Horseshoe Crab Spawning Activity in Delaware Bay: 1999 – 2012

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

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Summary

- This marks the fourteenth 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.
- Annual coefficients of variation for estimates of female spawning activity were below 14% for the entire series and remained at or below 10% for the last ten years. Annual coefficients of variation for estimates of male spawning activity were below 20% for the entire series.
- Female spawning activity in 2012 peaked during the second lunar period sampled (May 18 – May 22).
- High female spawning activity in 2012 was observed in May in New Jersey (92%) while Delaware was moderate (64%).
- Percent of female spawning that occurred in May was associated with water temperature (correlations were 0.56 and 0.62 for DE and NJ, respectively).
- Bay-wide female spawning activity over the past 14 years showed no significant trend; though, the slope was slightly negative (Slope = -0.01, SE = 0.01, 90% CI = -0.02 to 0.14, P = 0.22).
- No significant trends in state-specific female spawning were detected; though, the slope in both Delaware and New Jersey was negative.
- Bay-wide male spawning activity showed no significant trend from 1999 through 2012; though the slope was positive (Slope = 0.05, SE = 0.05, 90% CI = 0.02 to 0.14, P = 0.23).
- No significant trends in state-specific male spawning were detected; although, the slopes in both states were positive.

- Sex ratios (M:F) during the 14 year time series ranged from 3.1 to 5.2.

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; 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 bay-wide 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. Beginning in 2010, the previous software was no longer compatible with updated Windows OS, so an R program was used to calculate estimates. Data used in this report (both estimates and raw data) and the software used to calculate estimates are available by request.

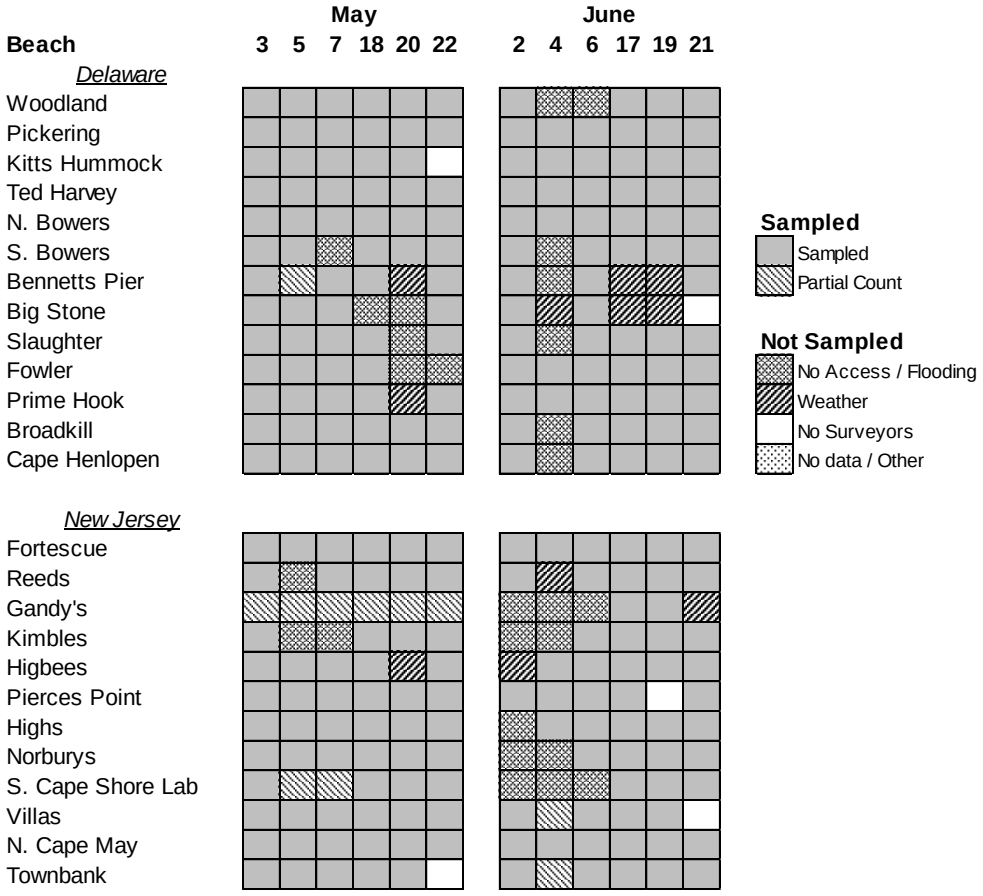
Summary Results

Sampling in 2012 was conducted during twelve nighttime high tides from 3 May through 21 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 258, with 43 sampling events missed or canceled (Table 1). Thirty of the 43 missed sampling events occurred during the second and third lunar periods when spawning horseshoe crabs were most abundant.

Due to unseasonably warm water temperatures, the Atlantic States Marine Fisheries Commission's Delaware Bay Ecosystem Technical Committee requested sampling 3 tides in April during the new moon lunar phase (April 19, 21, 23). A summary of this activity is included in Appendix III.

