Horseshoe Crab Spawning Activity in Delaware Bay: 1999 – 2008

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 tenth 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 female spawning activity were precise. Annual coefficients of variation were below 14% for the entire series and remained below 10% for the last seven years.
- A strong nor'easter reduced water temperatures, altered spawning habitat and likely influenced 2008 spawning activity.
- Female spawning activity peaked during the third lunar period sampled (June 1 - 5), but atypically declined from the first lunar period to the second lunar period.
- In 2008, most of the female spawning occurred in June (57% in DE and 77% in NJ). The percent spawning in May was higher in DE than NJ for the first time.
- Percent of female spawning that occurred in May was associated with water temperature (correlations were 0.74 and 0.66 for DE and NJ, respectively).
- Baywide female spawning activity over the past 10 years remained stable (Slope = 0.00, SE = 0.01, 90% CI = -0.02 to 0.02, P = 0.91).
- No significant trends in state-specific female spawning were detected; though, the slope in Delaware was negative and the slope in New Jersey was positive.
- Estimates of male spawning activity were precise. Annual coefficients of variation were below 20% for the entire series.
- Estimates of baywide male spawning activity showed no significant trend from 1999 through 2008 (Slope = 0.10, SE = 0.07, 90% CI = -0.02 to 0.22, P = 0.17).

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* amebocyte lysate (LAL).

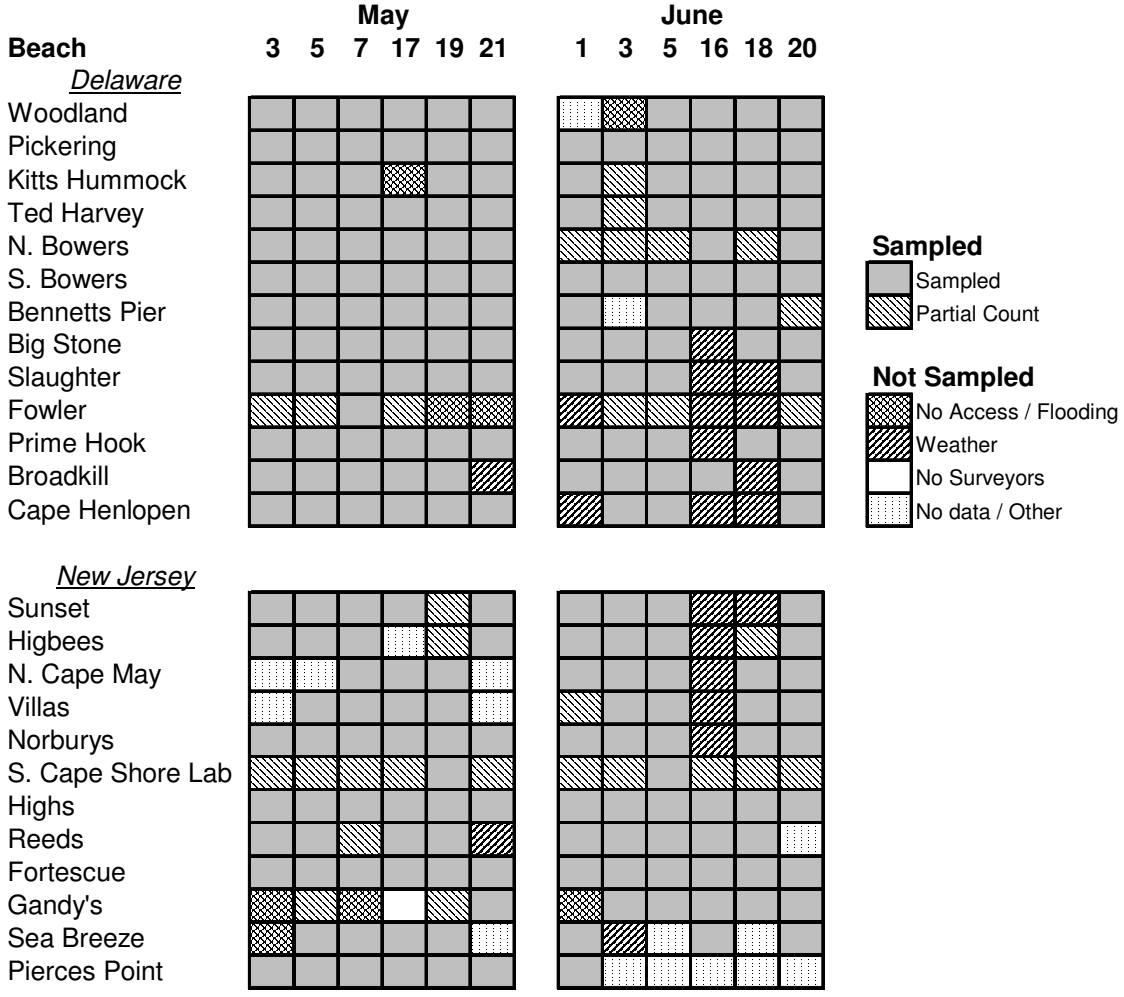
Data Availability

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 by request.

Summary Results

Sampling in 2008 was conducted during twelve nighttime high tides from 3 May through 20 June. Twenty-five (25) beaches were sampled in the Delaware Estuary – 13 in Delaware and 12 in New Jersey. The total number of tides sampled over the season was 254, with 46 sampling events canceled (Table 1).

Table 1. Beaches sampled in the 2008 Delaware Bay Horseshoe Crab Spawning Survey.



Temporal Spawning Distribution

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

Spawning during the first lunar period in 2008 was moderate relative to previous sampling (Figure 1). Spawning during the second lunar phase, however, declined in both states during the second lunar phase. This pattern is was unique as compared to previous sampling. In 2008, 43% of Delaware spawning activity and 23% of the New Jersey spawning activity occurred in May (Table 2). May spawning was consistently higher in New Jersey in all previous sampling (Table 2; Figure 2).

