

Horseshoe Crab Spawning Activity in Delaware Bay: 1999 – 2006

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

Stewart Michels, Delaware Division of Fish and Wildlife,
89 Kings Highway, Dover, DE 19901
(302) 739-4782 / stewart.michels@state.de.us

David Smith, USGS – Leetown Science Center,
11649 Leetown Road, Kearneysville, WV 25443
(304) 724-4467 / drsmith@usgs.gov

Sherry Bennett, New Jersey Division of Fish, Game and Wildlife,
PO Box 418, Port Republic, NJ 08241

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Summary

- This marks the eighth 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 five years.
- Spawning activity peaked during the second lunar period sampled (May 25, 27 & 29). This was similar to 2002 and 2004.
- In 2006, most of the spawning occurred in May (77% in DE and 85% in NJ). The percent spawning in May was higher in NJ than DE in each year of the survey.
- Percent of spawning that occurred in May was associated with water temperature (correlations were 0.77 and 0.83 for DE and NJ, respectively).
- Baywide spawning activity over the past 8 years remained stable (Slope = 0.01, SE = 0.013, 90% CI = -0.01 to 0.04).
- Trends in spawning activity differed in Delaware and New Jersey. On Delaware beaches, spawning activity declined significantly from 1999 to 2006 (Slope = -0.03, SE = 0.013, P = 0.04). On New Jersey beaches, spawning activity increased significantly (Slope = 0.06, SE = 0.023, P = 0.05). 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 (DE DFW) provided funding in subsequent years using Atlantic Coastal Fisheries Cooperative Management Act funds. The survey has been shown to provide levels of spatial and temporal coverage essential for understanding trends in spawning activity (Smith and Michels 2006).

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 and DE DFW staff oversee 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, wave height, and water temperature) 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 2006 was conducted during twelve nighttime high tides from 11 May through 27 June. Twenty-four (24) beaches were sampled in the Delaware Estuary – 13 in Delaware and 11 in New Jersey. The total number of tides sampled over the season was 258, with 30 sampling events canceled (Table 1).

Table 1. Beaches sampled in the 2006 Delaware Bay Horseshoe Crab Spawning Survey.

Beach Name	May					June						
	11	13	15	25	27	29	9	11	13	23	25	27
Delaware												
Bennetts Pier	Partial Count	No Access / Flooding					No Surveyors		No Surveyors			No Access / Flooding
Big Stone	Weather											Weather
Broadkill												
Cape Henlopen												
Fowlers										Weather		
Kitts Hummock	Weather											
North Bowers												
Pickering												
Prime Hook												
Slaughter										Weather		
South Bowers												Weather
Ted Harvey												Weather
Woodland	No Access / Flooding											
New Jersey												
Fortescue												
Gandys	No Access / Flooding	Weather	Other					No Surveyors				Weather
Highs Beach												
Norburys												
North Cape May		No Surveyors										
Pierces Point							No Surveyors					
Reeds												
Sea Breeze	No Surveyors		Other	Other								
S. Cape Shore Lab												Other
Sunset			No Surveyors					No Surveyors	Weather			Weather
Villas												Weather

Cancelations
 No Access / Flooding
 Weather
 No Surveyors
 Other

Sampled
 Sampled
 Partial Count

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 during the first lunar period in 2006 was high relative to previous sampling and peak spawning occurred during the second lunar period (Figure 1). The temporal distribution of spawning in 2006 was similar to 2002 and 2004 in both states. In 2006, more than 75% of Delaware spawning activity and 85% of the New Jersey spawning activity occurred in May (Table 2). The percentage of spawning that occurred in May has been consistently higher in NJ than DE (Table 2; Figure 2).

