Horseshoe Crab Spawning Activity in Delaware Bay: 1999 – 2005

Report to the Atlantic States Marine Fisheries Commission's Horseshoe Crab Technical Committee

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Summary

- This marks the seventh year that the Delaware Bay Horseshoe Crab Spawning Survey has been implemented in a standardized manner throughout May and June in the Delaware Bay.
- The survey is completed annually through the assistance and dedication of numerous volunteers and coordinators.
- Estimates of spawning activity were precise. Annual coefficients of variation were below 14% for the entire series and remained below 10% for the last four years.
- Spawning activity peaked during the third lunar period sampled (1st week in June). This was similar to 2003. Weather may have contributed to the delay in peak spawning in both years. Typically, spawning peaked in late May.
- Most of the 2005 spawning occurred in June. The percent spawning in May (18% in DE and 30% in NJ) was the lowest for the 1999-2005 time series. The percent spawning in May was higher in NJ than DE in each year of the survey.
- Baywide spawning activity over the past 7 years was either stable or declining at a rate of 3% or less per year (Slope = -0.004, SE = 0.013, 90% CI = -0.03 to 0.02). However, trends in spawning activity differed in Delaware compared to New Jersey. On Delaware beaches, spawning activity declined significantly from 1999 to 2005 (Slope = -0.05, SE = 0.01, P = 0.01). On New Jersey beaches, spawning activity followed an increasing trend, though not significant (Slope = 0.04, SE = 0.030, P = 0.21). The state-specific spawning activity in 2005 (0.65, in DE and 0.97 in NJ) was a mirror image of spawning activity in 1999 (0.93 in DE and 0.61 in NJ) when this survey began. These state-specific trends are compensatory and could represent a response to state-specific harvest or a shift in spatial distribution.

Introduction

The Atlantic States Marine Fisheries Commission's (ASMFC) Interstate Fishery Management Plan for Horseshoe Crab (ASMFC 1998) required that the states of Delaware, Maryland and New Jersey implement pilot horseshoe crab spawning surveys based on "standardized and statistically robust methodologies". In January 1999, the ASMFC convened a workshop that established a framework for such surveys in the Mid-Atlantic region. The framework built upon existing horseshoe crab spawning survey efforts by Finn et al. (1991) and Maio (1998). Using funds from the U.S. Geological Survey's (USGS) State Partnership Program, a comprehensive pilot study was designed and implemented in Delaware Bay during the spring of 1999 (Smith et al. 2002). The U.S. Fish and Wildlife Service provided further funding in 2000 to continue the survey in its present form, and the Delaware Division of Fish and Wildlife provided funding in subsequent years using Atlantic Coastal Fisheries Cooperative Management Act funds.

The survey is an excellent example of state, federal, non-governmental organization (NGO), corporate and citizen cooperation. Survey coordination is contracted through Limuli Labs and the University of Delaware. Data entry is completed by staff from the New Jersey Department of Environmental Protection and USGS staff oversees data analysis and report preparation. The vast sampling effort is conducted by a large contingent of dedicated private citizens, state and federal agencies, corporations, and NGO's.

This report is a continuation of a series of statistical reports on the survey and is meant to compliment the ongoing series of reports issued by the survey coordinators, Ms. Benjie Swan and Dr. William Hall in cooperation with Dr. Carl N. Shuster Jr.

Survey Objectives

The Delaware Bay Horseshoe Crab Spawning Survey has several important objectives:

1) provide a reliable index of spawning activity to monitor the temporal and spatial distribution of horseshoe crab spawning activity for comparing baywide spawning among years, beach-level spawning within Delaware Bay, and distributions of spawning horseshoe crabs and shorebirds;

2) increase our understanding of the relationship between environmental factors (tidal height and wave height) and spawning activity; and

3) promote public awareness of the central role of horseshoe crabs in shorebird population dynamics, Atlantic coast fisheries, and human health through the production of *Limulus* amoebocyte lysate (LAL).

Data Availability

The spawning survey database was converted to MS ACCESS in 2004. A visual basic program was also developed by USGS to calculate estimates of spawning activity in tabular and graphic form. The conversion process revealed a number of errors that were corrected and detailed in Smith and Bennett (2005). The overall patterns of spawning activity were largely unaffected by these corrections. Data used in this report (both estimates and raw data) and the software used to calculate estimates are available on the internet at http://www.lsc.usgs.gov/aeb/2065/SPAWNAR/index.asp.

Summary Results

Sampling in 2005 was conducted during twelve nighttime high tides from 6 May through 23 June. Twenty-three (23) beaches were sampled in the Delaware Estuary – 13 in Delaware and 10 in New Jersey. The total number of tides sampled over the season was 282, with 51 sampling events canceled (primarily due to weather and/or access). No reports were provided for 4 nights at Sea Breeze and 2 nights at Higbees. Restricted access due to road flooding is sometimes an issue at Sea Breeze.

