Chesapeake Bay Stock Assessment Committee

WORKSHOP REPORT · 2001

NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION

Chesapeake Bay Stock Assessment Committee Workshop Report 2001

February 2002

NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION

in association with members of the

Chesapeake Bay Stock Assessment Committee

Since 1985, NOAA has received between $1,100,000 and $1,600,000 per year for Chesapeake Bay fisheries stock assessment, environmental effects research, remote sensing and data management. NOAA's Chesapeake Bay Fisheries Research Program is administered by the NOAA Chesapeake Bay Office. The fisheries stock assessment efforts have been guided by the Chesapeake Bay Stock Assessment Committee. NOAA works closely with the Chesapeake Bay Program to ensure this effort is directly related to and in support of the research, monitoring and assessment commitments in the 1987 and 2000 Chesapeake Bay Agreements and the 1988 Stock Assessment Plan.

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The Chesapeake Bay Stock Assessment Committee was established in 1985 by the NOAA National Marine Fisheries Service, with the support of the NOAA Chesapeake Bay Office, to develop a Baywide, cooperative program for assessment of fishery resources in the Chesapeake Bay. The Committee has funded Bay area fisheries research every year to improve regional information required for stock assessment.

The 1987 Chesapeake Bay Agreement required the development of a compatible Baywide stock assessment program, and "to develop, adopt and begin to implement a Bay-wide plan for the assessment of commercially, recreationally and ecologically selected valuable species."

The Chesapeake Bay Stock Assessment Committee (CBSAC), developed the Chesapeake Bay Stock Assessment Plan, and now assesses Bay-wide fisheries resources and identifies data needs for stock assessment models. Recommendations include ways to collect catch, effort, and biological data from commercial and recreational landings, in addition to long-term surveys for estimating relative abundance of important species in all regions of the Bay and its tributaries. The Committee supports studies designed to estimate the relative influence of fishing mortality, natural mortality and habitat modification on patterns of trends in abundance.

Recently, there has been a collective effort to investigate an ecosystem-based approach to fisheries management in Chesapeake Bay rather than single species approaches. Continued modification and evolution of fisheries management is expected, both at the management and technical levels, as changes in management strategies are further developed and understood. In 2001, CBSAC underwent a slight restructuring. The Chesapeake Bay Fisheries Steering Committee was established to guide several fisheries related workgroups and activities including CBSAC, the Fishery Ecosystem Plan Technical Advisory Panel, an Ecosystem Modeling Advisory Panel, and the Chesapeake Bay Program's Fisheries Management Planning and Coordination Workgroup.

Fisheries Steering Committee Mission

The Fisheries Steering Committee will assist in coordinating management and research activities, investigating ecosystem-based fisheries management, and conserving the shared Chesapeake Bay and coastal fishery resources. With the recognition that fish do not adhere to political boundaries, the Bay jurisdictions have found that their mutual interest in sustaining healthy Chesapeake Bay and coastal fishery resources is best achieved by working together cooperatively, in collaboration with the the various CBP partners. This approach will permit the states to fulfill their respective fisheries management responsibilities within the Bay in a more cost effective and responsive fashion.

Fisheries Steering Committee Vision

Ecosystem-based fisheries management that encourages sustainable Chesapeake Bay fish populations that supports viable recreational and commercial fisheries and provides for natural ecosystem function.

Membership

Chesapeake Bay Fisheries Steering Committee

Maryland	Eric Schwaab
District of Columbia	Ira Palmer
Pennsylvania	Rick Hoopes
Virginia	Jack Travelstead
Chesapeake Bay Program - Chair Living Resources	Frank Dawson
Scientific and Technical Advisory Committee	Ed Houde
U. S. Fish and Wildlife	John Galves
Atlantic States Marine Fisheries Commission	Bob Beal
Potomac River Fisheries Commission	A. C. Carpenter
NMFS/NOAA Chesapeke Bay Office	Derek Orner (Chair)

CBSAC Members

Chris Bonzek	VA Institute of Marine Science
John Hoenig	VA Institute of Marine Science
Phil Jones (Chair)	MD Department of Natural Resources
Tom Miller	Chesapeake Biological Laboratory
Rob O'Reilly	VA Marine Resources Commission
Derek Orner	NMFS/NOAA Chesapeake Bay Office
Mark Terceiro	NMFS/NEFSC
Alexei Sharov	MD Department of Natural Resources
Douglas Vaughan	NMFS/SEFSC

Project Summaries

2001 Chesapeake Bay Blue Crab Advisory Report

Prepared by the Chesapeake Bay Stock Assessment Committee's
June 7, 2001
(For Graphs check http://noaa.chesapeakebay.net/reports/BCARpage2001.htm)

Status of the Stock: Analysis of long term juvenile and adult fishery-independent surveys conducted in Chesapeake Bay (Maryland and Virginia trawl surveys, Calvert Cliffs crab pot survey and Baywide winter dredge survey) indicate that blue crab abundance is below average and in decline in recent years. The current status of the stock was compared to thresholds and targets endorsed by regional management agencies. Exploitable stock abundance was above the overfished threshold in 2000 but below the action threshold for the fourth consecutive year (Figure 1). Length based estimates of fishing mortality indicate that the stock is fully exploited. The average fishing mortality rate (F) of 0.9 in 2000 is below the overfishing threshold ($F_{10\%}$ = 1.0) but well above the target ($F_{20\%}$ = 0.7) (Figure 2). The 2000 Chesapeake Bay blue crab harvest of 51 million pounds is well below the time series (1968 - 2000) average of about 75 million pounds (Figure 3). Early life history data collected in the Virginia portion of Chesapeake Bay by the Chesapeake Bay Program Zooplankton Monitoring Program indicate that megalopal abundance has generally declined since sampling began in 1985 (Figure 4.)

Data: Five fishery-independent surveys are used to determine stock status: Virginia trawl survey, Maryland summer trawl survey, Calvert Cliffs crab pot survey, Baywide winter dredge survey and Baywide zooplankton monitoring. The first four sample crabs after settlement, the latter samples megalopal abundance in the water column. Data from the two trawl surveys and the Calvert Cliffs pot survey are based on calendar year collections through 2000. The winter dredge survey data represent seasonal collections through the 2000/01 season. For abundance indices the dredge survey is referred to as 2001 data, but for estimates of fishing mortality rates the dredge survey is referred to as 2000 data since the mortality took place in 2000. Data from the zooplankton monitoring program is based on calendar year collections. Indices are expressed as the geometric mean catch per unit effort. The width-age cutoff values used to differentiate age classes for three of the four surveys (Maryland and Virginia trawl and Calvert Cliffs pot study), used to derive the abundance indices, were modified and standardized for this report. These procedural changes involved the use of sliding monthly cutoff values that model the growth of age-0 crabs. Age-0 crabs are defined as being less than 50-90 mm depending on month, and age-1+ are all crabs larger than the monthly cutoff values.

Biological Reference Points: A review of targets and thresholds for Chesapeake Bay blue crabs was conducted by Maryland and Virginia biologists in 2000 with the help of outside experts from the National Marine Fisheries Service. The workgroup identified exploitation and abundance limits, a precautionary zone in which exploitation is too high at low abundance, and an exploitation target. The overfishing threshold ($F_{10\%}$ = 1.0) and target ($F_{20\%}$ = 0.7) fishing mortality rates refer to the level of spawning potential which is 10% and 20% respectively, of the spawning potential expected in a stock on which no fishing occurs. Age-specific partial recruitment was based on the selectivity of the harvest gears and established as 10% (age 0), 75% (age 1), 95% (age 2) and 100% (age 3+). The overfished threshold (B_{low}) is equal to the lowest exploitable stock observed in the fishery independent trawl, pot and dredge surveys conducted in Chesapeake Bay from 1968 - present.

Spawning Stock Abundance (1998-00): Mature female spawning stock abundance was below the long term average for the Baywide winter dredge and Virginia trawl surveys and average for the Maryland trawl and the Calvert Cliffs pot surveys. Data for all surveys combined indicate that spawning stock abundance has declined since the early 1990s. It is also important to note that the 2000 abundance estimate is the lowest of the time series (Figure 7).

Harvest: The three-year (1998-2000) average, commercial Baywide harvest (60 million pounds) is below the long term (1968 - 2000) average of about 75 million pounds. The 2000 Baywide harvest of 50.8 million pounds is below average and is the lowest since the Maryland commercial crab reporting system changed in 1981. For the 1968-2000 period, Baywide commercial harvests exceeded 100 million pounds in 1966, 1981, 1983 and 1993. The 1993 harvest of 113 million pounds is the highest recorded harvest. Based on the historical relationship between winter dredge survey abundance and commercial harvest, we expect the Baywide commercial Chesapeake Bay harvest in 2001 to be less than 60 million pounds.

Management Advice: Based on a review of data collected in the Maryland and Virginia trawl surveys, the Calvert Cliffs crab pot survey and the Baywide winter dredge survey it appears that: (1) there is a declining trend in recruitment in recent years; (2) age 1+ blue crab stock size is approaching a low not seen since the late-1960s; (3) adult female abundance is currently below the previous historical low set in 1968; and (4) F is well above the target, and may be increasing.

Fishing Mortality The average fishing mortality rate was 0.91 in 2000 (range = 0.82 to 0.96). None of the current length based fishing mortality rates exceeded the threshold fishing mortality rate F = 1.0. All F estimates were above the target fishing mortality rate F = 0.7. However, it is important to note that an alternative method of calculating F's based on the Baywide winter dredge survey indicated that exploitation rates are increasing and may be substantially higher than the overfishing threshold (Sharov et al. 2001).

Recruitment (1998-00): Results from the Maryland and Virginia trawl surveys indicate that recruitment has been average whereas the Baywide winter dredge survey results suggest that recruitment has been below average in recent years. With data for the three surveys combined, there appears to be a declining trend in recruitment in recent years (Figure 5).

Exploitable Stock Abundance (1998-00): The average exploitable abundance of age 1+ crabs for the last three years was considered to be below average for all four surveys (Maryland and Virginia trawl surveys, Calvert Cliffs pot survey and Baywide winter dredge survey). Data for all surveys combined indicate that the exploitable stock abundance is declining and is approaching the low for the time series (Figure 6).

There is a consensus among biologists that action needs to be taken to reduce fishing effort as a way to reduce fishing mortality. The context of this consensus is important. A focused review of appropriate targets and thresholds for Chesapeake Bay blue crabs was conducted by Maryland and Virginia biologists in 2000 with the help of outside experts from the National Marine Fisheries Service. This workgroup identified an absolute minimum stock size below which it is dangerous to be, even if there is no fishing mortality. The danger is seen both on empirical grounds (comparison with other stocks) and experiential grounds – the stock size has never been below the overfished threshold. Of course, if fishing mortality is not zero, then being slightly above the overfished threshold can be dangerous. Hence, there is an "action threshold" depicted by the diagonal line in Figure 1. A situation to the left of this line is risky because of the combination of the low abundance and the existing fishing mortality rate. This action line has an extremely important practical consequence in terms of stability of the fishery. It calls for progressively stronger reductions in fishing as the abundance declines. If only an abundance threshold was specified (a vertical line), then a situation where biomass is equal to one crab more than the threshold would imply no action is needed while one crab less than the threshold would imply shutting down the fishery. With that type of control rule, there would be no intermediate level of action.

The current situation is thus risky because of the combination of low biomass and high fishing mortality rate. The nature of the risk is worthy of note. Recruitment is highly variable. If an exceptionally strong year class were to arrive, the population might increase for a year or two, though the high amount of effort would quickly reduce the population size. On the other hand, if a very poor year class was to occur, the already low biomass would drop much lower (due to lack of replenishment). Fishing mortality would likely increase as crabbers compensate for low catches by fishing harder which could lead to stock collapse. It is clear that weak year classes do occur from time to time, and they are more likely to occur when stock size is low. The consensus among technical committee members is that it is risky to remain in the current situation. When a weak year class arrives, there will be those that attribute the stock decline or collapse to unusual environmental conditions instead of fishing, but unusual environmental conditions are only unusual in the short term. Fishing mortality rate must be reduced and stock abundance should be increased as rapidly as possible.

Special comments: As was stated in the 2000 advisory report, it is critical that a carefully designed, Baywide data collection program be implemented for blue crabs in Chesapeake Bay. The design of the data collection program should be based, in part, on the need for improved information on: (1) harvest and effort data for the commercial and recreational fisheries; (2) growth and mortality rates; (3) size at maturity; and (4) the age, size, sex and maturity composition of the harvest and stock.

References:

Sharov, A. F., J.H. Vølstad, G.R. Davis, B.K. Davis, R.N. Lipcius and M.M. Montane. 2001. Abundance and exploitation rate of the blue crab (*Callinectes sapidus*) in Chesapeake Bay. Bull. Mar. Sci.

Abundance, Distribution and Diversity of Chesapeake Bay Fishes: Results from CHESFIMS
(Chesapeake Bay Fishery Independent Multispecies Fisheries Survey)

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Introduction

The potential for biological interactions and technical interactions within traditional single species management has motivated the development of multispecies approaches. Houde et al. (1998) reported the recommendations of a workshop to explore the utility and advisability of adopting multispecies approaches in Chesapeake Bay. An important conclusion of the workshop was the development of coordinated, baywide surveys to estimate key species abundances and to provide biological data on both economically and ecologically important species that are currently lacking (Houde et al. op. cit.). The workshop recommended that these surveys should permit the estimation of the temporal and spatial dynamics of key predator-prey relationships and trophic interactions (Houde et al. op. cit.).

Several fishery-independent surveys for the assessments of important fish and shellfish stocks in the Chesapeake Bay are currently ongoing but their study design and spatio-temporal coverage limits their applicability for exploring the multispecies question directly. From 1995 - 2000, a baywide investigation of biological production potential and its temporal and spatial variability was conducted. The objectives of TIES (Trophic Interactions in Estuarine Systems) research were broad and not focused solely on fish. Nevertheless, fish were sampled consistently using midwater trawls throughout the program's duration. Species abundances, diversity, size and biomass distributions were analyzed (Jung 2001).

Objectives

The TIES data form a foundation on which our Chesapeake Bay Fishery-Independent Multispecies Survey (CHESFIMS) builds, thereby representing an ongoing 7-year survey of the abundances and key trophic interactions in the Chesapeake Bay fish community. CHESFIMS includes two key survey elements. A broadscale component seeks to survey the bentho-pelagic fish community, focusing on young (juveniles, and yearling) fishes in the mainstem of Chesapeake Bay, thereby extending the TIES database. In a second component, we have initiated a survey of the shallow shoal areas not covered by TIES. These complemented surveys will yield an integrated estimate of the abundance, diversity, distribution and trophic status of economically and ecologically important members of the Chesapeake Bay fish community. Here we summarize results from CHESFIMS= first year, and provide indications of how the survey will be developed subsequently.

Methods

Broad Scale Survey

Three broad scale surveys were conducted in 2001, from 30 April - 5 May (CF 0101), 16 - 23 July (CF 0102) and 24 September - 1 October (CF 0103) (Table 1). All surveys were conducted from the University of Maryland Center for Environmental Science's R/V Aquarius. Samples of the fish community were collected from between 15 - 48 stations (Table 1). At each station we profiled the water column using a Seabird SBE 25 CTD profiler. Subsequently, a midwater trawl (18-m^2 mouth opening, 6-mm cod end mesh, as in the TIES program) was deployed in a single, oblique stepped tow. The net was fished for two minutes in each of ten depth zones distributed throughout the water column from the surface to the bottom. The nominal tow duration was 20 minutes, however, the actual deployment time was recorded. The section of the tow conducted in the deepest zone sampled epibenthic fishes close to or on the bottom. The remaining portion of the tow sampled pelagic and neustonic fishes. All survey deployments were conducted between 19:00 and 07:00 to reduce problems with gear avoidance and to take advantage of the diurnal distribution patterns of pelagic fish species.

Raw processing of net hauls was conducted on board the vessel. The total catch at each station was weighed. Fish were identified to species and total weights for individual species were recorded. Samples of length and weights of individual fish were taken for up to 30 randomly selected individuals of each species. Fish were then frozen whole, or preserved in ethanol, depending upon size for subsequently analysis in the laboratory. In the laboratory, identifications, lengths and weights were confirmed. Subsequently, stomachs and otoliths were dissected from individual fish for diet and age analysis. Stomach contents were flushed and identified to the lowest taxanomic level possible. Sizes and weights of subsamples of prey were quantified. No age analysis has yet been conducted.

Shoal Survey

The shoal survey was conducted as a stratified random survey. The survey area included shallow waters (< 5 m) from the MD line (approximately 37.5°N) to 38.5°N (below the mouth of the Choptank River). The strata for the pilot study were chosen to minimize travel time, and thus support the collection of data from a fairly large number of stations for the fixed budget. The four shoal survey strata were:

Stratum 1 - from the mouth of the Patuxent River to 38°25'16" N; the stratum was divided into six equal length sections, and one station was randomly selected in each longitudinal section.

Stratum 2: Shallow Eastern Shore waters between 37.54 °N (below Smith Island) and 38.03°N (above Smith Island). The region of this stratum includes one broadscale survey fixed transect and MDNR blue crab survey stations. Total stratum area 346.2 km^2; 33 stations sampled.

Stratum 3: Shallow Eastern Shore waters between 38.03°N and approximately 38.22°N (the north (side of the Patuxent R.). This region includes a transect from the mainstem survey and MDNR blue crab stations. Total stratum area 617 km^2; 56 stations sampled.

Stratum 4: Shallow Eastern Shore waters between 38.22°N and 38.32°N (below the Choptank R.). Total stratum area 64.4 km^2; 8 stations sampled.

Six minute tows were conducted at each station using a16' bottom trawl. We used the same trawl and trawling procedure as for the blue crab trawl survey for compatibility. All fish and crabs in the catch were identified by species, counted, measured and weighed. Environmental data such as air temperature, surface and bottom water temperature, salinity, dissolved oxygen, water clarity and wind conditions were recorded.

Table 1. Summary of sampling and results (mean ''' SE) from 2001 broadscale surveys

		Survey		
		CF0101	CF0102	CF0103
Dates		April 30 - May 5	July 16 -23	Sept 25 - 29
Number of Stations		31	48	15
Average CPUE (fish/haul)	Lower	63.4±22.21	1418±346.2	3280
	Mid	14±3.41	1745±586.6	9002±656
	Upper	63.66±48.45	1586±525.3	2814±1165
	Overall	49.9±14.91	1535±274.8	5639±563.4
Average CPUE (g/haul)	Lower	2179±1198	3197±1136	6361
	Mid	250.4±81.89	1054±372	8546±430.5
	Upper	6466±4884	4021±2155	3027±1294
	Overall	2044±878.7	2654±720.6	5957±568.2
Total N° S		27	29	26
Avg. Diversity (N°. Species)	Lower	5.31±3.01	6.05±1.77	10
	Mid	3.6±1.89	5.35±2.23	5±0
	Upper	4.66±3.44	5.66±2.87	5.88±2.31

Results

Broad Scale Survey

The first survey (CF0101) sampled 31 stations baywide and collected 1,452 fish (total weight ~ 67 kg). The second survey (CF0102) sampled 48 stations baywide, collecting 75,336 fish (total weight ~ 130 kg). The final survey sampled on 15 stations, mainly in the mid- and upper-Bay. Poor weather during the scheduled survey period prevented sampling of more stations. Despite this lower effort, 73,619 fish (total weight ~76 kg) were collected.

Patterns and distributions of diversity and abundance varied among the three surveys. The total number of species caught in each survey was approximately constant (Table 1). The average diversity of the fish community at each station increased slightly between spring and autumn. In general, the average diversity was higher in the lower-Bay region reflecting the increased diversity of marine ecosystems (Table 1). Average catch per tow increased over the three surveys (Table 1). However, within surveys the distribution of abundance changed. In April (CF0101), the abundance in the mid-Bay region was approximately one fifth of the abundance in the other two regions (Table 1). In the summer survey, abundance was equal in all regions (Table 1). Yet, by autumn, the pattern of abundance had shifted so that fish in the mid-Bay region were almost three times more abundant than in other regions (Table 1). Similar patterns were evident in biomass (Table 1).

Bay anchovy (*Anchoa mitchilli*) dominated the catches during all cruises (Fig. 1). Bay anchovy catches increased from 16.45 $fish.tow^{-1}$ in April, to 1,458 $fish.tow^{-1}$ in July and peaked at 4,871 $fish.tow^{-1}$ in September. However, estimates for September may be inflated because we were unable to sample the lower-Bay stations at which anchovy abundances were likely lower. The seasonal pattern of catches of bay anchovy reflects the underlying biology of this species (Kimura et al. 2000). In the spring survey, the highest catches of anchovy were taken in the lower Bay. In these regions, anchovy averaged 70.28 mm TL (range 33-94 mm TL). In the summer cruise, the center of anchovy distribution had moved slightly northward (Fig. 2), and the length range had broadened (15 - 99 mm TL, average = 38.27 mm TL). The average length of anchovy was lowest in the mid-Bay region. The abundance and both minimum and maximum sizes were higher in the upper Bay region, reflecting the northward

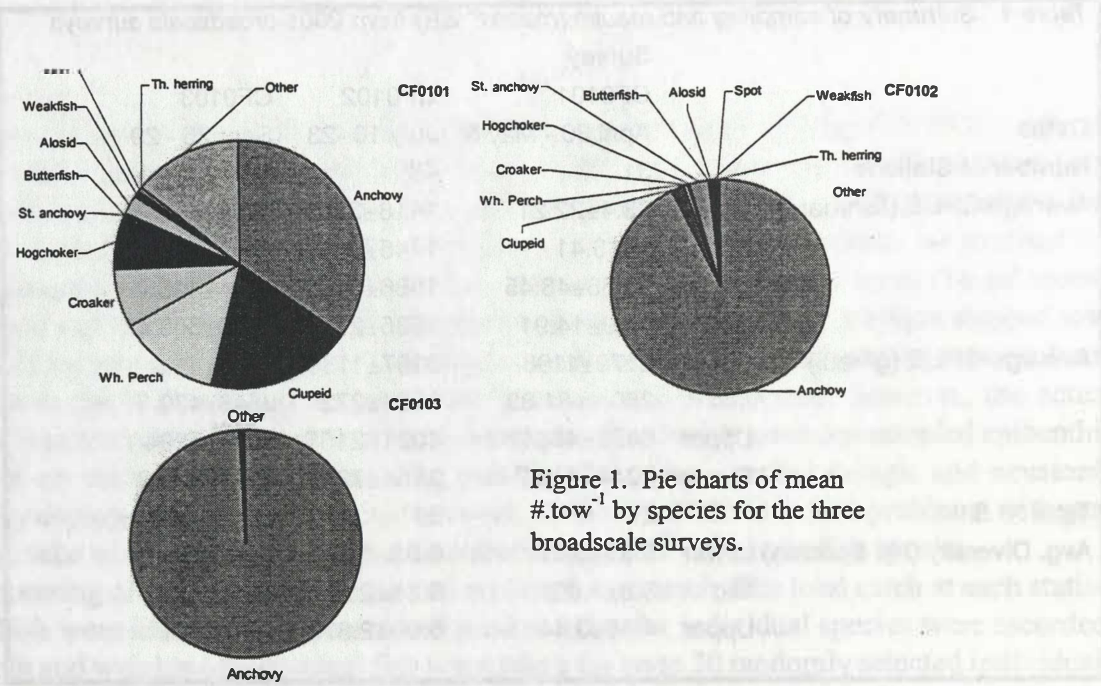

Figure 1. Pie charts of mean #.tow^{-1} by species for the three broadscale surveys.

migration of newly recruited bay anchovy. We cannot infer fully the distribution of anchovy in autumn, due to the weather-induced reduction of sampling in the lower bay. However, the available data are consistent with a general northward migration of young-of-year anchovy.

Young of year clupeids were the second most abundant fishes in both the spring and summer surveys (Fig. 1). Average catches of this species group during these surveys were 9.03 and 28.31 fish.tow^{-1} in spring and summer respectively. Young of year clupeids were only collected in the lower- and mid-Bay stations in the spring. In the summer, young of year clupeids were present in all three regions. Fish were smaller on average in the lower Bay than in either the mid- or upper-Bay. Only two fish were caught in the autumn survey; one each in the mid- and upper-Bay regions. Both fish were greater than 77 mm TL.

White perch was the 3rd, 5th and 2nd most abundant species in our collections in the spring, summer and autumn surveys (Fig. 1). In all surveys, white perch was collected only at upper-Bay stations. In the spring, the average CPUE was 11.23 fish.tow^{-1}. The average length of white perch was 192 mm TL (range 67-297 mm TL). By summer, white perch abundance had increased (95.4 fish/tow), but average size had decreased (186.7 mm TL, range 5 - 262 mm TL) due to recruitment of young of year to the survey gear.

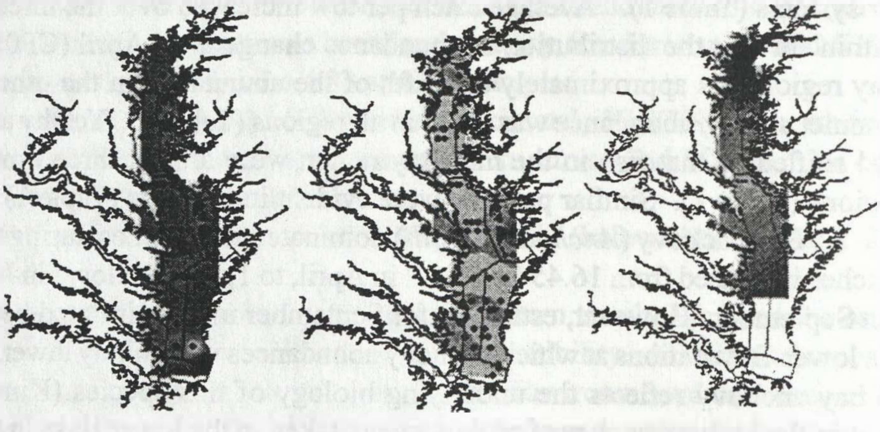

Figure 2. Distribution of bay anchovy (#.tow^{-1}). Lighter colors indicate higher concentrations

Sciaenids were also common in catches (Fig. 1). In springtime, the sciaenid catch was dominated by croaker (*Micropogonias undulatus*), which was the 4th single-most abundant species at that time. The average CPUE for croaker was 3.516 fish.tow^{-1}, with the majority of catches being taken in the lower-Bay. In this region, the average size of croaker was 270.3 mm TL (range 270 - 283 mm TL). By summer time croaker CPUE increased to 4.79 fish.tow^{-1}, but its rank abundance was reduced to 7th. The average size of croaker was relatively unchanged from springtime, but the size range increased greatly (31 - 366 mm TL), because of recruitment of young of year croaker to the gear. Only three croaker were collected in the autumn survey, due principally to the reduced spatial coverage of that survey. Weakfish (*Cynoscion regalis*) were seasonally abundant in survey catches in summer (1.4 fish.tow^{-1}) and autumn (4.9 fish.tow^{-1}). In springtime, weakfish abundance was concentrated in lower- and mid-Bay stations, and was comprised of relatively large weakfish (184 - 286 mm TL). Young of year weakfish recruited to the survey gear in summer (size range = 21 - 303 mm TL), and were more evenly distributed among regions. This relatively broad distribution was maintained in the autumn.