Table 1. Beaches sampled in the 2012 Delaware Bay Horseshoe Crab Spawning

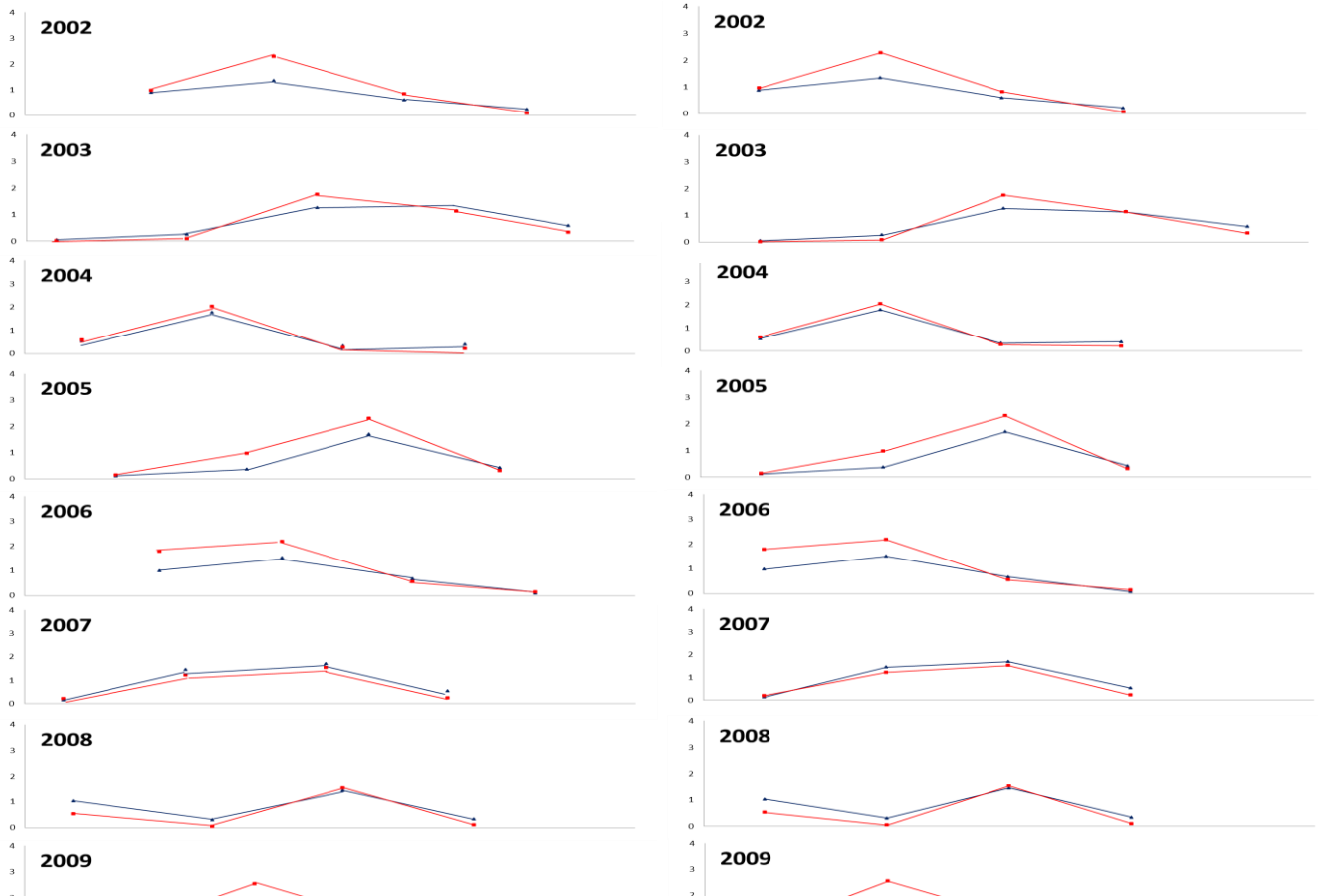
Survey.



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 may also affect the survival of egg, larvae and juvenile stages.

State-specific female spawning activity by sampling period was similar to 2010 (Figure 1). Female spawning activity peaked in New Jersey and Delaware in the second (May 3 – 7) and third (May 18 – 22) lunar periods, respectively. Fifty-eight percent (58%) of the annual female spawning activity in Delaware and 90% of the annual female spawning activity in New Jersey was observed in May (Table 2). The proportion of annual state-specific spawning activity that occurred in May was higher in New Jersey for all but 2 years of the 14-year survey.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of Female Spawner Abundance

Figure 1. Temporal distribution of female horseshoe crab spawning activity in the Delaware Bay by state for the years 2002 -2012. 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 female spawning activity in May (r_{DE} = 0.56, P_{DE} = 0.04; r_{NJ} = 0.62, P_{NJ} = 0.02; 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. Reduced spawning activity noted during the second lunar sampling period in 2008 coincided with a severe nor'easter that depressed water temperatures. In 2012, water temperatures reached 15°C by April and were consistently above 15°C throughout the survey period.

Table 2. Summary statistics reflecting the timing of female horseshoe crab spawning in Delaware and New Jersey and average May water temperatures. Water temperatures were recorded at the National Ocean Service station at Lewes, DE.