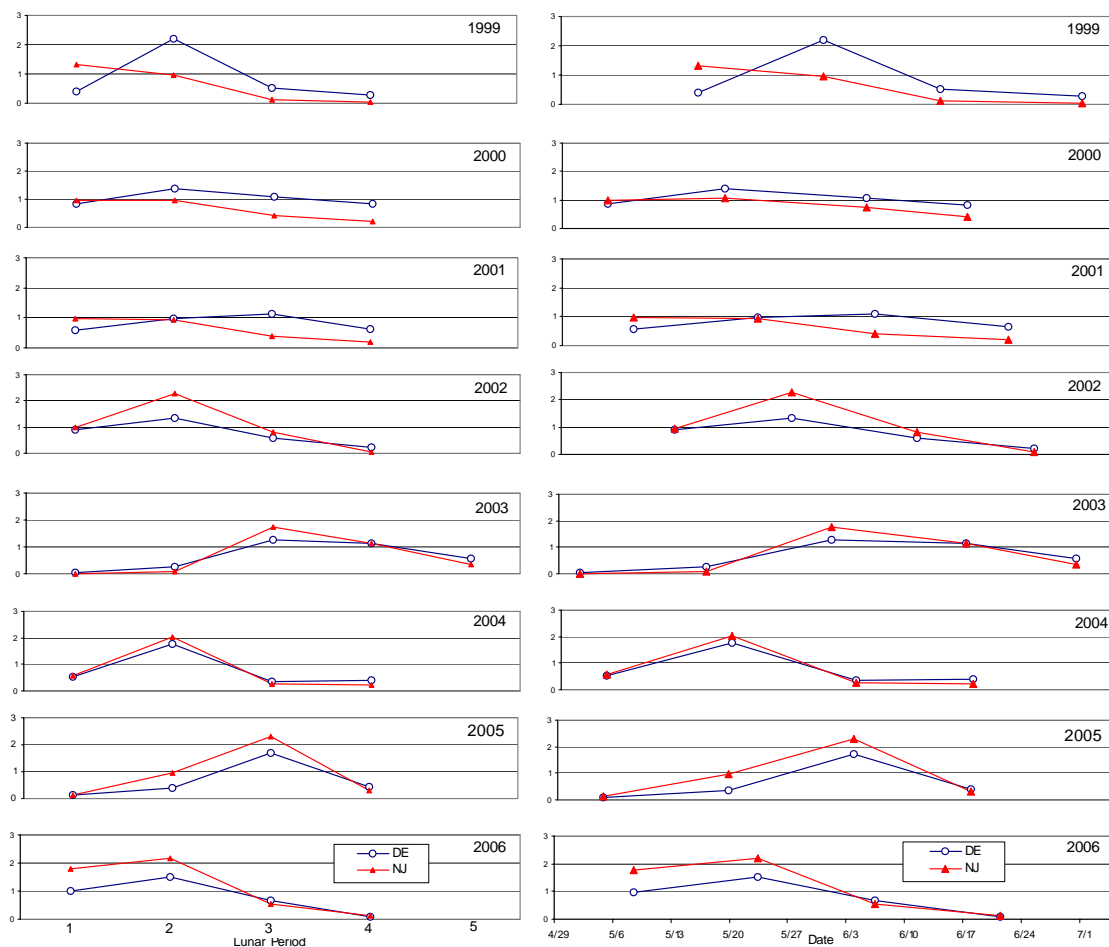


Figure 1. Temporal distribution of horseshoe crab spawning activity in the Delaware Bay by state. Lunar periods are defined as a 5 day period (sampled day of lunar event and 2 days before and 2 days after) around the new or full moons in May and June.

Water temperature may influence the timing of spawning (Smith and Michels 2006). Water temperature readings taken at Lewes, DE (Appendix I)

suggest spawning was delayed in 2003 and 2005 when water temperatures were not consistently above 15 °C until late May or early June. Water temperatures in 2006 remained consistently above 15 °C after 10 May, just prior to the initial sampling. In addition, there is a strong association between average May water temperatures recorded at Lewes, DE and the percentage state-specific spawning activity in May ($r_{DE} = 0.77$, $P_{DE} = 0.03$; $r_{NJ} = 0.83$, $P_{NJ} = 0.01$; Figure 2).

Table 2. Summary statistics reflecting the timing of horseshoe crab spawning in Delaware and New Jersey and average May water temperatures. Percentages are based on estimates of month-specific index of spawning activity (ISA). Water temperatures were recorded at the National Ocean Service station at Lewes, DE.

Year	Delaware		New Jersey		Average daily water temp. in May (C)
	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	16.2
2000	16 May - 18 May	54	16 May - 18 May	64	15.6
2001	3 June - 7 June	47	5 May - 9 May	76	16.0
2002	24 May - 28 May	73	24 May - 28 May	78	16.7
2003	29 May - 2 June	47	29 May - 2 June	56	13.4
2004	17 May - 21 May	76	17 May - 21 May	85	15.7
2005	4 June - 8 June	18	4 June - 8 June	30	13.7
2006	25 May - 29 May	77	25 May - 29 May	85	16.3

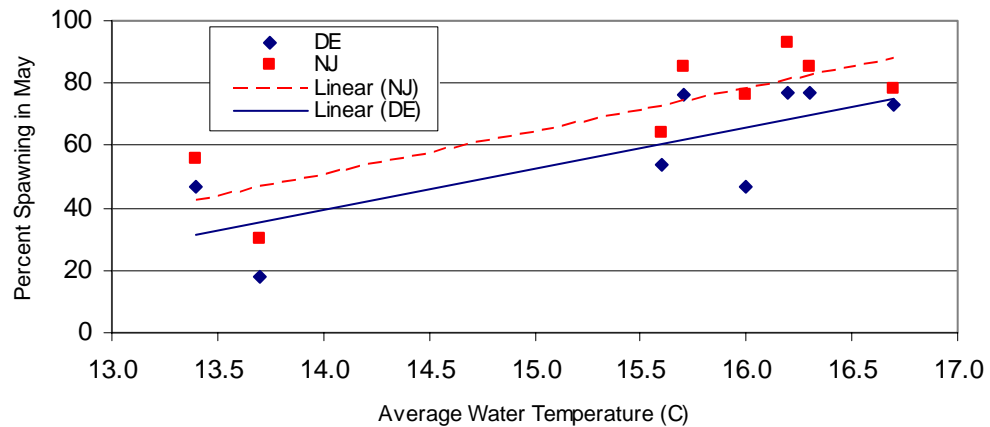


Figure 2. Percent of horseshoe crab spawning occurring in May by state versus May average daily water temperatures. Water temperatures were recorded at the National Ocean Service at Lewes, DE Station ID 8557380.

