more than one close-up; see Figure 9 for overall map).



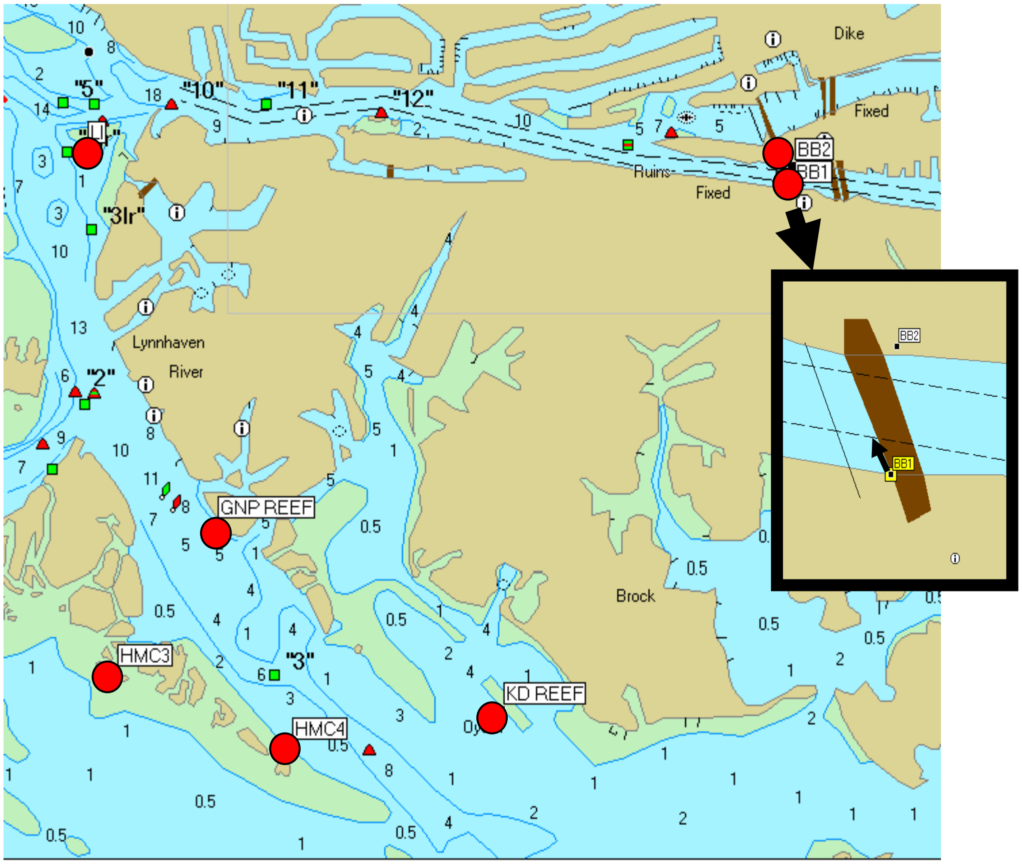


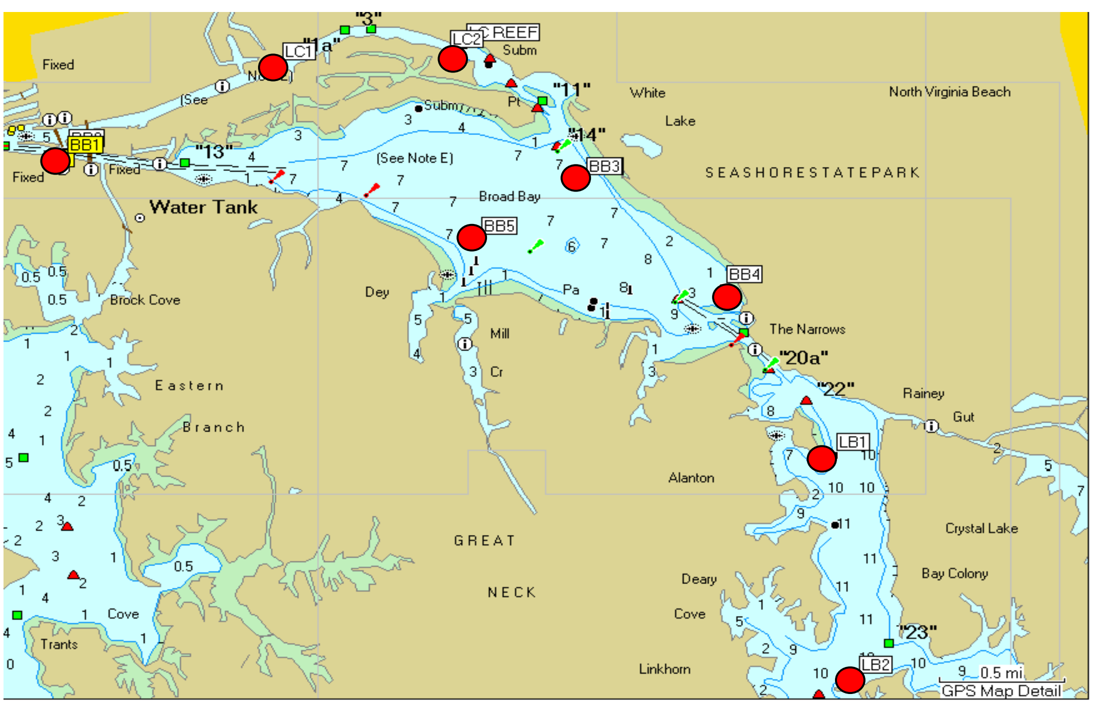
Appendix VIII Specific Lynnhaven settlement tile locations for 2006 (note that several sites appear on more than one close-up; see Figure 10 for overall map).



