Ten Years and Still Counting
1999 Horseshoe Crab Spawning Survey
Along the Delaware Bay Shore

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ABSTRACT

The estimated number of spawners along Delaware Bay Shores was 422,775 individuals during the highest tide on May 30, 1999. Nine beaches were surveyed in Delaware and 13 beaches in New Jersey. The majority of the spawners (66%) were found on the Delaware side of the bay. Two peaks of spawning activity occurred in New Jersey during the new and full moon in May and one peak of activity was found in Delaware during the May full moon phase. The 1999 overall estimate is slightly lower than the 1998 and 1997 estimate. Delaware spawners appear to be declining despite the addition of two more beaches in the 1999 survey.

INTRODUCTION

Responding to localized horseshoe crab population declines and increased fishing pressure on the crabs for bait, the Atlantic States Marine Fisheries Commission (ASMFC) in 1998 opted to establish an Interstate Fishery Management Plan for the Horseshoe Crab, Limulus polyphemus. One of the main results of the plan for the Delaware Bay area was the implementation of an increased spatial and temporal spawning survey during May and June of 1999, based on the methodology of previous surveys (1990-1998) and numerous discussions among the many scientists associated with the ASMFC deliberations.

This report continues our 1990-1998 series of annual reports. It seems appropriate, therefore, to begin with a brief history of the spawning survey.

THE HISTORY OF THE ANNUAL SPAWNING SURVEY

James J. Finn. The tagging program and spawning survey in the Delaware Bay area can be traced to one man, James J. Finn. Without his stimulus and tireless effort, several programs that stand as testimonials to his interest in Limulus probably would not have occurred, certainly not as timely as they did. Looking back, it can be truly said that Jim's ideas were at least 10 years ahead of time. Unfortunately, his untimely death, early in 1991, left Limulus without a foremost champion and us without a good friend. We believe that Jim would have been pleased with the evolution of the survey.

Beginnings

In the 1980's, Jim Finn's company, Marine Biologicals was housed in one of the New Jersey Sciences Consortium buildings near Marmora, NJ. By 1990, he had incorporated Finn-Tech Industries, Inc. and moved to Highs Beach in Cape May. His meetings with resident biologists at the consortium and at seminars had increased Finn's interest in horseshoe crabs. Through his business, he was already concerned about what appeared to be an increased harvest of horseshoe crabs and wondered what could be done to monitor the adult population, particularly in the Delaware Bay area. The tagging effort and spawning counts by Shuster (1950) in Cape Cod waters and the bay-wide spawning survey on the shores of Delaware Bay conducted by Shuster and Botton (1985) interested him.

In 1986, Finn supported a study on Limulus by Dr. Mark L. Botton of Fordham University. In 1987, Finn participated in a Rutgers-Lehigh seminar on the horseshoe crab at Stone Harbor, New Jersey coordinated by Liz Chornesky (Lehigh-Stone Harbor Marine Laboratory) and Tim Jacobsen (Rutgers University). Participants reported on their studies on the orientation of horseshoe crabs on beaches (Dr. Botton,); on mating behavior (Dr. Robert L. Loveland, Rutgers University); on the distribution of Limulus eggs in beaches (Karen L.0 Williams, NJ Marine Sciences Consortium); biomedical and tagging programs (Finn, Marine Biologicals, Inc.), and on fouling communities and injuries to Limulus (C. Wahle, E. Chornesky, Tony Totah, C. Pasche (Lehigh-SHML). Also in 1987, Finn began his Limulus tagging program.

In 1988, Dr. Tom Mikkelsen of Denmark, a producer of horseshoe crab lysate with bleeding facilities in China, planned a visit to the United States to see Mr. James J. Finn, also a producer of lysate (in New Jersey) and Carl Shuster. Dr. Koichiro Nakamura and his wife Dr. Reiko Nakamura (a visiting scientist at NIH) had been in contact with Dr. Shuster, so what started out as a three-person meeting soon escalated into a mini international seminar -- the Scientific Conference on Limulus polyphemus hosted by Marine Biologicals, Inc. (of which Finn was president). Several of the quickly assembled scientists reported on their current research: Dr. Elias Cohen (Roswell Park Memorial Institute) on lectins in Limulus blood; Dr. Gurdial Sharma (William Paterson College) on vitamin B-12, cobalamin binding factor; Dr. Mukesh K. Sahni (William Paterson College) on blood chemistry; Dr. James F. Cooper (Endosafe, Inc) on a distribution study of Limulus in South Carolina waters; Shuster summarized the scope of research in retrospect and prospect; Dr. Louis Leibovitz (Cornell University) on diseases of Limulus; Dr. Mark L. Botton (Fordham University) on horseshoe crabs as an economic resource, past, present, and future; Dr. Robert L. Loveland, (Rutgers University) on population dynamics of horseshoe crabs in Delaware Bay; Dr. Nakamura on studies in Japan led by Dr. Koichi Sekiguchi (University of Tsukuba), and Dr. Mikkelsen on his world-wide search for horseshoe crab populations. Dr. Bill Hall and Benjie L. Swan were also participants.

The Tagging Program

It was in 1987, after discussion with Shuster that Finn ordered special tags, printed with pertinent information including a reporting address, and began tagging horseshoe crabs as well as distributing the tags to others. The object was to explore the distances traveled by individual crabs and their longevity. That activity has continued to this day and Ms. Swan is preparing a report on the accumulated information.

Ms. Swan provided some of the results of the tagging program for the report by Shuster (1997). During the period 1990-1995, some 6,200 adult horseshoe crabs had been tagged on the shores of Delaware Bay (Delaware = 3,300 and New Jersey = 2,900). A few were recaptured almost immediately after tagging and release. Later, one was retaken alive after eight years (Swan, 1998 pers. Comm.). The tagging has documented the fact that the adults moved throughout the bay area in all directions and at least 30 miles out onto the continental shelf.

Other Activities

Finn sought to mobilize further attention to Limulus and the tagging program and the spawning survey by helping to organize Horseshoe Crab Fests and other programs.