State-specific Spawning Activity

Trends in spawning activity differed by state (Figures 3; Table 3). Spawning activity in New Jersey trended significantly upward from 1999 to 2006 (Slope = 0.06, SE = 0.023, P = 0.05). Spawning activity in Delaware has trended significantly downward since 1999 (Slope = -0.03, SE = 0.01, P = 0.04).

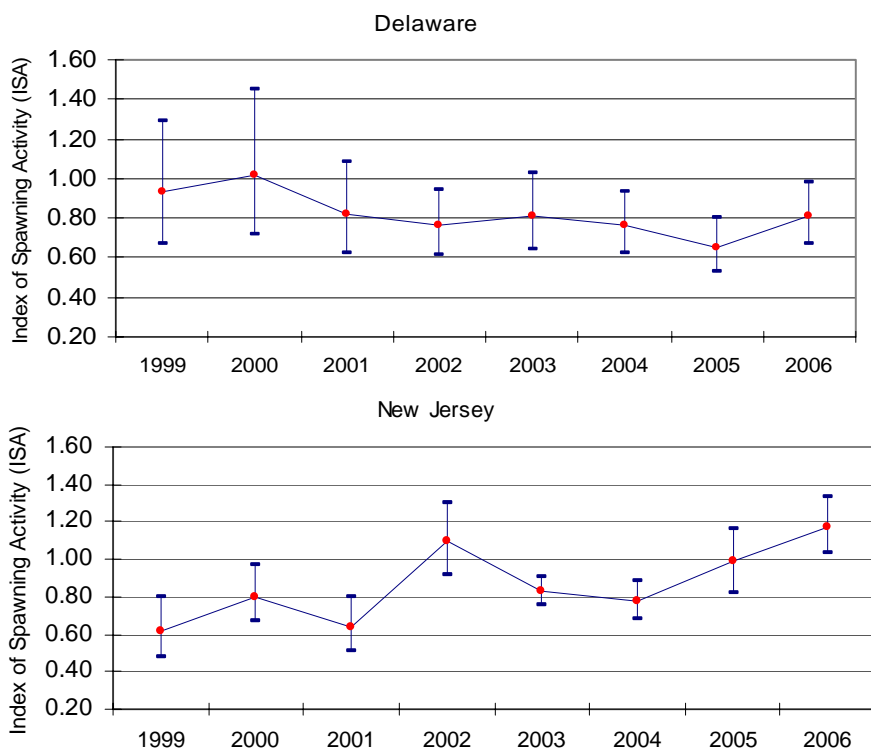


Figure 3. Indices of horseshoe crab spawning activity (ISA), expressed as the mean number of female crabs per m^2 per night, for the states of Delaware and New Jersey. Error bars are 90% confidence intervals.

Table 3. 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 2006.

Year	Delaware			New Jersey		
	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	0.99	0.84, 1.16	12
2006	0.81	0.67, 0.98	13	1.17	1.03, 1.33	11

Baywide Spawning Activity

Trends in state-specific spawning were compensatory, as no change in baywide spawning activity was detected (Figure 4; Table 4). The regression slope continues to be close to zero (Slope = 0.01, SE = 0.013, 90% CI = -0.01 to 0.04, P = 0.44).

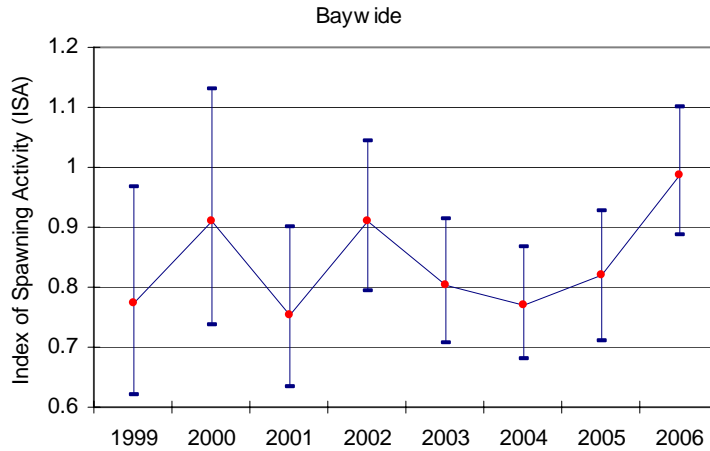


Figure 4. Index of horseshoe crab spawning activity (ISA) for the Delaware Bay from 1999 to 2006. Error bars are 90% confidence intervals.

