APPENDIX C

HASKIN SHELLFISH RESEARCH LABORATORY ADULT OYSTER REPORT

Haskin Shellfish Research Laboratory

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MEMORANDUM

TO: William Burton, Senior Scientist

FROM: Eric N. Powell
Director, Haskin Shellfish Research Laboratory

SUBJECT: Status, HSRL oyster monitoring program

Enclosed is the draft final report for our component of the monitoring study. I have not transmitted it to the Corps, assuming that you will be combining this report with your own for that purpose.

Rutgers, The State University of New Jersey
Institute of Marine and Coastal Sciences - New Jersey Agricultural Experiment Station

Army Corps of Engineers
Delaware River Main Channel Deepening Project
Monitoring Study

Oyster Component

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Introduction

Oysters and associated organisms were sampled monthly from April, 2000 to November, 2000 and in March, 2001 at nine locations in Delaware Bay as part of the monitoring study designed to set a pre-dredging baseline for the Delaware River Main Channel Deepening Project. The oyster community component of the monitoring study contained four work elements: (a) monthly sampling of the oyster population that included measures of abundance, condition, health, and the enumeration of associated predators and fouling organisms, (b) a dredge calibration study designed to permit quantification of oyster abundance, (c) a disarticulation study designed to evaluate the usefulness of box counts as a measure of the rate of natural mortality, and (d) a comparison of the monitoring data to the decadal time series obtained from the once-yearly stock assessment for the New Jersey seed beds to determine whether the baseline year was a typical year.

The dredge calibration study was analyzed as a separate unit and is attached as an appendix to this report (Appendix 1). The remaining three work elements are treated in the coming sections, following descriptions of the methods and site locations.

Methods

Sampling

Nine sites were chosen for the study. These sites were chosen to be representative of the New Jersey and Delaware oyster beds, and particularly, to be representative of beds covering the salinity gradient of Delaware Bay. A sampling location was identified at each site. The identification was based on historic data for the bed, such that the sampling location was representative of areas of the bed consistently characterized by relatively high oyster abundance. Each site was defined as a $0.2'$ latitude x $0.2'$ longitude rectangle, about 25 acres in size.

On approximately the 15th of each month (April-November, 2000; March, 2001), each site was sampled by taking three or more dredge hauls initiated at random positions within the 25 acre rectangle. Sufficient dredge hauls were made to provide 100 or more live oysters for analysis, unless total abundance was very low; however, no fewer than three hauls were made. Each haul was about 1 minute in duration and was tracked precisely by DGPS with positions in decimal minutes to three significant digits logged every 5 seconds.

The oyster boat *F/V Howard W. Sockwell* was used for this program. The *F/V Howard W. Sockwell* also carries out the annual stock assessment for the New Jersey seed beds. This facilitated dredge calibration by permitting use of information on dredge efficiency collected by the survey as well as information obtained during this study. The dredge used was a standard 24-tooth 1.27-m dredge. Tooth length was approximately 44 mm. Mouth opening was 1.27 m x 51 cm. The bag consisted of 17 rows of 50.8 mm rings.

The first three hauls were split into thirds and the respective thirds from each of the three hauls combined to produce three combined bushel samples. One of these bushel samples was used to provide information on oyster health, condition index, and gonadal index. The number of predators and fouling organisms was also estimated from this sample. The additional bushels were used to provide a larger sample size when the minimally-required number of animals was not present in the initial one.

Dredge swept area (m^2) was calculated from the DGPS positions and the mouth opening of the dredge (1.27 m).

Oyster Abundance and Size Frequency

Each oyster and box $\geq$20 mm was measured (longest dimension). Smaller oysters and boxes were counted as spat. With rare exceptions when abundances of live oysters or boxes was very low, the minimally-accepted count to define the size-frequency distribution was 100 boxes and 100 live oysters. Sufficient bushel samples were analyzed to meet this condition. Oyster abundance was quantitated from the measured swept area of the tow, the total volume collected by the dredge, the volume analyzed in the laboratory, and an estimate of dredge efficiency (Appendix 1).

Condition Index and Gonadal Index

For condition index, five animals were chosen from each of the following 4 size classes: 20-40 mm, 41-60 mm, 61-80 mm, >80 mm. Condition index was calculated as

$$\frac{dry\ weight\ (g)}{total\ weight - valve\ weight} * 100.$$

Gonadal index was calculated according to Ellis et al.[1]

Parasitism and Health

Five animals were chosen from each of the following 4 size classes: 20-40 mm, 41-60 mm, 61-80 mm, >80 mm. Histopathology followed NOAA Status and Trends

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[1] Ellis, M.S., R.D. Barber, R.E. Hillman and E.N. Powell, 1998: Gonadal analysis. In G.G. Lauenstein and A.Y. Cantillo (eds.) Sampling and analytical methods of the National Status and Trends Program Mussel Watch Project: 1993-1996 update. *NOAA Tech. Mem. NOS ORCA* 130:216-227.

methods as described by Ellis et al.,[2] with two exceptions. *Perkinsus marinus* was analyzed as described in Powell et al.[3] *Haplosporidium nelsoni* analysis followed Ford and Haskin[4].

Natural Mortality

Cumulative mortality was estimated from January 1, 2000 by counting all live and dead oysters in the analyzed bushels. Dead oysters were assigned to one of three categories: (1) old boxes, articulated shells with fouled inner valves; (2) new boxes, articulated shells with clean or lightly fouled inner valves; and (3) gapers, articulated shells with soft tissue present. The fraction of new boxes and gapers among all the live and dead oysters was counted as "recent mortality." The time interval required for a new box to foul enough to be recategorized as an old box varied from 3-4 weeks in the summer when the rate of fouling is high, to 10-12 weeks in the winter, when the rate of fouling is low. These times were groundtruthed using deployed recently-killed oysters, as described later. The recent mortality was then adjusted for the actual interval since the previous sampling date and the resulting "interval mortality" rates cumulated over the period of observation:

$$\begin{aligned} &Cumulative\ mortality\ at\ any\ sampling\ period = \\ &\quad((1 - total\ cumulative\ mortality\ at\ last\ sample) \\ &\quad\times\ (interval\ mortality) \\ &\quad+ cumulative\ mortality\ at\ last\ sample)) \times\ 100. \end{aligned}$$

The cumulative mortality method of estimating mortality can be used only if sampling is relatively frequent. The New Jersey stock assessment, however, represents a sample taken only once a year. In this cases, it is necessary to estimate total mortality using all boxes. This raises the question of how long "old boxes" last before they disarticulate. We examined this question in two ways: 1) by deploying artificially-made new boxes in a disarticulation study (see below) and 2) by calculating and plotting the total mortality $\left(\frac{all\ boxes\ +\ gapers}{all\ live\ oysters\ +\ boxes\ +\ gapers}\right)$ in each sample and comparing these estimates with the cumulative mortality estimates.

To measure disarticulation rate, oysters were killed in freshwater. Each resulting box was attached to a PVC pipe using cable ties threaded through a hole drilled into the lower valve. Twelve oysters covering a wide size range (30 - >100 mm) were attached to each PVC pipe. Rebar racks were constructed to hold a total of six PVC pipes. One rack was deployed at each site.

The experimental protocol involved deploying PVC pipes throughout the year so that new boxes could be followed more or less continuously. To do this, racks were

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[2] Ellis, M.S., R.D. Barber, R.E. Hillman, Y. Kim and E.N. Powell, 1998: Histopathology analysis. In G.G. Lauenstein and A.Y. Cantillo (eds.) Sampling and analytical methods of the National Status and Trends Program Mussel Watch Project: 1993-1996 update. *NOAA Tech. Mem. NOS ORCA* 130:198-215.

[3] Powell, E.N. and M.S. Ellis, 1998: *Perkinsus marinus* assay. In G.G. Lauenstein and A.Y. Cantillo (eds.) Sampling and analytical methods of the National Status and Trends Program Mussel Watch Project: 1993-1996 update. *NOAA Tech. Mem. NOS ORCA* 130:228-233.

[4] Ford, S. E. and H. H. Haskin, 1982: History and epizootiology of *Haplosporidium nelsoni* (MSX), an oyster pathogen, in Delaware Bay, 1957-1980. *J. Invertebr. Pathol.* 40: 118-141.

deployed with two PVC pipes (24 oysters) in May 2000. Two additional pipes were added in July and in October. Each month, the racks were recovered, articulation status quickly reviewed, the degree of fouling evaluated qualitatively in the manner done to separate new and old boxes, and the rack redeployed.

The data were first examined in plots of log_e(*time to disarticulation*) versus log_e(*Cumulative Hazard*), where cumulative hazard is the cumulative risk of disarticulating over time, to determine if the absolute or proportional risk of disarticulation varied according to time or site of deployment and whether the risk was proportionally the same. To test the possibility that the risk of disarticulation was associated with location along the salinity gradient, each station was numbered from presumed lowest to highest salinity (Arnolds, Ship John, Nantuxent Point, Lower Middle, Over the Bar, Bennies, New Beds, Egg Island, and Lease 554D) and tested using a nonparametric trend rank test (Mantel-Cox). The same test was applied to test for differences associated with time of deployment. Data plots suggested that the data could be fitted to a Weibull model for further analysis. To simplify the testing of a possible salinity effect, the sites were divided into two groups: a low salinity group (Arnolds, Ship John, Nantuxent Point, Lower Middle and Over the Bar), and a high salinity group (Bennies, New Beds, Egg Island, and Lease 554D). This model allowed us to employ size (shell height) as well as salinity (high and low) and time of deployment (May, July, and October) as factors. The resulting model coefficients are an estimate of the reduction in time to disarticulation associated with differences in each of the factors.

Predators and Fouling Organisms

All oyster predators were identified and measured. The ten largest oysters were reserved for biont analysis. Epibionts and endobionts were identified and their coverage estimated on each of eight shell areas on the inner and outer surface of the upper valve. Shell areas are described by Davies et al.[5] Average coverage was estimated as the weighted average of the coverage of each of the shell areas. Weights were defined to be proportional to the fraction of the total valve represented by that shell area. Identification was to species in most cases; however, for presentation, some of the bionts were summed into higher taxonomic categories.

Year Representativeness from Stock Survey

Year-to-year variation in population attributes of oyster beds is the norm. To address the question of whether the population attributes of the sampled oyster beds during the monitored year were representative of the long-term average condition requires that the data from the monitoring program be compared to a long-term time series. The data for comparison were taken from the Delaware Bay oyster stock assessment program that has produced a yearly survey of the New Jersey seed beds, in late October, since the early 1950s. A stratified random sampling method is used for the survey. Each bed is divided into a series of 25 acre grids that

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[5] Davies, D.J., G.M. Staff, W.R. Callender and E.N. Powell, 1990: Description of a quantitative approach to taphonomy and taphofacies analysis: all dead things are not created equal. In W. Miller III (ed.) *Paleocommunity temporal dynamics: the long-term development of multispecies assemblages. Spec. Publ. (Paleontol. Soc.)* 5:328-350.

fall into one of three strata. The strata consist of "test" areas, typifying the highest quality areas of the bed that sampling over the course of many years has shown to have a high percentage of living oysters 75% or more of the time, "high quality" areas in which oysters were abundant 25-75% of the time, and "low quality" areas in which oysters were abundant less than 25% of the time. The survey consists of about 100 samples covering the primary and most of the minor oyster beds. Each sample represents a composite of 3 one-third bushels from three randomly-directed one-minute tows within each sampled grid. Otherwise, sampling and quantification of abundance was as described previously for this study. A more complete history of the stock survey can be found in Fegley et al.[6]

Site Descriptions

Nine sites were sampled, two in Delaware and seven in New Jersey. All were natural beds except for one leased ground in New Jersey. The sites covered the salinity gradient and, thus, were representative of beds typically characterized by high and low rates of natural mortality from predators and disease. The sites also covered a range of fishing pressures from high (New Beds, Bennies) to virtually non-existent (Over the Bar, Upper Middle). Fishing and salinity are partially confounding factors in that the fishing impact is correlated with salinity. Although some beds with limited fishing impact occur at higher salinities, no beds with substantial fishing impact occur at low salinities. Some other variables, such as food supply, are also correlated with salinity. In general, comparisons between beds can be explained based on the location of the bed in the salinity gradient, as that determines most of the environmental conditions present, and on the degree of fishing, as that may impact abundance and bed structural characteristics on a more local scale.

Lease 554D

Lease 554D (Figure 1) is located southeast of Egg Island Point in the area of the bay that has historically been leased for oyster farming. As part of a previous study, oysters were transplanted to Lease 554D from Shell Rock in 1999. Over the course of the monitoring study, Lease 554D was plagued with an influx of sediment that was probably initiated by the activities of fouling organisms that trapped sediment in their tubes (e.g., tube-dwelling polychaetes) or within the three-dimensional structure created by erect hydroids and bryozoans. Lease 554D was not unique in the amount of sedimentation that occurred. The phenomenon was widespread on the leased grounds. Although only anecdotal, members of the oyster industry felt that the degree of sedimentation was higher in 2000 than in most previous years.

Egg Island

Egg Island (Figure 1) is one of the lowermost natural oyster beds in Delaware Bay. Historically, this bed has rarely been productive. Natural mortality rates have been high, both from predators and diseases, and, in recent years spat set has been

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[6] Fegley, S.R., S.E. Ford, J.N. Kraeuter and D.R. Jones, 1994: Relative effects of harvest pressure and disease mortality on the population dynamics of the Eastern oyster (*Crassostrea virginica*) in Delaware Bay. Final Report no. NA26FL0588 to the National Oceanic and Atmospheric Administration, Rutgers University, Haskin Shellfish Research Laboratory.

low. Those oysters that survive typically are among the largest found on any oyster bed in the bay.

New Beds and Bennies

New Beds and Bennies (Figure 1) lie within the region of the bay that has supported the majority of the oyster harvest during the 1990s. Estimates for 1999 and 2000 indicate that the industry effort directed on these two beds would have resulted in complete coverage of the bed by dredging one to two times during the fishing year (Table 1). Dredge efficiencies are high (Appendix 1), probably because the bottom is heavily worked and broken up by the fishery. In the last decade, mortality rates have been relatively high and spat recruitment rates relatively low on these beds. Area management of oyster industry fishing effort was introduced in 2001 to prevent overfishing on these beds.

Nantuxent Point and Ship John

Although both Nantuxent Point and Ship John (Figure 1) have received some fishing effort over the last decade, effort has been much lower than on beds downbay. Estimates of industry effort in 1999 and 2000 indicated little fishing on Nantuxent Point during these two years and 33% to 67% coverage of Ship John during 1999 and 2000, respectively (Table 1). Both beds have been characterized by relatively high levels of spat recruitment in the 1990s. Mortality rates are higher on Nantuxent Point. Total oyster abundance is near 1990s-record levels on Ship John. Oyster resource management goals include the diversification of industry effort from the New Beds/Bennies area onto these and other nearby beds, so industry effort can be expected to increase in coming years.

Arnolds

Arnolds (Figure 1) is a low salinity bed near the upbay limit of oyster growth in Delaware Bay. Mortality rates are low and growth rates are slow, so that the bed is characterized by a high abundance of small oysters. Fishing has been limited on this bed during the 1990s (Table 1).

Over the Bar and Upper Middle

These two beds are on the Delaware side of the bay (Figure 1). Neither has been fished in recent years. They may be the most 'natural' of the beds in the study, in that the absence of fishing has permitted the establishment of a 3-D structure of oyster clumps to a greater degree than most other beds in the monitoring study (except, perhaps, Arnolds). Not unexpectedly, dredge efficiencies were characteristic of upbay beds that have seen relatively little harvesting effort during the 1990s (Appendix 1).

Results and Discussion

Oyster Abundance

For the most part, the abundance of oysters increased with decreasing salinity (Figure 2). Lowest numbers were observed on Lease 554D and at Egg Island. Highest numbers were observed on Arnolds, then on Ship John. The two heavily-fished beds on the New Jersey side, Bennies and New Beds, had lower abundances than the other beds in the middle of the salinity gradient, Nantuxent Point and the two beds on the Delaware side, but the latter three were also in a somewhat lower salinity region than New Beds and Bennies. Abundances ranged from about 1 m^{-2} on Lease 554D to about 500 m^{-2} on Arnolds (Figure 2).

Oysters were assigned to three size classes, referred to as juvenile (20-63.5 mm), submarket (63.5-76 mm) and market ($\geq$76 mm). With the exception of Arnolds, these size classes make some biological sense. Growth rates are slow enough at Arnolds that some relatively old oysters will be allocated to the 'juvenile' size class.

With very rare exceptions, juveniles outnumbered submarkets and submarkets outnumbered markets (Figures 2). At lower salinities, such as Arnolds and Ship John, juveniles accounted for nearly all the oysters collected. At higher salinities, Lease 554D, Egg Island, and New Beds, submarket-size and market-size oysters were more common and occasionally as common as juveniles.

Trends in abundance could be referred to one of four time sequences. Oyster abundance on Lease 554D and the Lower Middle site in Delaware varied sporadically with sampling date, probably due to the patchy nature of these beds that inserted a significant amount of sample-to-sample variance in the catch (Figure 2). Abundance was relatively stable over time at New Beds and, with two months as exceptions, on Egg Island. The time series at Bennies and Over the Bar showed stability in the larger two size classes, but two pulses of juveniles were recorded, one in June (July at the Delaware site) and the other in October (Figure 2). In neither case did the pulses of juveniles survive long enough to permanently change the population structure at the site. Nantuxent Point, Ship John and Arnolds were characterized by a significant increase in juvenile abundance in July/August. Abundances remained high for the remainder of the study, although abundance was clearly declining again on Arnolds by March, 2001 (Figure 2).

Oyster Size Frequency

The largest oysters were normally present on New Beds, Egg Island, and Lease 554D (Figures 3-5). The smallest oysters were normally present on Arnolds and Lower Middle (Figures 3-5). This trend is consistent with the influence of the salinity gradient that results in a reduction in maximum size as salinity declines, probably as a consequence of the increase in metabolic demand at lower salinity and a concomitant decline in food resources that typically follows the salinity gradient in Delaware Bay[7].

With two obvious exceptions, Nantuxent Point and Ship John, the percentiles of the size-frequency distribution remained relatively stable over time (Figure 6). Median size was about 35 mm at Arnolds, with the 75^{th} percentile normally between 45 and 50 mm. The two Delaware sites were more variable, but the 75^{th} percentile normally remained above 60 mm and the median above 45 mm (Figure 6). Bennies oysters were about the same size, but the percentiles tended to be more stable over time than at the Delaware sites. Stability also characterized the three highest-

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[7] Powell, E.N., J.M. Klinck, E.E. Hofmann and S. Ford, 1997: Varying the timing of oyster transplant: implications for management from simulation studies. *Fish. Oceanogr.* 6:213-237.

salinity sites, but oysters were normally somewhat larger (Figure 6). Median size typically fell between 55 and 65 mm and the 75^{th} percentile typically fell between 65 and 80 mm. For Nantuxent Point and Ship John, the number of recruits to the juvenile size classes in July/August resulted in a distinct reduction in median and 75^{th} percentile size. Median size declined from about 50 mm to 40 mm and the 75^{th} percentile from 55 mm to about 45 mm.

Spat Abundance

The number of spat per bushel was highest at Ship John and was elevated during at least part of the year at all of the lower salinity sites. Values ranged from about 120 spat per bushel on Arnolds to over 800 on Over the Bar (Figure 7). The number of spat per bushel was lower downbay, declining into the 80 to 100 spat per bushel range on New Beds, Bennies and Nantuxent Point, and much lower, less than 20 spat per bushel, at the two highest salinity sites, Egg Island and Lease 554D.

With the exception of Egg Island and Lease 554D, the number of spat per bushel was highest in April-July, 2000 (Figure 7). Generally, the number of spat per bushel declined from May through August and then remained low through March, 2001. Declines typically exceeded 80% (Figure 8), except at the two highest salinity sites, where the number of spat was low in spring and in fall. In no case was any evidence present for a significant spat set in the summer and fall of 2000. Presumably, the April/May cohort recruited in 1999.

Dead spat were also recorded during the study (Figure 7). Few dead spat were observed, except in June at Bennies, when the number exceeded 60 bushel^{-1}. The number of dead spat never accounted for the decline in live spat. In four cases, Arnolds, Ship John, Bennies, and Nantuxent Point, the decline in live spat was followed by an observed increase in the number of juveniles (Figure 2). We compared the decline in spat during Spring, 2000 with the increase in juvenile abundance in Fall, 2000. Such a comparison must be viewed cautiously because survivorship of live spat is usually low and dead spat very likely do not remain intact for long, thereby failing to accurately record the rate of mortality during the time period. Consequently, the number of spat observed is likely to be a substantial underestimate of their time-integrated abundance.

Nevertheless, a comparison of the number of spat disappearing following the spring of 2000 with the number of juveniles appearing in the population in the summer of 2000 reveals that the decline in the number of spat was sufficient to explain the increase in juvenile abundance at Ship John and at the two Delaware sites where apparent survivorship appeared to vary from about 35% to 45% (Figure 9). An insufficient number of spat were present to explain the increase in juvenile abundance at Arnolds and Nantuxent Point, emphasizing the degree of undersampling of spat when relying on a monthly sampling protocol (Figure 9). At Bennies and New Beds, the number of juveniles also declined, emphasizing the poor survivorship of both spat and juveniles on these higher salinity beds.

Oyster Abundance – Summary

Overall, abundance was less stable than size frequency during the year and high salinity sites were more stable than low salinity sites in abundance and in size frequency. Instability in the size-frequency distribution was introduced primarily by variations in the number of oysters referred to the juvenile size classes, 20-63.5 mm, and specifically in cases where survivorship of spat from 1999 was high. The two Delaware sites were not atypical, despite the prohibition of fishing on these beds for many years.

Condition Index and Gonadal Index

Spawning normally takes place sometime between mid-June and mid-August in Delaware Bay. Gonadal index peaked in July or August at all sites and declined precipitously after August 15 (Figure 10). The pattern was similar at all sites, regardless of position in the salinity gradient or location on the Delaware or New Jersey side of the bay. The decline in gonadal index suggests that the main spawning event occured between August 15 and September 15 in 2000, although the number of oysters observed in spawning condition in July, plus the moderate declines in gonadal index after the July sampling indicate some spawning activity from July 15 onwards. Accordingly, spawning was, at least partly, delayed by at least one month in 2000. This delay may explain the bay-wide poor recruitment event during summer/fall 2000.

Overall, condition index followed the salinity gradient, with highest values found at the highest salinity sites (Figure 11). Condition index tended to be highest in April-July, coincident with the peak in food availability in Delaware Bay and coincident with the formation of gonadal material. Condition declined by August, probably due to spawning; however, condition tended to show a declining trend from the earliest sampling months, April and May, at many sites. The timing of the decline in condition index suggests that some portion of the decline may be due to restrictions in food supply, as well as spawning.

In some years, a fall phytoplankton bloom can increase condition index in October/November. A small increase in condition index in the fall was observed on some downbay beds where food resources are normally higher, and particularly on Bennies, New Beds and, to some extent Egg Island (Figure 11). The lower salinity beds did not show an equivalently obvious fall increase in condition index and its absence can probably best be explained by the overall lower concentration of phytoplankton available during this part of the year upbay of Bennies.

Box Abundance

Disregarding the occasional sampling date yielding an unusual box count, the number of boxes did not change much over time at most sites, as might be anticipated from a slow rate of disarticulation (Figure 12). Exceptions to this absence of trend include the following. The number of boxes increased sharply at Lease 554D in July/August. The number of boxes declined precipitously at Egg Island from August, 2000 onwards. Box counts were low on New Beds and Bennies in the early spring in both years (Figure 12). Each of these examples occurred on the higher salinity beds. The indication is that both the rate of box creation (by oyster death) and box loss (by disarticulation) occurs more rapidly at higher salinity, an observation that is in accordance with known gradients in mortality (see later discussion) and disarticulation rate[8].

Live oysters normally outnumbered boxes regardless of size class (Figure 13), except at the higher salinity sites where boxes tended to outnumber live oysters. Very likely, the proportionately higher box counts at the higher-salinity sites is an historical signal imposed by the 1998-1999 Dermo epizootic that resulted in high mortalities on the high-salinity beds. The ratio of live oysters to boxes was highest for juveniles at the lower salinity sites and frequently exceeded 10. That is, living juveniles were 10 times more abundant than juvenile-sized boxes. High survivorship and a large increase in juvenile abundance in 2000 produced these high ratios. At the higher salinity sites, the ratio of live oysters to boxes tended to be higher for submarket-size oysters, though still often less than 1. The ratio was always low for market-size oysters (Figure 13).

Box Size Frequency

Box size frequency did not vary much over the course of the study at any site (Figures 14-16). The percentiles of box size frequency, if anything, were more temporally stable than the percentiles of live oyster size frequency (Figure 17) and, in all cases, were similar to those observed in the live oyster population (Figure 6).

The ratio between the median size for live oysters and for boxes routinely fell slightly below 1.0 at the lower-salinity sites (Figure 18). Boxes tended to be a little larger, on the average, at these sites. Probably, the early 2000 incursion of juveniles at the low-salinity sites shifted the population size structure to smaller sizes and the low mortality rates minimized the number of new boxes added at these size classes, so that box size-frequency retained a record of the previous year's size-frequency distribution in the living community. In contrast, at the higher-salinity sites, live oysters tended to be a little larger than boxes (Figure 18). Although speculative, one scenario producing this effect would be the high mortality rates in the submarket size class in 1999, during the Dermo epizootic, and the lower mortality rates in 2000 that permitted an increase in average adult size in these populations during 2000.

The ratio between the median size for live oysters and for boxes varied little over the year (Figure 18). Exceptions included a temporary decline in late summer at Over the Bar and during mid-summer at Nantuxent Point and Bennies.

Parasitism and Health

Common parasites were the two disease-causing organisms, *Haplosporidium nelsoni* (MSX) and *Perkinsus marinus* (Dermo), and the relatively benign *Nematopsis*. A suite of other parasites were observed less commonly, but still frequently enough. These included gill ciliates, large and small ciliates in the gut and digestive gland, *Bucephalus* trematodes, xenomas, and rickettsial bodies. Rare parasites included the trematode *Proctoeces*, nematodes and parasitic copepods. Besides the parasites, ceroid bodies were observed in abundance. Ceroid bodies are thought to be indicative of stress, although cause and effect is not well established. A number of pathologies were also encountered, including diffuse and focal inflammation, tissue edema, and digestive gland atrophy. The latter is not necessarily a true pathology

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[8] Christmas, J.F., M.R. McGinty, D.A. Randle, G.F. Smith and S.J. Jordan, 1997: Oyster shell disarticulation in three Chesapeake Bay tributaries. *J. Shellfish Res.* 16:115-123.

as it may be related to feeding state in oysters[9].

At one time, *H. nelsoni* was the principal cause of mortality in market-size oysters in Delaware Bay. Prevalences have been low since 1990, however. During 2000, prevalence rarely exceeded 20% and weighted prevalence was generally low (Figure 19). With the exception of May at Lower Middle, prevalences above 20% only occurred at the two highest salinity sites, Egg Island and Lease 554D. Generally, prevalences peaked in early spring and again in June (Figure 19). This pattern is typical of the life history dynamics of this organism.[10]

Perkinsus marinus is presently the primary cause of adult oyster mortality in Delaware Bay. Prevalence and infection intensity typically decline with declining salinity, particularly at salinities below 15‰. Prevalence and infection intensity typically peak in late summer and early fall when temperatures are highest.[11] In 2000, prevalence of *P. marinus* reached 100% at all sites except Arnolds and Over the Bar (Figure 20). In 2000, infection intensity reached 3 or higher on the 0-to-5-point Mackin scale at all sites except the three lowest salinity sites, Arnolds, Ship John, and Over the Bar (Figure 20). In keeping with the normal infection pattern, prevalences and infection intensities peaked in late summer and early fall. Generally, population infection intensities above 3 are indicative of epizootic conditions producing significant mortality. Infection intensities this high were observed as far upbay as Ship John (Figure 20).

Most non-disease-causing parasites were counted, so that infection intensity is a measure of abundance. Counts were made per tissue section. Mean values are provided for two sizes of oysters, 20-60 mm and >60 mm. We estimate that a tissue section of the larger size class is about 4 times as large in area as a tissue section of the smaller oyster size class. Accordingly, we have plotted infection intensity of the two size classes on scales that take into account the expectation that an equivalent infection intensity would provide four times as many parasites in a large oyster as in a small oyster.

Nematopsis spp. is the most prevalent parasite of oysters on the East and Gulf coasts of the U.S. Although infection intensities can reach hundreds of cells per tissue section, the parasite appears to produce little or no pathological effect. The final host is a mud crab. Mud crabs are common denizens of Delaware Bay oyster reefs. In 2000, *Nematopsis* was found at all sites (Figures 21-22). Highest infection intensities occurred on Ship John and Bennies. Larger oysters tended to have infection intensities similar to small oysters, indicating that infection intensity increased more or less linearly with size (Figures 21-22). Little seasonality was present in infection intensity. Transient increases, such as observed in August on

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[9] Winstead, J.T. 1995. Digestive tubule atrophy in Eastern oysters, *Crassostrea virginica* (Gmelin, 1791), exposed to salinity and starvation stress. *J. Shellfish Res.*, 14:105-111.

[10] Ford, S., E. Powell, J. Klinck and E. Hofmann, 1999: Modeling the MSX parasite in Eastern oyster (*Crassostrea virginica*) populations. I. Model development, implementation, and verification. *J. Shellfish Res.* 18:475-500.

[11] Hofmann, E.E., E.N. Powell, J.M. Klinck, and G. Saunders, 1995: Modeling diseased oyster populations I. Modelling *Perkinsus marinus* infections in oysters. *J. Shellfish Res.* 14:121-151.

Ship John, may be due simply to the chanciness of collection, although transmission rates might be sufficient to accomplish the same. The most significant exception was a transient, but 3-month long, increase in abundance in large oysters at Egg Island.

Ceroid bodies were also present in all oysters. Numbers reached nearly 600 per tissue section in oysters from Arnolds (Figures 22-23). Frequency of occurrence was also relatively high in oysters from Nantuxent Point, though not nearly as high as in oysters from Arnolds. A tendency existed at some sites for the frequency of occurrence to peak in the summer or early fall, although no consistent seasonal trends were present among all sites (Figures 22-23). The higher abundances of ceroid bodies in oysters from Arnolds and Nantuxent Point suggest that some relationship with low salinity may exist. In general, the density of ceroid bodies did not vary disproportionately with oyster size (Figure 22).

Bucephalus trematodes were rare and encountered principally in late summer and early fall (Figure 24). Rickettsial bodies were most common in June and in oysters from Ship John (Figure 24). Otherwise rickettsiae were rarely observed (Figure 24). Ciliates were more commonly and consistently encountered. Small gill ciliates were most abundant in spring and in oysters from Bennies and Lease 544D (Figure 25). Small oysters normally had a disproportionate number of these ciliates, suggesting that infections lessen with age (Figure 25). Large ciliates were found in the gut, gill, mantle and digestive gland. Such ciliates were encountered throughout the year and on all oyster beds (Figure 25). Again, however, small oysters had a disproportionate infection intensity, indicating that infections lesson with age (Figure 25). A number of less common parasites were observed. These were observed overwhelmingly in July (Figure 26).

Digestive gland atrophy may well be a normal condition determined by feeding state. DGA was highest in the spring and at lower salinities (Figure 26). The precise reason of this pattern is unknown, but seems to be in conflict with Winstead[9] who observed increased DGA when food was restricted. In our study, highest values occurred during the spring phytoplankton bloom.

Pathologies included tissue edema and inflammation. Tissue edema was most common in the spring and at lower salinities (Figure 26), but tissue edema was not disproportionately more common in any oyster size class. Inflammation was also moderately more common in the spring and early summer, and distinctly more frequent at high salinities (Figure 26).