Horseshoe Crab Fests. The first fests were all-day affairs held in 1991-1993 at Wildwood Crest. Live horseshoe crabs, a crab race, the sale of crab/marine related novelties, several exhibits, slide presentations by Drs. Mark Botton, Robert Loveland, and Carl Shuster were part of the program. Annual fests have been held since then at other Cape May sites.

Adopt-a-Crab. Adopt-a-Crab's program raised money for research. Fund contributors received a certificate with the tag number and information on the specific crab that they had adopted. Adopters were informed the circumstances if their crab was recaptured.

International Directory. 1990 Finn circulated an open letter to a number of scientists to ask if they would be interested in being listed in an international directory he was compiling on individuals involved in various aspects of horseshoe crab research.

The Spawning Survey

In 1990, the spawning survey was activated after a well-attended meeting hosted by Dr. William R. Hall, Jr. at Lewes, Delaware. Among the early participants were Dr. Mark L. Botton (Fordham University), Karen Day (USFWS), Dr. Norman Dill (Delaware College), Jim Finn, Dr. John Kraeuter (Haskin Laboratory for Shellfish Research, Rutgers University), Pearl Burbage (Delaware DNREC), Marion Pohlman (USFWS), Grace Pierce-Beck (DE Audubon Society), Carl Shuster and Jeff Tinsman (DE DNREC). The conferees decided that a synoptic, same stage of the tide, bay-wide survey of the spawning crabs could provide an index to at least the minimum number of adults in the Delaware Bay population. Since a large number of volunteers would be needed to conduct such a survey much attention was given to developing an easy, replicable counting method, and to train the volunteers. Each succeeding year, a spawning survey meeting was held at Lewes to discuss dates, methods, and training.

For the first few years, Shuster, Hall, and Swan held several training sessions/workshops each year describing the animals and explaining the survey methods: -- introductory information on the basic biology and ecology of horseshoe crabs; their anatomy (especially how to distinguish between adult females and males); the fossil record, the significance of the eggs in the diet of migratory shore birds and on uses, including the Delaware Bay King Crab fertilizer industry; Limulus Amebocyte Lysate (LAL) derived from the crabs blood cells, chitin, and bait for eels and

conchs (whelks); -- spawning survey instructions. The last workshop, initiated by Dr. Hall, was a one-day forum sponsored by the Sea Grant College Program at the University of Delaware (Farrell & Martin, 1997).

The following briefly discusses questions that were resolved and basic ingredients of the Delaware Bay spawning survey. We should note, spawning patterns reported on a Buzzards Bay beach on Cape Cod (Barlow et al. 1986) were apparently similar to those in Delaware Bay. That study served as a useful guide in our planning.

Source of a Cadre of Volunteers? Each year approximately 150 volunteers representing a wide variety of backgrounds have conducted the spawning survey. Educational, environmental, and youth groups have also participated. In the beginning, advertising for volunteers was necessary. Now, since many of the volunteers are the same ones who started in the beginning, they provide a veteran cadre that both stabilizes the program and guides the neophytes.

What Beaches to Survey? Essentially, counting the spawning population determines the extent (distribution and numbers) of the adults in the Delaware Bay area. The spawners are the easiest segment of the population to survey as they literally come to the observer/counter. Historically, those beaches where spawning occurs have been well known for over 150 years (Cook 1857, Fowler 1908, Shuster & Botton 1985). Botton et al. (1988) further established that the broad distribution of spawning horseshoe crabs correlated with the availability of sandy beaches.

Initially all accessible, potential spawning sites were evaluated. We used a nautical chart (NO. 12304 -- Delaware Bay, National Ocean Service/NOAA), the series of USGS 7.5 minute topographic maps for the coastline of Delaware Bay, and on-site observations as guides to spawning areas and to record information about the sites.

When to Survey? In Delaware Bay the spawning season may extend from April through August. The peaks usually occur during the full moon periods in May or June (or both). Historically, the greatest abundance of spawners occurred over a period of a few days during the periods of peak high tides. Thus, since we were recruiting a large volunteer force we selected a Saturday date closest to the full or new moon as the best match between availability of volunteers and a period of potential maximum spawning.

Since horseshoe crabs come ashore with the high tide and there are two high tides per day, spawning activity on both high tides were surveyed. The times of high tides at a beach were predetermined from two NOAA publications and then confirmed by observations at the site. The predicted times of high tides were obtained from NOAA Tide Tables, with reference to Breakwater Harbor in Delaware Bay, and from a NOAA co-tidal chart for Delaware Bay. When a spawning area was inaccessible at high tide, as at bulkheaded beaches, the volunteers waited until the spawners were exposed.

Survey Preparation and Conduct. At least a two-hour window of time exists within which a spawning survey can be conducted. In most cases, depending upon the length of the beach and the number of spawners, there could be insufficient time to count. Over the years, various random sampling methods were employed. Survey instructions, along with Tally Sheets have been

distributed to each volunteer. In 1990 and 1991, the spawners within 10-meter segments along the water's edge were counted. If the crabs extended further into the water, the recorder noted this on the Tally Sheet.

When huge numbers of crabs are spawning, as in the year 1990, it is difficult to count all the crabs within a 10-meter segment, so the sampling segment was reduced to 5-meters in subsequent years. In 1990, the spawners on several beaches were not only piled up two and three tiers (occasionally four deep) above a beach but also covered a swath at least three meters wide. Usually the crabs in upper meter could be easily counted since they were above the water line or in shallow water. But the second meter row of crabs was in the swash zone and the third meter row was always under water. Not only were many of the crabs hidden from the observer but the movement of the crabs further contributed to the difficulty in making accurate counts.

A Finn-Shuster inclusion/exclusion cage was designed to count large numbers of spawners especially when the spawning activity was submerged. Carl N. Shuster III constructed the cage. It had two 1-meter square compartments framed by tubular steel and enclosed with a 2-inch plastic mesh. It was trapezoidal in side view. When placed over spawners on a beach, the partition between compartments was placed at the water's edge, thus the deeper compartment was under water. Although bulky, the cage was lightweight and could be handled by one person.