Table 4. Index of horseshoe crab (ISA), standard error (SE), coefficient of variation (CV), and 90% confidence intervals (CI) for the Delaware Bay from 1999 to 2006.

Year	Beaches				
	ISA	Surveyed	SE	CV(%)	90% CI
1999	0.77	17	0.10	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	0.82	23	0.07	9	0.72, 0.93
2006	0.99	24	0.07	7	0.89, 1.10

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 5 and Table 5.

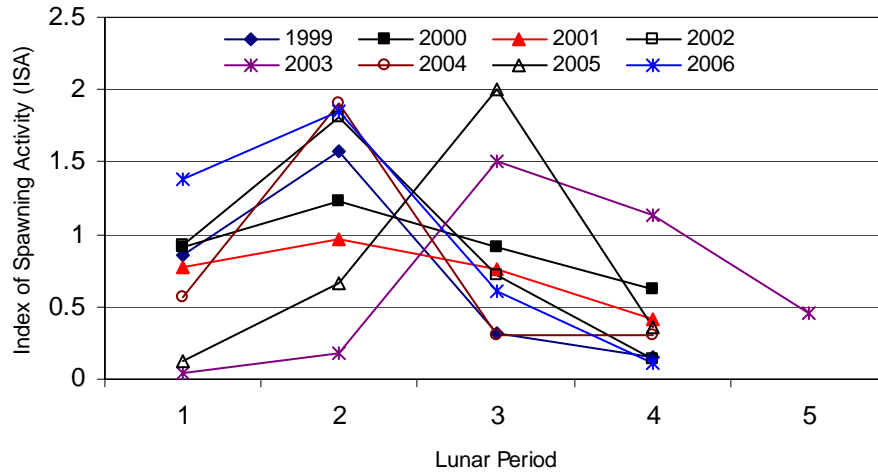


Figure 5. Baywide horseshoe crab spawning activity, expressed as mean number of spawning female crabs per m^2 per night, by lunar period for the years 1999 to 2006.

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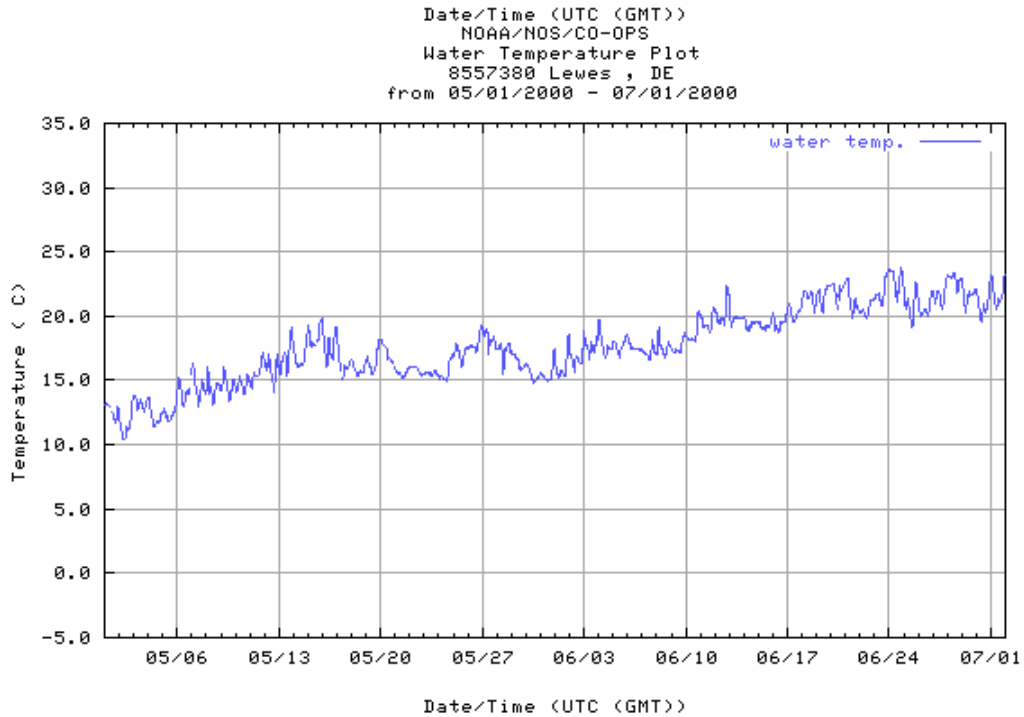
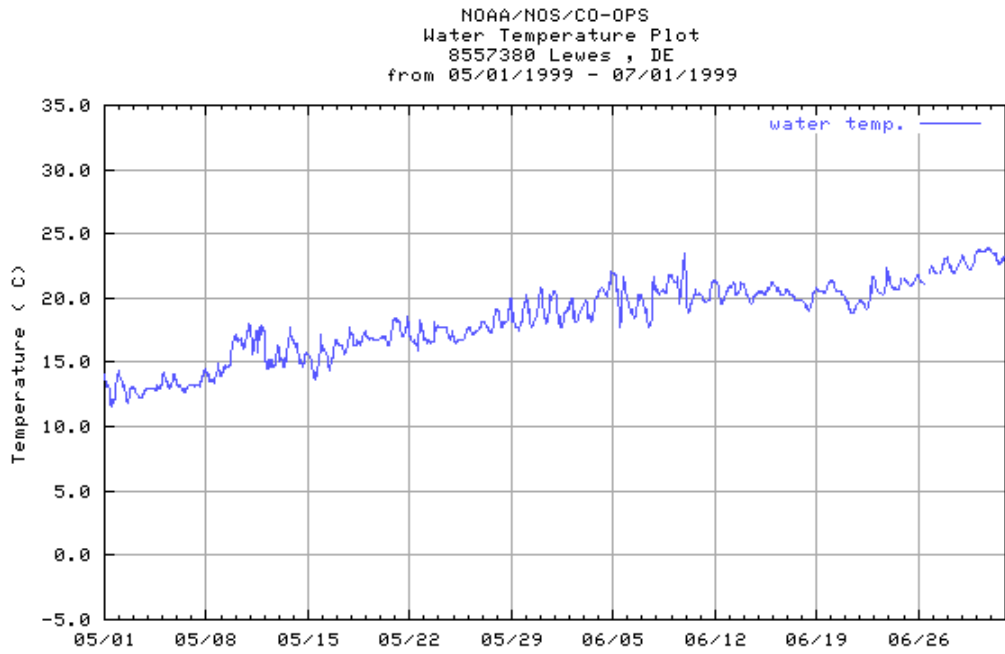
Year	Lunar Period				
	1	2	3	4	5
1999	0.86	1.58	0.32	0.15	
2000	0.92	1.23	0.91	0.62	
2001	0.77	0.96	0.76	0.42	
2002	0.92	1.81	0.71	0.14	
2003	0.04	0.17	1.51	1.13	0.46
2004	0.56	1.91	0.30	0.30	
2005	0.12	0.67	2.00	0.36	
2006	1.39	1.85	0.61	0.11	