	Delaware		New Jersey		
	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	26	15.2
2009	22 May - 26 May	59	22 May - 26 May	66	15.5
2010	12 May - 16 May	82	25 May - 29 May	88	15.6
2011	30 May - 3 June	52	30 May - 3 June	44	16.0
2012	2June - 6 June	64	18 May - 22 May	92	17.8

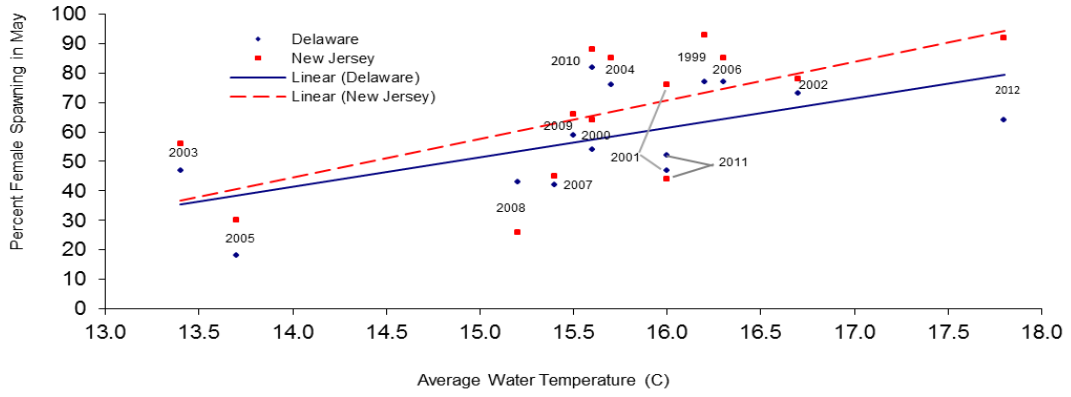


Figure 2. Percent of female horseshoe crab spawning occurring in May by state versus May average daily water temperatures. Water temperatures were recorded by the National Ocean Service at Lewes, DE Station ID 8557380.

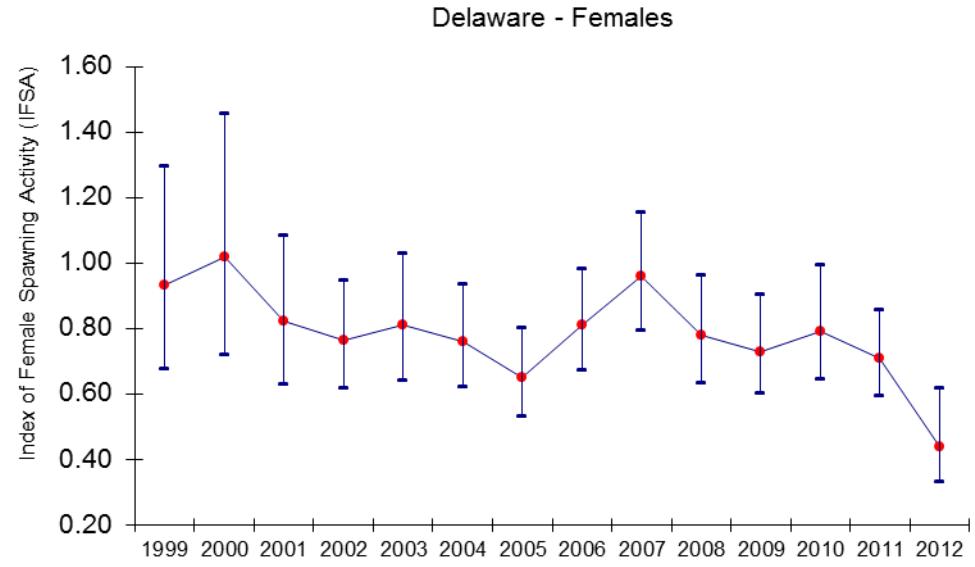
State-specific Spawning Activity

Although index values differ by state (Table 3; Figure 3), the trend from the index of female spawning activity in both states exhibited a slightly negative slope, though not significant (DE Slope = -0.01, SE = 0.01, P = 0.08; NJ Slope = -0.0001, SE = 0.02, P = 0.99).

Trends in male spawning activity were similar between states (Table 4; Figure 4). The index of male spawning activity in both states exhibited a positive slope, though not significant (DE Slope = 0.02, SE = 0.05, P = 0.69; NJ Slope = 0.09, SE = 0.07, P = 0.22).

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 2012.

Year	Delaware			New Jersey		
	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
2009	0.73	0.60, 0.90	13	1.26	1.11, 1.42	13
2010	0.79	0.64, 0.99	13	0.81	0.68, 0.96	12
2011	0.71	0.59, 0.85	13	0.56	0.48, 0.65	12
2012	0.45	0.33, 0.62	13	0.68	0.55, 0.83	12



