1 FISHERY STOCKS AND DYNAMICS

Convenor: Dr. Romuald Lipcius

Toward a Sustainable Coastal Watershed:
The Chesapeake Experiment. Proceedings of a Conference
1-3 June 1994. Norfolk, VA
Chesapeake Research Consortium Publication No. 149

PROFILING VIRGINIA HARD CRAB POT FISHERY TECHNIQUES AND RESULTS

Anne G. Rhodes and Leonard Shabman
Virginia Polytechnic Institute and State University, Survey Research Lab

Abstract: Effective fishery management requires accurate data on the harvest, effort, cost, and price levels in the fishery. This study uses a monthly sampling approach to gathering data from blue crab harvesters in Virginia. There has been much concern expressed recently that effort levels in the Chesapeake Bay blue crab fishery may be increasing due to the decline of the oyster and finfish fisheries. Before 1993 the only available data were harvest and price levels, which were gathered through a voluntary reporting system, which relied on crab processors rather than harvesters for information.

This study attempted to gather information on fishery characteristics through a monthly sampling of Virginia crab pot license holders. Our survey was well received by watermen, with a 60 % response rate. Harvest, effort, cost, and price data, reported by each respondent for only one month, were aggregated to the whole population and for the whole season. Our harvest and price estimates were two to three times higher than published levels. Another finding was the diverse nature of the fishery, with the number of pots fished ranging from 5 to 600 per day.

The most important finding of this study is that a sampling approach, rather than the current method of a full census which was implemented in 1993, will gather more complete and accurate data. Not only will the information be more complete because more questions can be asked without being cumbersome, but also because monthly sampling will engender more support among the watermen, who are the ones who must comply with fishery regulations.

INTRODUCTION

Historically, Maryland and Virginia have provided between 45 and 55 % of the U.S. hard blue crab harvest and over 60 % of the soft crab catch. In recent years, the blue crab has become the main source of income for Virginia's watermen, as harvests of oysters and finfish have declined. Over the last two decades, the total harvest of blue crabs has fluctuated, but shows no systematic trend. During the same period, however, the dockside value of blue crabs as a proportion of total Chesapeake Bay landings has risen. In 1970, the blue crab harvest was about 49 % of the total food fish and shellfish harvest value in the Bay. In contrast, by 1989, the hard blue crab harvest was about 70 % of the total value.

Despite the apparent long-term stability in harvest levels, the decline in other fisheries has focused attention on the status of the blue crab fishery. Overharvesting, which may reduce future population levels, is a concern, as 1992 was the lowest blue crab harvest on record in Virginia in the past 30 years. As catch levels fluctuate from year to year, showing no real trend in total harvest, the catch per crab gear license issued jumped sharply in the early 1980s and then exhibited a slight downward trend. This is a crude measure of fishing effort, in that a license is issued for a gear type rather than a number of gear units. There is currently no accurate measure of fishing effort in the Virginia blue crab fishery. However, the decline in catch per crab gear license issued is often cited as evidence of falling population levels.

Also, with increased recreational use of the Bay, the recreational harvest for direct home consumption may be rising. However, there are few recreational harvest data available, so the extent of this harvest pressure is simply a matter of speculation.

For the Bay's watermen, the increased reliance on the blue crab as a revenue source has caused those who harvest the crabs to complain of low prices received for their product. Price trends reveal that the real (inflation-adjusted) exvessel prices of blue crabs (prices received by harvesters for fish and shellfish landed at the dock) have not declined in recent years, although the wide fluctuations in price that occured in the early seventies are no longer apparent.

The lack of accurate data and careful economic analysis of such data is a serious problem within the industry. Landings reported to the National Marine Fisheries Service (NMFS) appear to have been underestimated in the past (Vance, 1982), and exvessel prices are gathered from large picking houses, that may currently be taking less and less of the market share of blue crabs.

The main purpose of this paper is to develop an accurate picture of Virginia's blue crab pot fishery. In 1991, crab pots accounted for over 70% of the hard and peeler crab commercial catch in Virginia. Because of this, the primary focus for this study is the hard and peeler crab harvest by pots. While hard crab catch far exceeds that of peeler crabs, the peeler crab industry in Virginia is important, as it provides close to 60% of the annual U.S. soft crab harvest. For this reason and because there are some harvesters who fish both hard crab and peeler crab pots, data will be gathered on both the hard and peeler crab industries, and comparisons between the two will be developed.

METHODS AND RESULTS

In order to characterize the fishery, a series of steps were taken to profile the Virginia blue crab pot fishery for 1992. The main source of data for this profile was a series of monthly surveys of individual license holders, conducted from March to November of 1992. (Before the extensive profile of the fishery began in 1992, a short survey was done in the summer of 1991. This survey was designed to determine the charactistics of people who enter and exit the blue crab pot fishery and if these characteristics differ from those people who remain in the fishery.) In order to make the survey as efficient and useful as possible, a series of interviews were conducted with people involved in the fishery. A rough draft of the survey instrument was sent to three watermen in Virginia, who included a peeler crabber and two hard crab potters. All of these watermen were members of the Virginia Marine Resources Commission (VMRC) Blue Crab Subcommittee. These watermen were personally interviewed, and they gave their comments on both the merits and problems of the survey instrument and on characteristics of the industry. The survey instrument was also sent to personnel at the VMRC and the Virginia Institute of Marine Science (VIMS) who, because they had both previously conducted surveys of watermen, were able to provide valuable insights on survey design and implementation.

In order to better understand the harvesting level, two watermen were accompanied on their daily crabbing runs-a peeler crab run on the York River and a hard crab run in the Rappahanock River and Chesapeake Bay. These trips provided insights into the everyday work of watermen -from how the boats are loaded in the morning to how the catch is marketed in the afternoon.

On the processing side, an interview was conducted with a large picking house company in Virginia. This interview provided information on how processors operate, the competition they face, and how the prices they offer to watermen are formed. Another interview was conducted with a soft crab harvester and wholesaler in Virginia, which gave some insights into peeler crab price determination.

The basic objective of the survey instrument in this study was to provide primary data on inputs and outputs from the crab pot sector of Virginia. The survey was designed to gather data to be used in estimating harvest and price functions for the 1992 season. Because both input and harvest levels vary throughout the year, the survey was conducted on a monthly basis from March to November. The potting season generally begins in mid-March and ends in mid-November, but surveys for March and November were combined with those for April and October, respectively, totaling seven separate survey instruments for the season.

A monthly survey was also chosen to avoid recall problems that might result from one mailing at the end of a season and also because watermen were required to provide catch data for only one month. Few questions on costs were asked, except for the fixed costs that the crabber pays annually. This helped to prevent nonresponses as the questions did not require the watermen to provide all the financial details of their operation. Costs for variable inputs were obtained in a telephone survey of selected crabbers (those who, through their comments on the survey, expressed concern for the fishery and a willingness to provide additional information). The survey was divided into two parts. Part I contained questions for all of the respondents to answer.

These included attitude questions about fisheries policy, general characteristics of the crabber, and fixed costs and inputs. Part II was to be answered by those who crab potted during the month they received a survey. This section included a monthly calendar, on which respondents were asked to fill in the number of bushels of peeler and/or hard crabs that they caught each day. The rest of the section asked questions about variable inputs (bait, pots, labor, etc.) and marketing channels. The survey ended with a section for additional comments by the crabber.

The response results of the 1991 entry/exit survey were used to determine the sampling procedure for the 1992 survey. Only those who held crab pot licenses in 1990 were considered for sampling, a total of 2,550 people (The 1990 list was used as the 1991 list of license holders was not available from the VMRC at the time of sampling). A total of 583 people who fit this criteria responded to the 1991 survey. These people, because they had responded to one survey, were removed from the complete census and marked as the first list. These 583 people were tested for representativeness of the population of license holders using chi-square tests. The only population characteristics available for all crab potters are age and county of residence. The sample taken in the 1991 survey was found not to be significantly different from the overall population in either characteristic. Therefore there was no age or location bias in this sample. If any other bias existed, it could not be detected. Those who did not respond to the 1991 survey were removed from the list, as they would probably not respond to a second survey. After removal of those from the list who were known to be deceased or had moved out of state, there were approximately 1,250 people on the list who had not been previously surveyed. These people made up the second list.

A total of 1,204 people were surveyed over the season. Because there were seven periods to be surveyed, 172 people were surveyed each period. These 172 people were drawn from two lists. The first list was the 583 people who had responded in 1991. Each period, 83 or 84 of these people were surveyed. These people were not drawn randomly, however. One of the questions on the 1991 survey asked the respondents in which months they usually crab potted. The list was divided over the months so that each person received a survey in a month in which he normally crab potted. This procedure ensured a higher response rate for part II of the survey than might otherwise occur. The remaining 87 or 88 people were drawn randomly from the previously unsurveyed license holders, using a random number generator.

The response rates for each period are shown in table 1. A total of 1,204 surveys were mailed, 36 of which were undeliverable. The overall response rate for the survey was 62% A total of 720 surveys were returned. Of this number, 490

Table 1. Responses to 1992 survey of crab potters

Period	Number of Responses	Response Rate %
March/April	97	58
May	95	57
June	103	62
July	113	68
August	110	66
September	115	69
October/November	87	52

Representativeness of survey responses based on chi-square test results

Age	.708	
Country of residence	.545	

.

were usable surveys, as a number of surveys were returned by those who did not crab pot in 1992 and some surveys contained incomplete information. (Many people who filled out part II of the survey (monthly data) filled out everything except the monthly calendar. These surveys were not considered incomplete because they provided much other useful information. Incomplete surveys included only those who did not fully complete part I (general data).