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.

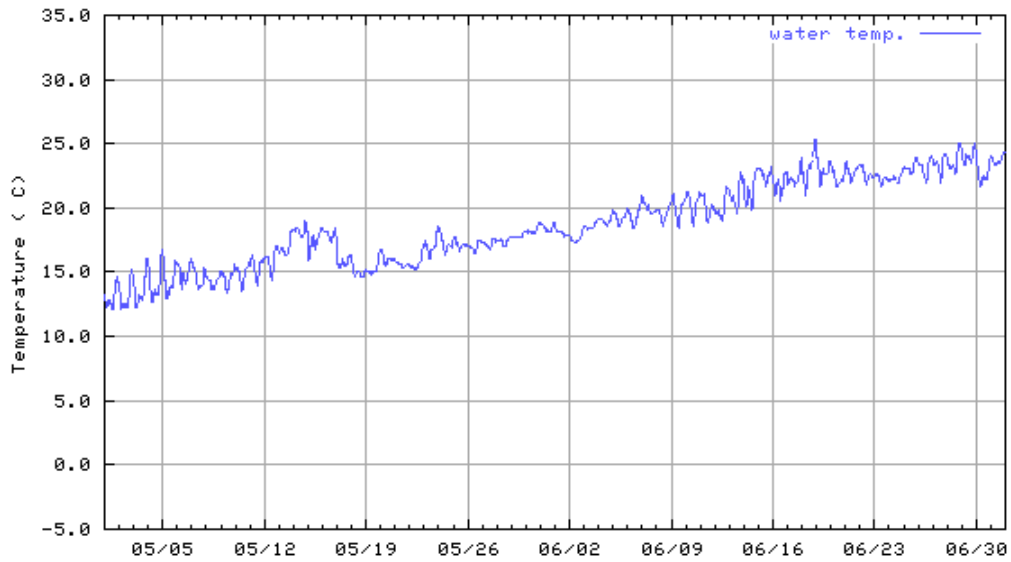
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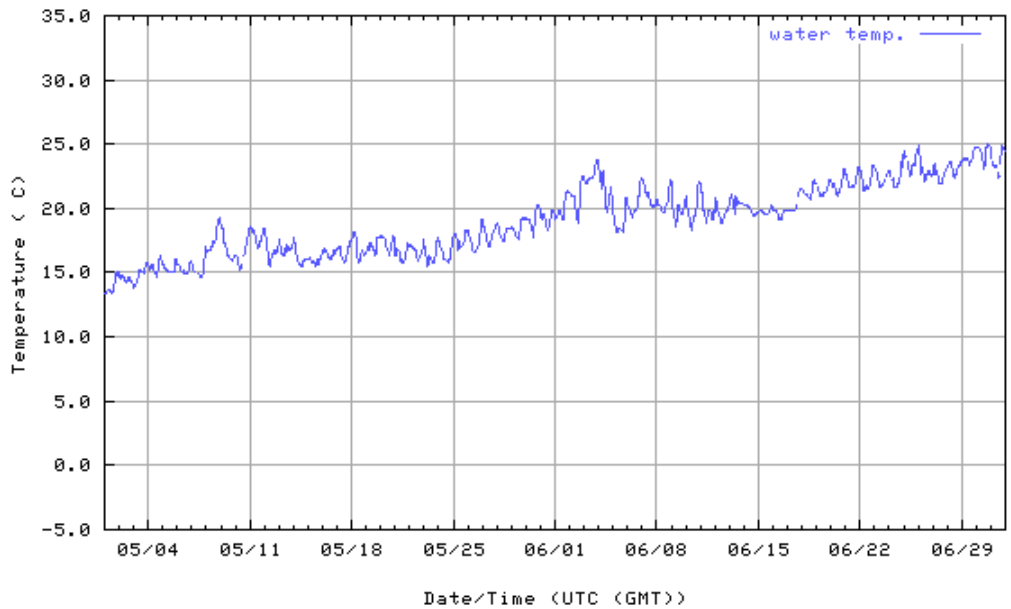
APPENDIX I. May 1 – July 1 water temperature data from Lewes, DE (Station identification Number 8557380; Latitude 38° 46.9' N / Longitude 75° 7.2' W) for the years 1999 through 2006. Source: Center for Operational Oceanographic Products and Services (CO-OPS).