Temporal Spawning Distribution

Timing of spawning is an important factor to examine as it gives an indication of potential food availability to migratory shorebirds. The timing of spawning could also affect the survival of egg, larvae and juvenile stages.

Spawning in 2005 peaked during the third lunar period. The temporal distribution of spawning in 2005 was similar to 2003 in both states and similar to Delaware in 2001 (Figure 1). Less than 20% of spawning activity in Delaware occurred in May and about 30% of the spawning activity in New Jersey occurred in May (Table 1). Water temperature may have influenced the timing of spawning. Water temperature readings taken at Lewes, DE (Appendix I) suggest that water temperatures were not consistently above 15 °C until about 30 May 2005. Similarly, water temperatures in 2003 were not consistently above 15 °C until late May or early June.

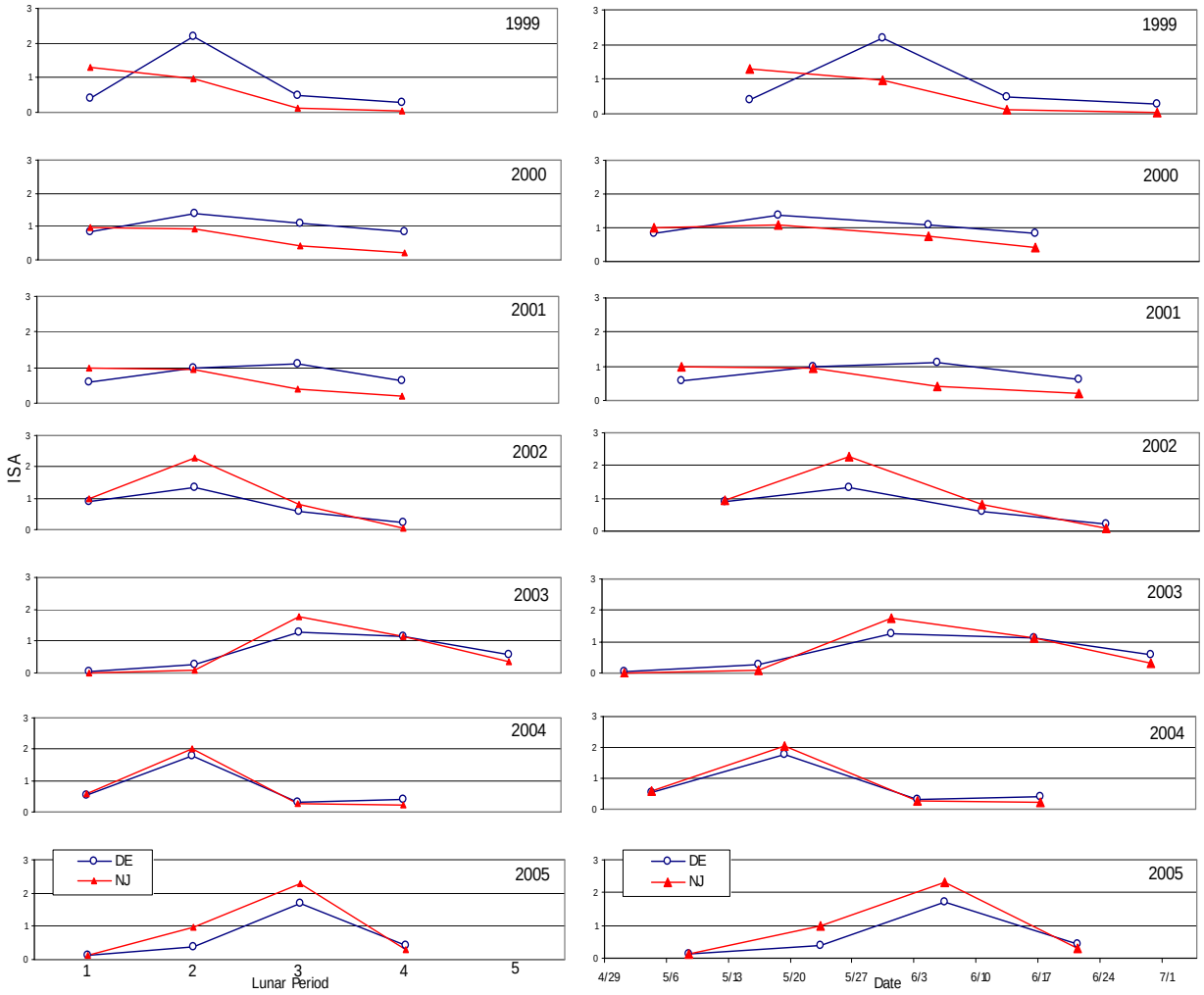


Figure 1. Temporal distribution of horseshoe crab spawning activity in the Delaware Bay by state. Lunar periods are defined as a 5 day period (sampled day of lunar event and 2 days before and 2 days after) around the new or full moons in May and June.