We combined CHESFIMS abundance data for the three of the most common species with the historical TIES data (Fig. 3). The composite time series for bay anchovy indicates a strong increase in autumn abundance over the period 1995 - 2001. The Atlantic croaker and white perch time series exhibit complementary patterns. White perch was most abundant early in the time series; Atlantic croaker is most abundant in the latter years of the time series.

We collected specimens for dietary analyses on all three surveys. To date we have dissected and analyzed the resultant data only for the springtime cruise. Data analysis is ongoing.

Shoal Survey

Abundances were highly variable from month to month (Table 2). Indices of abundance were highest in July and lowest in May. Catches were an order of magnitude higher, even greater for some species, in July than in May. September catches remained high for most species and were even greater than July catches for some species such as the blue crab.

Within each month, abundances were also variable between strata (Table 2). The Pocomoke Sound stratum contained the highest catches among the four strata during all sampling periods. Catches were lower in the Tangier Sound but remained much higher than the Choptank and Calvert Cliffs strata. Catch estimates in the Choptank and Calvert Cliffs strata were usually low or controlled by one catch. For example, one Calvert Cliffs trawl in May caught over 1000 bay anchovy but a total of only 25 anchovies were caught in the remaining five trawls, resulting in a high variance of the mean catch per tow.

Species composition also changed from month to month and from strata to strata. In May, catches mostly comprised of bay anchovy, blue crab (*Callinectes sapidus*), hogchoker (*Trinectes*

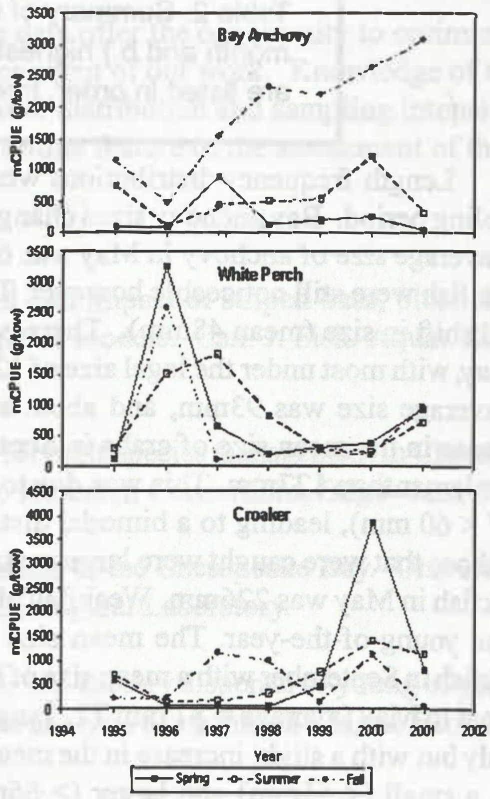

Figure 3. Time series of abundance of bay anchovy, white perch and croaker from TIES and CHESFIMS surveys

maculatus), and northern sea robin (*Prionotus carolinus*). July catches were also dominated by bay anchovy, but weakfish and spot (*Leiostomus xanthurus*) were also abundant. Anchovy abundance declined in September but still comprised a large amount of each trawl along with Atlantic croaker and blue crab. The Choptank and Calvert Cliffs strata were dominated by only a few species, in some cases only two different species were caught in a particular strata. There was anywhere from 15 – 19 different species caught in the Tangier and Pocomoke Sounds over the course of the sampling season.

a.)

May	July	September
Bay Anchovy	Bay Anchovy	Croaker
Blue Crab	Weakfish	Blue Crab
Hogchoker	Hogchoker	Bay Anchovy
Northern Sea Robin	Spot	Weakfish

b.)

May	July	September
Blue Crab	Blue Crab	Blue Crab
Summer Flounder	Weakfish	Spot
Hogchoker	Bay Anchovy	Summer Flounder
Bay Anchovy	Spot	Croaker

Table 2. Summary of a.) the most frequent species by month and b.) highest species biomass by month. Species are listed in order, from high to low.

Length-frequency distributions were calculated for the six most abundant species for the entire sampling period. Bay anchovy sizes changed similarly patterns observed in the broadscale survey data. The average size of anchovy in May was 66 mm TL. The average size declined to 44 mm TL. In July, larger fish were still noticeable however. The growth of smaller fish was apparent in September with a small shift in size (mean 48mm). There was wide range of smaller blue crabs (mean 66.9mm) caught in May, with most under the legal size of 127mm. The catch shifted to moderate and large crabs in July; the average size was 93mm, and about a third of the catch was greater than 127mm. There was a decrease in the mean size of crabs in September to 83mm even though there was a high frequency of crabs larger than 127mm. This was due to the appearance of large numbers of young of the year crabs (CW < 60 mm), leading to a bimodal distribution of crabs. There were few weakfish caught in May, and those that were caught were large in size compared to the other sampling periods. The mean size of weakfish in May was 226mm. Weakfish abundance increased dramatically in July with the appearance of the young-of-the-year. The mean size in July was 78mm. There was a slight shift to larger size weakfish in September with a mean size of 81mm. The size distribution of hogchoker was approximately normal in May (average = 87 mm TL, range 35 – 155 mm TL,). A similar distribution was observed in in July but with a slight increase in the mean (92 mm TL). The September size distribution was bimodal with a small (< 55mm) and larger (> 86mm) mode. The size distribution of summer flounder was bimodal in all three surveys, with a large (> 300mm TL) and a group of smaller flounder that steadily increased in size throughout the sampling period from 150mm in May to 225mm – 300mm by September. Finally, there was no clear pattern to the size of spot caught, with a wide range of fish from 20 – 211mm.

Conclusions

In the first year of CHESFIMS we completed three broadscale and three shoal surveys and met and exceeded the project goals. The results from the different surveys provide a solid foundation from which to address important questions relevant to multispecies management.

1) Our surveys provide apparently reliable indices of abundance and distribution of ecologically and economically important finfish species in Chesapeake Bay. Of note, is that these surveys provide the reliable, baywide estimates of bay anchovy abundance, a previous unsurveyed species. Though not exploited itself, bay anchovy is an important prey item for many economically important piscivores (Hartman and Brandt 1995). Consequently, the availability of an index of abundance will be an important component of future multispecies fisheries models. Not only do our surveys provide an accurate index of anchovy abundance and recruitment, but they also provide important baywide recruitment indices for several species including Atlantic croaker, weakfish, anadromous clupeids and probably white perch.

2) Our sampling will provide important information on the trophodynamics of key components of the Chesapeake Bay fish community. As regional agencies begin to explore multispecies management models, such as ECOPATH / ECOSIM, the need for diet data, collected coincidentally with abundance estimates will become acute. A full assessment of the utility of the dietary information provided by CHESFIMS awaits completion of the laboratory analysis of preserved samples. It is important to note that preserved TIES samples are also available for analysis and offer the potential to greatly broaden the potential inferences regarding dietary patterns.

3) On going efforts with regard to statistical analysis of the data offer the opportunity to optimize current survey designs. These efforts are an important component of our work. Knowledge of the relative efficiency of alternative stratification schemes, spatial distribution and sampling intensity will be important if multispecies surveys are to become a routine feature of the assessment of the Chesapeake Bay fish community.

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Chesapeake Bay Multispecies Monitoring and Assessment Program

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Introduction

We are currently in the second year of this phased project but because of funding dates and extensions we are operating under both years' projects. As neither project is completed this abstract is more progress report than a summary of results.

The purpose of this project is to design, and to implement a portion of, a comprehensive fishery independent monitoring system for the Chesapeake Bay. Such a system would involve multiple surveys using multiple gears. Some surveys would be wide in geographic and temporal scope and would cover many species, others would be narrow in scope and perhaps directed at only one species. Each would be designed to answer specific management questions or provide data for specific stock assessment model parameters.

Objectives

Both years' projects contain two parts, a conceptual element and a field element. It may seem that initiating field elements before surveys are deemed necessary is putting the cart before the horse. However, certain survey elements are easily predictable as necessary elements in a grand monitoring scheme and so in the interest of commencing them at the earliest possible date we included field elements as well. The conceptual design and the field portions of the project, for the two years are:

- In Year 1 the conceptual element is to design the survey set. We are following a specific process to accomplish this. Each survey must have a purpose, rather than just answering a general curiosity. Defining that purpose begins with asking specific management questions, for example, "How many summer flounder should we take each year to achieve an equitable balance between fishermen and the fish?", "How can we maximize the income of weakfish fishermen in our state?". If the manager asks the question of a stock assessment scientist, the scientist will immediately ask back, "What balance do you want, how much risk are you willing to accept, what portion of the population do you want to leave in the water each year?", and so on. From this the scientist can determine which stock assessment models are most appropriate in support of management, the models in turn define what parameters are necessary to estimate (e.g. catch, catch-at-age, estimates of recruitment, age/size structure, etc.). In turn then the parameters define the types of surveys needed to estimate each parameter. Depending on the management questions to be answered, you don't necessarily need to know everything there is to know about every species (you don't need a survey that can estimate seasonal biomass of a species if all you need for best management is catch-at-age data).
- The Year 1 field element that we first proposed was to begin a mid-water trawling program in the major Virginia tributaries. This was to be a complement to the CHESFIMS bay-wide (but Bay-only) mid-water program. The project was approved but the funding provided didn't allow us to implement the plan. We therefore redirected the funds to allow us to extend our existing bottom trawl survey and sample in the topmost section of the Virginia Bay mainstem, and in the lower Potomac.

- The Year 2 conceptual element will examine each survey proposed in the Year 1 grand design and perform a cost-benefit analysis. That is, the cost in terms of survey dollars, personnel, personnel time, vessel time, required infrastructure, etc. will be compared to the anticipated data benefits derived. Using this, administrators can have a basis to prioritize and schedule implementation of the entire survey suite. Of course this makes the rather bold assumptions that money would be available to implement the surveys and that managers and scientists would see them as worthy.
- The most exciting portion of the program in the short-term is the Year 2 field element. This is a Bay-wide (and Bay-only) large-mesh bottom trawl survey, concentrating on capturing adult fish. It complements the Bay-wide mid-water CHESFIMS project that primarily captures pelagics and forage fish, and the VIMS and DNR bottom trawl surveys that primarily capture juvenile fish.

Methods & Results-to-Date

Year 1 Conceptual Design

Because of contractual delays and our concentration on the field elements of the program, progress on this very important element has been slow. We have decided on a list of species of interest (Table 1). The list is broad, perhaps too broad to be realistic but we would like to start out ambitious and scale back rather than prejudge what isn't possible.

In the 'Objectives' section above we outlined a process whereby managers and assessment scientists agree on a management strategy and a set of models to implement that strategy. In reality the process is usually not so clear-cut. Managers don't necessarily know how to define the best balance between conservation and economics, or what the ideal economics of a fishery should be. They often look to the scientists to tell them those things. Scientists answer back that they can't set policy but can only give advice on how to reach a goal set by policy makers. Thus the first step in our process of designing surveys is short-circuited. Nonetheless, questionnaires have been prepared for distribution to the chairs of Atlantic States Marine Fisheries Commission (ASMFC) chairs of the Technical Committees for each species of interest. The questionnaires try to get the managers to spell out for us what the management goals are and what unanswered questions exist.

Table 1. List of species for which monitoring plans are to be developed.

Species Common Name	Species Latin Name(s)	Management Plan Entity*
American eel	*Anguilla rostrata*	ASMFC, CBP
Atlantic croaker	*Micropogonias undulatus*	ASMFC, CBP
Atlantic menhaden	*Brevoortia tyrannus*	ASMFC
Sturgeon, Atlantic and shortnose	*Acipenser oxyrhynchus, A. brevirostrum*	ASMFC, CBP (Atlantic)
Bay anchovy	*Anchoa mitchilli*	No management plan
Black drum	*Pogonius cromis*	CBP
Black seabass	*Centropristis striata*	ASMFC, CBP, MAFMC
Blue crab	*Callinectes sapidus*	CBP
Bluefish	*Pomatomus saltatrix*	ASMFC, MAFMC, CBP
Butterfish	*Peprilus triacanthus*	MAFMC
Catfish (several closely related species)	*Ictaluridae*	No management plan
Dogfish and coastal sharks	*Elasmobranchii*	ASMFC, MAFMC
Killifishes (several)	*Fundulus*	No management plan
Gizzard shad	*Dorosoma cepedianum*	No management plan
Mackerel, king and Spanish	*Scomberomorus cavallas. S.maculatus*	ASMFC (Spanish), CBP (both)
Red drum	*Sciaenops ocellatus*	ASMFC, CBP
River herring (alewife and blueback herring)	*Alosa pseudoharengus A.aestivalis*	ASMFC, CBP
Scup	*Stenotomus chrysops*	ASMFC, MAFMC
Spot	*Leiostomus xanthurus*	ASMFC, CBP
Shad (American and hickory)	*Alosa sapidissima A. mediocris*	ASMFC (American), CBP (both)
Spotted seatrout	*Cynoscion nebulosus*	ASMFC, CBP
Striped bass	*Morone saxatilis*	ASMFC, CBP
Summer flounder	*Paralichthys dentatus*	ASMFC, CBP, MAFMC
Tautog	*Tautoga onitis*	ASMFC, CBP
Threadfin shad	*Dorosoma petenense*	No management plan
Weakfish	*Cynoscion regalis*	ASMFC, CBP
White perch	*Morone Americana*	No management plan
Yellow perch	*Perca flavescens*	No management plan
Other species of possible interest:		
Cobia	*Rachycentron canadum*	No management plan
Horseshoe crab	*Limulus poytphemus*	ASMFC, CBP
Squid (long-finned & short-finned)	*Illex illecebrosus*	
Loligo pealei	MAFMC	
Others to be determined.		

* ASMFC = Atlantic States Marine Fisheries Commission
CBP = Chesapeake Bay Program
MAFMC = Mid Atlantic Fishery Management Council

We anticipate that in some-to-many cases the manager-scientist short-circuit will prevail. In those cases we have to approach the monitoring survey design in a more generic, broad based, and expensive way. In such cases a broader suite of fishery parameters must be gathered. In general, the fishery parameters required for single species stock assessments are:

Biological Parameters

- Population age and/or size structure.
- Growth: length at age, weight at age, growth rate, theoretical maximum length and weight, theoretical age at zero length – e.g., von Bertalanffy growth model parameters.
- Natural mortality rate.
- Longevity – theoretical maximum lifespan under no fishing.
- Maturity schedules by gender.
- Migration rates at age.

Survey Data

- Abundance - relative, absolute, or both.
  - Of recruits.
  - Of adults by age, which when combined with maturity schedules yields measures of standing stock and spawning stock biomass.
- Biological Data.
  - Length frequency.
  - Length-weight conversion or measurements of weight.
  - Age structure obtained from aging hard parts (e.g., scales, otoliths)
  - Morphometric measurements.
  - Maturity
    - Maturity schedule
    - Gonadosomatic Index to estimate spawning periodicity.
- Selectivity.
  - For each survey gear-species combination, the pattern of selection at length – i.e., the probability of retention at length of fish which contact the gear.

Fishery Dependent Data

- Catch.
- Effort.
- Biological Characterization:
  - Catch at age
  - Catch at length/weight
  - Catch by gender
- Discard and by-catch estimates.
- Partial Recruitment - the proportion of each age or size which is subjected to fully recruited F (instantaneous fishing mortality rate).

Multi-species assessments, in addition to each of the above data elements, require good estimates of food web characteristics obtained from regular stomach content sampling of both predator and prey species in the ecosystem.

Surveys designed to capture the suite of data elements defined above are also suitable platforms upon which to build numerous other studies. Along with the fishery data, basic habitat and physical/chemical parameters are easily recorded.

Year 1 Field Component

As mentioned above we had proposed to begin development of a mid-water trawling program to complement the VIMS bottom trawl survey and the University of Maryland bay-wide mid-water trawling program. Due to the funding level provided however we were not able to do this. Instead we are periodically extending the VIMS bottom trawl survey into areas that are not usually sampled. Namely, what we call our 'Top Bay' region (above $37^{0}40'$, or approximately the mouth of the Rappahannock River), and in the lower section (up to about river mile 20) of the Potomac River.

Three sampling cruises have been completed. In each cruise sixteen tows were completed in the Top Bay and 17 in the Potomac. The full complement of data was taken at each station; location, water quality, weather, catch counts, and individual fish measurements.

The primary advantage these data provide us is to fill a void in our routine sampling, especially in regards to habitat data. A few years ago the VIMS Trawl Survey began characterizing the living or non-living habitat types at each of their sampling stations. They did this by assigning and recording a categorical level of each of about a dozen bottom types that may get swept up into the net during their tows. Using these data we hope to earn funding to produce a fish habitat atlas of the lower Chesapeake Bay in which we would produce maps of the Virginia portion of the Bay and its tributaries with fish species abundance overlaid on each of the habitat types. Multivariate correlative relationships can be presented as well. Figure 1 presents, as an example of the kind of habitat utilization map that we hope to produce, a comparison of black seabass catch overlaid on abundance of "deadman's fingers." We will propose producing these maps for each habitat type (about a dozen) for each season, for each of about 20 species. Figure 2 presents abundance of four other habitat types, without any species layover, and shows the lack of data available in the topmost Bay region before our sampling under this grant.

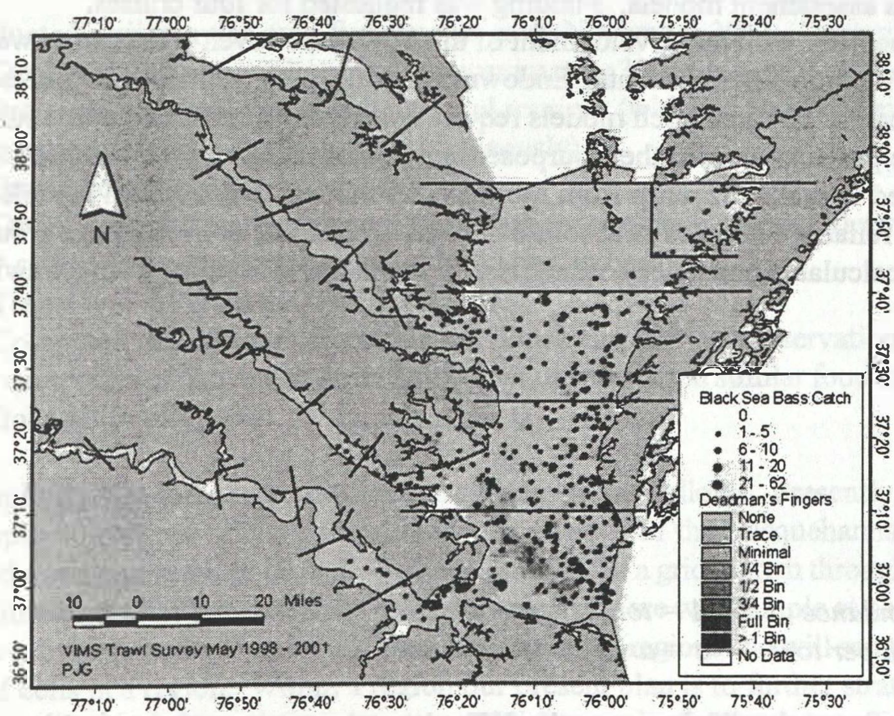
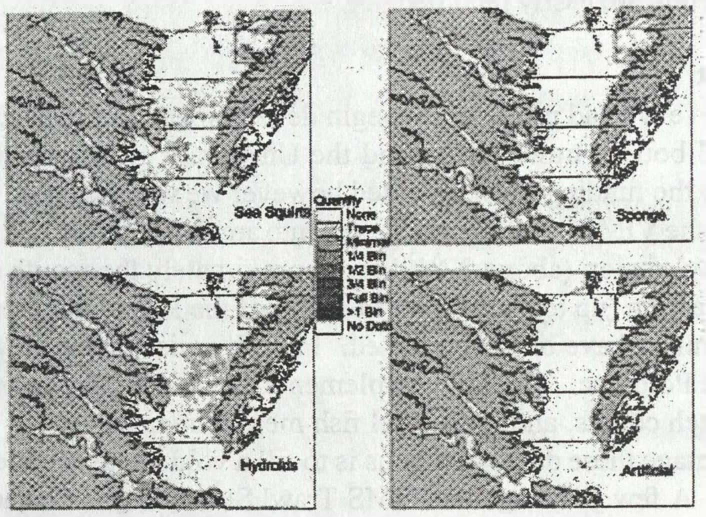


Figure 1. Comparison of black seabass abundance and concentration of "deadman's fingers" bottom in Virginia Chesapeake Bay and tributaries.

Figure 2. Concentration of four bottom types in Virginia Chesapeake Bay and tributaries.



Year 2 Conceptual Design

Work on this phase has not begun.

Year 2 Field Component

This survey was originally proposed as a Bay-wide general monitoring survey using a large mesh bottom trawl to capture adult fish of a variety of species. Taking subsamples of the catch for age determination would allow us to calculate abundance indices by age and provide population age structure data. Taking subsamples for gut contents analysis would add the predator-prey relationships necessary for multi-species assessment models. Funding was requested for four cruises.

Simultaneously with the development of this survey however, VIMS was awarded a three year grant from the Virginia Environmental Endowment to develop multispecies and ecosystem fishery management models. Because such models require exactly the kinds of data that surveys such as this provide, the two projects merged their purposes and pooled some of their resources. The added data elements required to make the jump from multispecies models to ecosystem models such as *Ecopath with Ecosim* are reliable estimates of absolute biomass by species, or even by age group within species. The formula to calculate abundance (or biomass if you factor in weight) from a trawl survey is:

$$N = \frac{\frac{cA}{a}}{e}$$

where:

N = abundance	*A = total survey area*	*e = net efficiency*
c = catch per tow	*a = area swept each tow*	

Area swept and net efficiency are the difficult parameters to estimate in this equation. Both can be assumed to be some constant, or range of constants, but the validity of such assumptions is unknown.

Technology however provides methods to produce reliable estimates of both parameters on a tow-specific basis.

Sensors attached to the net can give real-time measurements of the net opening and headrope height. Not only does this give accurate measurement of area swept (when combined with GPS coordinates for the tow) but also allows scientists to watch the net change shape during a tow as vessel speed, current, depth, and other factors combine to affect it. The captain can then make adjustments to the vessel speed and scope (ratio of the amount of line out to water depth) to assure that the net is fishing properly.

Net efficiency (the ratio of the number of fish caught to the number of fish susceptible to being caught during one tow) can be estimated by use of hydro-acoustics. On each tow we will deploy a split-beam 200KHz 12o beam-width transducer behind the vessel but in front of the net. After ground-truthing experiments that will allow us to identify species by their signal characteristics we will be able to calculate net efficiency on a species-by-species basis by comparing what the acoustics told us was in the water to what we actually caught in the net.

The final piece of our technology puzzle will be deployment, on a selected number of our tows, of side-scan sonar on FETCH, the VIMS-developed automated underwater vehicle (AUV). While quantitatively less valuable than the traditional sonar, the side-scan will give us a synoptic double check of our other gears and will provide further ground truthing of the traditional hydro-acoustics.

All these added measures were both made necessary, and enabled, by the pooling of resources between ChesMMAP and the VEE effort. Pooling will also allow us to add a fifth cruise to our 2002 schedule so we will sample every other month from May through November.

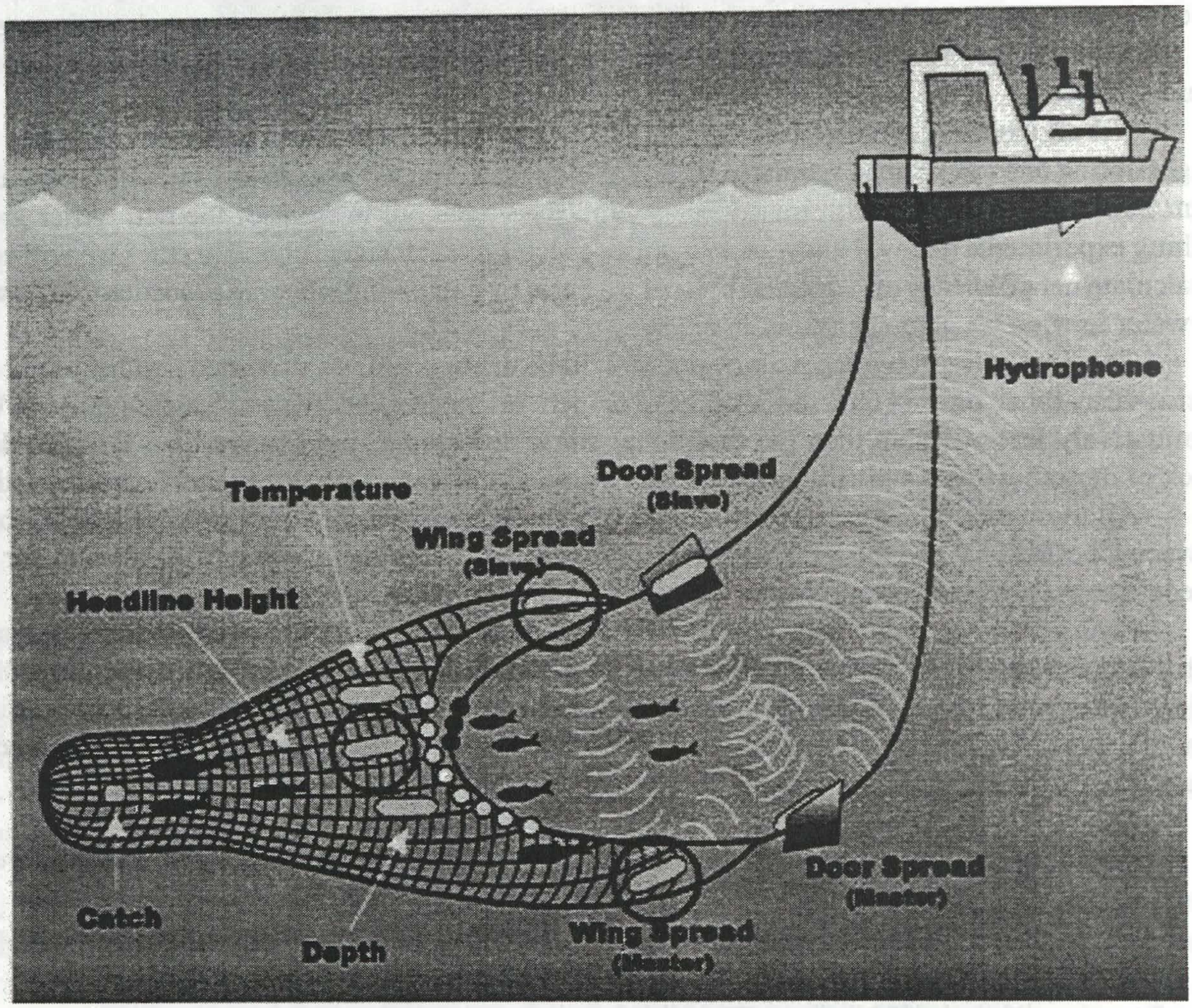
Figure 3 shows deployment of a trawl net with a variety of net sensors attached. The headline sensor and wingspread sensors we will use are circled. Figure 4 is a sample screen shot showing the real-time net parameters. Figure 5 shows deployment of a hydro-acoustic transducer in position in front of the net. Figure 6 is an annotated snapshot of the data gathered by the hydro-acoustic transducer. Figure 7 is two snapshots from the side-scan sonar during a tow.