The survey data were tested for representativeness of the crab pot license-holders by performing chi-square tests on the two statistics that were known for the population-age and county of residence. The results of these tests are shown in table 1. The chi-square statistics indicated no difference between the sample and the population, and therefore the sample is considered representative of the population and the following section that characterizes the fishery refers to percentages of the population rather than the survey responses.

The License Holders in the Crab Pot Fishery

Data on the differences among crab pot license holders and on the characteristics of their operations were generally unavailable before this study. No information on the number of gear units or number of days fished or vessel characteristics is gathered when licenses are sold. This study provides much of this previously unknown information.

Table 2 presents firm characteristics for the entire fishery, showing the range of license holders and the average and median license holders. One important feature to note is that this is an extremely diverse fishery, with vessel ages ranging from new to over 60 years and with the number of pots fished ranging from 1 to 600. The median values for pots fished and days fished per season are lower than the average values, indicating that the majority of license holders tend to be smaller operators. Also, the average boat length is 24 feet, demonstrating the smallscale of most license holders. There is a relatively small group (about 16 % of license holders) who are large-scale operators, but the general indications are that this is not a capital- intensive fishery, with much high-tech equipment and many big operators.

The crab pot license holders were divided into three general categories:

- Maryland Commercial. Those who live in Maryland but hold a Virginia crab pot license (3.4%).
- Virginia Commercial. Those who live in Virginia and derive any income from potting (64 %).
- Virginia Noncommercial. Those who live in Virginia and derive no income from potting (32.6 %).

The Virginia commercial sector was further divided by region, size of operation, and type of operation. The results of the 1991 survey on entry and exit in the fishery were also analyzed. The significant findings include:

1. A small percentage of license holders are from Maryland, but they are large operators.
2. One-third of the license holders are noncommercial, but they tend to fish more than five pots.
3. The majority of crab potters fish less than 200 pots per day.
4. The largest firms in Virginia are on the Eastern Shore.
5. Those who hard crab pot only are the largest segment of license holders.
6. People who buy a crab pot license every year tend to be larger operators than those who get in and out of the fishery.

Table 2. Firm characteristics of the crab pot fishery.

Variable:	Min.	Max.	Mean	Median
Hard pots fished	3	600	127	100
Peeler pots fished	1	500	135	100
Hard pot days per season	4	235	117	109
Peeler pot days per season	13	183	73	61
Length of crabbing vessel (feet)	12	50	24	20
Age of crabbing vessel (years)	1	66	15	12
Age of engine (years)	0.5	83	8	5
Income from potting %	0	100	37	25

Marketing Channels

In the survey, questions were asked about what percentage of the crabber's catch went to alternative marketing channels. Figure 1 gives the distribution of the catch of all license holders catch, including the catch of the noncommercial sector, who keep over 90% of their catch for personal use. About 8 % of the catch does not go through any marketing channel. Figure 2 gives the distribution of the catch of hard crabs and peeler crabs for commercial potters in Virginia. Approximately 60% of the hard crabs are going to a picking house, while the remaining 40% are going to a nontraditional marketing channel, with 2 % being kept for personal use. For peeler crabs, a higher percentage are kept for home use, just over 6%. About half of peeler crabs are sold to a shedder, with about one-third being shed by the harvester and sold to a retail market.

Harvest Levels in 1992

Harvest equations were modeled using monthly data obtained from the surveys, with the number of pot days fished in the month hypothesized to be the main factor influencing harvest levels for an individual firm. Other variables that were hypothesized to have influence included vessel length, years of crabbing experience, crabbing region, and season of the year.

Figure 3 shows the procedures used to obtain total industry harvest levels for both hard and peeler crabs. A monthly harvest equation was estimated from the survey data and this equation predicted monthly harvest levels for each individual firm. These harvest levels were summed over all months fished to obtain an annual harvest level for each firm. These annual harvest levels were summed over all firms and aggregated up to the industry level.

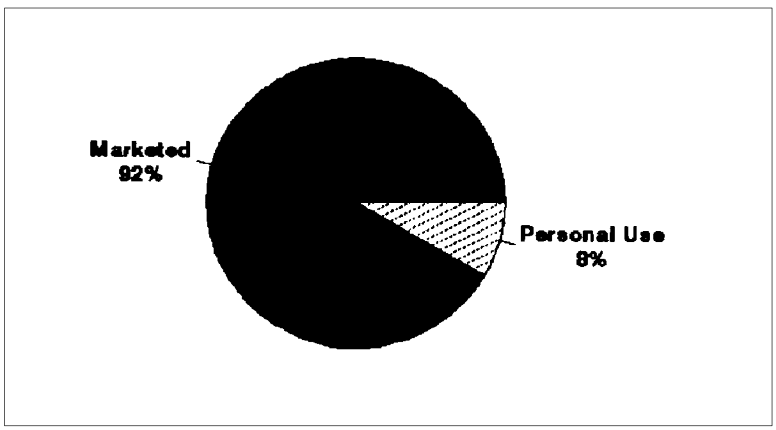

Figure 1. Distribution of catch of all crab pot license holders.

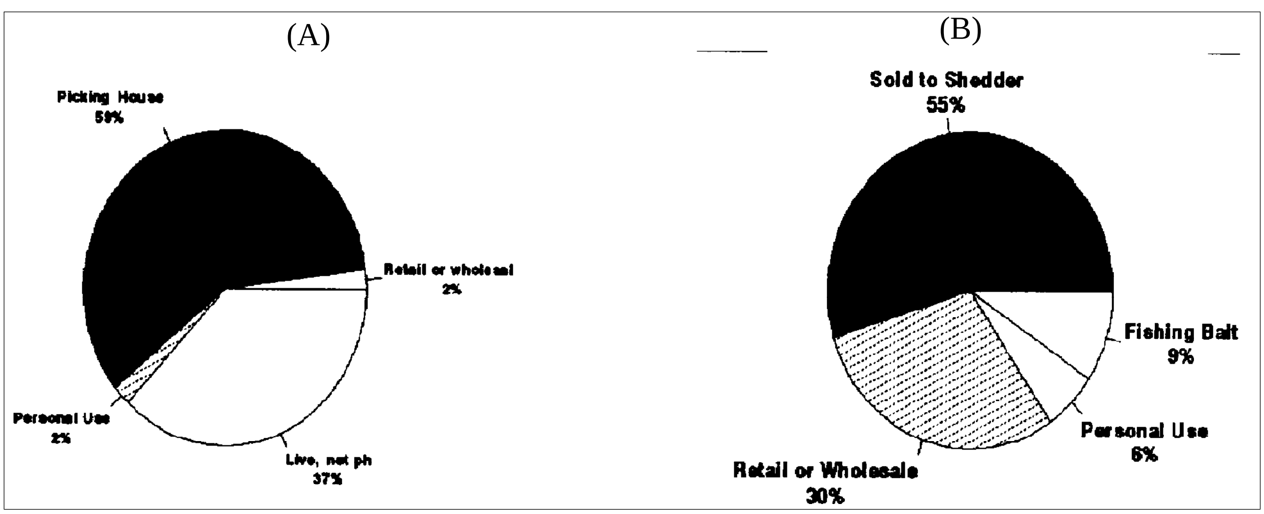

Figure 2. Commercial marketing channels for hard crabs (A) peeler crabs (B).

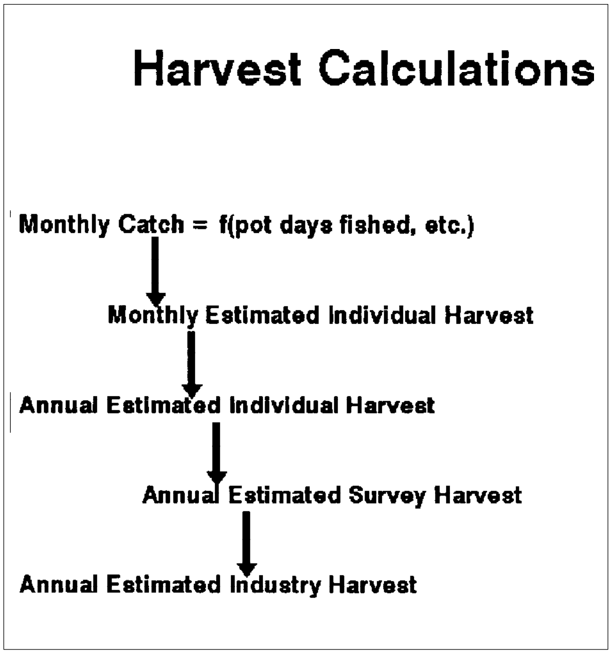

Figure 3. Harvest aggregation procdures.

For hard crabs, monthly harvest was a function of pot days fished, length of crabbing vessel, and season of the year. For peeler crabs, monthly harvest was a function of pot days fished, years of crabbing experience, and crabbing region. Annual harvest levels were estimated for four sectors of Virginia's blue crab fishery. (The first three of which are the same as the general categories cited above):

•Maryland Commercial
•Virginia Commercial
•Virginia Noncommercial
•Virginia Recreational

Table 3 gives the blue crab harvest levels for each of these sectors, along with their 95% confidence intervals. The aggregation techniques given in figure 3 were used to obtain the blue crab harvest levels for the Virginia and Maryland commercial sectors and the Virginia noncommercial sector. The harvest estimates for the recreational sector were based on a report published by the U.S. Department of Commerce in 1985 on recreational shellfishing in the United States. Using that report's estimates of the number of annual recreational shellfishing days in Virginia and the number of recreational shellfishers, and assuming that recreational fishers catch one-quarter of a bushel of hard crabs a day, the recreational catch in Virginia was estimated to be approximately 16% of the commercial catch.

These numbers show that the commercial harvest is 84.5% of the total harvest of blue crabs in Virginia. This result demonstrates that harvest levels, which are usually reported only as commercial landings, may be significantly underestimated, and may not be a true indicator of the total output of the blue crab fishery.