Table 1. Summary statistics reflecting the timing of horseshoe crab spawning in Delaware and New Jersey. Percentages are based on estimates of month-specific index of spawning activity (ISA).

	Delaware		New Jersey	
	Dates of Peak Spawning	% of Spawning in May	Dates of Peak Spawning	% of Spawning in May
1999	28 May - 1 June	77	28 May - 1 June	93
2000	16 May - 18 May	54	16 May - 18 May	64
2001	3 June - 7 June	47	5 May - 9 May	76
2002	24 May - 28 May	73	24 May - 28 May	78
2003	29 May - 2 June	47	29 May - 2 June	56
2004	17 May - 21 May	76	17 May - 21 May	85
2005	4 June - 8 June	18	4 June - 8 June	30

State-specific Spawning Activity

Trends in spawning activity differed by state (Figure 2; Table 2). Spawning activity in New Jersey trended upward from 1999 to 2005, though not significantly (Slope = 0.04, SE = 0.030, P = 0.21). Spawning activity in Delaware has trended significantly downward since 1999 (Slope = -0.05, SE = 0.01, P = 0.01).

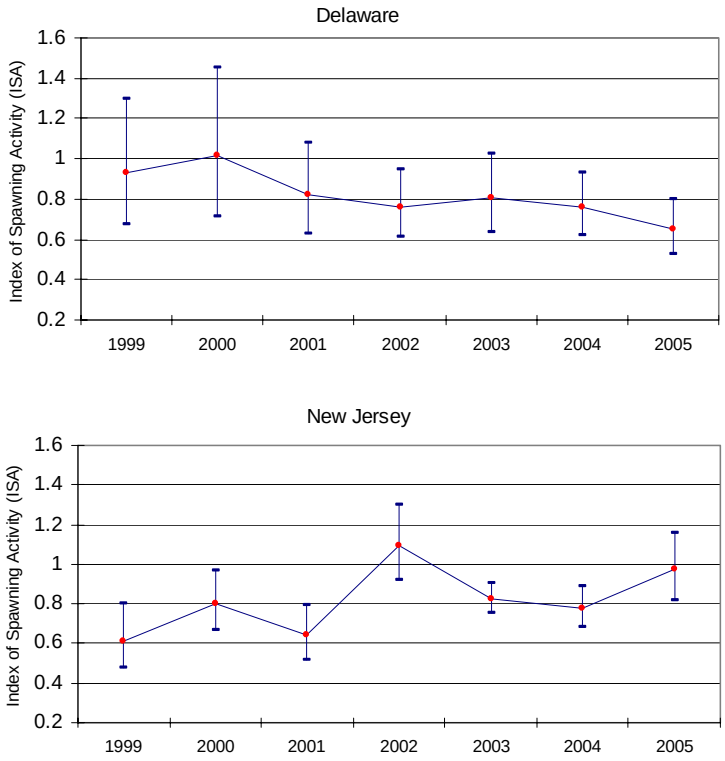


Figure 2. Indices of horseshoe crab spawning activity (ISA), expressed as the mean number of female crabs per m^2 per night, for the states of Delaware and New Jersey. Error bars are 90% confidence intervals.

Table 2. Indices of horseshoe crab spawning activity (ISA), expressed as the mean number of female crabs per m^2 per night, by state from 1999 to 2005.

	Delaware			New Jersey		
Year	ISA	90% CI	Beaches Surveyed	ISA	90% CI	Beaches Surveyed
1999	0.93	0.67, 1.29	8	0.61	0.47, 0.80	9
2000	1.02	0.72, 1.45	11	0.80	0.67, 0.96	11
2001	0.82	0.63, 1.08	12	0.64	0.51, 0.80	10
2002	0.76	0.61, 0.94	13	1.09	0.92, 1.30	10
2003	0.81	0.64, 1.03	13	0.83	0.76, 0.91	10
2004	0.76	0.62, 0.93	13	0.78	0.68, 0.89	12
2005	0.65	0.53, 0.80	13	0.97	0.82, 1.16	10

Baywide Spawning Activity

Trends in state-specific spawning were compensatory, as no change in baywide spawning activity was detected (Figure 3; Table 3). The regression slope continues to be close to zero (Slope = -0.004, SE = 0.013, 90% CI = -0.031 to 0.023, P = 0.76).