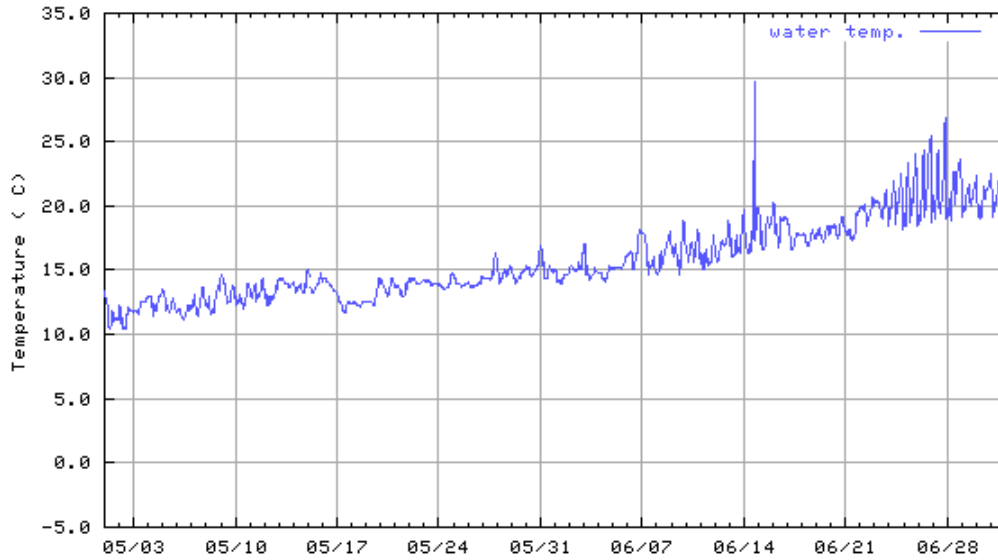
NOAA/NOS/CO-OPS
Water Temperature Plot
8557380 Lewes, DE
from 05/01/2001 - 07/01/2001



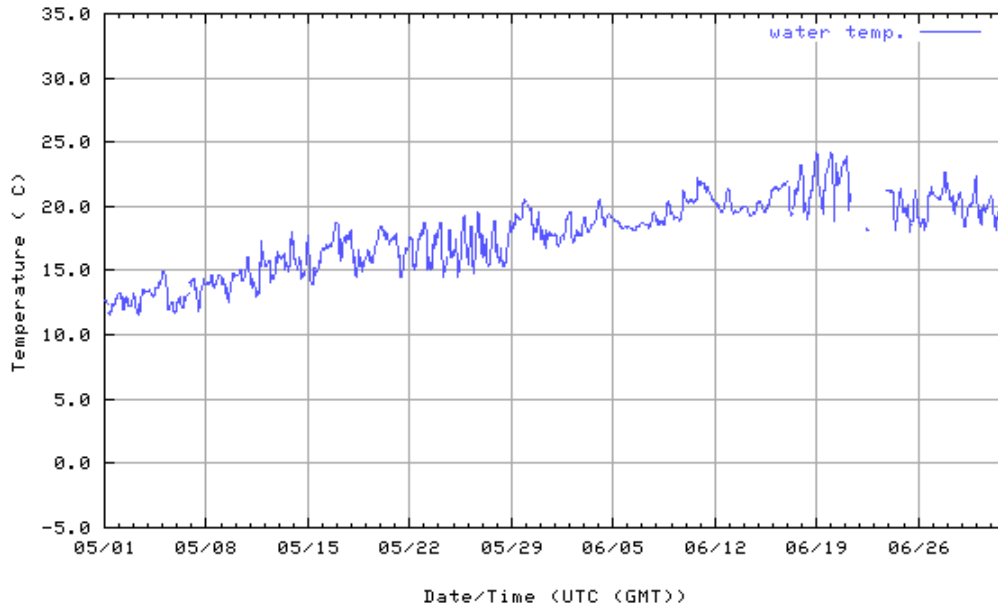
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from 05/01/2002 - 07/01/2002