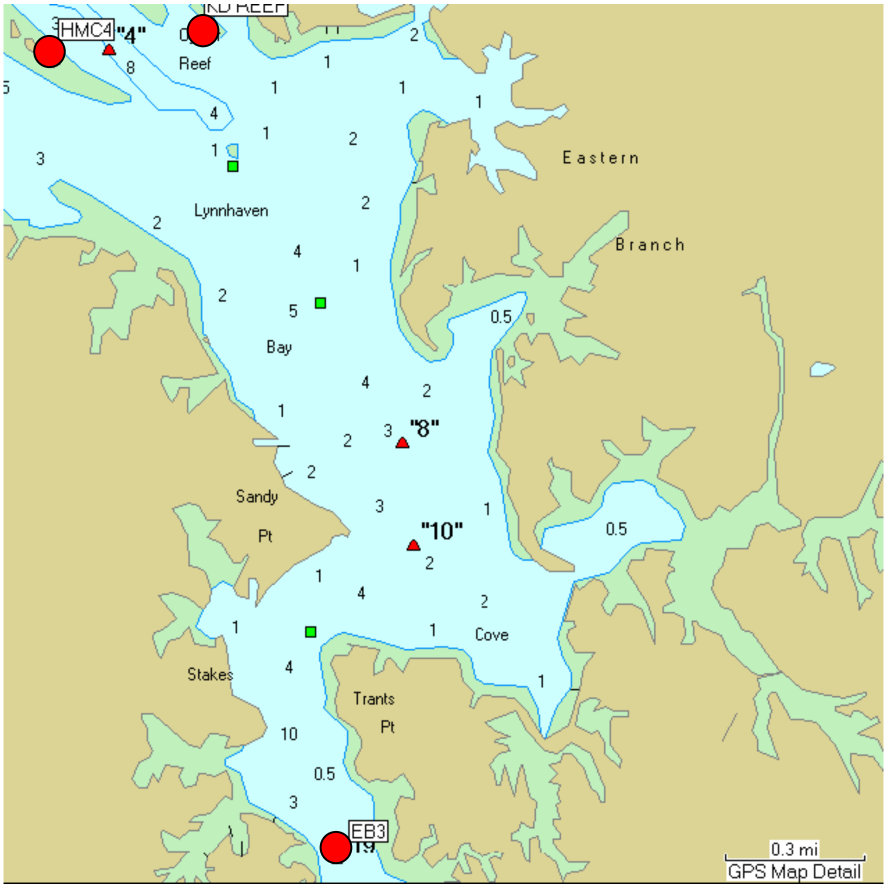


Appendix VIII (cont.). Specific Lynnhaven settlement tile locations for 2006 (note that several sites appear on more than one close-up; see Figure 10 for overall map).





Appendix VIII(cont.). Specific Lynnhaven settlement tile locations for 2006 (note that several sites appear on more than one close-up; see Figure 10 for overall map).



Appendix IX– Time frames and types of replicate samples collected at reefs in this study for 2004-2006. See footnote for explanation of reef abbreviations. Sample types are denoted by: Q=quadrate, D=dredge, T=transect (see methodology section for descriptions).

		Reefs[a]							
Season	**Sample Time Frame**	**Great Wicomico**		**Piankatank**		**Rapp.**		**Lynnhaven**	
		CC	**SB**	**BP**	**PB**	**DG**	**PR**	**GN**	**LC**
Spring 2004	May	Q	Q	Q	Q	Q	Q	-	-
Summer 2004	July	Q	Q,T	Q	Q	Q	Q	-	-
Fall 2004	October	Q	Q,T	Q	Q	Q	Q	-	-
Spring 2005	May/June	Q	Q,T	Q	Q	Q	Q	Q	Q
Summer 2005	August	Q	Q,T	Q	Q	Q	Q	Q	Q
Fall 2005	October	-	Q,T	-	-	-	-	Q	Q
Spring 2006	May	-	-	-	-	-	-	Q	Q
Summer 2006	July	D	Q[b]	D	D	D	D	Q	Q
Fall 2006	October	D	D	D	D	D	D	Q	Q

[a] See Table 1 for reef abbreviations
[b] Quadrates collected by VMRC and delivered to VIMS-ESL for further processing

Appendix X – Mean (+/- SE) % clean shell, % *Cliona* prevalence, and reef particle size (mm^2) for each reef sampled during each season during 2004, 2005 and 2006. See Table 1 for reef abbreviations.

			% Clean Shell			% Cliona Prevalence			Reef Particle Size (mm^2)		
RIVER	**REEF**	**DATE**	**N**	**MEAN**	**SE**	**N**	**MEAN**	**SE**	**N**	**MEAN**	**SE**
GW	CC	5/24/04	6	76.7	3.6	6	74.7	9.3	88	2189.4	189.8
GW	CC	7/14/04	6	78.3	6.4	6	89.0	6.3	60	2600.9	196.8
GW	CC	10/5/04	6	64.4	6.7	6	85.5	7.5	156	1598.9	114.5
GW	CC	8/5/05	6	65.9	5.7	6	100.0	0.0	102	1913.7	156.1
GW	CC	7/18/06	4	18.8	6.6	4	97.9	1.2	97	2691.2	183.2
GW	CC	10/19/06	4	40.3	5.2	4	92.0	5.3	39	3136.4	288.8
GW	SB	5/24/04	6	72.1	8.5	6	69.8	8.4	162	1358.6	129.5
GW	SB	7/14/04	6	85.8	4.1	6	71.6	12.5	105	1423.9	141.3
GW	SB	10/5/04	6	83.4	3.8	6	86.8	4.4	153	1454.8	100.5
GW	SB	6/10/05	6	78.0	5.2	6	77.6	7.1	107	1668.0	156.7
GW	SB	8/5/05	6	90.3	3.7	6	84.5	5.2	80	1565.3	141.5
GW	SB	10/19/05	6	85.3	5.8	6	83.8	7.2	174	1258.3	102.6
GW	SB	7/18/06	4	77.1	10.4	4	87.0	8.1	152	1568.0	116.8
GW	SB	11/9/06	4	88.6	0.4	4	100.0	0.0	42	2579.2	221.8
PIANK	BP	5/24/04	6	80.0	4.2	6	68.7	5.7	146	1495.3	139.8
PIANK	BP	7/14/04	6	95.8	1.2	6	75.5	6.2	244	784.0	73.3
PIANK	BP	10/5/04	6	91.7	1.2	6	79.7	4.9	149	1455.7	128.6
PIANK	BP	5/16/05	6	59.5	4.7	5	90.6	2.6	.	.	.
PIANK	BP	8/4/05	.	.	.	6	93.5	4.1	51	881.4	186.5
PIANK	BP	7/18/06	4	52.4	6.6	4	94.2	2.3	104	2204.4	126.7
PIANK	BP	10/19/06	4	95.5	1.0	4	98.2	1.8	43	3489.7	305.9
PIANK	PB	5/24/04	6	70.1	15.2	6	55.7	16.5	477	489.1	36.9
PIANK	PB	7/14/04	6	82.5	5.9	6	87.5	5.1	135	1136.7	125.7
PIANK	PB	10/5/04	6	66.5	3.5	6	69.6	12.3	378	541.3	45.6
PIANK	PB	5/16/05	6	91.5	1.0	6	67.0	13.2	.	.	.
PIANK	PB	8/4/05	.	.	.	6	63.7	15.8	12	3555.0	600.1
PIANK	PB	7/18/06	6	36.7	5.3	6	93.0	2.2	290	1187.9	69.9
PIANK	PB	10/19/06	4	97.9	1.3	4	100.0	0.0	45	2616.4	237.7
RAPP	DG	5/24/04	6	76.6	6.1	6	38.0	14.4	410	769.9	47.7
RAPP	DG	7/14/04	6	92.8	4.8	6	30.4	15.4	555	389.2	18.7
RAPP	DG	10/5/04	6	86.9	4.1	6	36.3	17.4	600	506.0	18.6