We conducted a pilot cruise over five days in early November 2001. During this time we:

- Deployed and retrieved our gear approximately 30 times.
- Practiced our deployment and retrieval routines (which is no trivial matter given all the gear we will have overboard simultaneously).
- Practiced our workup procedures.
- Optimized our towing parameters (speed and scope) for our gear under various conditions.
- Assured that our electronics would all work in harmony.
- Tested two different net configurations.
- Compared two methods (formalin vs. liquid nitrogen) of preservation of stomachs for two species of fish, black drum (consumer of worms and similar food items) and summer flounder (a piscivore).

Our sampling procedures and stratification strategy are as follows. Presently our goal for each cruise is to sample 90 stations ranging from the southern edge of the Susquehanna Flats to the Bay mouth in all depths to a minimum of 10 feet. We have established a grid system throughout the sampling range of approximately 1,700 1-square mile cells, meaning that we will sample at about a 5% rate (90 , 1,700). We have divided the Bay into five 30-second latitudinal regions and will sample proportionally to the number of cells in a region. Within a region our present plan is to further stratify in three depth strata but we are still examining existing data to establish meaningful depth cutoffs. Stations within each latitudinal region will be randomly and proportionally selected within depth strata, with a minimum

Figure 3. Deployment of a trawl net with net sensors attached.



of three stations chosen in each depth stratum within each region. Our net is a 45-foot 4-seam balloon otter trawl with 6-inch stretch mesh in the wings and body, and 3-inch stretch mesh in the cod end, with no liner. The doors are four-foot steel V doors weighing 185lbs. each with a tickler chain attached between them. We hope that this net will allow us to capture the species and size ranges we have targeted but we will be keeping a careful eye on whether or not we need to make modifications. During each cruise we will be at sea for two one-week periods. Figure 8 contains two maps showing a possible range of stations for a typical cruise.

Figure 4. Sample screen showing net parameters during a tow

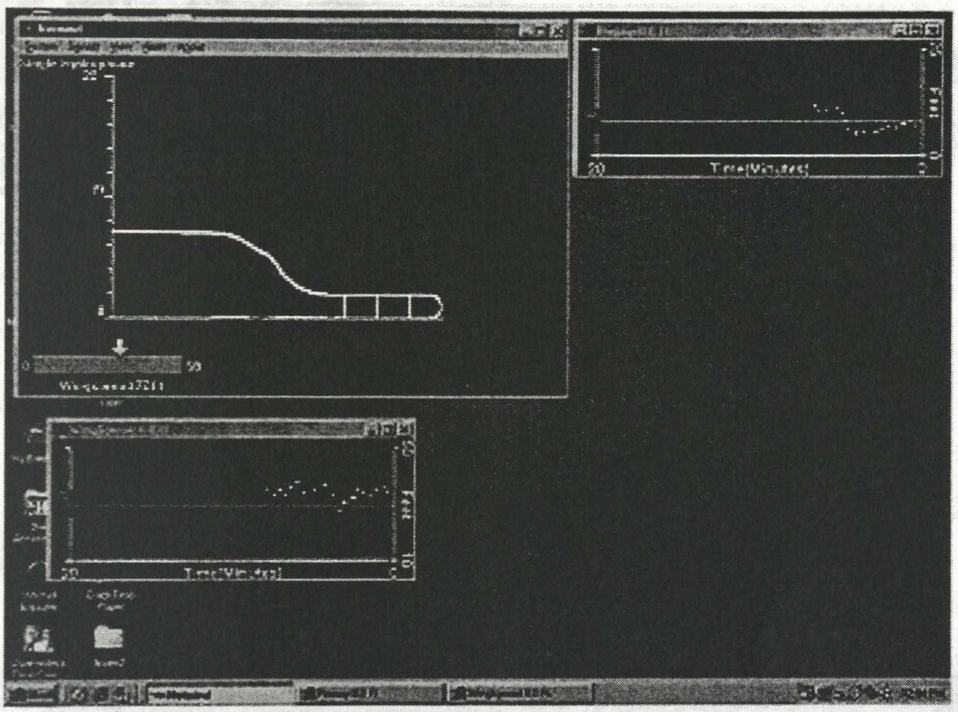


Figure 5. Schematic of positioning of hydro-acoustic transducer during a tow.

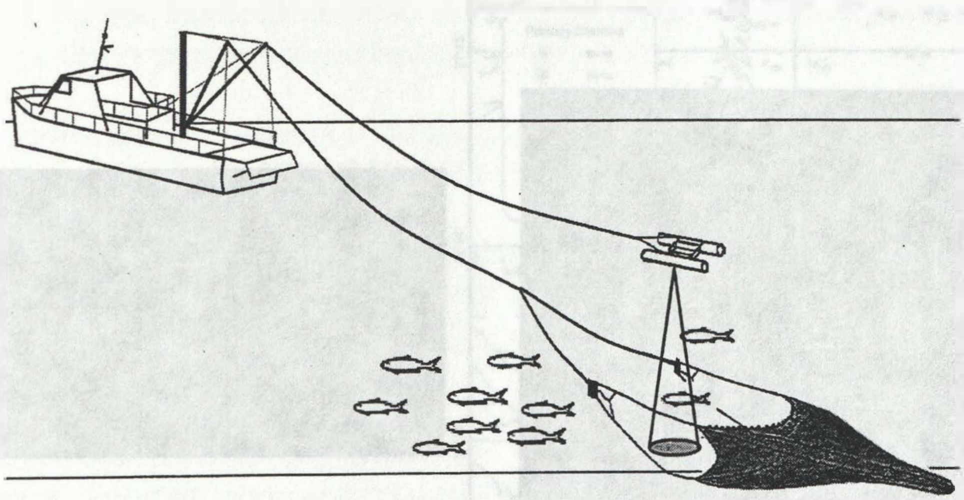


Figure 6. Annotated snapshot of data screen from the hydro-acoustic software

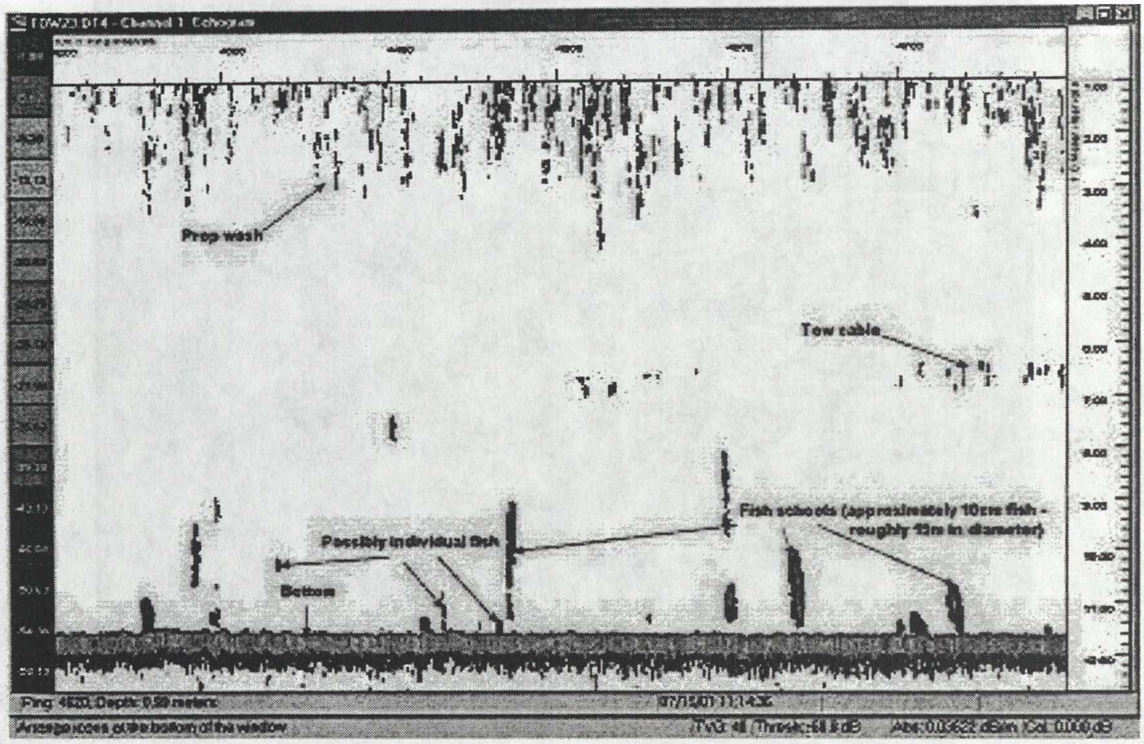


Figure 7. Two sample pictures from the side-scan sonar showing a school of bait fish and several larger individuals of an unidentified species

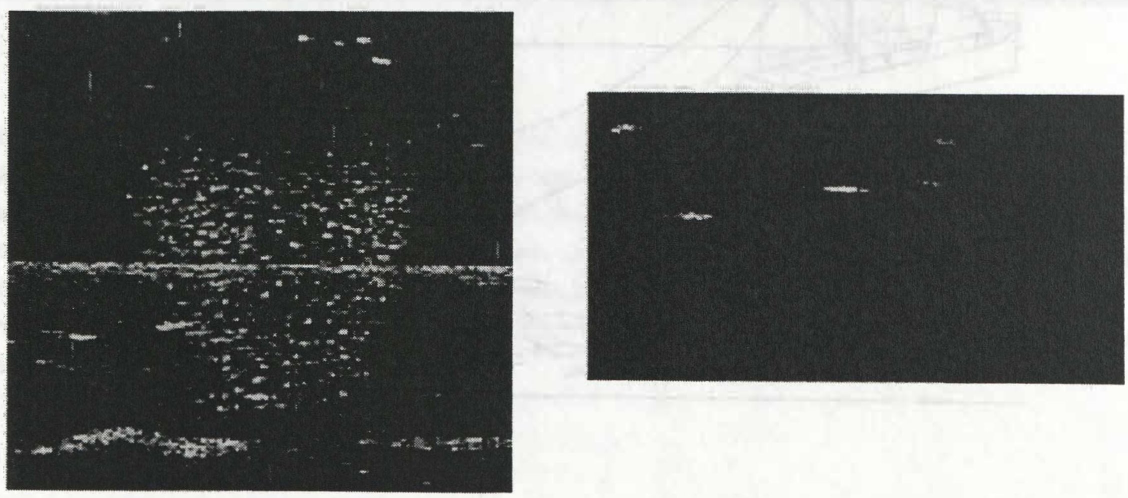
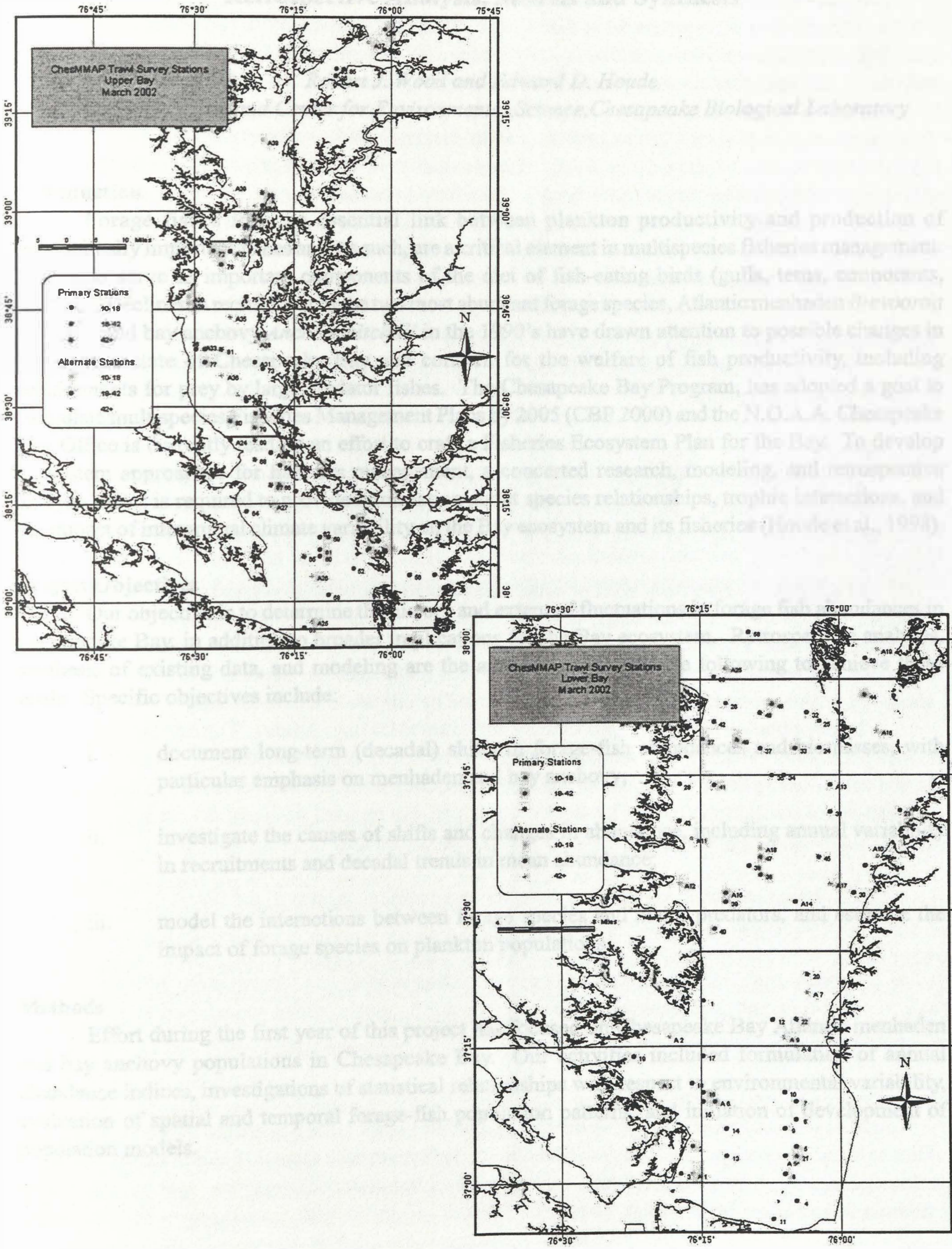


Figure 8. A typical selection of sampling sights in the upper and lower regions of Chesapeake Bay.



Variability in the Dynamics of Forage Fish Abundances in Chesapeake Bay: Retrospective Analysis, Models and Synthesis

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Introduction

Forage fishes form an essential link between plankton productivity and production of economically important fishes and, as such, are a critical element in multispecies fisheries management. They also serve as important components of the diet of fish-eating birds (gulls, terns, cormorants, ospreys). Declines in recruitment of the two most abundant forage species, Atlantic menhaden *Brevoortia tyrannus* and bay anchovy *Anchoa mitchilli* in the 1990's have drawn attention to possible changes in the trophic state of Chesapeake Bay and concern for the welfare of fish productivity, including requirements for prey by large predator fishes. The Chesapeake Bay Program, has adopted a goal to formulate multispecies Fisheries Management Plans by 2005 (CBP 2000) and the N.O.A.A. Chesapeake Bay Office is currently leading an effort to craft a Fisheries Ecosystem Plan for the Bay. To develop ecosystem approaches for fisheries management, a concerted research, modeling, and retrospective analysis effort is required to provide information about species relationships, trophic interactions, and the impact of interannual climate variability on the Bay ecosystem and its fisheries (Houde et al., 1998).

Project Objectives

Our objective is to determine the history and extent of fluctuations in forage fish abundances in Chesapeake Bay, in addition to broader implications for the Bay ecosystem. Retrospective analyses, synthesis of existing data, and modeling are the approaches that we are following to achieve these goals. Specific objectives include:

i. document long-term (decadal) shifts in forage-fish abundances and biomasses, with particular emphasis on menhaden and bay anchovy;

ii. investigate the causes of shifts and changes in abundance, including annual variability in recruitments and decadal trends in mean abundance;

iii. model the interactions between forage species and major predators, and estimate the impact of forage species on plankton populations.

Methods

Effort during the first year of this project has focused on Chesapeake Bay Atlantic menhaden and bay anchovy populations in Chesapeake Bay. Our activities included formulation of annual abundance indices, investigations of statistical relationships with respect to environmental variability, evaluation of spatial and temporal forage-fish population patterns, and initiation of development of population models.

Abundance indices

Indices of abundance were calculated for Atlantic silverside, Atlantic menhaden, and bay anchovy. Fishery-independent survey data from the Maryland Department of Natural Resources (MDNR) and the Virginia Institute of Marine Science (VIMS) were used to generate individual indices for the upper Bay, lower Bay, and the Potomac, Choptank, Nanticoke, Rappahannock, York, and James Rivers. Indices were generated by summing the $\log_{10}$ annual catches of species for 'permanently surveyed' stations by Bay region or river system. These time series were standardized by subtracting the mean index value and dividing by the standard deviation for data in each time series to allows direct comparison of abundance indices across sampling method and location. Because bay anchovy are well sampled in the main body (mainstem) of Chesapeake Bay, we were able to construct and analyze spatial abundance maps for this species with relatively high resolution using data from the VIMS 'random' lower Bay trawl sampling program and the TIES 'bay-wide' surveys.

Environmental relationships and population modeling

The impact of environmental variability on both bay anchovy and Atlantic menhaden populations in the bay also was studied.

Bay anchovy

The impact of differing interannual flow regimes on spatial distribution and annual abundance was investigated. The climate patterns responsible for strong interannual streamflow variability also were analyzed and compared to the spatial distribution of the spring spawning stock biomass of bay anchovy.

In addition to riverflow, river specific analyses compared anchovy abundance time series to nitrogen and phosphorous loadings, dissolved oxygen, salinity, and July *Acartia tonsa* copepod abundance. These analyses were conducted to evaluate the possibility that bay anchovy abundance is influenced by annual hydrographic conditions or prey abundance (*A. tonsa* is a primary prey of bay anchovy), which might itself be ultimately influenced by climate and nutrient input.

Two population modeling approaches were initiated for bay anchovy. The first is a stage-based, matrix population model and the second is a stage-based, spatially explicit, stock-flow model. The first model will be used primarily to estimate basic demographic parameters and sensitivity of the population to stage-based mortality values. The stock-flow model can be used similarly but, in addition, it also provides a basic, robust modeling structure that can be linked to:

- population modules representing different geographical regions in the Bay to provide greater spatial resolution;

- environmental data or the output of other existing models (e.g. water quality or hydrodynamic) or new (e.g. bioenergetic or predator-prey) models, which can be used to drive the population module(s).

Atlantic menhaden

Many aspects of the Atlantic menhaden's early life history in the Bay are poorly known, especially the late larval and early juvenile stages. Menhaden also have proven more difficult to survey than many other fish species. However, Atlantic menhaden is a commercially important species, and coastal Atlantic spawning population estimates are available. Coupled with the long-term MDNR-derived indices of annual recruitment to Maryland tributaries and the upper Bay, these estimates allowed construction of a simple Ricker stock-recruitment relationship describing the possible dependency of annual Chesapeake Bay recruitment on coast-wide spawning stock biomass. The difference between annual recruitment levels predicted by the Ricker relationship and the actual survey recruitment index was then calculated and assumed to be driven by extrinsic (to the population itself) factors. These data then were used to investigate the statistical relationship between interannual climate variability and the variability in menhaden recruitment that is unrelated to spawning population levels.

A temporal synoptic index (TSI) was constructed to describe interannual climate variability during the winter-spring transitional months of March-May. These months span the period of late-larval-stage Atlantic menhaden migration from oceanic spawning grounds to Chesapeake Bay nursery areas, a period in which menhaden recruitment strength may be established. Frequently used in climatological studies, temporal synoptic classification describes and quantifies typical weather patterns using a two-step multivariate procedure involving principal components and cluster analyses. Sea-level pressure was the input variable for this study because the goal was to investigate the role of large-scale climate patterns in influencing recruitment of Atlantic menhaden to Chesapeake Bay. The resulting temporal synoptic classification defined characteristic circulation patterns that occur during the late winter and early spring. Further, the resulting temporal synoptic index classified each day's daily observation (March-May, 1966-1998) as one of these patterns.

Traditionally, climate-recruitment relationships for estuarine and marine fishes have used individual weather variables such as rainfall, temperature, and wind patterns as potential predictors of recruitment success. The temporal synoptic classification is statistically and theoretically better because it recognizes that individual weather variables are not independent. Instead, they vary together in predictable patterns, in association with a few regionally dominant, reoccurring, weather features. In addition to these analyses, the response of Atlantic menhaden to riverflow and nutrient input were analyzed.

Results & Discussion

<u>Bay anchovy</u>

Spatial Patterns

Analyses of monthly abundance patterns indicate that downbay or downstream migration of adult bay anchovies occurs from late winter through July. Peak spawning occurs in July and peak monthly-aggregated survey catch occurs a few months later as the new year class recruits to the gear. New recruits begin an upbay or upstream migration that results in a distribution shift from the lower Bay to the middle and upper reaches of the Bay and its tributaries. The mean monthly catch, which is predominantly YOY anchovy, peaks in September and then declines through November. A secondary peak often occurs in December. There are three possible explanations for the secondary peak: 1) anchovy become more vulnerable to the trawl as temperatures drop; 2) there is a downbay movement of recruited anchovy in the late fall months (supported by TIES data); 3) there is an influx of anchovies from the coastal ocean in some years.

Riverflow apparently influences spatial distribution of bay anchovy by impacting springtime downstream and downbay migration. In years when spring flow is high and salinity is low, the spawning population is distributed further downbay relative to low-flow years. This pattern is evident in the significant statistical relationship between the abundance of bay anchovy in April (the spawning population) and salinity during the TIES cruise years (1995-2000). In each year, peak abundance occurs within a relatively narrow salinity band between 10 and 14psu.

Abundance trends & causal mechanisms

Abundance indices indicate that bay anchovy has experienced a decline from high abundance years in the mid-1980's through early-1990's. Lowest abundance occurred in 1994. In recent years there are indications that the population may be recovering. An important conclusion from this analysis was that mechanism(s) influencing bay anchovy annual abundance appear to act on a Bay-wide scale.

Anchovy abundance apparently varies synchronously with that of a preferred summer prey, the copepod *Acartia tonsa*. Correspondence between July *A. tonsa* densities is strong in system-specific analyses of the upper Bay and in the Rappahannock, York, and James Rivers. The smoothed low-frequency patterns of interannual variability between the anchovy and Acartia time series are similar in each river system. Correlations between lowess-smoothed (low frequency) time series were high and significant in all four systems (figure 1). The bay anchovy-*Acartia tonsa* relationship potentially results from a single causal mechanism influencing both populations independently. Our ongoing investigation is focusing on the covariability among hydrographic variables and these two populations. Preliminary results suggest that bay anchovy and *A. tonsa* may be influenced by interannual variability in riverflow and its impact on hydrographical conditions such as salinity, dissolved oxygen, and the extent of water column stratification. It is possible, however, that reduced prey (*A. tonsa*) abundance may directly affect the bay anchovy population by inducing conditions that lead to poor growth.

We are constructing matrix and stock-flow population models for bay anchovy. The matrix model is a mathematical structure that facilitates sensitivity and demographic analyses. The stock-flow model provides a conceptual framework that can also be used for sensitivity and demographic studies, and provides a means to examine the influence of spatially explicit environmental and predator-prey forces on bay anchovy. Currently the stock-flow model yields a realistic equilibrium population abundance estimate when initialized with a realistic initial spawning stock. Mortality and demographic parameters in the model were available from the literature on bay anchovy in Chesapeake Bay.

Atlantic menhaden research

Efforts have focused on potential physical and chemical (nutrient) forcing mechanisms. Using USGS tidal tributary nutrient-loading data http://va.water.usgs.gov/chesbay/RIMP/ loads.html), we compared total phosphorus input with YOY menhaden abundance in seven tributaries. There is strong interannual variability in phosphorus loadings, but the low-frequency interannual loading patterns (or multi-year trends) in each river system covary with annual menhaden recruitment patterns (young-of-the-year abundance) over time.

Analysis of the influence of large-scale atmospheric circulation patterns on the Bay's Atlantic menhaden population also was conducted. The residual time series from a Ricker spawning stock-recruitment relationship was used as the independent variable in this analysis. One large-scale sea-level pressure pattern appears to influence recruitment success in menhaden throughout the Bay. This pattern, the Azores-Bermuda high (ABH) pressure system, migrates seasonally and typically dominates the Chesapeake region during summer when it is centered over Bermuda. During winter, this pattern is centered over the Azores before it begins a westward migration in late winter. Nearly half of the variation in the 1966-1997 Ricker-residual time series was accounted for by the number of days each March that the ABH pattern dominated the region's weather, as described by the TSI. In comparison, the best model of Atlantic menhaden recruitment that could be constructed using individual weather variables (including temperature, river discharge, wind direction, and wind velocity) included only March temperature and accounted for only half (22%) of the recruitment variability attributed to the ABH model. Mechanisms driving this relationship are not known, but ongoing investigations indicate

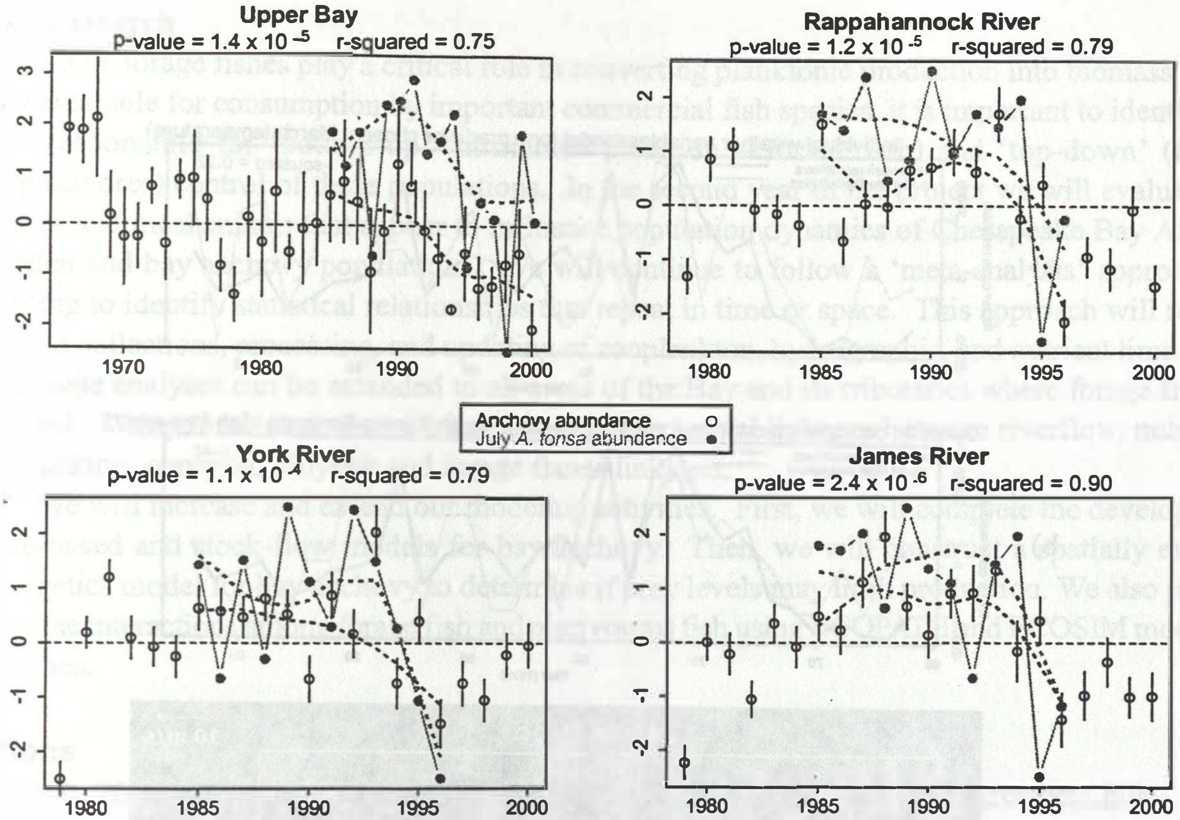

Figure 1. Annual bay anchovy (open circles) and July *Acartia tonsa* abundance indices (solid circles) derived from the Maryland Department of Natural Resources' and Chesapeake Bay zooplankton sampling programs, respectively. Only permanently sampled stations were used to calculate annual anchovy mean catch for each river system. Error bars represent one-half standard deviation above and below the mean. Lowess smoothed (f = 0.5) curves are plotted for each time series (dashed). The proportion of shared variance (r-squared values) and associated significance levels (p-value) for anchovy and *A. tonsa* time series are reported for each plot.

that the abundance of dominant mesozooplankton prey in the oligohaline Bay and tributaries peaks earlier in the year when the ABH dominates in March. This observation is important because postlarval menhaden migrate, or are transported, to oligohaline environments during this period when they consume zooplankton as their primary food.