Overall, parasites, diseases and pathologies tended to follow one of four patterns. Some, such as tissue edema, digestive gland atrophy, small gill ciliates, a suite of minor parasites, and rickettsiae tended to be more common in the spring and early summer. In contrast, *Bucephalus*, MSX and Dermo disease were most prevalent in late summer and early fall. DGA, tissue edema, and ceroid bodies were most common at lower salinities. In contrast, tissue inflammation, Dermo and MSX disease, were more common at higher salinities.

Natural Mortality

Cumulative mortality estimated from new boxes and gapers, that occurred between January 1, 2000 and the final sampling on March 26, 2001 ranged from 12% at Arnolds Bed to 87% on Lease 554D (Figure 27). In general, mortality lessened in an upbay direction. Exceptions were Egg Island and Nantuxent Point. The unusually low mortality at Nantuxent Point may be explained by its location at the mouth of Nantuxent Creek, where it was under the influence of low salinity water leaving the creek; however, there is no particular explanation for the relatively low mortality at Egg Island. Mortality on the low salinity beds (Arnolds, Ship John, Over the Bar, and Nantuxent Point) increased fairly regularly over the study period. In contrast, there was a clear elevation of death rates during the summer (June through September) on the other beds. The fraction of total mortality attributable to predation (mostly oyster drills, but also including crabs and occasional dredge damage) was high in the high salinity region (25 to 50%) from Egg Island to Bennies, where its temporal pattern paralleled that of total mortality, but about 15% or less elsewhere (Figure 28). The very low predation-caused loss on Lease 554D is probably due to the lack of small, predation-susceptible, oysters at that location.

Mortality computed from box counts was relatively high at the start of sampling in April, 2000, ranging from about 16% at Arnolds Bed to nearly 80% on Lease 554D and remained at that level through June at most locations (Figure 27). Although considerable variation existed in the pattern, at most sites mortality estimated from the box counts decreased through the summer before increasing again in late summer and autumn. The marked decrease in total box count mortality in the summer indicates that the disarticulation rate of boxes at this time greatly exceeded new mortality that would produce more boxes. The increase in total box count mortality later in the summer and fall indicates that the rate of production of new boxes from ongoing mortality exceeded the disarticulation rate of older boxes (most of which had probably broken apart earlier in the summer). By the final sample in 2000 (November) the cumulative mortality estimate was typically higher than the box count mortality, although the difference was only between 0 and 7 percentage points at the New Jersey sites. The difference was between 10 and 18 percentage points at the two Delaware sites. The results of this study indicate that a major disarticulation event occurred during the mid-summer, probably the result of accelerated bacterial action on the hinge ligament during the high temperature period.

Disarticulation Rate of Boxes

Of the three deployments in the disarticulation experiment, the May 2000 deployment is the most comparable to disarticulation of naturally-occurring boxes present at the start of the monthly sampling in April, 2000. With the exception of Bennies, the experimentally-created boxes showed a relatively steady rate of disarticulation throughout the summer (Figure 29). Disarticulation continued over the winter at some sites, but not at others. Cumulative disarticulation over 300 days of observation ranged from 30 to 70%. At Bennies, the boxes deployed in both May and July experienced a large disarticulation event between mid July and mid August, which raised the total disarticulation to 100% for the May deployment and 83% for the July deployment. We have no explanation for this. The oysters from both deployments were on the same rack, but there was no obvious damage to the rack that would explain the observation. For the most part, the deployments in July and October also experienced a relatively steady rate of disarticulation, with final values reaching 10 to 50% for the July deployment (excluding Bennies) and 0 to 21% for the October deployment. With the exception of Bennies, there did not appear to be any association of the temporal disarticulation pattern with location in the bay.

Analysis of the disarticulation data using both parametric (Logrank [Mantel-Cox]) and parametric (Proportional Hazards test using the Weibull model) survival statistics revealed certain additional similarities and differences in the results of the disarticulation experiment. a) Disarticulation rates were linked to salinity, with boxes on the higher salinity locations having a significantly higher probability of disarticulation than those in the lower salinity areas. b) Although the risk of disarticulation was a function of salinity, the proportional risk was approximately the same at all sites (i.e., changes in the cumulative risk of disarticulating over time were the same at all sites). c) The risk of disarticulation was also a function of time of deployment. Boxes deployed in May and in July had equal chances of disarticulation over time; those deployed in October had a much lower risk of disarticulation over the same length of time. Nevertheless, the proportional risk was the same for all deployments. d) The proportional hazards test with the data fitted to a Weibull model allowed the introduction of shell length (longest dimension), as well as deployment time and site, into the analysis. All three factors were highly significant in the model ($P < 0.0001$). The coefficients for each of the variables indicated the following: i) For each 1-mm increase in shell length, the time to disarticulation decreased by 2.2%. ii) Compared to the October deployment, the time to disarticulation of boxes in the May and July deployments decreased by 62% and 56%, respectively. iii) Compared to the low salinity sites, the time to disarticulation of boxes at the high-salinity sites decreased by 55%.

Predators

Predation accounted for a significant fraction of total mortality (Figure 28), although identified predatory events never accounted for the majority of deaths, emphasizing the importance of disease in controlling oyster population dynamics. Like the diseases, MSX and Dermo, the distribution of predators was consistent with the higher mortality rates downbay at the higher-salinity sites. Predators included mud crabs, blue crabs, and drills. Blue crabs were relatively rare and sporadic in their capture because oyster dredges are inefficient sampling devices (Figure 30). Drills were mostly caught on the higher-salinity sites, Bennies, New Beds, Egg Island, and Lease 554D (Figure 30). Numbers tended to be highest in the summer because drills migrate into deeper water or burrow into the sediment as the weather cools. Two drill species were captured, *Urosalpinx cinerea* and *Eupleura caudata.* Both were collected at the same sites. *E. caudata* tended to be present in early and late summer. *U. caudata* tended to be present more uniformly over the year (Figure 30).

Four species of mud crabs were collected. *Rithropanopeus harrisii* was relatively uncommon. The other three species, *Dyspanopeus sayi, Eurypanopeus depressus,* and *Panopeus herbstii* were more common. *D. sayi* was restricted to the higher salinity beds from Bennies downbay (Figure 31). *P. herbstii* was commonly collected only at these beds as well. *E. depressus* was more widespread in abundance across the salinity gradient (Figure 31). Mud crab abundance increased with increasing salinity, with numbers rising from about 5-15 bushel^{-1} at Arnolds and Ship John to about 20-40 bushel^{-1} at Egg Island and Lease 554D. Seasonal cycles in abundance were not dramatic or consistent among sites. As crabs outnumbered drills and have higher feeding rates and feed for a more extended period of time through the year[7], crabs very likely account for a disproportionate amount of total predatory mortality in Delaware Bay oyster populations.

Oyster drills varied from <6 mm in size up to about 38 mm in size. Most drills were 20 to 30 mm in size. The range of sizes collected did not vary much among beds, although a tendency existed for the few drills caught on the lower-salinity beds to be from the lower half of the size range (Figure 32).

With rare exceptions, the mud crabs collected were within the size range of 6 to 20 mm. The size-frequency distribution was relatively similar on all beds. The larger mud crabs tended to be *P. herbstii.* The remaining three species were of about the same size (Figure 33).

Fouling Organisms

Most bionts were observed on the outer surface of the shell, because the oysters were collected alive. Bionts on the inner surface were limited to borers that bored through or nearly through the shell. *Polydora* blisters dominated this latter category (Figure 34). In contrast, a diversity of bionts was observed on the shell outer surface. Bryozoans and borers dominated the mix, although encrusting polychaetes and barnacles were also abundant (Figure 34). Among the encrusting polychaetes, sabellariids were most common. Among the borers, *Polydora* accounted for a much greater proportion of total coverage than the boring sponge, *Cliona*. However, we made no effort to evaluate the volume of *Cliona* galleries, so clionid coverage is consistently underestimated. Among the bryozoans, encrusting bryozoans accounted for much more coverage than the erect forms. A variety of other bionts, including egg cases, fungi, green algae, hydroids, and molluscs contributed significantly to biont coverage locally, but were of limited importance bay-wide (Figure 34).

Figure 35 shows examples of the time series of epibiont coverage for each site. Generally, constant temporal trends were not apparent over all sites. For example, encrusting bryozoans increased in abundance during the summer on Lease 554D, but declined in abundance on Bennies and New Beds (Figure 35). Coverage was consistently high during the entire sampling program on Arnolds. Total biont coverage (Figure 35) declined sharply in July at six sites, but remained high on Bennies and Lease 554D and at moderate levels at Lower Middle. Because of the diversity of temporal and spatial responses among the nine sites, further evaluation of biont coverage was restricted to summary comparisons of coverage among sites and sampling dates.

Total biont coverage on the outer shell surface did not follow any obvious temporal trends (Figure 36). Coverage tended to increase with increasing salinity, with the exception of Arnolds, where coverage was unusually high, judged on this basis (Figure 36). Total biont coverage on the inner shell surface was highest at the two Delaware sites, Bennies and New Beds. These four beds are near the center of the salinity gradient. Coverage declined at both salinity extremes (Figure 36). Biont coverage on the inner shell surface averaged higher during the second half of the study (Figure 36).

Molluscan epibionts included oysters, ribbed mussels (*Geukensia demissa*), and *Crepidula* gastropods. Molluscan bionts were most common at the two Delaware sites, Over the Bar and Lower Middle (Figure 37). A monthly trend in coverage did not exist. *Geukensia demissa*, was most common at the two Delaware sites, but was equally as common on New Beds and Bennies. Abundances declined at the extremes of the salinity gradient (Figure 38). The time series showed distinctively lower coverages during the summer months (Figure 38). Oysters were routinely found as 'bionts' on other oysters. Their occurrence was particularly more common at the two Delaware sites where the vertical 'clump' structure of unfished reefs was best developed. Coverage declined at both extremes of the salinity gradient (Figure 38). Temporal trends were not observed (Figure 38). *Crepidula* was only observed on Lease 554D (Figure 38).

Encrusting polychaetous bionts included sabellariids, serpulids, and mudtube-dwelling polychaetes. Coverage by encrusting polychaetes was highest at the two Delaware sites, Over the Bar and Lower Middle, and on Lease 554D (Figure 37). Coverage was highest in spring and declined during the summer months (Figure 37). Higher coverage in the spring originated from a distinctly increased frequency of occurrence of polychaete mudtubes during that time (Figure 39). Mudtubes increased in abundance with increasing salinity in a nearly monotonic fashion (Figure 39). A significant increase in coverage of mudtubes at Lease 554D was partially responsible for the high total coverage of encrusting polychaetes at this site. Sabellariid polychaetes were most common at the two Delaware sites and Lease 554D, thus determining, in large measure, the trend in total coverage of encrusting polychaetes (Figure 39). However, no time-dependent trends were present (Figure 39). Serpulid tubes were much more common on Lease 554D than elsewhere. Coverage increased with increasing salinity at the other sites (Figure 39). Coverage showed a decline in late summer (Figure 39).

Barnacles were most abundant at Arnolds, and somewhat more abundant at Ship John and Nantuxent Point than at the other sites (Figure 40). Coverage did not show a significant temporal trend (Figure 40).

Bryozoans were both of the encrusting forms (e.g., *Electra, Membranipora*) and the erect forms (e.g., *Bugula, Alcyonidium, Amathia*). Total bryozoan coverage was highest at Arnolds, Bennies, Nantuxent Point and Lease 554D (Figure 41). Coverage declined somewhat after June 2000 and stabilized for the remainder of the study (Figure 41). Encrusting bryozoans followed the identical trends (Figures 41). Erect bryozoans followed a distinctively different pattern. Erect bryozoans were most common at the highest salinity sites, Egg Island and Lease 554D (Figure 41). Coverage peaked in June, 2000 (Figure 41).

Encrusting sponges (*e.g., Microciona*) were present in highest abundance at the higher salinity sites, however not at all of them. Coverage at Bennies, New Beds and Egg Island was much higher than at other sites. Coverage peaked in late summer in 2000 and than peaked again in March, 2001 (Figure 40).

Hydroids were present in greatest abundance on the New Jersey side of the bay. Abundance was high at five of seven New Jersey sites (Figure 40). Coverage peaked in the spring, April 2000 and March 2001 (Figure 40).

A few anemones and tunicates were also present. These organisms were present in highest abundance on Lease 554D (Figure 42). Abundances peaked in fall, 2000 and remained relatively high in March, 2001 (Figure 42).

Borers were present on the inner and outer surfaces of the oyster shell. Coverage on the outer shell was normally greater. The surface expression of these bionts typically reflects a minimal estimate of their presence. For example, a shell extensively bored by *Cliona* sponge may, nevertheless, show less than 10% surface coverage because the ostial openings are small in comparison to the total area of the galleries.

Borers, estimated for the outer shell surface, reached higher coverages at the high salinity sites (Figure 43). These included all sites downbay of Shell Rock (Figure 1) except Nantuxent Point. Total coverage tended to increase through the course of the study, with highest values in November, 2000 and March, 2001 (Figure 43). Coverage on the inner surface was dominated by *Polydora* blisters and followed a distinctly different pattern (Figures 43). No time trends were observed and, except for the low occurrence at Arnolds, little spatial variation was observed (Figure 43).

Cliona sponge was distinctly more common at the higher salinity sites. Highest coverage was reached on Egg Island. Lower coverage on Lease 554D is probably due to the origin of these oysters on Shell Rock where coverage likely was low. Coverage peaked distinctly in August, 2000 and was relatively high in the Fall of 2000 (Figure 43). Outer shell coverage of *Polydora* tended to increase with increasing salinity. Coverage declined markedly in late summer 2000 and in March 2001 (Figure 42). Inner and outer shell coverage of *Polydora* were dissimilar, probably because the shell blisters on the inner shell integrate a longer amount of time and identify the larger bionts, as opposed to the dynamic nature of biont coverage on the outer shell (Figure 42).

Representativeness of 2000

Year-to-year variations in oyster abundance and health are the norm. Yearly changes are produced by a combination of the demands of a changing environment and the demands of the present state of the population that limits the range and type of change that can occur for a given change in the environment. This 'system memory' seems to integrate over a period of about two to three years, depending on location.[12]

Given that year-to-year changes in population attributes is the norm, a useful endeavor is to evaluate how typical the monitored year was within the range of variation observed in previous years. The State of New Jersey has supported a yearly stock assessment of the New Jersey seed beds since the early 1950s. This survey covers six of the nine sites in the present study (all Jersey sites except Lease 554D). Although the time series extends into the 1950s, Dermo disease did not become important until approximately 1990. Accordingly, the time series since 1989 is the only portion of the long-term time series that can be reliably compared to the data collected in this monitoring study. Although the stock assessment makes a variety of measurements, comparisons can be most easily made for oyster abundance and size frequency, spat abundance, mortality, and prevalence of Dermo and MSX disease. Evaluation of representativeness will rely on these variables.

Oyster abundance on the New Jersey seed beds in 2000 was about average for the decade of the 1990s (Figure 44). Abundance was increasing after a severe Dermo epizootic in 1998-1999 that significantly reduced abundance from 1996-1997 levels. Oyster abundance downbay of Shell Rock, including the monitoring sites of Bennies, New Beds, Egg Island, and Nantuxent Point, was lower than observed in seven of the twelve years from 1989-2000, but only significantly lower than 1996 (Figure 45). Oyster abundance upbay of Shell Rock, including the monitoring sites of Arnolds and Ship John, was at historic highs, and significantly higher that in six of the previous 11 years (Figure 45).[13]

Abundance of market-size oysters in the New Beds/Bennies/Nantuxent Point area was about average in 2000 and well below historic highs (Figure 46). Upbay, market-size abundance was relatively high, but still well below historic highs (Figure 47). The increase in abundance between 1999 and 2000 for harvestable oysters (weighted mean of market and submarket abundance) on the high-mortality beds was greater than observed in 8 of the 10 previous biannual pairings (Figure 46). Thus, the increase in abundance that occurred in 2000 was unusually high. For the medium-mortality beds, the yearly increase was larger than observed in 9 of the previous 10 biannual pairings (Figure 47). Thus, the increase in abundance on these beds in 2000 was anomalously high. The increasing number of juveniles observed in the monitoring study and the management policy adopted by NJDEP to increase oyster abundance on the high-mortality beds in 2001 by limiting harvest on these beds suggests that market-size abundance may increase again in 2001 throughout the Bay. The trends in increasing abundance accrue from unusually good spat recruitment in 1997, 1998 and 1999. These three years account for three of the four highest spat-recruitment years in the decade of the 1990s.

Spat recruitment in 2000 was among the lowest of the decade of the 1990s and

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[12] Soniat, T.M., E.N, Powell, E.E. Hofmann and J.M. Klinck, 1998: Understanding the success and failure of oyster populations: the importance of sampled variables and sample timing. *J. Shellfish Res.* 17:1149-1165.

[13] HSRL. 2001. Report of the 2000 Stock Assessment Workshop for the New Jersey oyster seed beds. Haskin Shellfish Research Laboratory, Rutgers University, 23 pp.

significantly lower than observed in six of the twelve years form 1989-2000 (Figure 48). Spat abundance was low throughout the bay, from Shell Rock upbay and below Shell Rock. Spat abundance ranked fourth or fifth from the bottom in the 12-year time series in both areas. The low recruitment observed in 2000 suggests that abundance will be impacted sometime in the 2002-2003 period, even if Dermo mortality rates remain at average levels.

The monitoring study time series provides clues as to the origin of the low spat abundances in Fall 2000. Oyster spawning was unusually late in 2000. A significant component of the spawn must have occurred after August 15, probably due to the cool summer. Larval modeling studies indicate that a late summer spawn is likely to be characterized by poor survivorship because food supplies will be too low and declining temperatures will impact growth rates.[14] Consequently, unusually low spat counts in Fall, 2000 would be anticipated from the data on gonadal index that records the delayed spawning event in 2000.

Condition index was about average in November, 2000, in comparison to previous years at the same time period, throughout the salinity range of the seed beds (Figure 49). Dermo weighted prevalence was relatively high, although not unusually so for the last decade (Figure 50). Natural mortality rates during 2000 were at historic lows on the low-mortality beds, including Arnolds, and near historic lows on the medium-mortality beds, including Ship John (Figure 51) and this fits with the significant increase in total abundance observed on these beds. Natural mortality rate was near average on the high-mortality beds, including Nantuxent Point, Bennies, New Beds, and Egg Island.

In summary, 2000 was a relatively unusual year. A number of population attributes were at or near historic highs or lows. These included the historically-high abundances on the upbay seed beds, historically-significant increases in market-size abundance upbay and downbay of Shell Rock, the low spat counts in Fall 2000 indicative of poor survivorship of a late season spawn, and historically-low levels of natural mortality upbay of Bennies. In gestalt aspect, then, year 2000 was atypical for the period of the 1990s and this atypical nature is likely to impact the natural course of population change over the coming two to three years.

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[14] Dekshenieks, M.M., E.E. Hofmann and E.N. Powell, 1993: Environmental effects on the growth and development of Eastern oyster, *Crassostrea virginica* (Gmelin, 1791), larvae: a modeling study. *J. Shellfish Res.* 12:241-254.

Table 1

Seed bed	1999 Effort (m^2 coverage)	1999 Fraction of bed covered	1999 Bushels caught	2000 Effort (m^2 coverage)	2000 Fraction of bed covered	2000 Bushels caught
Arnolds	572,458	0.268	1,219	0	0.000	0
Ship John	1,096,627	0.348	2,062	2,061,195	0.653	2,086
Bennies	14,449,313	2.491	17,157	5,544,236	0.956	5,993
New Beds	7,258,492	1.230	5,908	5,973,385	1.012	5,349
Egg Island	63,606	0.016	90	0	0.000	0

Legends for Figures

Figure 1. Map of Delaware Bay showing the locations of the sampled oyster beds.

Figure 2. Trends in oyster abundance on the nine sampled oyster beds over the course of the monitoring study.

Figure 3. Size-frequency distributions for each oyster bed for the months of April, May and June, 2000.

Figure 4. Size-frequency distributions for each oyster bed for the months of July, August, and September, 2000

Figure 5. Size-frequency distributions for each oyster bed for the months of October and November, 2000 and March, 2001.

Figure 6. Percentiles of the size-frequency distributions for live oysters from each oyster bed over the course of the study.

Figure 7. Time series of spat abundance, live and dead, for each oyster bed over the course of the study.

Figure 8. Ratio of spat abundance for each oyster bed, calculated as:

$$\frac{\textit{average spat abundance : April, May, June}}{\textit{average spat abundance : August, September, October}}.$$

Figure 9. Ratio of the change in spat abundance in 2000 and the change in juvenile abundance (20-63.5 mm) in 2000 for each oyster bed, calculated as:

$$\frac{\textit{average spat abundance : April, May, June} - \textit{average spat abundance : August, September, October}}{\textit{average juvenile abundance : August, September, October} - \textit{average juvenile abundance : April, May, June}}.$$

The straight line indicates the case where the number of spat lost balances the number of juveniles gained (e.g., apparent 100% survivorship).

Figure 10. Trends in oyster gonadal index on the nine sampled oyster beds over the course of the monitoring study. Categories were: sexually undifferentiated (1), early development (2), mid-development (3), late development (4), fully developed (5), spawning (6), spawned, evidence of renewed reproductive activity (7), spawned out (8).

Figure 11. Trends in oyster condition index on the nine sampled oyster beds over the course of the monitoring study.

Figure 12. Trends in box abundance on the nine sampled oyster beds over the course of the monitoring study.

Figure 13. Trends in the ratio of live oysters to boxes on the nine sampled oyster beds over the course of the monitoring study.

Figure 14. Box size-frequency distributions for each oyster bed for the months of April, May and June, 2000.

Figure 15. Box size-frequency distributions for each oyster bed for the months of July, August, and September, 2000

Figure 16. Box size-frequency distributions for each oyster bed for the months of October and November, 2000 and March, 2001.

Figure 17. Percentiles of the size-frequency distributions for boxes from each oyster bed over the course of the study.

Figure 18. Trends in the ratio between the 50^{th} percentiles of the size-frequency distributions for live oysters and boxes for each oyster bed over the course of the study.

Figure 19. Trends in the prevalence and infection intensity of *Haplosporidium nelsoni* (MSX disease) for each oyster bed over the course of the study.

Figure 20. Trends in the prevalence and infection intensity of *Perkinsus marinus* (Dermo disease) for each oyster bed over the course of the study.

Figure 21. Trends in the infection intensity of *Nematopsis* in small and large oysters for each oyster bed over the course of the study. Note that the y-axis dimensions for small and large oysters differ by a factor of 4 to take into account the estimated difference in average section area between the two size groups. For infection density to be the same, about four times as many parasites must be present in a large oyster than in a small oyster.

Figure 22. Summary trends in the infection intensity of *Nematopsis* and abundance of ceroid bodies in small and large oysters for each oyster bed and for each month. Note that the y-axis dimensions for small and large oysters differ by a factor of 4 to take into account the estimated difference in average section area between the two size groups. For infection density to be the same, about four times as many parasites must be present in a large oyster than in a small oyster.

Figure 23. Trends in the abundance of ceroid bodies in small and large oysters for each oyster bed over the course of the study. Note that the y-axis dimensions for small and large oysters differ by a factor of 4 to take into account the estimated difference in average section area between the two size groups. For infection density to be the same, about four times as many parasites must be present in a large oyster than in a small oyster.

Figure 24. Summary trends in the infection intensity of *Bucephalus*, rickettsial bodies, and focal and diffuse inflammation in small and large oysters for each oyster bed and for each month. Note that the y-axis dimensions for rickettsial bodies in small and large oysters differ by a factor of 4 to take into account the estimated difference in average section area between the two size groups. For infection density to be the same, about four times as many parasites must be present in a large oyster than in a small oyster.

Figure 25. Summary trends in the infection intensity of ciliates in small and large oysters for each oyster bed and for each month. Note that the y-axis dimensions for small and large oysters differ by a factor of 4 to take into account the estimated difference in average section area between the two size groups. For infection density to be the same, about four times as many parasites must be present in a large oyster than in a small oyster.

Figure 26. Summary trends in the infection intensity of minor parasites (including copepods, nematodes and non-*Bucephalus* trematodes), tissue edema, and digestive gland atrophy in small and large oysters for each oyster bed and for each month. Note that the y-axis dimensions for minor parasites in small and large oysters differ by a factor of 4 to take into account the estimated difference in average section area between the two size groups. For infection density to be the same,

about four times as many parasites must be present in a large oyster than in a small oyster.

Figure 27. Trends in natural mortality estimated by the cumulative count method and the total box method as described in the Methods section for each oyster bed and for each month.

Figure 28. Trends in total natural mortality estimated by the cumulative count method and the fraction attributable to identified predatory events for each oyster bed and for each month.

Figure 29. Trends in cumulative disarticulation in boxes deployed on racks in May, July and October at seven of the nine sampling sites.

Figure 30. Trends in the abundance of predatory blue crabs and oyster drills for each oyster bed over the course of the study.

Figure 31. Trends in the abundance of four species of mud crabs for each oyster bed over the course of the study.

Figure 32. Trends in the size frequency of the two species of oyster drills collected on the Delaware Bay oyster beds over the course of the study.

Figure 33. Trends in the size frequency of the four species of mud crabs collected on the Delaware Bay oyster beds over the course of the study.

Figure 34. Summary average shell coverages of the various biont types observed during the study. All molluscs included oysters + *Crepidula* + *Geukensia*. All encrusting polychaetes include *Sabellaria* + *Hydroides* + mudtubes. All bryozoans include encrusting bryozoans + erect bryozoans. All borers include *Polydora* + *Cliona.*

Figure 35. Trends in total biont coverage (outer shell surface) and total coverage by encrusting bryozoans (outer shell surface) for each oyster bed during the course of the study.

Figure 36. Summary trends in total biont coverage for the inner and outer surfaces of the shell for each oyster bed and each sampling date.

Figure 37. Summary trends in total molluscan biont coverage and total encrusting polychaete biont coverage for the inner and outer surfaces of the shell for each oyster bed and each sampling date. Molluscs include oysters, *Crepidula* spp., and *Geukensia demissa.* Encrusting polychaetes include *Sabellaria*, the serpulid *Hydroides*, and mudtube-dwelling polychaetes.

Figure 38. Summary trends in molluscan biont (oysters, *Crepidula spp.*, and *Geukensia demissa*) coverage for the outer surface of the shell for each oyster bed and each sampling date.

Figure 39. Summary trends in polychaete biont (*Sabellaria, Hydroides*, mudtubes) coverage for the outer surface of the shell for each oyster bed and each sampling date.

Figure 40. Summary trends in barnacle, encrusting sponge, and hydroid coverage for the outer surface of the shell for each oyster bed and each sampling date.

Figure 41. Summary trends in bryozoan biont coverage for the outer surface of the shell for each oyster bed and each sampling date.

Figure 42. Summary trends in anemone/tunicate coverage for the outer surface of the shell

and for *Polydora* polychaetes for the inner and outer surfaces of the shell for each oyster bed and each sampling date.

Figure 43. Summary trends in total borer coverage for the inner and outer surfaces of the shell for each oyster bed and each sampling date. Borers include *Cliona* sponge and *Polydora* polychaetes. Summary trends in *Cliona* coverage for the outer surface of the shell for each oyster bed and each sampling period. Coverage is an underestimate, because coverage was based on the area of ostial openings rather than the area of galleries.

Figure 44. Time-series of oyster abundance on the New Jersey seed beds since 1989, estimated from the late-October stock assessment survey.

Figure 45. Average annual oyster abundance per 37-qt bushel for the high-mortality and medium-mortality New Jersey seed beds for the period 1989-2000. Underlined values are not significantly different according to the 95% least significant difference confidence intervals. High-mortality beds include Bennies, Bennies Sand, Egg Island, Hawk's Nest, Hog Shoal, New Beds, Strawberry, Vexton, Beadons, and Nantuxent Point. Medium-mortality beds include Upper Middle, Middle, Cohansey, Sea Breeze, Ship John and Shell Rock.

Figure 46. Time-series of weighted-mean oyster abundance on the New Jersey high-mortality seed beds since 1989, in rank order, and the rank order of the ratio of weighted-mean abundance in consecutive years. Values are estimated from the late-October stock assessment survey time series. Weighted means were calculated as: $market\ abundance + (.5 \times submarket\ abundance)$. Ratio of consecutive years calculated as: $\frac{weighted\ abundance(T+1)}{weighted\ abundance(T)}$. High-mortality beds defined in Figure 45.

Figure 47. Time-series of weighted-mean oyster abundance on the New Jersey medium-mortality seed beds since 1989, in rank order, and the rank order of the ratio of weighted-mean abundance in consecutive years. Values are estimated from the late-October stock assessment survey time series. Weighted means were calculated as: $market\ abundance + (.5 \times submarket\ abundance)$. Ratio of consecutive years calculated as: $\frac{weighted\ abundance(T+1)}{weighted\ abundance(T)}$. Medium-mortality beds defined in Figure 45.

Figure 48. Average spat abundance per 37-qt bushel for all of the seed beds and for the high-mortality and medium-mortality New Jersey seed beds for the period 1989-2000. Underlined values are not significantly different according to the 95% least significant difference confidence intervals. Bed categories defined in Figure 45.

Figure 49. Average condition index for four groups of New Jersey seed beds covering the salinity gradient for the period 1989-2000.

Figure 50. Average *Perkinsus marinus* infection intensity for the New Jersey seed beds for the period 1989-2000.

Figure 51. Rank-order of the estimates of yearly natural mortality rate for the high-mortality, medium-mortality, and low-mortality New Jersey seed beds for years 1990-2000. High-mortality beds include Bennies, Bennies Sand, Egg

Island, Hawk's Nest, Hog Shoal, New Beds, Strawberry, Vexton, Beadons, and Nantuxent Point. Medium-mortality beds include Upper Middle, Middle, Cohansey, Sea Breeze, Ship John and Shell Rock. Low-mortality beds include Arnolds, Upper Arnolds, and Round Island.