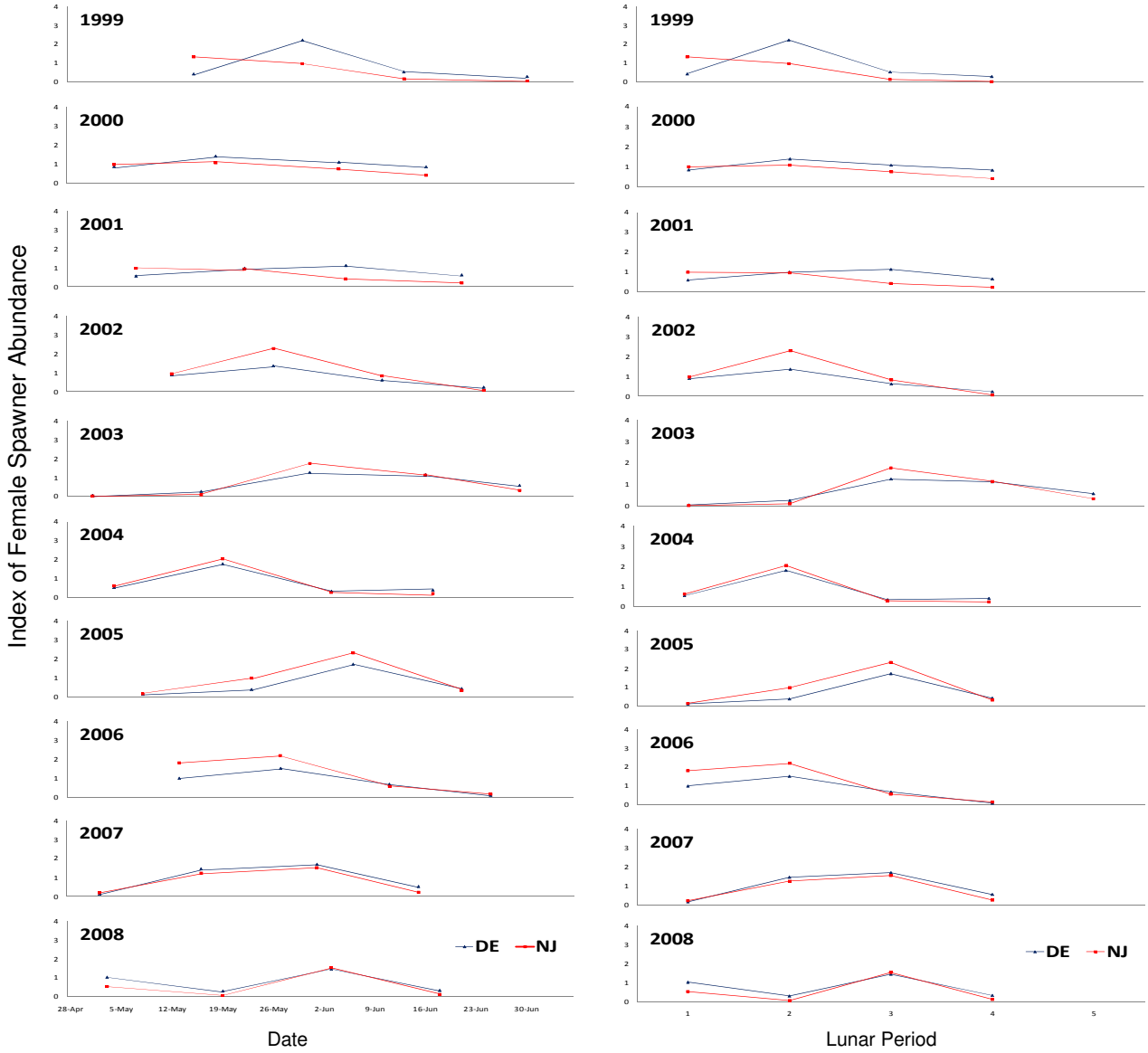


Figure 1. Temporal distribution of female horseshoe crab spawning activity in the Delaware Bay by state. Lunar periods are defined as a 5 day period (sampled day of lunar event and 2 days before and 2 days after) around the new or full moons in May and June.

Water temperature may influence the time of spawning (Smith and Michels 2006). There was a strong association between average May water temperatures recorded at Lewes, DE and the percentage state-specific spawning activity in May (r_{DE} = 0.74, P_{DE} = 0.01; r_{NJ} = 0.66, P_{NJ} = 0.04; Figure 2). Daily average water temperatures recorded at Lewes, DE (Appendix I) suggested 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 2008 were above 15 °C by May 3, but fell below 15 °C after a significant nor'easter (Appendix II) on May 12 and fell below 15 °C during the second lunar sampling event. The nor'easter and the associated low water temperatures were thought to have contributed to the low spawning activity in May. Further, coastal erosion greatly disturbed Delaware spawning beaches and reduced egg availability to migratory shorebirds (Kalasz and Weber 2008).

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

	Delaware		New Jersey		
Year	Dates of Peak Female Spawning	% of Female Spawning in May	Dates of Peak Female Spawning	% of Female Spawning in May	Average daily water temp. in May (C)
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
2007	30 May - 3 June	42	30 May - 3 June	45	15.4
2008	1 June - 5 June	43	1 June - 5 June	24	15.2

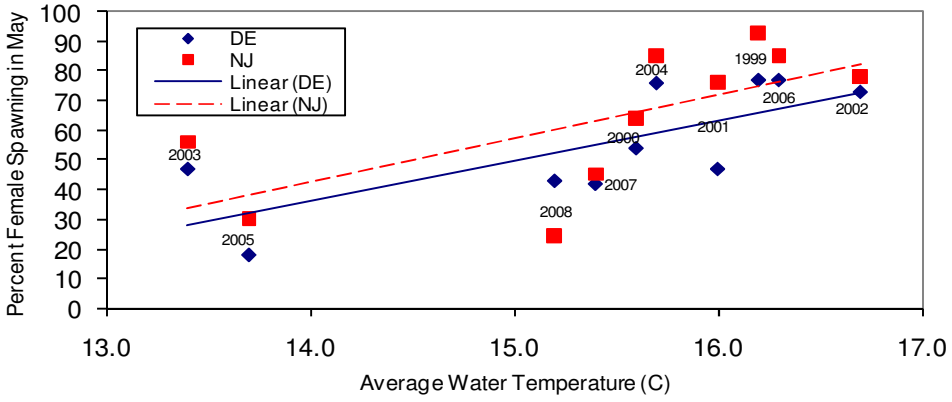


Figure 2. Percent of female horseshoe crab spawning occurring in May by state versus May average daily water temperatures. Water temperatures were recorded at the National Ocean Service at Lewes, DE Station ID 8557380.

State-specific Spawning Activity

Trends in female spawning activity differed by state (Figures 3; Table 3). Female spawning activity in New Jersey trended upward from 1999 through 2008, though not significantly (Slope = 0.01, SE = 0.02, P = 0.61). Spawning activity in Delaware exhibited a slightly negative slope, though not significant (Slope = -0.01, SE = 0.01, P = 0.27).