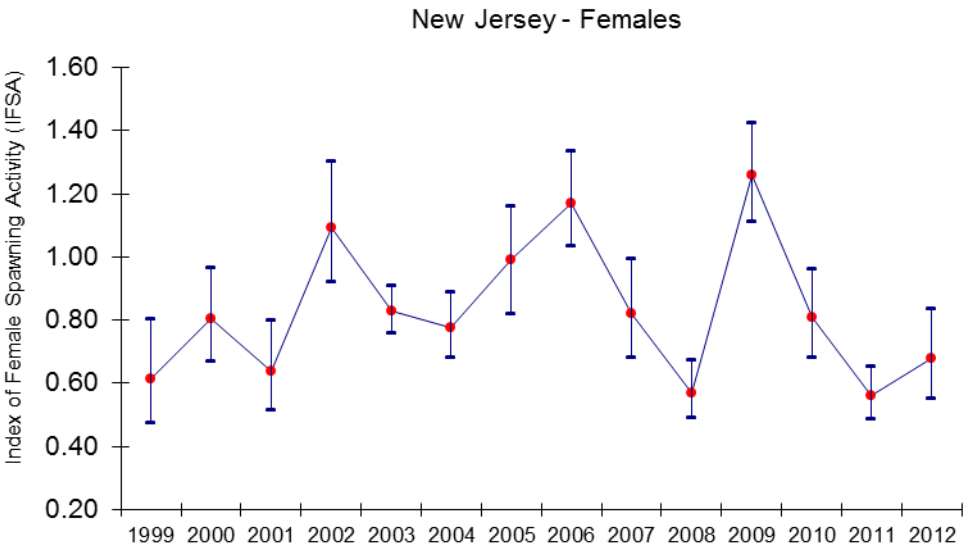


Figure 3. Indices of female horseshoe crab spawning activity (IFSA), expressed as the mean number of female crabs per m^2 per night, for the states of Delaware and New Jersey. Error bars are 90% confidence intervals.

Table 4. Indices of male horseshoe crab spawning activity (IMSA), expressed as the mean number of male crabs per m^2 per night, by state from 1999 to 2012.

Year	Delaware			New Jersey		
	IMSA	90% CI	Beaches Surveyed	IMSA	90% CI	Beaches Surveyed
1999	3.78	2.65, 5.37	8	1.82	1.24, 2.65	9
2000	3.93	2.76, 5.60	11	2.00	1.55, 2.59	11
2001	2.76	2.02, 3.76	12	2.01	1.50, 2.69	10
2002	2.74	2.13, 3.52	13	3.43	2.91, 4.06	10
2003	2.90	2.23, 3.77	13	2.98	2.67, 3.33	10
2004	2.85	2.27, 3.59	13	3.07	2.64, 3.57	12
2005	2.49	1.99, 3.11	13	4.00	3.30, 4.85	12
2006	3.80	3.03, 4.75	13	4.45	3.84, 5.15	11
2007	4.64	3.81, 5.66	13	4.00	3.22, 4.97	11
2008	4.03	3.16, 5.14	13	2.23	1.86, 2.69	12
2009	3.87	3.08, 4.87	13	5.46	4.74, 6.30	13
2010	3.48	2.77, 4.38	13	3.31	2.75, 3.99	12
2011	4.36	3.49, 5.45	13	2.24	1.93, 2.61	12
2012	2.10	1.48, 3.01	13	2.77	2.15, 3.57	12

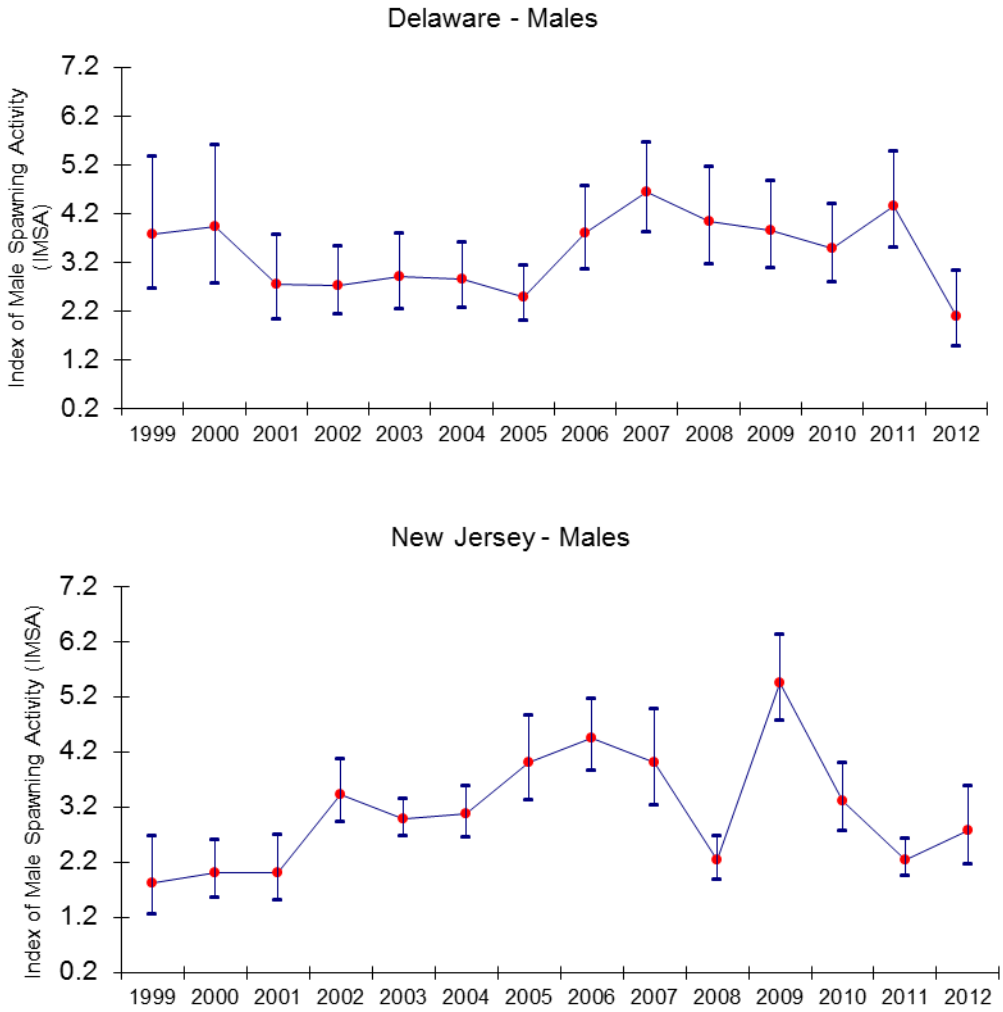


Figure 4. Indices of male horseshoe crab spawning activity (IMSA), expressed as the mean number of male crabs per m^2 per night, for the states of Delaware and New Jersey. Error bars are 90% confidence intervals.