Subsequent Changes in Survey Methodology. The sampling segment length was reduced to six 5-meter segments during 1983-1995. In 1996, the number of 5-meter samples was increased to 18, in response to a recommendation from Dr. Kraeuter aimed at making the survey more "statistically robust".

By 1998, prior to coming to the beach, each volunteer team randomly marked three 5-meter segments on a 50-meter long string. At the beach, preferably 2 hours before high tide, they placed three stakes on a beach at least 100 meters apart. At the time of high tide, in preparation to make the count, they extended the 50-meter string to the left and to the right of each stake. Spawners within the 5-meter segments were then counted and the results recorded on the Tally Sheets (number of males and females in each 5-meter segment). Other data were also recorded: the beach, date and time of survey, the recorder, with notes on the location, weather conditions, and any other observations deemed pertinent. Usually one person recorded the data while another made the count.

Other Observations. In 1990, recorders noted whether a spawner was single or in a group. This acquainted the first-year volunteers with the fact that virtually all spawning females have one or more males with her. Sometimes even a dead female or a large oval stone at the water's edge will have males with them. In subsequent years, spawners were listed only as male or female.

In 1991, a column for listing stranded crabs was added to the Tally Sheet. At the time it was thought that this might expand upon the study by Botton & Loveland (1989) that ascertained mortality levels associated with spawning. This tally was soon discontinued for several reasons. It was adding too much work to an already tedious survey, good Samaritans were flipping the crabs over, and unless a beach was cleared of all stranded animals prior to the spawning survey, those stranded crabs associated with the spawning episode could not be discerned with certainty. It was concluded that such studies are better suited to research projects.

In 1992, an experimental aerial survey was flown along the spawning beaches. Such aerial surveys are expensive and, without available funding, the idea was not further explored. Also in this year, a packet containing spawning activity history was distributed as informational guide. It gave travel directions to the beaches, crab numbers previously found on certain beaches, and any history of records on spawning activity for that beach.

In 1993, in addition to the regular random method, we experimented with a "rapid survey" that involved rapidly pacing along a beach and estimating the number of crabs within a square meter at every 15 meters. The counts were tallied by checking off a box on a special tally sheet denoting whether the number of crabs was none, few, moderate, or many (piled up on one another). The estimates were quite different from the random sampling so the method was abandoned. If there were few crabs on a beach, volunteers were instructed to survey 200 meters instead of the usual 5-meter segments.

In 1994, daily counts of the spawners were initiated at Highs Beach during the spawning season. The Highs Beach information was useful as a baseline of data in the interpretation of spawning counts in 1995. In New Jersey during 1996-1998, creek mouths and back marshes were surveyed because many spawners were observed during previous surveys and field trips. Weather conditions in 1997 affected spawning therefore observers were requested to take more weather information.

In 1998, volunteers counted the young male spawners (those with shiny shells and no abrasions or epibionts) within eighteen 5-meter segments. This estimate was begun to develop some information on year classes and recruitment. Volunteers were trained to discern the age of horseshoe crabs from the external appearance. We concluded examination of the "age" would be better served as a separate study.

Dates of Surveys. In Delaware Bay, peak numbers of spawning horseshoe crabs usually occur within a few-day period associated with the new or full moon phase of the moon. Although the greater numbers of spawners appear on the high tides associated with these phases of the moon, weather conditions ultimately determine the level of spawning activity. Thus, selection of a spawning survey date in advance of the actual event could result in picking a windy day when the numbers of spawners is reduced.

In the beginning, 1990, one day was selected as the survey date. In subsequent years the impact of weather conditions forced the selection of additional survey dates. This can be demonstrated, in review. For example, the lower estimate of spawners in 1992 was probably partially due to weather conditions. This led to sampling representative beaches on four dates in 1993, 1994, and 1995. As a result, the multi-date surveys picked up differences due to the weather. In 1994, three weeks of cold weather preceded the May 23rd survey date. The crabs did not spawn on the 23rd but high numbers were recorded on June 11th, where a daily count of spawners was recorded. Similarly, in 1995, on the June 12th survey date few crabs spawned but peak counts had occurred earlier based on the daily counts at Highs Beach on May 14th.

Beaches Surveyed. Subsequent to the first two years, fewer beaches have been surveyed for spawning activity because the experience gained in 1990 and 1991 indicated that, even with fewer

beaches being examined, the majority of the spawners were being counted. This is due to the fact that the general distribution of spawners can be defined by a bell-shaped curve, south to north along the bay shores. Thus the middle beaches containing the majority of the spawners have been consistently surveyed. Those beaches not regularly surveyed were either at the extreme ends of the bell-shaped distribution curve, inaccessible, or had been lost to spawning through beach erosion or bulkheading, etc.

THE EXPANDED 1999 SPAWNING SURVEY

Since the 1999 spawning survey expanded upon the procedures used in the years from 1990 through 1998, the following reviews those modifications and the rationale for the change. In essence, selections of survey dates, beaches, and sampling techniques were designed to bracket the abundance and distribution of the spawners as well as to satisfy a statistical program.

Selection of Survey Dates

The objectives were to obviate weather-related impacts and minor fluctuations in the behavior of the crabs within a sampling program amenable to statistical analysis. The generalist behavior of Limulus stimulated a discussion about their activities. Do they react precisely or generally in response to environmental conditions? Can their generalist behavior be bracketed? Date selection was also based on several other observations:

-- horseshoe crabs spawn in greater numbers during the highest tides.
-- The tidal cycle is sinusoidal, with only slight changes in tidal amplitude during the days when the tides are at the top of the curve.
-- In past years, the impact of weather on the amount of spawning activity during the survey dates corroborated the observation by Shuster (1955) that wave height governed the numbers.

These observations guided the selection of survey dates. When possible, twelve surveys were made, including four lunar dates (May 15th, May 30th, June 13th and June 28th) and two days before and after each lunar date. It was assumed that the five dates would profile spawning intensity at the most favorable tidal phase and thus "capture" the absolute peak in the numbers of spawners. Additional survey dates (on a day 1 week after the lunar dates during May and June), designated as "off" dates, were selected to further establish the observation that spawning crabs normally concentrated on the days of the highest of the high tides.