1992 Exvessel Prices

Because the marketing channel analysis showed that much of the blue crab catch in Virginia goes to nontraditional outlets where the price received may be considerably higher than in traditional channels, a two-step process was used to obtain 1992 monthly exvessel price estimates for both hard and peeler crabs. This process allowed for higher prices for a portion of each waterman's catch.

Hard Crab Prices

For hard crabs, the first step was to build a predictive econometric model, based on historical data. Monthly hard crab exvessel prices were a function of monthly landings, monthly wholesale price, and month of the year. The historical price data were used to build this model was gathered

Table 3: Harvest Estimates by Sector

Sector	Lower Limit (lbs)	Upper Limit (lbs)	Average (lbs)
Maryland	4,952,470	6,205,270	5,578,870
Va. Commercial	44,216,705	66,025,613	55,121,159
Va. Noncommercial	849,019	2,018,011	1,433,515
Va. Recreational	3,124,620	16,538,804	9,786,712
Total	53,142,814	90,787,698	71,920,256

mainly from large picking houses, and so this model only predicts the price the waterman will receive at the picking house for crabs. The data in figure 2 suggested that exvessel prices, which are currently reported as averages from the large picking houses, may not accurately represent the price that the waterman receives. Anecdotal data suggest that while picking house prices may correctly represent the prices crabbers receive for their smaller (#2) crabs, the prices for the larger (#1) crabs appear to be two to three higher than the prices for the #2 crab, (#1 crabs account for approximately one-third of a crab potter's daily catch). However, there are no data on prices in alternative marketing channels, nor are there any time series on the percentage of catch going to each marketing channel.

A telephone survey of crabbers in early 1993 revealed that, on average, crabbers sell one-third of their catch to a retail or wholesale market where the price they receive is two or three times higher than the picking house price. Therefore, a two-price model was used to predict the average price the crabber receives for his catch. The picking house price, given by the estimated econometric equation, was paid for two-thirds of the crabber's catch. The other one-third of the crabber's catch was assumed to bring a price 2.5 times higher than the picking house price. The overall monthly exvessel price was, therefore, 1.5 times higher than the picking house price. The monthly prices estimated by this method are given in table 4. Prices are highest in the summer months, when demand for crab meat is at its highest. Prices are lowest the fall, when stocks of blue crabs are high and demand is beginning to lessen.

Peeler Crab Prices

Soft crab exvessel price and landings data were obtained from the National Marine Fisheries Service. Soft crab wholesale prices were obtained from Umer-Barry, a private marketing company in New Jersey. Initial attempts at modeling Virginia soft crab exvessel prices as a function of Virginia landings, wholesale soft crab prices, and season of the year demonstrated no significant relationship among these variables. Talks with soft crab harvesters, processors, and wholesalers revealed that because soft crabs are often shipped to northern markets for wholesaling and can often be kept frozen for months, price discovery is often difficult. Another important factor in exvessel price formation is that Virginia has a much lower share of the national soft crab market today than it did 15 years ago. Currently Virginia provides about 60% of the national soft crab harvest, compared with almost 90% 15 years ago (Whittaker, 1993). This means that Virginia soft crab exvessel prices are dictated more by national landings than by Virginia landings.

Consequently, monthly exvessel peeler crab prices were not modelled, but rather were taken from VMRC estimates for 1992. To account for higher prices in alternative marketing channels, the published price series was multiplied by 1.5. table 4 summarizes the monthly 1992 estimates of exvessel prices for peeler crabs. Prices are lowest in April, when there are wide fluctuations in day-to-day prices offered. Exvessel prices tend to settle in May and remain fairly constant for the remainder of the season.

Table 4. Exvessel prices per pound for hard and peeler crabs in 1992.

Period	Hard Crabs ($)	Peeler Crabs ($)
March	.51	N/A
April	.62	1.78
May	.77	2.91
June	.74	2.76
July	.71	2.76
August	.71	2.79
September	.48	2.70
October	.42	N/A
November	.55	N/A

Comparison with Published Harvest and Price Levels

One of the main objectives of this study was to gather accurate data on the fishery. These data included both data currently unavailable, such as characteristics of the license holders and the marketing channels used for hard and peeler crabs, and data currently collected, such as harvest and price levels, which may not be accurately reported.

The 1992 method for gathering published harvest and price data for Virginia's blue crab fishery was a voluntary reporting system, whereby the VMRC collected data from those watermen and crab buyers who were willing to report on harvest and prices. One official at VMRC conceded that, through this system, only about 60% to 65% of the harvest was being captured (Ner, 1993). In 1982, Vance concluded, through evidence of other surveys and calculations of net returns in the fishery, that harvest levels for Virginia's blue crab fishery were underreported by one-half (Vance, 1982).

Table 5 presents the data on harvest totals and prices estimated from this study and the data collected by VMRC. The report harvest in table 5 from this study does not include the harvest by Maryland crabbers in Virginia, as these numbers are not counted by VMRC. The published data's hard crab catch is about 40% of the catch estimated in this study, while the peeler crab catch is only about 30 % of the catch estimated in this study. Hard crab and peeler crab prices are significantly higher in this study, mainly due to the use of the two-price model that accounts for alternative marketing channel prices.

IMPLICATIONS FOR FUTURE DATA COLLECTION

An important finding of this study is the characterization of the blue crab fishery. This fishery was found not to be capital-intensive as some fishery managers and watermen claim. Instead the majority of watermen are small scale, working from small boats and fishing fewer than 200 pots and can easily enter and exit. A small segment, about 15% of license holders are large scale, fishing up to 600 pots a day with large boats. The diversity of the fishery is also captured in the finding of a large noncommercial sector, almost one-third of crab pot license holders. There is also a large recreational sector, which is not counted among license holders or in published harvest estimates.

Much has been written about and debated regarding in the blue crab fishery, but little in-depth data collection has been done. This study has shown conclusively that there are serious underreporting problems in the published data on the blue crab fishery, both in harvest and price levels. This appears to mainly be a result of the voluntary reporting system that was in place until 1993.

In 1993, a mandatory reporting plan was put in place for all of Virginia's fisheries, whereby each waterman must fill out a daily record of his catch and the price he receives. This policy has generated much rancor among the watermen, who feel it is an unnecessary burden on them. The watermen feel they are not benefiting at all from this policy.

This study has provided an alternative and effective method for gathering data in the fishery, through a series of monthly surveys. The survey instrument was well-accepted by the watermen, with over a 60% response rate and over 75% of the responses providing comments on fisheries policy. If this type of system were continued over a period of years, each waterman would be surveyed once every 2 years and only asked to provide a month's worth of data for his operation. In the end, this type of sampling, rather than a full census, would probably gather better data, not only because the information it would provide would be more complete (marketing channels, characteristics of the firm), but also because it

Table 5. Comparison of this study's estimates and published VMRC data on harvest totals and prices.

Category	This Study	VMRC Data
Hard crab commercial harvest (lbs)	53,201,713	19,712,233
Peeler crab commercial harvest (lbs)	1,919,446	518,770
Hard crab exvessel price per pound ($)	0.61	0.41
Peeler crab exvessel price per pound ($)	2..62	1.73

would engender support among the watermen.

Perhaps the most significant finding of this study is that the current information on the Virginia blue crab fishery too often is incomplete. In order to effectively monitor the fishery, managers need both a better picture of the effort and harvest levels in the fishery.

REFERENCES

Casey, James. 1992. Personal communication, February.

Chesapeake Bay Commission. 1991. Annual report to the general assemblies of Maryland, Pennsylvania, and Virginia. Annapolis, MD: Chesapeake Bay Program.

Chesapeake Executive Council. 1989. Chesapeake Bay Blue Crab Management Plan. Annapolis, MD: Chesapeake Bay Program, July.

Furlong, William J. 1991"The Deterrent Effect of Regulatory Enforcement in the Fishery." Land Economics. 67(February): 116-129.

Mid-Atlantic Fishery Management Council (MFMC). 1988. Primer on Federal Marine Fisheries Management in the Northeastern United States. Dover, DE: MFMC, October.

National Marine Fisheries Service. 1973. Basic Economic Indicators: Blue Crab, 1947-1972. Washington, D.C.: U.S. Department of Commerce.

Ner, Sonya.1993. Personal Communication, June.

Nixon, Peter. 1992. Personal Communication, July.

Rhodes, Anne, and L. Shabman. 1994. Virginia's Blue Crab Pot Fishery: The Issues and Concerns. Virginia Sea Grant Publication, VSG 94-09.

Smoller, Ellen. 1992-1993. Personal Communication.

U.S. Department of Commerce and US Department of the Interior. 1991. Addendum to 1985 National Survey of Fishing, Hunting, and Wildlife-Associated Recreation: Recreational Shellfishing in the United States.

U.S. Department of the Interior, Fish and Wildlife Service, Bureau of Commercial Fisheries. 1970-1992. Fisheries of the United States. Washington, D.C.: Bureau of Commercial Fisheries.

Vance, Tamara Ann. 1982."Returns to Effort Management in the Virginia Blue Crab Pot Fishery". Thesis: Department of Agricultural Economics, Virginia Polytechnic Institute and State University.

Virginia Marine Resources Commission. 1992. "Commercial Crabbing in Virginia", Circular. Newport News, VA: VMRC.

Wesson, James. 1992. Personal Communication, February.

Whittaker, Louis. 1993. Personal Communication, March.