FIGURE 1

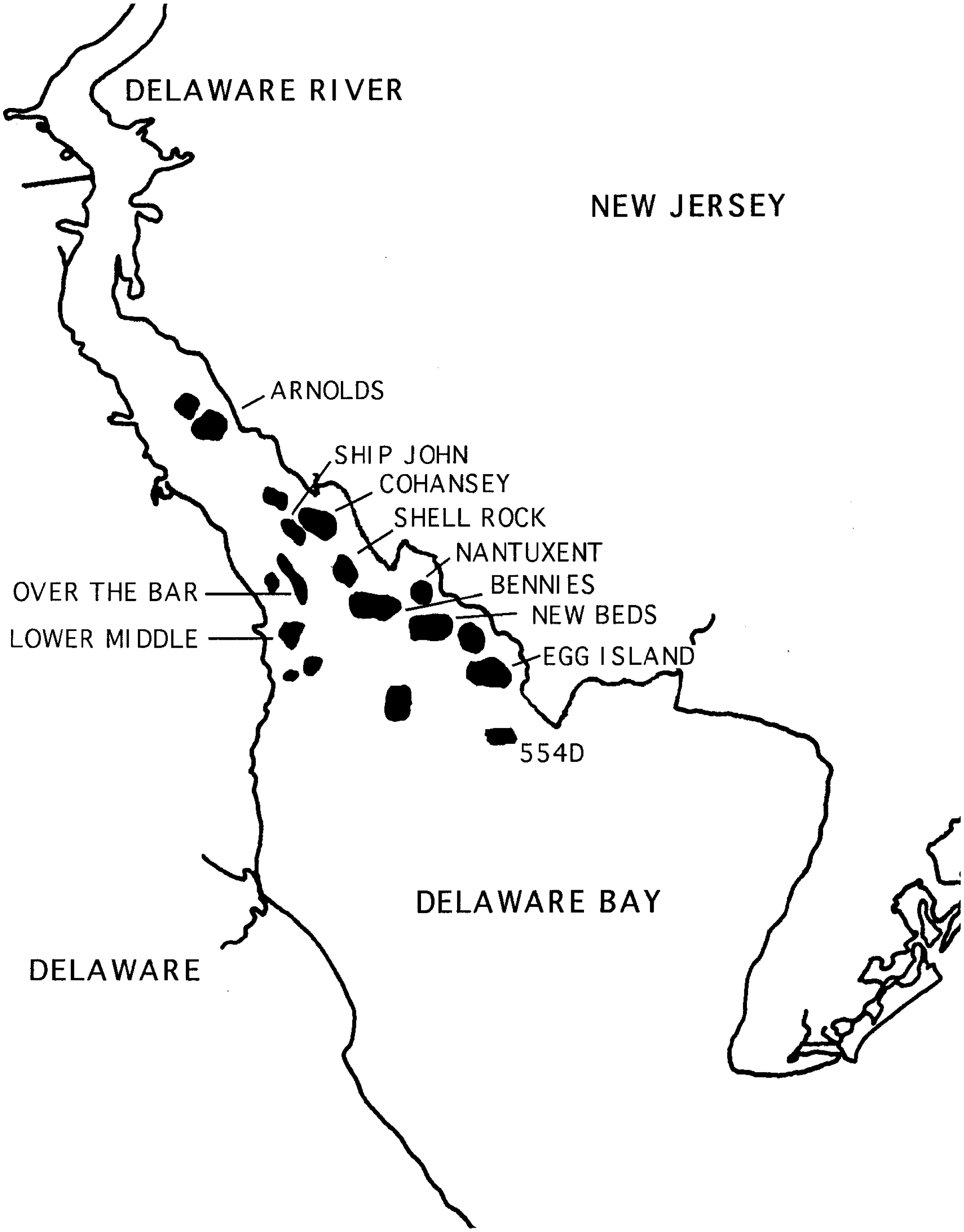

DELAWARE RIVER
NEW JERSEY
ARNOLDS
SHIP JOHN
COHANSEY
SHELL ROCK
NANTUXENT
BENNIES
NEW BEDS
EGG ISLAND
OVER THE BAR
LOWER MIDDLE
554D
DELAWARE BAY
DELAWARE

FIGURE 2
OYSTERS PER M^2

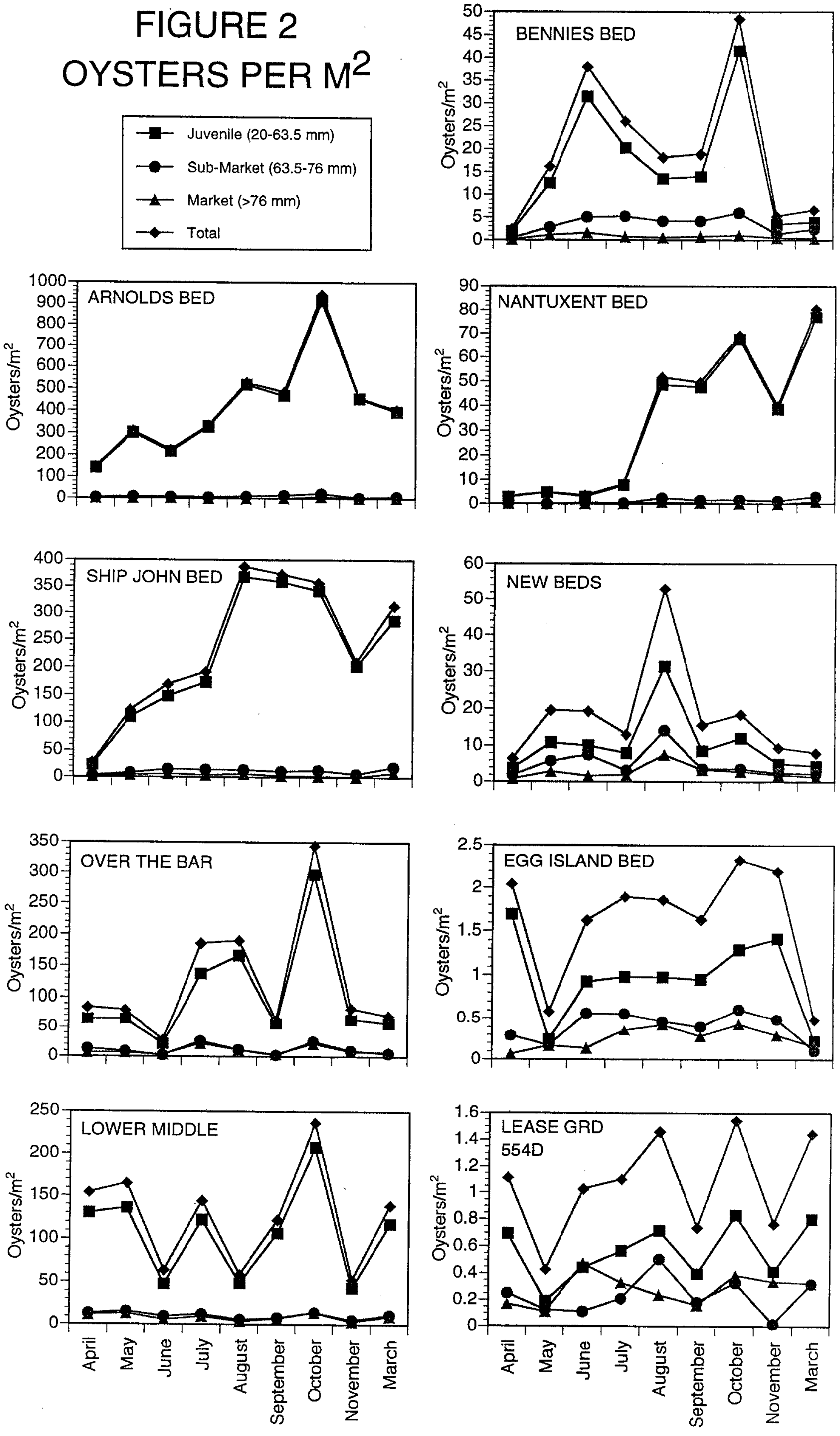
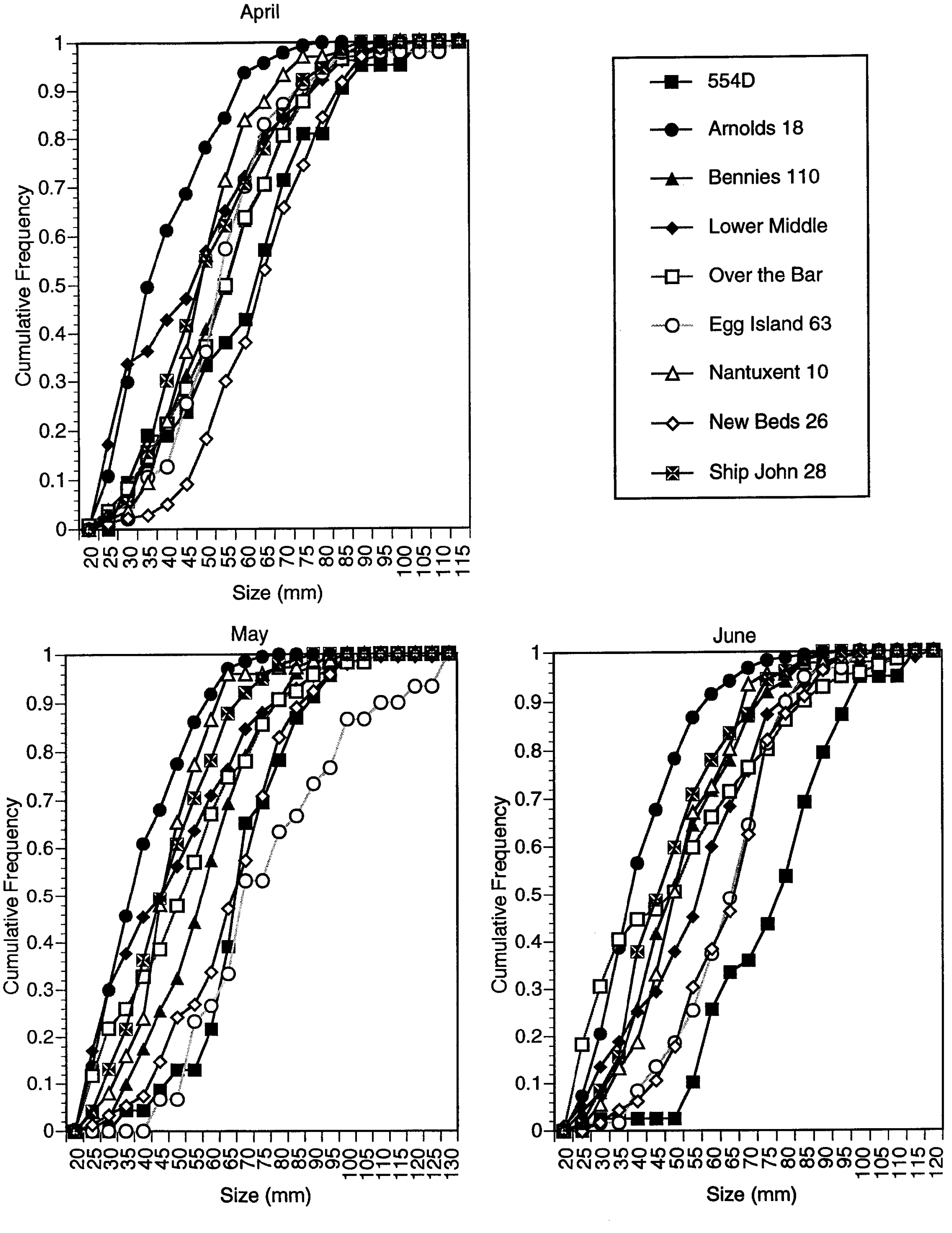


Figure 3


April

May

June

Figure 4

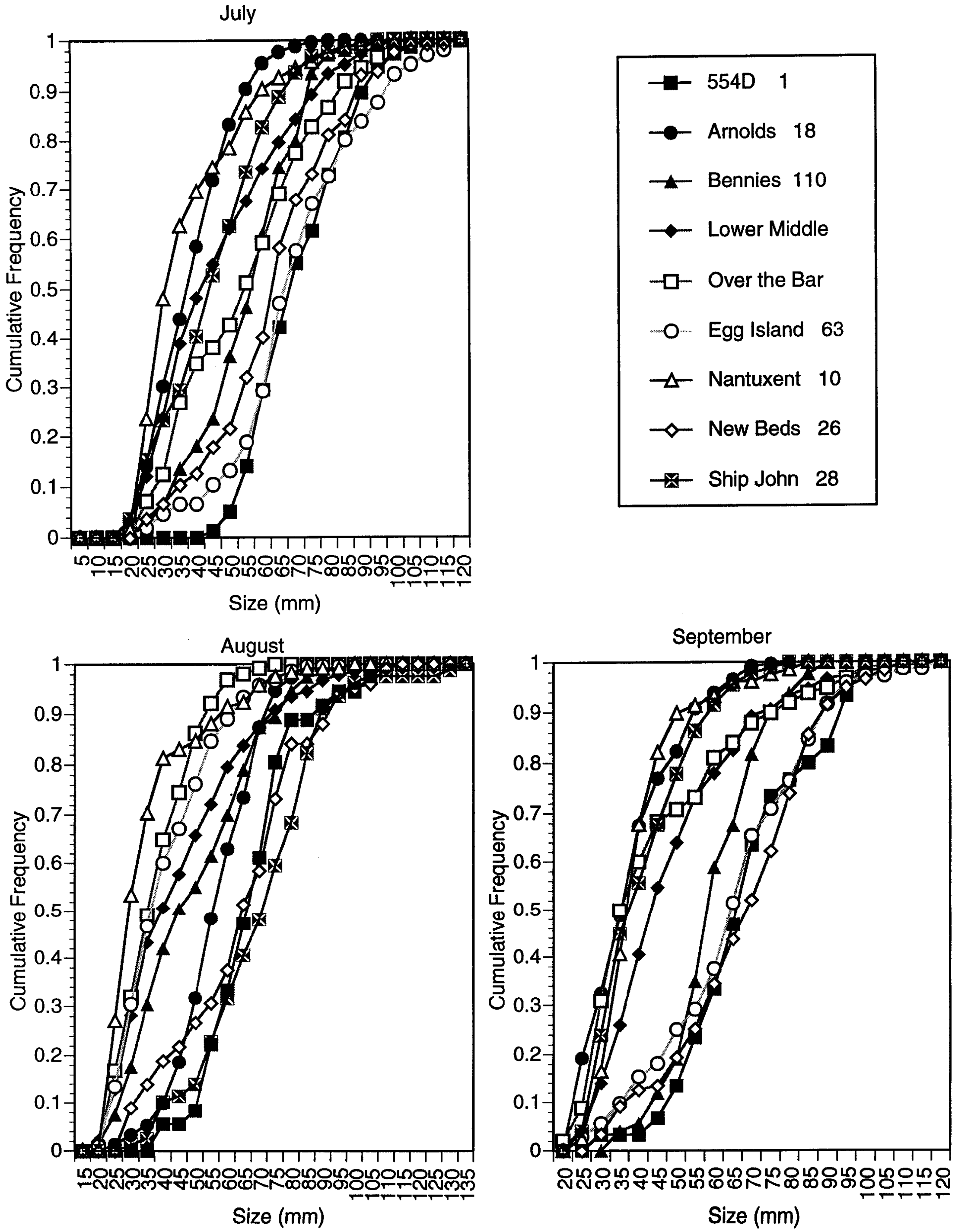

July
August
September
Cumulative Frequency
Size (mm)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 85 90 95 100 105 110 115 120
15 20 25 30 35 40 45 50 55 60 65 70 75 80 85 90 95 100 105 110 115 120 125 130 135
20 25 30 35 40 45 50 55 60 65 70 75 80 85 90 95 100 105 110 115 120
■ 554D 1
● Arnolds 18
▲ Bennies 110
◆ Lower Middle
□ Over the Bar
○ Egg Island 63
△ Nantuxent 10
◇ New Beds 26
☒ Ship John 28

Figure 5

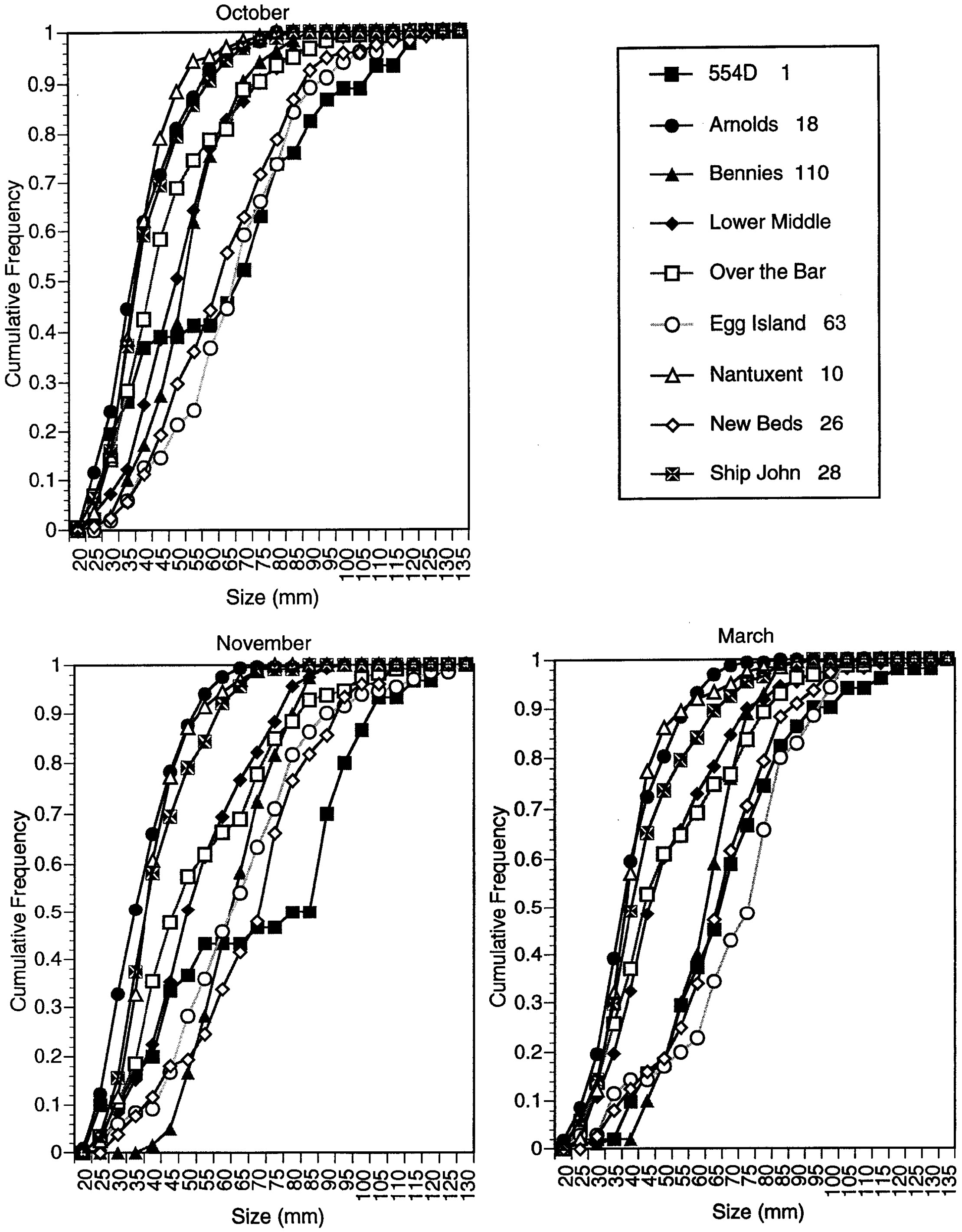
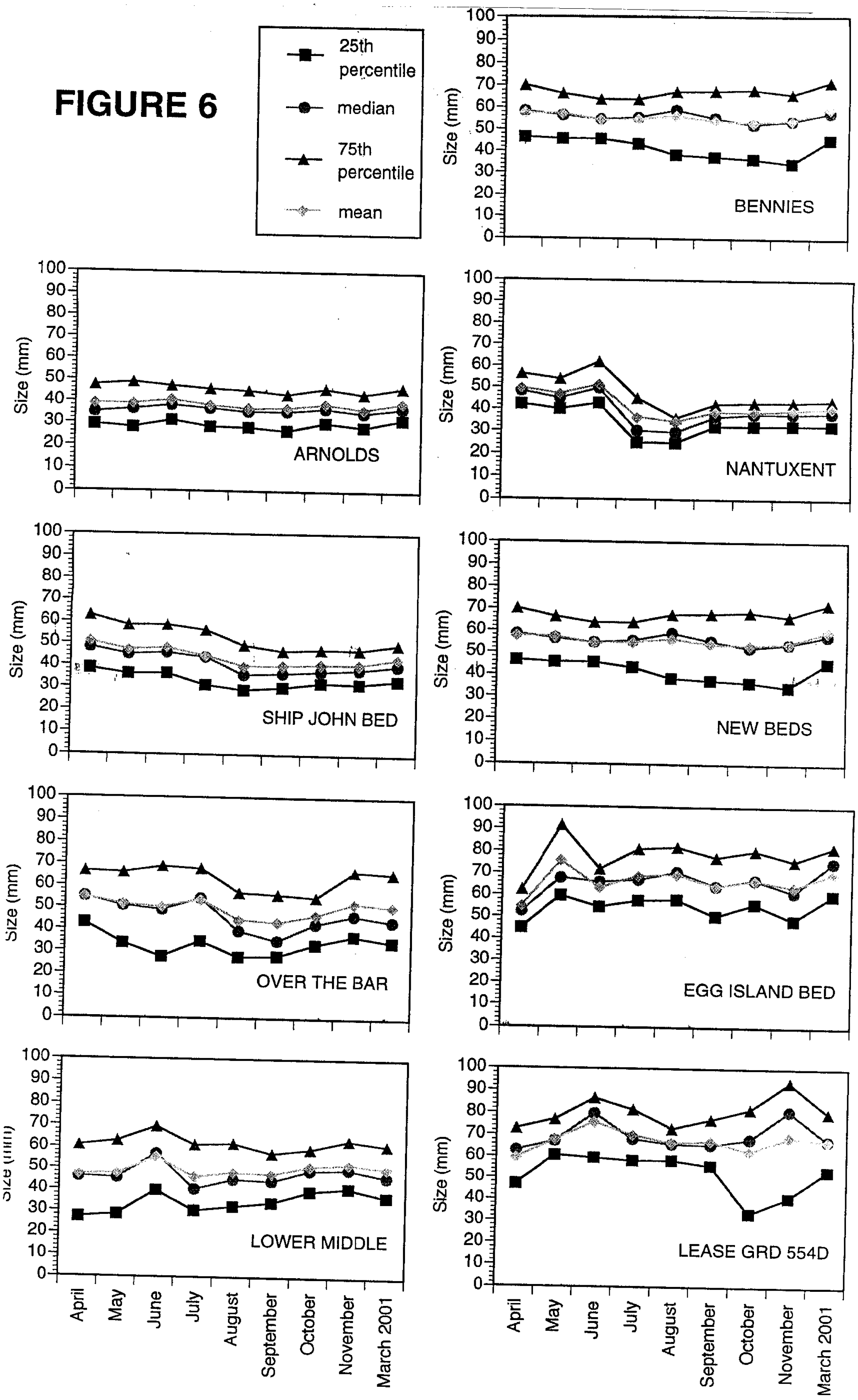

October
November
March
Cumulative Frequency
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Size (mm)
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90
95
100
105
110
115
120
125
130
135
554D 1
Arnolds 18
Bennies 110
Lower Middle
Over the Bar
Egg Island 63
Nantuxent 10
New Beds 26
Ship John 28

FIGURE 6



25th percentile
median
75th percentile
mean
Size (mm)
0
10
20
30
40
50
60
70
80
90
100
BENNIES
ARNOLDS
NANTUXENT
SHIP JOHN BED
NEW BEDS
OVER THE BAR
EGG ISLAND BED
LOWER MIDDLE
LEASE GRD 554D
April
May
June
July
August
September
October
November
March 2001