Baywide Spawning Activity - Females

Trends in state-specific female spawning activity were compensatory, as no change in baywide spawning activity was detected (Figure 5; Table 5). The regression slope was close to zero (Slope = -0.01, SE = 0.01, 90% CI = -0.02 to 0.14, P = 0.22). Coefficients of variation were below 14% over the entire survey period and at or below 10% since 2002.

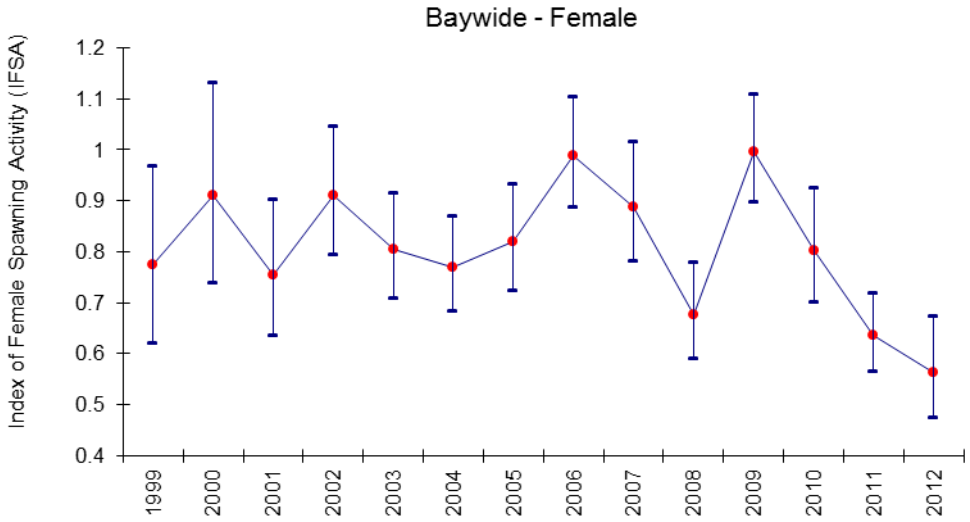


Figure 5. Index of female horseshoe crab spawning activity (IFSA) for the Delaware Bay from 1999 to 2012. Error bars are 90% confidence intervals.

Table 5. Indices of baywide male and female horseshoe crab spawning activity (ISA), number of beaches surveyed, standard errors (SE), coefficient of variations (CV), 90% confidence intervals (CI) and sex ratio for the Delaware Bay from 1999 to 2012.

Year	Beaches Surveyed	Male				Female				Annual Sex Ratio (M:F)
		ISA	90% CI	SE	CV (%)	**ISA**	90% CI	SE	CV (%)	
1999	17	**2.50**	1.86, 3.37	0.45	18	**0.77**	0.62, 0.97	0.10	13	3.2
2000	22	**2.96**	2.31, 3.80	0.45	15	**0.91**	0.74, 1.13	0.12	13	3.2
2001	22	**2.37**	1.91, 2.95	0.31	13	**0.75**	0.63, 0.90	0.08	10	3.1
2002	23	**2.86**	2.45, 3.34	0.27	9	**0.91**	0.79, 1.04	0.07	8	3.1
2003	23	**2.89**	2.50, 3.33	0.25	9	**0.80**	0.71, 0.91	0.06	8	3.6
2004	24	**2.93**	2.55, 3.36	0.24	8	**0.77**	0.68, 0.87	0.06	7	3.8
2005	23	**3.23**	2.79, 3.74	0.29	9	**0.82**	0.72, 0.93	0.07	9	3.9
2006	24	**3.99**	3.49, 4.56	0.33	8	**0.99**	0.89, 1.10	0.07	7	4.0
2007	24	**4.22**	3.63, 4.90	0.38	9	**0.89**	0.78, 1.01	0.07	8	4.7
2008	25	**2.30**	1.83, 2,90	0.32	14	**0.68**	0.59, 0.78	0.06	9	3.4
2009	26	**4.67**	4.11, 5.29	0.36	8	**1.00**	0.89, 1.11	0.06	6	4.7
2010	25	**3.39**	2.93, 3.94	0.31	9	**0.80**	0.70, 0.92	0.07	8	4.2
2011	25	**3.31**	2.83, 3.87	0.31	10	**0.64**	0.57, 0.72	0.05	7	5.2
2012	25	**2.44**	1.97, 3.01	0.31	13	**0.56**	0.47, 0.67	0.06	10	4.4

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 bay-wide male spawning abundance. Male spawning activity increased slightly, though not significantly (Slope = 0.06, SE = 0.05, 90% CI = -0.02 to 0.14, P = 0.23) from 1999 to 2012 (Figure 6; Table 5). Coefficients of variation for the male component of the survey were below 20% for the entire sampling period.