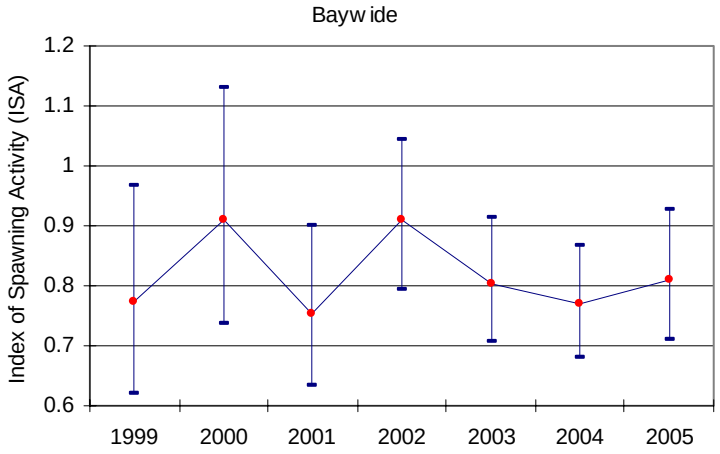


Figure 3. Index of horseshoe crab spawning activity (ISA) for the Delaware Bay from 1999 to 2005. Error bars are 90% confidence intervals.

Table 3. Index of horseshoe crab (ISA), standard error (SE), coefficient of variation (CV), and 90% confidence intervals (CI) for the Delaware Bay from 1999 to 2005.

Year	ISA	Beaches Surveyed	SE	CV(%)	90% CI
1999	0.77	17	0.1	13	0.62, 0.97
2000	0.91	22	0.12	13	0.74, 1.13
2001	0.75	22	0.08	10	0.63, 0.90
2002	0.91	23	0.07	8	0.79, 1.04
2003	0.80	23	0.06	8	0.71, 0.91
2004	0.77	24	0.06	7	0.68, 0.87
2005	0.81	23	0.07	9	0.71, 0.93

Recommendations from Shorebird Technical Committee

The Shorebird Technical Committee (SBTC) requested a summary of baywide spawning activity by half month periods, which is important for understanding the synchronization of bird migration with horseshoe crab spawning. Lunar periods are essentially half-month periods. This information is provided in Figure 4 and Table 4.

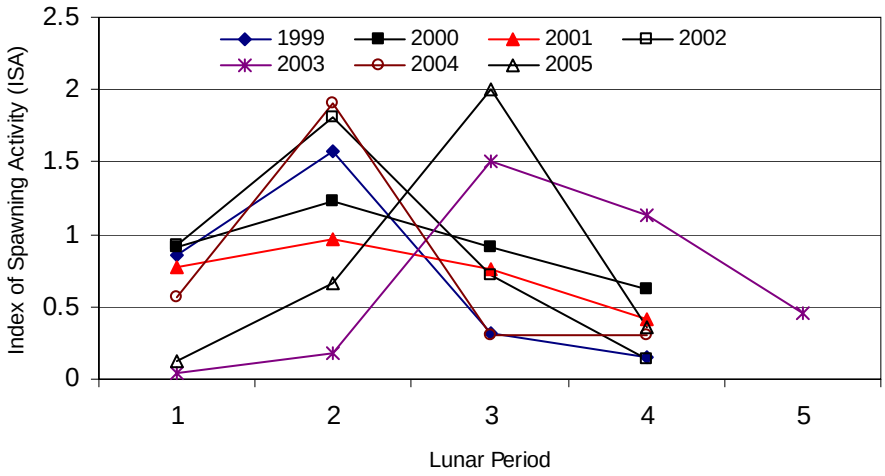


Figure 4. Baywide horseshoe crab spawning activity, expressed as mean number of spawning female crabs per m^2 per night, by lunar period for the years 1999 to 2005.

Table 4. Baywide horseshoe crab spawning activity, expressed as mean number of spawning female crabs per m^2 per night, by lunar period for the years 1999 to 2005.

	Lunar Period				
Year	1	2	3	4	5
1999	0.86	1.58	0.32	0.15	
2000	0.92	1.23	0.91	0.62	
2001	0.77	0.96	0.76	0.42	
2002	0.92	1.81	0.71	0.14	
2003	0.04	0.17	1.51	1.13	0.46
2004	0.56	1.91	0.30	0.30	
2005	0.12	0.67	2.00	0.36	

The SBTC also recommended the inclusion of the season's "weather and tide stage conditions" in the spawning survey report. Though an attempt to incorporate some of this information was made (see Appendix I), it is beyond the scope of this summary report to more fully account for the influence of weather and tide on spawning activity.

Though the SBTC requested, "an analysis of just the beaches consistently sampled for all years of the study", this would be contrary to the survey's design. Appendix II, however, provides a summary of spawning activity by beach for all years.

Recommendations from Stock Assessment Framework Review Committee (2005)

The ASMFC Stock Assessment Framework Review Committee (SAFRC) recommended the expansion of this and other surveys if a coastwide assessment is desired. In its present form, application of the sampling methods used in this survey may not be appropriate for areas outside Delaware Bay. However, the survey may be useful in guiding survey design.

The SAFRC recommended the inclusion of environmental covariates that explain a significant portion of the index's variability when creating standardized indices. The inclusion of environmental covariates is desirable, but difficult to incorporate into a volunteer survey such as this, except in the most general terms.