RIVER	REEF	DATE	% Clean Shell N	% Clean Shell MEAN	% Clean Shell SE	% Cliona Prevalence N	% Cliona Prevalence MEAN	% Cliona Prevalence SE	Reef Particle Size (mm^2) N	Reef Particle Size (mm^2) MEAN	Reef Particle Size (mm^2) SE
RAPP	DG	5/16/05	6	71.2	8.0	6	39.8	16.3	759	330.3	12.0
RAPP	DG	8/4/05	6	63.3	2.4	6	47.9	17.1	643	493.4	15.6
RAPP	DG	7/18/06	4	69.8	7.5	4	47.5	4.6	282	988.6	46.0
RAPP	DG	10/19/06	4	85.5	3.2	4	83.8	5.6	176	949.6	56.2
RAPP	PR	5/24/04	6	88.8	3.3	6	65.2	5.8	164	1462.4	152.3
RAPP	PR	7/14/04	6	84.4	2.7	6	84.9	10.3	160	1395.4	118.7
RAPP	PR	10/5/04	6	76.8	4.8	6	75.7	9.1	178	1292.8	112.0
RAPP	PR	5/16/05	6	73.7	6.2	5	87.0	6.9	72	1459.1	174.2
RAPP	PR	8/4/05	6	66.5	7.4	6	89.5	4.7	62	2346.1	244.0
RAPP	PR	7/18/06	4	43.8	6.6	4	93.5	3.4	107	2442.2	152.5
RAPP	PR	10/19/06	4	70.1	7.0	4	96.7	1.9	50	2714.3	238.5
LYNN	GN	7/5/05	5	91.4	1.9	6	86.7	4.3	67	1678.8	179.1
LYNN	GN	8/2/05	6	82.9	5.3	6	91.3	3.9	71	1992.3	201.7
LYNN	GN	10/17/05	5	90.9	2.5	6	95.4	2.1	.	.	.
LYNN	GN	05/31/06	6	52.6	9.2	.	.	.	170	1390.6	117.5
LYNN	GN	7/18/06	4	74.9	8.8	4	50.7	9.9	164	2716.9	486.1
LYNN	GN	10/20/06	4	83.8	7.1	4	84.4	8.7	116	1533.2	121.3
LYNN	LC	7/5/05	6	83.3	6.8	6	94.5	2.5	70	2760.7	194.7
LYNN	LC	8/2/05	6	86.8	4.4	5	100.0	0.0	22	2503.7	354.4
LYNN	LC	10/17/05	6	69.6	6.6	6	98.7	1.3	.	.	.
LYNN	LC	05/31/06	6	74.3	11.0	.	.	.	95	2665.0	167.4
LYNN	LC	7/18/06	4	83.3	6.5	4	89.7	4.6	106	1904.2	140.1
LYNN	LC	10/20/06	4	96.4	2.2	4	90.2	3.8	94	4242.3	700.3

Appendix XI – Details of replicate transects sampled at Shell Bar Reef in this study for 2004-2005 (see methodology section for sampling descriptions).

Season	Date	Transect #	Transect Length (m)	# of Quadrates
Summer 2004	7/13	1	14	8
		2	8	5
		3	10	6
Fall 2004	10/5	1	8	5
		2	6	4
		3	8	5
Spring 2005	6/10	1	10	6
		2	8	5
		3	18	10
Summer 2005	8/5	1	14	8
		2	6	4
		3	6	4
Fall 2005	10/19	1	8	5
		2	16	9
		3	8	5

Appendix XII – Density of live and box oysters (# · m^{-2}) and mean (+/- SE) shell height (mm) for each quadrate collected along replicate transects during the post-deployment evaluation at Shell Bar Reef from summer 2004 through fall 2005.

							Live Oyster Shellheight	
Season	**Sample Date**	**Rep.**	**Dist. From Crest (m)**	**% from Crest to Seabed**	**Live Oyster Density**	**Box Oyster Density**	**Mean**	**SE**
Summer 2004	7/13/04	1	0	0.000	48	0	63.1	17.5
Summer 2004	7/13/04	1	2	0.143	80	0	57.8	6.1
Summer 2004	7/13/04	1	4	0.286	176	0	49.7	7.5
Summer 2004	7/13/04	1	6	0.429	160	16	48.2	5.9
Summer 2004	7/13/04	1	8	0.571	96	0	58.5	8.6
Summer 2004	7/13/04	1	10	0.714	64	0	60.0	2.7
Summer 2004	7/13/04	1	12	0.857	112	16	59.4	3.4
Summer 2004	7/13/04	1	14	1.000	0	0	.	.
Summer 2004	7/13/04	2	0	0.000	48	32	50.6	1.4
Summer 2004	7/13/04	2	2	0.250	272	32	60.2	2.6
Summer 2004	7/13/04	2	4	0.500	144	32	61.8	4.6
Summer 2004	7/13/04	2	6	0.750	144	32	60.6	3.6
Summer 2004	7/13/04	2	8	1.000	0	0	.	.
Summer 2004	7/13/04	3	0	0.000	32	0	32.0	6.0
Summer 2004	7/13/04	3	2	0.200	80	0	46.4	6.1
Summer 2004	7/13/04	3	4	0.400	32	16	62.8	1.4
Summer 2004	7/13/04	3	6	0.600	96	32	62.3	4.6
Summer 2004	7/13/04	3	8	0.800	128	0	62.3	3.5
Summer 2004	7/13/04	3	10	1.000	0	0	.	.
Fall 2004	10/5/04	1	0	0.000	48	32	49.9	7.7
Fall 2004	10/5/04	1	2	0.250	192	48	59.6	4.7
Fall 2004	10/5/04	1	4	0.500	176	0	60.1	3.4
Fall 2004	10/5/04	1	6	0.750	64	48	73.2	5.9
Fall 2004	10/5/04	1	8	1.000	0	0	.	.
Fall 2004	10/5/04	2	0	0.000	0	0	.	.
Fall 2004	10/5/04	2	2	0.333	0	32	.	.
Fall 2004	10/5/04	2	4	0.667	128	80	59.8	3.1
Fall 2004	10/5/04	2	6	1.000	16	0	54.4	.
Fall 2004	10/5/04	3	0	0.000	48	32	44.7	2.8
Fall 2004	10/5/04	3	2	0.250	0	0	.	.
Fall 2004	10/5/04	3	4	0.500	96	96	51.0	8.9
Fall 2004	10/5/04	3	6	0.750	64	48	56.4	4.8
Fall 2004	10/5/04	3	8	1.000	176	80	61.5	2.8
Spring 2005	6/10/05	1	0	0.000	0	0	.	.
Spring 2005	6/10/05	1	2	0.200	0	0	.	.
Spring 2005	6/10/05	1	4	0.400	496	32	34.2	1.4
Spring 2005	6/10/05	1	6	0.600	400	128	56.9	2.3
Spring 2005	6/10/05	1	8	0.800	816	80	56.9	1.6
Spring 2005	6/10/05	1	10	1.000	64	32	62.9	7.0

Appendix XII (cont.) – Density of live and box oysters (# · m^{-2}) and mean (+/- SE) shell height (mm) for each quadrate collected along replicate transects during the post-deployment evaluation at Shell Bar Reef from summer 2004 through fall 2005.