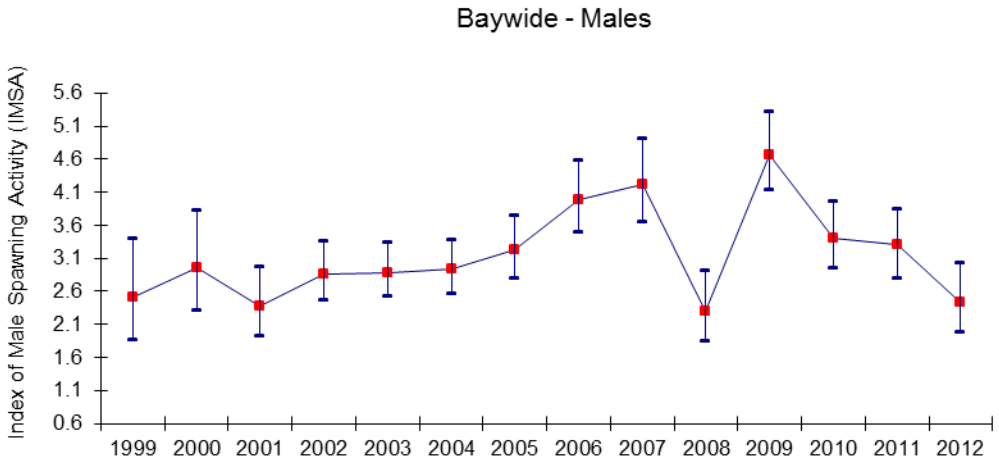


Figure 6. Index of male horseshoe crab spawning activity (IMSA) for the Delaware Bay from 1999 to 2012. Error bars are 90% confidence intervals.

Survey Sex Ratios

Current horseshoe crab harvest management strategies in the Delaware Bay area favor the harvest of male crabs. Concern was expressed that these strategies may cause spawning sex ratios (M:F) to drop and negatively affect spawning and egg fertilization. Annual sex ratio has ranged from 3.1 to 5.2 over the course of the survey and has been ≥4.0 in 5 of the last 6 years (Table 5).

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 7 and Table 6.

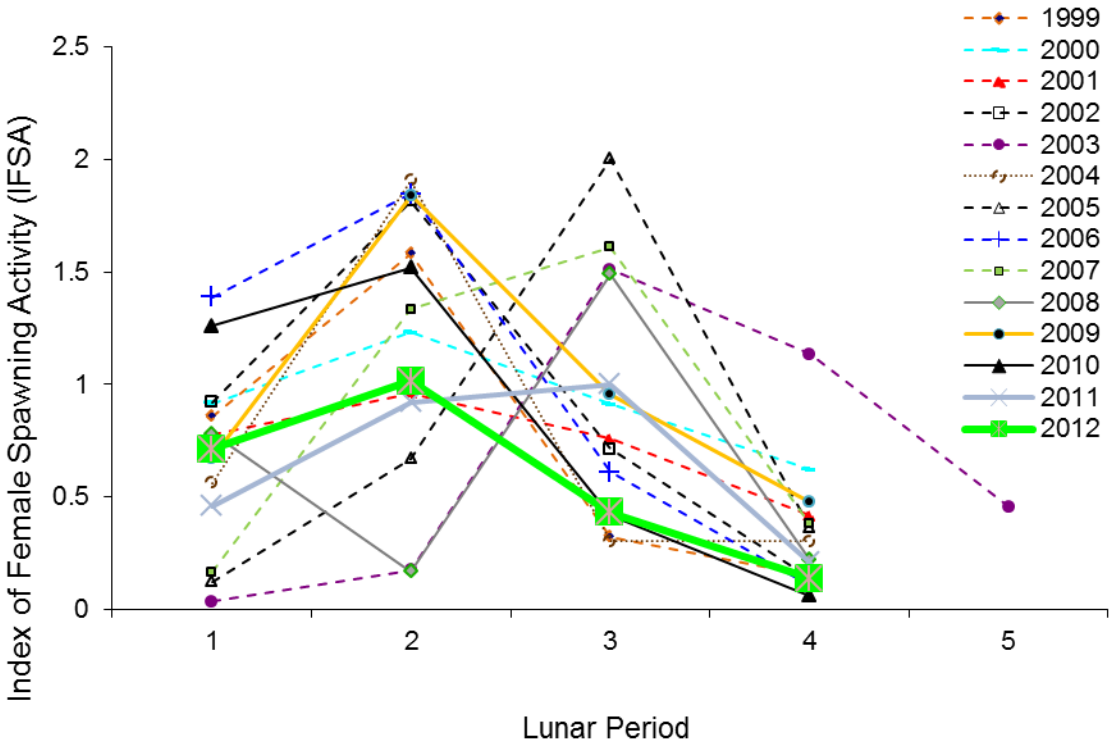


Figure 7. Baywide horseshoe crab spawning activity, expressed as mean number of spawning female crabs per m^2 per night, by lunar period for the years 1999 to 2012.

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 2012.