Toward a Sustainable Coastal Watershed:
The Chesapeake Experiment. Proceedings of a Conference
1-3 June 1994. Norfolk, VA
Chesapeake Research Consortium Publication No. 149

EVIDENCE FOR A RELATION BETWEEN A WHITE PERCH YOUNG-OF-THE-YEAR INDEX AND INDICES OF LATER LIFE STAGES

Thomas C. Mosca III, Herbert M. Austin, and David M. Plotner
Virginia Institute of Marine Science

Abstract: Juvenile indices are employed in fisheries management to predict the future abundance of harvestable adults. Frequently, regulations on the utilization of the resource, and a lack of fishery independent abundance data, make verification of the prediction accuracy impossible. In the case of white perch in Virginia, this is not so. Using the weighting system developed for a Chesapeake Bay-wide index of juvenile striped bass abundance based on summertime beach seine data collected in nurseryground waters, we developed a similar index for white perch in the Virginia portion of the Bay. Regressions against Virginia Institute of Marine Science otter trawl survey indices (taken in deep, mesohaline water during winter months) for young-of-the-year ($r^2 = 0.719$, $p = 0.001$) and age 1+ ($r^2 = 0.666$, $p = 0.001$) white perch were significant and positive. These results lend support for the continued use of juvenile indices for finfish management.

INTRODUCTION

Indices of juvenile abundance are increasingly being used as fisheries management tools. The 1981 striped bass management plan adopted by the Atlantic States Marine Fisheries Commission (ASMFC) used an index of juvenile abundance as an indicator for tightening or relaxing fishing regulations. This juvenile index is constructed from the beach seine survey of the Maryland Department of Natural Resources. The ASMFC plan contained no enforcement provisions. The federal Atlantic Coast Striped Bass Conservation Act of 1986 codified the use of the Maryland striped bass juvenile index, and is the first instance of a juvenile index becoming part of law. The Atlantic Coast Fisheries Conservation and Management Act of 1994 makes ASMFC management plans binding on the states, with noncompliance triggering a federal moratorium. Many of the ASMFC management plans rely on juvenile indices, such as those for summer flounder, bluefish, and weakfish.

The use of a juvenile index assumes there to be a positive relationship between the abundance of young-of-the-year (YOY) fish one year and subsequent adults. It is highly desirable to confirm the existence of this relationship. The Maryland striped bass index was validated by comparison with the commercial harvest on following years (Goodyear 1985). When the size of the commercial catch depends on regulation instead of stock abundance (as does striped bass now), this method cannot be employed. What is needed then, is a fishery-independent measure of adult stock size. For white perch (*Morone americana*), we were able to construct a juvenile index and demonstrate a solid relationship to subsequent one-year-olds.

The Virginia Institute of Marine Science (VIMS) conducts a summer beach seine survey to evaluate the abundance of YOY striped bass (Colvocoresses 1984). This survey takes place in the upper reaches of the rivers, in shallow water, adjacent to shore. Because the congeneric white perch uses the same spawning and nursery grounds (Rinaldo 1971, Setzler-Hamilton 1991, Cowan and Rose 1993), this species is captured as well, and data on all species in the seine are kept.

VIMS also operates a year-round trawl survey of the lower portion of the Chesapeake Bay and the major Virginia tributaries. Each month, sites in the James, York, and Rappahannock Rivers, and the Bay proper, are visited and sampled with a 9.7-meter semi-balloon otter trawl (Bonzek et al. 1993). The survey is designed "to produce annual indices of juvenile (young-of-year) abundance of commercially, recreationally and ecologically important marine and estuarine finfish and crustaceans" (Bonzek et al. 1993). White perch is among the species for which a juvenile index is produced. This makes possible a second index of abundance produced concurrently with the beach seine survey.

While the VIMS trawl survey program is not designed to sample adult populations, in the case of white perch it does so very well. From these data, an index of age 1+ fish is produced (Bonzek et al. 1993).

METHODS

Using a Chesapeake Bay-wide striped bass juvenile index as a model (Austin et al. 1993), we constructed a similar index for white perch in the major Virginia tributaries of the Bay. These indices are weighted, geometric means. The basis of the white perch juvenile abundance index is catch -per -unit effort data collected by the VIMS beach seine survey (see Colvocoresses 1984) in the months July - September. The Chesapeake Bay-wide striped bass index used a weighting system based on the surface area of the respective spawning areas within the major tributaries of the Bay - the James, York, and Rappahannock Rivers (in Virginia), and the Potomac, Choptank, and Nanticoke Rivers and the area known as the Head of the Bay (in Maryland). We used the weights from the Virginia rivers.

On a monthly basis, the VIMS trawl survey visits each of the three major Virginia rivers and the Chesapeake Bay proper. Data for certain months and certain areas are used in the construction of abundance indices for particular species. In the case of white perch, it would not make sense to include Chesapeake Bay data in the index, because the salinity precludes white perch being found there. Also, in warm-water months, white perch leave the deep-water areas sampled by the otter trawl. Thus, the white perch otter trawl indices are constructed from data from the upper reaches of the rivers, taken in the months December-February (YOY) and November-February (age 1+) (Geer et al. 1993). Further, there are two strata per river (up-river and down-river), of which only the up-river strata are used in calculating white perch indices (Geer et al. 1993). The trawl survey white perch indices used here were prepared by VIMS (Christopher F. Bonzek, VIMS pers. comm).

The indices are constructed by taking the weighted means of the log-transformed catch-per-haul data, and performing a "back-transformation," as follows:

Here k = 1 = James River, 2 = York River, and 3 = Rappahannock River. The weighting factors (wt) for the beach seine index were calculated from the spawning areas of the respective rivers, and the weights for the trawl indices were calculated from the surface areas of strata within the rivers. In the above equation, n represents the number of times the k^{th} river system was visited in a particular year.

The construction of the beach seine juvenile index presented here differs slightly from the index of Austin et al. (1993) in the location of the weights and the back-transformation. The index was modified so that it would be directly comparable to the indices constructed by the trawl survey team. The VIMS beach seine survey was not conducted during 1974-79, owing to a lack of funding. We used the uninterrupted data from 1980 to the present. However, the trawl survey juvenile index begins in 1982, so data for the years from 1982 to 1992 were used when comparing the two juvenile indices. The VIMS age 1+ index begins earlier, and we were able to compare the beach seine survey juvenile index from 1980 to 1992 with the trawl survey age 1+ index from 1981 to 1993, respectively lagged one year.

Indices of juvenile abundance were compared using linear regression, with the seine survey index being the independent variable. Because the two indices are spatially and temporally independent, this provided a corroboration of the validity of the beach seine survey to accurately reflect trends in the juvenile population.

The beach seine juvenile index was regressed as the independent variable against the trawl survey age 1+ index, lagged one year. This tested the ability of the juvenile index to predict trends in the population abundance of subsequent one-year-olds. This analysis assumes that the trawl survey age 1+ population is dominated by one-year-old fish.

RESULTS

Regression of the beach seine juvenile index against trawl survey juvenile index (figure 1) produced a highly significant relationship ($r^2 = 0.597$, $p = 0.003$). These indices are entirely independent of each other, and are also spatially and temporally disjoint. If two independent measures of a population disagree, it is impossible to say that one or the other is correct. However, an analysis such as this one gives strong support to the hypothesis that both sampling methods are adequately sampling the populations on which they are employed, and that the populations are one and the same.

The juvenile index created from the beach seine data was used to predict the abundance of age 1+ fish, again by linear regression (figure 2). The fit of these data ($r^2 = 0.219$, $p = 0.107$) was flawed by a single outlier in Y (1985). This outlier was confirmed by examination of the residuals, and was determined to be elevated by large trawl survey catches in the Rappahannock River. Inspection of the raw data revealed that catches were consistently high in the Rappahannock River that year, and we feel that some environmental effect (e.g., freshwater discharge, temperature) probably caused survival of the 1984 yearclass to be particularly high, despite it being a fairly small yearclass.

After deleting the 1984/85 data pair, the beach seine juvenile index predicted the trawl survey age 1+ index very well. Regression (figure 3) yielded a highly significant relationship ($r^2 = 0.703$, $p < 0.001$).

DISCUSSION

Several attempts at validating indices of juvenile white perch abundance have been made, but with little success. One attempt (Barth et al. 1988) met with difficulties in the fishery-dependent data such as inconsistent and unusable estimates of effort, keypunch errors, and a lack of age-structure information. Difficulties were also found in the fishery-independent (beach seine) data, in particular the break in the Virginia time series during 1974-79. Another attempt at validating a white perch juvenile index against commercial landings on the Choptank River in Maryland. (Bolgiano and Boswell 1987) met with limited success by lagging the index three years.

There exists a question of the age composition of the age 1+ stock. At present researchers at VIMS are pursuing research designed to reveal a length-at-age relationship in the age 1+ trawl survey catch. When this information becomes available it will be possible to know with better certainty the

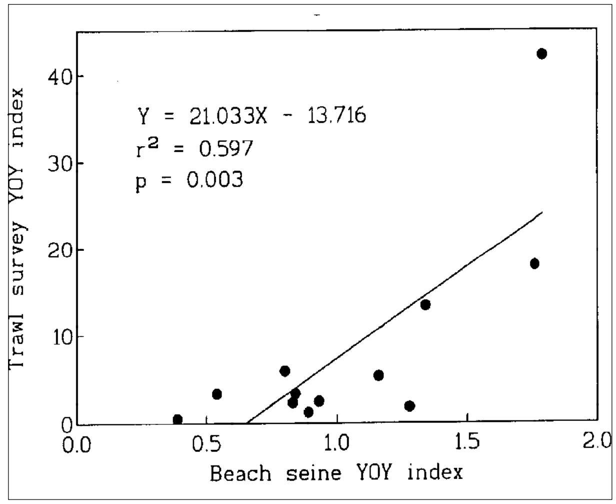

Figure 1. Trawl survey YOY index regressesd against the beach seine survey YOY index.