FIGURE 7
OYSTER SPAT
2000-01

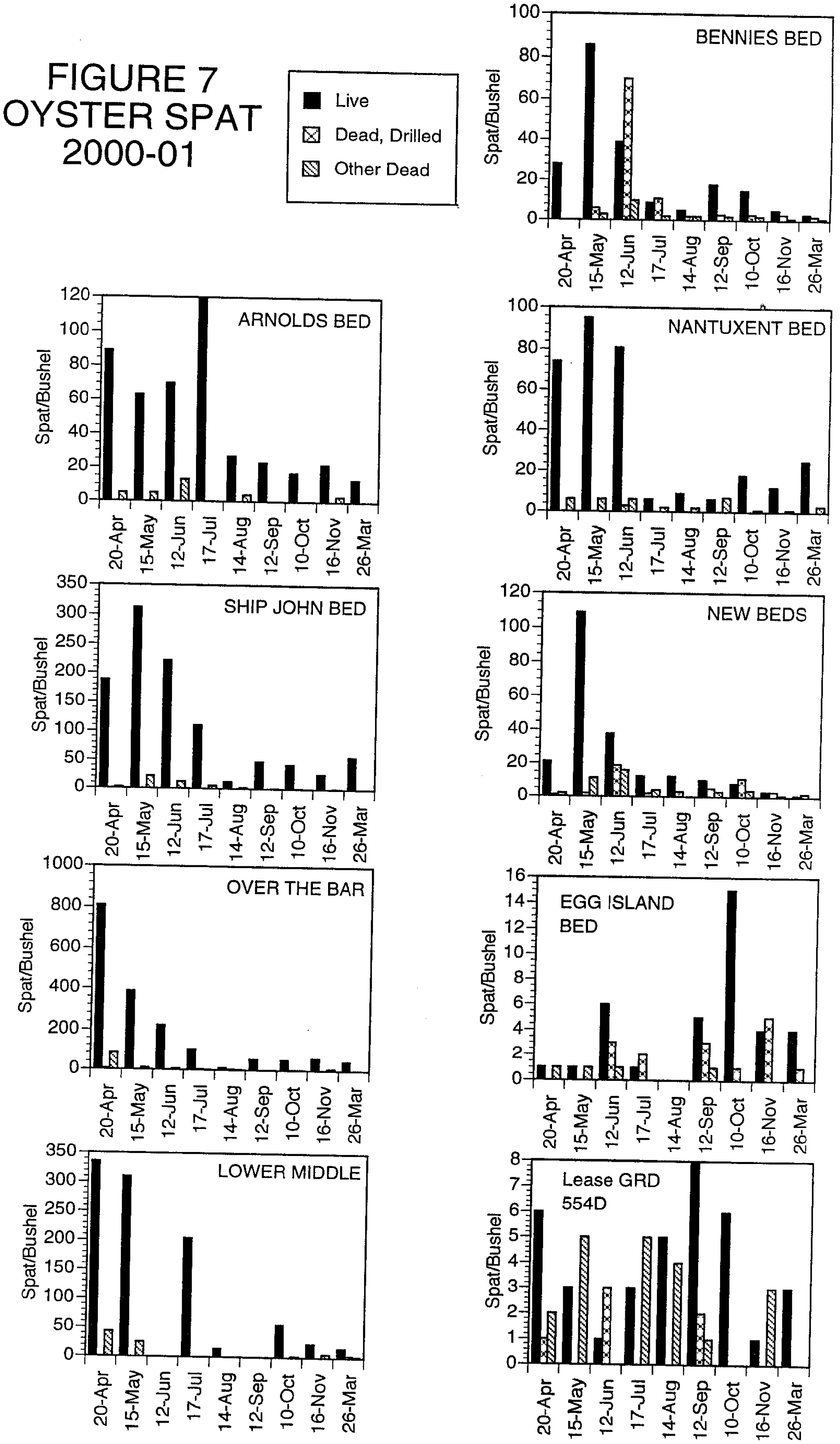


FIGURE 8
RATIO OF SPRING SPAT TO FALL SPAT

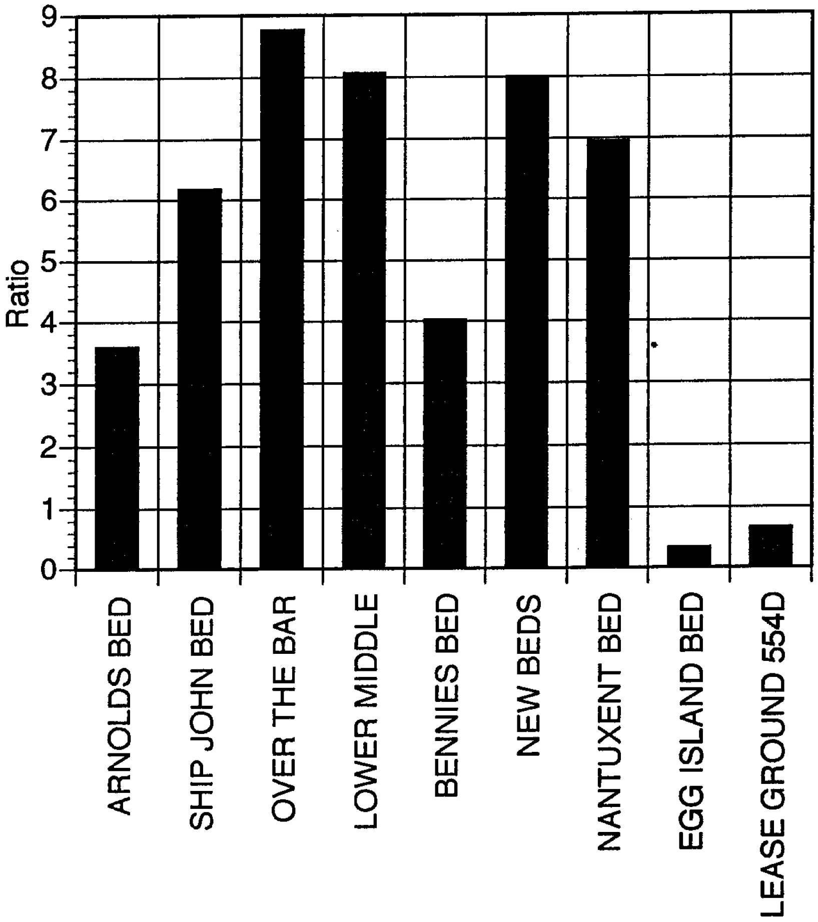


Figure 9
Survivorship of Spat to Juveniles

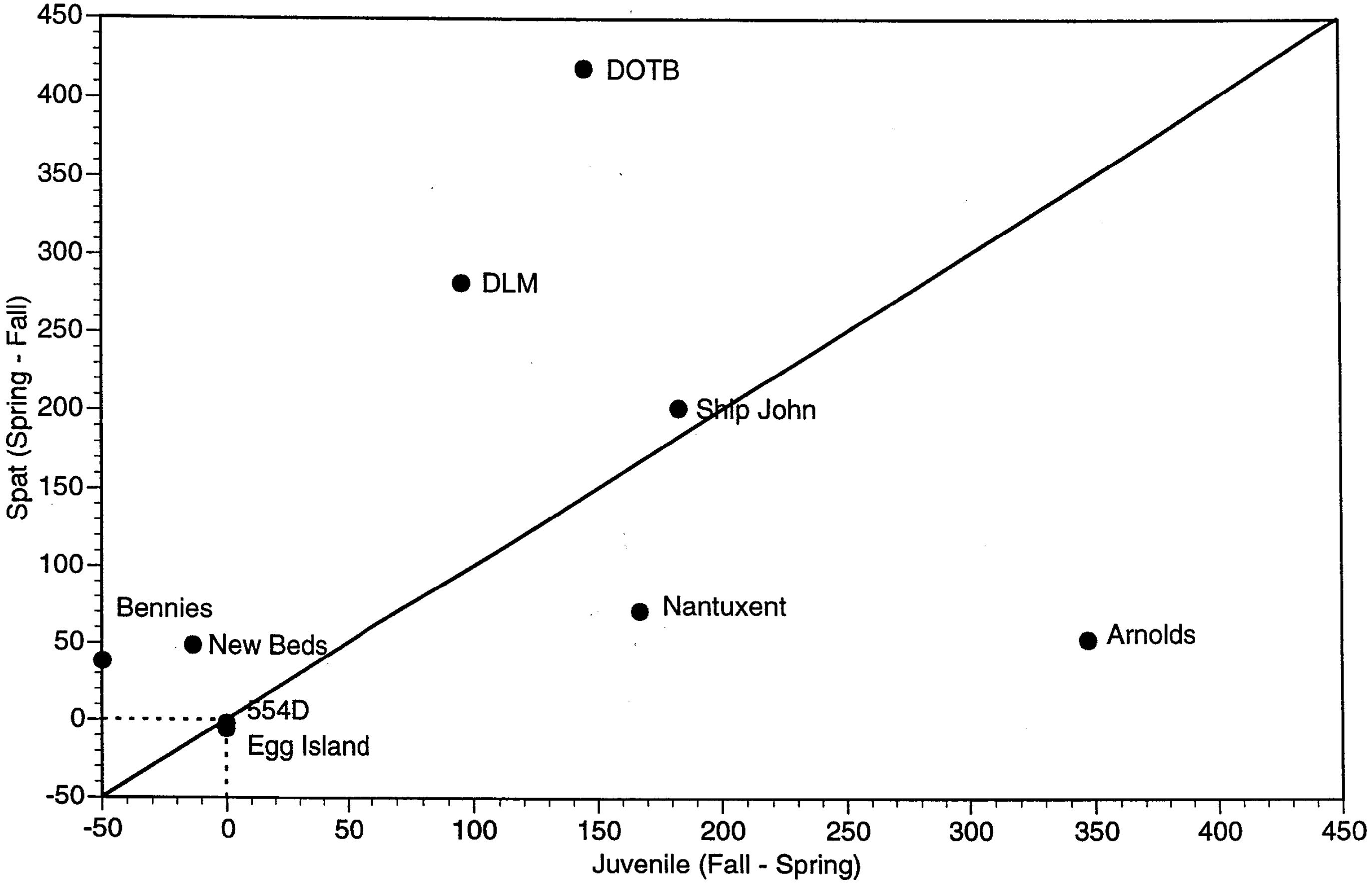


FIGURE 10
GONADAL INDEX
2000-01

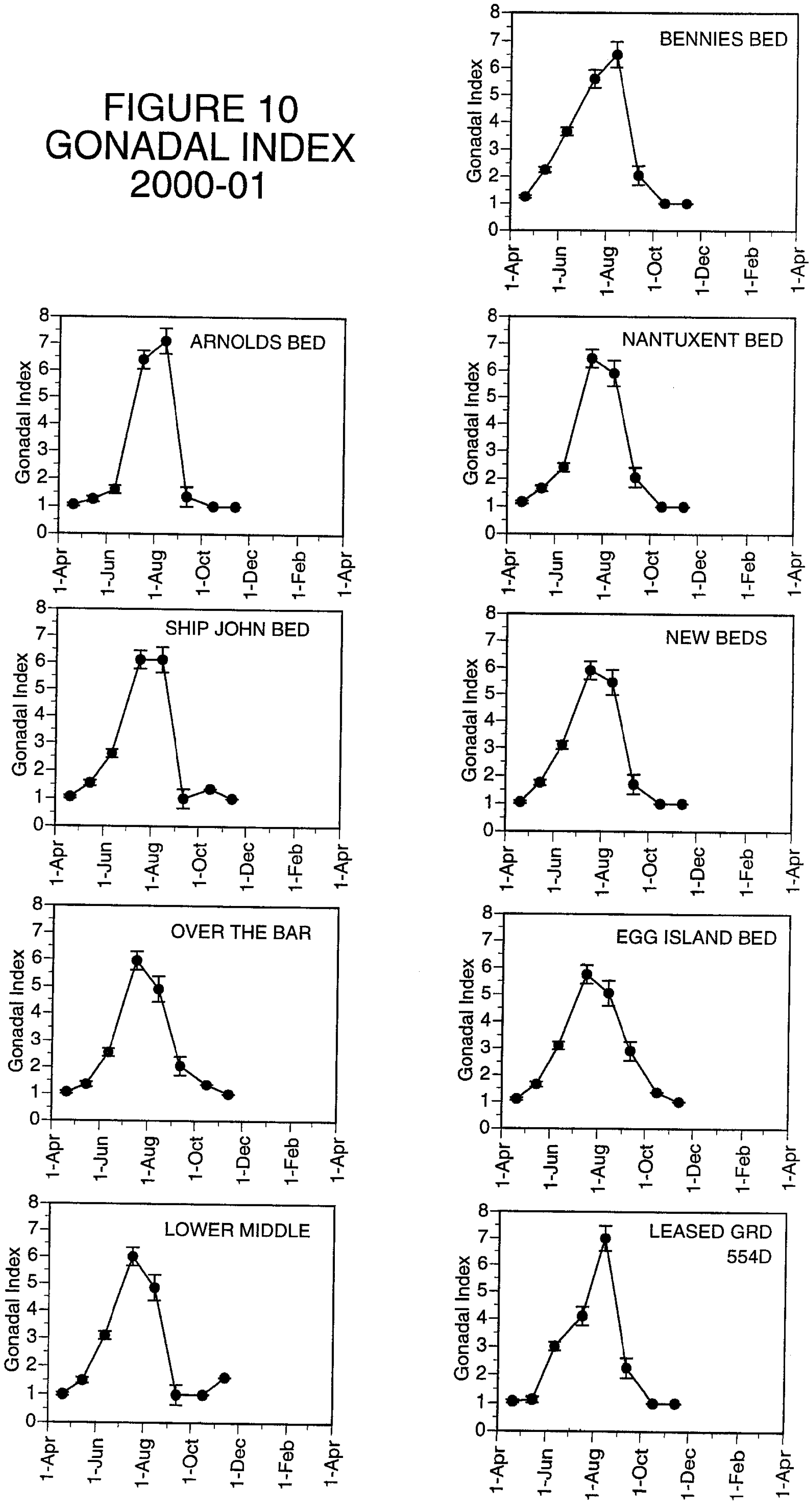


FIGURE 11
CONDITION INDEX
2000-01

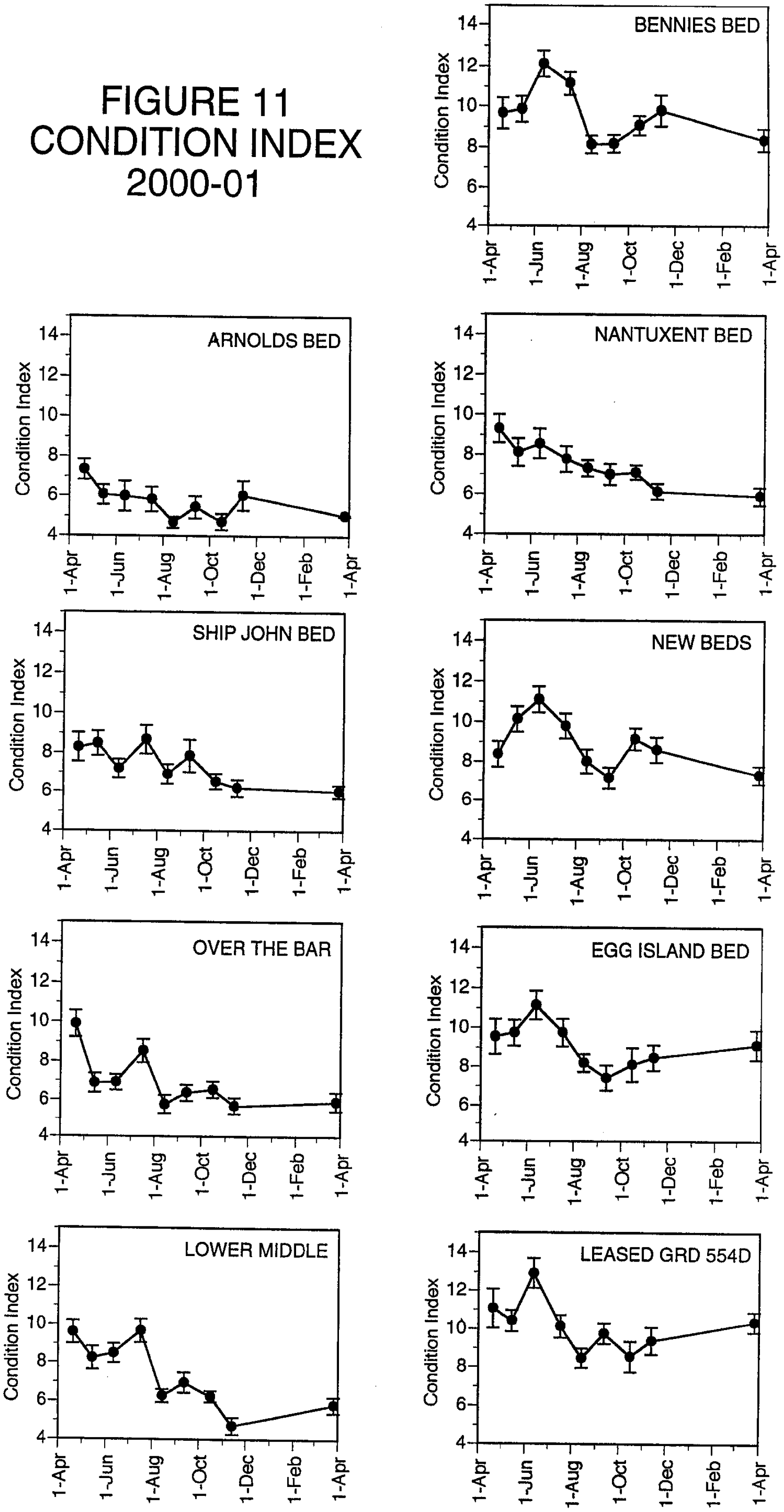


FIGURE 12
BOXES PER M^2

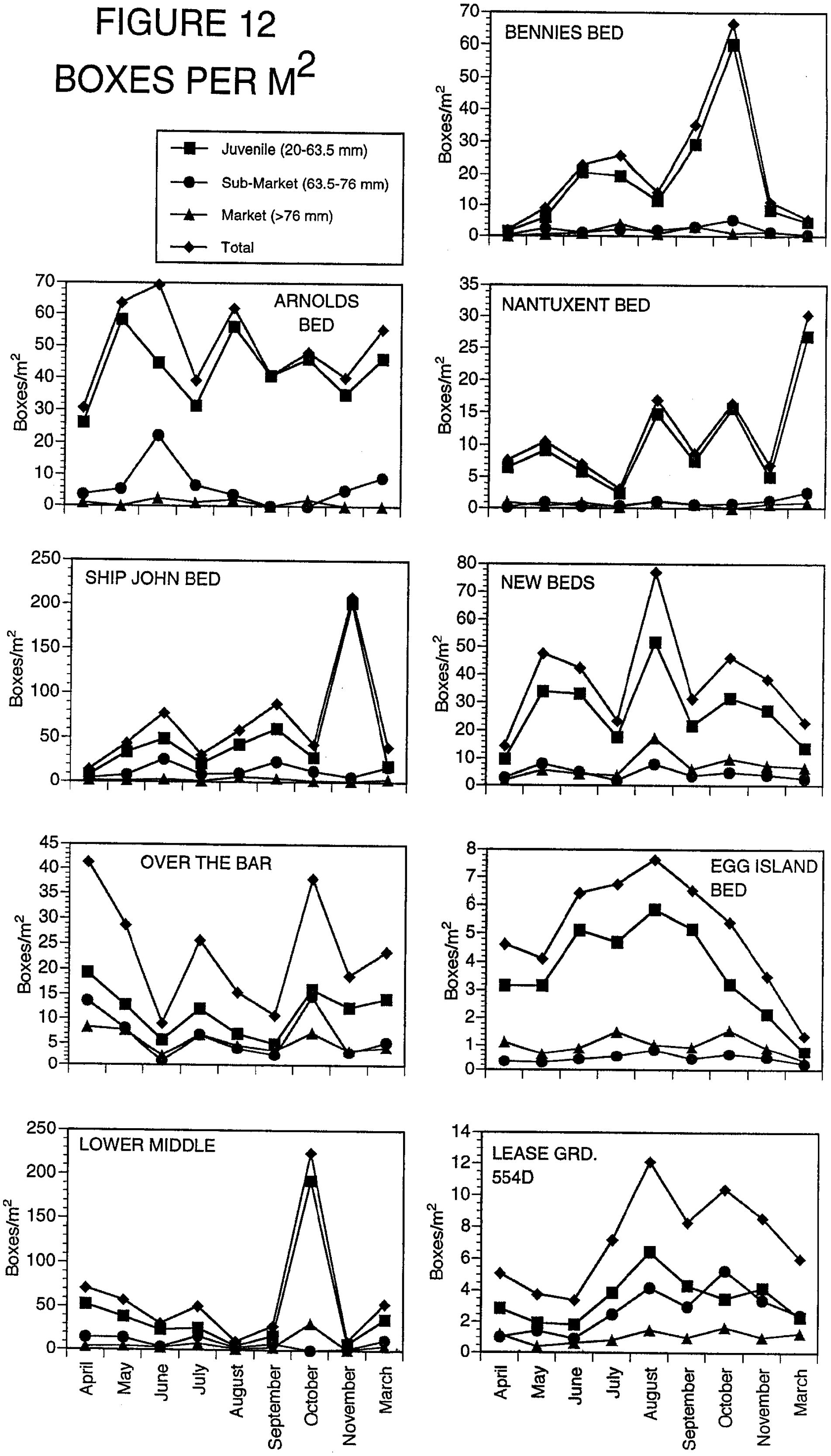


FIGURE 13

Ratio of Oysters per m^2 to Boxes per m^2

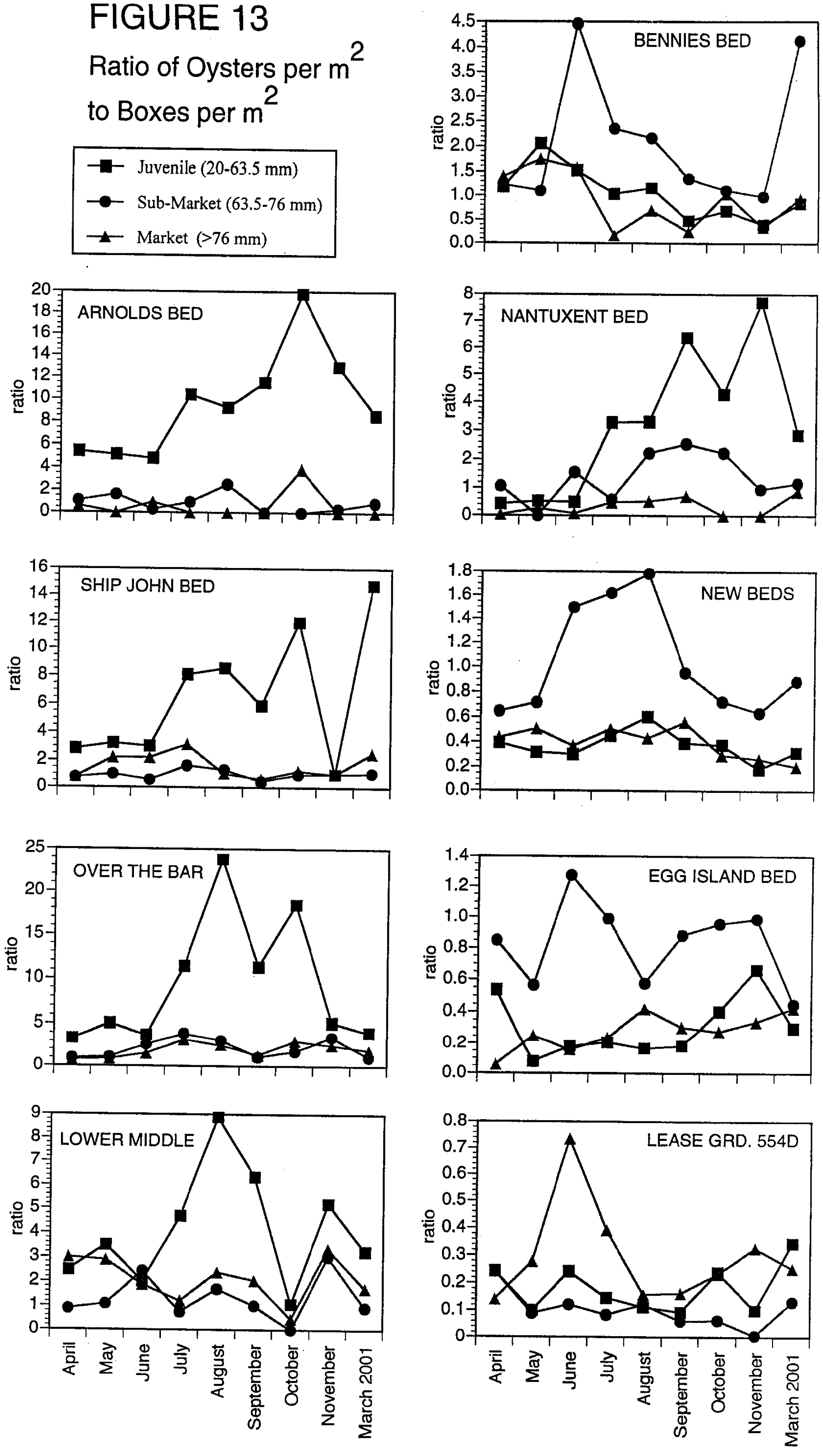
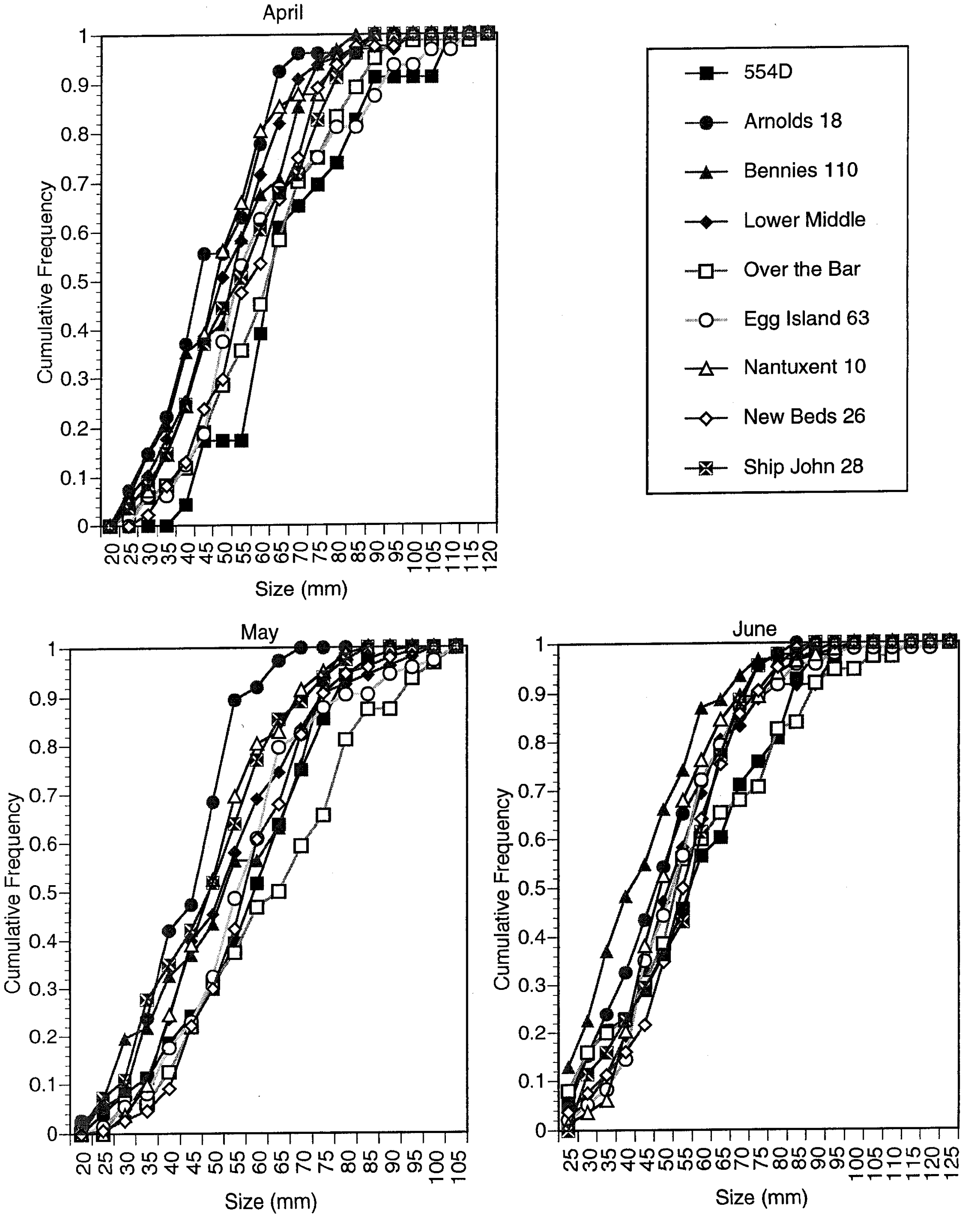
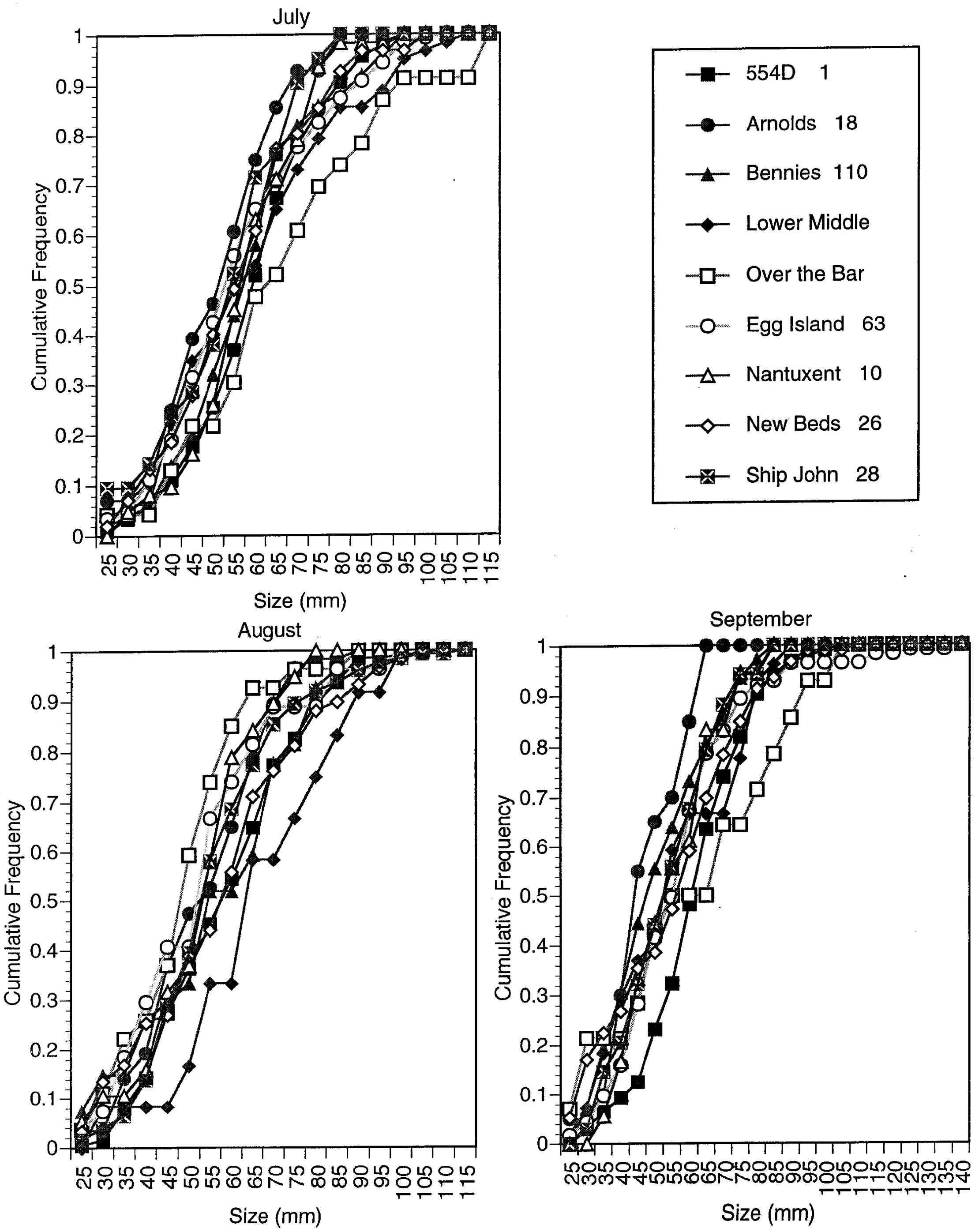


Figure 14



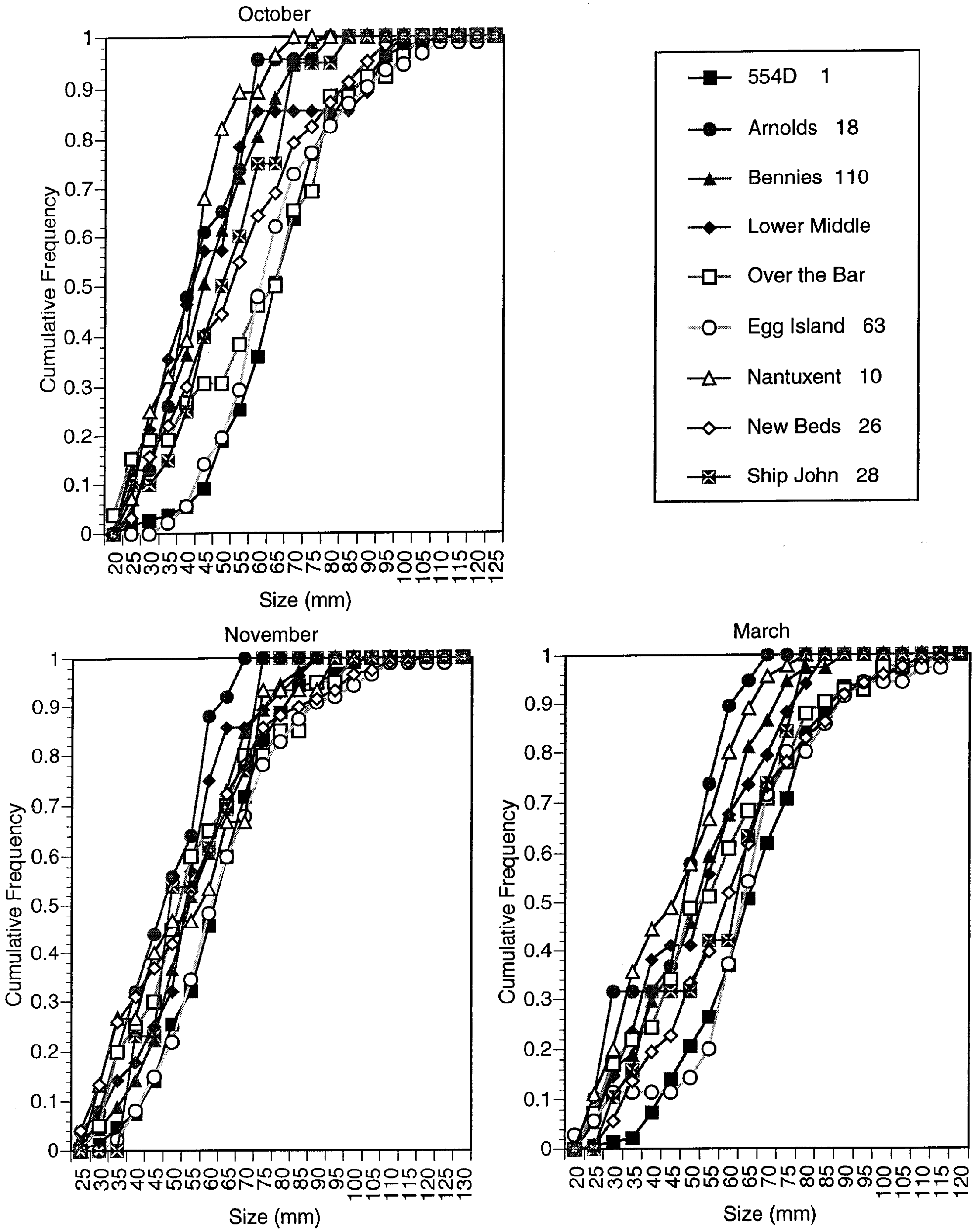
April
May
June
Cumulative Frequency
Size (mm)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90
95
100
105
110
115
120
125
554D
Arnolds 18
Bennies 110
Lower Middle
Over the Bar
Egg Island 63
Nantuxent 10
New Beds 26
Ship John 28

Figure 15



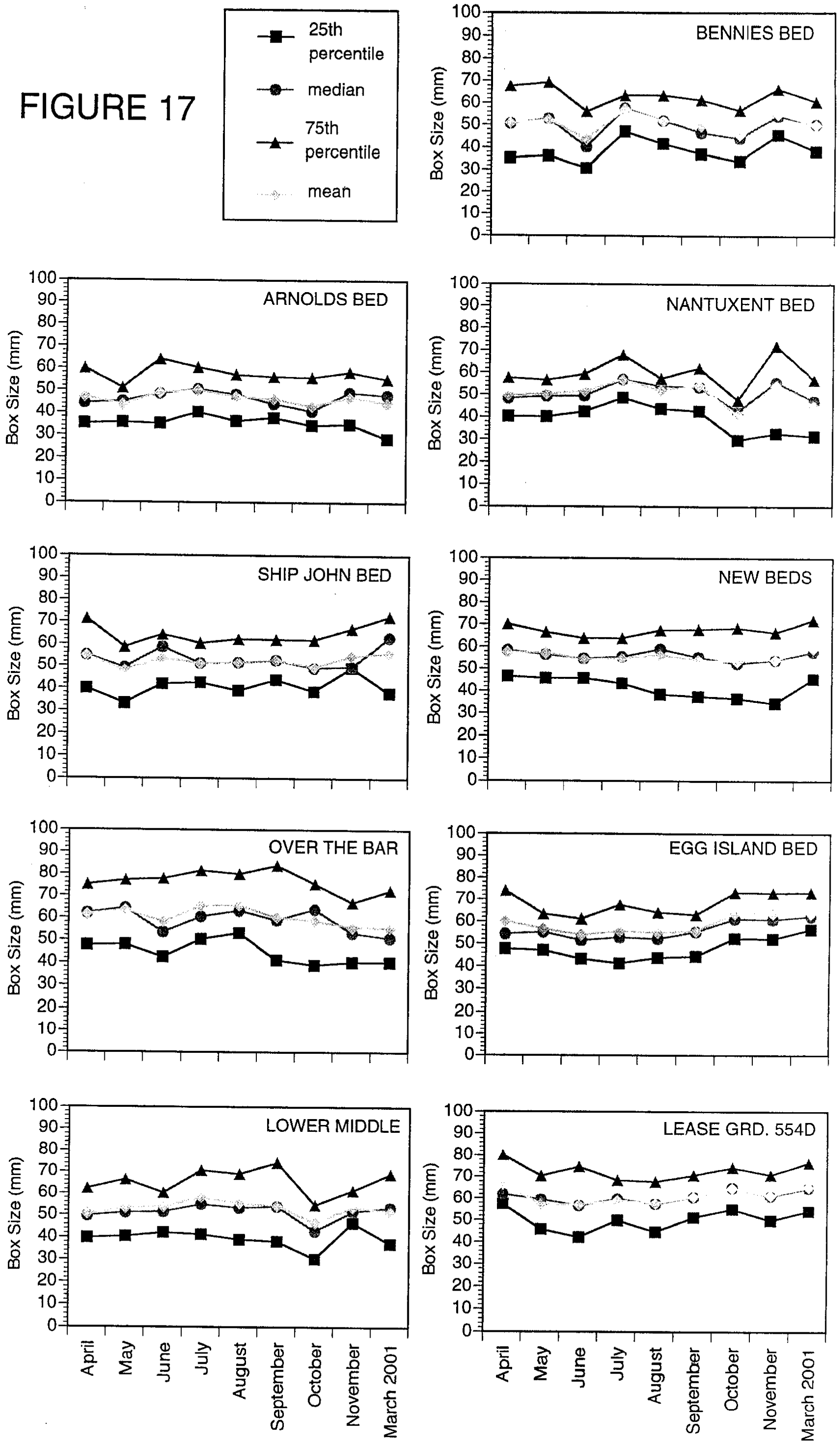
July
August
September
Cumulative Frequency
Size (mm)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
25
30
35
40
45
50
55
60
65
70
75
80
85
90
95
100
105
110
115
120
125
130
135
140
554D 1
Arnolds 18
Bennies 110
Lower Middle
Over the Bar
Egg Island 63
Nantuxent 10
New Beds 26
Ship John 28

Figure 16



October
November
March
Cumulative Frequency
Size (mm)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
20 25 30 35 40 45 50 55 60 65 70 75 80 85 90 95 100 105 110 115 120 125 130
554D 1
Arnolds 18
Bennies 110
Lower Middle
Over the Bar
Egg Island 63
Nantuxent 10
New Beds 26
Ship John 28