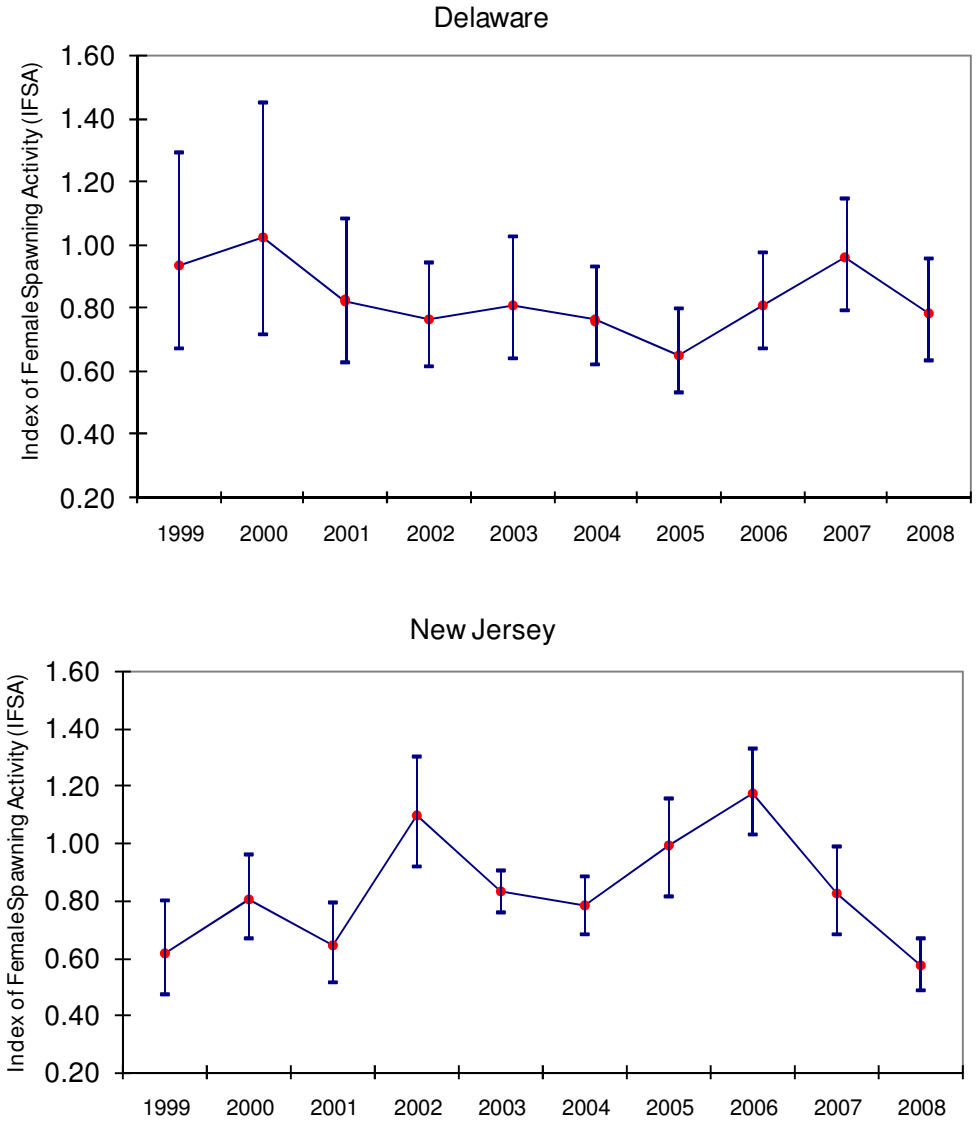


Figure 3. Indices of female horseshoe crab spawning activity (IFSA), expressed as the mean number of female crabs per m^2 per night, for the states of Delaware and New Jersey. Error bars are 90% confidence intervals.

Table 3. Indices of female horseshoe crab spawning activity (IFSA), expressed as the mean number of female crabs per m^2 per night, by state from 1999 to 2008.

	Delaware			New Jersey		
Year	IFSA	90% CI	Beaches Surveyed	IFSA	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
2007	0.96	0.79,1.15	13	0.82	0.68, 0.99	11
2008	0.78	0.63, 0.96	13	0.57	0.49, 0.67	12

Baywide Spawning Activity - Females

Trends in state-specific female spawning were compensatory, as no change in baywide spawning activity was detected (Figure 4; Table 4). The regression slope was zero (Slope = 0.00, SE = 0.01, 90% CI = -0.02 to 0.02, P = 0.91). Coefficients of variation were below 14% over the entire survey period and below 10% since 2002.

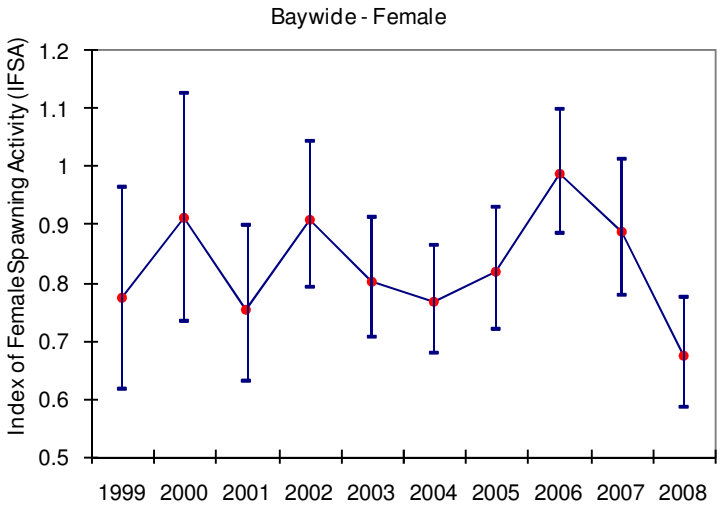


Figure 4. Index of female horseshoe crab spawning activity (IFSA) for the Delaware Bay from 1999 to 2008. Error bars are 90% confidence intervals.

Table 4. Index of female horseshoe crab (IFSA), standard error (SE), coefficient of variation (CV), and 90% confidence intervals (CI) for the Delaware Bay from 1999 to 2008.

Year	IFSA	Beaches 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
2007	0.89	24	0.07	8	0.78, 1.01
2008	0.68	25	0.06	9	0.59, 0.78

Baywide Spawning Activity - Males

Sex-specific harvest requirements contained in Addendum IV to the Interstate Fishery Management Plan for Horseshoe Crab (ASMFC 2006) for Delaware and New Jersey (specifically a male-only harvest) prompted an examination of male spawning abundance. Male spawning activity was stable (Slope = 0.10, SE = 0.07, 90% CI = -0.02 to 0.22, P = 0.17) for the period 1999 through 2008 (Figure 5; Table 5). Coefficients of variation for the male component of the survey were below 20% for the entire sampling.

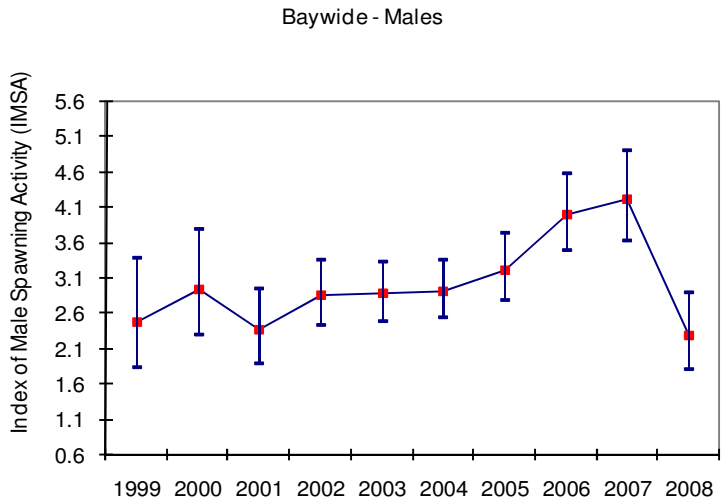


Figure 5. Index of male horseshoe crab spawning activity (IMSA) for the Delaware Bay from 1999 to 2008. Error bars are 90% confidence intervals.

Table 5. Index of male horseshoe crab (IMSA), standard error (SE), coefficient of variation (CV), and 90% confidence intervals (CI) for the Delaware Bay from 1999 to 2008.

Year	IMSA	Beaches Surveyed	SE	CV(%)	90% CI
1999	2.50	17	0.45	18	1.86, 3.37
2000	2.96	22	0.45	15	2.31, 3.80
2001	2.37	22	0.31	13	1.91, 2.95
2002	2.86	23	0.27	9	2.45, 3.34
2003	2.89	23	0.25	9	2.50, 3.33
2004	2.93	24	0.24	8	2.55, 3.36
2005	3.23	23	0.29	9	2.79, 3.74
2006	3.99	24	0.33	8	3.49, 4.56
2007	4.22	24	0.38	9	3.63, 4.90
2008	2.30	25	0.32	14	1.83, 2,90

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 6 and Table 6.

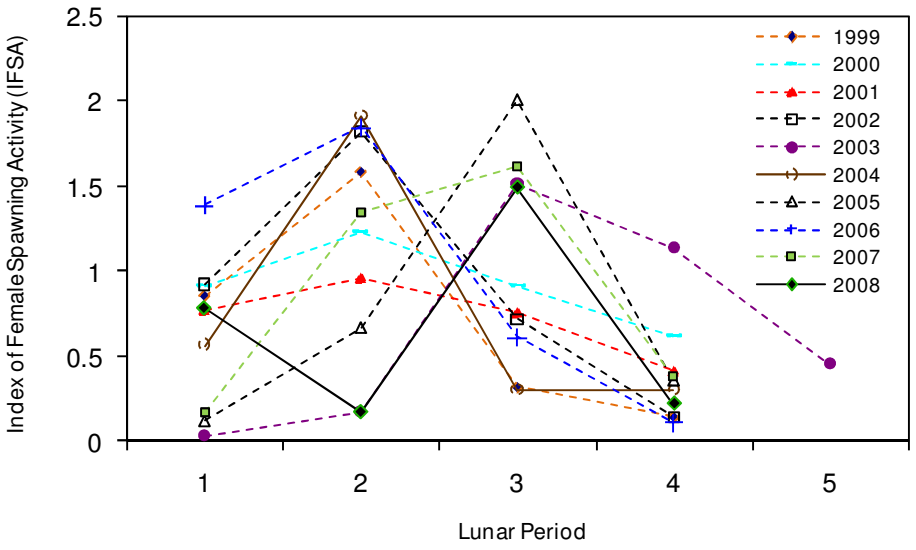


Figure 6. Baywide horseshoe crab spawning activity, expressed as mean number of spawning female crabs per m^2 per night, by lunar period for the years 1999 to 2008.