							Live Oyster Shellheight	
Season	Sample Date	Rep.	Dist. From Crest (m)	% from Crest to Seabed	Live Oyster Density	Box Oyster Density	Mean	SE
Spring 2005	6/10/05	2	0	0.000	0	0	.	.
Spring 2005	6/10/05	2	2	0.250	512	96	57.3	1.6
Spring 2005	6/10/05	2	4	0.500	144	64	46.0	5.2
Spring 2005	6/10/05	2	6	0.750	48	16	62.2	5.1
Spring 2005	6/10/05	2	8	1.000	0	16	41.3	.
Spring 2005	6/10/05	3	0	0.000	80	48	31.5	3.2
Spring 2005	6/10/05	3	2	0.111	16	0	50.2	.
Spring 2005	6/10/05	3	4	0.222	64	16	62.6	6.6
Spring 2005	6/10/05	3	6	0.333	208	16	54.6	3.1
Spring 2005	6/10/05	3	8	0.444	256	128	51.1	2.5
Spring 2005	6/10/05	3	10	0.556	1248	0	54.1	1.3
Spring 2005	6/10/05	3	12	0.667	832	112	57.1	1.9
Spring 2005	6/10/05	3	14	0.778	32	32	62.8	5.1
Spring 2005	6/10/05	3	16	0.889	624	128	56.9	2.5
Spring 2005	6/10/05	3	18	1.000	464	64	44.4	1.2
Summer 2005	8/5/05	1	0	0.000	1104	112	37.5	0.9
Summer 2005	8/5/05	1	2	0.143	432	96	46.8	1.3
Summer 2005	8/5/05	1	4	0.286	608	240	41.5	1.2
Summer 2005	8/5/05	1	6	0.429	768	96	53.7	1.6
Summer 2005	8/5/05	1	8	0.571	256	64	50.5	1.3
Summer 2005	8/5/05	1	10	0.714	16	160	52.5	.
Summer 2005	8/5/05	1	12	0.857	352	96	56.4	2.3
Summer 2005	8/5/05	1	14	1.000	176	80	61.7	4.1
Summer 2005	8/5/05	2	0	0.000	112	48	10.9	1.5
Summer 2005	8/5/05	2	2	0.333	64	16	10.3	0.8
Summer 2005	8/5/05	2	4	0.667	528	80	56.3	1.7
Summer 2005	8/5/05	2	6	1.000	256	144	66.6	2.6
Summer 2005	8/5/05	3	0	0.000	64	16	47.2	14.9
Summer 2005	8/5/05	3	2	0.333	32	0	32.8	25.3
Summer 2005	8/5/05	3	4	0.667	112	64	46.3	5.4
Summer 2005	8/5/05	3	6	1.000	64	64	39.6	17.9
Fall 2005	10/19/05	1	0	0.000	384	16	59.3	3.0
Fall 2005	10/19/05	1	2	0.250	240	48	48.1	1.6
Fall 2005	10/19/05	1	4	0.500	1120	304	50.6	1.0
Fall 2005	10/19/05	1	6	0.750	192	272	51.8	2.9
Fall 2005	10/19/05	1	8	1.000	64	80	42.9	3.9

Appendix XII (cont.) – Density of live and box oysters (# · m^{-2}) and mean (+/- SE) shell height (mm) for each quadrate collected along replicate transects during the post-deployment evaluation at Shell Bar Reef from summer 2004 through fall 2005.

							Live Oyster Shellheight	
Season	Sample Date	Rep.	Dist. From Crest (m)	% from Crest to Seabed	Live Oyster Density	Box Oyster Density	Mean	SE
Fall 2005	10/19/05	2	0	0.000	1456	96	55.3	1.2
Fall 2005	10/19/05	2	2	0.125	336	192	53.7	2.7
Fall 2005	10/19/05	2	4	0.250	16	16	41.3	.
Fall 2005	10/19/05	2	6	0.375	224	64	66.5	2.9
Fall 2005	10/19/05	2	8	0.500	336	48	55.9	2.8
Fall 2005	10/19/05	2	10	0.625	416	272	62.9	2.2
Fall 2005	10/19/05	2	12	0.750	464	112	60.2	2.4
Fall 2005	10/19/05	2	14	0.875	448	144	59.1	2.4
Fall 2005	10/19/05	2	16	1.000	64	32	64.7	8.1
Fall 2005	10/19/05	3	0	0.000	32	0	39.2	1.1
Fall 2005	10/19/05	3	2	0.250	32	32	51.3	25.3
Fall 2005	10/19/05	3	4	0.500	80	32	40.1	3.6
Fall 2005	10/19/05	3	6	0.750	16	16	33.1	.
Fall 2005	10/19/05	3	8	1.000	624	128	39.5	1.1

Appendix XIII. Trimble® GPS, field data collector and post-processing proprietary software used to map oyster habitat in the Lynnhaven River. For other questions or more details, please contact the authors.

Pro XR™ *GPS Receiver* with remote mushroom antenna as a backpack unit (12-channel, DGPS & WAAS signal ready, 1 Hz update time, sub-meter accuracy with real-time WAAS correction)

Ranger GIS TSCe Data Collector™ (color TFT screen, Windows CE.NET, 64MB RAM, 512MB Flash, 209 Mhz processor, two data ports: DB9 & 17-pin to DB adapter)

TerraSync Professional™ for linking unit to GPS and *ActivSync* software for linking unit to office computer

GPS Pathfinder Office™ software for post-processing data

Appendix XIV. Some GPS and mapping export settings for field files collected during initial mapping of oyster habitats in the Lynnhaven River. Some parameters and their values are discussed in the Methods section.

Setup Used:	New dBASE
Export Format:	dBASE
Data Type:	Features
Feature Selection:	Export All Features
Not In Feature Positions:	Not Used
Export Notes:	No
Export Velocity Records:	No
Export Sensor Records:	No
Export Menu Attribute As:	Attribute Value
Generated Attributes:	GPS Length
	GPS Area
	GPS Perimeter
Filter By:	GPS Criteria
Maximum PDOP:	Any
Maximum HDOP:	Any
Min Number Of SVs:	2D (3 or more SVs)
Uncorrected:	No
P(Y) Code:	Yes
Real-time WAAS:	Yes
Real-time Code:	Yes
Postprocessed Code:	Yes
Real-time Carrier Float:	Yes
Postprocessed Carrier Float:	Yes
RTK Fixed:	Yes
Postprocessed Carrier Fixed:	Yes
Non-GPS:	Yes
Coordinate System:	US State Plane 1983
Coordinate Zone:	Virginia South 4502
Datum:	NAD 1983 (Conus)
Coordinate Units:	Feet
Altitude Units:	Feet
Altitude Reference:	MSL
Geoid Model:	GEOID99 (Conus)
Include Altitude:	No
Distance Units:	Meters
Area Units:	Square Meters
Velocity Units:	Kilometers Per Hour
Precision Units:	Meters
North/East DP:	3
Altitude DP:	3
Distance DP:	3
Area DP:	3

Appendix XV. Data dictionary used with Trimble Data Logger to collect descriptive information during initial habitat mapping. Attributes are bold with details following.