The SAFRC recommended ground-truthing the survey by conducting total counts at small beaches to test accuracy, precision and calibration to "population" scale. It is recognized that such an effort would be beneficial and could be incorporated when additional funding and man-power become available. Alternatively, such work could be the basis of thesis research.

The SAFRC further recommended that investigations on the timing of peak spawning activity be carried out (e.g. Is there an increase in spawning activity one-hour after the tide goes out?). The survey assumes that spawning activity measured at high tide is proportional to the true number of spawning horseshoe crabs.

Literature Cited

Atlantic States Marine Fisheries Commission (ASMFC). 1998. Interstate fishery management plan for horseshoe crab. Fishery Management Report No. 32, Atlantic States Marine Fisheries Commission, Washington D.C.

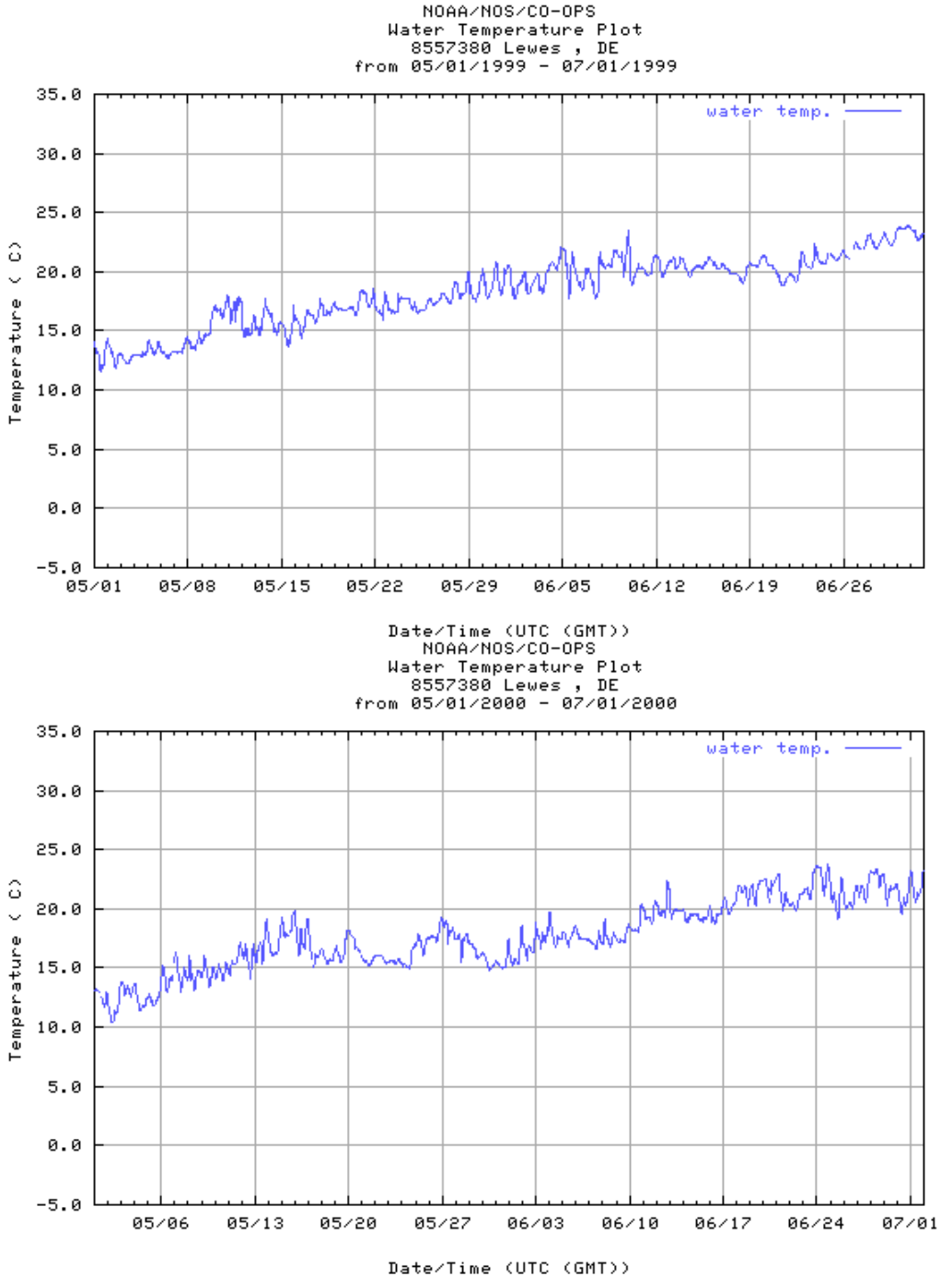
Finn, J.J., C.N. Shuster, Jr. and B.L. Swan. 1991. *Limulus* spawning activity on Delaware Bay shores 1990. Finn-Tech Inc., Cape May Courthouse, NJ.