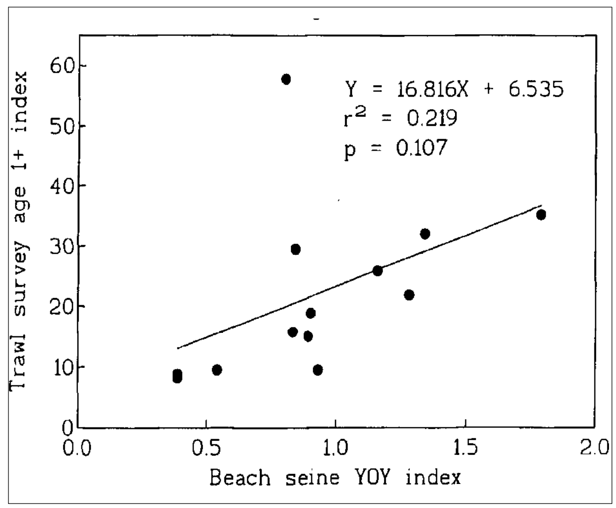

Figure 2. Trawl Survey age 1 + index regresed against the beach seine YOY index.

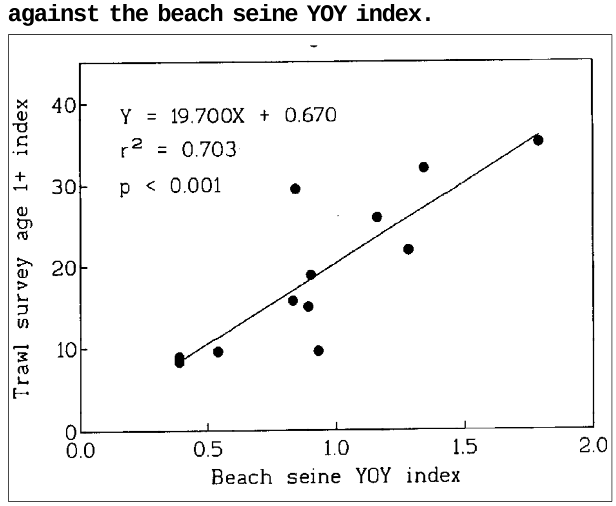

Figure 3. Trawl survey age 1 + index regressed against the beach seine YOY index with one extreme data pair deleted.

age composition of the 1+ stock. We feel that the very significant relationship seen in the juvenile index versus age 1+ scatter plot (figure 3) could not have occurred were the age 1+ stock not dominated by one-year-old fish.

The recreational and commercial fisheries for white perch in Virginia are important, and considerable fishing pressure exists (pers. obs.). Although no long-term downward trend is apparent in the index of age 1+ white perch abundance (figure 4), or the Virginia commercial landings data (figure 5), the potential certainly exists. It is interesting to note that the 1987 commercial harvest in Virginia is unusually large (figure 5), following two years after an anomalously high age 1+ trawl survey index (figure 4), suggesting that the commercial catch may have been dominated by three-year-old fish. However, this seems unlikely. Three year old white perch would be 100-125 mm in length (Piavis 1993), which is too small for the food market. The catch would have been early in the spring, before crab-potting activity, and we do not know of white perch being used by the cat food canners. Also, gill nets are sized to avoid catching fish this size.

Until such time as the age composition of the commercial harvest is established, we are unable to predict trends in the catch. We propose to sample the harvest in the near future to determine the age structure of the market catch. This will enable us to construct a model predicting catch from the beach seine juvenile index. Effort data remain problematic.

Using fisheries-independent data, we have confirmed that the beach seine juvenile index accurately predicts the subsequent size of the one- year-old population. Because so few indices of juvenile abundance have been validated, the good agreement of the white perch juvenile index with the age 1+ index should be taken as circumstantial evidence for the credibility of using juvenile indices in making management decisions. Ideally, each index should be tested for prediciting accurately the trend in adult population size. However, this is not always possible (e.g., Austin et al. 1993). This study lends support to the concept that management agenciees (and undoubtedly will) continue to use indices of juvenile abundance as a key management tool to provide stock assesment.

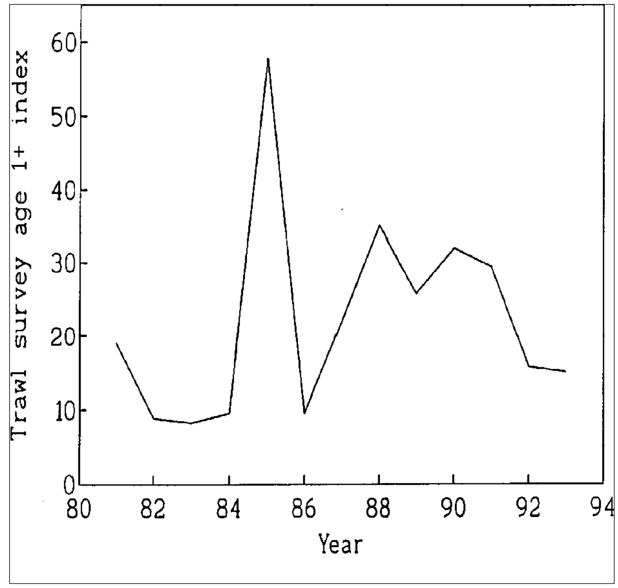

Figure 4. Trawl survey age 1 + index time series.

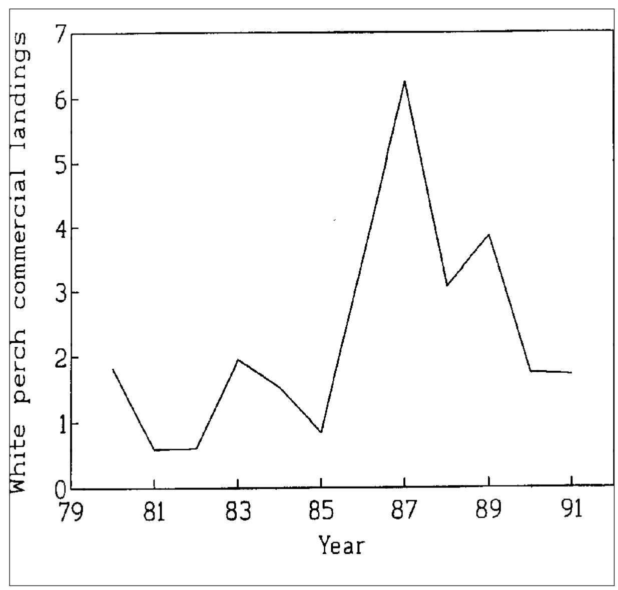

Figure 5. Virginia commercial landing time series.

ACKNOWLEDGEMENTS

We are grateful to Christopher Bonzek and Pat Geer of VIMS for providing data and valuable advice. We thank Denise Mosca for her keyboarding help. Funding was provided, in part, by a cooperative agreement between U.S. Fish and Wildlife Service and the Commonwealth of Virginia and coordinated by Virginia Marine Resources Commission, with additional direct funding by VMRC, contract number F104-(R1 through R4).

REFERENCES

Austin, H.M., J.A. Colvocoresses, and T.C. Mosca, III. 1993. Develop a Chesapeake Bay-wide young-of-the-year striped bass index. Final report to the Chesapeake Bay Stock Assessment Committee, cooperative agreement number NA16FU0393-01, 87 pp.

Barth, E., N. Bolgiano, J. Boreman, M. Boswell, J. Colvocoresses, G. Patil, M. Prager, and L. Rugolo. 1988. Use of historical data sets to determine causes of variability and long-term trends in the abundance of white perch in the York and Choptank Rivers (draft copy, 4/7/88). Working Group on Data Set Identification and Interpretation, Ches. Bay Stock Assessment Comm., 23 pages.

Bolgiano, N.C., and M.T. Boswell. 1987. An examination of the relationship between white perch juvenile index and commercial catch from the Choptank River by time series analysis. The Center for Statistical Ecology and Environmental Statistics, Penn State Univ., 19 pages.

Bonzek, C.F., P.J. Geer, J.A. Colvocoresses, and R.E. Harris, Jr. 1993. Juvenile finfish and blue crab stock assessment program bottom trawl survey annual data summary report series. VIMS Spec. Sci. Rept. No. 124, 217 pp.

Colvocoresses, J.A. 1984. Striped bass research in Virginia, Part I, Juvenile seining, Completion Rept., Emerg. Striped Bass Study, 64 pp.

Cowan, J.H., Jr., and K.A. Rose. 1993. Individual-based model of young-of-the-year striped bass population dynamics. II. Factors affecting recruitment in the Potomac River, Maryland. Trans. Am. Fish. Soc. 122:439-458.

Geer, P.J., J.A. Colvocoresses, H.M. Austin, and C.F. Bonzek. 1993. Estimation of relative abundance of recreationally important finfish in the Virginia portion of Chesapeake Bay. Annual progress report to the U.S. Fish and Wildlife Service, Sportfish Restoration Project F104R2 , 104 pp.

Goodyear, P. 1985. Relationship between reported commercial landings and abundance of young striped bass in the Chesapeake Bay, Maryland. Trans. Amer. Fish. Soc. 114:92-96.

Mansueti, R.J. 1964. Eggs, larvae, and young of the white perch, *Roccus americanus*, with comments on its ecology in the estuary. Ches. Sci. 5:3-45.

Piavis, P. 1993. Review of white perch status in Maryland. Tidal Fish. Tech. Report Series No. Seven, February, 21 pp

Rinaldo, R.G. 1971. An analysis of *Morone saxatilis* and *Morone americanus* spawning and nursery area in the York-Pamunkey River, Virginia: School of Marine Science, Virginia Institute of Marine Science, College of William and Mary, M.A. thesis. Gloucester Point, Va. 56 pp.