Table 6. 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 2008.

	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	
2006	1.39	1.85	0.61	0.11	
2007	0.17	1.34	1.61	0.38	
2008	0.78	0.17	1.49	0.22	

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 III, however, provides a summary of spawning activity by beach for all years.

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.

Atlantic States Marine Fisheries Commission (ASMFC). 2006. Addendum IV to the Interstate Fishery Management Plan for Horseshoe Crab. Fishery Management Report No. 32d, Atlantic States Marine Fisheries Commission, Washington D.C.

Carmichael, R.H., D. Rutecki and I. Valiela. 2003. Abundance and population structure of the Atlantic horseshoe crab Limulus polyphemus in Pleasant Bay, Cape Cod. *Marine Ecol. Prog. Ser.* 246:225-239.

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.

Kalasz, K.S. and R.G. Weber. 2008. 2008 Delaware Horseshoe Crab (limulus polyphemus) Egg Survey Project Final Report. Delaware Natural Heritage and Endangered Species Program. Delaware Division of Fish and Wildlife. Dover, DE.

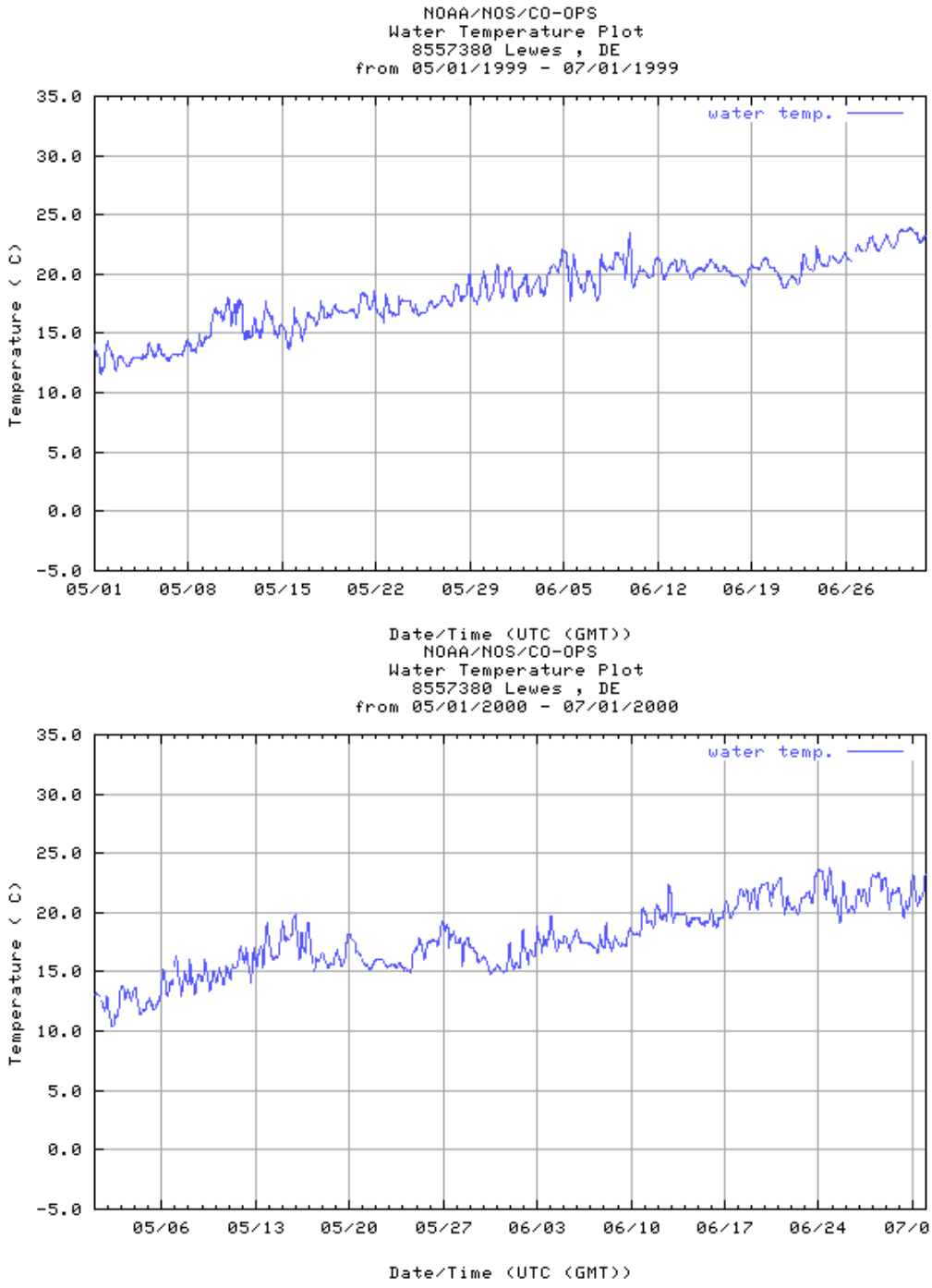
Maio, K.J. 1998. Quantitative description of the temporal and spatial patterns in spawning activity of the horseshoe crab, *Limulus polyphemus*. Master's thesis. University of Maryland Eastern Shore, Princess Anne, Maryland.

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.

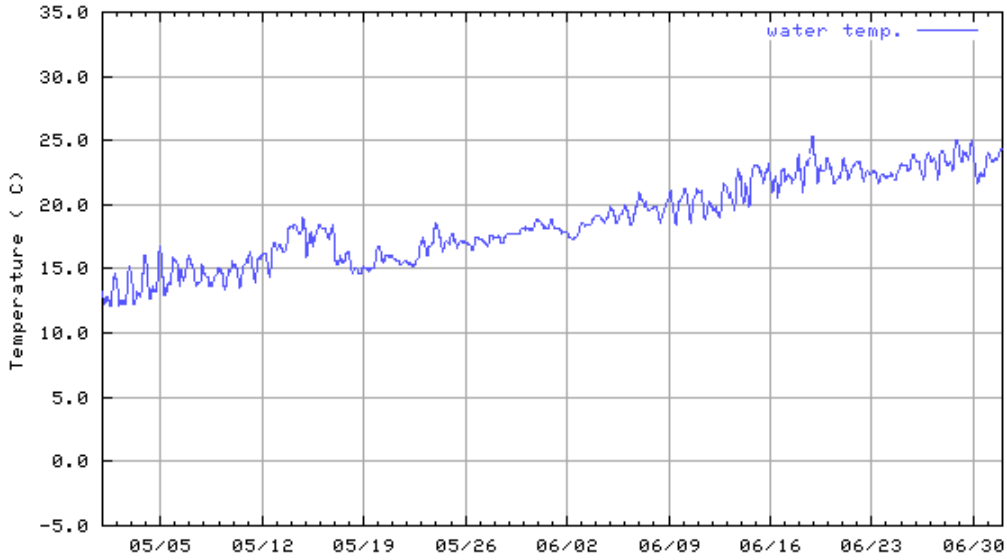
Smith D.R. and S. Bennett. 2005. Horseshoe crab spawning activity in Delaware Bay: 1999 – 2004. Report to the ASMFC Horseshoe Crab Management Board. Unpublished.