FIGURE 17



25th percentile
median
75th percentile
mean
BENNIES BED
ARNOLDS BED
NANTUXENT BED
SHIP JOHN BED
NEW BEDS
OVER THE BAR
EGG ISLAND BED
LOWER MIDDLE
LEASE GRD. 554D
Box Size (mm)
0
10
20
30
40
50
60
70
80
90
100
April
May
June
July
August
September
October
November
March 2001

FIGURE 18
Ratio of oysters to boxes in the 50th percentile size class

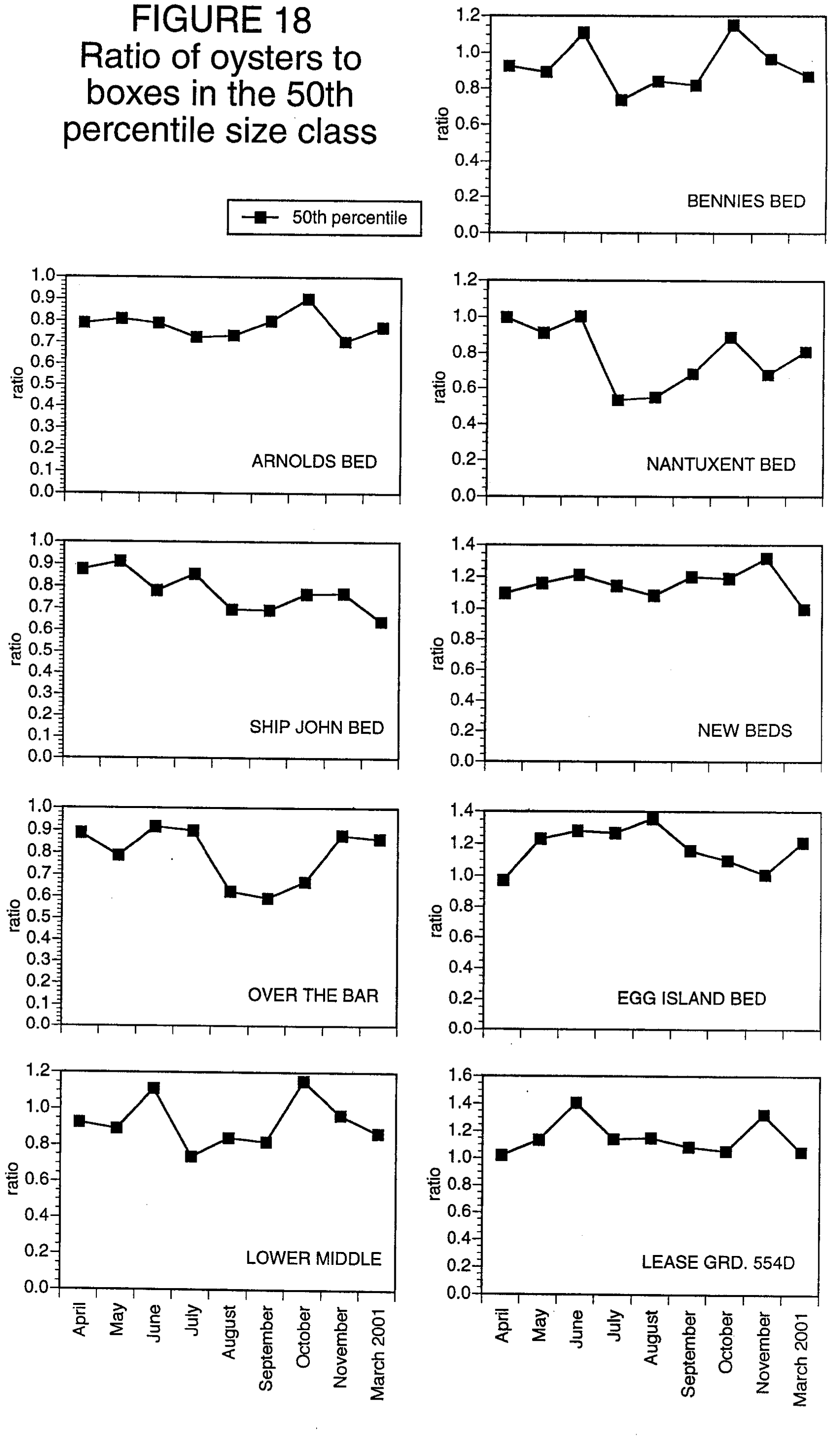
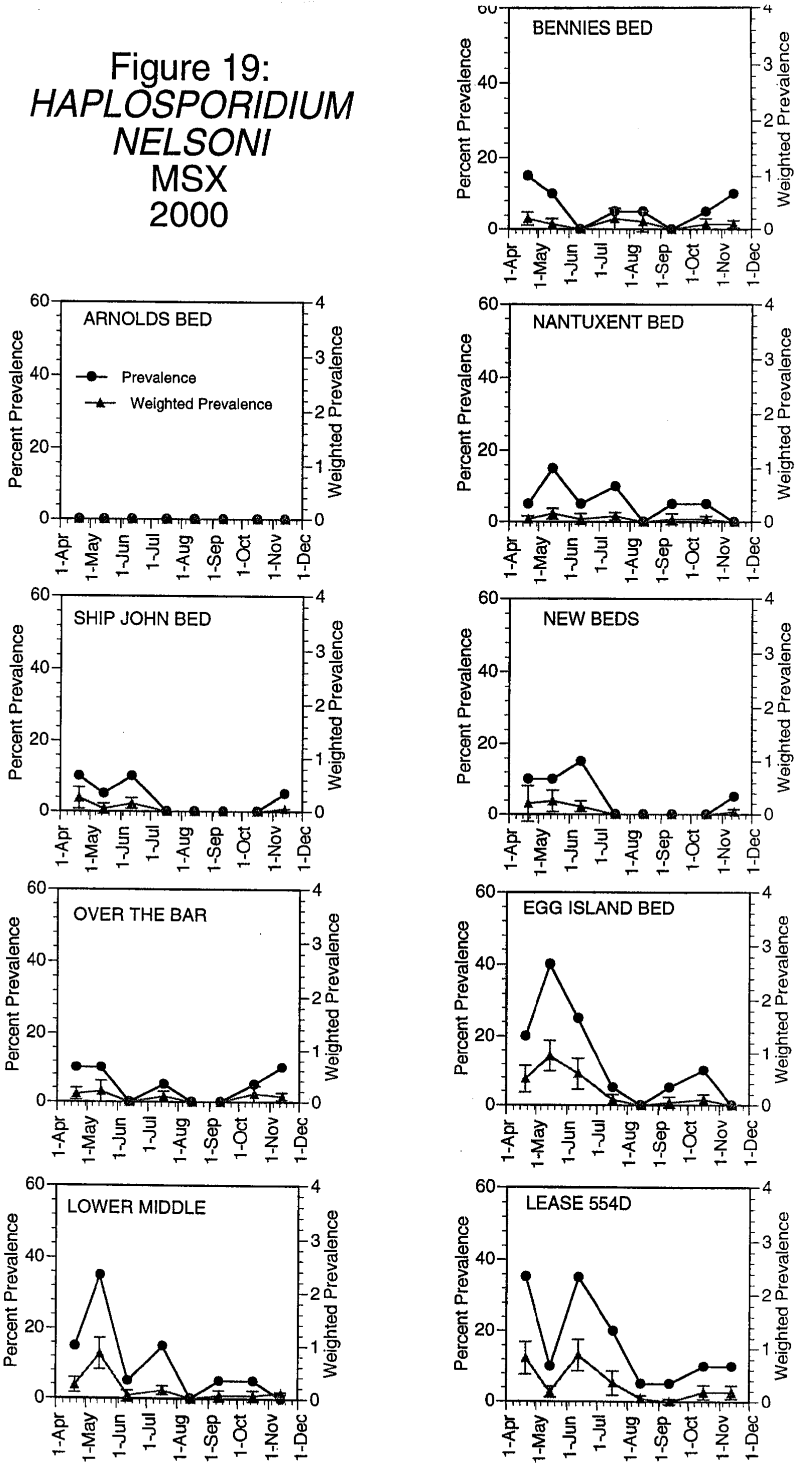


Figure 19:
HAPLOSPORIDIUM
NELSONI
MSX
2000



FIGURES 20: *PERKINSUS MARINUS* DERMO 2000-01

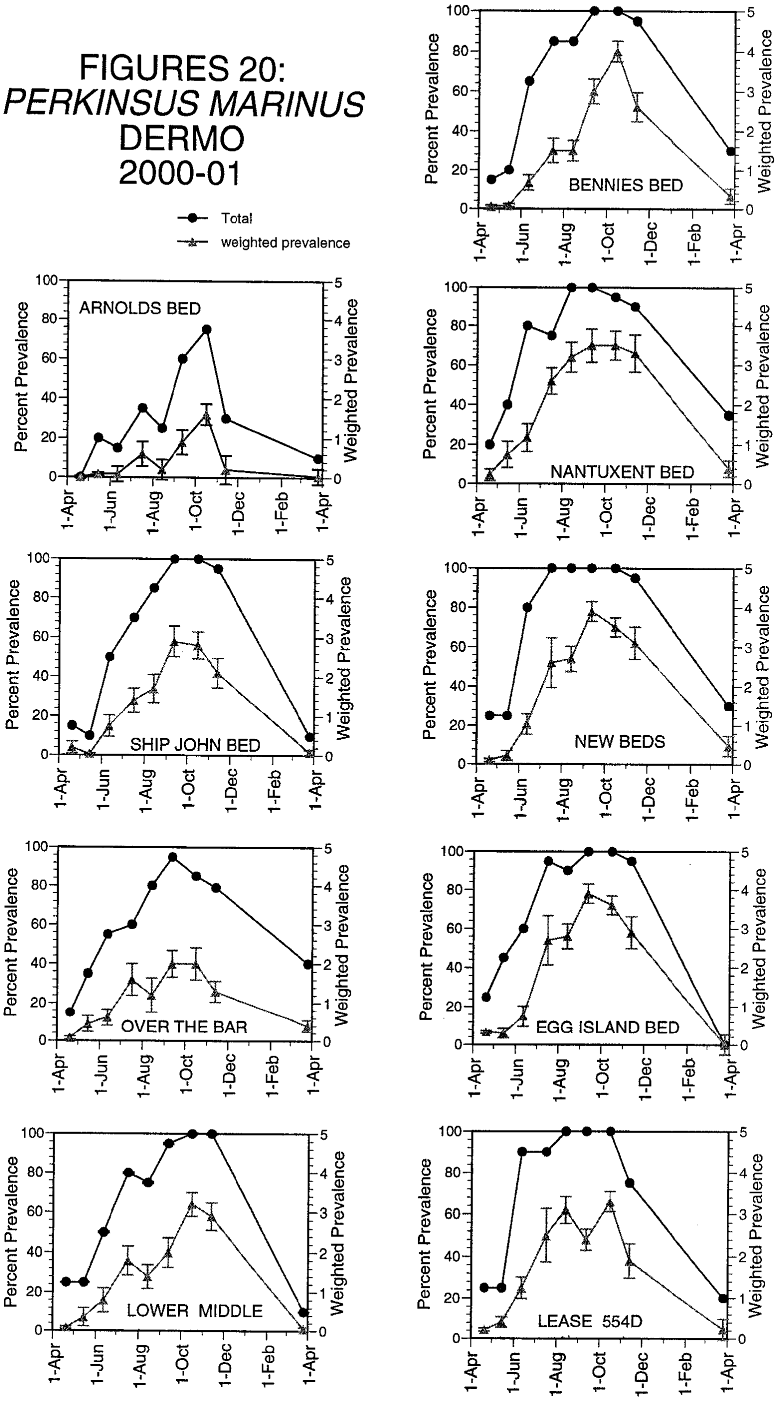


Figure 21: NEMATOPSIS 2000-01

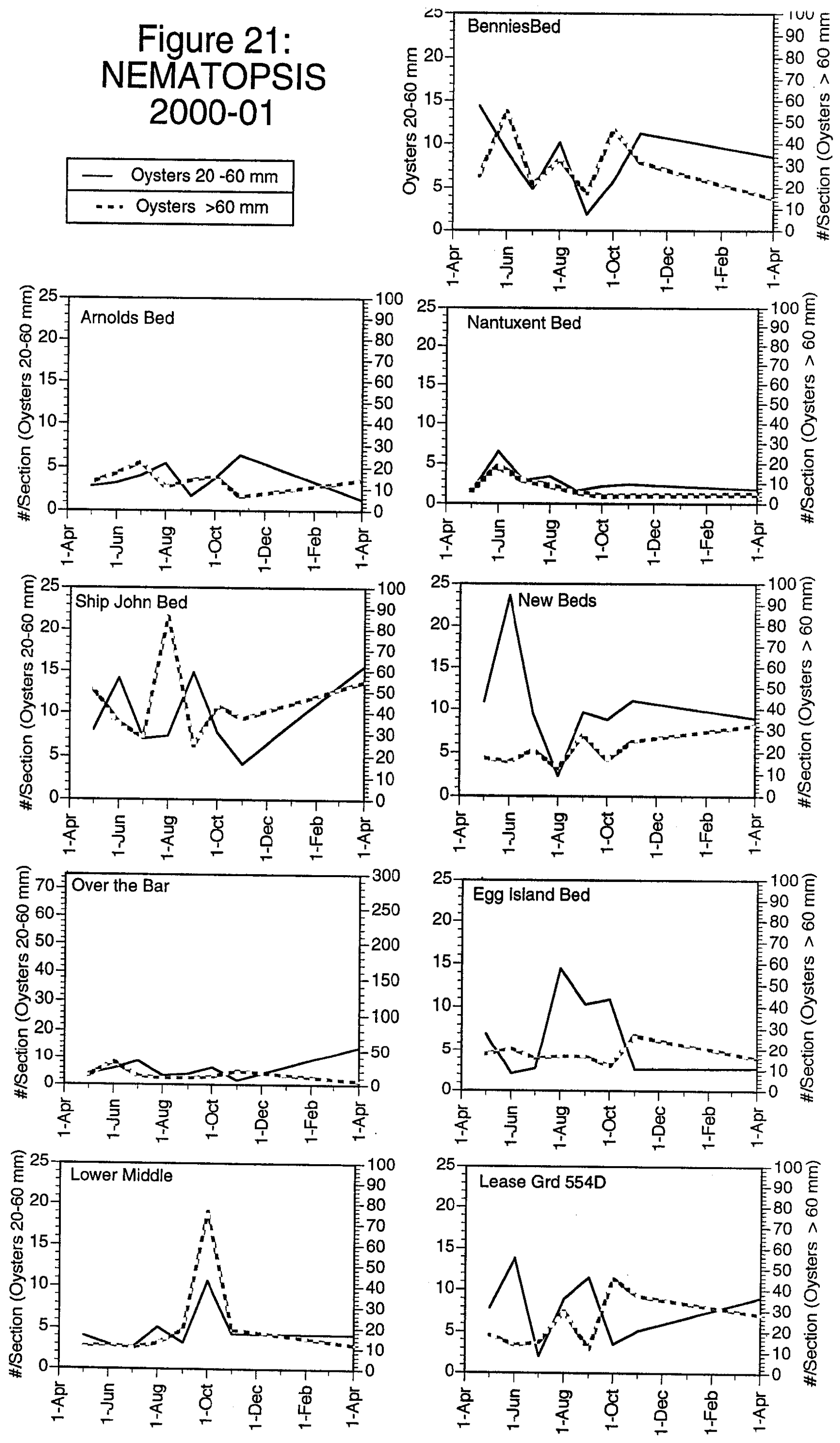
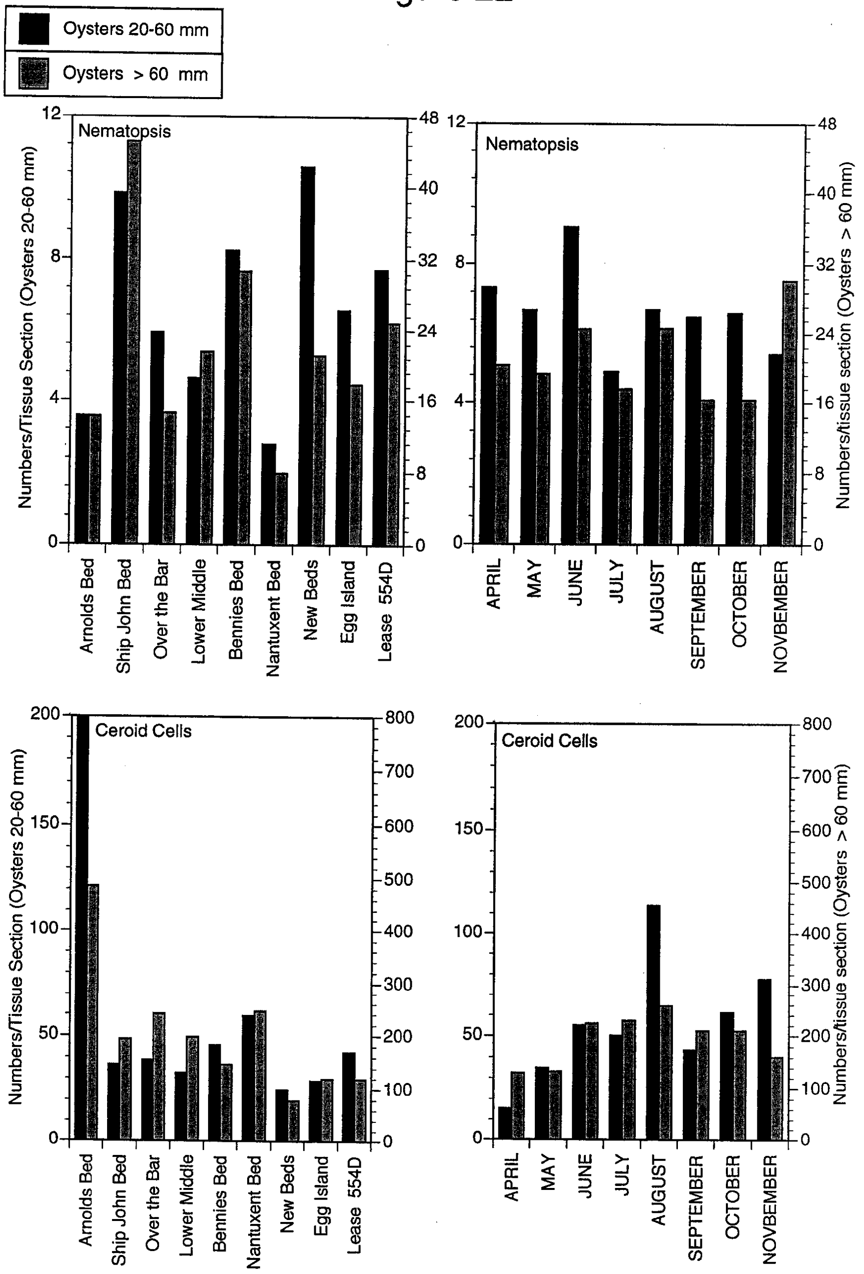


Figure 22



Oysters 20-60 mm
Oysters > 60 mm
Nematopsis
Numbers/Tissue Section (Oysters 20-60 mm)
Numbers/tissue section (Oysters > 60 mm)
0
4
8
12
0
8
16
24
32
40
48
Arnolds Bed
Ship John Bed
Over the Bar
Lower Middle
Bennies Bed
Nantuxent Bed
New Beds
Egg Island
Lease 554D
APRIL
MAY
JUNE
JULY
AUGUST
SEPTEMBER
OCTOBER
NOVBEMBER
Ceroid Cells
0
50
100
150
200
0
100
200
300
400
500
600
700
800

Figure 23: CEROID CELLS 2000-01

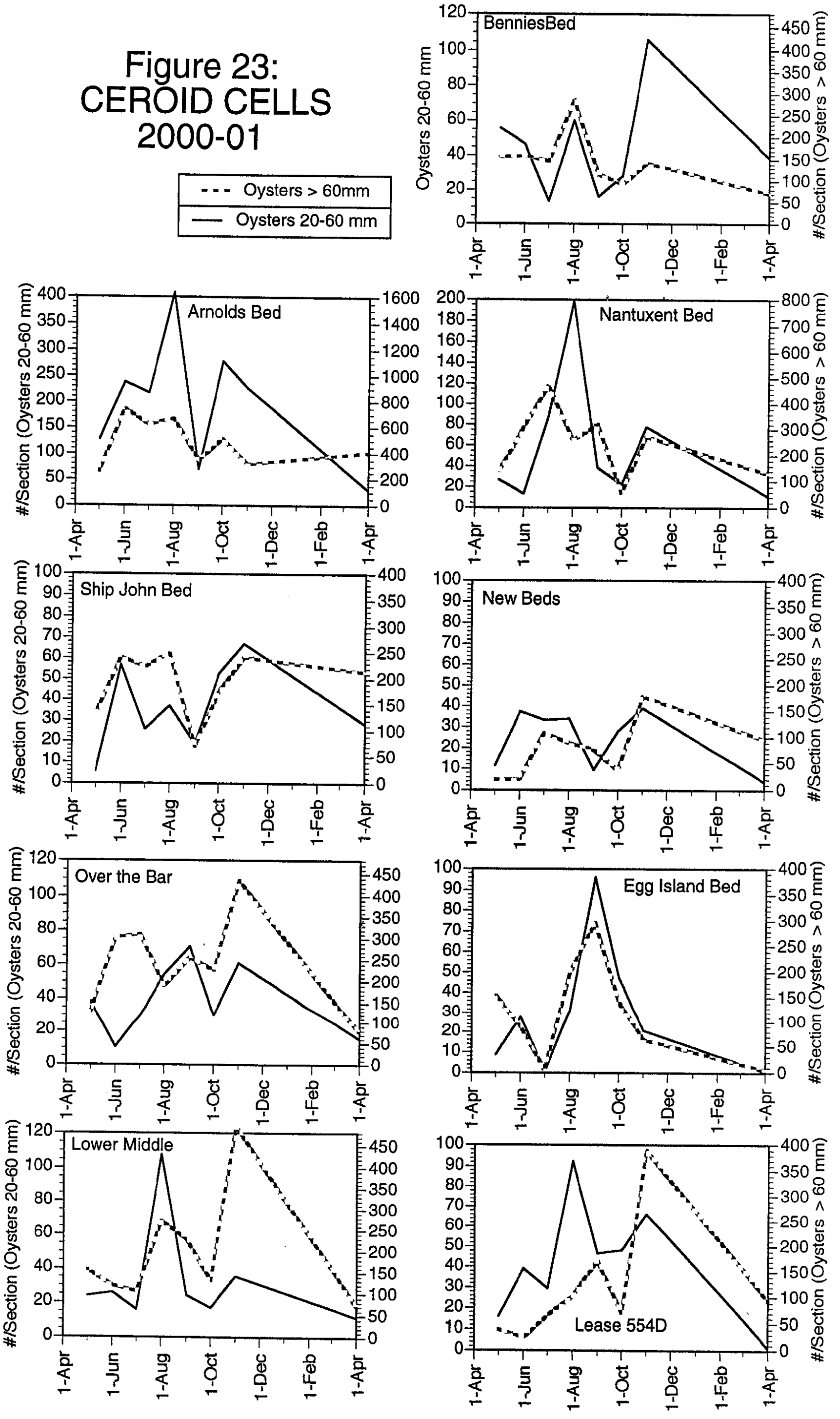
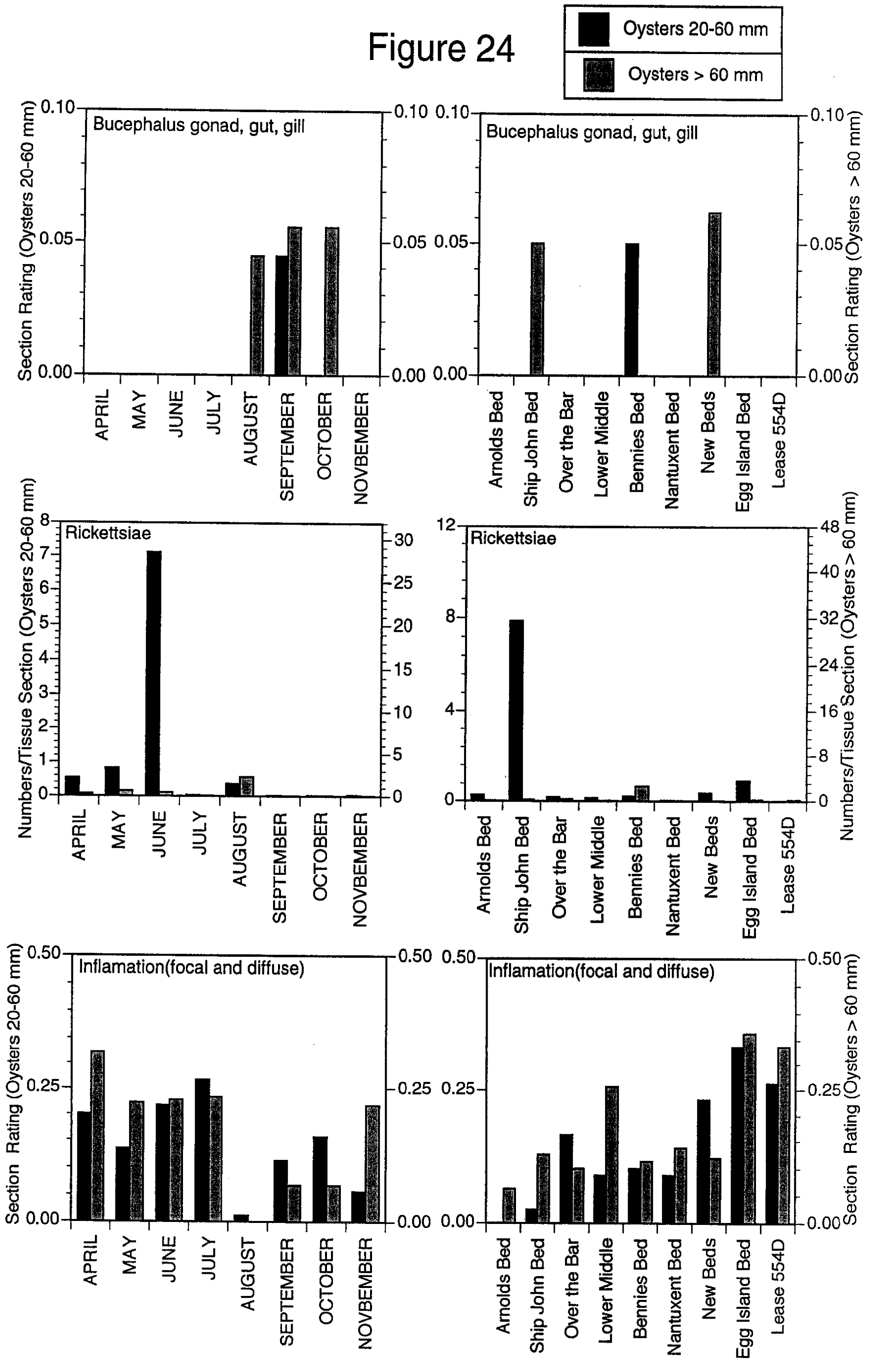
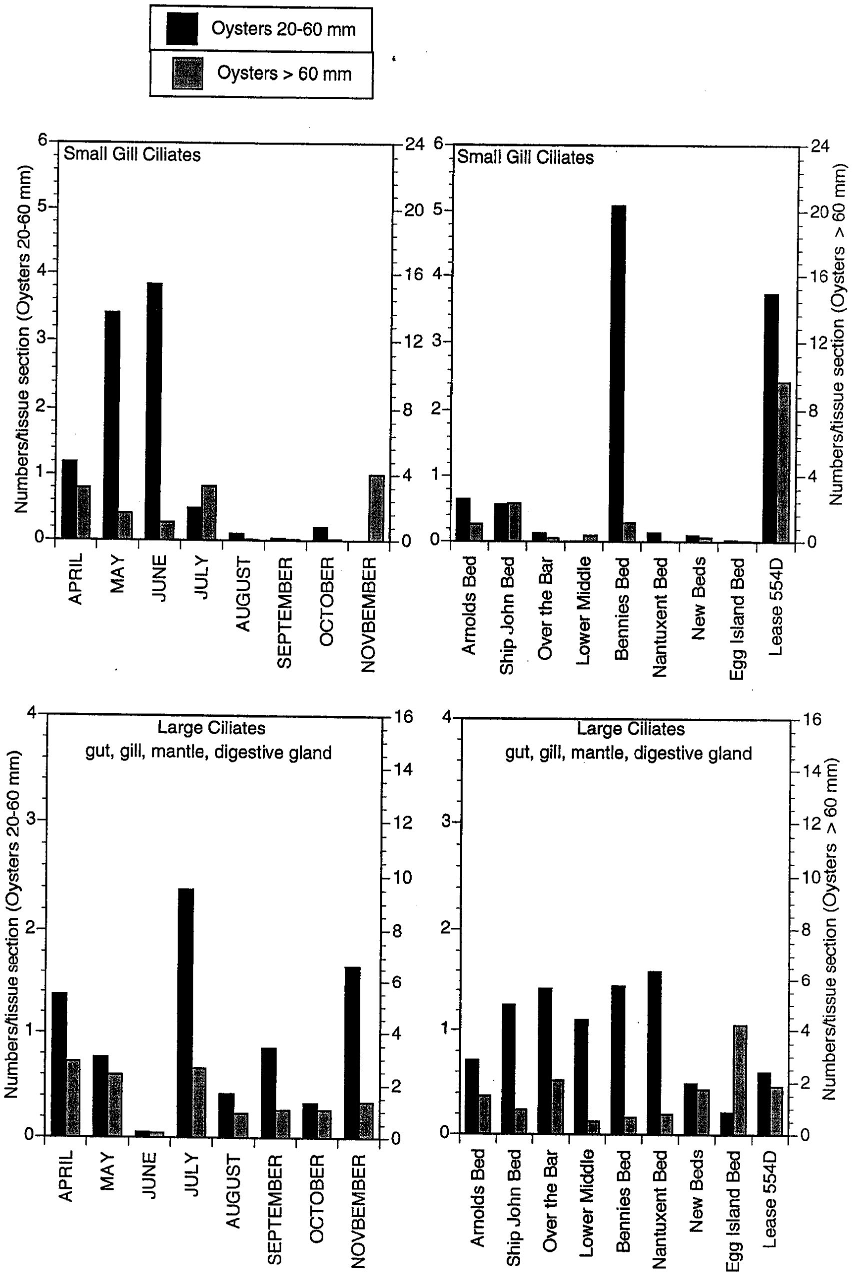


Figure 24



Oysters 20-60 mm
Oysters > 60 mm
Bucephalus gonad, gut, gill
Rickettsiae
Inflamation(focal and diffuse)
Section Rating (Oysters 20-60 mm)
Section Rating (Oysters > 60 mm)
Numbers/Tissue Section (Oysters 20-60 mm)
Numbers/Tissue Section (Oysters > 60 mm)
0.00
0.05
0.10
0.25
0.50
0
1
2
3
4
5
6
7
8
10
12
15
16
20
24
25
30
32
40
48
APRIL
MAY
JUNE
JULY
AUGUST
SEPTEMBER
OCTOBER
NOVBEMBER
Arnolds Bed
Ship John Bed
Over the Bar
Lower Middle
Bennies Bed
Nantuxent Bed
New Beds
Egg Island Bed
Lease 554D

Figure 25



Oysters 20-60 mm
Oysters > 60 mm
Small Gill Ciliates
Numbers/tissue section (Oysters 20-60 mm)
Numbers/tissue section (Oysters > 60 mm)
0
1
2
3
4
5
6
0
4
8
12
16
20
24
APRIL
MAY
JUNE
JULY
AUGUST
SEPTEMBER
OCTOBER
NOVBEMBER
Arnolds Bed
Ship John Bed
Over the Bar
Lower Middle
Bennies Bed
Nantuxent Bed
New Beds
Egg Island Bed
Lease 554D
Large Ciliates
gut, gill, mantle, digestive gland
0
1
2
3
4
0
2
4
6
8
10
12
14
16