Setzler-Hamilton, E.M. 1991. White perch *Morone americana*. Pages 12.1-12.19 in S.L. Funderburk, J.A. Mihursky, S.J. Jordan, and D. Riley, editors. Habitat requirements for Chesapeake Bay living resources, 2nd edition. annapolis, Md.: Chesapeake Bay Program, Living Resources Subcommittee.

Toward a Sustainable Coastal Watershed:
The Chesapeake Experiment. Proceedings of a Conference
1-3 June 1994. Norfolk, VA
Chesapeake Research Consortium Publication No. 149

Lost and Found Generations of Chesapeake Bay Striped Bass: Improvement in Yearclass Representation Due to the 1985-1989 Maryland Striped Bass Moratorium

D. H. Secor
Center for Environmental and Estuarine Studies

H. Hornick, R. Schaefer and J. Markham
Maryland Department of Natural Resources

Abstract: The decline in abundance of Chesapeake Bay striped bass in the 1970s was believed to be the result of recruitment overfishing in Chesapeake Bay and the high rate of exploitation on the coastal migratory stock. A 12-inch minimum size limit in the Chesapeake resulted in large catches of immature 2-, 3-, and 4-year-old female striped bass, which may have drastically curtailed the population's ability to replenish itself. Fishery - independent stock assessments conducted in the early 1980s indicated that few fish produced in the 1970s were contributing to reproduction. Recently, it was found that ten generations of striped bass spawned from 1972 to 1981 were missing, based upon otolith age estimates of large female striped bass (36 to 51 inches, total length) sampled in 1992. Striped bass spawned between 1961 and 1971 persisted in the 1992 population and probably were the most important contributors to recruitment throughout the 1970s and early 1980s. Since the moratorium was emplaced, age-classes that make up 2% or more of the total spawning stock catch-per-unit effort in Maryland have risen. The number of such age-classes steadily increased from four to ten, and two years of good recruitment have been observed (1989 and 1993). These are positive signs that the population is recovering. Striped bass populations can persist during long periods of poor recruitment due to longevity of individual females. This tactic probably evolved in response to variable environmental conditions in nursery habitats, which frequently cause poor recruitments in anadromous species with temporally restricted spawning times. Longevity also affords striped bass a level of resiliency against an extended period of recruitment overfishing.

Toward a Sustainable Coastal Watershed:
The Chesapeake Experiment. Proceedings of a Conference
1-3 June 1994. Norfolk, VA
Chesapeake Research Consortium Publication No. 149

Linking Ecosystem-Level Processes with Population-Level Responses: The Importance of Variation Among Species in Predicting Effects of Estuarine Eutrophication

Denise Breitburg
The Academy of Natural Sciences

Abstract: In 1926 N. A. Gleason published "The Individualistic concept of the Plant Association" (*Bulletin of the Torrey Botanical Club* 53:7-26), in which he emphasized the importance of focusing on each species's response to a variable and varying environment in order to understand species associations. In contrast, studies of coastal eutrophication often deal with broad taxonomic categories, trophic levels, or whole communities for investigations of the dynamics and effects of high nutrient loadings. This broader approach may be entirely appropriate for certain kinds of research questions, especially those focusing on lower trophic levels. However, my research on effects of low dissolved oxygen on trophic interactions involving fish larvae, their predators, and their prey strongly indicates that Gleason's "individualistic" approach is critical to an understanding of the excess nutrient loadings and resultant oxygen depletion on upper trophic levels.

The goal of ongoing research in my laboratory and in collaboration with Houde and Kiester at the Chesapeake Biological Laboratory is to determine how oxygen depletion, which is common in bottom waters of stratified coastal systems, influences trophic interactions and recruitment of estuarine fishes. In Chesapeake Bay, subpycnocline oxygen concentrations decline during summer to levels that can be physiologically stressful or lethal to animals dependent on aerobic respiration. Field sampling (Keister, Houde, and Breitburg, unpublished data), laboratory behavior experiments (Breitburg, this paper and Breitburg et al., *Marine Ecology Progress Series* 104 [1994]:235-246, in press), small-scale predation experiments (Breitburg et al. 1994 and this paper) and mesocosm studies (this paper) indicate that the effects of low oxygen vary among interacting pairs of species in a single zooplankton /fish larvae /larval predator food web. The net effects of oxygen depletion are therefore determined by how dissolved oxygen influences each individual species's vertical distribution, attack rate, and escape behavior.

During 1992-93, I tested the effects of low oxygen on capture of naked goby (*Gobiosoma bosc*) and bay anchovy (*Anchoa mitchilli)* larvae by two important predators, sea nettles (*Chrysaora quinquecirrha*) and juvenile striped bass *(Morone saxatilis*) in 1-m^3 mesocosms. In addition, for one predator, the sea nettle, I tested the effects of low oxygen in 80-liter cylindrical containers on a suite of prey that varied in swimming velocity and escape ability under oxygen-saturated conditions. These prey were bay anchovy eggs (passive prey, no escape behavior), naked goby larvae (most rapid swimmer and lowest capture rate under oxygen saturated conditions), and copepods (mostly *Acartia tonsa*, assumed to be intermediate in both swimming speed and probability of capture).

Low, but nonlethal, dissolved oxygen concentrations resulted in dramatically increased predation on fish larvae by sea nettles, but decreased predation by juvenile striped bass and adult naked goby on these same prey. Predation by a single predator, the sea nettle, increased for fish larvae, decreased for fish eggs, and was not significantly affected for copepods at low dissolved oxygen concentrations. Increased predation occurred when the escape behavior of active prey was compromised; decreased predation was likely a function of decreased encounter and attack rates resulting from decreased swimming and feeding behaviors of predators.

Because of the variation in effects on trophic interactions, low dissolved oxygen may cause major alterations in the relative importance of different pathways of energy flow in the Bay system. Furthermore, because the shifts seen occur at moderately low oxygen concentrations, they may be important in a wide variety of systems. The extent of shifts is likely to depend on the requirements and behaviors of the individual species in each system. Spatially explicit and individual-based modeling techniques are now being used to link the effects of nutrient loading to recruitment of estuarine-resident fishes, and to predict the net effect of the varied interactions caused by summer oxygen depletion.

Toward a Sustainable Coastal Watershed:
The Chesapeake Experiment. Proceedings of a Conference
1-3 June 1994. Norfolk, VA
Chesapeake Research Consortium Publication No. 149

Nest Predation and Hatchling Sex Ratio in the Diamondback Terrapin: Implications for Management and Conservation

Willem M. Roosenburg
Ohio University

Allen R. Place
Center of Marine Biotechnology

Abstract: We report the effects of differential survivorship and environmental sex determination on the nesting habitat requirements of the diamondback terrapin *(Malaclemys terrapin)*. Nesting beaches used by the diamondback terrapin covary in nesting density and predation, rate suggesting that nest predation is density-dependent. Additionally, we report the results of an experiment that manipulated nests on a single nesting beach for 2 years. These nests were placed in a variety of microhabitat types throughout the nesting seasons of 1989 and 1990. Of the 185 hatchlings that were produced from these nests, 184 were male and 1 was female as a result of environmental sex determination. The consequences of density-dependent predation and environmental sex determination strongly suggest that effective management or conservation of the terrapin includes the preservation of a wide variety of nesting habitats. Preserving only high-density or south-facing nesting areas could disrupt recruitment and alter population sex ratio.

INTRODUCTION

Habitats used for reproduction are essential to the successful existence of a species. Frequently, these habitats may be used for an extremely brief period during the life cycle of the organism; however, even partial destruction or alteration of these habitats could adversely affect population dynamics. Additionally, variation in the predation, resource, or biophysical environments among habitats used by a particular species frequently has differential effects on its population level processes (Dunham et al. 1989, Dunham 1993). We present evidence from the diamondback terrapin (*Malaclemys terrapin*) and illustrate how variation in the predation and biophysical environment can affect nesting success and sex ratio.

The diamondback terrapin, is an estuarine emydid turtle that ranges from the Gulf Coast of Texas to Cape Cod, Massachusetts. Though typically a coastal species restricted to the lagoons and embayments that lie behind the sand dunes of barrier islands in Chesapeake Bay terrapin populations penetrate far inland in the tributaries where estuarine conditions exist. Inland waters of the Bay lack the elevated sand dunes that are used by terrapins for nesting in coastal populations; instead, terrapins nests on narrow isolated sandy beaches found on the fringes of salt marshes (Roosenburg 1994). The nesting areas in Chesapeake Bay vary considerably in size, elevation above high tide, orientation with respect to the sun, and distance from the water.

The diamondback terrapin has two unusual requirements for its reproduction. First, the terrapin is one of the few species that lives and feeds in the waters of the Bay, but must be able to transcend the intertidal zone to successfully reproduce. Failure to reach areas above the mean high tide frequently results in the death of developing embryos. Second, terrapins require a restricted range of thermal conditions on nesting beaches to ensure appropriate sex ratios because they exhibit environmental sex determination (ESD) as a species (Jeyasuria et al. 1994, Roosenburg and Kelley in press). ESD occurs in most species of turtles and all crocodilians (Bull 1980, 1983 Ewert and Nelson 1991; Janzen and Paukstis 1991).

Temperature is the primary environmental factor that influences sex in turtles, and when eggs are incubated at a constant temperature, there is a narrow threshold range (approximately 2º C) that produces mixed sex ratios. For terrapins, constant incubation temperatures of 28.5º C to 29.5º C produce mixed sex ratios. Ecologically, the most interesting consequences of ESD are that a nest placed in a particular nesting location usually results in offspring that are all the same sex (Bull 1985, Vogt and Bull, 1984).