Maio, K.J. 1998. Quanitative description of the temporal and spatial patterns in spawning activity of the horseshoe crab, *Limulus polyphemus*. Master's thesis. University of Maryland Eastern Shore, Princess Anne, Maryland.

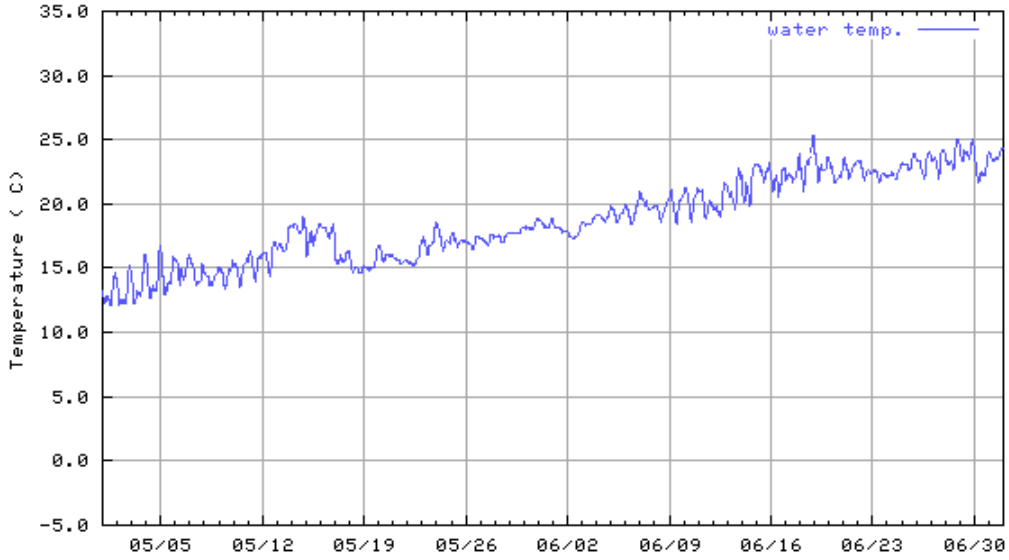
Smith, D.R., P.S. Pooler, B.L. Swan, S.F. Michels, W.R. Hall, P.J. Himchak, and M.J. Millard. 2002. Spatial and temporal distribution of horseshoe crab (*Limulus polyphemus*) spawning in Delaware Bay: implications for monitoring. Estuaries 25(1):115-125.

Smith D.R. and S. Bennett. 2005. Horseshoe crab spawning activity in Delaware Bay: 1999 – 2004. Report to the ASMFC Horseshoe Crab Management Board. Unpublished.

APPENDIX I. May 1 – July 1 water temperature data from Lewes, DE (Station identification Number 8557380; Latitude 38° 46.9' N / Longitude 75° 7.2' W) for the years 1999 through 2005. Source: Center for Operational Oceanographic Products and Services (CO-OPS).



NOAA/NOS/CO-OPS
Water Temperature Plot
8557380 Lewes , DE
from 05/01/2001 - 07/01/2001



Date/Time (UTC (GMT))

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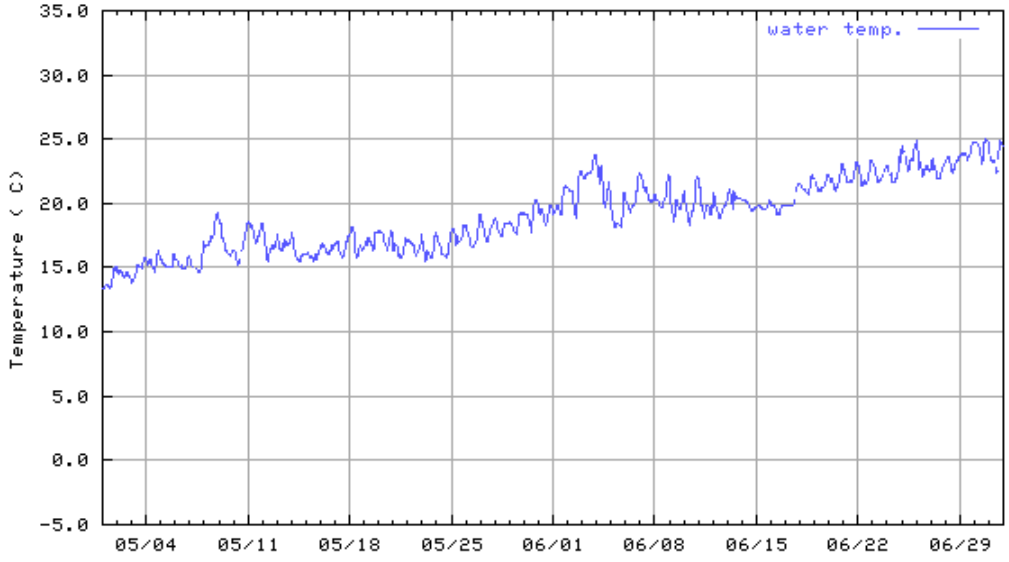