Smith, D.R., and S.F. Michels. 2006. Seeing the elephant: importance of spatial and temporal coverage in a large-scale volunteer-based program to monitor horseshoe crabs. Fisheries 31(10):485-491.

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 2007. 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))

NOAA/NOS/CO-OPS
Water Temperature Plot
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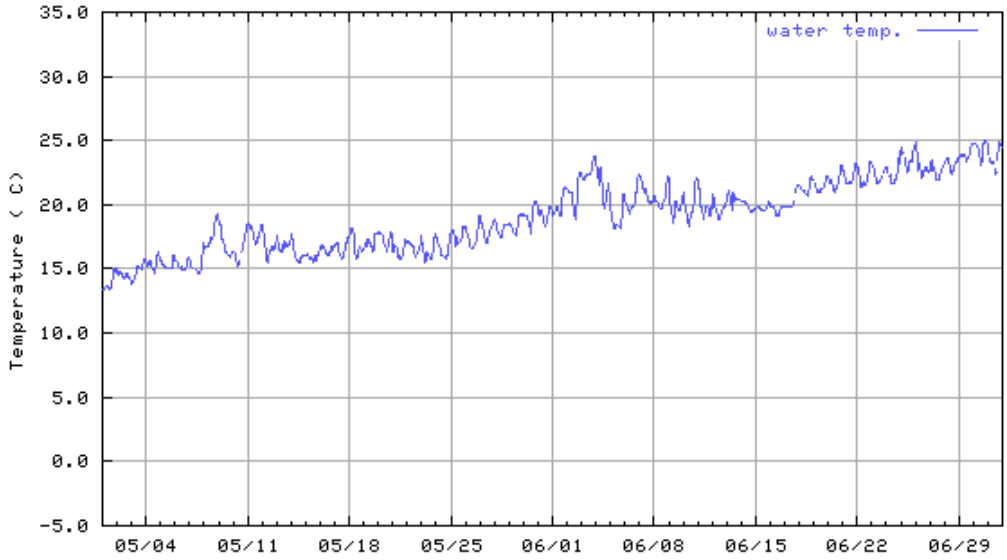
from 05/01/2002 - 07/01/2002



Date/Time (UTC (GMT))

NOAA/NOS/CO-OPS
Water Temperature Plot
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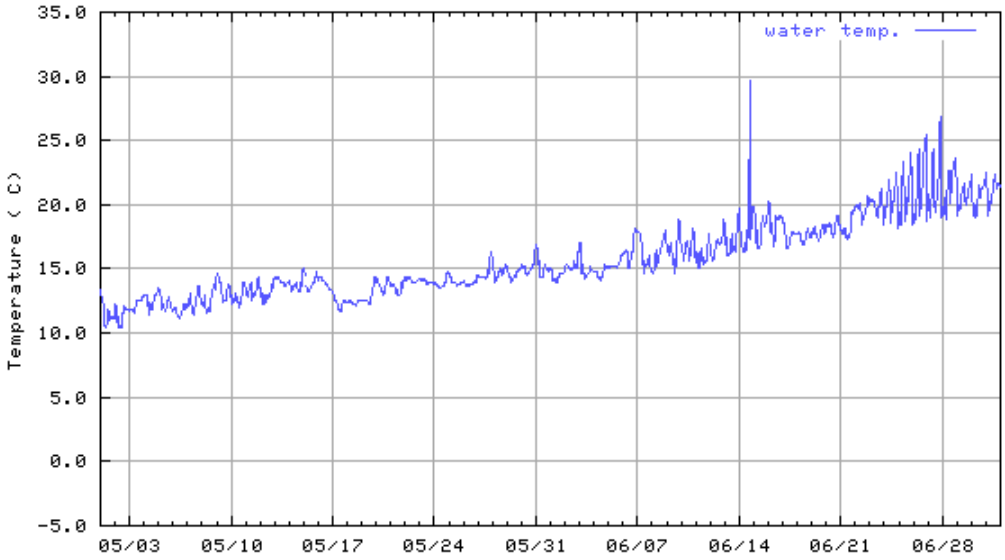
from 05/01/2003 - 07/01/2003



Date/Time (UTC (GMT))

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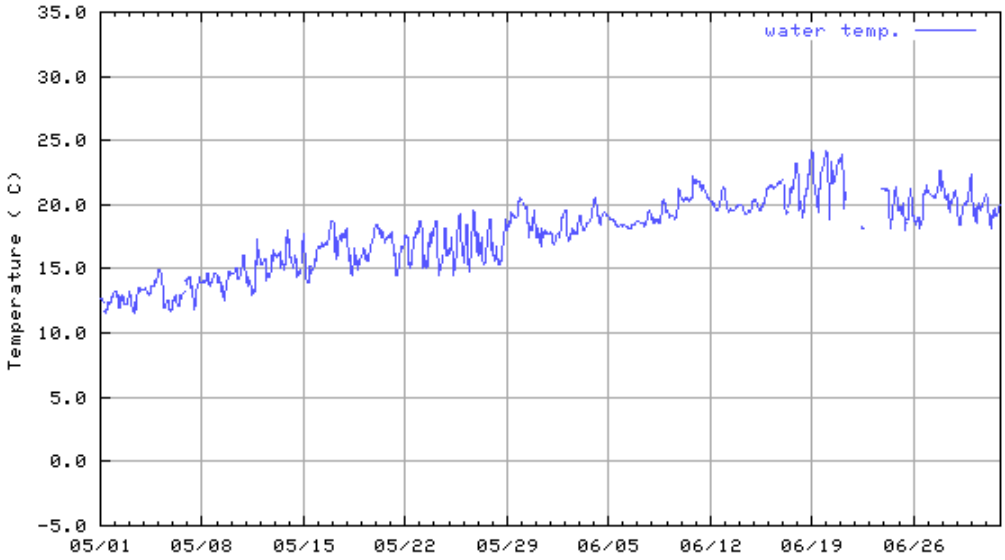
from 05/01/2004 - 07/01/2004