Selection of Beaches

Sixteen beaches along the Delaware Bay shore were surveyed during 1999. The process for choosing these beaches took into account the accessibility of the beaches, the historical spawning activity at each beach, and random selection.

Accessible Beaches (from South to North):

-- In Delaware: Cape Henlopen, Roosevelt Inlet, Broadkill, Primehook, Fowler, Slaughter/Cedar, Bennetts Pier, Big Stone, South Bowers, North Bowers, Kitts Hummock, Pickering, and Woodland.

-- In New Jersey: Sunset Beach, Higees, Townbank, Villas, Norburys Landing, South Cape Shore Lab, Highs, Pierces Point, Kimbles, Cooks, Reeds, Moores, Thompsons, East Point, Raybins, Fortescue, Gandys, and Sea Breeze.

Historical Spawning Activity. Three categories were recognized:

-- Southern beaches with less-utilized spawning habitat;
-- Middle beaches with high spawning activity, and;
-- Northern beaches with generally low spawning activity.

Random Selection. Eleven accessible beaches were randomly selected from the historical categories for 16 surveys:

-- Five in Delaware: Broadkill, Primehook, Slaughter, North Bowers and Woodland.
-- Six in New Jersey: North Cape May, Cape Shore Lab, Kimbles, Raybins, Gandys, and Sea Breeze.

In addition, six beaches were selected for 23 dates (including the off dates):

-- Three in New Jersey: Highs, Reeds, and Fortesque.
-- Three in Delaware: Fowler, Big Stone, Kitts Hummock.

Further, five beaches that had been surveyed during the previous nine years were also surveyed on the four lunar dates in May and June, thus providing additional comparisons:

-- In New Jersey: Townbank, Sunray Beach, Pierces Point and East Point.
-- In Delaware: Pickering.

Selection of Methodology

In 1999, three modifications were made in the methodologies used in previous surveys:

1. Counting the spawners was done only during the night high tide. Previous surveys had established that more horseshoe crabs spawned during the highest of the daily high tides and that these are, invariably, the nighttime high tides. In the past, the surveying of a beach during daylight hours helped to familiarize the volunteers with the beach and practice the methodology. This also helped to alleviate difficulties during the night count when it was more difficult to see and the horseshoe crabs were more numerous. In 1999, due to the extra survey dates, it was assumed that scheduling day counts during the week would be more exhaustive. It was decided that by concentrating on the nighttime high tides, more night counts could be made yet not jeopardize the overall survey results.

2. Sampling consisted of counting the number of horseshoe crabs within 1- meter quadrats, 100 each per beach. This method yielded a total sample length of 100 square meters. In previous surveys, eighteen 5 by 1-meter segment along a beach yielded a 90-

square meter sample. Statistically, the count within a 1-meter square helped to reduce the variation between segments, that making the count more valid. The 1-meter quadrat was easy to place and to count the enclosed crabs the four-sided structure of white plastic pipe clearly defined the area to be counted, even those areas that extended into the water.

3. In 1999, the survey counts were made within 100 square meter quadrats along a 1 kilometer strand along a beach. In previous surveys an entire beach was sampled. In 1999, when a beach had an accessible area of less than 1 kilometer the survey was modified to obtain the necessary 100 quadrats at shorter intervals. Two beaches in New Jersey, Raybins and Sea Breeze, only had small accessible strands, 160 and 200 meters respectively. The entire strand was counted, therefore, at both beaches.

1999 RESULTS

Table 1A summarizes the survey data collected in New Jersey and Delaware (Table 1B) during 1999 (see appendix). Each beach is listed in the first column along with an estimate of the length of its spawning strand. The next columns give the dates of the related lunar phase or the "off" date. Two numbers are given for each date for each beach - the density of the horseshoe crabs and the estimated number of horseshoe crabs. The density of the crabs was computed by calculating the total number of spawners counted within the 1-meter square quadrats divided by the number of quadrats surveyed. The estimated number of the crabs was extrapolated from the density of horseshoe crabs per square meter multiplied by the length of the spawning strand of the beach. Totals are given for each date and for each beach. For convenience, we have summarized all the data in Figure 1 in the appendix.

DISCUSSION OF 1999 RESULTS

New Jersey Spawning Activity

Two peak counts were recorded for New Jersey - May 17th (two days after the new moon), 73,222 and May 30th (the full moon date) 68,837. In early May, the water on the shore of New Jersey was relatively calm during a predominately northeast wind. Weather-wise the conditions for spawning were favorable during the new moon in May and spawning activity was high. Spawning activity on the northern beaches in New Jersey increased later in May during the full moon date. The majority of the spawners (74%) were observed during the days surrounding the new and full moon dates in May. Counts dropped off in June with relatively few spawners observed.

Bay-wide, the Cape Shore Laboratory in Green Creek had the most spawning activity (43%) during the 1999 season and the greatest density of horseshoe crabs (20.37 crabs per square meter) during the peak count on May 17th.

Densities in New Jersey were variable. Peak densities occurred during both the new and full moon periods. The "middle" beaches reached their peak counts during the new moon period with the exception of Kimbles Beach. Spawners on the southern and northern beaches reached their peak numbers during the full moon or 2 days after the full moon date.

Delaware Spawning Activity

Spawning individuals were more numerous along the Delaware side of the bay this year (as in the past six years). Low numbers of spawners on the Delaware side during early May coincided with the prevailing northeast winds. Spawning peaked on June 1st (2 days after the full moon date in May) 193,670. Fifty-three percent of the Delaware spawning activity occurred during the three days around the full moon date in May. Spawning at Kitts Hummock apparently was not affected by the wind in early May; good numbers of spawners were reported throughout May.

Big Stone Beach had the most spawners (30%) in Delaware during the spawning season. That might be attributable to the extensive length of this beach -- some 7.6 km. Kitts Hummock had the greatest density of spawners, 24.8 crabs per square meter during the peak count on June 1st. Delaware beaches reached their peak numbers during the full moon period in May. The greatest numbers of spawners occurred during the full moon date and two days after the date in May.