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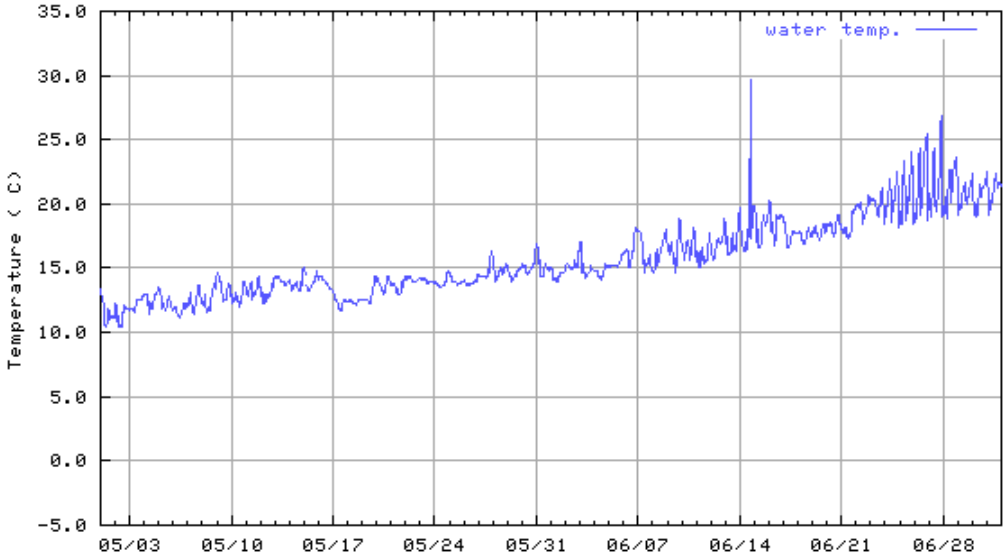

Date/Time (UTC (GMT))

NOAA/NOS/CO-OPS
Water Temperature Plot
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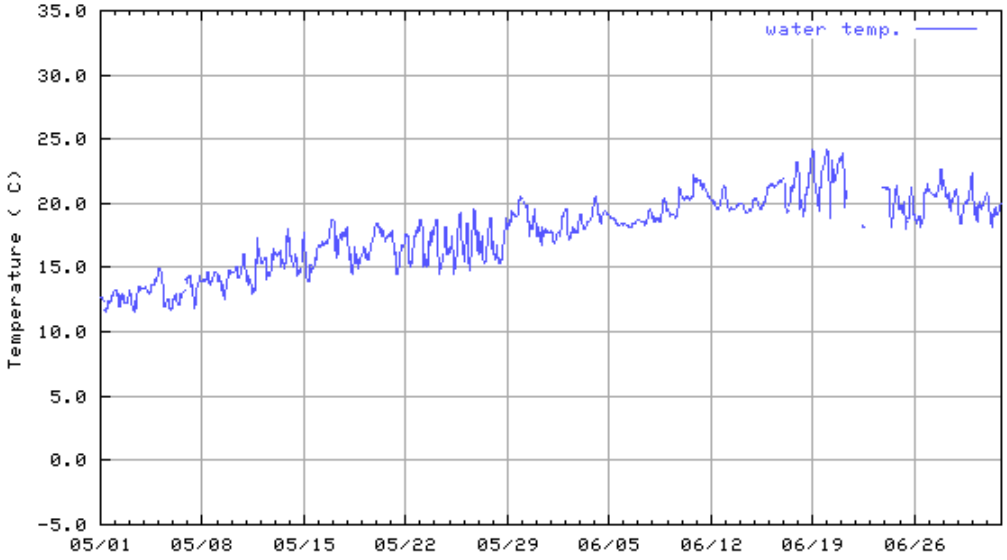
from 05/01/2004 - 07/01/2004