Figure 26

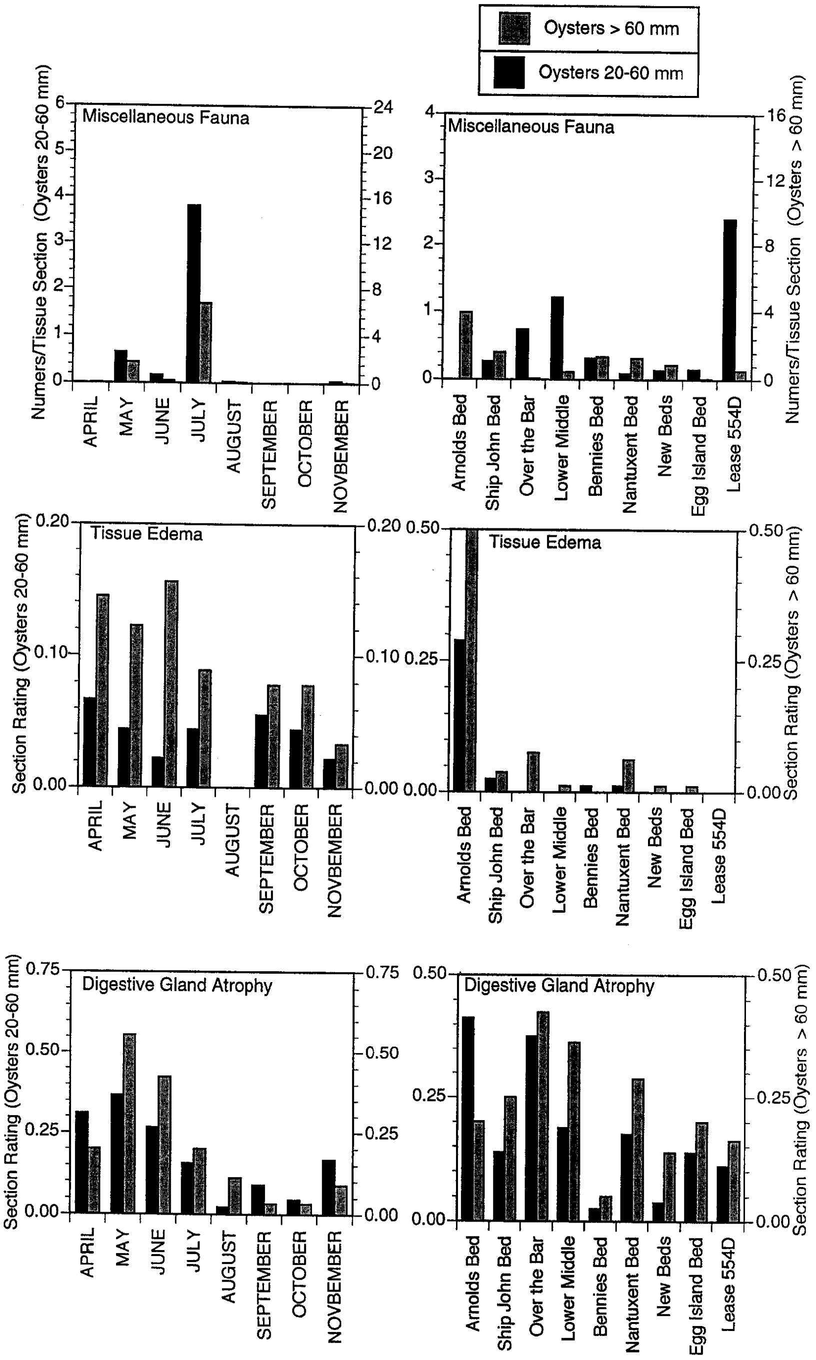
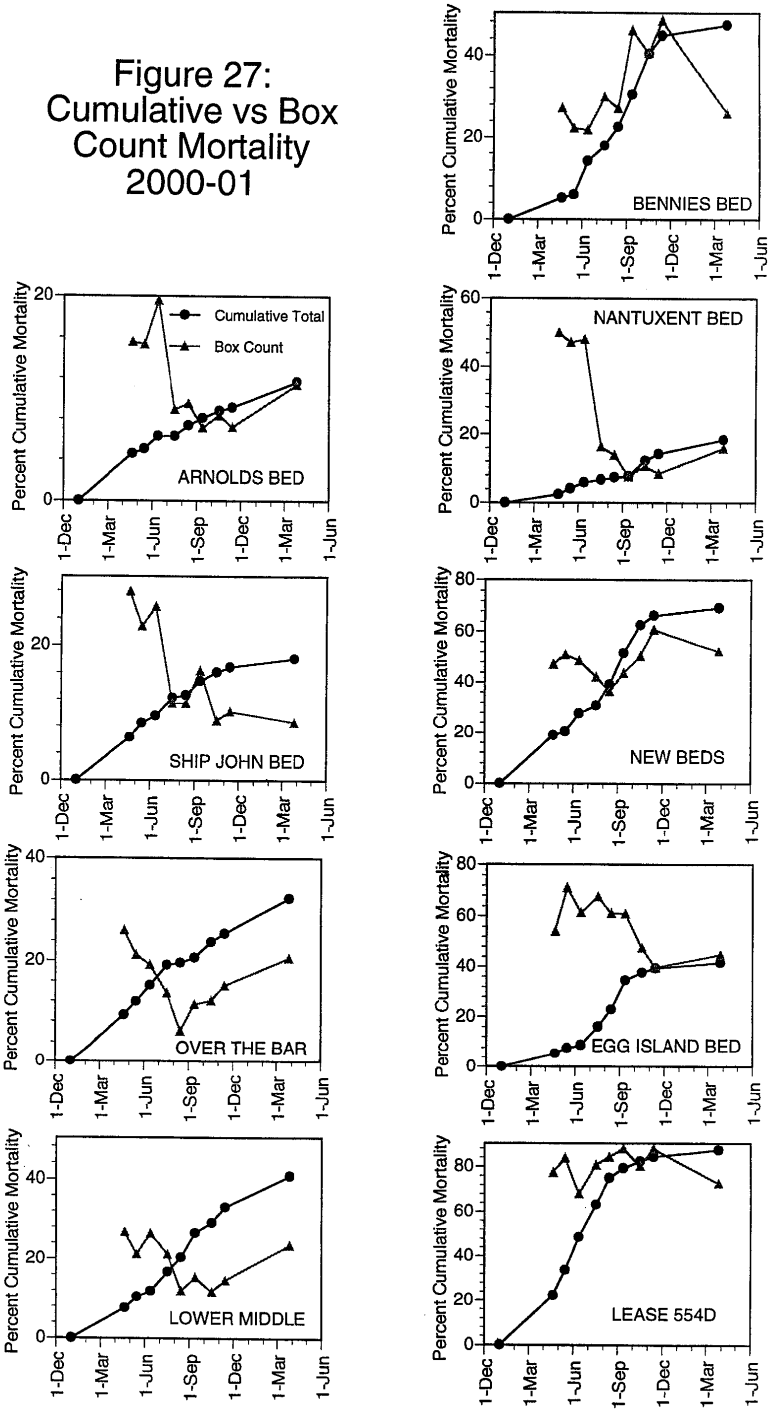

Oysters > 60 mm
Oysters 20-60 mm
Miscellaneous Fauna
Numers/Tissue Section (Oysters 20-60 mm)
0
1
2
3
4
5
6
0
4
8
12
16
20
24
APRIL
MAY
JUNE
JULY
AUGUST
SEPTEMBER
OCTOBER
NOVBEMBER
Miscellaneous Fauna
0
1
2
3
4
0
4
8
12
16
Numers/Tissue Section (Oysters > 60 mm)
Arnolds Bed
Ship John Bed
Over the Bar
Lower Middle
Bennies Bed
Nantuxent Bed
New Beds
Egg Island Bed
Lease 554D
Tissue Edema
Section Rating (Oysters 20-60 mm)
0.00
0.10
0.20
0.00
0.10
0.20
APRIL
MAY
JUNE
JULY
AUGUST
SEPTEMBER
OCTOBER
NOVBEMBER
Tissue Edema
0.00
0.25
0.50
0.00
0.25
0.50
Section Rating (Oysters > 60 mm)
Arnolds Bed
Ship John Bed
Over the Bar
Lower Middle
Bennies Bed
Nantuxent Bed
New Beds
Egg Island Bed
Lease 554D
Digestive Gland Atrophy
Section Rating (Oysters 20-60 mm)
0.00
0.25
0.50
0.75
0.00
0.25
0.50
0.75
APRIL
MAY
JUNE
JULY
AUGUST
SEPTEMBER
OCTOBER
NOVBEMBER
Digestive Gland Atrophy
0.00
0.25
0.50
0.00
0.25
0.50
Section Rating (Oysters > 60 mm)
Arnolds Bed
Ship John Bed
Over the Bar
Lower Middle
Bennies Bed
Nantuxent Bed
New Beds
Egg Island Bed
Lease 554D

Figure 27: Cumulative vs Box Count Mortality 2000-01



Figures 28: Total and Predation Mortality 2000-01

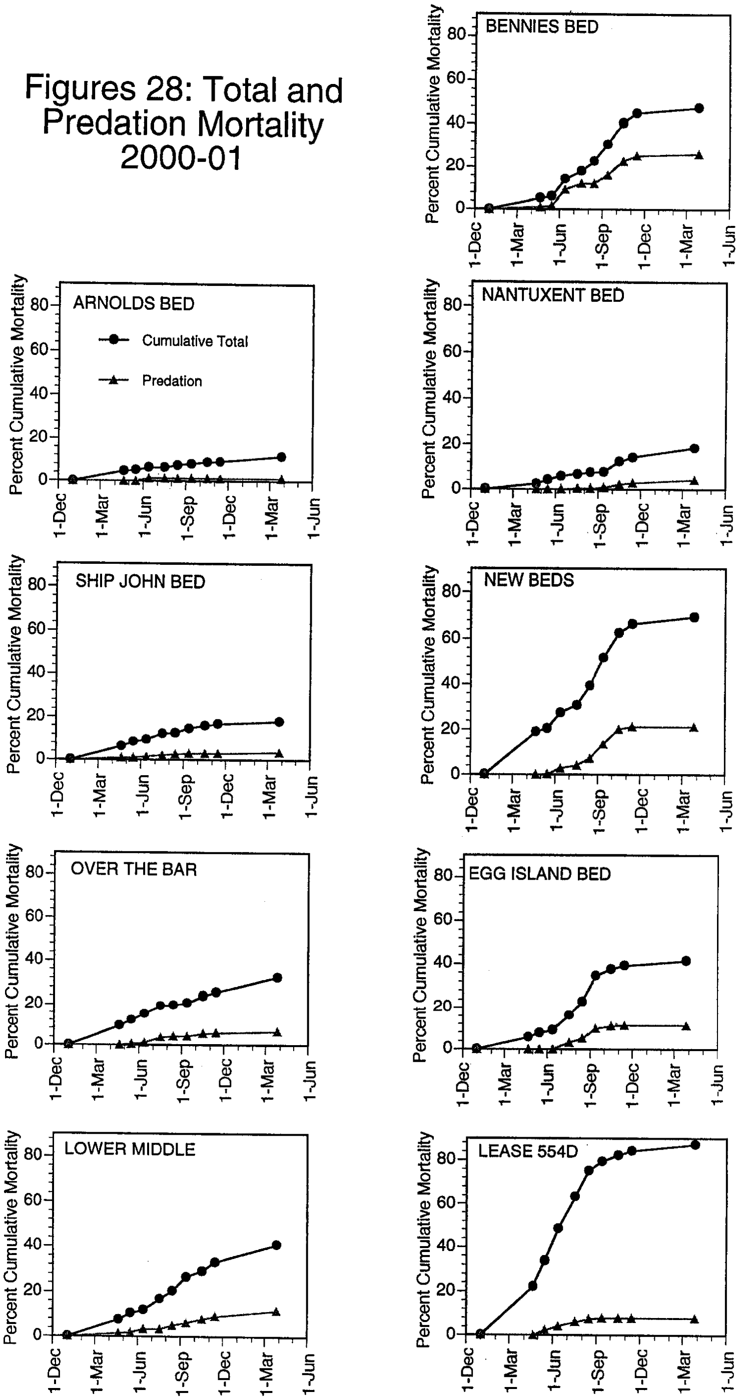


Figure 29: Cumulative % Disarticulation

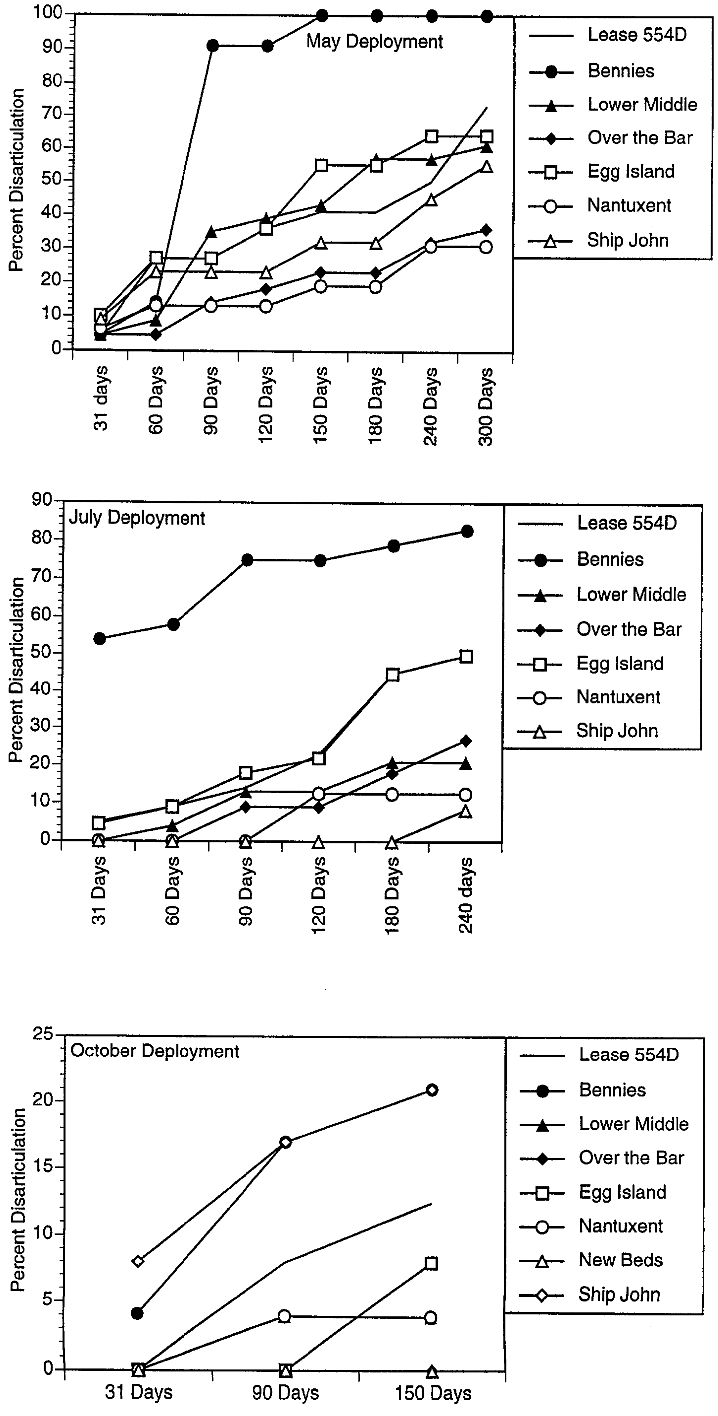


Figure 30
Blue Crabs and Drills - Number of Individuals per Bushel

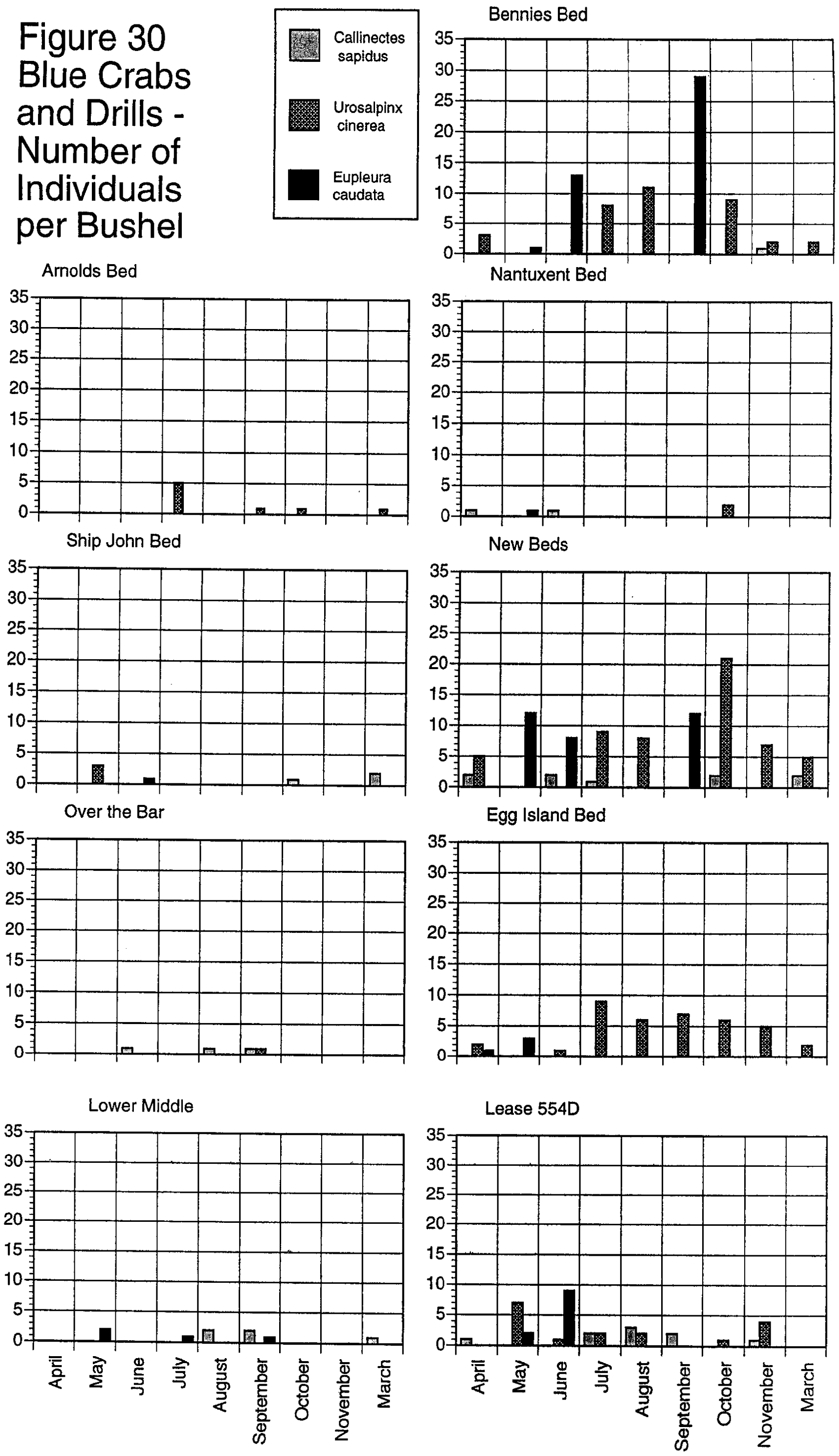


Figure 31 Mud Crabs - Number of Individuals per Bushel

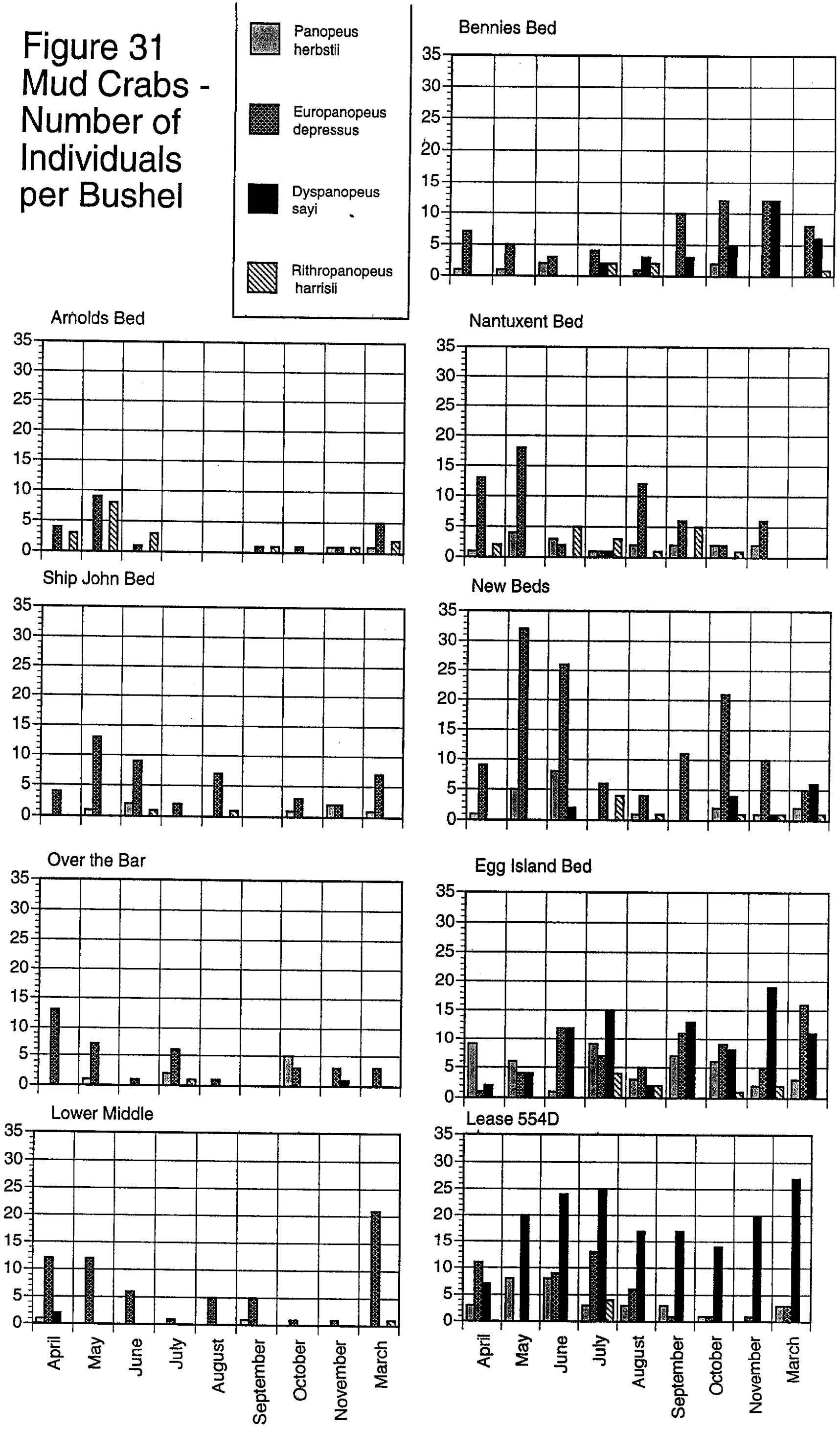


Figure 32
Size Frequency of Oyster Drills 2000 - 2001

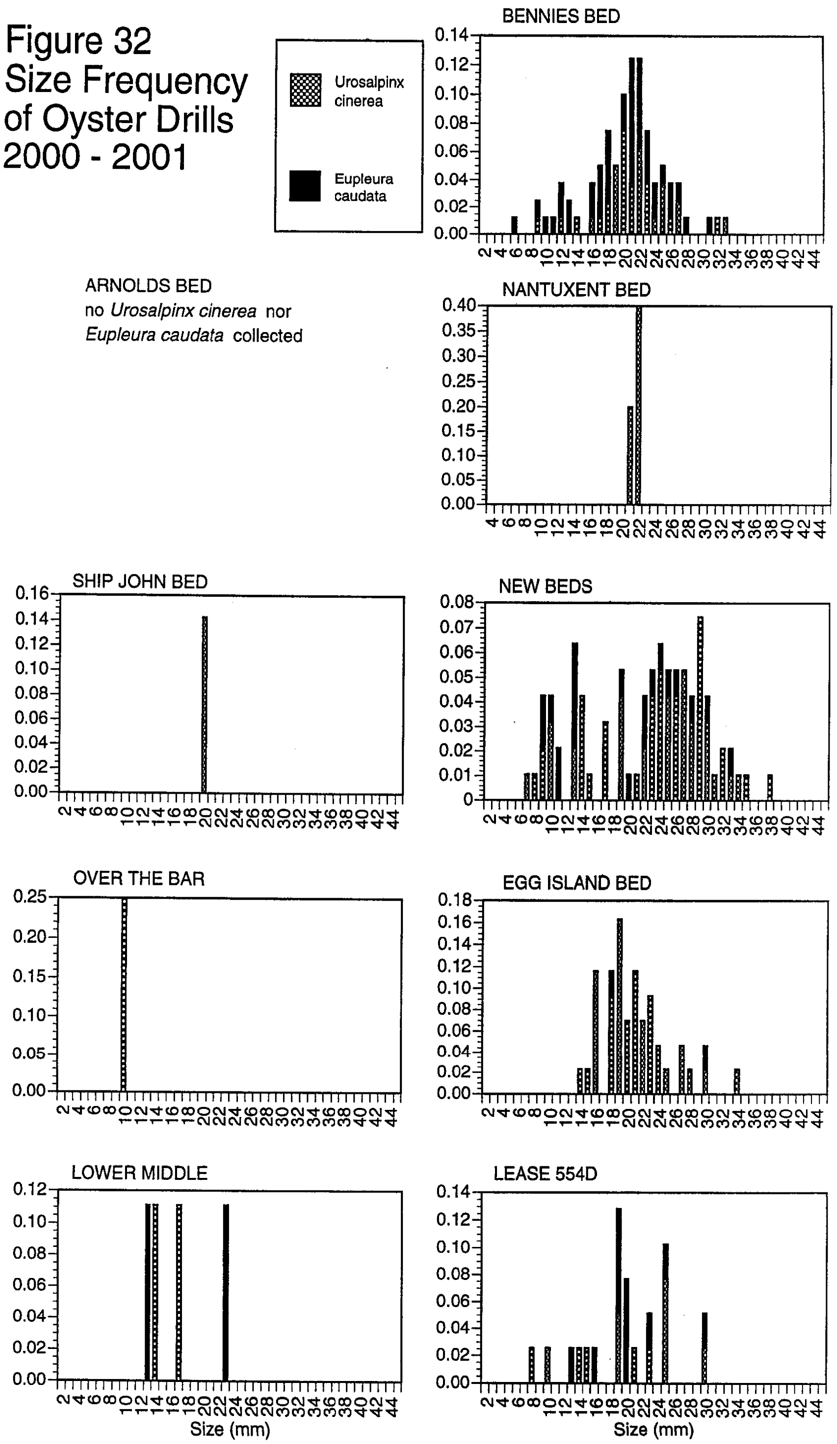


Figure 33
Size Frequency
of Mud Crabs
2000-2001

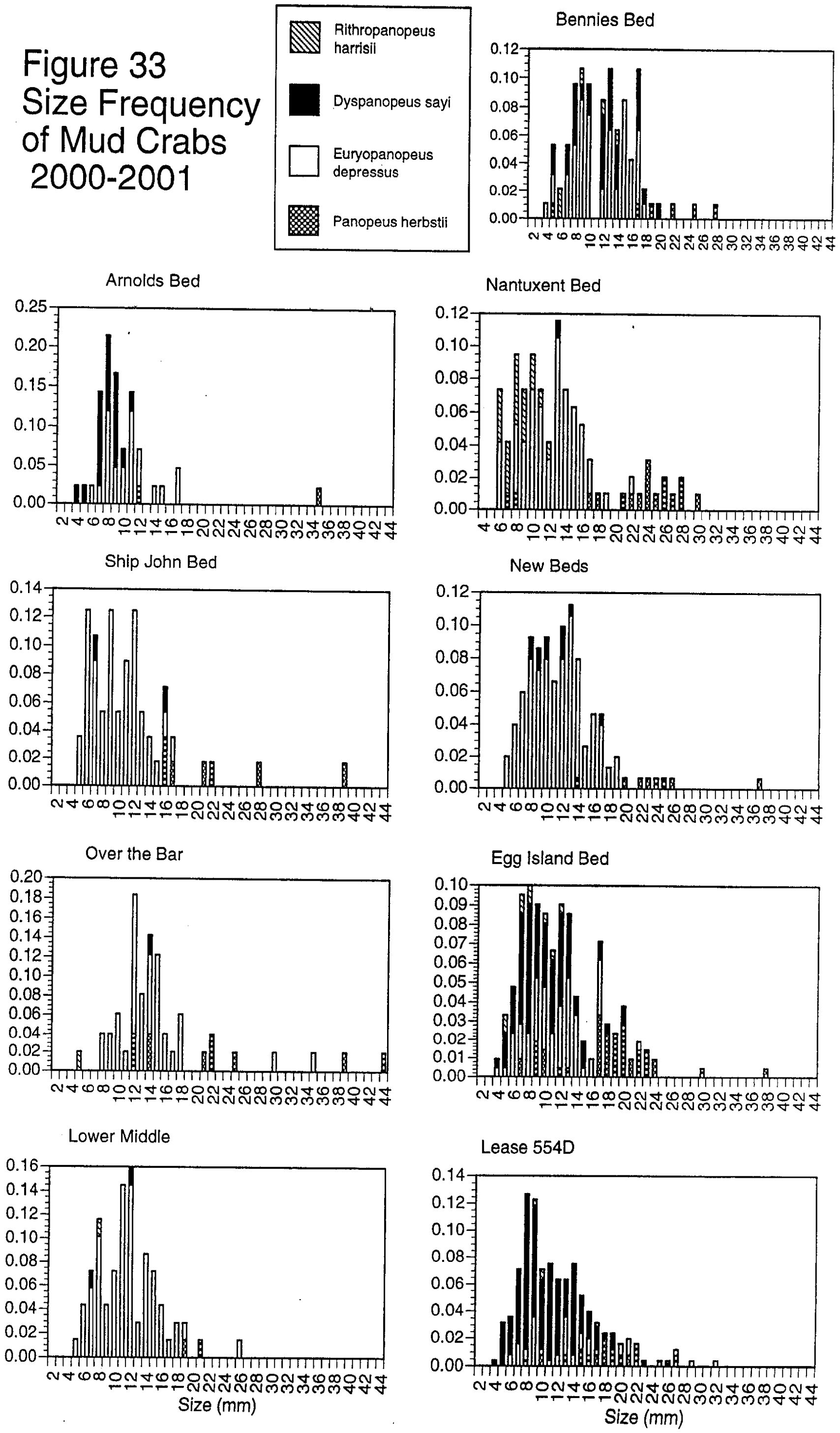
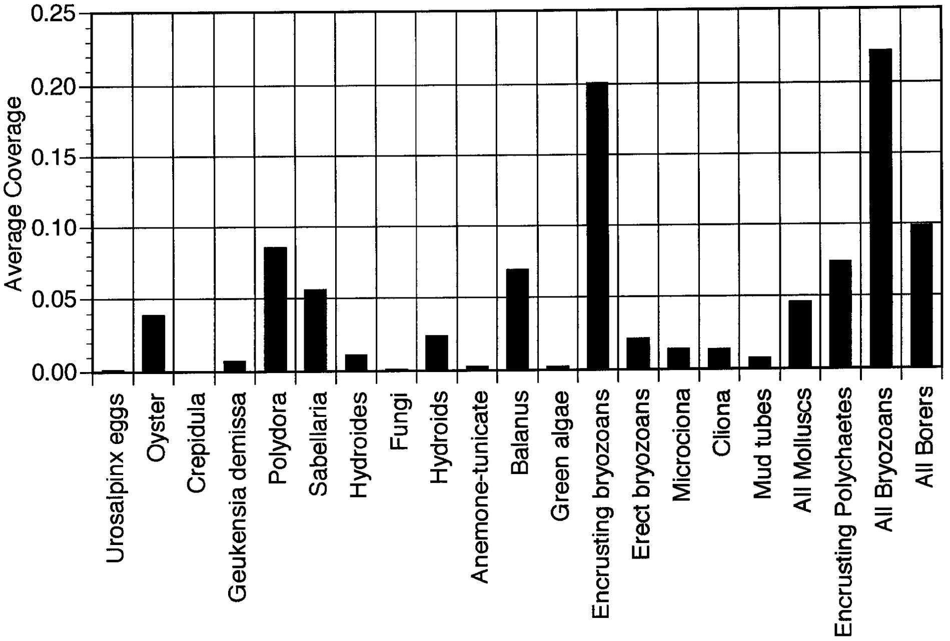