This observed statistical relationship might not represent a predator-prey causal relationship between menhaden and zooplankton. The warm conditions associated with the ABH would be expected to promote an earlier peak in springtime production. Further, because winds within high pressure systems do not favor storminess, the Azores-Bermuda high also promotes dry conditions and winds from the south. These conditions could favor upbay transport of larval menhaden from their coastal spawning grounds to their oligohaline nursery areas, thereby enhancing recruitment to Chesapeake Bay. Because menhaden are spawned near the Gulf Stream front during winter and spend their first 60-90 days in the coastal ocean, future analyses will emphasize the potential role of climate variability during winter.

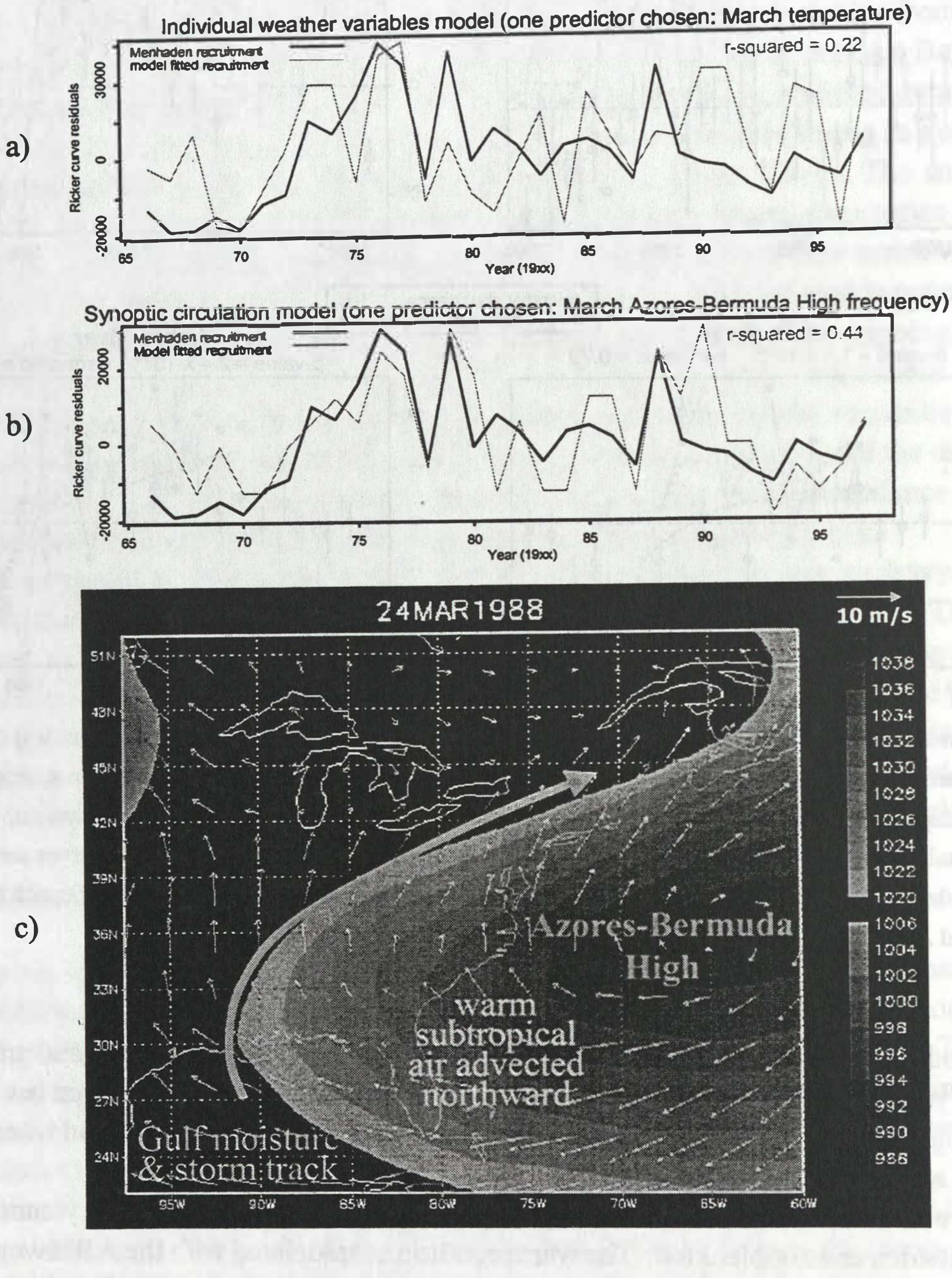

Figure 2a-c. Chesapeake Bay Atlantic menhaden climate-recruitment models. Residuals from a Ricker spawning stock-recruitment relationship (recruitment variability independent of spawning stock size-see methods) served as the dependent variable. **a)** Using a potential predictor pool comprised of individual weather variables, the best statistically-significant model constructed used only March air temperature and explained 22% of Ricker model residual time series variance. **b)** This statistic rose to 44% when the model was constructed from a potential predictor pool of regional, spring circulation pattern frequencies resulting from the temporal synoptic classification. This model utilized only the frequency of Azores-Bermuda high days in March. **c)** A map of regional atmospheric circulation conditions for March 14, 1998 is also provided. This date serves as an example of the circulation and weather patterns that occur when the Azores-Bermuda high influences the study area. Sea level atmospheric pressure is color coded in millibars.

Future Research

Since forage fishes play a critical role in converting planktonic production into biomass that is readily available for consumption by important commercial fish species, it is important to identify the factors responsible for 'bottom-up' (nutrients⇨plankton ⇨forage fish) and 'top-down' (forage fish⇦piscivores) control of these populations. In the second year of the project we will evaluate the processes and mechanisms that appear to influence population dynamics of Chesapeake Bay Atlantic menhaden and bay anchovy populations. We will continue to follow a 'meta-analysis' approach by attempting to identify statistical relationships that repeat in time or space. This approach will require continued collections, processing, and updating of zooplankton, hydrographic, and nutrient time series so that these analyses can be extended to all areas of the Bay and its tributaries where forage fish are monitored. Using these data, we will further explore potential linkages between riverflow, nutrients, phytoplankton, copepod, jellyfish and forage fishes linkages.

We will increase and extend our modeling activities. First, we will complete the development of state-based and stock-flow models for bay anchovy. Then, we will construct a spatially explicit bioenergetics model for bay anchovy to determine if prey levels may limit production. We also plan to explore the interactions among forage fish and piscivorous fish using ECOPATH and ECOSIM modeling approaches.

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A Multispecies Modeling Approach for Assessment of the Atlantic Menhaden Stock

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Introduction

Atlantic menhaden (*Brevoortia tyrannus*) is a commercially important species with a long history of exploitation in coastal waters of the United States. In addition to its commercial importance, menhaden plays ecological roles as a forage species and a consumer of primary production in estuarine and coastal ecosystems. This species is a significant prey item for major coastal piscivores that are themselves commercially exploited, including bluefish (*Pomatomus saltatrix*), weakfish (*Cynoscion regalis*), and striped bass (*Monroe saxatilis*, Hartman & Brandt 1995a, 1995b). The consumption by these predators may have a significant influence on the stock dynamics of menhaden by modulating the abundance of young fish, and they may compete with the fishery for exploitable biomass (e.g., bluefish, Buckel *et al.* 1999). The abundance of these predators has changed dramatically over time (NEFSC 1998) likely resulting in interannual variability in predation mortality experienced by menhaden.

Recent trends in the Atlantic menhaden population have highlighted the importance of environmental effects and natural mortality rates. The exploitation rate of menhaden has been relatively low in recent years and the spawning stock biomass is high. However, despite the apparent health of the stock, recruitment of age 1 menhaden has been declining over the last several years (Vaughn *et al.*, 2001). The rebuilding of the striped bass stock over the last decade and a resulting increase in predation on Atlantic menhaden has been cited as a potential cause for the declining recruitment success. To fully evaluate the effect of increasing predator abundance, it is necessary to calculate predator consumption and directly incorporate this mortality source into a model of the Atlantic menhaden stock.

The goal of this study was to develop an extension of single species stock assessment models that directly incorporates the effects of mortality due to predation on the population dynamics, age structure, and fishery yields of an exploited forage species. We have applied this model to the Atlantic menhaden stock and evaluated the effects of major piscivores on population dynamics and fishery yields.

Objectives

The model developed in this study was explicitly designed to provide a tool for fishery stock assessment scientists and managers that are evaluating the effects of predators on a targeted forage species stock. The model was designed to address four major topic areas of interest to fishery managers:

1) Evaluate the nature and magnitude of linkages among menhaden and its key predators.

2) Evaluate the current utilization of menhaden: 1) as a directed fishery, 2) its role in the ecosystem (forage base), and 3) sustainability of the stock.

3) Evaluate whether there is an optimal size (or age) composition of Atlantic menhaden to balance its ecological role with the goals of the directed fishery.

4) Evaluate any adjustments required of the biological reference points from single species management when predation is included in multispecies modeling.

Methods

Retrospective assessment model

We have developed a multispecies extension of the Murphy virtual population analysis (VPA, Tomlinson, 1970) that incorporates an evacuation rate consumption model for predator removals (Elliot and Persson, 1978). The approach is similar to the MSVPA approach described by Pope (1989). Model inputs include age-specific abundance and diet information for each predator, seasonal catch-at-age information for a forage species, and growth and maturity data for a forage species. Predator information is fixed in the model framework, and there is currently no feedback between predator and prey population dynamics. In all cases, predator diet information is age-specific to account for ontogenetic changes in predator diets and consumption rates. Consumption in biomass is converted to numbers removed at age based upon the size composition of fish prey in predator diets and the length and weight at age of the prey species. The outputs from this retrospective analysis include age specific population size, fishery mortality rates, and predation mortality rates. Yield and spawning stock biomass per recruit analyses are conducted, supplemented by the additional age-specific natural mortality rates calculated within the model.

Uncertainty analysis

In single species fisheries models, there are relatively few sources of uncertainty in the parameter estimation beyond the basic assumptions of the model. The multispecies approach introduces a number of additional sources of uncertainty into the calculations. Diet information is generally developed through a sampling program, and there is statistical variance in these estimates and associated uncertainty in model outputs. Uncertainty in model parameters is calculated using a Monte Carlo simulation based upon coefficients of variation (CV = std error / mean) for entered data. The confidence bounds for major outputs including predation mortality rates, fishery mortality rates, prey abundance, and yield per recruit are calculated from the randomized distribution.

Prospective simulation

The prospective simulation is designed to provide a short-term forecast of predator and prey populations under varying management strategies. The model is an extension of a simple age structured population model using the basic equation for population growth assuming exponential mortality rates. In this simulation, predator population dynamics are regulated by recruitment and changes in fishing mortality patterns. Prey populations are regulated by recruitment, fishing mortality, and changes in predation mortality rates that are a function of predator abundance. The simulation requires additional biological information for the predators including natural mortality rates, growth parameters, fishing mortality rates, and partial recruitment factors for fishery removals. Stock-recruit relationships using a variety of functional forms for both predators and prey are fit within the simulation. Model outputs are resolved annually and provide trajectories for age structured predator abundance, prey abundance, and prey predation mortality rates. Annual fishery yield predictions are also calculated for the predators and prey. The user is able to enter changes in fishing and recruitment patterns across the simulated time period to evaluate effects of management actions or recruitment variation for both the predators and prey on overall yields.

Implementation

The multispecies model is executed in Microsoft Visual Basic as a stand-alone application and includes a suite of graphical interfaces for model inputs and outputs. The program is designed to allow flexibility in inputs and configurations. The user interface is also designed to allow exploratory analysis of model outputs in both graphical and numerical formats. The goal was to provide an analysis tool that could be used interactively to perform technical assessments of a forage species stock under a variety of management scenarios and input parameters.

Data Sources and Analyses

In addition to developing a general multispecies model that can be applied to any exploited forage species, we have gathered data and conducted preliminary runs focusing on the Atlantic menhaden stock and its major predators. The model inputs require information on fishery catch at age and growth normally used within the single species assessments, and these have been supplied courtesy of Doug Vaughn, National Marine Fisheries Service. The model also requires information on predator population size at age, growth, and fishery exploitation patterns. These data have been gathered from appropriate stock assessment documents or supplied directly by the species' technical committees through the Atlantic States Marine Fisheries Commission. Finally, the model requires information on predator diets and evacuation rates. Predator diet and evacuation rate information has been gathered and summarized from a variety of published sources and data sets. These data inputs have been used to develop preliminary retrospective and prospective analyses of the Atlantic menhaden stock.

Results and Utility to Management

The multispecies model addresses project objectives both as a general application and with specific issues surrounding Atlantic Menhaden. We describe outputs from the model that address each of these issues below.

1) Evaluate the nature and magnitude of linkages among menhaden and its key predators.

These are the primary outputs of the retrospective analyses that both calculate predator removals of Atlantic Menhaden and incorporate these into a population model by calculating associated mortality rates. The retrospective analysis identifies those predator age-classes that are responsible for significant removals and the primary prey age classes that experience significant predation mortality rates. A general result from this and other multispecies models is that predation typically impacts pre-recruit age classes, generally Age 0 and Age 1 fish. This is a function of size-selectivity by the predators where the size, and therefore age, of prey consumed is limited by the predator to prey size ratio. Interannual variability in predator abundance and diet composition result in significant variability in predation rates and therefore productivity of the stock. Stock-recruit relationships, yield per recruit, and spawning stock biomass per recruit metrics are significantly impacted by predator removals.

2) Evaluate the current utilization of menhaden: 1) as a directed fishery, 2) its role in the ecosystem (forage base), and 3) sustainability of the stock.

Both the retrospective analysis and the prospective simulation directly address these management questions. The outputs from the multi-species VPA and YPR analyses evaluate the current and historical status of the stock relative to standard reference points. The multispecies results indicate that menhaden has historically been fished at mortality rates well above the maximum YPR level, and this is consistent with the findings of the single species approach. However, because of early age at maturity and high recruitment, the stock has generally been able to sustain this high level of fishing mortality and currently has a high level of spawning stock biomass (Vaughn *et al.* 2001). Preliminary results indicate that increasing striped bass abundance has resulted in greater Age 0 and Age 1 mortality rates associated with the observed decline in recruitment success. The prospective simulations allow further testing of this hypothesis and exploration of expected trends in stock size and fishery yields as a result of changes in predator abundance. These simulations allow managers and stock assessment scientists to explore the short term implications of management actions such as reducing or increasing fishing pressure on one or more species.

3) Evaluate whether there is an optimal size (or age) composition of Atlantic menhaden to balance its ecological role with the goals of the directed fishery.

The prospective simulation and resulting fishery yield curves allows exploration the implications of management actions for both the population size and age structure of the prey species and the predators. Predation interactions are strongest between large size classes of the predator populations and small size classes of the prey population. Therefore, management actions that impact the abundance of large predators such as reducing fishery mortality rates or changing minimum size limits will have the most significant effects on prey removals, prey population size, and stock productivity. In an example simulation, we evaluated the potential effect of recovering the currently depleted bluefish stock on the yield potential and recruitment of Atlantic menhaden. Under current conditions with relatively high fishing mortality on bluefish, the Atlantic menhaden stock is expected to recover as the predation mortality rate declines with continuing declines in the bluefish stock. However, if the fishing mortality on the bluefish stock is reduced to stabilize fishery yields, the menhaden stock equilibrates at a lower long term yield. The prospective analysis allows interactive exploration of the numerous possibilities and their potential impacts on fishery yields from each stock.

4) Evaluate any adjustments required of the biological reference points from single species management when predation is included in multispecies modeling.

The majority of the biological reference points for Atlantic Menhaden are catch-dependant indices that are not calculated by either single species or multispecies stock assessment models. The notable exception to this is the abundance of age 1 recruits, which is significantly effected by predation. However, multispecies models in general provide an advantage over single species models by expanding the framework for biological reference points and fishery management decisions. For example, increases in predator biomass due to a stock rebuilding program may have a significant effect on the recruitment of the forage species. In this case, the rebuilding targets for the predator may be adjusted to reduce the impact on the forage species. Alternatively, the fishery removal rate or minimum size limits of the prey species may be adjusted to reduce stress on the stock due to higher predator abundance. Thus, the primary effect of multispecies models is to allow a broader view of decision making for individual species. Biological reference points can therefore be adjusted to account for the interactions between species.

The application developed here provides a flexible tool to supplement current single species assessments of the Atlantic menhaden stock and allows both technical and non-technical users to evaluate the implications of alternative management scenarios. The tool has been presented to several technical workshops with ASMFC and stock assessment scientists. We are continuing to work with ASMFC and the Atlantic Menhaden Technical Committee to apply the multispecies model to assessment of this stock. These analyses and the general model approach will be developed into appropriate assessment documents as well as peer reviewed publications.

Future Work

We are continuing our work with ASMFC to further develop this application and its utility for multispecies stock assessments. Two major extensions to the model are currently under development. First, a stochastic feeding model is being developed and incorporated into the MSVPA framework to account for the effects of changes in prey populations on predator diets and consumption patterns. This model will require additional inputs on the relative abundance of alternative prey types and will allow predator diets to change dynamically in both retrospective analyses and projected simulations. Piscivores are generally omnivorous in their diets and diet composition is frequently driven by encounter rates. During periods of low abundance of a particular prey species, predators tend to switch to other more abundant prey, thereby reducing mortality rates on a depressed prey population. The proposed feeding model will allow simulation of these dynamics. Second, there is the potential for diet composition to influence growth and dynamics of predator populations. While it is unlikely that the overall quantity of all potential prey species will decline, it is possible that a reduction in a high quality prey item may impact predator growth and subsequent population dynamics. In the continuing model development, we will explicitly model predator growth and population dynamics, incorporating the "bottom-up" effects of prey availability, diet composition, and feeding rates.

This multispecies model developed here should be viewed as a first step toward incorporating ecological considerations into the management of interacting predator and forage species. The model provides a formulation of predator removal rates and incorporates these into single species stock assessment approaches to evaluate the impacts of predator removals and their potential effects on fishery yields. Multispecies models in general should be considered "works in progress" as greater complexity is incorporated and understanding of model behavior is improved. We are continuing to refine the model formulation to incorporate a broader suite of ecological processes and further evaluate the role of Atlantic menhaden as an ecologically and commercially important species.

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Oyster population estimation in support of the ten-year goal for oyster restoration in the Chesapeake Bay Fishery: estimation of Virginia stocks.

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Introduction

The Chesapeake Bay Stock Assessment Committee (CBSAC) has funded a collaborative research effort to effect a bi-state (Maryland and Virginia) program entitled "Oyster population estimation in support of the ten year goal for oyster restoration in the Chesapeake Bay Fishery." This program involves investigators from the Maryland Department of Natural Resources (Dr. S. J. Jordan), the University of Maryland (Dr. K. Paynter), the Virginia Institute of Marine Science (Dr. Roger Mann) and the Virginia Marine Resources Commission (Dr. James Wesson). Dr. S. Jordan serves as Principal Investigator. This summary of first year activity covers objectives effected by the Virginia Institute of Marine Science (VIMS) and the Virginia Marine Resources Commission (VMRC.

Objectives

Objective 1: To complete a stock assessment of oyster resources on that portion of the Public (Baylor) Grounds of Virginia that are currently subject to commercial exploitation using a combination of dredge and patent tong sampling.

Objective 2: To estimate oyster stocks by appropriate methods (including but not limited to patent tongs, dredges and diver surveys) in sanctuary and restoration sites that are closed to commercial exploitation. This includes sanctuaries developed as collaborative efforts between the (1) Virginia Marine Resources Commission and the Virginia Institute of Marine Science, and (2) the Virginia Marine Resources Commission, private non profit groups (including but not limited to the Chesapeake Bay Foundation) and citizen volunteer groups (including schools).

Objective 3: To estimate standing stocks of oysters on leased ("private") oyster grounds within the Commonwealth that are outside of the boundaries of the Public (Baylor) Grounds. These oyster stocks are typically supported by transplant to these regions of "seed" oysters from Public Grounds or selected locations on "private" grounds where oyster settlement occurs. Estimates will be developed through interviews with "private" leaseholders.

Objective 4: To estimate standing stocks of oysters produced form hatchery seed by commercial aquaculture companies and "recreational" oyster gardeners. Estimates will be developed through interviews with hatchery operators and, as required, commercial and "recreational" group participants.

Objective 5: In order to facilitate population estimation for the entire Chesapeake Bay resource co-ordination of data collected by both Maryland and Virginia is required. Co-ordination of data sets and data collection protocols will be pursued such that relevant information is synthesized and stored in a standard format.

Objective 6: The standard format information from the previous objective will be used to generate state specific and bay wide presentation quality and World Wide Web accessible graphics for use in support of the current project.

Methods and Results

Objective 1.

Intensive sampling of the actively exploited section of the James River was effected in the Fall of 2000 using a stratified random sampling design with individual samples being collected by a hydraulic patent with a one square meter sample capability. This technique was previously refined under CBSAC funding in 1993-1998 and has become a standard sampling and population estimation tool for this exploited stock since that time. A data summary from the study is given in Table 1 (file VApatenttong.xl) together with data for the 1997 – 1999 period for comparison. While small oysters have remained relatively unchanged in total stock size (bushels) since 1997 the 1998-2000 period has been marked by a decrease in market oyster abundance from an estimated 168,000 bu. to approximately 65,000 bu. These values can be converted to numbers of oysters using the conversion factors of 1000 oysters/bu for small oysters, that is oysters of less than the market size of three inches (76mm) length, and 500 oyster/bu for oyster of marketable size.

In addition to patent tong sampling both the exploited James River stocks and stocks on other public grounds in Virginia waters are subject to regular examination within surveys effected using a traditional oyster dredge. Quantification of dredge data is more difficult than patent tong data in that dredges accumulate organisms as they move over the bottom, may not sample with constancy throughout a single dredge haul, and may fill before completion of the haul thereby providing biased sampling in favor of the "early" portion of the haul. Finally, selectivity of dredges versus patent tongs with respect to demographics has not been rigorously examined. Conversely dredges provide semi-quantitative data, have been used with consistency over extended periods (decades), and thus provides exceptional data on population trends. The challenge in the current objective of estimating absolute numbers of oysters is to use dredge data in a consistent quantitative approach.

Dredge data available to the current project comes from two sources: surveys effected by VIMS in conjunction with VMRC, and surveys conducted by VMRC alone. Both use the same boat and dredge combination. VIMS surveys are more limited in geographical scope but have higher levels of replication at a single sampling site. Sampling sites follow consistent historical locations. VMRC surveys cover a much wider geographical region, typically have lower levels of replication, and include both historical sites and recent sites of replenishment activity. The employment of both of these survey databases in the current project is based on two assumptions:

(1) that there is no selective retention of live oysters with respect to shell substrate by the dredge, and
(2) that oyster habitat (reef, rock or hard bottom in common use terminology) can be characterized by density of substrate per unit area.