Comparison of the Years 1996-1999

Overall spawning activity has decreased slightly from 1998 and 1997. Spawners along the New Jersey shore of the bay have increased since 1996, but the numbers are still much lower than the earlier estimates of roughly 800,000 spawners in 1990 and 1991. Delaware spawning numbers appear to be declining despite the addition of two more beaches in the 1999 survey. Estimated numbers of Delaware spawners are lower than the numbers from 1996-1998. (Figure 2)

A Possible Population Trend?

At present the only information available is in the historical harvest records on the Delaware Bay population of horseshoe crabs, the 1990-1999 spawning survey records, and personal observations. Based on these, we hypothesize that when an abundant population of horseshoe crabs is continuously and heavily harvested, a sharp decrease in its numbers does not appear until numerically strong year classes of juveniles are exhausted. It appears that a plateau of marked decrease may not happen for approximately ten years - the life span of juveniles. When harvesting adults you are actually harvesting multiple year classes which may impact a population for several decades. Further, the decrease probably is gradual until the input into the adult population drops. When the new level is established it may be at about 50% of the former plateau in numbers. If harvesting continues, the somewhat step-like downward trend of about 50% per decade continues.

The comparison of the abundance of spawners during the surveys of 1990-1992 with those in subsequent years seems to mirror this hypothetical downward trend. Although harvests within the Delaware Bay and other state waters have been regulated for several years, heavy harvests are continuing on the continental shelf outside the regulated waters. If our concept is correct, then a 50% plateau (down from the 1990-1991 level) may occur within the next two or three years.

DISCUSSION OF THE 1999 SURVEY

In 1999, the survey force was supplemented by many newcomers from state and federal agencies, including the U.S. Geological Survey (USGS). The greatest contribution to the survey

was statistical guidance from the USGS to increase the numbers of observations to obtain more data amenable to statistical analysis. Modifications in that direction - more survey dates and better sampling techniques - were hampered by lack of a comprehensive statistical model and by insufficient manpower. We are not convinced that the problem of enumerating spawning activity can be done solely by a statistical approach. The results of previous surveys spurred both interest and recognition that it was a species requiring interstate management.

Statisticians at the USGS are analyzing the 1999 horseshoe crab spawning survey data, with the goal of producing an index of spawning activity (ISA) based on horseshoe crab density. The ISA will be used by fisheries management, instead of an estimate of the numbers of spawners, as the index is deemed to be statistically more robust and can be used to detect population trends. The USGS results will be available at a later date. We understand the value of the ISA number to statisticians and fisheries biologists but to the general public this number may result in confusion and frustration. Therefore, we will continue to report actual numbers to satisfy the public.

About the Selection of Survey Dates

The beaches were surveyed on either 18 or 23 days when possible. These dates were comprised of those bracketing the new and full moon dates and days in between (designated in this report as the "off" dates). This was an increase over the survey dates on four Saturdays nearest to the lunar phases in the recent previous years. The restricted sampling was due to the limited time that the volunteer force and coordinators could devote to the survey. The 1999 survey had financial and manpower support from both state and federal agencies, hence it was possible to greatly increase sampling the spawning population. It appears we have sufficient data by surveying three times around the moon to obviate weather-related impacts and other phenomenon and to detect trends in abundance.

About the Selection of Beaches

A sub-sample of all the accessible beaches was necessary to have a manageable number of survey sites and lengths. The rationale for surveying as many beaches as possible can be summarized as follows: Horseshoe crab spawning activity appears to be concentrated during optimum times and at optimum areas. The middle beaches are optimum spawning areas with high numbers while the southern/northern beaches experience sharp decreases in numbers. Further, declining horseshoe crab numbers sharpens the relationship between spawning activity, the lunar phase and the duration of the spawning. Where possible more beaches were surveyed in addition to the sub-sample of 8 beaches mandated per side for the 1999 survey.

About Changes in Methodology

Two changes in survey methodology, counting during the higher of the daily two tides (the nighttime tide) and the 1-meter square quadrat, produces a better utilization of time and energy and aides statistical analyses by permitting accurate counts of the animals.

We are unsure of the third change, - whether it is the best way to survey a beach. In past years, surveying was randomly performed along the entire stretch of beach. Those surveys showed

that the spawners were unevenly distributed. For example, they tend to congregate around the mouth of a tidal stream and in creeks. At times, spawning counts may be higher in those areas than on the open beach. Since disparity in numbers occurs at various locations, it is important, where possible, to survey spawning activity at random intervals along an entire beach, not just within a 1 kilometer stretch.

Theoretical Considerations

Do female horseshoe crabs spawn once a year? If so, do they spawn all of the apparently mature eggs that they bear? Do the females contain mature eggs at all times during a year? There appears to be two groups of eggs in a female -- mature and immature. How long does it take for the eggs to mature? Some of these and other questions are only partially answerable by the following information.

Number and Size of Eggs.

Both Dr. Osgood R. Smith of the U.S. Fish & Wildlife Service (in Shuster 1955: Table 21) and Shuster & Botton (1983: Table 3) found at least two distinct egg sizes in adult females. One group of eggs (sometimes referred to as a clutch) was macroscopic and presumably mature since they were of the size that a female deposits in beach nests. Another clutch of eggs was much smaller but of a relatively large volume. Shuster & Botton reported an average of 212 cc of immature eggs and 238 cc of mature eggs [approximately 80,300 eggs, assuming some to most of the immature eggs would mature] from pooled results of 14 adult females.

Number of Eggs in a Nest.

Shuster (1950) reported 200-300 eggs in a nest dug up late in August at Pleasant Bay, Massachusetts. That number is obviously a gross under representation since Shuster & Botton (1985: Table 2) found from 3,430 to 3,960 in four nests in a Delaware Bay beach.

How Long Does Spawning Take?

If a female makes an average of 5 nests on a single high tide, the eggs in a nest average 3,650, and a gravid female contains at least an estimated 80,300 eggs, she should be able to completely spawn those eggs within 5 tides.

Gravid Females.