METHODS

Since 1987 one of us (Roosenburg) has been conducting a detailed study of the nesting biology of the diamondback terrapin. Two nesting areas, Marsh Point Beach and Burton's Beach, located on the western shore of the Patuxent River approximately 8 km south of Benedict, Maryland, were monitored throughout the nesting season from 1987 to 1991. Marsh Point Beach is a small sandy strip that faces southeast and is approximately 0.20 hectare; Burton's Beach faces east-northeast and is approximately 0.25 hectare (Roosenburg 1994). (Further details of the methodology can be found in Roosenburg 1990, 1991, 1992). Briefly, all nests that were discovered were identified and monitored daily throughout the incubation period for predation.

To understand how the natural incubation environment affects sex determination, we conducted a series of experiments in which we placed artificial nests of terrapin eggs in different microhabitats on Burton's Beach. Eggs were collected from several different beaches along the Patuxent River, but away from the study site. The eggs were taken back to the laboratory, weighed and randomly assigned to experimental nests of 12 eggs each. During 1989 and 1990 three nests were placed in each of nine different microhabitat types. Microhabitat types were cross-classified according to exposure to direct solar radiation, in terms of sun (> 8 hrs), semishade(4-8 hrs), and shade (< 4 hrs), and to the amount of vegetation in the area, in terms of open (0 stems/0.25 m^2), edge (1 - 50 stems/0.25m^2), and vegetation, (> 50 stems/0.25 m^2). We took advantage of natural variation in vegetation to manipulate the vegetation and we used artificial shade cloth (70% blockage) to manipulate the exposure. Our expectation was that warmer microhabitat types would produce females while cooler sites would produce males.

All hatchlings that emerged were taken back to the laboratory, killed, dissected, and sexed based on the gross morphology. Females were identified by the presence of Muellerian ducts and the presence of a translucent ovary. Males were diagnosed by the presence of a small opaque testis and lack of or regressing Muellerian ducts (Yntema 1981).

RESULTS AND DISCUSSION

Marsh Point Beach had a greater number of nests than Burton's Beach during each of the 5 years of the study (figure 1). Predation rates of nests varied (30-94%) depending on the year and the beach (figure 2). Raccoons destroyed from 59% to 70% of the nests, followed by foxes (5-9%) and otters (1-3%) during the 5-year study. The predator could not be determined for 18-35% of the nests destroyed. Predation rates of terrapin nests were greater on Marsh Point Beach than Burton's Beach for each of the 5 years of the study (figure 2). These results suggest that predation may be density-dependent because Marsh Point, which has a higher density, had a much greater predation rate than Burton's Beach, the low-density nesting area. To corroborate the findings that predation rate may be positively correlated with nesting density, data of additional nesting areas are needed. As a consequence of the density-dependent predation, Burton's Beach produced 369 hatchlings over 5 years, compared to 30 hatchlings produced on Marsh Point Beach. The difference in recruitment between the two beaches suggests that sites that have low nesting densities may actually have a greater impact on the terrapin populations than similar sized beaches with higher nesting densities.

We do not know what the predation rates on terrapin nests have been over the evolutionary history of the species. However, anthropogenic causes have eliminated the natural predators of raccoons and foxes, increasing their density. Additionally, the collapse of the fur market owing to public opinion concerning the use of fur has further decreased mortality of turtle nest predators. Our study and others suggests that increasing raccoon and fox populations pose a serious threat to turtle populations (Congdon et al. 1993). The nest predator problem in Chesapeake Bay may be further exacerbated by the increased development of shoreline areas, reducing the trapping and hunting of raccoons and foxes that traditionally have taken place in rural areas. Raccoons, in particular, are opportunistic animals that appear to thrive in suburban environments that are rapidly developing in waterfront areas. The combination of all these factors may result in historically high levels of predation on terrapin nests, shifting the burden of recruitment on nesting areas that may be marginal or somewhat less preferred for nesting.

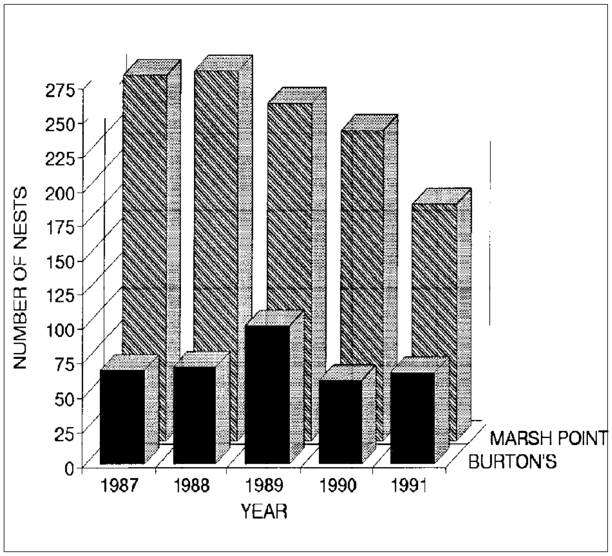

Figure 1. The number of nests found on the two nesting beaches during the 5-year study. Both beaches are almost equivalent in size (see text). Marsh Point Beach is a high-density nesting site, Burton's Beach is a low density site.

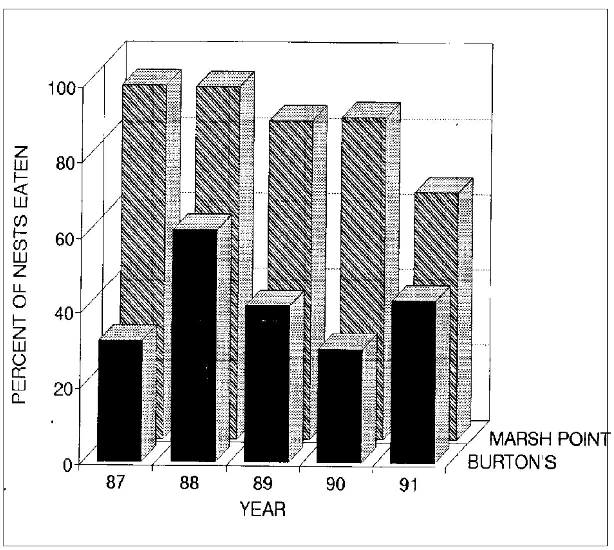

Figure 2. The percentage of nests destroyed during the 5 years of the study for both beaches. Predation was greater on Marsh Point during each of the 5 years of the study suggesting that predation of terrapin nests may be density dependent.

The interesting question remains, Why do terrapins continue to nest in areas with high predation rates? We offer two hypotheses. The first hypothesis is predator satiation-saturating a beach with eggs may provide enough food to satiate the predators and ensure that some terrapins are left to hatch before the predators can discover them, analogous to the masting phenomenon observed in many trees. Unfortunately, the increases in predator populations may result in the inability of terrapins to satiate the predators. The second hypothesis suggests that nest site fidelity observed in terrapins (Roosenburg 1990) constrains terrapins to nesting on particular beaches and that naturally fluctuating levels of predator populations in certain years produce a high number of terrapin offspring on high-density beaches when predation is low.

Our experimental nests produced 185 hatchlings from 648 eggs. Of these 185 hatchlings, 63 resulted from nests that were placed in warmer microhabitats that were anticipated to produce a high proportion of females. Contrary to our expectations, 184 of the 185 hatchlings were male and 1 was a female. This result suggested that there may be qualitative differences among beaches with regard to the sex ratio of the recruits that are produced on these beaches. Because the majority of the microhabitat types that we chose were cooler sites (Roosenburg 1992), we expected a male bias in our sex ratio. However, the sex ratio bias we observed was far greater than we anticipated. Vogt and Bull (1984) observed variation in sex ratios of nests owing to microhabitat differences; however the hatchling sex ratio of their nesting areas was female-biased.

Two likely explanations exist for the biased sex ratio we observed. First, nests were planted at times that resulted in the temperature-sensitive stage occurring when it was too cool to produce females. This explanation, however is unlikely because nest, were planted in both warm and cool microhabitats throughout the summer, and the likelihood is low that they all would incur only male producing temperatures based on the ambient climatic conditions during the time of sex determination. The second explanation is that the beach that was used for the experiment has certain properties that constrain it to being a male-producing beach.

There are two physical features of nesting beaches that might have an overriding effect on the microclimatology of a nesting area. First, orientation of the nesting beach with regard to the sun (e.g., beaches that face to the south) may be warmer beaches compared to beaches that face to the north. The solar flux that impinges on an object is a function of the cosine of the angle created by the "normal" (a line extending perpendicular from the surface) and the angle of the suns rays (figure 3 [Gates 1980]). As the angle created by the normal and the suns rays decrease, the solar flux owing to solar radiation increases (figure 3). Thus, beaches that face to the south have a smaller angle and are likely to have warmer sand temperatures than beaches that face to the north (figure 3). The beach used in our experiment faced east-northeast. Although it was exposed to direct sunlight, the angle of the incoming solar radiation may not have warmed the sand as much as on beaches that faced to the south where the angle may have been less acute throughout the day.

Second, elevation of the nesting area above mean high tide could affect temperatures of the nest. Terrapins usually nest within 10 m of the water's edge. The proximity of the nest to the water indicates that the subterranean water level under the nest is determined by the rise and fall of the tide. Nests on beaches with less elevation are cooler than nests at higher elevation simply by decreasing the length of the thermal gradient between the water and the nest (figure 4). Thus, nesting areas well above mean high tide are likely to be warmer than beaches with less elevation. Conversely, nests that are on higher beaches may be buffered from the cooling via a greater distance from the high tide. Burton's Beach has comparatively less elevation than some of the other nesting areas we have observed along the Patuxent River.