There exist from patent tong data a considerable archive of statistically defensible estimates of substrate quantities per unit area that can be associated with habitat of known oyster density and demographics. If typical values of substrate abundance per unit area (bushels/area = B/A) are examined in concert with dredge data describing oysters per bushel (N/B) for a unit habitat (reef, rock) of known area (A') then the number of oysters on the area A' is given by the relationship $[(N/B) \times (B/A)] \times A' = [N \times A'/A]$. Estimates of the required parameters were developed as follows. Dredge surveys give data in oysters per bushel. Data is summarized by station location. Stations for the entire Virginia portion

Table 1: Fall 2000 oyster survey: James River VA with a comparions of totals for 1993 onwards

Data by numbers of oysters per unit area

	Site	Area (acres)*	Area (m2)	No. of samples	Avg. No. Spat m2	SE spat	Avg No. Small m2	SE small	Avg No. Market m2	SE Market
1	Upper Deep Water Shoal	234	946985	30	1.3	0.4	16.5	5.2	6.6	2.4
2	Lower Deep Water Shoal	20	80939	8	0.6	0.3	3.6	1.0	1.4	0.6
3	Upper Horsehead	3	12141	7	23.1	11.8	229.7	57.7	27.6	3.9
4	Middle Horsehead	19	76892	10	9.6	3.3	145.6	31.6	13.3	4.3
5	Lower Horsehead	19	76892	12	34.6	4.0	253.4	34.5	17.1	2.6
6	Moon Rock	4	16188	7	40.6	8.1	246.3	16.0	36.0	4.3
7	V Rock	72	291380	21	8.2	1.9	249.1	22.0	14.2	2.0
8	Point of Shoals	132	534197	33	4.8	1.5	115.3	18.3	13.3	2.8
9	Cross Rock	37	149737	21	7.2	2.2	141.0	26.0	4.9	1.1
10	Shanty Rock	4	16188	7	4.4	2.4	20.0	8.6	0.7	0.4
11	Dry Lumps	6	24282	7	5.6	1.3	52.7	13.2	1.1	0.6
12	Mulberry Point	87	352084	10	0.3	0.2	6.5	4.8	1.6	1.0
13	Swash	165	667746	22	0.5	0.3	9.6	4.1	1.1	0.5
14	Upper Jail Island	612	2476730	30	0.1	0.1	3.4	1.1	0.4	0.1
15	Swash/Mud Slough	1245	5038446	30	1.7	0.7	20.5	8.0	0.9	0.4
16	Offshore Swash	627	2537434	30	1.6	0.6	16.9	5.5	0.5	0.2
17	Lower Jail Island	629	2545528	30	1.2	0.7	7.7	3.5	0.7	0.3
18	Offshore Jail Island	1017	4115743	30	0.4	0.2	2.4	0.8	0.1	0.1
19	Wreck Shoal	585	2367463	30	1.2	0.3	2.2	0.7	0.1	0.1

Data by estimated bushels of oysters per unit area
estimators: 1000 small oysters per bushel. 500 market oysters per bushel

		Area (m2)	spat/reef	small/reef	bu. small	market/reef	bu. market
1	Upper Deep Water Shoal	946985	1.23E+06	1.57E+07	15657	6.25E+06	12500
2	Lower Deep Water Shoal	80939	5.06E+04	2.93E+05	293	1.11E+05	223
3	Upper Horsehead	12141	2.81E+05	2.79E+06	2789	3.35E+05	669
4	Middle Horsehead	76892	7.38E+05	1.12E+07	11195	1.02E+06	2045
5	Lower Horsehead	76892	2.66E+06	1.95E+07	19486	1.31E+06	2627
6	Moon Rock	16188	6.57E+05	3.99E+06	3987	5.83E+05	1166
7	V Rock	291380	2.39E+06	7.26E+07	72581	4.15E+06	8297
8	Point of Shoals	534197	2.54E+06	6.16E+07	61611	7.11E+06	14213
9	Cross Rock	149737	1.08E+06	2.11E+07	21106	7.27E+05	1455
10	Shanty Rock	16188	7.17E+04	3.24E+05	324	1.16E+04	23
11	Dry Lumps	24282	1.35E+05	1.28E+06	1280	2.78E+04	56
12	Mulberry Point	352084	1.06E+05	2.29E+06	2289	5.63E+05	1127
13	Swash	667746	3.64E+05	6.43E+06	6435	7.59E+05	1518
14	Upper Jail Island	2476730	3.30E+05	8.42E+06	8421	9.08E+05	1816
15	Swash/Mud Slough	5038446	8.40E+06	1.03E+08	103120	4.70E+06	9405
16	Offshore Swash	2537434	4.14E+06	4.28E+07	42798	1.35E+06	2707
17	Lower Jail Island	2545528	2.97E+06	1.97E+07	19685	1.87E+06	3733
18	Offshore Jail Island	4115743	1.65E+06	9.88E+06	9878	5.49E+05	1098
19	Wreck Shoal	2367463	2.84E+06	5.29E+06	5287	2.37E+05	473
	Reefs 1-19 inclusive	22326993	3.26E+07	4.08E+08	408222	3.26E+07	65150

Comparative historical totals by bushels		small	market	total
	1993	577076	106464	683540
	1994	556745	121169	677913
	1995	541565	83753	625318
	1996	585348	159274	744621
	1997	387897	135882	523779
	1998	409939	168746	578685
	2000	408222	65150	473372
Comparative historical totals by number (small and market oysters only)				
	1993	5.77E+08	5.32E+07	6.30E+08
	1994	5.57E+08	6.06E+07	6.17E+08
	1995	5.42E+08	4.19E+07	5.83E+08
	1996	5.85E+08	7.96E+07	6.65E+08
	1997	3.88E+08	6.79E+07	4.56E+08
	1998	4.10E+08	8.44E+07	4.94E+08
	2000	4.08E+08	3.26E+07	4.41E+08

of the Chesapeake Bay were aggregated in units corresponding to the Baylor Chart revisions of Haven et al (1981). The extensive data summaries in Haven et al (1981) provide descriptions of the relative areas of bottom type within the prescribed polygon boundaries originally set by Baylor. Bottom is described as hard rock, shell-sand, shell-mud, and other sand or mud substrates. These bottom types are also categorized by depth, less than or greater than 18 feet depth. For the current application each individual chart summary from Haven et al. has been considered as high potential bottom (sensu Haven et al. hard rock bottom only), or moderate potential (sensu Haven et al, includes both shell sand and shell mud substrates). Thus each chart has a summary of two values, acres of high potential bottom, and acres of moderate potential bottom. To each of high and moderate is assigned a working value of shell substrate abundance, typically 1.0 bu/m-2 for high and 0.5 bu/m-2 for moderate potential. Simple, mean values of number of oyster/bu. are taken from dredge samplings within the chart area and numbers of oysters computed for that area by multiplication. A grand total is then estimated from the sum of the individual chart regions. Data is presented in summary form in Table 2 (file VAdredge.xl). Several important points are worthy of note. The table contains a number of "no data" cells for regions which have both not been productive in fishery terms and have not been surveyed in the previous decade (older data do exist but have not been completely examined at this time). The sum of James River charts 1, 2 and 3 on Table 2 are approximately equivalent to the region covered by the patent tong survey in Table 1. There is stability in the 1993-2000 total for Table 1 between 4.41 and 6.30E+08. On Table 2 the data show greater variability (8.68E+09 and 5.98E+11 for VIMS data in 1995 and 1998 respectively, 4.27E+09 for VMRC 1999 data) and higher values. The sensitivity of the data to the substrate abundance estimates for high and moderate potential bottom types has not been fully examined, although this may be a significant contributor to this discrepancy, as will be the validity of assumptions 1 and 2 a given earlier. Examination of these sensitivities and assumptions remain to be investigated in the 2001-2002 funding year. The grand total estimates for the Virginia productive bottoms vary between 6.00E+11 as a high value to 5.31E+09 for a low value in Table 2. Again, the sensitivity of these values to variation in substrate availability estimates remains to be investigated. Note as part of this analysis the rather modest values for high and moderate potential bottom area compared to the Baylor total within the Virginia portion of the bay; together they constitute only 24.85% of the total Baylor area.

Table 2: Estimated oyster population size (individual oysters = or > 1yr) by Baylor Chart designation.

Bottom type T: total acres, H:High potential, M: moderate potential(see text). Sq. m = acres x 4046.9.

VIMS 1995 and 1998 are VIMS survey, VMRC 1999 is VMRC survey (see text).

River, chart	Section	Baylor area (acres) T	H	M	VIMS 1995 total oysters	VIMS 1998 total oysters	VMRC 1999 total oysters
James River,1	DWS to Mulberry Point	737	38	371	4.10E+08	1.99E+08	1.58E+08
James River,2	Mulberry to POS	6259	1750	3274	5.04E+09	3.43E+09	1.74E+09
James River,3	POS to White Shoal	9643	1356	4824	3.23E+09	5.95E+11	2.37E+09
James River,4	White Shoal to Fishing Pt	3624	1032	1333	2.40E+08	2.60E+08	1.02E+08
James River,5	Fishing Pt to Nansemond	4890	135	2134	3.47E+07	1.07E+08	6.32E+07
Tangier,1	pub grounds 1,2,3,5,6,9	2257	21	158	no data	no data	1.51E+07
Tangier,2	pub grounds 4,7,8	2406	165	395	no data	no data	5.50E+07
Eastern Shore,3	pub grounds 17,1 8,1 9	2507	145	250	no data	no data	no data
Pocomoke Sound,4	pub grounds 12,13	7743	190	952	no data	no data	no data
Eastern Shore,5	pub grounds 10,11	2340	2518	420	no data	no data	no data
Pocomoke Sound,5	pub ground 14	7548	387	1093	no data	no data	no data
Pocomoke Sound,6	pub ground 15	4677	465	962	no data	no data	no data
Pocomoke Sound,8	pub ground 16	1492	4	91	no data	no data	no data
Pungoteague Creek,9	chart9	215	1	20	no data	no data	no data
Occohannock Creek,10	chart 10	132	2	15	no data	no data	no data
Nassawadox Creek,11	chart 11	174	1	45	no data	no data	no data
Nomini Bay & Creek,1	Potomac trib: chart1	1448	84	367	no data	no data	1.24E+08
Lower Machodoc,2	Potomac trib:chart 2	544	39	53	no data	no data	no data
Yeocomico Rive,3	Potomac trib: chart 3	395	44	59	no data	no data	1.81E+07
Coan River,4	Potomac trib: chart 4	381	41	132	no data	no data	2.59E+07
Rappahannock	Bowlers to Jones Pt	3029	112	632	2.16E+07	4.04E+07	7.44E+07
Rappahannock	Morattico to Weeks Creek	8223	1013	2333	6.61E+07	1.63E+08	6.32E+07
Rappahannock	Weeks Creek to Towles Pt.	10811	947	1961	1.95E+07	2.18E+08	no data
Rappahannock	Towles Pt. To Mosquito Cr.	12890	557	1749	5.79E+06	7.75E+07	8.98E+07
Rappahannock	Mosquito Cr. To mouth	7739	130	462	1.68E+07	1.32E+07	5.65E+07
Corrotoman		1561	30	189			1.01E+07
Great Wicomico,1	above Sandy Point	1012	36	163	1.50E+07	1.53E+08	1.33E+07
Great Wicomico,2	Sandy Pt. To E. of G.W. light	5979	170	127	3.87E+07	1.45E+08	8.37E+07
Great Wicomico,3	Dameron Marsh to Dividing Creek	7486	0	25	no data	no data	no data
Piankatank River,1	above Stove Point	3530	136	320	2.50E+07	1.00E+08	4.86E+07
Piankatank River,2	Stove Pt. To Stingray Pt.	12471	157	322	no data	no data	no data
Piankatank River,3	Milford Haven	509	13	92	no data	no data	no data
Piankatank River,4	in Chesapeake Bay	8496	24	383	no data	no data	1.56E+08
Mobjack Bay,1&3	Ware,North and East Rivers, part of Mobjack Bay	5609	116	296	3.53E+05	3.50E+07	1.16E+07
Mobjack Bay,2	Severn River	195	12	36	no data	no data	no data
York River,1	Bell Rock	170	0	8	2.79E+05	1.02E+06	1.04E+06
York River,2	mid river to bridge	1753	382	476	no data	no data	3.01E+07
York River,3	below bridge	525	15	208	no data	no data	no data
York River,4	Poquoson River	8931	83	725	no data	no data	no data
TOTAL		**160333**	**12350**	**27453**	**9.17E+09**	**6.00E+11**	**5.31E+09**

Objective 2.

Data describing reef (sanctuary) supplementation is drawn from a summary prepared by the Chesapeake Bay Foundation (with thanks to Dr. R. Brumbaugh of the VA Office of CBF). As of 4/19/2001 this effort involves 13 reefs with an estimated total of 3E+06 oyster being planted. These are oysters that have been grown from seed (hatchery stock) and obtained by buy-back programs from industry. Thus their size is not directly comparable with the sizes used in calculations under Objectives 1 and 3. Diver surveys of survival of these oysters vary, but an examination of divers surveys for reefs in the Coan River, Yeocomico River, Great Wicomico River, Lynnhaven River, and four reef systems in the Piankatank River over the 1997-2001 period (J. Wesson, unpublished data) suggest that less than 10% of seed survive to market size oysters of four years of age. Thus boundaries for the total oyster calculation for this component vary between 3E+06 as a high value to 3E+05 as a low value.

Objective 3.

Approximately 100,000 acres of lease bottom are available to private citizens of the Commonwealth through approximately 3,000 leases. Lease fees are collected annually by VMRC. To survey the leaseholders for lease use we developed a anonymous reporting form, which was provided to the leaseholders with their annual billing in the summer of 2001. The reporting form was a pre-paid post card addressed to Roger Mann at VIMS. It contained a request for the numbers of acres leased and estimates of bushels of oysters on those lease by river system (categories being (1) James River and tributaries, (2) Poquoson and Back River, (3) York River and Mobjack Bay, (4) Piankatank, Rappahannock and Corrotoman Rivers, (5) Great Wicomico River, (6) Potomac River tributaries, (7) Eastern Shore: bayside, (8) Eastern Shore: seaside, and (9) Other. Returns as of 10/11/01, with approximately 15% of returns by number and area leased in hand, provide an estimated bushel count of 66852 bushels at 500 oyster/bu (using the market estimator as reported earlier for an overall conservative estimate of total number present) suggesting a total number of individuals of 3.34E+07 for the reported leases, with extrapolation to 2.21E+08 for the entire lease bottom area of 100,000 acres. This is within an order of magnitude of the lower estimate for the entire public oyster grounds based on dredge data (see Objective 1 above).

Objective 4.

A survey of hatcheries supporting aquaculture revealed the following estimates of seed production for delivery to grow out efforts by year for the period 1994 through 2000 as follows: 20,000, 70,000, 910,000, 2,107,000, 2,761,000, 3,011,000, and 2,879,000 respectively. As with Objective 2 the estimation of survival to market size is challenging, but given that off bottom cage culture reduces mortality considerably compared to on bottom deployment then mortalities in the 50% range are not unreasonable to expect. Thus, maximal production in the period 1998-2000 can be estimated to contribute approximately 1.5E+06 oysters.

Objective 5.

The investigators and their support personnel have met four times to date to develop, among things, the common reporting format, both as project personnel alone and in a larger forum to include non-profit and citizen groups (included, for example at the International Conference on Shellfish restoration at Hilton Head in November 2000). The common data reporting form requiring common data on a river basin designation has been developed and is being distributed for data reporting.

Objective 6.

This objective is dependent in time sequence on objectives 1-5. Data managers in both VA and MD have completed primary discussions on web development and are awaiting data input before pursuing site construction. Following a 10/2001 meeting of project personnel with program management personnel from NOAA a discussion has also been opened on production of a short summary paper for distribution by NOAA based on the first year collective effort of the MD and VA investigator team.

Future Work

Each of the Objectives will mature in 2001-2002. Objective 1 will involve more extensive examination of sensitivity of estimates to inherent assumptions as described earlier. Further, continuing survey work in the Rappahannock in support of the VA Oyster Heritage Program promises to provide more timely and more rigorous data for description of that geographical region. Objective 2 will be updated as new data and continuing monitoring provides greater fidelity of estimates of survival to market size. Objective 3, at 15% reporting, is already at a level that is expected for terminal responses for user surveys, although additional responses continue to arrive in low numbers. Individual reports continue to arrive as this report is being developed, and the data has yet to be analyzed on a river basin specific basis to increase the fidelity of the calculations. Finally, distribution of the project data to users and interested parties has been a small component of the effort to date give that the first funding year has been a data collection and method evaluation exercise. End product delivery will be come a greater component of the effort in the 2001-2002 funding year.

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SURVEY OF THE VIRGINIA BLUE CRAB RECREATIONAL FISHERY - 2001

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Introduction

Management of the exploitation of blue crabs in the Chesapeake Bay has been impeded by a lack of consensus on the stock's status. The lack of consensus is primarily a result of the paucity of data including total harvest, sex ratios of harvested crabs, fishing effort, and age and growth (Anon. 2000). Crabs are caught commercially using pots, dredges, and trot-lines; they are also caught by anglers in the recreational fishery, using a variety of gears, including pots, trot-lines, dip-nets, traps, and handlines. A substantial proportion of the blue crab harvest may be taken by the recreational fishery. Because all blue crabs in the Chesapeake Bay are considered to represent one stock, lack of reliable data on crabs taken recreationally will affect not only the management decisions that can be taken in the recreational fishery, but also those for the commercial fishery.

In a collaboration between the Center for Quantitative Fisheries Ecology (CQFE) at Old Dominion University, the Virginia Marine Resources Commission (VMRC) and the Maryland Dept. of Natural Resources (MDNR), we have initiated an integrated program to sample the recreational blue crab fishery in the Chesapeake Bay for data on effort, harvest, catch rate, and biological data including size and sex. Randomised sampling methodologies have been used to sample representatively, using a combination of telephone surveys, intercept interviews at public boat access points, and logbook records by waterfront property owners to provide information on the spatial and temporal composition of effort and harvest for the recreational fishery.

In this report, we provide preliminary estimates of activity by recreational anglers in the state of Virginia based on results from a telephone survey using random dialing of numbers for households in the coastal counties. The estimates cover the period May-October 2001 for 1) the total number of crabbers, 2) the number of crabbers active each month during the fishing season, 3) the number of trips made each month by recreational crabbers, stratified also by access method, 4) the recreational harvest each month, stratified also by access method.

Sampling method for RD survey

The sampling frame consisted of the telephone numbers for all households in Virginia counties within 40 miles of the shore. Sampling was undertaken by the Survey and Evaluation Research Laboratory at Virginia Commonwealth University in Richmond. Households were contacted randomly: at the beginning of every month between June and November, telephone numbers were selected from the sampling frame by simple random sampling.

The numbers were dialled and interviews conducted with respondents to establish if members of the household had participated in the recreational fishery over the previous month. If they had, a full interview was conducted: a standardised questionnaire was used to confirm the angler's eligibility and household details; obtain data on the method of access to the fishery and the fishing gear used; and provide information on harvest and on how effort was allocated during the month.

Based on results from the pilot study by Miller et al (2001), anglers were predicted to use a consistent capture methodology, including method of access to the fishery and gear used. Questions were therefore phrased to provide information on the total number of trips, and harvest taken, by the household interviewed; and then identify the gear and access type used. Thus, a respondent was asked how many trips were taken using each access method, and then which gear was used. For households using mixed access methods, the further questions on gear type concentrated only on the access method most used. In this way, the respondent's answers could be checked for consistency by comparing the total number of trips stated with the sum of trips by access method. The response for harvest by gear was also compared to the response for total harvest, and used as a second internal check in the survey instrument to indicate inconsistency in respondents' answers.

To allocate sampling effort between months, we used data from the pilot survey of Miller et al (2001) to estimate variability associated with month and the relative intensity of activity expected; these were used to calculate the number of telephone calls needed to provide estimates within a target confidence interval. The target numbers of completed interviews with active crabbers are given in Table 1 for each month. Survey effort was concentrated on the late afternoon and early evening when the response rate was highest, and scheduled to complete calling by the 10th of each month.

Analysis and Results

Preliminary examination of data

Out of a total of 63 109 telephone calls made between June and November 2001 for the Random Dialling Survey, a total of 23 091 (36.6%) resulted in interviews. Of these, 337 interviews (1.5%) were with households with active crabbers who had caught crabs during the month preceding the interview. Data were collected from these households on the number of active crabbers/household, the harvest/month/household and trips/month/household. The number of interviews with active crabbing households are shown by month in Table 1. The frequency distributions for the number of active crabbers/household, total number of trips/household, and total harvest/household for each month departed strongly from normality. Of the 337 observations, the eleven respondents (3.2%) who reported capturing 250 crabs or more, accounted for 61% of the total of 25 548 crabs reported taken by survey respondents.

For the internal check on the consistency of respondents in answering questions, the numbers of trips by access method were summed across all access methods, and compared to the total number of trips given by the respondents. There was considerable scatter around the expected 1:1 relationship, and evidence of bias. However, when examined by access method, most of the bias was found to be due to nine observations where the respondent used shore access from waterfront property, and may have

Table 1. The number of interviews (from 63 109 telephone calls) with Virginia households reporting active crabbing a) targetted for each month covered by telephone sampling, b) completed each month c) observations for crabbing households used in the analysis (n=299), who caught <250 crabs in the month covered by the interview.

	No. targetted	No. completed	No. with moderate crabbers
May	40	34	31
June	50	52	42
July	40	40	35
August	170	153	140
September	40	35	32
October	40	24	19

changed definition of a trip between the two questions. These data were removed from the data set to be examined, as well as twelve observations in which there was a divergence of >8 between the number of trips and totaled number of trips by access type. A further check, comparing the total harvest with the total of harvests by gear, revealed a respondent with a similar inconsistency between responses for total harvest and harvest by gear type. Including nine observations with no data for number of trips or harvest, thirty-one observations (9.2%) were removed from the data set as a result of these checks. Four of the observations removed were from the eleven crabbing households reporting the largest catches. Four of the remaining seven households reported taking between 1200-2000 or more crabs over only 1-5 trips: these observations were also removed from the data set. The remaining three households are likely to have included full or part-time commercial crabbers, and to have responded by mistake to the question.

Expansion

The telephone numbers to be used in each month of the survey were randomly selected from a list of 1,020,385 listed telephone numbers for households in Virginia coastal counties. Including unlisted numbers which could not be used in the survey, the full list of telephone numbers for households in Virginia coastal counties consisted of 1,205,903 numbers (T_h). Of the numbers selected each month, no information was obtained from a proportion (mean = 14.6%) from which to establish whether they were households or not. From the remaining numbers, a proportion were not households (mean = 24.9%), leaving an estimated 905,633 numbers corresponding to households. We then divided by the mean number of 1.356 telephone numbers/household given by respondents overall, to obtain an estimate of N = 667 871 households within the coastal counties of Virginia.

$$Expansion : N = \frac{1}{1.38}\{T_h - \left[\frac{T_h}{6}\sum_{i=5}^{i=10}\frac{n_{k_i}}{n_{l\,i}}\right]\} = 667{,}871$$

where i is the index of month from May (i=5) to October (i=10) covering six months of surveys, n_k is the number of responses that were not households, and n_l is the number of responses giving information on whether the telephone number belonged to a household or not.

For crabbing households responding with moderate catches, we then estimated the mean value/ household each month for each parameter of interest, and multiplied by N to give monthly estimates of each parameter. For the number of trips and harvest, the monthly estimates were summed to provide overall estimates for the period May-October.

Estimation of parameters

Data from moderate crabbing households were used to estimate the total number of crabbers, active crabbers, trips made, and harvest taken in Virginia. Definitions were taken from the pilot study by Miller et al (2001).

To estimate the total number of active crabbers, the number of active crabbers were summed for all households interviewed for each month. However, some households reported the presence of active crabbers in the household but gave no information on how many, so the sum was corrected to account for these households. The corrected sum was divided by the total number of households successfully interviewed that month, to give an estimate of the mean number of active crabbers/household for each month. This mean was then expanded to give the estimated number of active crabbers (T_{ai}) for each month i in the coastal counties of Virginia.

$$\hat{T}_{ai} = N\bar{a}_i$$

where

$$\bar{a}_i = \frac{1}{n_i} \cdot \sum_{j=1}^{n_i} \hat{a}_{ij}$$

where, to correct for households reporting active crabbers but no information on how many,

$$\sum_{j=1}^{n_{ai}} \hat{a}_{ij} = \frac{n_{r_i} + n_{n_i}}{n_{r_i}} \cdot \sum_{j=1}^{n_{ri}} a_{ij}$$

where a_{ij} = the number of actively crabbing members reported by household for month *i*.
$\hat{a}_{ij}$ = the number of actively crabbing members reported by household for month *i*, corrected for missing data.
$\bar{a}_i$ = mean number of active crabbers/household for month *i*.
n_i = the number of households interviewed in month *i*.
n_a = the number of households reporting active crabbers
n_r = the number of households reporting active crabbers and giving the number of active crabbers
n_n = the number of households reporting active crabbers but not reporting the number of active crabbers

To estimate the total number of crabbers, trips and harvest taken for each month, a similar analysis was used. Results are shown in Tables 2-3. The October estimate of crabbers was considered to represent the total number of crabbers in the Virginia coastal counties for 2001.

We also estimated the total number of trips and the total harvest between May and October, based on the pooled data for households that reported crabbing moderately and intensively. All values for 302 observations were summed, corrected for those households which reported crabbing during the

Table 2. Estimates for the number of crabbers (the number who had crabbed at some point during 2001 prior to being interviewed) and the number of active crabbers/month (the number who crabbed during the month prior to interview) in Virginia coastal counties. Estimates are based on data from households reporting less than 250 crabs caught/month.

	Crabbers	Active crabbers
May	93 100	40 200
June	84 000	33 300
July	70 400	32 300
August	65 100	25 400
September	73 900	20 100
October	70 200	13 500

Table 3. Estimates for the number of trips made/month, and the total harvest/month by crabbers from Virginia coastal counties. Data used are taken from households reporting less than 250 crabs caught/month. Also shown are estimates for the total no. of trips and total harvest between May and October 1) using data from moderate crabbers only (ie. from households reporting less than 250 crabs caught/month) 2) using pooled data from all crabbers.

	Trips	Harvest
May	37 700	363 000
June	56 300	413 000
July	48 300	377 600
August	45 800	430 300
September	30 400	303 500
October	22 900	217 600
Total (moderate crabbers)	241 400	2 105 000
Total (all crabbers)	258 100	3 267 000

previous month but gave no data, and divided by the total number of interviews conducted to get the mean value/household/month. This was then expanded by $6N$ to get the total value for the six-month period May-October 2001.

The total harvest for the period was estimated as 3 267 000 crabs, and the total number of trips was estimated as 258 100 trips, giving an average of 12.7 crabs caught/trip.

Stratification by access method, gear type and area

All observations reported by households crabbing moderately each month were pooled. Ten households did not report their access methods. For each access method, the number of trips/household were summed for those households using only that access method; the number of trips/household made by households using mixed access methods were summed separately. The fraction of trips made by households using each access method and mixed access methods, was then calculated; each fraction was multiplied by the estimate for total number of trips taken by households crabbing moderately calculated in section 3.3.1, to give an estimate for the total number of trips made by each access method (T_{tm}) (Table 4).

$$\hat{T}_{tm} = \hat{T}_t \left[\frac{\sum_{i=1}^{n_m} t_{mij}}{\sum_{1}^{6} \left(\sum_{i=1}^{n_m} t_{mij} \right)} \right]$$

where t_{mij} = the number of trips reported using access method m for month i by each household j.

n_m = the number of households reporting using access method m for crabbing during a month.

T_t = the estimated total number of trips taken by households reporting crabbing moderately, from section 3.3.1.

Similarly, for each access method, the number of crabs harvested/household was summed and the total number of crabs harvested using each access type calculated (Table 4).

Table 4. Estimates for the proportion of trips and total harvest made using each access method by households in Virginia coastal counties reporting less than 250 crabs caught/month: 1) private boat from waterfront property, 2) shoreline of waterfront property, 3) private boat from public boat access point, 4) private boat from other access point, 5) other access method, and 6) mixed access methods. *n* = no. of anglers using access method.

Trips:	*n*	*no. trips*	*%*	*total trips*
Private boat/private	48	200	20	48 300
Shoreline/private	117	463	46	111 000
Private boat/public	22	58	06	14 500
Private boat/other	3	26	03	7 200
Other access	43	108	11	26 600
Mixed access	56	144	14	33 800
Harvest:	*n*	*no. crabs*	*%*	*total crabs*
Private boats/private	48	2188	25	526 300
Shoreline/private	117	3162	36	757 900
Private boat/public	22	900	10	210 500
Private boat/other	3	45	00	00
Other access	43	1017	12	252 600
Mixed access	56	1469	17	357 900

For the stratification by gear type, all observations reported by households crabbing moderately using a single access method were pooled. Observations from households using mixed access methods were not included in the analysis, because data on gear type were only available for the access method most used: information was not available on how the harvest was divided between the different access methods, and what gear was used for less-used access methods. For making estimates by gear type, we therefore assume that overall, households using mixed access methods used gear types on the same proportion of trips and had similar success in capturing crabs as single access method households. Analysis proceeded similarly to that for the stratification by access-type. Results are shown in Table 5.