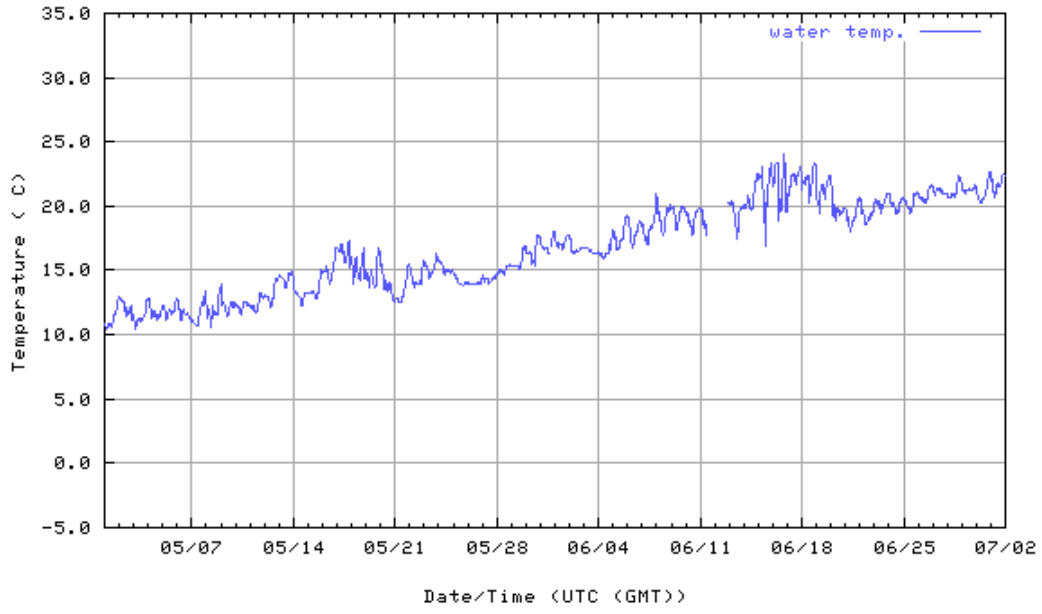
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from 05/01/2003 - 07/01/2003



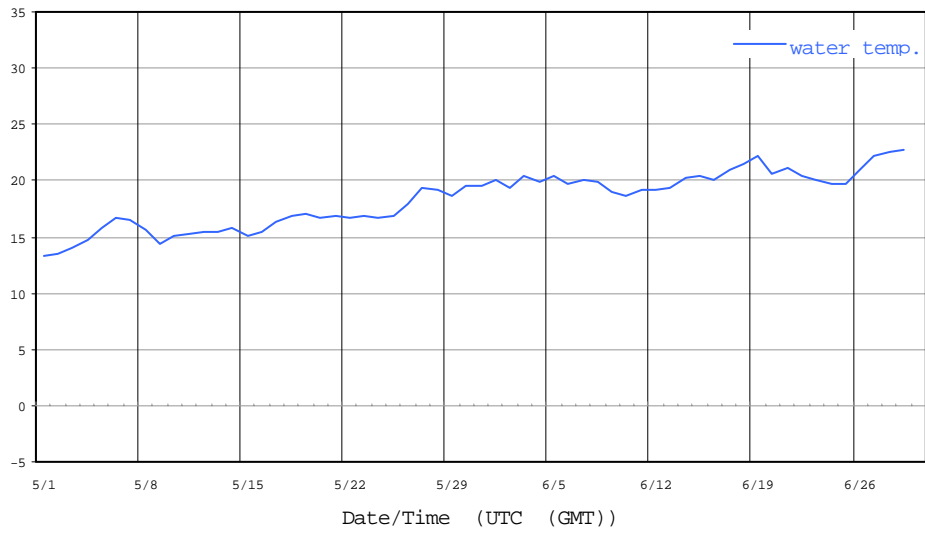
Date/Time (UTC (GMT))
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Water Temperature Plot
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from 05/01/2004 - 07/01/2004