"Lynn. Init. Mapping", Dictionary, "Version: 4/1/05"

Technician, menu, required, normal, Label1
"Ross"
"Birch"
Basin Section, menu, normal, "See reference map", normal, Label2
"Broad Bay"
"Long Creek"
"Eastern Branch"
"Western Branch"
"Lynnhaven Bay"
"Lynnhaven River"
Density Zone, menu, normal, "See Reference map", normal
"Low"
"Medium"
"High"
"Ultra-High"
Adjacent Water Depth, menu, required, "Estimate for mean low water", required
"Ebbed out at low"
"0.1-1 m at low"
">1m at low"
Tidal Stage, menu, required, "Estimate to nearest", required
"High"
"Mid Ebb"
"Low"
"Mid Flood"
Habitat, menu, required, "See reference description for details", required
"Sub 2-d reef"
"Sub 3-d reef"
"Int patch reef"
"Int fringe reef-mars"
"Int fringe reef-mud"
"Mudflat-subtidal"
"Mudflat-intertidal"
"Mud/Marsh"
"High Marsh"
"Riprap-granite (sm)"
"Riprap-granite (lg)"
"Riprap-gabion bag"
"Riprap-concrete"
"Riprap-other"
"Bulkhead-wood"
"Bulkhead-metal"
"Bulkhead-composite"
"Pilings/dock"
"Other"
Habitat Subtype, menu, required, required
"Natural"
"Private Built"
"State Built"
"Unknown"

Appendix XV (cont.). Data dictionary used with Trimble Data Logger to collect descriptive information during initial habitat mapping. Attributes are bold with details following.

"Other"
Avg Cv band ht (cm), numeric, 0, 0, 200, 0, required, "Measure using ref. pole (nearest 5 cm)", required
Hab. shaded by dock, menu, required, "Estimate % of habitat shaded by a dock", required
"0%"
"1-25%"
"26-50%"
"51-75%"
"76-100%"
Collection Number, numeric, 0, 0, 1000, 1, not_permitted, 1
Date, date, auto, ymd, manual, normal, normal
Time, time, auto, 24, manual, normal, normal
Notes, text, 30, normal, normal

Appendix XVI. Hardcopy example of metadata for shoreline features mapped in the Lynnhaven River. For other questions or more details, please consult layer-specific digital metadata or contact the authors.

Comprehensive Shoreline Survey and Oyster Population Assessment in the Lynnhaven Basin: Shoreline Features

Metadata:

- Identification_Information
- Data_Quality_Information
- Spatial_Data_Organization_Information
- Spatial_Reference_Information
- Entity_and_Attribute_Information
- Distribution_Information
- Metadata_Reference_Information

Identification_Information:

Citation:

Citation_Information:

Originator:

Ross, P.G. and Luckenbach, M.L., College of William and Mary, Virginia Institute of Marine Science, Eastern Shore Laboratory

Publication_Date: 5/4/07

Title:

Comprehensive Shoreline Survey and Oyster Population Assessment in the Lynnhaven Basin: Shoreline Features

Geospatial_Data_Presentation_Form: vector digital data

Other_Citation_Details:

Companion report: Ross, P. G., Jr. and M. W. Luckenbach. 2007. Comprehensive Shoreline Survey and Oyster Population Assessment in the Lynnhaven Basin. Final Report submitted to NOAA Chesapeake Bay Office, Gloucester Point, VA.

Online_Linkage:

\\V15895\Data 1\GIS Data and Projects\Lynnhaven Projects\Lynnhaven Data\Lynnhaven Assessment-ESL Final GIS Data Bundle\Oyster Mapping\Lynnhaven Mapping-Line.shp

Description:

Abstract:

These data are part of a comprehensive survey to describe and quantify oyster habitat and the oyster population in the Lynnhaven River, a tidal sub-estuary of the lower Chesapeake Bay. Anecdotal observations suggested that large portions of the oyster population in this basin are unaccounted for in traditional stock surveys. Our focus, therefore, was to include restoration and traditional natural reef structure in addition to areas that have received no attention in stock assessments: marsh habitats and non-traditional manmade habitats such as shoreline armoring structures. These specific data represent shoreline features as polylines. A companion dataset for patch and fringing reef polygons is available.

Appendix XVI (cont.)

Purpose:
These data were developed to support ongoing oyster restoration and research by various federal, state and NGO groups within the Lynnhaven River basin.
Supplemental_Information:
Companion report: Ross, P. G., Jr. and M. W. Luckenbach. 2007. Comprehensive Shoreline Survey and Oyster Population Assessment in the Lynnhaven Basin. Final Report submitted to NOAA Chesapeake Bay Office, Gloucester Point, VA.
Time_Period_of_Content:
Time_Period_Information:
Range_of_Dates/Times:
Beginning_Date: 4/1/05
Ending_Date: 5/1/07
Currentness_Reference: publication date
Status:
Progress: Complete
Maintenance_and_Update_Frequency: None planned
Spatial_Domain:
Bounding_Coordinates:
West_Bounding_Coordinate: -76.126050
East_Bounding_Coordinate: -76.000636
North_Bounding_Coordinate: 36.912910
South_Bounding_Coordinate: 36.847283
Keywords:
Theme:
Theme_Keyword: oyster
Theme_Keyword: oyster restoration
Theme_Keyword: population estimate
Theme_Keyword: shoreline survey
Theme_Keyword: oyster biomass
Theme_Keyword: stock assessment
Place:
Place_Keyword: Chesapeake Bay
Place_Keyword: Lynnhaven River
Place_Keyword: mid-Atlantic United States
Place_Keyword: Virginia Beach
Place_Keyword: Virginia
Access_Constraints: None
Use_Constraints:
Under no circumstances can this data be published in any peer-reviewed outlet without the direct consent of the authors
Point_of_Contact:
Contact_Information:
Contact_Person_Primary:
Contact_Person: P.G. Ross

Appendix XVI (cont.)

Contact_Organization:
College of William and Mary, Virginia Institute of Marine Science, Eastern Shore Laboratory
Contact_Position: Marine Scientist, Sr.
Contact_Voice_Telephone: 757-787-5816
Contact_Electronic_Mail_Address: pg@vims.edu
Data_Set_Credit:
Ross, P.G. and Luckenbach, M.L., College of William and Mary, Virginia Institute of Marine Science, Eastern Shore Laboratory
Native_Data_Set_Environment:
Microsoft Windows XP Version 5.1 (Build 2600) Service Pack 2; ESRI ArcCatalog 9.1.0.722

Data_Quality_Information:
Attribute_Accuracy:
Attribute_Accuracy_Report:
see Ross, P. G., Jr. and M. W. Luckenbach. 2007. Comprehensive Shoreline Survey and Oyster Population Assessment in the Lynnhaven Basin. Final Report submitted to NOAA Chesapeake Bay Office, Gloucester Point, VA.
Completeness_Report:
see Ross, P. G., Jr. and M. W. Luckenbach. 2007. Comprehensive Shoreline Survey and Oyster Population Assessment in the Lynnhaven Basin. Final Report submitted to NOAA Chesapeake Bay Office, Gloucester Point, VA.
Positional_Accuracy:
Horizontal_Positional_Accuracy:
Horizontal_Positional_Accuracy_Report:
see Ross, P. G., Jr. and M. W. Luckenbach. 2007. Comprehensive Shoreline Survey and Oyster Population Assessment in the Lynnhaven Basin. Final Report submitted to NOAA Chesapeake Bay Office, Gloucester Point, VA.
Quantitative_Horizontal_Positional_Accuracy_Assessment:
Horizontal_Positional_Accuracy_Value: 0.4-0.8 m
Horizontal_Positional_Accuracy_Explanation:
see Ross, P. G., Jr. and M. W. Luckenbach. 2007. Comprehensive Shoreline Survey and Oyster Population Assessment in the Lynnhaven Basin. Final Report submitted to NOAA Chesapeake Bay Office, Gloucester Point, VA.
Vertical_Positional_Accuracy:
Vertical_Positional_Accuracy_Report: n/a
Lineage:
Process_Step:
Process_Description: Dataset copied.
Source_Used_Citation_Abbreviation:
\\V15895\Data 1\GIS Data and Projects\Lynnhaven Projects\Lynnhaven Data\Final, Humes\Humes Line
Process_Step:

Process_Description: Dataset copied.
Source_Used_Citation_Abbreviation:
\\V15895\Data 1\GIS Data and Projects\Lynnhaven Projects\Lynnhaven Data\Final, Lynnhaven Mapping\Lynnhaven Mapping-Line
Process_Step:
Process_Description: Dataset moved.
Source_Used_Citation_Abbreviation:
\\V15895\Data 1\GIS Data and Projects\Lynnhaven Projects\Lynnhaven Data\Lynnhaven Assessment-ESL Final GIS Data Bundle\Lynnhaven Mapping-Line

---

Spatial_Data_Organization_Information:
Direct_Spatial_Reference_Method: Vector
Point_and_Vector_Object_Information:
SDTS_Terms_Description:
SDTS_Point_and_Vector_Object_Type: String
Point_and_Vector_Object_Count: 634

Spatial_Reference_Information:
Horizontal_Coordinate_System_Definition:
Planar:
Map_Projection:
Map_Projection_Name: Lambert Conformal Conic
Lambert_Conformal_Conic:
Standard_Parallel: 36.766667
Standard_Parallel: 37.966667
Longitude_of_Central_Meridian: -78.500000
Latitude_of_Projection_Origin: 36.333333
False_Easting: 11482916.666667
False_Northing: 3280833.333333
Planar_Coordinate_Information:
Planar_Coordinate_Encoding_Method: coordinate pair
Coordinate_Representation:
Abscissa_Resolution: 0.000064
Ordinate_Resolution: 0.000064
Planar_Distance_Units: survey feet
Geodetic_Model:
Horizontal_Datum_Name: North American Datum of 1983
Ellipsoid_Name: Geodetic Reference System 80
Semi-major_Axis: 6378137.000000
Denominator_of_Flattening_Ratio: 298.257222

Entity_and_Attribute_Information:
Detailed_Description:
Entity_Type:

Appendix XVI (cont.)

Entity_Type_Label: Lynnhaven Mapping-Line
Entity_Type_Definition: Shoreline features for oyster mapping
Entity_Type_Definition_Source: Eastern Shore Lab (ESL)
Attribute:
Attribute_Label: FID
Attribute_Definition: Internal feature number.
Attribute_Definition_Source: ESRI
Attribute_Domain_Values:
Unrepresentable_Domain:
Sequential unique whole numbers that are automatically generated.
Attribute:
Attribute_Label: Shape
Attribute_Definition: Feature geometry.
Attribute_Definition_Source: ESRI
Attribute_Domain_Values:
Unrepresentable_Domain: Coordinates defining the features.
Attribute:
Attribute_Label: CODE
Attribute_Definition:
Truncated code to identify region, habitat type and estimated oyster cover density
Attribute_Definition_Source: ESL
Attribute:
Attribute_Label: BASIN_SECT
Attribute_Definition: Geographic region within Lynnhaven River
Attribute_Definition_Source: ESL
Attribute:
Attribute_Label: HABITAT
Attribute_Definition: Shoreline habitat type
Attribute:
Attribute_Label: __CV_COVER
Attribute_Definition:
Visually estimated % aerial coverage of oysters (estimated during initial mapping)
Attribute_Definition_Source: ESL
Attribute:
Attribute_Label: ADJACENT_W
Attribute_Definition: Water depth directly adjacent feature
Attribute_Definition_Source: ESL
Attribute:
Attribute_Label: TIDAL_STAG
Attribute_Definition: Nearest tidal stage during mapping
Attribute_Definition_Source: ESL
Attribute:
Attribute_Label:
HABITAT_SU

Appendix XVI (cont.)

Attribute_Definition: Habitat subtype
Attribute:
Attribute_Label: AVG_CV_BAN
Attribute_Definition: Estimated average oyster "band ht."
Attribute_Definition_Source: ESL
Attribute:
Attribute_Label: NOTES
Attribute_Definition: Notes
Attribute_Definition_Source: ESL
Attribute:
Attribute_Label: Length_ft
Attribute_Definition: Feature length in feet (calculated in ArcMap)
Attribute_Definition_Source: ESL
Attribute:
Attribute_Label: Length_m
Attribute_Definition: Feature length in meters (calculated in ArcMap)
Attribute_Definition_Source: ESL
Attribute:
Attribute_Label: Cv_Model
Attribute_Definition: Model used to estimate feature-specific oyster abundance
Attribute_Definition_Source: ESL
Attribute:
Attribute_Label: Cv_Mult
Attribute_Definition:
"Multiplier" used in model to estimate feature-specific oyster abundance
Attribute_Definition_Source: ESL
Attribute:
Attribute_Label: Cv_Abun
Attribute_Definition: Feature-specific oyster abundance (calculated in ArcMap)
Attribute_Definition_Source: ESL
Overview_Description:
Entity_and_Attribute_Overview:
see Ross, P. G., Jr. and M. W. Luckenbach. 2007. Comprehensive Shoreline Survey and Oyster Population Assessment in the Lynnhaven Basin. Final Report submitted to NOAA Chesapeake Bay Office, Gloucester Point, VA.
Entity_and_Attribute_Detail_Citation:
Ross, P. G., Jr. and M. W. Luckenbach. 2007. Comprehensive Shoreline Survey and Oyster Population Assessment in the Lynnhaven Basin. Final Report submitted to NOAA Chesapeake Bay Office, Gloucester Point, VA.

Distribution_Information:
Resource_Description: Downloadable Data
Standard_Order_Process:
Digital_Form:

Appendix XVI (cont.)