In our experience and that of others (e.g., Dr. Thurlow C. Nelson, Rutgers University pers. comm. ca. 1947; Stewart Michels, Delaware DNREC, pers. comm. 2000), no matter the season of year that adult females have been examined, they appear to bear mature eggs.

Do We Have Any Answers?

There seem to be more questions than answers. Any gap in knowledge may be important, depending upon what we try to infer from the spawning counts. For example, if there are two

spawning peaks during the year, as during a May and a June full moon period, are the same females spawning during both full moon periods? If so, does that mean the tiny eggs that they carried in May matured sufficiently that they were laid in June? Or has another cohort of adults, perhaps from way offshore on the continental shelf arrived and are the main spawners in June (Shuster & Botton 1985)?

OVERALL COMMENTS

Interest in the horseshoe crab survey has grown over the years in part due to the clash between those increasingly harvesting the crabs for bait and a more environmentally sensitive public. This clash forced local economic, political, and social decisions, starting in the Delaware Bay area. When harvesting was curtailed in the Delaware Bay, it impacted other horseshoe crab populations up and down the coast. The resulting impact was greater than these small populations could sustain, resulting in some adult populations being fished out on an annual basis. This coast-wide situation worsened until 1997, when the Atlantic States Marine Fisheries Commission initiated the development of a horseshoe crab management plan.

The present level of attention to the horseshoe crabs, has spurred many groups to become involved and increased funding for research. Overall there appears to be a lack of coordination between funding and selection of basic and applied studies. The fundamental question, in terms of stock assessment and resource management, however, is the longevity of funding. Is it sufficient to furnish results that may be applicable to managing the resource?

The horseshoe crab survey from its inception in 1990 has been a project driven by a real concern for the fate of the horseshoe crab. Dedicated volunteers and coordinators gave their time and expertise, without pay or recognition, believing that the data collected would be beneficial. The list of accomplishments of the spawning survey include:

-- an accumulation of a mass of information concerning the spawning behavior of horseshoe crabs in Delaware Bay.
-- contributions to the management of the species.
-- its use as a model for surveys in other states along the eastern seaboard of the United States, and
-- best of all, evidence that mere dedication and concern can turn around public opinion and make a volunteer project a respected and valuable resource for understanding and managing a living resource.

A sincere THANK YOU to everyone who made and continue to make the Delaware Bay horseshoe crab spawning survey a success!

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February 2000

Table 1. 1999 Survey Results - Densities and Estimates
A. New Jersey Beaches (2 pages)

Moon Phase	"Off"	"Off"	New -2	New	New +2	"Off"	"Off"	"Off"	Full -2	Full	Full +2	"Off"
Date	**7-May**	**10-May**	**13-May**	**15-May**	**17-May**	**20-May**	**22-May**	**25-May**	**28-May**	**30-May**	**1-Jun**	**4-Jun**
North Cape May (3 km)												
Density of HSC, Crabs/m			0.46	0.07	0.33		0.16			3.42	4.75	
Estimated Number of HSC			1,380	210	990		480			10,260	14,250	
South CSL (2.2 km)												
Density of HSC, Crabs/m	1.87		14.71	7.29	20.37		0.56		4.36	11.78	12.06	
Estimated Number of HSC	4,114		32,367	16,047	44,806		1,238		9,592	25,916	26,532	
Highs (0.8 km)												
Density of HSC, Crabs/m	2.61	2.05	11.92	4.43	11.28	0.24	0.39	0.22	4.28	8.80	6.11	0.46
Estimated Number of HSC	2,090	1,640	9,536	3,544	9,024	192	312	176	3,424	7,040	4,888	368
Kimbles (1 km)												
Density of HSC, Crabs/m	1.47		8.24	2.76	9.18		5.72		8.27	9.44	6.60	
Estimated Number of HSC	1,467		8,240	2,760	9,181		5,723		8,270	9,440	6,596	
Reeds (1.53 km)												
Density of HSC, Crabs/m	2.04	4.54	7.72	0.76	3.38	6.56		0.02	1.80	2.80	1.13	0.08
Estimated Number of HSC	3,127	6,946	11,815	1,166	5,171	10,037	0	31	2,754	4,281	1,729	122
Fortescue (2.6 km)*												
Density of HSC, Crabs/m	0.01	0.28	1.54	0.78	1.16	0.71	1.41	0.87	0.70	2.27	2.40	
Estimated Number of HSC	32	728	4,004	2,028	3,016	1,857	3,673	2,262	1,820	5,909	6,252	
Gandys (1.2 km)												
Density of HSC, Crabs/m			0.72	0.58	0.78		1.23		0.55	4.14	5.43	
Estimated Number of HSC			867	696	935		1,481		660	4,968	6,520	
Sea Breeze (1.65 km)												
Density of HSC, Crabs/m	0.005			0.32	0.06		0.39		0.47	0.62		
Estimated Number of HSC	8			528	99		644		776	1,023		
Totals	**10,837**	**9,314**	**68,208**	**26,979**	**73,222**	**12,086**	**13,550**	**2,469**	**27,296**	**68,837**	**66,766**	**490**

* Raybins Beach is included with Fortescue

Table 1. 1999 Survey Results - Densities and Estimates
A. New Jersey Beaches (2 pages)