For the stratification by area, all observations reported by households crabbing moderately using a single access method were pooled. A similar procedure as for gear, was used to calculate the number of trips and total harvest stratified by state (Virginia and Maryland) and Chesapeake Bay/Eastern Shore Seaside. Almost all activity by coastal households was reported to have occurred in the Virginia Chesapeake Bay area (Table 6).

Preliminary Conclusions

This RD survey is the first attempt using a rigorous statistical approach to provide estimates of total recreational blue crab angler activity in the State of Virginia. The frame sampled consisted of households in the coastal counties of Virginia, covering the period May-October 2001, during which a total of 3.3 million crabs were estimated to have been caught.

This estimate was based on a strongly non-normal distribution in the underlying data. It assumed that data from households reporting 250 or more crabs caught/month were valid, and were not covered by surveys of the commercial fishery. It remains to be established whether data from these households should be included in analyses; if so, future coverage needs to be sufficient to overcome stochastic effects on the estimates due to the distribution of the data. Furthermore, data from these households have a large influence on estimates; however, observations from eight of the eleven households reporting more than 250 crabs caught/month were eliminated from the analysis because they did not fulfill quality control requirements. As a result, the harvest estimate may have been biased downwards. Finally, it should be noted that the frame did not cover anglers from households outside the coastal counties travelling in to use public access points, although it did cover anglers from areas outside the coastal counties staying with coastal county households.

These results demonstrate that almost all blue crab angler activity is based on five access methods. Of these, the most important are private boat from private waterfront property, and shoreline from private waterfront property. Access using private boat from public access point; public piers; and public beaches or banks account for most of the remaining activity. Parallel surveys examining the first four of these access methods have been undertaken during the 2001 season: analysis of these will give substantially more information for each of these sectors of the recreational fishery, and throw light on the amount of activity associated with anglers travelling in to use public boat access sites. The data will also allow further analysis of activity by households reporting 250 or more crabs captured/month. The parallel surveys were conducted with a higher level of coverage, which may allow stochastic effects in the data due to these households to be reduced. We are also currently developing a maximum likelihood estimator for the recreational fishery: we anticipate this will allow us to provide confidence intervals for parameter estimates consistent with the data distribution.

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Table 5. Estimates for the proportion of trips and total harvest using each gear type, made by households in coastal Virginia counties reporting less than 250 crabs caught/month and using a single access method. Gear types are: 1) crabpot, 2) trap 3) trotline 4) handline 5) other 6) mixed gear. *n* = no. of anglers using gear type.

Trips	*n*	*no. trips*	*%*	*Total trips*
Crabpot	50	247	32	77 200
Trap	11	21	03	7 200
Trotline	1	4	00	00
Handline	42	129	17	41 000
Other	9	39	05	12 100
Mixed gear	91	331	43	103 800
Harvest:	*n*	*no. crabs*	*%*	*Total crabs*
Crabpot	50	1890	28	589 400
Trap	11	284	04	84 200
Trotline	1	60	01	21 100
Handline	42	905	13	273 700
Other	9	307	05	105 300
Mixed gear	91	3265	49	1 031 500

Table 6. Estimates for the proportion of trips and total harvest taken by households in Virginia coastal counties reporting less than 250 crabs caught/month from the following areas: 1) Maryland Chesapeake Bay, 2) Maryland Oceanside 3) Virginia Chesapeake Bay 4) Virginia Eastern Shore Seaside 5) Other. *n* = no. of anglers visiting area.

Trips:	*n*	*no. trips*	*%*	*Total trips*
MD Bay	18	37	04	9 700
MD Ocean	3	6	01	2 414
VA Bay	183	703	84	202 800
VA Seaside	13	64	08	19 300
Other	10	29	03	7 200
Harvest:	*n*	*no. crabs*	*%*	*Total crabs*
MD Bay	18	407	06	126 312
MD Ocean	3	56	01	21 100
VA Bay	183	6337	86	1 810 500
VA Seaside	13	372	05	105 300
Other	10	205	03	63 200

MIGRATION OF ADULT FEMALE BLUE CRABS TO SPAWNING GROUNDS: MECHANISMS AND ROUTES

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Introduction

Successful migration of adult female blue crabs to spawning grounds is vital in order for the stock to actually spawn. A positive relationship between female spawning stock and recruitment has been demonstrated in the Chesapeake (Lipcius & van Engel, 1990) as well as in the Delaware Bay (Kahn *et al.,* 1998) and in North Carolina sounds (Eggleston, 1998). Long-term datasets indicate that the male spawning stock is under severe pressure (Abbe & Stagg, 1996), but since the crab fishery tends to target large "jimmies", there has been less concern about the female spawning stock. More recent research has shown that the average size, and the biomass, of the female spawning stock also is declining (Lipcius & Stockhausen, 2002), indicating that steps may become necessary to protect it to maintain reproductive potential of the population.

Despite the obvious importance of the spawning migration, its energetics, timing, and orientation mechanisms are poorly understood. We remain ignorant of when and where females provision for the demands of migration and subsequent brood production. As scientists we know little about the onset of migration, although crabbers move their pots in response to their perceptions of females' movements. Does migration begin promptly after mating, allowing females that mature early enough in the warm season to begin brooding that same year, using fresh sperm? ...or does it occur at the end of the warm season, after females have used the abundant food of tributaries to build up reserves for migrating and brooding, but so late that females must store sperm over winter? ...or do mated females overwinter up-estuary before migrating?

Do female crabs have maps and [sun-]compasses (Nishimoto & Herrnkind, 1982) to swim down-Bay, or selectively ride ebb tides by rhythmically swimming up into the water Olmi, 1994, 1995; Tankersley *et al.*, 1998) , or simply walk along the bottom? Do they use the deep channels or the shoals nearer shore?. Do they move continuously, or continue to forage en route; if the latter, what food resources are available along their route?

A clearer understanding of the "when, how and where" of migration to spawning grounds will become necessary if it is deemed advisable to protect migrating females as a means of preserving the spawning stock. A network of deep-water migration sanctuaries has been established (Seitz *et al.*, 1998; Lipcius *et al.*, 2001, 2002) because in the lower Bay many adult females are caught in water deeper than 10m by the summer/fall pot fishery in the lower Bay, and by the winter dredge fishery. These data are somewhat circumstantial, however; the distribution of actively migrating females may be influenced by both the swifter currents available for transport in deep channels, but also the threat of anoxia, and by the more abundant food available in the shallower margins.

Objective(s)

We will collect detailed information from migrating female crabs to elucidate migratory behaviors, timing, and routes—up to 16,000 records per animal *v.* the 2 data points yielded by standard mark-recapture techniques.

We will intensively observe the horizontal and vertical movements of "focal animals" continuously to provide a detailed picture of how representative crabs interact with their environment.

These observations will be extraordinarily useful in framing hypotheses to be tested by quantitative methods at the population level.

Over 3 years we also will release about 1500 crabs fitted with modules that collect time-stamped records of depth, temperature and salinity (as a surrogate for distance down-Bay). Data uploaded from loggers returned by the fishery, will allow us to determine

a) when females initiate migration,
b) whether certain habitats in the Bay are consistently utilized during migration,
c) whether females usually swim, use ebb currents or walk along the bottom
d) how quickly they move down-Bay, and whether females from the upper and lower Bay can brood in the year of mating,
e) how often females [that remain at large long enough] produce broods, and
f) if females migrate offshore to release larvae (Tankersley *et al.*,1998)

Data will be uploaded from loggers returned by the fishery, and interpreted. We expect recapture of (post)migratory females from shallow-water & deep-water pot fisheries (females *en route* via shallow or deep corridors, respectively), as well as from the winter dredge fishery. The latter will provide data from overwintering females; individuals taken below the York River may have produced one or more broods before capture and yield data about brooding times/intervals (if migration toward the sea to release larvae produces clear salinity traces).

From modest returns (2-5%), we will be able to provide qualitative data on migration behaviors and routes. With higher returns (5-10%), which we confidently expect from previous years' mark-recapture studies (return rates of 5-24%), our conclusions (especially interpretations of migration routes) will become more quantitative and amenable to statistical treatment. We will also have some estimate of fishing pressure. For instance, of eight animals tagged in 1998, seven were returned by the fishery prior to reaching the spawning grounds. Of the 400 crabs release in 1999, >12% were returned by the fishery. In fact, it is the increased effort in the blue crab fishery that enhances the utility of mark/ recapture studies compared to studies conducted in previous decades.

Methods

Novel biotelemetry systems (similar to others developed in our laboratory—Wolcott & Hines, 1989; Wolcott & Hines, 1990; Shirley & Wolcott, 1991; Wolcott, 1995; Clark *et al.*, 1999a, b) are providing continuous data on location, depth and foraging of "focal animals". Each crab is fitted with a microcontroller-based ultrasonic transmitter that incorporates a micromachined silicon pressure transducer and a biopotential amplifier connected to electrodes inserted into the mandibular adductor muscle. It is released and followed by a surface vessel, using a directional hydrophone for tracking and data collection (depth and number of bites taken).

Crab-borne microelectronic dataloggers that we are designing for this project will provide long-term records from enough animals (500/year) for statistically robust testing of hypotheses. Instrumented crabs will be released in a stratified design that will shed light on behavior of the population as a whole. Data uploaded from loggers returned by the fishery (for a reward) will show how depth, salinity and temperature changed over periods as long as two years. Using salinity and temperature as surrogates for distance down-Bay (by comparison with CTD profiles when/where available) will provide estimates of migratory progress. Depth profiles will reveal if crabs migrate in channels or marginal shallows, and whether they perform rhythmic vertical migrations to ride tidal currents. The data may also reveal spawning frequency of females that have reached spawning grounds, if their egg-shedding migrations cross a detectable salinity gradient.

These techniques will reveal what happens in the usual data vacuum between "we released the animal here" and "the animal was caught there". The results will offer insights that can help managers make more informed decisions based on behavior of female crabs.

Additional information on timing and routes of migration is being collected under the Smithsonian Institution subcontract, including tag returns from monthly releases of 100+ females fitted with conventional across-the-back tags. SERC also has made substantial modifications to their largest research vessel to collaborate in a Bay-wide trawl survey of when/where females are found; these data will dovetail with the electronically-obtained behavioral observations.

Results / Utility to Management

A novel salinity sensor, resistant to fouling, has been designed with assistance of the graduate student engaged for this project (Mr. Sean Ramach). It has been tested on the backs of crabs through the warm months at Beaufort NC, in a location famous for intense biofouling, and has maintained calibration very well. To our knowledge this will provide the first long-term data of microhabitat salinity from free-ranging animals.

The datalogger design (hardware and 3000-line microcontroller program) has been completed, and incorporates the following functions:

timekeeping
standby mode (minimizes power and memory use until deployed)
waking at precalculated intervals to collect data
sensing of salinity, depth and temperature
on-board data reduction (temperature-correction, linearization, ranging/scaling)
parsing of data to save only readings showing significant change
logging of data to 64K of non-volatile memory
communication with host (command menu, test/calibration modes, data upload)
conservative power and memory usage—2 years life on lithium coin cell.

A perplexing bug in the prototype logger unfortunately could not be resolved until too late for the 2001 migration season. Because the microcontroller engineers could only offer "it shouldn't be able to do that", several months of diagnostic programming were required to identify what was causing random behaviors and loss of timekeeping that would have been fatal to data integrity. A minor modification has been made to the microcontroller's crystal oscillator, and the circuit now performs flawlessly. Design of printed circuit boards and encapsulation molds, and mass-production of loggers, now can proceed.

In the fall 2001 migrating season we conducted two tracks of focal animals fitted with transmitters telemetering both depth and foraging behavior. The females were released in about 20' depths off the mouth of the Rhode/West Rivers. Unlike animals tracked in July/August of previous years (before we realized that migration begins in October), these crabs tended to move fairly continuously, at over 2 nautical miles per day, in fairly consistent directions that took them progressively deeper. Neither left the bottom; i.e., they gave no evidence of tidal stream transport. They foraged at all times of day and night, apparently opportunistically upon prey encountered en route, rather than engaging in the typical "meander and feed, move long distance, meander and feed" pattern. The first female moved almost due south, and had reached 40' depths by the time tracking was terminated by 20 kt winds. The second moved generally northeast, raising questions about if/when she would respond to cues that would re-direct her down-Bay. She reached 50' depths east of Thomas Point Light by the time tracking was terminated. These tracks suggest that migrating females may indeed use the deeper channels set aside as the "migration corridor". although only dataloggers can provide enough samples for confident interpretation.

Returns from the across-the-back tagging at SERC continue to come in, and the emerging picture is consistent with H. V. Turner's previous thesis work in our laboratory: upper-Bay females remain near their mating sites through the summer, presumably foraging, and begin migrating seaward fairly synchronously around the end of September. Some get all the way to high-salinity waters below the York River in the next 8 weeks, but others interrupt migration and overwinter en route. These individuals are presumed to emerge from the mud and continue migration when waters warm in the following May-June. We hypothesize that few upper-Bay females produce their first brood until the year following mating. The "deepwater migration corridor" apparently is opened to fishing prior to the onset of migration; thus, its closure in the next summer appears to protect only those females that overwinter en route and resume migration in spring.

Future Work

Sufficent components have been purchased for construction of the first 500 loggers. The circuit board design will be revised to increase battery life, and sent out for production. Molds will be created for encapsulating the circuitry, incorporating battery cavities (so returned loggers can be refurbished and re-deployed) and data-download connectors. This will be followed by prototype construction, field testing, and then mass production. In May-June 2002 we plan to deploy some loggers on females that are resuming migration after overwintering up-Bay, on the eastern and western sides of the Bay near Annapolis; and in Sept-Oct 2002 to deploy large numbers (again, on either side) for the 2002 fall migration. As time and weather permit we will attempt to procure additional tracks of focal animals.

In subsequent years (dependent on continued funding) additional releases will be made on each side of the oligohaline zone well above the Bay Bridge (to elucidate behaviors and routes of the real "marathon runners") and in polyhaline waters below the Rappahannock River (to gather data on larval-release migrations and thus brooding frequency). This program of multiple releases will allow us to flesh out the picture of migratory behavior throughout the Chesapeake Bay system.

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Design of a Blue crab fishery dependent survey for the Chesapeake Bay

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Introduction

The lack of accurate information on total removals in numbers due to fishing is a major impediment to effective assessment of the status of the stock. Historical data on hardshell crab commercial landings in weight are generally considered to be fairly accurate, while the landings and effort for the peeler/soft crab fishery may be substantially underestimated (Rugolo, 1998). Currently, estimates of commercial harvest both in Maryland and Virginia are reported in total weight, although the processors and fishermen primarily report landings in number of bushels by market category. Standard conversion factors are applied to estimate landings in weigh. Thus, spatial or temporal variation in the mean weight per bushel by market category could introduce biased in the estimated landings. The estimation of landings in numbers by category is subject to significant uncertainty because no data on size frequency distribution in the landings are collected on a routinely basis.

Uncertainty in the estimated landings by weight, and spatial and temporal variation in mean crab weight in the landings may significantly affect the estimates of total removals in numbers and, consequently, the estimates of the exploitation rate. Absolute estimates of total removals compared with absolute abundance estimates of population size, if available, can provide direct estimates of exploitation rate and fishing mortality (Volstad et al., 2000; Sharov et al., 2002). Representative monthly sampling of the commercial landings at processing facilities, or by observers onboard fishing vessels, is necessary to obtain accurate estimates of removals in numbers or weight. In this study we developed and implemented a pilot study to estimate the characteristics of the commercial landings of blue crabs in Maryland. Representative samples of catches were collected onboard fishing vessels from June through October. We also evaluated data on landings characteristics from a sampling survey of the blue crab commercial fishery conducted in 1988 by the University of Maryland (Stagg and Knotts, 1991).

Objectives

The primary objectives of this study were:

1. Design and implement a pilot survey of the hardshell and peeler blue crab fishery in Maryland.
2. Characterize sex and size composition of blue crab commercial landings in Maryland.
3. Conduct statistical analyses of existing and new data to provide recommendations for survey extension to baywide scale.

Methods

Field data collection in the 2001 Pilot study

A total of six observers collected data on the biological characteristics of landings from June through October in seven Maryland counties: Baltimore, Anne Arundel, Calvert and St Mary's counties on the western shore and Kent, Queen Annes and Talbot counties on the eastern shore. The sampling of catches was conducted from 28 vessels, either by observers onboard vessels or at processing plants during delivery. Data on the blue crab size (carapace width), weight (g), and number of crabs per bushel by market category were collected on board fishing vessel, along with information on time, location, and fisherman identity. Between one and three bushels of crabs was sampled for each market category from each trip. It was not feasible to weigh the bushels onboard the vessels. When the data were collected at processing plants, a total weight of each sampled bushel was recorded in addition to the standard sampling protocol.

Data from the 1988 survey of commercial landings characteristics

In a study of the blue crab commercial fishery conducted in 1988 by the University of Maryland (Stagg and Knotts, 1991) data were collected on the carapace width (CW), number of crabs per bushel, and bushel weight by market category from a group of 19 crab processors located on the eastern shore of Maryland. Each processor was sampled on a monthly basis from July through October, with multiple visits each month. The sampling days for each dealer were randomly selected each month. Data were generally collected from one bushel per market category on each visit. We analyzed these date to evaluate spatial and temporal differences in the characteristics of the landings.

Analytical methods

The 2001 Pilot study and the 1988 survey included multistage cluster sampling (Cochran 1977; Gilbert 1987). The sampling levels and sampling units are indicated in Table 1.

We conducted analysis of variance (ANOVA) to estimate the means of: (1) Carapace width (CW), (2) crab weight (g), (3) number of crabs per bushel, and (4) bushel weight by market category and to test for statistical differences among different levels in the model. The model in the general case is

$$Y_{ijk} = \mu + A_i(M_k) + B_k(A_i * M_k) + C_l(A_i * B_j * M_k) + \varepsilon_{l(ijk)} \qquad (1.1)$$

where Y_{ijkl} is the dependent variable of interest (e.g., mean CW) for bushel l (l=1,2,...,b) collected ,t) during month k (k=1,...,m), μ is a from vessel (or dealer) i (i=1,2,...,v) on trip (day) j (j=1,2,...grand mean, $A_i(M_k)$ represents the dealers sampled within each month , $B_j(A_i * M_k)$ represents different sampling days for each dealer within a month, and $C_l(A_i * B_j * M_k)$ represents the different bushels

Table 1. Sampling stage and sampling units within each month. For each bushel sampled, the number of crabs, bushel weight (1988 only), and carapace width (CW) weight of all crabs were recorded.

Sampling stage	Sampling unit		# units in population	# units in sample	variables
	2001 Pilot	1988 survey			
1	vessel	dealer	V	v	all
2	trips	days	T_i	t_i	all
3	bushels	bushels	B_{ij}	b_{ij}	all
4	Crabs	crabs	C_{ijl}	c_{ijl}	CW, crab weight (g)

sampled on the same day. This is a mixed effects model, where month is considered a fixed level, while the other factors are random effects. This model was applied separately to each market category. Because of the unbalanced design (unequal number of dealers and days within dealers sampled each month) we used a generalized linear model (GLM) to fit the model.

To evaluate the effects of sample sizes at each sampling stage on the precision of an estimate we partitioned the variance into three sources:

Sources of variation	Degrees of freedom	Mean square error
Between different vessels (dealers)	$v-1$	$\sigma^2_{VTB} + b\sigma^2_{VT} + tb\sigma^2_{V}$
Between different days from the same vessels	$v(t-1)$	$\sigma^2_{VTB} + b\sigma^2_{VT}$
Between different bushels on the same day	$vt(b-1)$	σ^2_{VTB}
Total	$vtb-1$	

An estimator for the variance of an estimate $\bar{\bar{\bar{y}}}$ is (e.g., Gilbert 1987):

$$\text{var}(\bar{\bar{\bar{y}}}) = \left(1-\frac{v}{V}\right)\frac{s_V^2}{v} + \frac{v}{V}\left(1-\frac{t}{T}\right)\frac{s_T^2}{vt} + \frac{v}{V}\left(\frac{t}{T}\right)\left(1-\frac{b}{B}\right)\frac{s_B^2}{vtb} \qquad (1.2)$$

where each variance component s_V^2, s_T^2, s_B^2 was estimated from the pilot survey and 1988 data. The fourth sampling stage (crabs within baskets) does not contribute to the variance of the mean since all crabs were measured from each basket selected in the sample and, hence, was omitted for simplicity. Residual maximum likelihood (REML) was used to estimate the variance components between dealers, between days within dealers, and between bushels within days and dealers while examining the significance of the fixed effect of month. Allen et al. (2002) used a similar approach to estimate fish discard from commercial trawlers.

Equation (1.2) was used to evaluate the effect of different sampling strategies on the precision of the estimated mean. The effects of different sampling strategies were evaluated by estimating the expected standard error (SE) and relative standard error (RSE=SE/mean) for different (fixed) sample sizes of dealers, days within dealers, and baskets within dealers and days. In practice, only a small fraction of sampling units would be selected each month, and thus the finite population correction factors (Cochran 1977) can generally be ignored.

Results

Landings characteristics

We present the results for 1988 and 2001 surveys for four market categories, males 1, males 2, females and mixed crabs.

The 2001 pilot survey of commercial landings

Summary landings characteristics by month and market category are in Table 2.

The sampling intensity in the pilot study generally produced highly accurate estimates for all variables of interest, with relative standard errors across months generally less than 5%. The means for each market category varied by month, but were not significantly different at the 95% level (ANOVA, $p<0.05$).

variable	Month	market category 1Males mean	Error	2Males mean	Error	Females mean	Error	Mixed Mean	Error
	6	97.75	3.77	n/a	n/a	106.33	3.87	84.00	11.00
number	7	87.07	2.49	122.58	1.5	94.03	2.57	86.00	7.19
of crabs	8	89.60	2.04	103.96	1.7	106.92	2.37	105.56	5.85
per bushel	9	76.51	2.89	98.33	1.8	102.25	2.17	107.66	4.88
	10	88.85	2.14	96.50	0.9	95.75	1.74	90.39	7.58
	overall	86.77	1.47	93.73	3.46	98.07	1.91	93.16	2.69
	6	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
bushel	7	n/a	n/a	41.50	n/a	n/a	n/a	n/a	n/a
weight	8	36.29	1.09	n/a	n/a	38.50	0.71	n/a	n/a
	9	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
	10	40.50	1.84	n/a	n/a	43.00	0.75	n/a	n/a
	overall	37.09	1.46	41.50	1.50	40.50	1.38	n/a	n/a
	6	154.6	0.68	n/a	n/a	155.54	0.71	158.12	0.7
carapace	7	156.9	0.39	139.9	0.41	156.48	0.45	152.46	0.97
width,	8	151.6	0.36	141.58	0.61	158.19	1.68	153.33	0.57
mm	9	158.0	0.54	140.65	0.55	159.04	0.85	151.97	0.38
	10	163.2	0.44	145.40	0.45	159.06	0.49	151.22	0.62
	overall	156.27	0.13	143.59	0.17	154.50	0.12	154.47	0.16
	7	n/a	n/a	0.29	n/a	n/a	n/a	n/a	n/a
crab weight	8	0.37	0.03	n/a	n/a	0.31	0.00	n/a	n/a
lb	9	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
	10	0.54	0.04	n/a	n/a	0.43	0.00	n/a	n/a
	overall	0.41	0.03	0.29	0.01	0.37	0.03	n/a	n/a

Table 2. Means of number of crabs per bushel, carapace width (CW), and crab weight, with associated standard errors (SE) based on the 2001 survey of commercial landings.

The 1988 survey of commercial landings

Summary landings characteristics by month and market category are in Table 3. The estimated mean number of crabs ($\bar{N}$) with each market by month does not significantly differ at the 95% level, but significant differences occur between market categories (ANOVA, $p<0.05$). The monthly variation in $\bar{N}$ is likely due to sampling variability caused by variation in crab sorting accuracy. In general, the mean crab size (CW) and weight within market category exhibited minimal variation over the season, but the size (CW) in the male1 category was significantly higher in July as compared to the other months.

		Market category							
variable		1Males		2Males		Females		Mixed	
	month	mean	St. error	mean	St. error	mean	St. error	mean	St. error
number of crabs per bushel	7	89.2	1.6	109.4	1.3	121.5	n/a	104.3	2.2
	8	93.7	1.3	114.3	1.3	113.0	n/a	115.0	2.0
	9	88.0	1.8	106.0	2.2	104.7	n/a	101.1	2.0
	10	91.9	2.2	107.8	1.9	113.2	n/a	97.7	3.1
	total	89.5	1.5	109.2	2.2	115.0	2.3	101.5	3.0
bushel weight	7	40.2	0.2	39.6	0.2	41.5	n/a	36.7	2.4
	8	41.8	0.2	39.2	0.2	40.6	n/a	39.1	2.2
	9	38.8	0.2	37.0	0.3	36.0	n/a	35.6	2.1
	10	40.3	0.3	37.2	0.3	37.7	n/a	32.5	3.1
	total	40.3	0.4	38.7	0.6	39.2	0.7	36.0	1.0
carapace width, mm	7	150.20	0.26	136.00	0.19	147.30	0.24	136.80	0.33
	8	146.10	0.19	133.00	0.16	149.20	0.23	135.10	0.27
	9	147.20	0.26	136.00	0.29	145.60	0.25	137.90	0.43
	10	147.40	0.34	136.00	0.26	146.80	0.25	143.50	0.61
	total	146.71	0.13	134.52	0.10	146.01	0.11	136.81	0.15
crab weight lb	7	0.42	0.005	0.34	0.003	0.32	n/a	0.33	0.020
	8	0.42	0.004	0.33	0.002	0.34	n/a	0.32	0.018
	9	0.43	0.005	0.34	0.004	0.32	n/a	0.34	0.017
	10	0.42	0.007	0.33	0.004	0.32	n/a	0.32	0.026
	total	0.42	0.006	0.33	0.004	0.32	n/a	0.33	0.007

Table 3. Means of number of crabs per bushel, bushel weight, carapace width, and crab weight with associated standard errors (St. error) for the 1988 survey of commercial landings.

Estimation of landings in weight and numbers.

Blue crab landings are generally reported either in number of bushels, weight in pounds or number of crabs for each market category. Official Maryland landings are recorded in pounds. Landings that are reported to MD DNR in bushels or numbers are usually converted into weight in pounds using a fixed conversion factor of 40 pounds or 84 crabs per bushel. We estimated Maryland hard crab landings in weight and number of crabs for 1988 and 2001 based on landings characteristics obtained in this study (Tables 2 and 3) and compared these estimates with the official landings for those years. The estimated landings in weight by category and overall were similar to the official landings for both years. The estimated harvest in numbers of crabs was significantly higher in both years, suggesting a bias when a fixed conversion factor is used (Fig. 1, 2). The mean number of crabs per bushel in each category differed among years, and generally exceeded 84 crabs per bushel (Figure 3). The number of crabs per bushel for male 2 and female crabs were significantly lower in 2001 as compared to 1988 (Figure 3).