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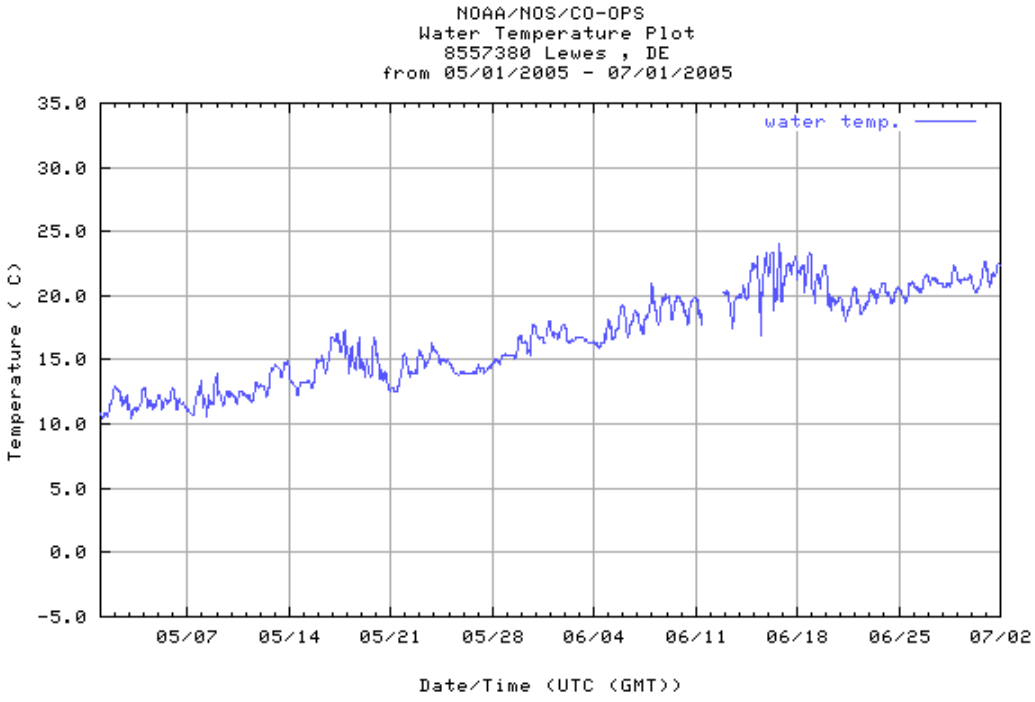
NOAA/NOS/CO-OPS
Water Temperature Plot
8557380 Lewes , DE
from 05/01/2005 - 07/01/2005
water temp.
Temperature (C)
35.0
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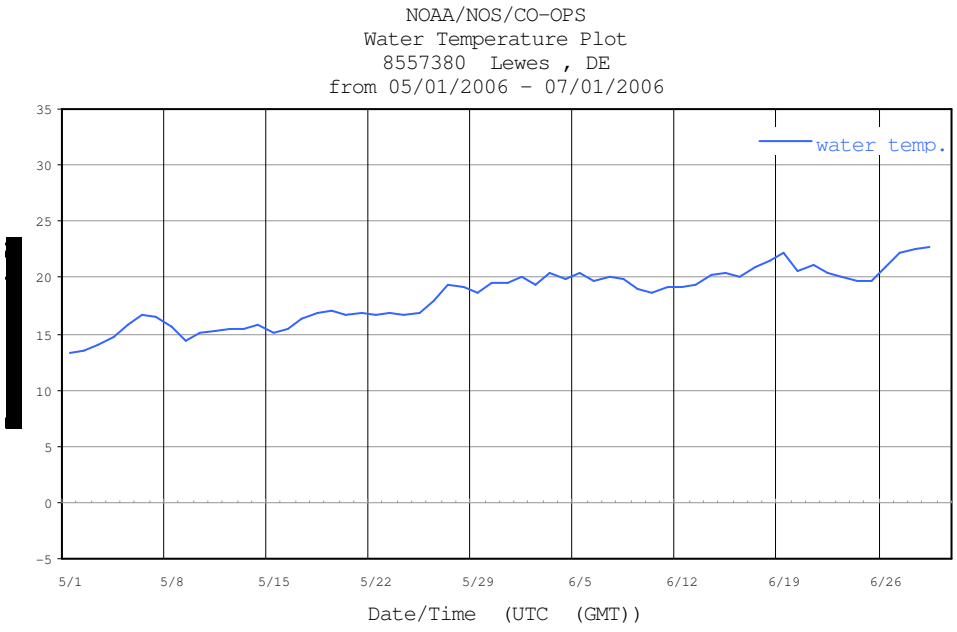
06/11
06/18
06/25
07/02
Date/Time (UTC (GMT))


NOAA/NOS/CO-OPS
Water Temperature Plot
8557380 Lewes , DE
from 05/01/2006 - 07/01/2006
water temp.
35
30
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15
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-5
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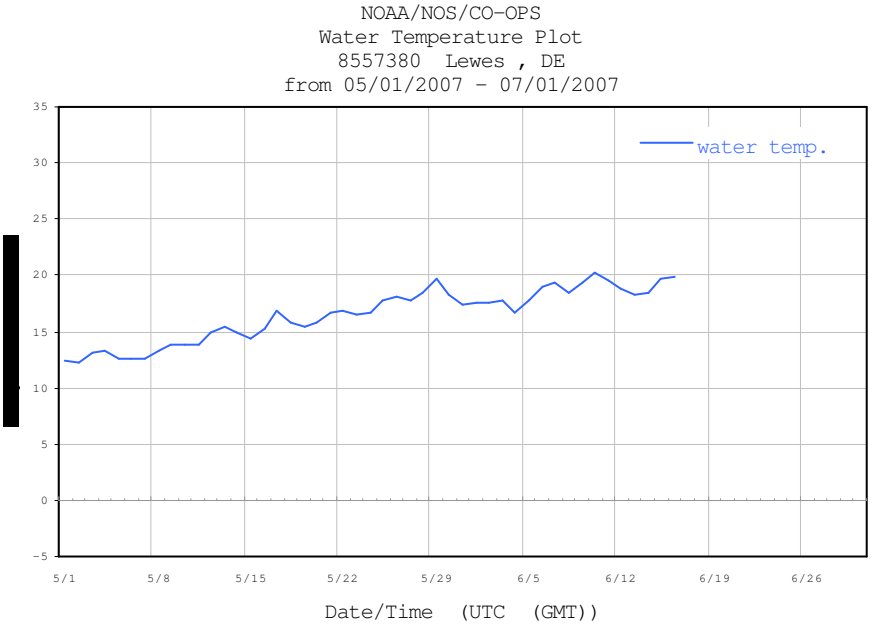
5/22
5/29
6/5
6/12
6/19
6/26
Date/Time (UTC (GMT))


NOAA/NOS/CO-OPS
Water Temperature Plot
8557380 Lewes , DE
from 05/01/2007 - 07/01/2007
water temp.
35
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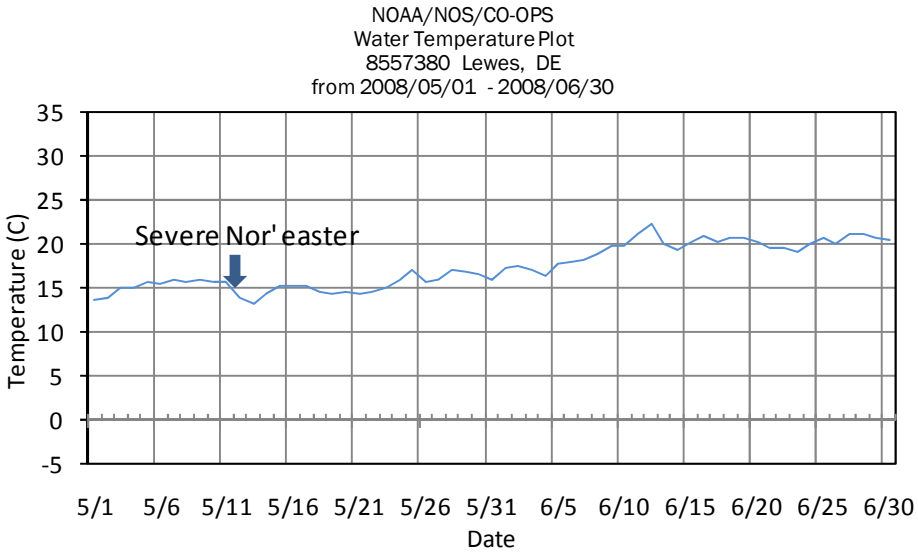
6/5
6/12
6/19
6/26
Date/Time (UTC (GMT))


NOAA/NOS/CO-OPS
Water Temperature Plot
8557380 Lewes, DE
from 2008/05/01 - 2008/06/30
Severe Nor' easter
Temperature (C)
35
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6/20
6/25
6/30
Date

APPENDIX II. National Climatic Data Center synopsis of a significant May 12, 2008 nor'easter that impacted Delaware Bay. Source: http://www4.ncdc.noaa.gov/cgi-win/wwcgi.dll?wwevent~ShowEvent~710231.