Digital_Transfer_Information:
Transfer_Size: 0.673

Metadata_Reference_Information:
Metadata_Date: 20070507
Metadata_Contact:
Contact_Information:
Contact_Person_Primary:
Contact_Person: P.G. Ross
Contact_Organization:
College of William and Mary, Virginia Institute of Marine Science, Eastern Shore Laboratory
Contact_Position: Marine Scientist, Sr.
Contact_Address:
Address_Type: mailing address
Address: PO Box 350
City: Wachapreague
State_or_Province: VA
Postal_Code: 23350
Country: USA
Contact_Voice_Telephone: 757-787-5816
Contact_Electronic_Mail_Address: pg@vims.edu
Metadata_Standard_Name: FGDC Content Standards for Digital Geospatial Metadata
Metadata_Standard_Version: FGDC-STD-001-1998
Metadata_Time_Convention: local time
Metadata_Access_Constraints: None
Metadata_Use_Constraints:
Under no circumstances can this data be published in any peer-reviewed outlet without the direct consent of the authors
Metadata_Extensions:
Online_Linkage: <http://www.esri.com/metadata/esriprof80.html>
Profile_Name: ESRI Metadata Profile

Generated by `mp` version 2.8.6 on Mon May 07 12:42:42 2007

Appendix XVII. Hardcopy static metadata for Virginia Base Mapping Program aerial images (©Commonwealth of Virginia, 2002). For other questions or more details, please consult the VGIN-VBMP website (http://www.vgin.state.va.us/VBMP/VBMP.html) or contact the authors.

```
Identification_Information:
  Citation:
    Citation_Information:
      Originator: Commonwealth of Virginia, through the Virginia Geographic
Network Division of its Department of Technology Planning (VGIN).
      Publication_Date: 03012003
      Publication_Time: Unknown
      Title: Virginia Base Mapping Program (VBMP) 2002; 1 Foot Resolution
(1"=200' scale) Digital Orthophotography for the North Zone of the Virginia
State Plane Grid
      Geospatial_Data_Presentation_Form: Remote-sensing image
      Publication_Information:
        Publication_Place: Richmond, Virginia
        Publisher: Commonwealth of Virginia, through the Virginia Geographic
Network Division of its Department of Technology Planning (VGIN).
      Online_Linkage: http://www.vgin.state.va.us/VBMP/VBMP.html
  Description:
    Abstract: These files contain 1-foot GSD high-resolution orthorectified
aerial image map products in GeoTIFF version 6.0 file format.  GeoTIFF files
are uncompressed raster images complete with coordinate information.  The
VBMP project encompasses the entire land area of the Commonwealth of
Virginia.  The State boundary is buffered by 1000 feet.  Coastal areas of the
State bordering the Atlantic Ocean or the Chesapeake Bay are buffered by 1000
feet or the extent of man-made features extending from shore.  1-foot
resolution digital orthoimagery was developed over the majority of
urban/suburban areas of the Commonwealth covering approximately 7,167 square
miles and 2-foot resolution digital orthoimagery was developed over the rural
areas of the Commonwealth covering approximately 31,923 square miles as
defined by VGIN.  6-inch resolution digital orthoimagery was developed in
limited urban areas covering approximately 1000 square miles.
    Purpose: In October of 2001 the Commonwealth of Virginia began work on an
initiative termed the Virginia Base Mapping Program (VBMP), to develop
digital orthoimagery for the entire land base of the Commonwealth.  The VBMP
was funded by the Public Safety Services Board to support statewide
implementation of Phase II wireless E911 (E911 for Cell Phones) by
establishing one consistent, accurate, foundational base map upon all local
government and many regional, state and federal spatial data applications
could be built in order to establish and maintain an efficient statewide
spatial information infrastructure.  The VBMP was implemented and
administered by the Virginia Geographic Information Network, a division of
the Department of Technology Planning under the Commonwealth's Secretary of
Technology.  It can also serve as a reference layer for GIS analysis.
    Supplemental_Information: Digital Terrain Models were collected for the
purposes of orthorectification as well as a variety of other purposes
including planning and field reference.
  Time_Period_of_Content:
    Time_Period_Information:
      Range_of_Dates/Times:
        Beginning_Date: 02012002
        Beginning_Time: unknown
        Ending_Date: 04012002
        Ending_Time: unknown
```

Appendix XVII (cont.)

```
      Currentness_Reference: Ground condition
  Status:
    Progress: Complete
    Maintenance_and_Update_Frequency: None planned
  Spatial_Domain:
    Bounding_Coordinates:
      West_Bounding_Coordinate: -79.200
      East_Bounding_Coordinate: -76.742
      North_Bounding_Coordinate: 38.364
      South_Bounding_Coordinate: 37.759
  Keywords:
    Theme:
      Theme_Keyword_Thesaurus: MEL Product Thesaurus
      Theme_Keyword: Digital Orthophotography
      Theme_Keyword: Land use or land cover
      Theme_Keyword: Emergency management
      Theme_Keyword: Miscellaneous
      Theme_Keyword: Planimetric
      Theme_Keyword: Economic development
      Theme_Keyword: Environment
      Theme_Keyword: Wetlands
      Theme_Keyword: Infrastructure or ground transportation
      Theme_Keyword: Tourism or recreation
    Place:
      Place_Keyword_Thesaurus: MEL Location Thesaurus
      Place_Keyword: Commonwealth of Virginia
      Place_Keyword: Virginia
      Place_Keyword: USA
  Access_Constraints: The VBMP data are property of the Commonwealth of
Virginia, copyright 2002.  Distribution of any of these data to anyone not
licensed by the Commonwealth is strictly prohibited.
  Use_Constraints: This VBMP data has been developed using procedures
designed to produce data to National Standard for Spatial Data Accuracy
(NSSDA) and is intended for use at 1" = 200' scale.
  Point_of_Contact:
    Contact_Information:
      Contact_Person_Primary:
        Contact_Person: Robert Rike
        Contact_Organization: Virginia Geographic Information Network
      Contact_Address:
        Address_Type: Mailing address
        Address: 110 South 7th Street, Suite 135
        City: Richmond
        State_or_Province: VA
        Postal_Code: 23219
        Country: United States of America
      Contact_Voice_Telephone: 804.786.6156
      Contact_Electronic_Mail_Address: VBMP@vgin.state.va.us
  Browse_Graphic:
    Browse_Graphic_File_Name: Not Available
    Browse_Graphic_File_Description: Not Available
    Browse_Graphic_File_Type: Not Available
  Security_Information:
    Security_Classification_System: Not Available
```