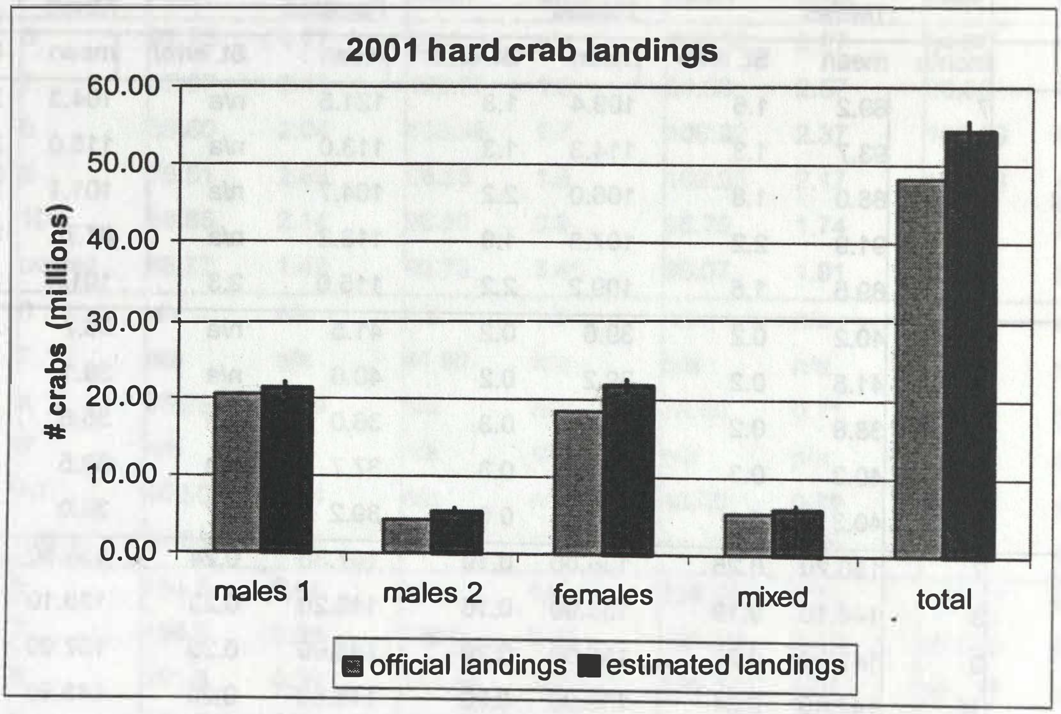

Figure 1. Official and estimated landings of hard crabs in numbers in Maryland in 2001.

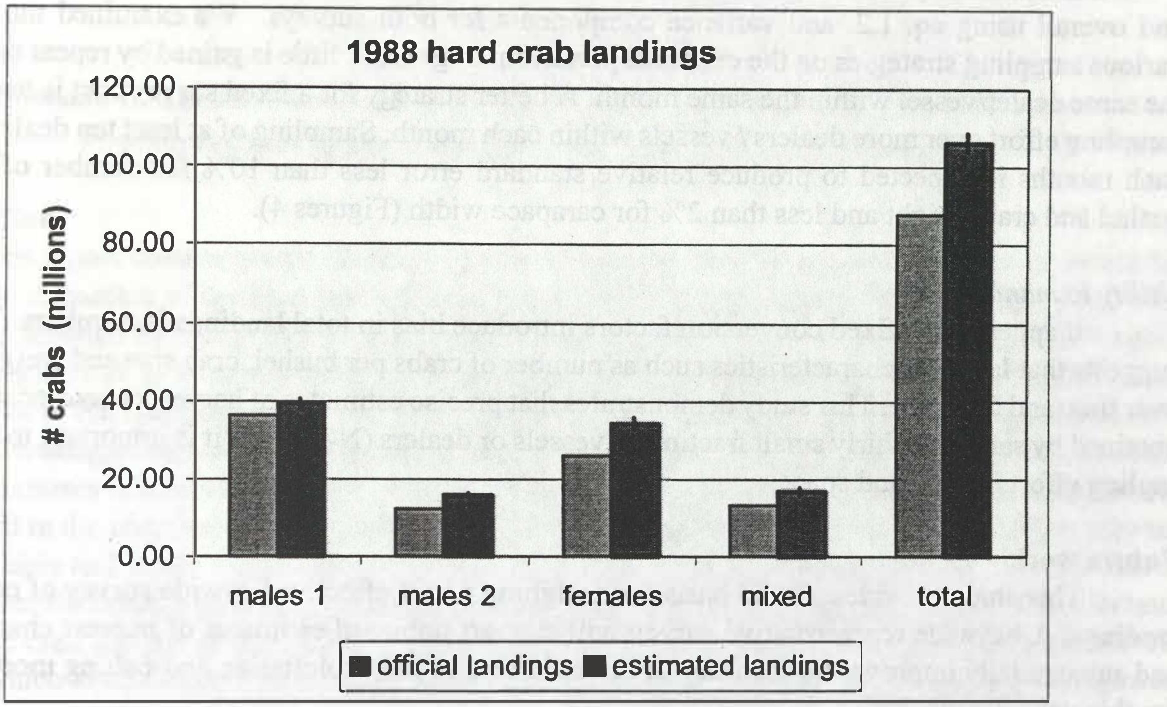

Figure 2. Official and estimated hard crab landings in numbers in 1988

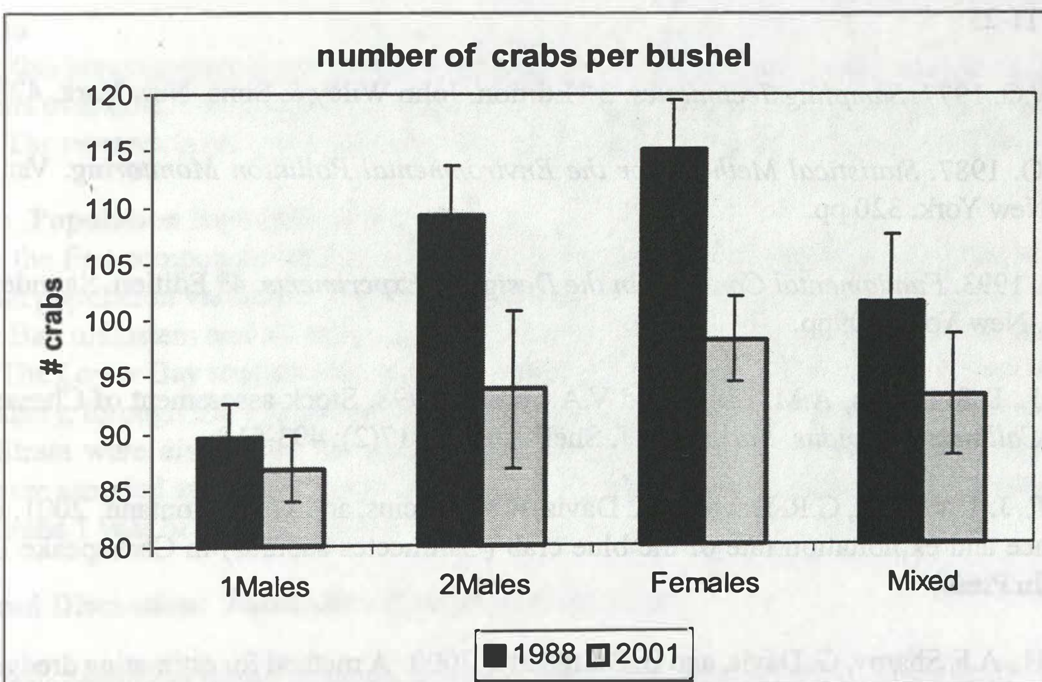

Figure 3. Number of crabs per bushel by market category in 1988 and 2001 commercial landings.

Evaluation of the sampling strategy

We estimated expected relative standard error across months for each parameter by market category and overall using eq. 1.2. and variance components for both surveys. We examined the effects of various sampling strategies on the expected precision. In general, little is gained by repeat sampling of the same dealer/vessel within the same month. A better strategy for a fixed survey cost is to spread the sampling effort over more dealers / vessels within each month. Sampling of at least ten dealers or more each months is expected to produce relative standard error less than 10% for number of crabs per bushel and crab weight and less than 2% for carapace width (Figures 4).

Utility to management

It appears that fixed conversion factors introduce bias in total landings in numbers. This study suggests that landings characteristics such as number of crabs per bushel, crab size and weight change over time and /or space. This study demonstrates that precise estimates of harvest characteristics can be obtained by sampling fairly small fraction of vessels or dealers (N>10) but it is important to spread the sapling effort in time and space.

Future work

This study provides a solid basis for designing a cost effective baywide survey of commercial landings. A baywide representative survey will support unbiased estimates of harvest characteristics and substantially improve the accuracy of the estimates of the exploitation and fishing mortality rates for this valuable resource.

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Population Status and Conservation of Chesapeake Bay Blue Crab

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Introduction

This report documents the findings of a collaborative, baywide research program to assess the population dynamics of the blue crab (*Callinectes sapidus*) in Chesapeake Bay. The study has been conducted through the cooperation of the Virginia Institute of Marine Science (VIMS), the Virginia Marine Resources Commission (VMRC), Chesapeake Biological Laboratory (CBL), and the Maryland Department of Natural Resources (MDNR). The program was initiated in 1987 in response to serious public and management concerns about the apparent high levels of fishing effort, a cyclical catch record, and the unknown relationship between fishing effort, the stock and the environment. This concern was manifested in the idea that the present harvesting of the Chesapeake Bay blue crab population may not be sustainable and might lead to the eventual collapse of the stock, as appears to have been the fate of several other historically important Chesapeake Bay fishery resources. Despite the economic importance of the blue crab and the need to maintain stable harvests, a baywide estimate of stock abundance was lacking, which in turn limited the formulation of sound management policy. Effective stock management depends upon a clear understanding of blue crab population dynamics and the stock response to exploitation. Estimates of abundance and rates of recruitment are required to assess the current status of the fishery with respect to biological and economic optima and to develop prudent management strategies.

Objectives

In this investigation of the blue crab population in Chesapeake Bay, we examined (1) population fluctuations over time, and (2) spatial dynamics of the spawning stock in a protected sanctuary-corridor network. The research is being published as Lipcius et al. (2002a) and Lipcius et al. (2002b), respectively.

Methods: Population fluctuations over time

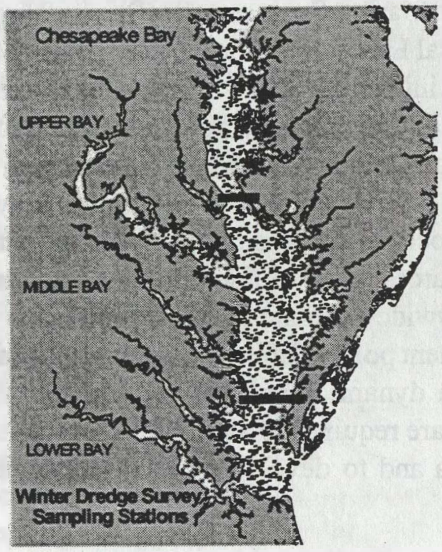
In the first component with the Chesapeake Bay blue crab population in winter, we quantified interannual population variation. The sampling strata for the Baywide winter dredge survey included (i) Upper Bay mainstem and all tributaries, (ii) Middle Bay mainstem, and (iii) Lower Bay mainstem (Fig. 1). The Lower Bay stratum was sampled monthly from November, before the onset of the winter dredge fishery, through the fishery's closing in March; approximately 50 stations were sampled each month. Strata were divided by the solid horizontal lines slicing Chesapeake Bay. Typically 1500 stations were sampled annually. The 1+ segment of the population (i.e. crabs > 60 mm carapace width) includes crabs 1 year of age and older.

Results and Discussion: Population fluctuations over time

Baywide indices for all crabs decreased from 1990 to 2001 (Fig. 2). Age 0 (male and female) crabs exhibited a decreasing, non-significant trend, though the last four years have been four of the five lowest of the sampling survey (Fig. 2). Age 1 + (male and female) crabs and adult females decreased significantly (Fig. 2) throughout Chesapeake Bay. Thus, the population remains in a low phase, which requires limitation of fishing effort to prevent population collapse.

Figure 1. Representative sampling stations by the winter dredge survey in Chesapeake Bay for the 1990-1991 winter season. The sampling strata include the (i) Upper Bay mainstem and all tributaries, (ii) Middle Bay mainstem, and (iii) Lower Bay mainstem. The Lower Bay stratum was sampled monthly from November, before the onset of the winter dredge fishery, through the fishery's closing in March; approximately 50 stations were sampled each month. Strata are divided by the solid horizontal lines slicing Chesapeake Bay. Typically 1500 stations were sampled annually.

Figure 1. Winter Dredge Survey Coverage



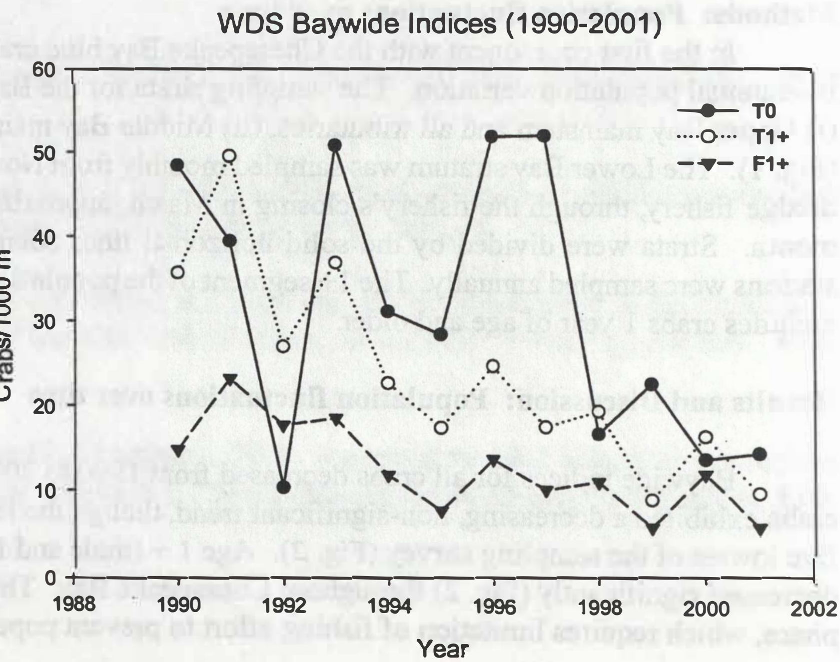


Figure 1. Dredge Survey. Baywide density of AGe 0 crabs (T0), male and female 1+ crabs (T1+), and adult females (F1+) in Chesapeake Bay (1992-2001)

Methods: Spatial dynamics of the spawning stock in a protected spawning sanctuary and corridor

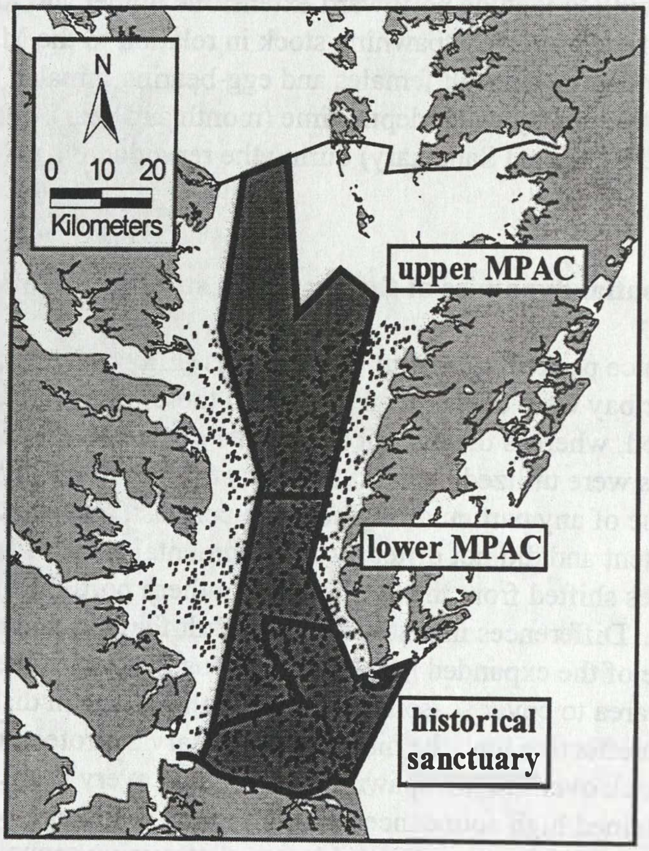
In lower Chesapeake Bay, a 172,235 ha marine protected area and corridor (MPAC) was recently established to protect blue crab adult females either en route to or at the spawning grounds during the reproductive period (Fig. 3). The MPAC was justified due to a recent substantial decline in spawning stock biomass; it was situated in waters deeper than 10 m throughout the lower bay due to the high abundances of adult females in this zone; and, it was an expansion of a historical spawning sanctuary near the bay mouth to include northward extensions (upper and lower MPACs). We examined spatial dynamics of the blue crab spawning stock in relation to the MPAC through analyses of trawl survey data (abundances of adult females and egg-bearing females from 1989-1997 and 1995-1997, respectively) partitioned by water depth, time (month and year), and spatial zone (upper MPAC, lower MPAC, MPAC Historical Sanctuary) during the reproductive period (June-September).

Results and Discussion: Spatial dynamics of the spawning stock in a protected spawning sanctuary and corridor

Adult female abundance peaked at 6-14 m water depths (Fig. 4). Consequently, nearly half of all adult females in the lower bay were deeper than 10 m, and therefore protected by the MPAC during the reproductive period, whereas the historical sanctuary protected about 1/3 that of the MPAC. All MPAC segments were utilized by adult females at different times of the spawning season, without consistent use of any particular segment. In contrast, abundance patterns of egg-bearing females were consistent and did not differ by developmental stage of the eggs. Peak abundances of egg-bearing females shifted from the northern to southern portions of the MPAC as the spawning season progressed. Differences in distribution of adult females and egg-bearing females demonstrated the importance of the expanded MPAC to the conservation of the spawning stock, which requires an extensive area to cover seasonal and yearly alterations in distribution. The expanded MPAC is much more effective than the historical sanctuary at protecting a consistent fraction of the blue crab spawning stock over the full spawning season and every year. Both the lower MPAC and historical sanctuary contained high abundances of adult females and egg-bearing females, and these segments therefore potentially function as corridors and spawning grounds. In contrast, whereas adult females were equally abundant in all MPAC segments, egg-bearing females were rarely common in the upper MPAC segment. Hence, the upper MPAC serves primarily as a corridor for females migrating to spawn or hatch their egg masses in the lower MPAC and historical sanctuary. The MPAC protects a major fraction of the spawning stock and spawning grounds both seasonally and yearly, and it encompasses a dispersal corridor for adult females in the deeper waters of Chesapeake Bay. The MPAC therefore serves as a foundation for long-term protection of the blue crab spawning stock, and should be utilized concurrently with complementary management measures to conserve the blue crab population in Chesapeake Bay.

Figure 3. Chesapeake Bay marine protected area and corridor (MPAC, shaded area in bay), and trawl survey sampling stations (dots). Progressing from north to south in the MPAC, the first horizontal line splits the upper MPAC and lower MPAC. Near the southern end of the MPAC, the crooked boundary separates the upper MPAC from the historical spawning sanctuary. The line at the northern end of the MPAC defines the Maryland and Virginia border.

Marine Protected Area and Corridor (MPAC)



Future work

We recommend that the MPAC be expanded to include a larger fraction of the population (e.g., nurseries and migration routes) and that evaluation of the MPAC and other management measures be conducted.

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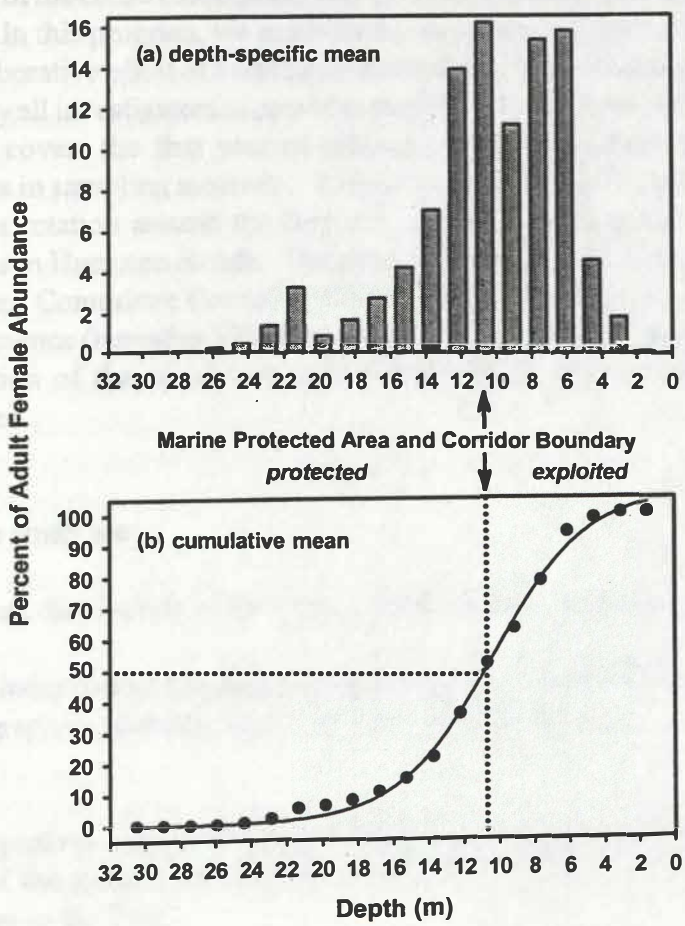
Figure 4. Depth-specific mean (a) and cumulative mean (b) percent of adult female abundance (normalized by year) as a function of water depth in lower Chesapeake Bay. The depth boundary of the marine protected area and corridor is indicated by the arrows between the two graphs, and by the vertical dotted line at 10.7 m depth in graph b.



Fishery independent standing stock surveys of hard clam populations in the Chesapeake Bay and a comparison with continuing estimates from fishery dependent data

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Introduction

The hard clam, *Mercenaria mercenaria*, supports one of the most valuable fisheries in the Virginia portion of the Chesapeake Bay. Unlike many Virginia fisheries it remained a fairly stable fishery for an extended number of years. In recent years, and notably in the past decade, with the decline of the oyster fishery displaced watermen have moved to clam harvesting as an alternate source of income. The result has been increasing concern for the clam stocks and a gradual decline in catch per unit effort by active fishermen. A number of management options have been discussed and are employed in the fishery including size, time and area limits, as well as formation of broodstock sanctuaries. Clam habitat in the Bay is continually threatened and disturbed by activity associated with shoreline industry - dredging for shipping and dock access takes a continuing toll on the resource with little long term planning for appropriate mitigation. Recent mitigation efforts have employed a sanctuary program.

Despite a number of small-scale surveys of clam stocks in the Bay there has been only one recent effort focused on stock assessment for management purposes (Wesson, 1995) and no comprehensive study of the entire Chesapeake Bay hard clam stocks. The lack of such data compromises management efforts. In this program, we examine the extensive area occupied by extant stocks of hard clams through a collaborative effort of investigators from Virginia agencies using well proven techniques that have been used by all investigators in previous studies of both oyster and hard clam stock assessment efforts. This report covers the first year of effort in what we propose to be a multi-year program because of limitations in sampling methods. Within Virginia, we propose a long-term plan to examine areas of interest on a rotation around the Bay but include more frequent return to the most heavily exploited clam stocks in Hampton Roads. The program is supported by direct funds from Chesapeake Bay Stock Assessment Committee (hereafter CBSAC), and matching funds provided by the Virginia Institute of Marine Science (hereafter VIMS) and the Virginia Marine Resource Commission (hereafter VMRC). Participation of the regulatory agencies (VMRC) insures rapid availability of data for management purposes.

Objectives

The objectives of the study are:

1. Describe the current distribution of hard clam stocks in the Virginia portion of the Chesapeake Bay.

2. Complete fishery independent standing stock assessments of these stocks including descriptions, by area, of stock demographics (density, length, height, weight, and age).

In the case of both Objectives 1 and 2 we propose in depth comparisons with historical data on distribution and demographics of the species from studies in the 1960's and 1970's as barometers of long-term environmental change in the Bay.

3. Compare fishery independent estimates with continuing estimates of stock size generated from catch and effort data as described in mandatory reporting by commercial fishermen.

4. Prepare the results of both fishery dependent and fishery independent studies in a format useful to resource managers, together with suggestions for optimal resource management.

Methods

Effort during the year from September 2000 through August 2001 has focused on objectives 1 and 2. To this end we have obtained the original field data sheets for the clam studies of Loesch and Haven (1973a, b), Fritz and Haven (1973), Haven and Kendall (1974, 1975), and Wesson (1995). These constitute significant quantitative studies of clam distribution to date in the Virginia portion of the Bay. They used a mixture of patent tongs and dredges in varying designs with varying statistical rigor, and focus on the James and York Rivers and Mobjack Bay – areas which today support the bulk of the fishery in a seasonal rotation of open and closed exploitation areas (described in detail in regulation VAC20-560-10, see http://www.state.va.us/mrc/fr560.htm, full citation in literature under VMRC 2000). While there is extensive documentation of clams elsewhere in the Bay (review by Roegner and Mann 1991), this historical record covers the regions that remain the focus of current fishing activity in Hampton Roads, Poquoson, the Lower York River and Mobjack Bay.

The current study proposed and is employing a stratified random sampling design with the individual samples (= stations) being collected by a hydraulic patent tong of one square meter opening (see below). The application of stratified random sampling is optimized by use of appropriate strata and a central purpose in our review of historical data was to examine option for strata (the exploited distributions cover regions of notable salinity clines and small scales spatial variation in sediment type and bathymetry) rather than simply adopt previously employed sampling regions, which were not always based on stratified random areas. In pursuing this goal we exhumed not just the written summaries from the above cited reports, but also the original data sheets from the field collections. Only a few of these datasets had been archived in digital form and then with limited quality control. After due consideration, we decided to digitally archive the bulk of the historical data sets in support of the current effort. This had not been an explicit component of the original proposal; however, there is considerable advantage to be gained from such a digitized archive.

These include the ability to present the entire historical dataset, including that to be collected as part of this effort, in a GIS format using common terminology (e.g., latitude and longitude values in consistent format), to potentially use the GIS tools to develop strata given the availability of bathymetry and substrate maps in the same format, and possibly the ability to estimate standing stocks from all surveys by uniform approaches using spatial statistics (kriging) subsumed in GIS software. This latter option for use of spatial statistics is being considered (together with our CBSAC funded oyster data) by a graduate student under other funding. The end product will, of course, be available, to CBSAC and resource managers.