Figure 34

Outer Shell Surface



Inner Shell Surface

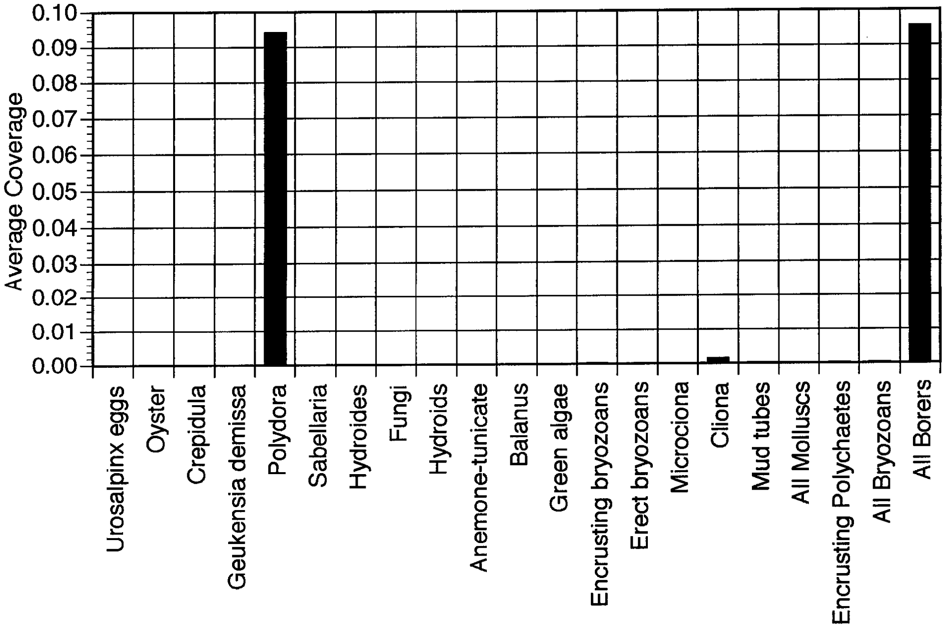
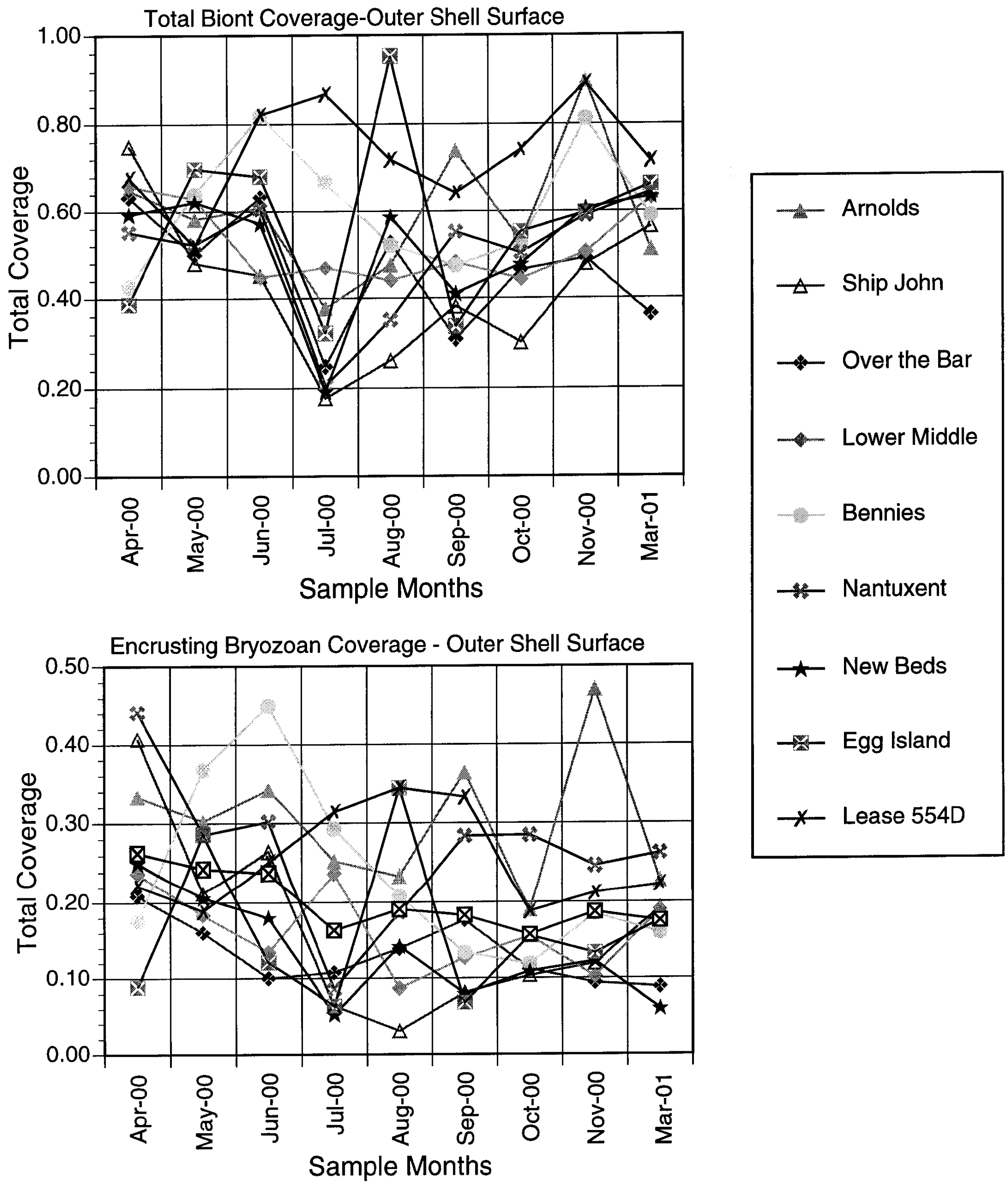


Figure 35



Total Biont Coverage-Outer Shell Surface

Encrusting Bryozoan Coverage - Outer Shell Surface

Figure 36

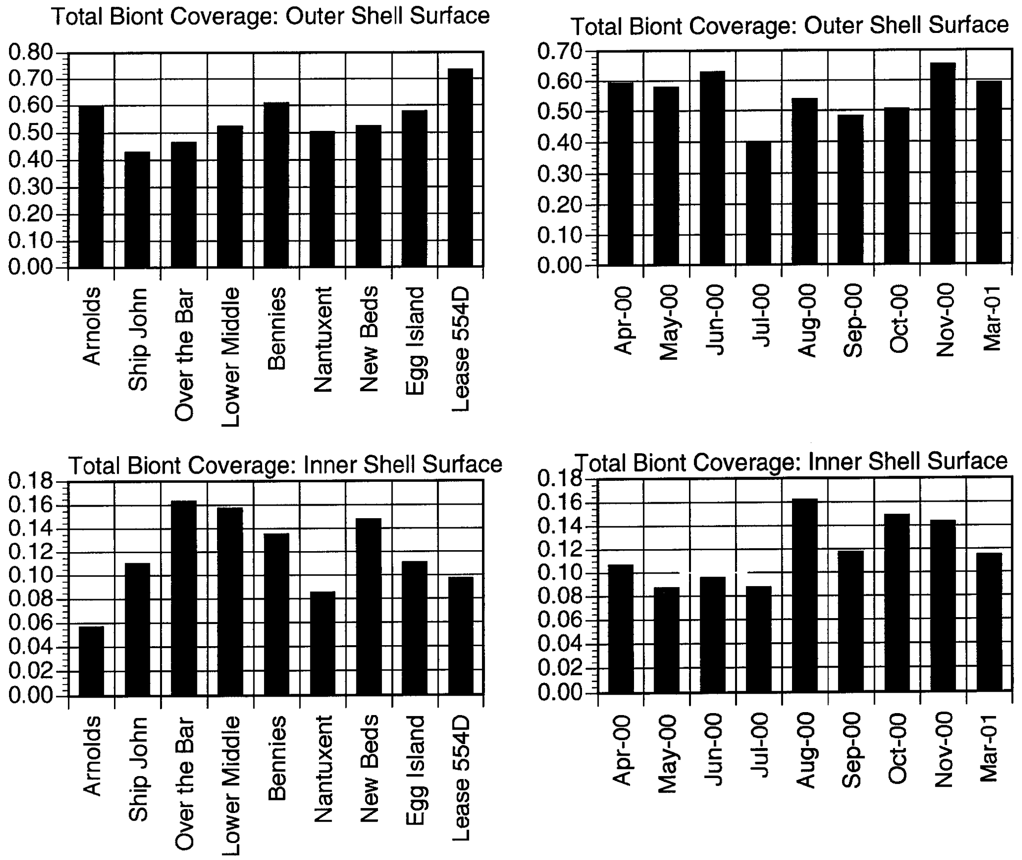

Total Biont Coverage: Outer Shell Surface
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
Arnolds
Ship John
Over the Bar
Lower Middle
Bennies
Nantuxent
New Beds
Egg Island
Lease 554D
Total Biont Coverage: Outer Shell Surface
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
Apr-00
May-00
Jun-00
Jul-00
Aug-00
Sep-00
Oct-00
Nov-00
Mar-01
Total Biont Coverage: Inner Shell Surface
0.18
0.16
0.14
0.12
0.10
0.08
0.06
0.04
0.02
0.00
Arnolds
Ship John
Over the Bar
Lower Middle
Bennies
Nantuxent
New Beds
Egg Island
Lease 554D
Total Biont Coverage: Inner Shell Surface
0.18
0.16
0.14
0.12
0.10
0.08
0.06
0.04
0.02
0.00
Apr-00
May-00
Jun-00
Jul-00
Aug-00
Sep-00
Oct-00
Nov-00
Mar-01

Figure 37

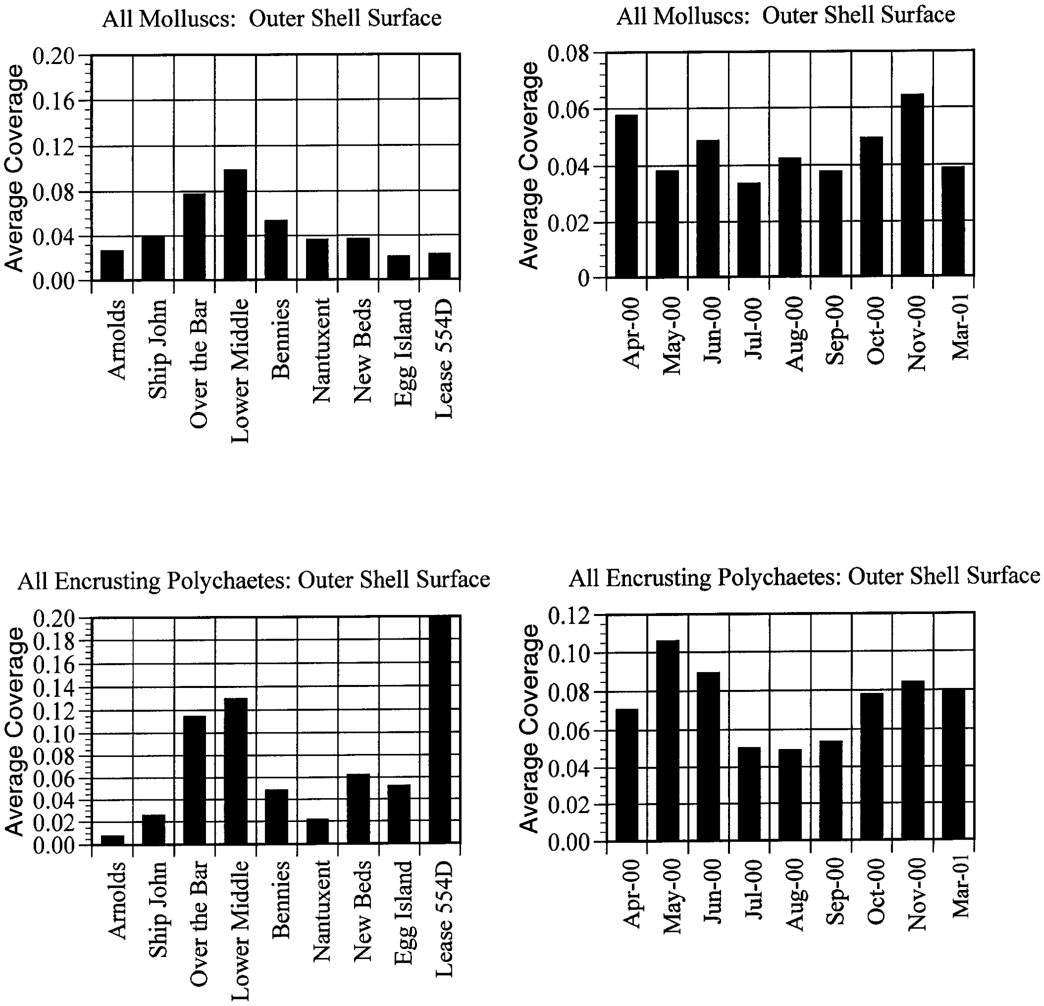

All Molluscs: Outer Shell Surface
Average Coverage
0.20
0.16
0.12
0.08
0.04
0.00
Arnolds
Ship John
Over the Bar
Lower Middle
Bennies
Nantuxent
New Beds
Egg Island
Lease 554D
All Molluscs: Outer Shell Surface
Average Coverage
0.08
0.06
0.04
0.02
0
Apr-00
May-00
Jun-00
Jul-00
Aug-00
Sep-00
Oct-00
Nov-00
Mar-01
All Encrusting Polychaetes: Outer Shell Surface
Average Coverage
0.20
0.18
0.16
0.14
0.12
0.10
0.08
0.06
0.04
0.02
0.00
Arnolds
Ship John
Over the Bar
Lower Middle
Bennies
Nantuxent
New Beds
Egg Island
Lease 554D
All Encrusting Polychaetes: Outer Shell Surface
Average Coverage
0.12
0.10
0.08
0.06
0.04
0.02
0.00
Apr-00
May-00
Jun-00
Jul-00
Aug-00
Sep-00
Oct-00
Nov-00
Mar-01

Figure 38

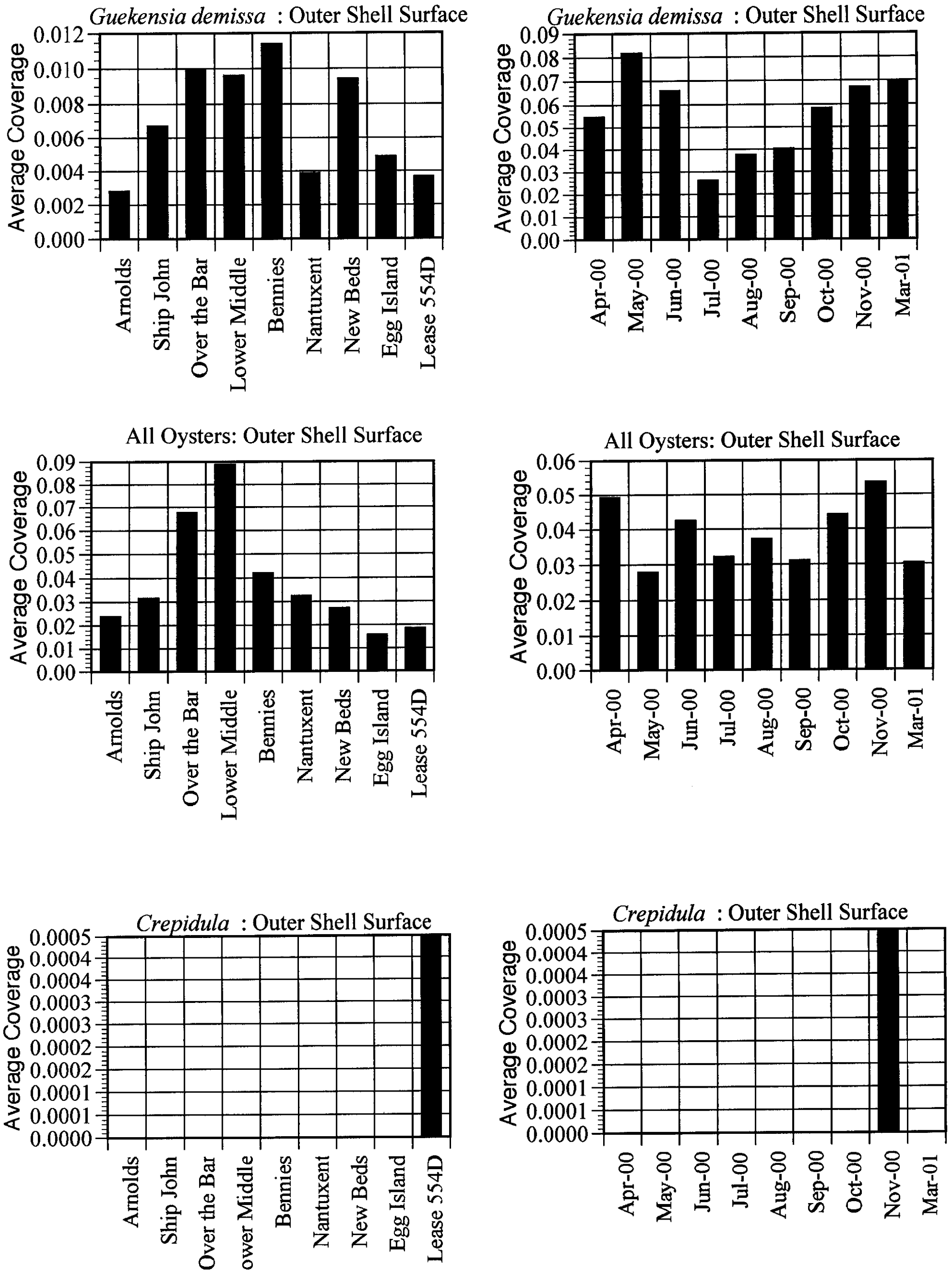
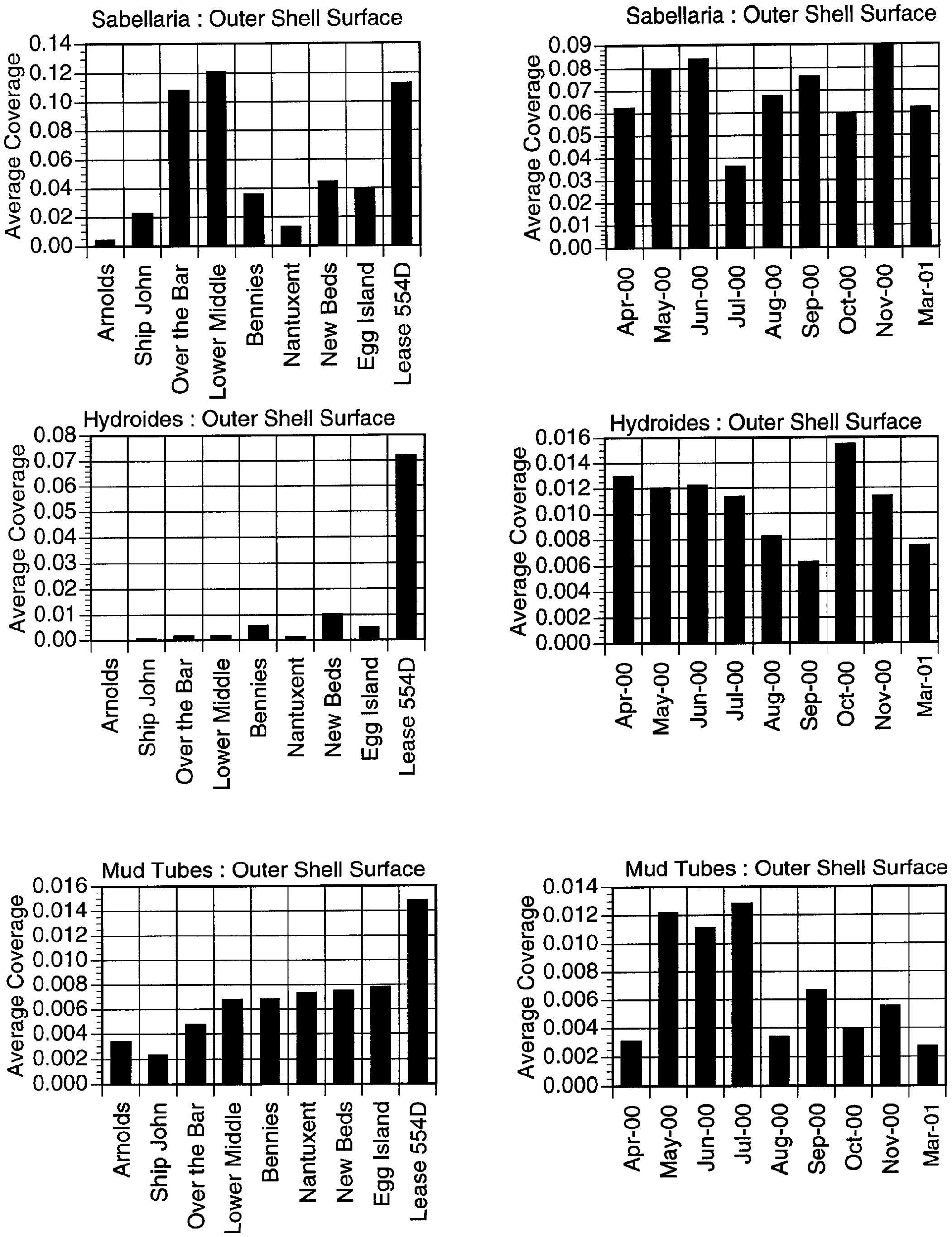

Guekensia demissa : Outer Shell Surface
Average Coverage
0.012
0.010
0.008
0.006
0.004
0.002
0.000
Arnolds
Ship John
Over the Bar
Lower Middle
Bennies
Nantuxent
New Beds
Egg Island
Lease 554D
Guekensia demissa : Outer Shell Surface
Average Coverage
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0.00
Apr-00
May-00
Jun-00
Jul-00
Aug-00
Sep-00
Oct-00
Nov-00
Mar-01
All Oysters: Outer Shell Surface
Average Coverage
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0.00
Arnolds
Ship John
Over the Bar
Lower Middle
Bennies
Nantuxent
New Beds
Egg Island
Lease 554D
All Oysters: Outer Shell Surface
Average Coverage
0.06
0.05
0.04
0.03
0.02
0.01
0.00
Apr-00
May-00
Jun-00
Jul-00
Aug-00
Sep-00
Oct-00
Nov-00
Mar-01
Crepidula : Outer Shell Surface
Average Coverage
0.0005
0.0004
0.0004
0.0003
0.0003
0.0002
0.0002
0.0001
0.0001
0.0000
Arnolds
Ship John
Over the Bar
Lower Middle
Bennies
Nantuxent
New Beds
Egg Island
Lease 554D
Crepidula : Outer Shell Surface
Average Coverage
0.0005
0.0004
0.0004
0.0003
0.0003
0.0002
0.0002
0.0001
0.0001
0.0000
Apr-00
May-00
Jun-00
Jul-00
Aug-00
Sep-00
Oct-00
Nov-00
Mar-01

Figure 39


Sabellaria : Outer Shell Surface

Sabellaria : Outer Shell Surface

Hydroides : Outer Shell Surface

Hydroides : Outer Shell Surface

Mud Tubes : Outer Shell Surface

Mud Tubes : Outer Shell Surface

Figure 40

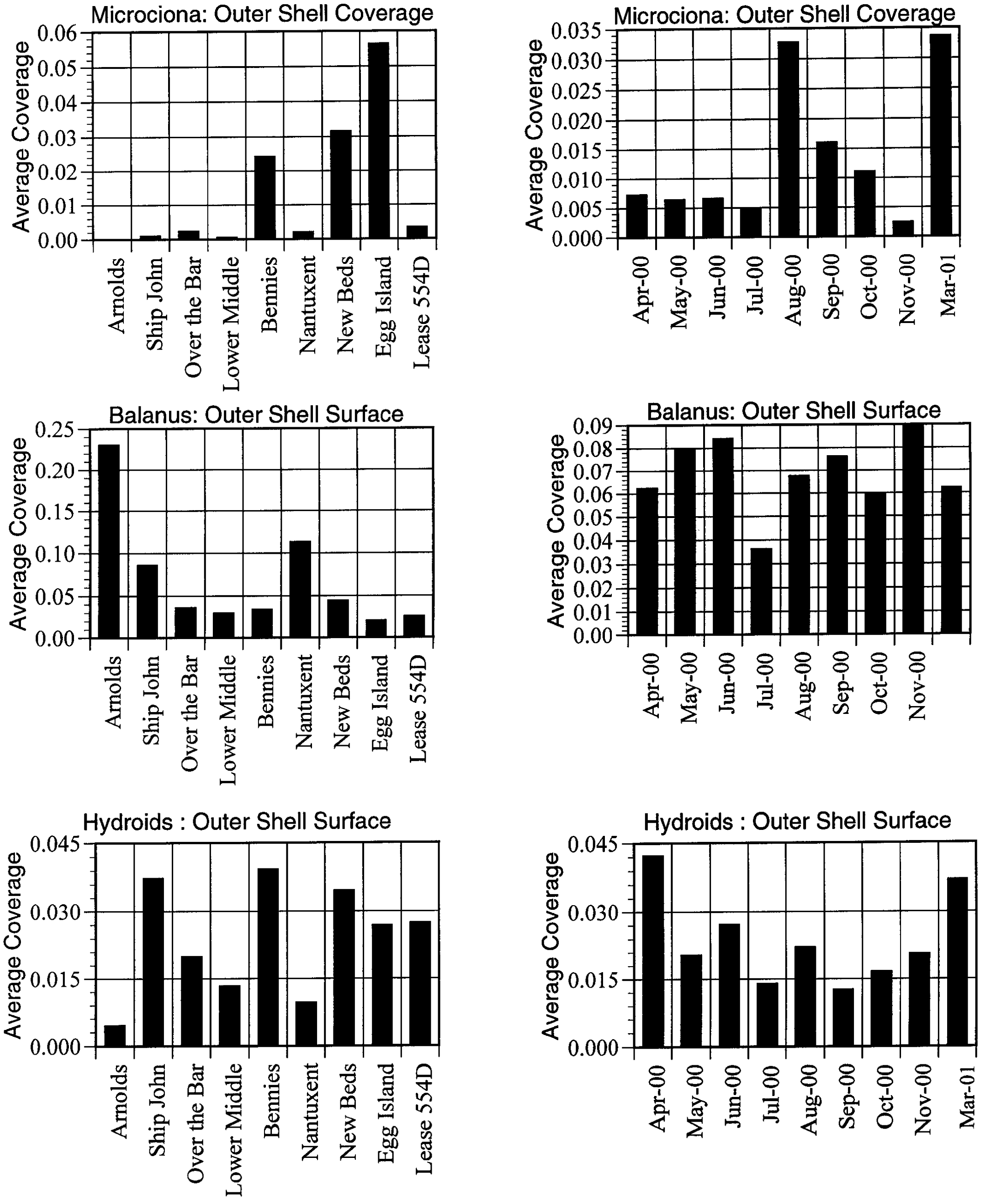

Microciona: Outer Shell Coverage
Average Coverage
0.06
0.05
0.04
0.03
0.02
0.01
0.00
Arnolds
Ship John
Over the Bar
Lower Middle
Bennies
Nantuxent
New Beds
Egg Island
Lease 554D
Microciona: Outer Shell Coverage
Average Coverage
0.035
0.030
0.025
0.020
0.015
0.010
0.005
0.000
Apr-00
May-00
Jun-00
Jul-00
Aug-00
Sep-00
Oct-00
Nov-00
Mar-01
Balanus: Outer Shell Surface
Average Coverage
0.25
0.20
0.15
0.10
0.05
0.00
Arnolds
Ship John
Over the Bar
Lower Middle
Bennies
Nantuxent
New Beds
Egg Island
Lease 554D
Balanus: Outer Shell Surface
Average Coverage
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0.00
Apr-00
May-00
Jun-00
Jul-00
Aug-00
Sep-00
Oct-00
Nov-00
Hydroids : Outer Shell Surface
Average Coverage
0.045
0.030
0.015
0.000
Arnolds
Ship John
Over the Bar
Lower Middle
Bennies
Nantuxent
New Beds
Egg Island
Lease 554D
Hydroids : Outer Shell Surface
Average Coverage
0.045
0.030
0.015
0.000
Apr-00
May-00
Jun-00
Jul-00
Aug-00
Sep-00
Oct-00
Nov-00
Mar-01