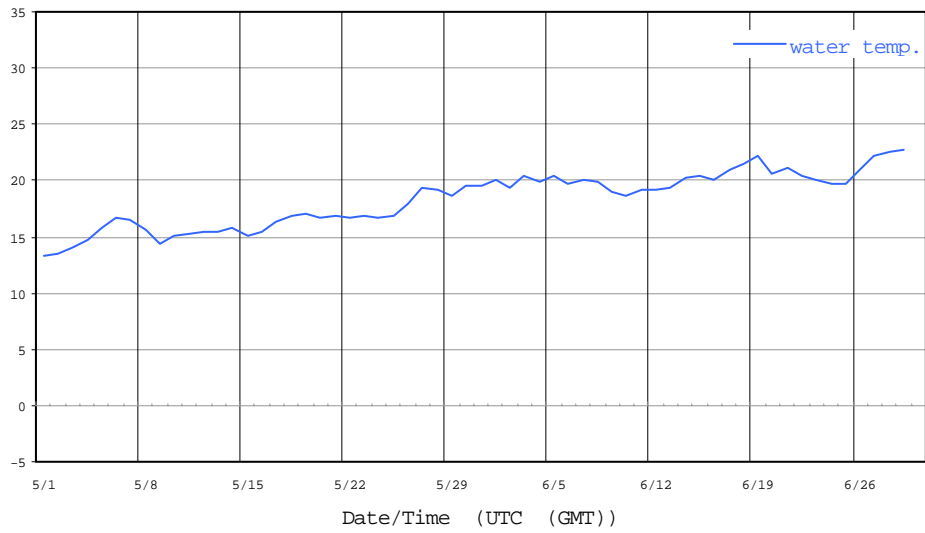
NOAA/NOS/CO-OPS
Water Temperature Plot
8557380 Lewes, DE
from 05/01/2005 - 07/01/2005



NOAA/NOS/CO-OPS
Water Temperature Plot
8557380 Lewes , DE
from 05/01/2006 - 07/01/2006



NOAA/NOS/CO-OPS
Water Temperature Plot
8557380 Lewes , DE
from 05/01/2006 - 07/01/2006



APPENDIX II. Index of spawning horseshoe crabs abundance, expressed as the mean number of females crabs per m² per night, for Delaware Bay beaches surveyed from 1999 to 2006.

State	Beach	1999	2000	2001	2002	2003	2004	2005	2006
DE	Bennetts Pier		0.2233	0.6399	0.4713	0.2762	0.5470	0.6992	0.6117
DE	Big Stone	0.7462	0.7290	0.8562	0.6265	0.6370	0.7617	0.8088	1.0896
DE	Broadkill	0.3197	0.0638	0.1170	0.1347	0.2083	0.1741	0.1911	0.1208
DE	Cape Henlopen				0.0857	0.1816	0.1255	0.2694	0.1000
DE	Fowlers	0.7779	0.4933	0.7033	0.2370	0.4532	0.6110	0.2148	0.4077
DE	Kitts Hummock	2.1510	2.5830	2.3545	1.4667	1.5529	1.2394	1.4175	1.7237
DE	Lewes				0.0838				
DE	North Bowers	0.8806	1.1836	1.0383	1.2142	0.9802	0.4995	0.6012	0.7479
DE	Pickering		3.3047	1.6244	1.6950	1.6417	1.6380	1.4708	1.4933
DE	Prime Hook	0.5984	0.1872	0.4446	0.5908	0.4733	0.7596	0.6500	0.7283
DE	Slaughter	1.6190	1.3254	1.0962	0.7265	1.6508	1.5237	0.6805	1.0396
DE	South Bowers		0.9196	0.8433	1.1265	0.4685	0.4796	0.6343	0.7192
DE	Ted Harvey				1.4446	1.9852	1.5220	0.8162	1.4579
DE	Woodland	0.1368	0.1033	0.0292	0.0792	0.0075	0.0012	0.0062	0.2700
NJ	East Point		0.3458						
NJ	Fortescue	0.2473				0.4184	0.5408	0.5818	0.6525
NJ	Gandys	0.4014	0.3922	0.4521	1.4122	0.5498	0.8166	0.8788	1.1652
NJ	Higbees		0.0361					0.1368	
NJ	Highs Beach	0.7892	0.9594	0.7950	0.4685	0.5275	0.6963	0.7583	0.6933
NJ	Kimbles	0.7063	0.8521	0.4773	0.4976	0.4970	0.4054		
NJ	Norburys			0.4600	0.6242	0.5362	0.6707	0.9391	0.6936
NJ	North Cape May	0.2250	0.0500	0.0904	0.0845	0.1233	0.0200	0.1233	0.0229
NJ	Pierces Point		0.6138		0.6730	0.7300	0.9602	0.8275	0.7447
NJ	Raybins	0.0259							
NJ	Reeds	0.3808	0.6468	0.4049	0.8768	0.8225	0.4162	0.2398	0.9650
NJ	Sea Breeze	0.0947	0.1094	0.2991	1.6283	0.3892	0.4275	0.2088	0.8471
NJ	Cape Shore Lab	1.2452	1.3311	1.2775	0.6850	0.6283	0.9042	1.1684	0.8183
NJ	Sunset			0.1139					0.0119
NJ	Townbank			0.7362	0.3958	0.4589	0.2037		
NJ	Villas							0.7075	0.4833