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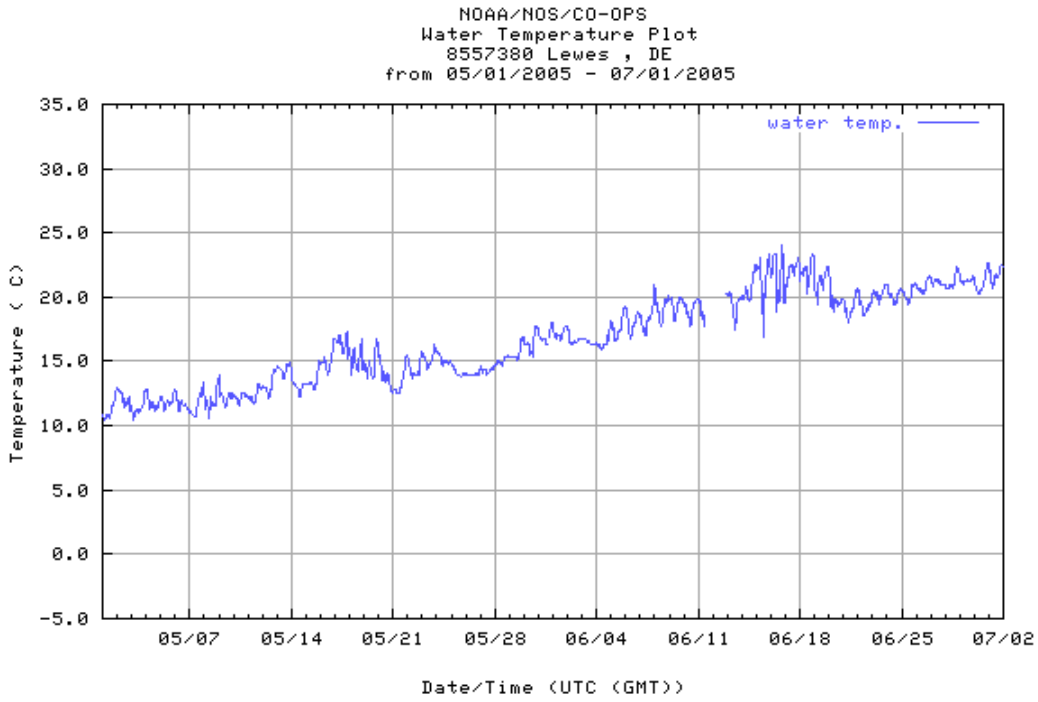
NOAA/NOS/CO-OPS
Water Temperature Plot
8557380 Lewes , DE
from 05/01/2005 - 07/01/2005
water temp.
35.0
30.0
25.0
20.0
15.0
10.0
5.0
0.0
-5.0
Temperature (C)
05/07
05/14
05/21
05/28
06/04
06/11
06/18
06/25
07/02
Date/Time (UTC (GMT))

APPENDIX II. Index of spawning horseshoe crabs abundance, expressed as the mean number of females crabs per m^2 per night, for Delaware Bay beaches surveyed from 1999 to 2005.

	State Beach	1999	2000	2001	2002	2003	2004	2005
DE	Bennetts Pier		0.2233	0.6399	0.4713	0.2762	0.547	0.6992
DE	Big Stone	0.7462	0.729	0.8562	0.6265	0.637	0.7617	0.8088
DE	Broadkill	0.3197	0.0638	0.117	0.1347	0.2083	0.1741	0.1911
DE	Cape Henlopen				0.0857	0.1816	0.1255	0.2694
DE	Fowlers	0.7779	0.4933	0.7033	0.237	0.4532	0.611	0.2148
DE	Kitts Hummock	2.151	2.583	2.3545	1.4667	1.5529	1.2394	1.4175
DE	Lewes				0.0838			
DE	North Bowers	0.8806	1.1836	1.0383	1.2142	0.9802	0.4995	0.6012
DE	Pickering		3.3047	1.6244	1.695	1.6417	1.638	1.4708
DE	Prime Hook	0.5984	0.1872	0.4446	0.5908	0.4733	0.7596	0.65
DE	Slaughter	1.619	1.3254	1.0962	0.7265	1.6508	1.5237	0.6805
DE	South Bowers		0.9196	0.8433	1.1265	0.4685	0.4796	0.6343
DE	Ted Harvey				1.4446	1.9852	1.522	0.8162
DE	Woodland	0.1368	0.1033	0.0292	0.0792	0.0075	0.0012	0.0062
NJ	East Point		0.3458					
NJ	Fortescue	0.2473				0.4184	0.5408	0.5818
NJ	Gandys	0.4014	0.3922	0.4521	1.4122	0.5498	0.8166	0.8788
NJ	Higbees		0.0361					0.1368
NJ	Highs Beach	0.7892	0.9594	0.795	0.4685	0.5275	0.6963	0.7583
NJ	Kimbles	0.7063	0.8521	0.4773	0.4976	0.497	0.4054	
NJ	Norburys			0.46	0.6242	0.5362	0.6707	0.9391
NJ	North Cape May	0.225	0.05	0.0904	0.0845	0.1233	0.02	0.1233
NJ	Pierces Point		0.6138		0.673	0.73	0.9602	0.8275
NJ	Raybins	0.0259						
NJ	Reeds	0.3808	0.6468	0.4049	0.8768	0.8225	0.4162	0.2398
NJ	Sea Breeze	0.0947	0.1094	0.2991	1.6283	0.3892	0.4275	
NJ	Cape Shore Lab	1.2452	1.3311	1.2775	0.685	0.6283	0.9042	1.1684
NJ	Sunset			0.1139				
NJ	Townbank			0.7362	0.3958	0.4589	0.2037	
NJ	Villas							0.7075