At each sampling station the bottom was sampled with a hydraulic patent tong with coverage of one square meter. Water depth (from the vessel sounding) and substrate type (direct observation of sample) were recorded for each station. Water temperature was recorded at every tenth station, and a water sample collected for subsequent determination of salinity. The entire tong contents for each station were retrieved and returned to the cull board of the vessel (this often being in excess of 50 kg of material including substrate). The patent tong and cull board was attended by two experienced crew members who effected a preliminary sorting of the material for molluscs within the sample. The preliminary sorting included a significant amount of mud and/or shell. The results of this preliminary sorting were transferred to a second cull board, attended by three or four field technicians where the entire sample was carefully washed and all molluscs (and in some instances other organisms of interest) were carefully separated during washing of the sample. Molluscs were separated by species. The length (maximum dimension parallel to the hinge) and height (maximum dimension from hinge to the ventral margin) for each specimen was recorded to the nearest mm. All mollusc specimens were retained live for return to the Gloucester Point laboratory. In addition to hard clam (*Mercenaria mercenaria)* data was also collected on distribution and demographics of the razor clams (*Tagelus plebeius* and *Ensis directus*), the angel wing clam (*Cyrtopleura costata*) and the soft shell clams (*Mya arenaria*).

CBSAC provided funds for a high-end PC with database software to support this program. This was purchased early in the funding year and is on line with ARCINFO software. It is employed in concert with an Apple G3 dedicated database unit running FileMaker software to develop the historical archive. Data entry and quality control of the historical data was a mid year focus of activity and continues as more historical data is identified from hand records. The field assessment component of the program was effected in the mid summer period of 2001 to accommodate the prior commitment of the proposed platform (VMRC vessel R/V Baylor) and crew to oyster stock assessment (part CBSAC funded) and VMRC oyster replenishment through the winter months of 2000-2001.

In addition to exhuming the historical distribution data we have also uncovered data from a numbered of previously unpublished growth studies for hard clams effected by the same group of investigators responsible for the various surveys of the 1970's and 80's (work of Haven, Loesch, Kendall and collaborators). When these are examined in concert with a critical hard clam growth and age study of that period (M.A. thesis by Fritz, 1982 which resulted in Fritz and Haven 1983 publication) the option emerged to develop a production model for hard clams in the Bay during the period of the 1970's and 80's. Addition of a growth component to the current program (by representative examination of shell growth lines by acetate peel or comparable techniques) can provide a similar model with a time delay of approximately 25 years.

The utility of production models over and above simple stock estimators has been well established by NMFS in management of offshore clam resources (*Spisula solidissima* and *Arctica islandica*) in the Mid Atlantic Bight and would be a welcome addition to the arsenal of tools available to managers of the Bay hard clam stock. This opportunity will be discussed later in the current document as details of results from the current funding are presented.

Finally, as the partner program in oyster stock assessment for the 2000-2001 year (also supported by contributions from CBSAC and EPA Bay Program) approached completion personnel effort (which is shared between the programs in the VIMS component) was devoted to working with the Statistics Division at VMRC on options to estimate standing stock levels using DeLury analysis on catch and effort data. As mentioned earlier the current fishery operates in a rotation of four exploited regions. Mandatory reporting of catch is required. The current database for this reporting by region is essentially complete from 1993 onwards, resulting in 32 data compilation exercises (4 regions in sequence over 8 years, 1993-2000 inclusive in that 2001 data is still in the quality control process). We are still in the process of effecting this data compilation. Data reporting is by numerically identified (coded) region on the reporting forms. Each of the designated exploitation regions (VMRC 2000) encompasses several of these numerical codes. Further, the evolution of the rotationally exploited regions has involved minor changes in boundaries and periods of exploitation over the 1993-present time frame. The sequence of work currently underway is to recreate with the assistance of the mapping personnel at VMRC, spatial maps of the exploited areas since 1993, from that define which coded reported regions are included or excluded at any one time, then sort the database to include only the appropriate codes in one of the previously mentioned 32 data compilation exercise. We are in the midst of this process at the current time. Although some reports distinguish size classes of clam, this distinction is not universal.

The target output from these exercises for DeLury analysis is therefore a simple, four column listing of day, area, effort and catch. This is generated as individual records with the identifiers of the vessel captain excluded for anonymity reasons.

Results / Utility to Management

Field estimates of clam standing stock: Progress in 2001

Field efforts in the initial funding year focused on Hampton Roads. Logistics limitations of vessel and crew availability, in addition to funding dictated that this region would consume the 2000-2001 funding effort. The remaining geographical regions will be covered in subsequent funding cycles. Figure 1 illustrates the sampling strata developed for the Hampton Roads region. Strata were based in part on bathymetry with the major navigation channel separating the north and south strata. This is also in part a sedimentary division, especially in the upstream region above the James River Bridge and state route 258. Finally, a salinity gradient exists from west to east along the region of active examination. When all variables were considered a sampling grid was constructed as shown on Figure 1. The large number of strata also facilitated data management purposes in that each stratum was approximately one day worth of field effort.

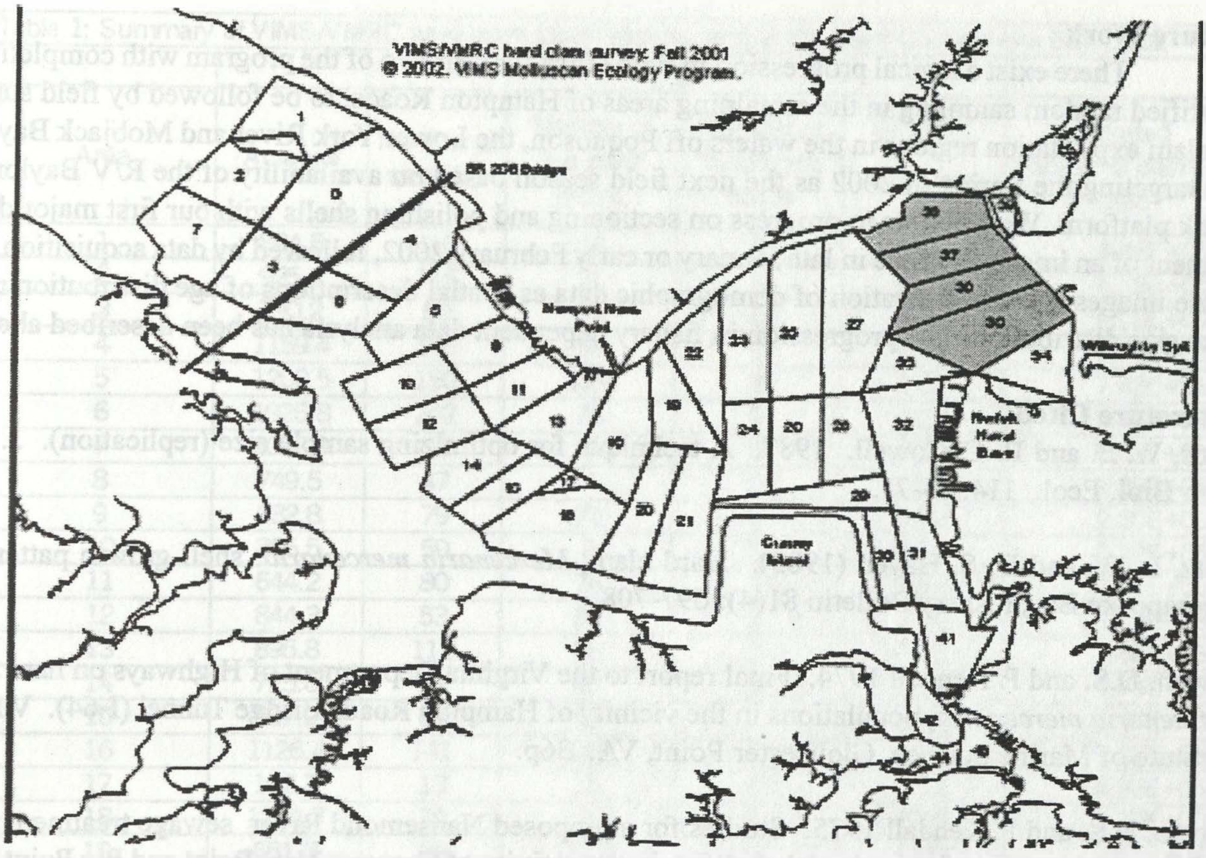
Individual stations within each stratum were identified by random number locations on a grid covering each stratum. A station list was generated for each day together with LAT and LONG coordinates. Bros and Cowell (1987) provide a method for estimation of minimum sample size (number of stations) within each stratum. This approach has been employed successfully for oyster stock assessment in the James River since 1993. This is an iterative procedure in that an initial data set is required to investigate the relationship between number of stations and standard error of the mean. Thus initial sampling should comfortably over sample or the procedure must be effected in the field in real time. The only limitation of the real time application in the current context is the lack of recent information on uniformity of habitat within each stratum.

While effort is made in designing strata to seek within strata uniformity this is not assured until the initial coverage is made. Thus a protocol of over sampling was employed with an initial sampling rate of one station per 10-15 acres. Table 1 provides companion data to Figure 1 with a listing of acreage and number of stations occupied for each Area (= strata) sampled. Note that strata numbers 35-38 inclusive were not examined in the 2000-2001 funding year. These will be included in the 2001-2002 funding year, together with previously listed regions outside of Hampton Roads.

Spatial aggregation is evident from Table 1. An overall mean density across all strata of 0.93 live hard clams m^{-2} was recorded with mean individual strata values varying from 0.0 to 8.38 m^{-2}, the latter being recorded in Area (= strata) number 19. Densities in excess of 2.0 m^{-2} were also recorded in Area (=strata) numbers 22, 23, 25, and 27. The region north of the navigation channel between Newport News Small Boat Harbor and the mouth of Hampton Creek thus forms a continuous region of high density hard clams. Only one region upstream of Newport News Point, Area 5, had mean clam density of > 1.0 hard clams m^{-2}. None the less clams were present in limited numbers upstream of the James River Bridge on the north side of the navigation channel. Densities in excess of 1.5 hard clams m^{-2} were also observed in Area 24, which includes the Middle Ground Light region, and Area 40, in the mouth of the Lafayette River. Areas to the south of the navigation channel between the James River Bridge and the western boundary of Craney Island were generally low. Soft muds were often encountered in these Areas. Low densities were also encountered in the mouth of the Elizabeth River (Areas 29-32 inclusive).

Estimated standing stocks of hard clams per Area varies between zero and > 10^7. The estimated total standing stock for all Areas examined is 1.21×10^8 individual hard clams with approximately 60% of these occurring in Area (= strata) numbers 19, 22, 23, 25, and 27. At the time of preparation of this

Figure 1. Sampling areas occupied during the VIMS/VMRC hard clam stock assessment. Numbers with polygons represent area designations. Unshaded area polygons have been sampled in 2001. Shaded areas will be sampled in 2002.



report analysis of population demographics is still in progress. Complete description of demographics will be discussed in the next report (schedule for 3/2002).

Development of production models: Progress on 2000-2001.

As mentioned earlier the historical database is being continually developed. Development of a current growth component will be based on a subsample of individual hard clams from the live specimens collected in the Areas described above. Over 1500 individual hard clams of all sizes, whose individual site of origin can be identified to sample Area, have been opened and the soft tissues removed. The tissues have been provided to a collaborating program in the VIMS Aquaculture and Breeding Center as the basis or investigation of introgression of genes from cultured hard clams into natural hard clam populations in the Hampton Roads region. Funding for the molecular portion of this study is being sought from other federal sources. The valves from each specimen have been air-dried, labeled to identify source, and archived. A shell cutting saw has been purchased, together with a polishing wheel (a $2500 purchase with VIMS funds) to facilitate preparation of shell sections for counting of growth rings (methods in Fritz and Haven, 1993). A small number of shells were initially examined for the purpose of identifying the optimal orientation of sectioning. A protocol for polishing and specimen examination has been developed (we intend to use image analysis for this process having gained considerable experience in morphometric application in recent studies of gastropod biology) and the first 200 of a projected 350 specimens have been sectioned for subsequent polishing. We intend to complete sectioning of this group and continue polishing during the remainder of the current calendar year.

Development of fishery dependent estimates of standing stock: Progress on 2000-2001.

Progress on this component of the study has been summarized in the Methods section of the text. In brief, we are still in data reduction and compilation prior to analysis.

Future Work

There exist a logical progression in field effort for year two of the program with completion of stratified random sampling in the remaining areas of Hampton Roads, to be followed by field surveys of clam exploitation regions in the waters off Poquoson, the Lower York River and Mobjack Bay. We are targeting the Spring of 2002 as the next field season based on availability of the R/V Baylor as a work platform. We continue to progress on sectioning and polishing shells with our first major development of an image database in late January or early February 2002, followed by data acquisition from those images and the generation of demographic data as spatial descriptions of age distribution rather than size distribution. The progression in fishery dependent data analysis has been described above.

Literature Cited

Bros, W. E. and B. C. Cowell. 1987. A technique for optimizing sample size (replication). J. Exp. Mar. Biol. Ecol. 114: 63-71.

Fritz, L, W. and D, S, Haven (1983). Hard clam, *Mercenaria mercenaria*: shell growth patterns in Chesapeake Bay, Fishery Bulletin 81(4): 697-708.

Haven, D.S. and P. Kendall 1974. Final report to the Virginia Department of Highways on hard clam, *Mercenaria mercenaria*, populations in the vicinity of Hampton Roads Bridge Tunnel (I-64). Virginia Institute of Marine Science, Gloucester Point, VA. 36p.

Haven, D.S. and P. Kendall 1975. Studies for a proposed Nansemond River sewage treatment plant. Volume 4. A survey of commercial shellfish in the vicinity of Newport New Point and Pig Point in the lower James River. Virginia Institute of Marine Science, Gloucester Point, VA. 30p.

Loesch, J, G. and D. S. Haven (1973), "Estimated growth functions and size-age relationships of the hard clam, *Mercenaria mercenaria*, in the York River, Virginia," The Veliger 16(1): 76-81.

Loesch, J, G, and D, S, Haven (1973), "Estimates of hard clam abundance from hydraulic escalator samples by the Leslie method," Chesapeake Science 14(3): 216-216.

Roegner, G. C. and R. Mann. 1991. The Hard Shell Clam. in; Habitat Requirements for Chesapeake Bay Living Resources. S. Funderburk, J. A. Mihursky. S. J. Jordan, D. Riley (Eds.) U.S.F.W.S. Annapolis, MD.

VMRC, 2000. A regulation is promulgated pursuant to the authority contained in §§ 28.2-201 and 28.2-503 of the Code of Virginia. This regulation amends Regulation 4 VAC 20-560-10 et seq. which was adopted on November 23, 1998 and made effective on December 1, 1998. The effective date of this regulation is December 1, 2000. Full text available at : http://www.state.va.us/mrc/fr560.htm

Wesson, J.A. 1995. Fishery independent stock assessment of Virginia's clam population of the Chesapeake Bay. Final report to Virginia Coastal Resources Management Program, Dept. of Environmental Quality. NOAA Grant # NA37OZ 036-01. 21p.

Table 1: Summary of VIMS/VMRC hard clam stock assessment in the lower Chesapeake Bay, 2001						
Area	Acreage	Number of samples	Number of live hard clams	Number of hard clam boxes	Number of live hard clams per sq. m	Estimated number of clams in area
1	894.5	113	14	0	0.12	4.48E+05
2	925.4	116	21	0	0.18	6.78E+05
3	790.2	50	0	0	0.00	0.00E+00
4	1159.4	145	54	0	0.37	1.75E+06
5	1200.5	150	229	30	1.53	7.42E+06
6	1926.8	242	76	9	0.31	2.45E+06
7	1098.9	69	0	0	0.00	0.00E+00
8	749.5	47	4	0	0.09	2.58E+05
9	632.8	79	71	9	0.90	2.30E+06
10	805.5	50	8	0	0.16	5.22E+05
11	644.2	80	74	0	0.93	2.41E+06
12	844.3	53	35	3	0.66	2.26E+06
13	895.8	112	58	3	0.52	1.88E+06
14	725.6	91	45	0	0.49	1.45E+06
15	597.2	74	13	3	0.18	4.25E+05
16	1126.4	141	149	5	1.06	4.82E+06
17	102.7	13	15	0	1.15	4.80E+05
18	1248.7	78	0	0	0.00	0.00E+00
19	681.8	85	712	4	8.38	2.31E+07
20	902.7	57	17	0	0.30	1.09E+06
21	1118.9	70	20	1	0.29	1.29E+06
22	731.3	92	241	3	2.62	7.75E+06
23	986.5	123	358	0	2.91	1.16E+07
24	722.6	45	70	1	1.56	4.55E+06
25	1253.4	157	469	3	2.99	1.52E+07
26	741.5	47	46	0	0.98	2.94E+06
27	1567.5	196	442	2	2.26	1.43E+07
28	711.7	45	27	0	0.60	1.73E+06
29	544	34	9	0	0.26	5.83E+05
30	452.3	28	1	0	0.04	6.54E+04
31	649.5	46	29	0	0.63	1.66E+06
32	1209.7	41	0	0	0.00	0.00E+00
33	466.4	58	33	0	0.57	1.07E+06
34	645.2	81	39	0	0.48	1.26E+06
39	112.2	16	12	0	0.75	3.41E+05
40	74.99	9	17	0	1.89	5.73E+05
41	672.99	40	21	0	0.53	1.43E+06
42	362.7	41	14	0	0.34	5.01E+05
43	367.7	38	9	0	0.24	3.52E+05
44	38.1	7	1	0	0.14	2.20E+04
TOTAL or MEAN	31382.1	3059	3453	76	0.93	1.21E+08

Projects Funded by the Chesapeake Bay Stock Assessment Committee: Fiscal Years 1995-2000

1995____

Brian J. Rothschild
University of Maryland, Center for Estuarine and Environmental Studies
Chesapeake Biological Laboratory
$150,000
Stock assessment of blue crabs in the Maryland portion of Chesapeake Bay.

Rom Lipcius
Virginia Institute of Marine Science
$150,000
A fiend study of the population dynamics of the blue crab, *Callinectes sapidus* Rathbun, in the Chesapeake Bay.

Roger Mann
Virginia Institute of Marine Science
$77,345
Fishery independent standing stock surveys of oyster populations in the Virginia subestuaries of the Chesapeake Bay and a comparison with continuing estimates.

Phil Jones
Maryland Department of Natural Resources
$162,646
Maryland Fisheries Information System.

1996____

Harley Speir
Maryland Department of Nartural Resources
$140,000
Stock assessment of blue crabs in the Maryland portion of Chesapeake Bay.

Rom Lipcius
Virginia Institute of Marine Science
$160,000
A field study of the population dynamics of the blue crab, Callinectes sapidus Rathburn, in the Chesapeake Bay.

Roger Mann
Virginia Institute of Marine Science
$12,000
Fishery independent standing stock surveys of oyster populations in the James River, Virginia.

David Secor, Rodger Harvey
University of Maryland, Center for Estuarine and Environmental Studies
Chesapeake Biological Laboratory
$34,938

Age determination in the blue crab, *Callinectes sapidus.*

John McConaugha
Old Dominion University Research Foundation
$45,011

Age determinination in the blue crab, *Callinectes sapidus.*

Thomas Miller
University of Maryland, Center for Estuarine and Environmental Studies
Chesapeake Biological Laboratory
$14,762

Chesapeake Bay Stock Assessment Committee: Plans and priorities for research.

1997

Harley Speir
Maryland Department of Natural Resources
$140,000

Abundance estimation and stock analysis of the blue crab in Chesapeake Bay.

Rom Lipcius
Virginia Institute of Marine Science
$153,000

A field study of the population dynamics of the blue crab, *Callinectes sapidus* Rathburn, in the Chesapeake Bay.

John McConaugha
Old Dominion University Research Foundation
$24,933

Winter dredge fishery: impact on blue crab spawning stock.

Mike Fogarty
University of Maryland, Center for Estuarine and Environmental Studies
Chesapeake Biological Laboratory
$34,833

Design for a recreational fishing survey and mark-recapture study for the blue crab, *Callinectes sapidus* Rathbun, in the Chesapeake Bay.

Rom Lipcius
Virginia Institute of Marine Science
$82,211

Design for a recreational fishing survey and mark-recapture study for the blue crab, *Callinectes sapidus* Rathbun, in the Chesapeake Bay.

John McConaugha
Old Dominion University Research Foundation
$89,710
Biochemical measures of age in the blue crab: lab and field verification.

Rodger Harvey
University of Maryland, Center for Estuarine and Environmental Studies
Chesapeake Biological Laboratory
$75,382
Biochemical measures of age in the blue crab: lab and field verification.

1998

Harley Speir
Maryland Department of Natural Resources
90,000
Abundance estimation and stock asalysis of the blue crab in Chesapeake Bay.

Rom Lipcius
Virginia Institute of Marine Science
$105,000
A field study of the population dynamics of teh blue crab, *Callinectes sapidus,* Rathburn, in the Chesapeake Bay.

Mike Fogarty
University of Maryland, Center for Estuarine and Environmental Studies
Chesapeake Biologcial Laboratory
$122,578
Design of a recreational fishing survey and mark-recapture study for the blue crab, *Callinectes sapidus* Rathbun, in the Chesapeake Bay.

Rom Lipcius
Virginia Institute of Marine Science
$30,403
Design of a recreational fishing survery and mark-recapture study for the blue crab, *Callinectes sapidus* Rathbun, in the Chesapeake Bay.

John McConaugha
Old Dominion University Research Foundation
$106,229
Biochemical measures of age in the blue crab: lab and field verification.

1999

Harley Speir
Maryland Department of Natural Resources
$127,393
Abundance estimation and stock analysis of the blue crab in Chesapeake Bay.

Rom Lipcius
Virginia Institute of Marine Science
$127,393

A field study of the population dynamics of the blue crab, *Callinectes sapidus* Rathbun, in the Chesapeake Bay.

John McConaugha
Old Dominion University Research Foundation
$ 86,555

Biochemical measures of age in the blue crab: Lab and field verification.

Rodger Harvey
University of Maryland, Center for Estuarine and Environmental Studies
Chesapeake Biological Laboratory
$112,538

Biochemical measures of age in the blue crab: Lab and field verification.

John Hoenig, Chris Bonzek
Virginia Institute of Marine Science
$39,743

Studies in Support of Blue Crab Stock Assessment.

Tom Miller
University of Maryland, Center for Environmental Studies
Chesapeake Biological Laboratory
$39,849

Improvements to the Stock Assessment of Chesapeake Bay Blue Crab: Implications of Blue Crab Size-at-Age.

2000

Rom Lipcius
Virginia Institute of Marine Science
$127,400

A field study of the population dynamics of the blue crab, *Callinectes sapidus* Rathbun, in the Chesapeake Bay.

Lisa Kline, Geoff White
Atlantic States Marine Fisheries Commission
$70,000

Development of a Multispecies Modeling Approach for Management of the Coastal Fishery for Atlantic Menhaden.

Ed Houde, Bob Wood
University of Maryland, Center for Environmental Studies
Chesapeake Biological Laboratory
$41,724
Variability in the Dynamics of Forage Fish Abundances in Chesapeake Bay: Retrospective Analysis, Models and Synthesis.

Tom Miller, Ed Houde
University of Maryland, Center for Environmental Studies
Chesapeake Biological Laboratory
$310,000
Development and Implementation of CHESFIMSS: Chesapeake Bay Fishery-Independent Multispecies Survey

Roger Mann
Virginia Institute of Marine Science
$70,163
Fishery-Independent Standing Stock Surveys of Hard Clam Populations in the Chesapeake Bay and a Comparison with Continuing Estimates from Fishery-Dependent Data.

Chris Bonzek, John Hoenig, Herb Austin, Dave Hata
Virginia Institute of Marine Science
$115,000
Design and Implementation of a Chesapeake Bay Multispecies Monitoring and Assessment Program (ChesMMAP)

Tom Wolcott, Tuck Hines
North Carolina State University, Smithsonian Environmental Research Center
$281,088
Migration of Adult Female Blue Crabs to Spawning Grounds; Mechanisms and Routes

Alexi Sharov
Maryland Department of Natural Resources
$73,817
Design of a Blue Crab Fishery Dependent Survey for the Chesapeake Bay

Steve Jordan, Roger Mann, Jim Wesson, Ken Paynter
Maryland Department of Natural Resources, Virginia Institute of Marine Sciences, Virginia Marine Resource Commission, Horn Point Environmental Laboratory
$74,506
Oyster Population Estimation in Support of the Ten Year Goal for Oyster Restoration in the Chesapeake Bay Fishery

2001

Ed Houde, Bob Wood
University of Maryland, Center for Environmental Studies
Chesapeake Biological Laboratory
$44,981
Variability in the Dynamics of Forage Fish Abundances in Chesapeake Bay: Retrospective Analysis, Models and Synthesis.

Tom Miller, Ed Houde
University of Maryland, Center for Environmental Studies
Chesapeake Biological Laboratory
$212,483
Development and Implementation of CHESFIMSS: Chesapeake Bay Fishery-Independent Multispecies Survey.

Roger Mann
Virginia Institute of Marine Science
$69,041
Fishery-Independent Standing Stock Surveys of Hard Clam Populations in the Chesapeake Bay and a Comparison with Continuing Estimates from Fishery-Dependent Data.

Chris Bonzek, John Hoenig, Herb Austin, Dave Hata
Virginia Institute of Marine Science
$188,236
Design and Implementation of a Chesapeake Bay Multispecies Monitoring and Assessment Program (ChesMMAP).

Tom Wolcott, Tuck Hines
North Carolina State University, Smithsonian Environmental Research Center
$81,287
Migration of Adult Female Blue Crabs to Spawning Grounds; Mechanisms and Routes.

Steve Jordan, Roger Mann, Jim Wesson, Ken Paynter
Maryland Department of Natural Resources, Virginia Institute of Marine Sciences, Virginia Marine Resource Commission, Horn Point Environmental Laboratory
$50,945
Oyster Population Estimation in Support of the Ten Year Goal for Oyster Restoration in the Chesapeake Bay Fishery.

Dave Secor, Rodger Harvey
University of Maryland, Center for Environmental Science
Chesapeake Biological Laboratory
$71,925
Age Composition Analysis of Chesapeake Bay Blue Crab.

Cynthia Jones, Julian Ashford
Old Dominion University Research Foundation
$149,971
A Randomized Sampling Program to Obtain Effort, Harvest, and Harvest Composition Data from the Recreational Blue Crab Fishery in the Chesapeake Bay.

Mark Homer, Mitchell Tarnowski, Christopher Dungan
Maryland Department of Natural Resources
Cooperative Oxford Laboratory
$14,985
Assessment of Chesapeake Bay Commercial Softshell Clams.

John Hoenig, Romuald Lipcius, Marcel Montane, Daniel Hepworth
Virginia Institute of Marine Science
$131482
Tagging Studies of Blue Crabs in Chesapeake Bay.

Villy Christensen, Carl Walters, Ratana Chuenpagdee
University of British Columbia, Virginia Institute of Marine Science
$85,000
A Dynamic Mass Balance Model of the Chesapeake Bay Ecosystem.