Event Record Details

Event: **Coastal Flood**
Begin Date: **12 May 2008, 03:00:00 AM EST**
Begin Location: **Not Known**
End Date: **12 May 2008, 06:00:00 AM EST**
End Location: **Not Known**
Magnitude: **0**
Fatalities: **0**
Injuries: **0**
Property Damage: **$ 0.0K**
Crop Damage: **$ 0.0K**

State: **Delaware**
Map of Counties
Forecast Zones affected: **Delaware Beaches, Kent**

Description:
Tidal flooding of minor to moderate occurred along coastal Delaware. The tidal gage at Lewes peaked at 7.9 feet mean lower low water at 6:00 AM EDT on the 12th. Moderate flooding begins at 7.7 feet mean lower low water.A potent low pressure system in the Ohio Valley during the early morning hours of May 11th moved eastward and gradually weakened. A secondary low formed over northeastern North Carolina during the late afternoon on the 11th and eventually absorbed the other low pressure system, becoming the dominant storm. This storm gradually moved east northeastward late on the 11th into the 12th. Early on the morning of the 12th, the storm was centered over the southern Delmarva. As this storm strengthened fairly rapidly, a strong northeasterly wind developed and persisted through the evening of the 12th. The prolonged northeast flow combined with higher than normal tides, caused widespread minor to moderate tidal flooding along the coast of Delaware. Heavy rain also impacted the state, especially central and southern sections. By the evening of the 12th, the coastal storm tracked eastward and gradually moved away from the region. It was reported that downtown Delaware City (New Castle County) flooded at high tide, which took place from 5:30 AM to 6:00 AM EDT on the 12th. Locations that were impacted by flooding included the first blocks of Clinton and Washington streets, as well as around the entrance to the trailer park. The high tide also caused damage to the Delaware City Park off of Clinton Street as the waves tore up some of the brick sidewalk along the sea wall. At 6:10 AM EDT on the 12th, crews responded to a report of an automobile stranded in high water on Old State Road in Middletown (New Castle County). Another call came in at 9:10 AM EDT with a report of another vehicle stranded at the same location. In Christiana Hundred (New Castle County), a large tree fell into a home in the 300 Block at around 11:00 AM EDT on the 12th. There was considerable damage to the second floor of the home. At Slaughter Beach (Sussex County), heavy wind pushed water over the area???s sand dunes and onto roadways, which blocked off Route 36 and Slaughter Beach Road. Fire trucks and

rescue personnel ran a ferry service across the waters to bring Slaughter Beach residents who needed to go home, and those who wanted to leave. The water rose as high as four and a half feet at some points, and by the end of the morning of the 13th, the Army National Guard had to deploy full-sized transports to navigate the roads, and for evacuation only. While the town itself suffered only light damage, major roads were not usable again until the afternoon of the 13th. Perhaps the hardest hit by the storm were the residents of Milford Neck at the end of Lighthouse Road at Slaughter Beach. The ???That???s Right Fresh Seaford??? processing facility suffered heavy damage when wind blew water into the steel building at a height of four feet. In addition, the home at the point, many not raised to avoid flood waters, suffered damage. A car was swamped by rising water from Canary Creek on New Road in Lewes (Sussex County) on the 12th. The road was closed when high tides caused the banks to overflow. Several roads in and around Bethany Beach (Sussex County) were still flooded on the 13th, a day after the storm. Peters Field Ditch, which runs behind Broadkill Beach (Sussex County) from the Broadkill River, overflowed its banks during the Nor???easter on the 12th, which created an inland bay behind the Delaware Bay community. Water from Delaware Bay, on the 12th, spilled into the marsh near Prime Hook National Wildlife Refuge (Sussex County) between Broadkill Beach and Slaughter Beach when a breach occurred from strong winds and higher tides. Lighthouse Road, which is just north of Slaughter Beach (Sussex County), was completely flooded. In Prime Hook Beach, flooding started around 5:00 AM EDT on the 12th, and roads, including the one to the nature center were closed about 7:00 AM EDT. Cedar Beach Road was also closed back to Clark's Board Storage, and the other avenue into the bayfront community. Trees were knocked down in Rehoboth Beach (Sussex County) on the 12th as high winds and soggy ground proved to be too much. Major erosion along the dune was noted at the north end of the boardwalk in Rehoboth Beach. Although a new dune held in Bethany Beach (Sussex County), large waves created from the Nor???easter on the 12th eroded a section, which created a large drop-off. Erosion was also noted at many other beaches, such as Dewey Beach (Sussex County). Road closures and flooding were reported from coastal Sussex inland to the Oak Orchard area. In Dewey Beach (Sussex County), a stretch of Route 1, including the Indian River Inlet Bridge, was closed due to flooding. Portions of Cupola Park, in Millsboro (Sussex County), were flooded as storm water from Millsboro Pond ran over. Strong winds completely toppled over a Food Lion sign on Route 16 in Georgetown (Sussex County), and Wilmington University and Del Tech were forced to reschedule graduation ceremonies when the graduation tent collapsed because of strong winds. Cape Henlopen (Sussex County) students were sent home by 1:00 PM EDT on the 12th because of the affects of the storm. At 1:00 PM EDT on the 12th, The Delaware Department of Transportation closed three Sussex County roads because of high water. These included Route 209 and 224 in the Slaughter Beach area and Route 312 in the Oak Orchard area. High tide flooding resulted in the closing of Route 1 along the coast between Dewey Beach and Fred Hudson Road. State Police had numerous reports of downed wires, trees and tree limbs in roadways, and flooding on some streets and highways. Storm-driven tides flooded Savannah Road on Lewes Beach on the 12th and surrounded the Howard Seymour Water Reclamation Plant (Sussex County). In South Bowers (Kent County), the dunes that were between the surf???s edge and the elevated homes were essentially wiped away. Several boats appeared to have been missing as a result of the wind and storm surge. The homes on Route 36 before the bridge were those that were primarily affected by the flooding. West Milford (Kent County) was covered with between one and two feet of water during the storm that roared through the region on the morning of the 12th. Several downtown structures suffered minor water damage, including the Department of Health and Social Service building on Southeast Front Street, which was closed until the 16th. In Milford (Kent County),