Moon Phase	"Off"	"Off"	New -2	New	New +2	"Off"	"Off"	"Off"	Full -2	Full	Full +2	Totals
Date	**6-Jun**	**9-Jun**	**11-Jun**	**13-Jun**	**15-Jun**	**18-Jun**	**20-Jun**	**23-Jun**	**26-Jun**	**28-Jun**	**30-Jun**	
North Cape May (3 km)												
Density of HSC, Crabs/m	0.99		0.11	0.15			2.44		0.04	0.01		
Estimated Number of HSC	2,970		330	450			7,320		120	30		**38,790**
South CSL (2.2 km)												
Density of HSC, Crabs/m	6.30		0.43	0.50	1.45		3.04		0.22	0.95	0.76	
Estimated Number of HSC	13,860		946	1,100	3,190		6,688		484	2,090	1,672	**190,641**
Highs (0.8 km)												
Density of HSC, Crabs/m		0.20	0.02	0.17	0.12	0.02	0.08	0.08	0.13	0.01	0.07	
Estimated Number of HSC		160	16	136	96	16	64	64	104	8	56	**42,954**
Kimbles (1 km)												
Density of HSC, Crabs/m	0.44		0.03	0.03	0.34		0.38		0.00	0.00		
Estimated Number of HSC	440		30	33	344		385		0	0		**52,909**
Reeds (1.53 km)												
Density of HSC, Crabs/m		0.12	0.15	0.11	0.37	0.30	0.53	0.00	0.01	0.01	0.10	
Estimated Number of HSC	0	184	230	168	566	459	811	0	15	15	153	**49,779**
Fortescue (2.6 km)*												
Density of HSC, Crabs/m	1.54	0.17	0.66		0.27	0.30	0.41	0.02	0.04	0.05	0.02	
Estimated Number of HSC	4,004	442	1,714		712	788	1,066	52	104	121	52	**40,635**
Gandys (1.2 km)												
Density of HSC, Crabs/m	3.82		0.73		3.92		1.43		0.00	0.00	0.28	
Estimated Number of HSC	4,584		876		4,704		1,716		0	0	336	**28,342**
Sea Breeze (1.65 km)												
Density of HSC, Crabs/m												
Estimated Number of HSC												
												3,078
Totals	**25,858**	**786**	**4,141**	**1,888**	**9,612**	**1,263**	**18,050**	**116**	**827**	**2,264**	**2,269**	**447,128**
												447,128

* Raybins Beach is included with Fortescue

Table 1. 1999 Survey Results - Densities and Estimates
B. Delaware Beaches (2 pages)

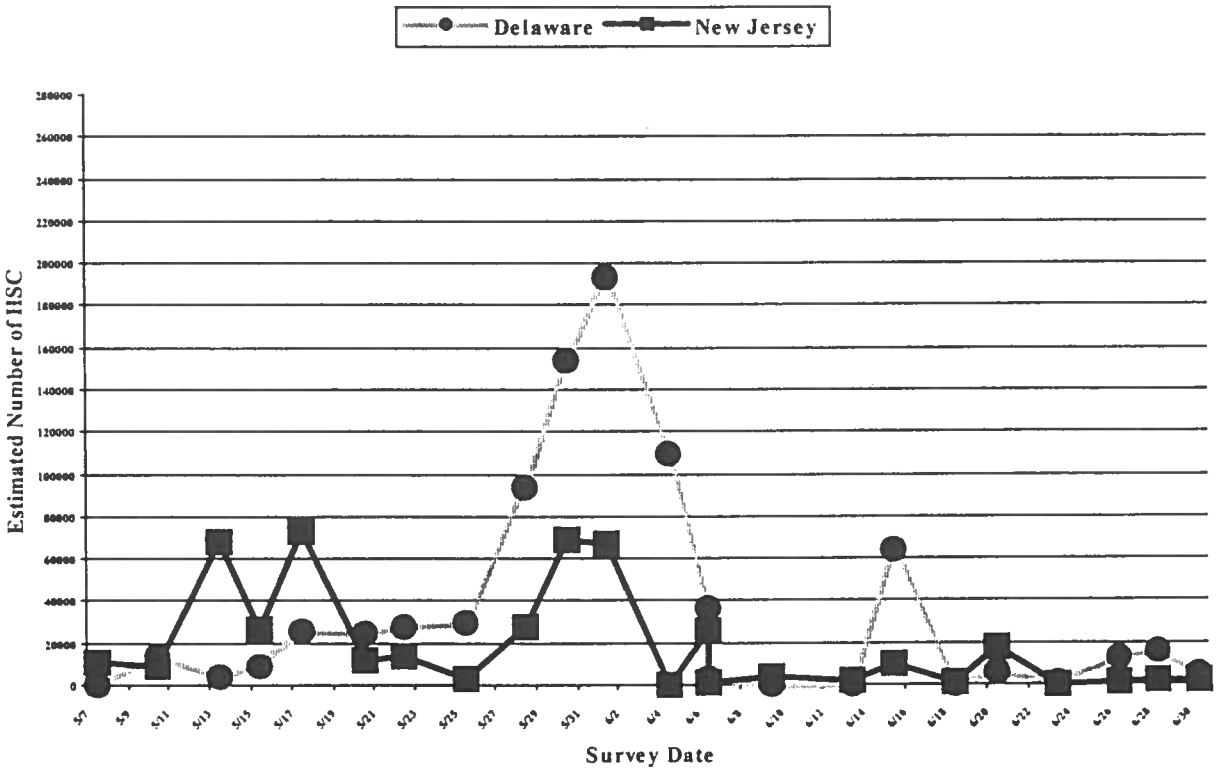
Moon Phase	"Off"	"Off"	New -2	New	New +2	"Off"	"Off"	"Off"	Full -2	Full	Full +2	"Off"
Date	7-May	10-May	13-May	15-May	17-May	20-May	22-May	25-May	28-May	30-May	1-Jun	4-Jun
Broadkill (1.5 km)												
Density of HSC, Crabs/m	0.00		0.01	0.00	0.01		0.05		2.31	4.03	5.01	
Estimated Number of HSC	0		15	0	19		75		3,465	6,045	7,515	
Primehook (2.0 km)												
Density of HSC, Crabs/m			0.26	0.02					3.94	9.62	4.28	
Estimated Number of HSC			520	40					7,880	19,240	8,560	
Fowler (3 km)												
Density of HSC, Crabs/m		1.04	0.06		0.68	1.91	0.84			11.53	10.23	3.26
Estimated Number of HSC		3,120	180		2,040	5,730	2,520			34,590	30,690	9,780
Slaughter (3 km)												
Density of HSC, Crabs/m									16.28	19.10		
Estimated Number of HSC									48,840	57,288		
Big Stone (7.6 km)												
Density of HSC, Crabs/m	0.00	0.05	0.07	0.00	0.30	0.00	0.32	1.00			14.04	10.04
Estimated Number of HSC	0	380	532	0	2,280	0	2,432	7,600			106,704	76,304
North Bowers (1.3 km)												
Density of HSC, Crabs/m				4.45			9.79		9.03	9.28	11.31	
Estimated Number of HSC				5,788			12,727		11,741	12,063	14,701	
Kitts Hummock (1.0 km)												
Density of HSC, Crabs/m	0.02	9.89	3.07	3.23	21.13	19.35	10.00	22.09	21.21	24.03	24.77	22.93
Estimated Number of HSC	20	9,890	3,070	3,225	21,130	19,350	10,000	22,090	21,210	24,030	24,770	22,930
Woodland (0.5 km)												
Density of HSC, Crabs/m				0.00		0.02	0.44		0.22	1.59	1.46	
Estimated Number of HSC				0		11	220		110	795	730	
Totals	**20**	**13,390**	**4,317**	**9,053**	**25,469**	**25,091**	**27,974**	**29,690**	**93,246**	**154,052**	**193,670**	**109,014**