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	
2009	0.67	1.84	0.96	0.48	
2010	1.26	1.52	0.42	0.06	
2011	0.46	0.92	1.00	0.21	
2012	0.71	1.02	0.43	0.14	

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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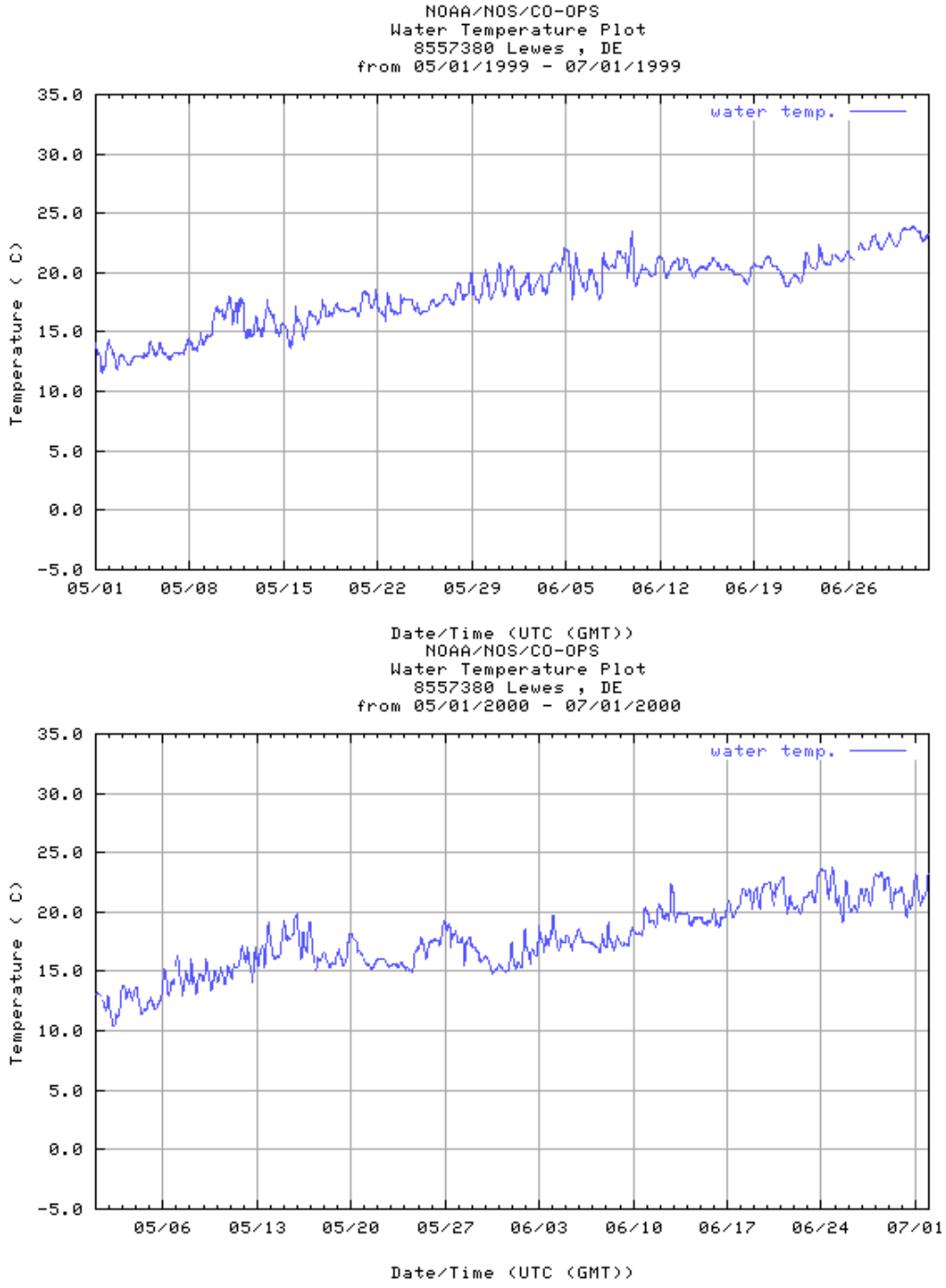
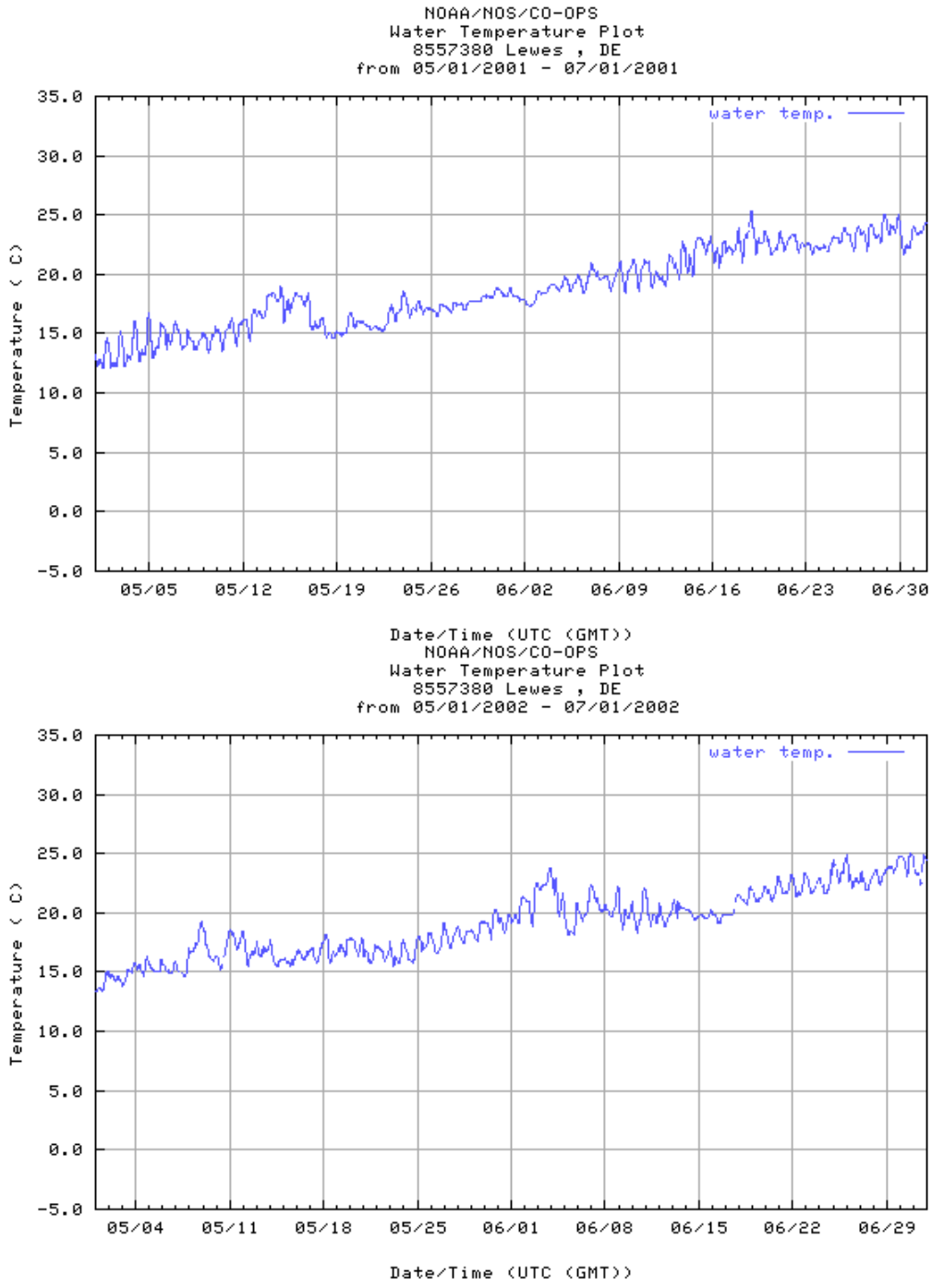
APPENDIX I. Water temperature data from Lewes, DE (Station identification Number 8557380; Latitude 38° 46.9' N / Longitude 75° 7.2' W) for the years 1999 through 2012. Source: Center for Operational Oceanographic Products and Services (CO-OPS).