police evacuated employees from two state service centers, one on Church Street and the other on Walnut Street, as the Mispillion River overflowed its banks starting the night of the 11th. Bicentennial Park was under water, as were portions of Washington Street, Park Avenue and North East Front Street. The flooding persisted until early on the 13th. Some 150 residents of Kent County along the Delaware Bay were evacuated from their homes early on the 12th as high winds and heavy rains from a Nor'easter caused severe coastal flooding. Some took shelter at the Little Creek Fire Hall. The coastal regions of Kitts Hummock and Pickering Beach received the brunt of the high water, with reports of flooding nearing 6 feet. About 175 people were evacuated from Kitts Hummock and about 50 from Pickering Beach. Initially rescuers plucked people from homes in Pickering Beach and Kitts Hummock using nine boats, but then as the tide receded and water levels became shallower, National Guard trucks went from home to home. The water in some homes was nearly knee deep. At Pickering Beach, east of Dover Air Force Base, National Guard trucks ferried about 50 residents to safety early on the 12th after the churning surf washed over the dune line and swirled around the pilings of the small cottages. Some vehicles were buried in the sand and water. The Bowers Fire Department reported that about 30 evacuees stayed temporarily at the fire station during the morning of the 12th, and about 40 others had sought refuge elsewhere. The flooding began around 2:30 AM EDT on the 12th. A Pickering Beach resident reported that the waves during the morning of the 12th, crashed over the two family cars. Downed trees and flooding occurred in the Smyrna area (Kent County) on the 12th. On Hillyard Road, a large tree fell onto a home around 2:30 AM EDT, which damaged the homes roof. The Delaware Army National Guard assisted with a voluntary evacuation of Woodland Beach (Kent County) on the 12th, after the only road to the community was impassable after sections of the road were lifted up and washed away. At South Bowers Fire Company (Kent County), firefighters evacuated people from Big Stone and South Bowers beaches at about 3:00 AM EDT on the 12th. Water flooded about a mile and a half inland. In South Bowers (Kent County), fishing boats were washed up into the marshes and tidal flooding of the Mispillion River, which runs through Milford (Kent County), caused officials to cut electricity to the area. There were also vehicles stranded in the water in Milford. The American Red Cross of the Delmarva Peninsula and Kent County Emergency Management opened a shelter at the Little Creek Fire Department on Main Street in Little Creek (Kent County) at 4:00 AM EDT on the 12th. About 15 people were at the shelter. After a mandatory evacuation of Kitts Hummock and Pickering Beach (Kent County), the numbers at the shelter rose to 25 or 30. A large tree was blown over in Dover (Kent County) at the corner of Governors Avenue and Governors Boulevard. There were also reports of other fallen trees along with downed power lines throughout Dover. Delaware Electric Cooperative reported that they had some 10,500 outages by 9:00 AM EDT on the 12th, as two substations were lost. Problem areas included Long Neck, Selbyville and Frankford (Sussex County). Crews found that because the rain drenched the ground, which combined with high winds, downed poles and even snapped some cross-arms. About 23,500 Delmarva Power customers were without power on the 12th as high winds downed trees and power lines, most of which were in Sussex County. The peak of the outages was about 23,000, which included about 675 Delmarva Power customers in Kent County. Power outages, as a result of the storm, forced the courts in Georgetown (Sussex County) to close on the 12th, as well as schools across Sussex County. Electric customers east of U.S. 113 (Sussex County) were hit the hardest by the outages, but power was largely restored by the early afternoon hours of the 12th. Multiple schools across the state let students out early on the 12th and excused students in overly flooded areas from attending classes. Officials shut down service of the Cape May-Lewes Ferry on the 12th because of the strong winds and higher tides. The Nor???easter on May 12th added insult to injury as 2 to 4 inches of rain that

fell up until then in parts of Delaware impacted crops. A couple of corn crops that were newly planted were completely flooded, which could mean they may likely not produce. The coastal storm produced tidal flooding, which caused the most damage, as the salty water can be lethal to crops, according to experts. An estimated 1,000 acres of farmland may have been affected by the tidal flooding from this storm. Tidal flooding from Delaware Bay impacted the state during the night of the 11th and through at least midday on the 12th. Tidal flooding of minor to moderate occurred along coastal areas. The tidal gage at Reedy Point peaked at 8.3 feet mean lower low water at 6:00 AM EDT on the 12th. Moderate flooding begins at 8.2 feet mean lower low water. In addition, the Delaware City tidal gage peaked at 9.1 feet mean lower low water at 6:00 AM EDT on the 12th. This was reported to be a new record since the gage was installed in 2001. The tidal gage at Lewes peaked at 7.9 feet mean lower low water at 6:00 AM EDT on the 12th. Moderate flooding begins at 7.7 feet mean lower low water. The tidal gage at Bowers Beach peaked at 9.78 feet mean lower low water at 4:00 AM EDT on the 12th (flood state is 7.0 feet), and this was reported to be an all-time record height. Some peak wind gusts included: 68 mph at Lewes; 67 mph at Brandywine Light and Brandywine Harbor; 60 mph at Dover Air Force Base; 51 mph at the Georgetown Airport; 48 mph at the New Castle County Airport in Wilmington; and 46 mph in Sandtown. Some rainfall totals included: 4.07 inches in Redden; 3.21 inches in Millsboro; 2.37 inches in Greenwood; 2.36 inches in Prime Hook National Wildlife Refuge; 1.98 inches in Bethany Beach; and 1.82 inches in Dover.

APPENDIX III. Index of female 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 2008.

State	Beach	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
DE	Bennetts Pier		0.2233	0.6399	0.4713	0.2762	0.5470	0.6992	0.6117	0.5496	0.3726
DE	Big Stone	0.7462	0.7290	0.8562	0.6265	0.6370	0.7617	0.8088	1.0896	1.3475	0.7064
DE	Broadkill	0.3197	0.0638	0.1170	0.1347	0.2083	0.1741	0.1911	0.1208	0.1775	0.5533
DE	Cape Henlopen				0.0857	0.1816	0.1255	0.2694	0.1000	0.0579	0.3000
DE	Fowlers	0.7779	0.4933	0.7033	0.2370	0.4532	0.6110	0.2148	0.4077	0.5033	0.5260
DE	Kitts Hummock	2.1510	2.5830	2.3545	1.4667	1.5529	1.2394	1.4175	1.7237	1.4394	1.2296
DE	Lewes				0.0838						
DE	North Bowers	0.8806	1.1836	1.0383	1.2142	0.9802	0.4995	0.6012	0.7479	1.1088	0.3646
DE	Pickering		3.3047	1.6244	1.6950	1.6417	1.6380	1.4708	1.4933	1.6350	1.9908
DE	Prime Hook	0.5984	0.1872	0.4446	0.5908	0.4733	0.7596	0.6500	0.7283	1.1088	0.9221
DE	Slaughter	1.6190	1.3254	1.0962	0.7265	1.6508	1.5237	0.6805	1.0396	1.2360	1.1005
DE	South Bowers		0.9196	0.8433	1.1265	0.4685	0.4796	0.6343	0.7192	1.3026	0.5700
DE	Ted Harvey				1.4446	1.9852	1.5220	0.8162	1.4579	1.9279	1.4746
DE	Woodland	0.1368	0.1033	0.0292	0.0792	0.0075	0.0012	0.0062	0.2700	0.0312	0.0000
NJ	East Point		0.3458								
NJ	Fortescue	0.2473				0.4184	0.5408	0.5818	0.6525	0.1600	0.3267
NJ	Gandys	0.4014	0.3922	0.4521	1.4122	0.5498	0.8166	0.8788	1.1652	0.8257	0.2975
NJ	Higbees		0.0361					0.1368			0.0321
NJ	Highs Beach	0.7892	0.9594	0.7950	0.4685	0.5275	0.6963	0.7583	0.6933	0.7527	0.4558
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	0.4334	0.4133
NJ	North Cape May	0.2250	0.0500	0.0904	0.0845	0.1233	0.0200	0.1233	0.0229	0.0417	0.0308
NJ	Pierces Point		0.6138		0.6730	0.7300	0.9602	0.8275	0.7447	0.9410	0.7123
NJ	Raybins	0.0259									
NJ	Reeds	0.3808	0.6468	0.4049	0.8768	0.8225	0.4162	0.2398	0.9650	0.3050	0.3404
NJ	Sea Breeze	0.0947	0.1094	0.2991	1.6283	0.3892	0.4275	0.2088	0.8471	0.9250	0.6650
NJ	Cape Shore Lab	1.2452	1.3311	1.2775	0.6850	0.6283	0.9042	1.1684	0.8183	1.2610	0.3886
NJ	Sunset			0.1139					0.0119	0.0038	0.0097
NJ	Townbank			0.7362	0.3958	0.4589	0.2037			0.2883	
NJ	Villas							0.7075	0.4833		0.3431