Table 1. 1999 Survey Results - Densities and Estimates
B. Delaware Beaches (2 pages)

Moon Phase	"Off"	"Off"	New -2	New	New +2	"Off"	"Off"	"Off"	Full -2	Full	Full +2	Totals
Date	6-Jun	9-Jun	11-Jun	13-Jun	15-Jun	18-Jun	20-Jun	23-Jun	26-Jun	28-Jun	30-Jun	
Broadkill (1.5 km)												
Density of HSC, Crabs/m	0.55		0.00	0.12	0.63		0.00		0.08	0.73	0.20	
Estimated Number of HSC	825		0	180	945		0		120	1,095	300	**20,599**
Primehook (2.0 km)												
Density of HSC, Crabs/m	0.49		0.01				0.01			0.34		
Estimated Number of HSC	980		20				20			678		**37,938**
Fowler (3 km)												
Density of HSC, Crabs/m	1.65	0.03			7.45	0.15	0.25	0.10	0.52	1.41	0.30	
Estimated Number of HSC	4,950	90			22,350	450	750	300	1,560	4,230	900	**124,230**
Slaughter (3 km)												
Density of HSC, Crabs/m	1.06								1.66			
Estimated Number of HSC	3,180								4,980			**114,288**
Big Stone (7.6 km)												
Density of HSC, Crabs/m	3.50	0.16	0.00	0.00	3.06		0.00	0.00	0.00	0.55	0.08	
Estimated Number of HSC	26,600	1,216	0	0	23,256		0	0	0	4,180	608	**252,092**
North Bowers (1.3 km)												
Density of HSC, Crabs/m									2.03			
Estimated Number of HSC									2,639			**59,661**
Kitts Hummock (1.0 km)												
Density of HSC, Crabs/m		1.39	0.18	0.28	16.86		5.08	0.73	3.37	5.79	3.23	
Estimated Number of HSC	0	1,390	180	280	16,860	0	5,080	730	3,370	5,791	3,230	**218,626**
Woodland (0.5 km)												
Density of HSC, Crabs/m	0.08		0.07		1.92		0.12		0.00	0.00	0.02	
Estimated Number of HSC	40		35		960		61		0	0	10	**2,971**
												830,405
Totals	**36,575**	**2,696**	**235**	**460**	**64,371**	**450**	**5,911**	**1,030**	**12,669**	**15,974**	**5,048**	**830,405**

FIGURE 1.

Horseshoe Crab Estimates - 1999

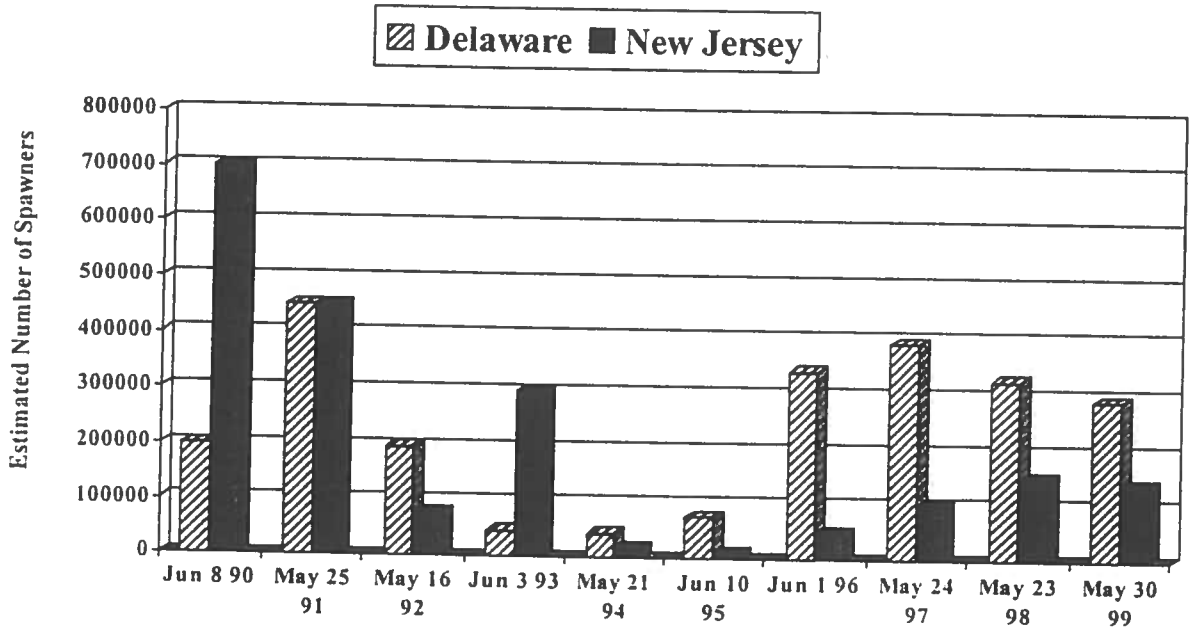


NEW MOON: 5/15; 6/13

FULL MOON: 5/30; 6/28

FIGURE 2.

HORSESHOE CRAB ESTIMATES DURING HIGHEST TIDE 1990-1999



1994 Estimates were adversely affected by weather

1995 Estimates missed the peak number of spawners