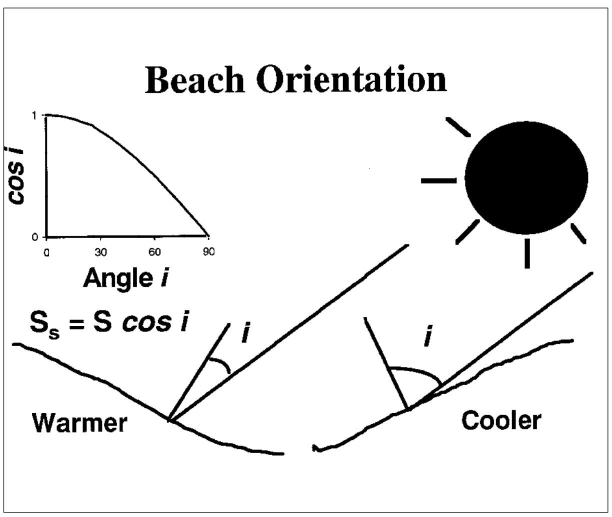

Figure 3. The relationship between the angle of a nesting site and the solar flux on that site. The solar flux is a function of the cosine of the angle ***i*** determined by the "normal" of the surface and the sun's ray. Beaches facing to the south decrease the angle *i* and thus receive a greater heat load than do beaches facing to the north. Thus, north-facing beaches may be predominately male-producing while south-facing beaches may be predominately female producing.

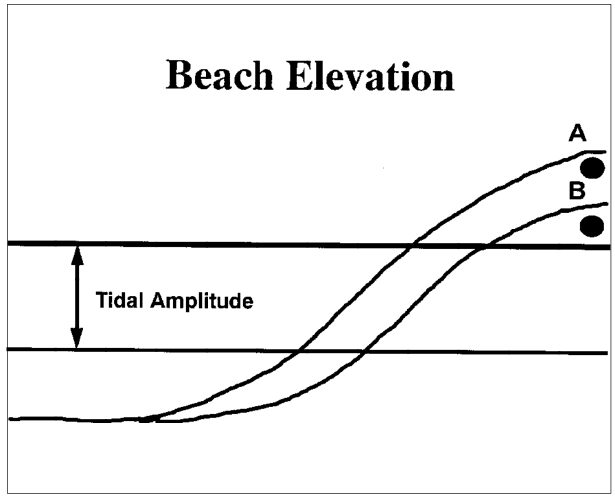

Figure 4. Relationship between the subterranean water level determined by the tide and the elevation of the beach. Beaches with lower elevation decrease the length of the thermal gradient and thus are likely to have lower temperatures than beaches with greater elevation. A represents a nest on a high (warmer) elevation beach and B represents a nest on a low (cooler) elevation beach.

CONCLUSIONS

Biased sex ratios of recruits and density-dependent predation have interesting consequences for the management and conservation of terrapin populations. First, our findings indicate that nesting areas that are not as heavily used by females may play an important role in maintaining populations. Second, environmental sex determination may result in certain beaches that produce mostly males and other beaches that produce mostly females. Though our data do not equivocally demonstrate that this is the case, they do suggest that there are nesting areas that contribute differentially to the different sexes. Currently, there is a need to understand the ecological consequences of ESD in terrapins and in other reptiles that exhibit this peculiar form of sex determination, particularly as it relates to management and conservation.

A management strategy for terrapins within the Bay needs to consider the possibility that some beaches may be important for producing females while other beaches may be important for producing males. Elimination of certain beaches through bulkheading or other forms of shoreline development could ultimately have an impact on the sex ratio of local populations. Additionally, shoreline manipulation that may affect the elevation of the available nesting area might also affect the sex ratio of the recruits on a particular nesting beach.

Preservation of a few high-density nesting areas in locations where terrapins are known to occur may not be sufficient to maintain local populations. As historical nesting sites are eliminated by bulkheading or predator populations continue to increase, there are two consequences that can impinge on terrapin populations. First, terrapin populations can decrease because females are forced to nest in marginal habitats where nest survivorship is low (Roosenburg 1992). Combined with large or increasing predator populations, the number of recruits entering a population may be dramatically reduced. The second consequence is the alteration of the sex ratio. Beaches targeted for preservation may be biased in the sex ratio of recruits resulting in an unbalanced adult sex ratio. The importance of our findings to management considerations of terrapins and other species with ESD is far reaching. Further work is needed to determine the interaction between, and the elevation, orientation, and sex ratio of nesting areas to adequately describe critical attributes of nesting beaches. Until this information is available, preserving areas where nesting occurs represents the only logical choice. Similarly, preserving only high-density nesting areas may not adequately maintain viable terrapin populations or balanced sex ratios.

ACKNOWLEDGEMENTS

We are grateful to N. Dodge and L. McCormirk-Goodhart for the use of their properties as a study site. Numerous field assistants helped in the collection of data on the nesting biology of terrapins. We are grateful to R. Morin and K. Kelley for helpful comments on previous versions of this manuscript. This work was funded by the Maryland Department of Natural Resource Contract No. F218-90-008 and # S183-89-008, Shell Foundation Award to the University of Pennsylvania, Sigma Xi, Patuxent River Appreciation Days Grant, Optimist Club, and Dr. and Mrs. W. Deshler, Calvert County. The contents of this document do not in any way reflect the views, opinions, or policies of the Maryland Department of Natural Resources. This is contribution number 256 from the Maryland Center of Marine Biotechnology at the University of Maryland Biotechnology Institute.

REFERENCES

Bull, J. J. 1980. Sex determination in reptiles. Q. Rev. Biol. 55:3-20.

Bull, J. J. 1983. Evolution of sex determining mechanisms. Menlo Park, CA: Benjamin Cummings.

Bull, J. J. 1985. Sex ratio and temperature in turtles: Comparing field and laboratory data. Ecology 66:1115-1122.

Congdon, J. D., A. E Dunham, and R. C. van Loben Sels. 1993. Delayed sexual maturity and demographics of Blanding's turtle (*Emydoidea blandingii*): Implications for conservation and management of long-lived organisms. Cons. Biol. 7:826-833.

Dunham, A. E., B. W. Grant, and K. L. Overall. 1989. Interfaces between biophysical and physiological ecology and the population ecology of terrestrial vertebrates ectotherms. Phys. Zool. 62:335-355.

Dunham, A. E. 1993. Population response to environmental change: Operative environments, physiologically structured models, and popula tion dynamics. In: P. M., Kareiva, J. G. Kingsolver, and R. A. Huey, (eds.) Biotic interactions and global change. Sinauer Sunderland.

Ewert, M. A., and C. E. Nelson. 1991. Sex determination in turtles: Diverse patterns and some possible adaptive values. Copeia 1991:50-69.

Gates, D. M. 1980. Biophysical ecology. New York: Springer-Verlag.

Janzen, F. J., and G. Paukstis. 1991. Environmental sex determination in reptiles: Ecology, evolution, and experimental design. Q. Rev. Biol. 66:149-179.

Jeyasuria, P., W. M. Roosenburg, and A. R. Place. 1994. The role of P-450 aromatase in sex determination in the diamondback terrapin, *Malaclemys terrapin*. J. Exp. Zool. 270:95-111.

Roosenburg, W. M. 1990. Chesapeake diamond back terrapin investigation for the period 1987, 1988, and 1989. Solomons, MD: Chesapeake Research Consortium. CRC Publication No. 133.

Roosenburg, W. M. 1991. The diamondback terrapin: Population dynamics, habitat requirements, and opportunities for conservation. In: J. A. Mihursky and A. Chaney, (Eds.), New perspectives in the Chesapeake system: A research and management partnership. Solomons Md: Chesapeake Research Consortium, CRC Publication No. 137.
Roosenburg, W. M. 1992. Lie history consequence of nest site choice in the diamondback terrapin, *Malaclemys terrapin*. Ph.D. dissertation. Philadelphia: University of Pennsylvania.
Roosenburg, W. M. 1994. Nesting habitat requirements of the diamondback terrapin: A geographic comparison. Wetlands Journal 6(2):8-11.
Roosenburg, W. M., and K.C. Kelley. In press. The effect of egg size and incubation temperature on growth in the turtle, *Malaclemys terrapin*. J. Herp.
Vogt, R. C., and J. J. Bull. 1984. The ecology of hatchling sex ratio in map turtles. Ecology 65:582-587.
Yntema, C. L. 1981. Characteristics of gonads and oviducts in hatchlings and young of *Chelydra serpentina* resulting from three incubation temperatures. J. Morph. 167:297-304.

Toward a Sustainable Coastal Watershed:
The Chesapeake Experiment. Proceedings of a Conference
1-3 June 1994. Norfolk, VA
Chesapeake Research Consortium Publication No. 149

Studying the Migratory Population of Coastal Bottlenose Dolphins (*Tursiops truncatus*) in Virginia

W. M. Swingle
Virginia Marine Science Museum

S. G. Barco, W. A. McLellan, and D. A. Pabst
James Madison University

Abstract: Following the mass mortality of bottlenose dolphins, *Tursiops truncatus*, along the U.S. East Coast in 1987-88, it was clear that little was known of their population status in the region. In 1989, the Virginia Marine Science Museum (VMSM) initiated Operation Dolphin, a long-term study of Virginia's coastal bottlenose dolphins. Primary components of the study include (1) development and curation of a dolphin photo-identification catalogue for Virginia, (2) analysis of the structure, movements, distribution, and size of this transient dolphin population, and (3) examination and analysis of stranded dolphins in the state. Currently the Virginia catalogue contains more than 250 individuals that have been identified. Results from the photo-ID study indicate both annual and within season migrations of bottlenose dolphins through Virginia coastal waters. Resights include one dolphin present during all 5 years of the study and many individuals present in multiple years. Observational and stranding data support the hypothesis that dolphins congregate and raise their young primarily around the Chesapeake Bay mouth. Shore-based and boat surveys along Virginia's ocean coast have provided a broad picture of the distribution of the dolphin population and generated population size estimates of over 300 dolphins. Operation Dolphin provides preliminary data for the long-term study of the migratory population of coastal bottlenose dolphins found off the coast of Virginia.