Appendix XVII (cont.)

```
      Security_Classification: Unclassified
    Security_Handling_Description: Not Available
  Native_Data_Set_Environment: Photographic film scanned to TIFF/JPEG format
on a high-resolution photogrammetric scanner
Data_Quality_Information:
  Logical_Consistency_Report: The dataset contains raster images of digital
orthophotography so the logical consistency report is not applicable.  The
file naming convention is based on the lower left/southwest corner of the
image.  Tile names are 14 characters long with a 3 character extension.  An
example tile name is:  DO_N17_5100_11.TIF.  The first two characters
represent the product code (DO = digital orthophotograph, TM = terrain
model).  After an underscore to separate the code, the following three
characters are the Prefix to maintain uniqueness in the project.  The first
character indicates the state plane zone (N = North, S = South), and the next
two numbers indicate the coordinate pairing of the million units of the
Easting and Northing coordinates for the lower left/southwest corner of the
tile.  An underscore separates the Prefix from the BMU (Base Modular Unit) of
the next four numbers.  The Base Modular Unit designates the name for 1:4800
scale imagery tiles which correspond to a 10,000 foot grid based on even
10,000 increments of the Virginia State Plane. Following another separator is
a two number suffix.  The first digit of the Suffix number designates the
quadrant of the BMU that a nested 5,000 foot tile grid occupies. Quadrants
are numbered from 1 to 4 starting with the Lower Left quadrant of the BMU,
increasing in a clockwise direction.  The second digit of the Suffix number
designates the quadrant of the 5,000 foot tile that a nested 2,500-foot tile
grid occupies. Quadrants are numbered from 1 to 4 starting with the Lower
Left quadrant and  increasing in a clockwise direction.
  Completeness_Report: The project consisted of a total of 4806 total images
in the Virginia North State Plane Zone for 1' = 200' scale imagery.
  Positional_Accuracy:
    Horizontal_Positional_Accuracy:
      Horizontal_Positional_Accuracy_Report: See
http://www.vgin.state.va.us/VBMP/VBMP.html
      Quantitative_Horizontal_Positional_Accuracy_Assessment:
        Horizontal_Positional_Accuracy_Value: 1.49
        Horizontal_Positional_Accuracy_Explanation: Compiled to meet 4.9 feet
horizontal accuracy at 95% confidence level in accordance with National
Standards for Spatial Data Accuracy (NSSDA).  Tested accuracy will be
reported in future versions of the metadata posted at
http://www.vgin.state.va.us/VBMP/VBMP.html
    Vertical_Positional_Accuracy:
      Vertical_Positional_Accuracy_Report: Not Available
      Quantitative_Vertical_Positional_Accuracy_Assessment:
        Vertical_Positional_Accuracy_Value: 0
        Vertical_Positional_Accuracy_Explanation: Not Available
  Lineage:
    Process_Step:
      Process_Description: The Commonwealth is divided into three major
production areas for this project. A different producer was assigned to each
major area. The following is a general description of the process. For more
specific information on each producer's methods and equipment by production
block, go to the project procedures guide at the VGIN web site
http://www.vgin.state.va.us/vbmp/vbmp.html. Aerial film was acquired and
imaged in 2002.  The imagery was scanned at 21 microns. Ground control used
```

Appendix XVII (cont.)

```
to support the ortho mapping was collected by identifying strategic locations
on the aerial photography plan and then determining the coordinates by GPS
ground survey techniques.  The Aerial Triangulation was performed using
softcopy workstations.  Bundle adjustment was performed and Digital Elevation
Models were created using standard photogrammetric collection techniques on
soft copy workstations.  A "DTM apron" was created around each elevated
bridge for orthorectification purposes.  The images were then ortho rectified
and color balanced.  Seamless mosaicing was performed and the seamless mosaic
was clipped into tiles.  Final deliverables in tiff format with tfw files
were placed on DVD, DLT or FireWire.
      Process_Date: 01012002
  Cloud_Cover: 0
Spatial_Data_Organization_Information:
  Direct_Spatial_Reference_Method: Raster
  Raster_Object_Information:
    Raster_Object_Type: Pixel
    Row_Count: 5000
    Column_Count: 5000
    Vertical_Count: 1
Spatial_Reference_Information:
  Horizontal_Coordinate_System_Definition:
    Planar:
      Grid_Coordinate_System:
        Grid_Coordinate_System_Name: State Plane Coordinate System 1983
        State_Plane_Coordinate_System:
          SPCS_Zone_Identifier: 4502
          Lambert_Conformal_Conic:
            Standard_Parallel: 36.766667
            Standard_Parallel: 37.966667
            Longitude_of_Central_Meridian: -78.500000
            Latitude_of_Projection_Origin: 36.333333
            False_Easting: 3500000.000000
            False_Northing: 1000000.000000
      Planar_Coordinate_Information:
        Planar_Coordinate_Encoding_Method: row and column
        Coordinate_Representation:
          Abscissa_Resolution: 1.000000
          Ordinate_Resolution: 1.000000
        Planar_Distance_Units: US Survey Foot
    Geodetic_Model:
      Horizontal_Datum_Name: North American Datum of 1983 (HARN)
      Ellipsoid_Name: Geodetic Reference System 80
      Semi-major_Axis: 6378137.000000
      Denominator_of_Flattening_Ratio: 298.257222
Entity_and_Attribute_Information:
  Detailed_Description:
    Entity_Type:
      Entity_Type_Label: Band 1
      Entity_Type_Definition: Blue Band
      Entity_Type_Definition_Source: Scanned from film
  Detailed_Description:
    Entity_Type:
      Entity_Type_Label: Band 2
      Entity_Type_Definition: Green Band
```

Appendix XVII (cont.)

```
      Entity_Type_Definition_Source: Scanned from film
  Detailed_Description:
    Entity_Type:
      Entity_Type_Label: Band 3
      Entity_Type_Definition: Red Band
      Entity_Type_Definition_Source: Scanned from film
Distribution_Information:
  Distributor:
    Contact_Information:
      Contact_Person_Primary:
        Contact_Person: Robert Rike
        Contact_Organization: Virginia Geographic Information Network
      Contact_Address:
        Address_Type: Mailing address
        Address: 110 South 7th Street, Suite 135
        City: Richmond
        State_or_Province: VA
        Postal_Code: 23219
        Country: United States of America
      Contact_Voice_Telephone: 1.804.786.6156
      Contact_Electronic_Mail_Address: VBMP@vgin.state.va.us
  Distribution_Liability: The VBMP data are the property of the Commonwealth
of Virginia, copyright 2002.  Distribution of any of these data to anyone not
licensed by the Commonwealth is strictly prohibited.  VBMP license Agreement
and distribution policies are available at
http://www.vgin.state.va.us/VBMP/VBMP.html
  Standard_Order_Process:
    Digital_Form:
      Digital_Transfer_Information:
        Format_Name: GeoTIFF 6.0
        Format_Version_Number: 6.0
        File_Decompression_Technique: No compression applied
        Transfer_Size: 71.565
      Digital_Transfer_Option:
        Online_Option:
          Computer_Contact_Information:
            Network_Address:
              Network_Resource_Name: Not Available
          Access_Instructions: http://www.vgin.state.va.us/vbmp/vbmp.html
    Fees: Contact VGIN at http://www.vgin.state.va.us/VBMP/VBMP.html
Metadata_Reference_Information:
  Metadata_Date: 20030106
  Metadata_Contact:
    Contact_Information:
      Contact_Organization_Primary:
        Contact_Organization: Virginia Geographic Information Network
        Contact_Person: Robert Rike
      Contact_Address:
        Address_Type: 110 South 7th Street, Suite 135
        City: Richmond
        State_or_Province: VA
        Postal_Code: 23219
      Contact_Voice_Telephone: 1.804.786.6156
```

Appendix XVII (cont.)

```
      Metadata_Standard_Name: FGDC Content Standards for Digital Geospatial
Metadata
  Metadata_Standard_Version: FGDC-STD-001-1998
  Metadata_Time_Convention: local time
  Metadata_Security_Information:
    Metadata_Security_Classification_System: Not Available
    Metadata_Security_Classification: Unclassified
    Metadata_Security_Handling_Description: Not Available
  Metadata_Extensions:
    Online_Linkage: This version of the VBMP metadata accompanies initial
data distribution.  Updated metadata for this dataset will be maintained on
the VGIN web site at the following address:
http://www.vgin.state.va.us/VBMP/VBMP.html
    Profile_Name: ESRI Metadata Profile
```