Figure 41

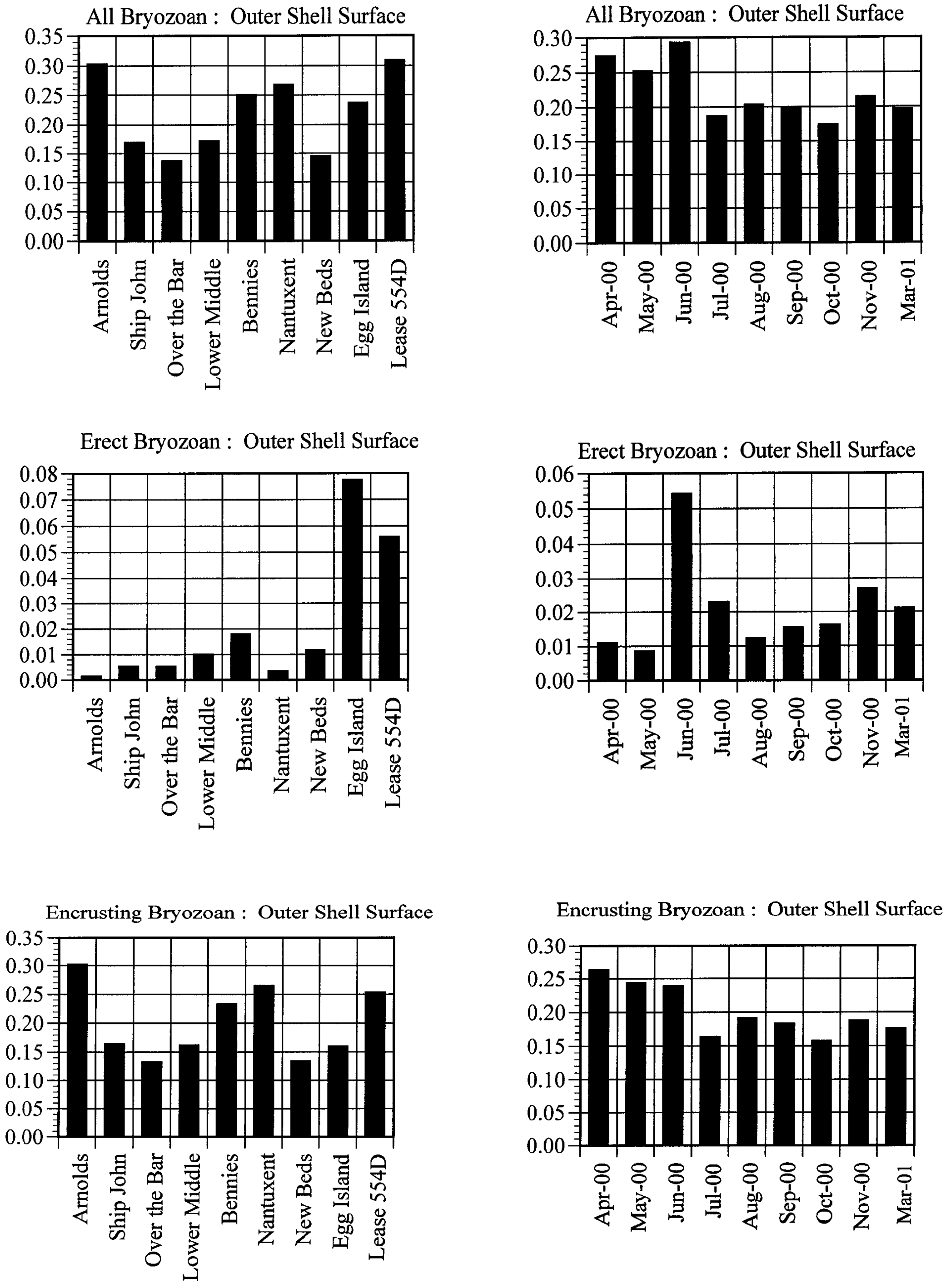

All Bryozoan : Outer Shell Surface
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
Arnolds
Ship John
Over the Bar
Lower Middle
Bennies
Nantuxent
New Beds
Egg Island
Lease 554D
All Bryozoan : Outer Shell Surface
0.30
0.25
0.20
0.15
0.10
0.05
0.00
Apr-00
May-00
Jun-00
Jul-00
Aug-00
Sep-00
Oct-00
Nov-00
Mar-01
Erect Bryozoan : Outer Shell Surface
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0.00
Arnolds
Ship John
Over the Bar
Lower Middle
Bennies
Nantuxent
New Beds
Egg Island
Lease 554D
Erect Bryozoan : Outer Shell Surface
0.06
0.05
0.04
0.03
0.02
0.01
0.00
Apr-00
May-00
Jun-00
Jul-00
Aug-00
Sep-00
Oct-00
Nov-00
Mar-01
Encrusting Bryozoan : Outer Shell Surface
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
Arnolds
Ship John
Over the Bar
Lower Middle
Bennies
Nantuxent
New Beds
Egg Island
Lease 554D
Encrusting Bryozoan : Outer Shell Surface
0.30
0.25
0.20
0.15
0.10
0.05
0.00
Apr-00
May-00
Jun-00
Jul-00
Aug-00
Sep-00
Oct-00
Nov-00
Mar-01

Figure 42

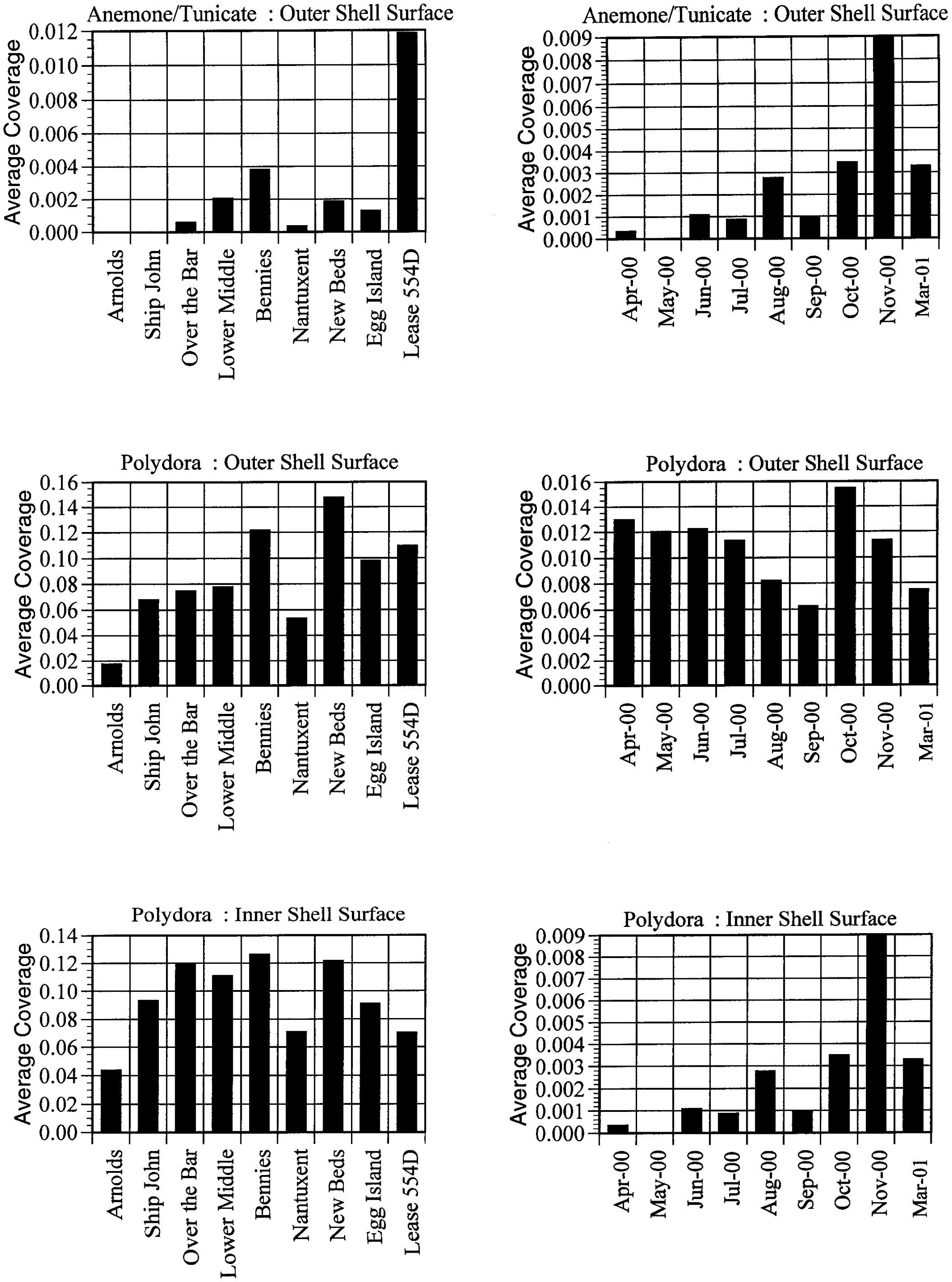
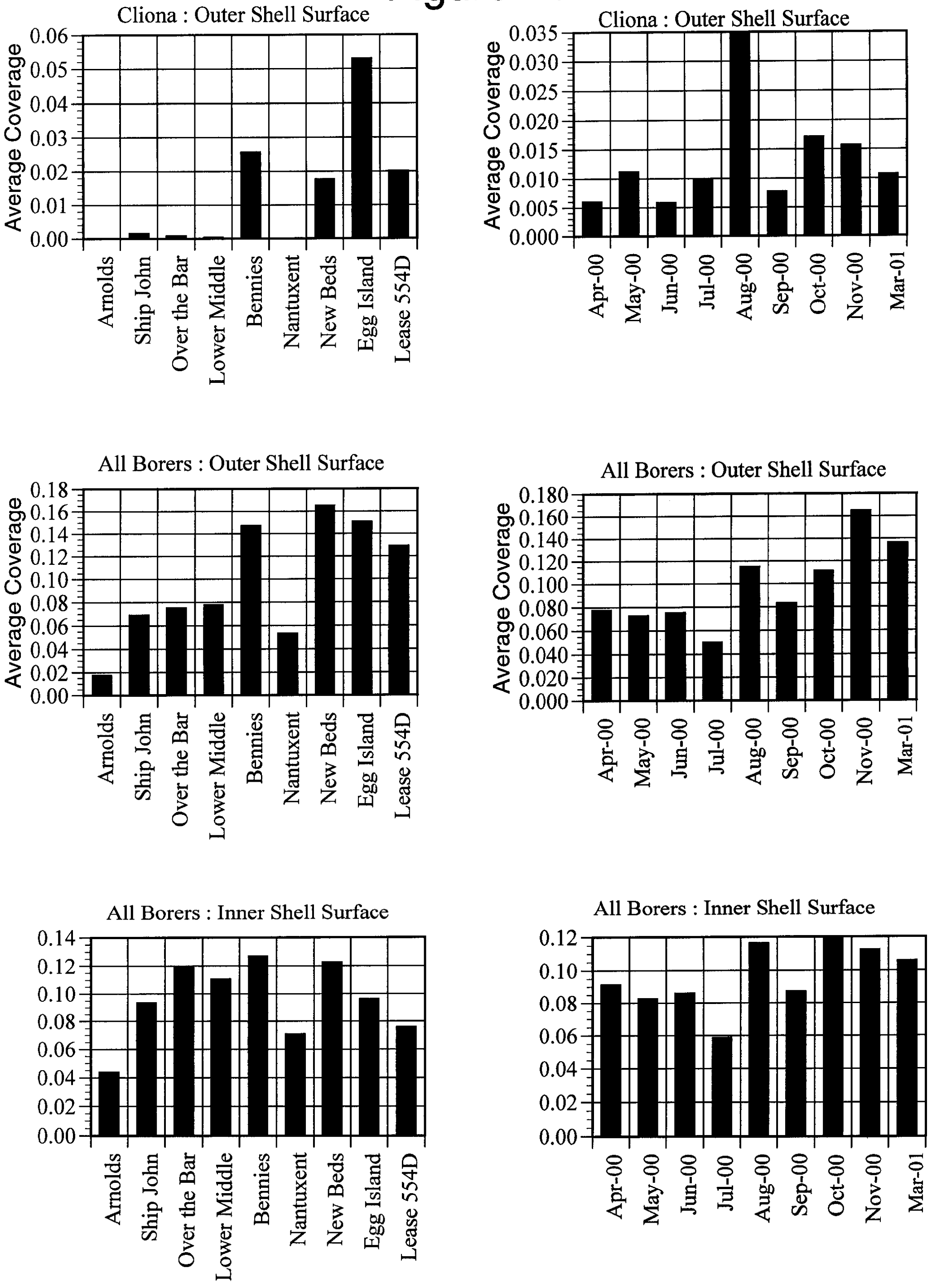

Anemone/Tunicate : Outer Shell Surface
Average Coverage
0.012
0.010
0.008
0.006
0.004
0.002
0.000
Arnolds
Ship John
Over the Bar
Lower Middle
Bennies
Nantuxent
New Beds
Egg Island
Lease 554D
Anemone/Tunicate : Outer Shell Surface
Average Coverage
0.009
0.008
0.007
0.006
0.005
0.004
0.003
0.002
0.001
0.000
Apr-00
May-00
Jun-00
Jul-00
Aug-00
Sep-00
Oct-00
Nov-00
Mar-01
Polydora : Outer Shell Surface
Average Coverage
0.16
0.14
0.12
0.10
0.08
0.06
0.04
0.02
0.00
Arnolds
Ship John
Over the Bar
Lower Middle
Bennies
Nantuxent
New Beds
Egg Island
Lease 554D
Polydora : Outer Shell Surface
Average Coverage
0.016
0.014
0.012
0.010
0.008
0.006
0.004
0.002
0.000
Apr-00
May-00
Jun-00
Jul-00
Aug-00
Sep-00
Oct-00
Nov-00
Mar-01
Polydora : Inner Shell Surface
Average Coverage
0.14
0.12
0.10
0.08
0.06
0.04
0.02
0.00
Arnolds
Ship John
Over the Bar
Lower Middle
Bennies
Nantuxent
New Beds
Egg Island
Lease 554D
Polydora : Inner Shell Surface
Average Coverage
0.009
0.008
0.007
0.006
0.005
0.004
0.003
0.002
0.001
0.000
Apr-00
May-00
Jun-00
Jul-00
Aug-00
Sep-00
Oct-00
Nov-00
Mar-01

Figure 43



Cliona : Outer Shell Surface

Cliona : Outer Shell Surface

All Borers : Outer Shell Surface

All Borers : Outer Shell Surface

All Borers : Inner Shell Surface

All Borers : Inner Shell Surface

Figure 44: Delaware Bay Seed Beds

Oyster Abundance

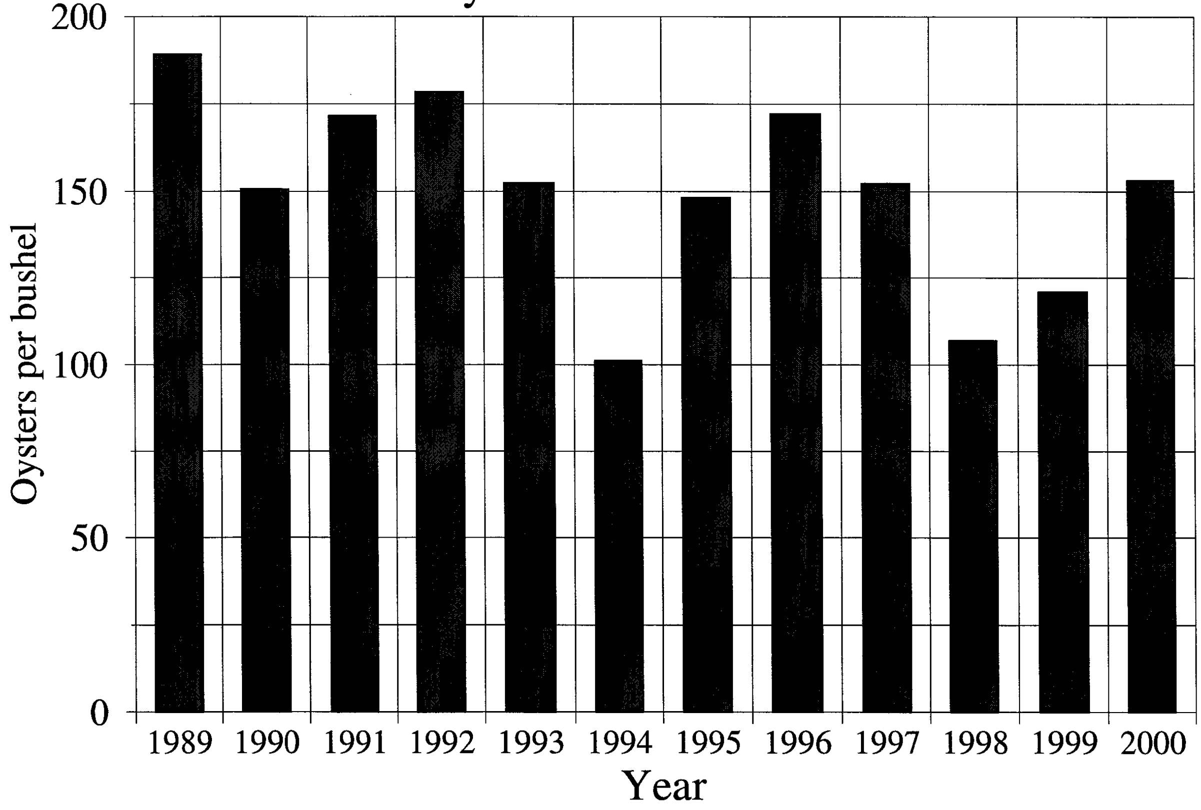


Figure 45: Delaware Bay Seed Beds

Medium Mortality Beds

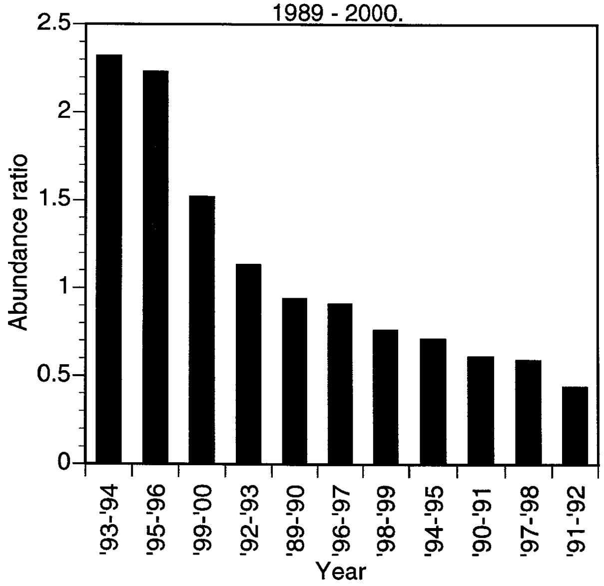
Year	**0**	**96**	**97**	**92**	**90**	**91**	**89**	**98**	**93**	**99**	**94**	**95**	**Mean**
Oysters	321	309	265	243	225	222	214	193	190	170	143	138	**219***

High Mortality Beds

Year	**96**	**89**	**95**	**90**	**97**	**92**	**91**	**98**	**0**	**99**	**93**	**94**	**Mean**
Oysters	153	105	95	91	91	91	84	80	80	78	55	52	**88***

Figure 46

Rank order of the ratio of weighted mean abundance (T+1/T) for the high-mortality direct-market beds for 1989 - 2000.



Rank order of weighted mean abundance in 1989-2000 for the high-mortality direct market beds calculated for the period 1989-2000.

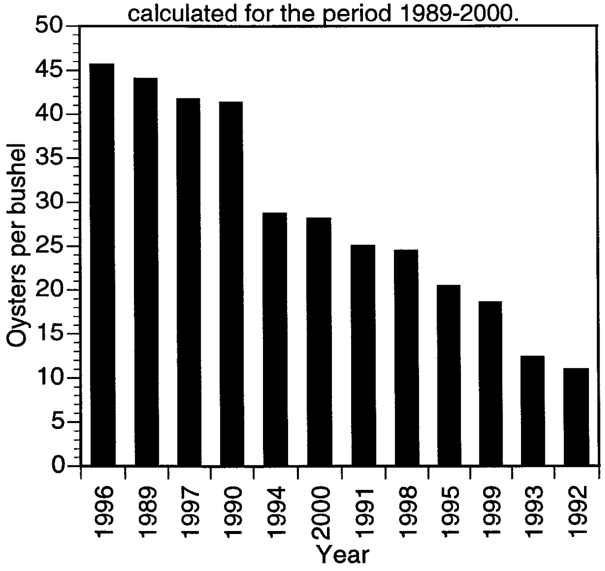
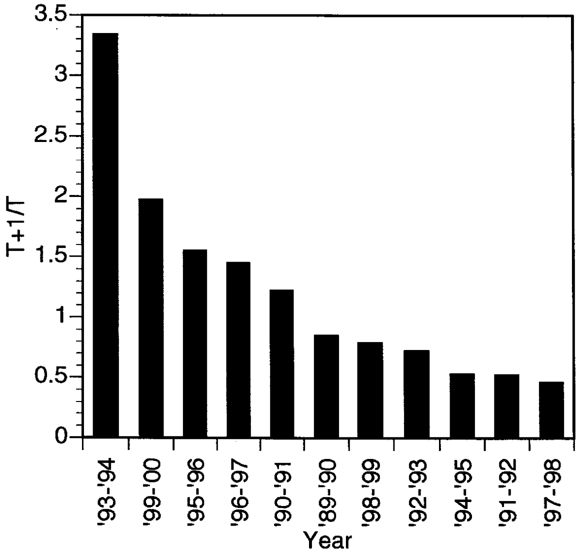


Figure 47

Rank order of the ratio of weighted mean abundance (T+1/T) for 1989-2000 on medium-mortality beds.



Rank order of weighted mean abundance from 1989-2000 on medium-mortality beds calculated as
≥ 3"+0.5(#2.5-3.0")

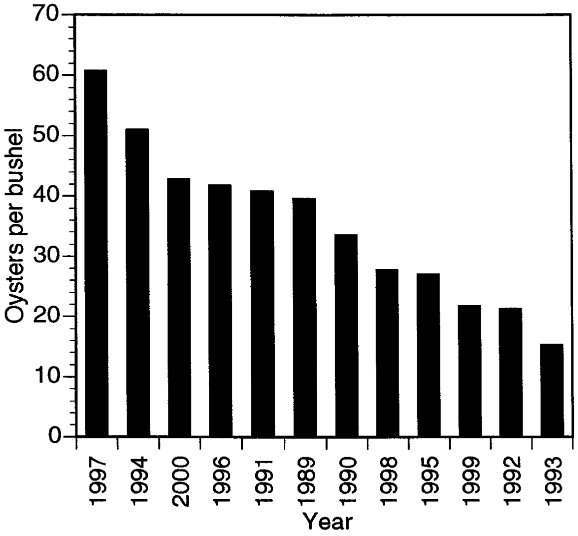


Figure 48: Delaware Bay Seed Beds

Delaware Bay - All Beds

Year	**91**	**99**	**97**	**98**	**95**	**94**	**90**	**89**	**0**	**93**	**92**	**96**	**Mean**
Spat	268	190	151	128	127	124	112	69	55	44	25	22	**110**

Medium Mortality Beds

Year	**99**	**91**	**98**	**95**	**94**	**90**	**97**	**0**	**89**	**93**	**96**	**92**	**Mean**
Spat	351	295	209	179	164	122	113	97	70	60	36	31	**144**

High Mortality Beds

Year	**91**	**97**	**99**	**94**	**98**	**95**	**90**	**89**	**0**	**93**	**92**	**96**	**Mean**
Spat	273	221	175	166	146	137	107	70	69	46	21	16	**121**

Figure 49: Delaware Bay Seed Beds

Condition Index: Dry Meat/Hinge to Lip

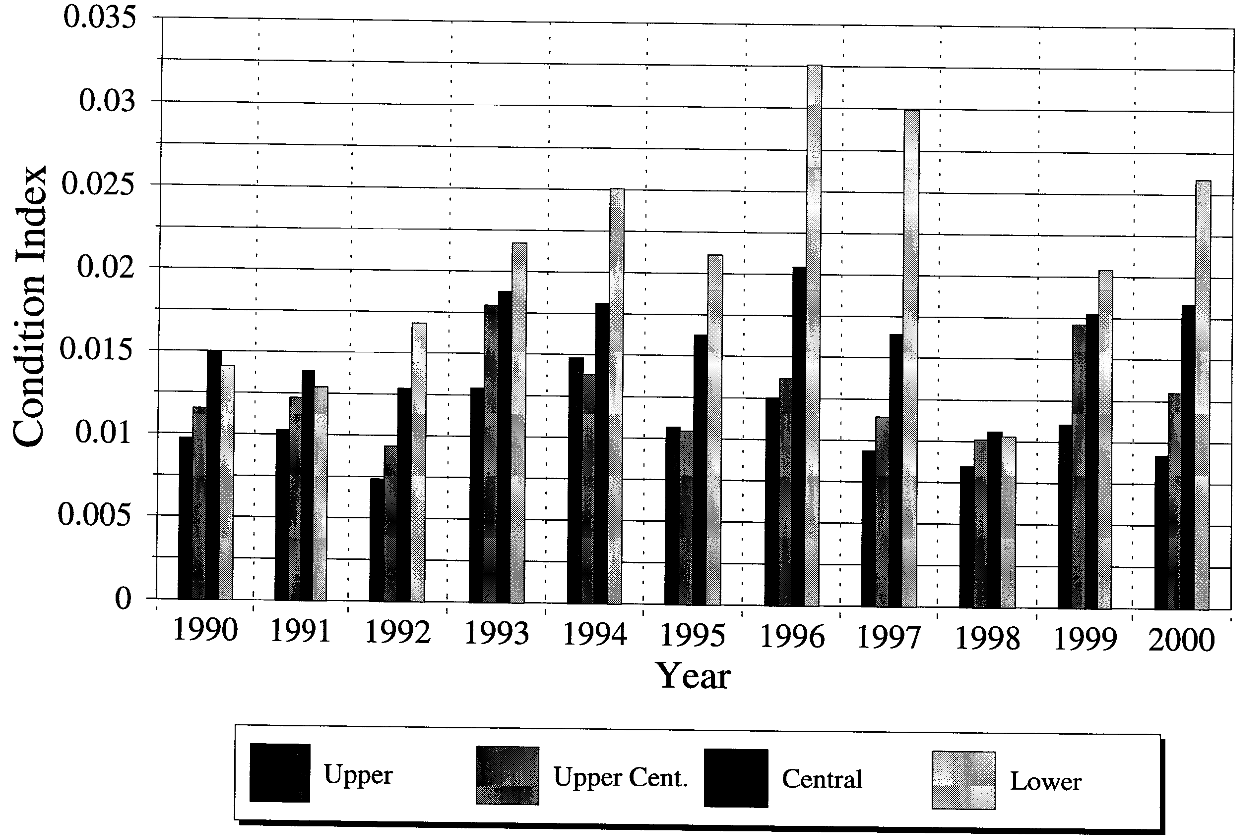


Figure 50: Delaware Bay Seed Beds

Dermo (Perkinsus marinus)

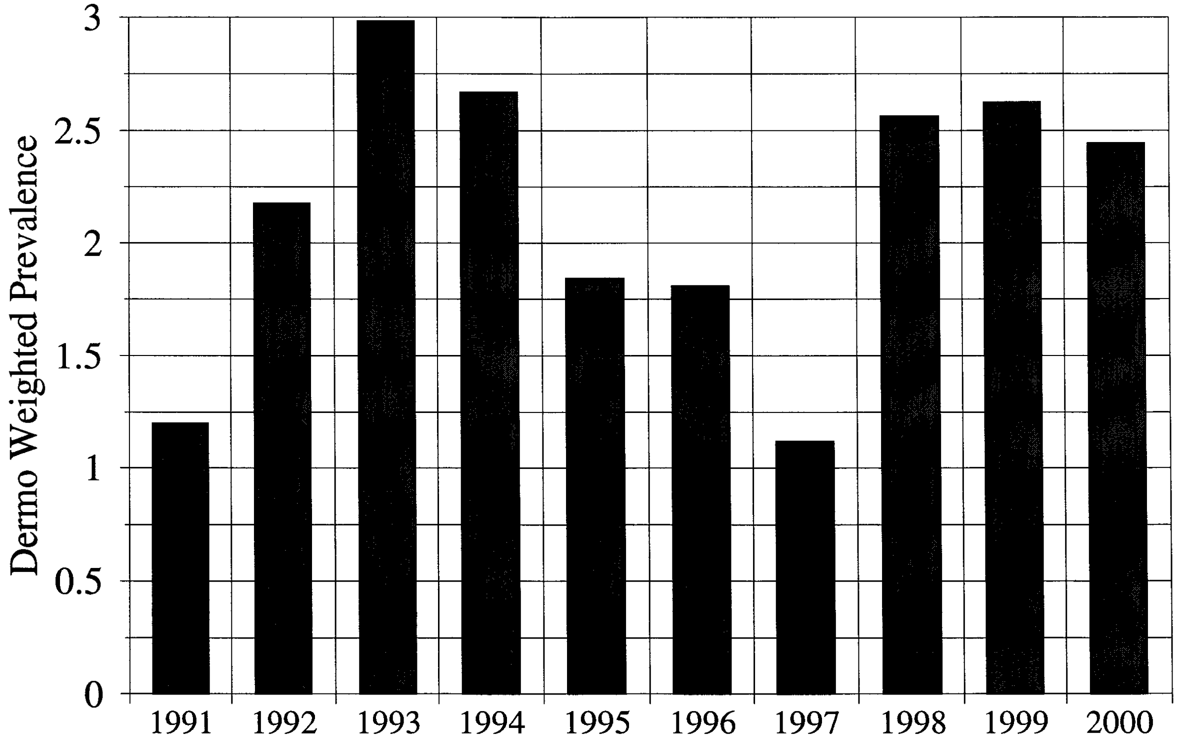
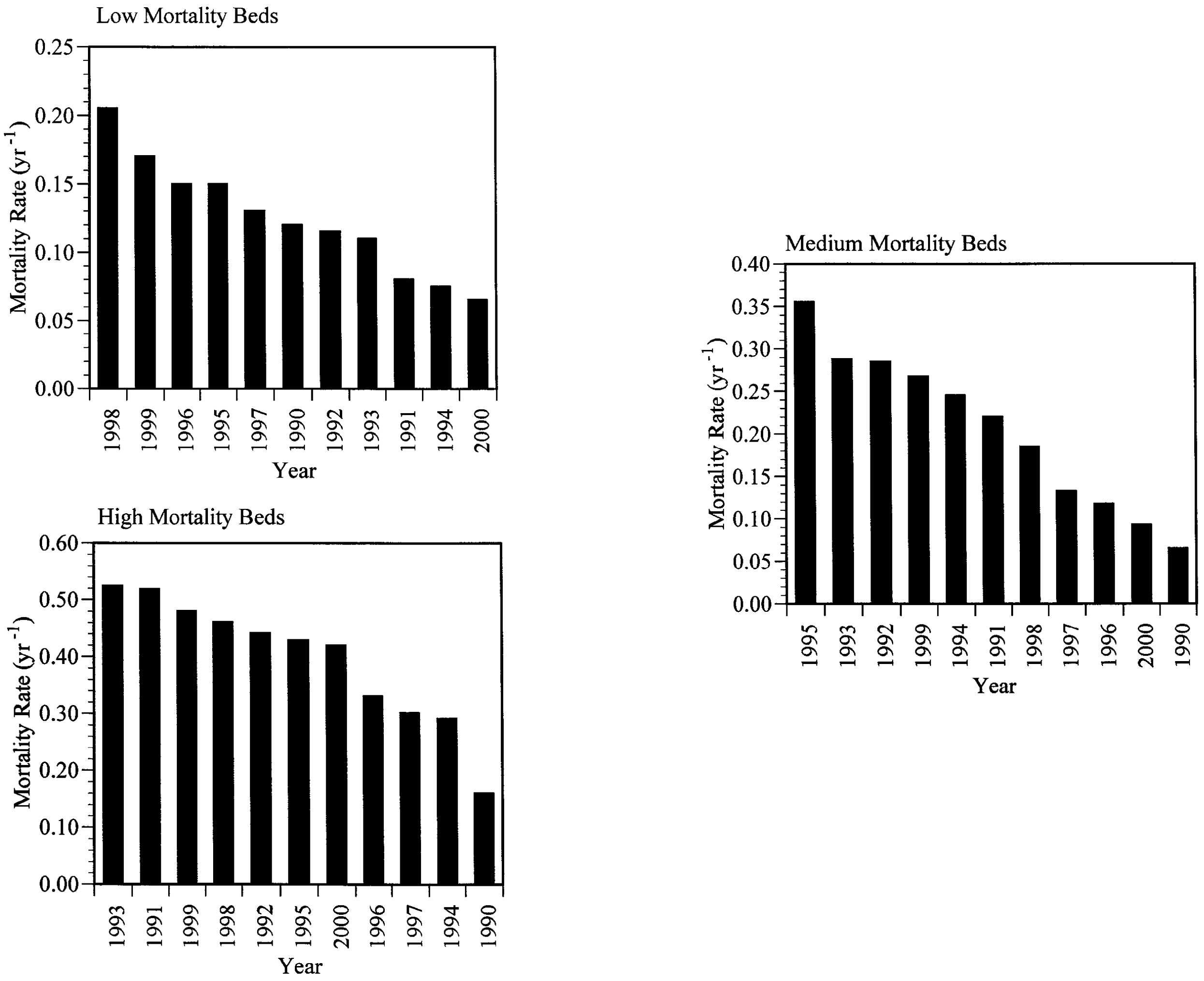


Figure 51: Rank order of yearly natural mortality rates.



Low Mortality Beds

High Mortality Beds

Medium Mortality Beds