NOAA/NOS/CO-OPS
Water Temperature Plot
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Water Temperature Plot
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from 05/01/2002 - 07/01/2002
water temp.
Temperature (C)
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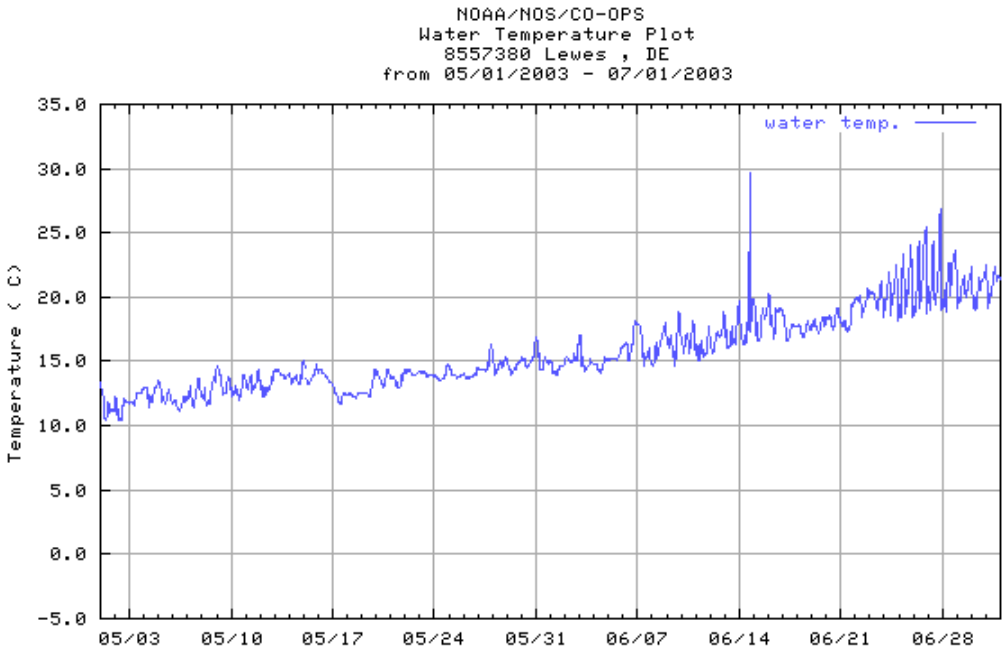
NOAA/NOS/CO-OPS
Water Temperature Plot
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from 05/01/2003 - 07/01/2003
water temp.
Temperature (C)
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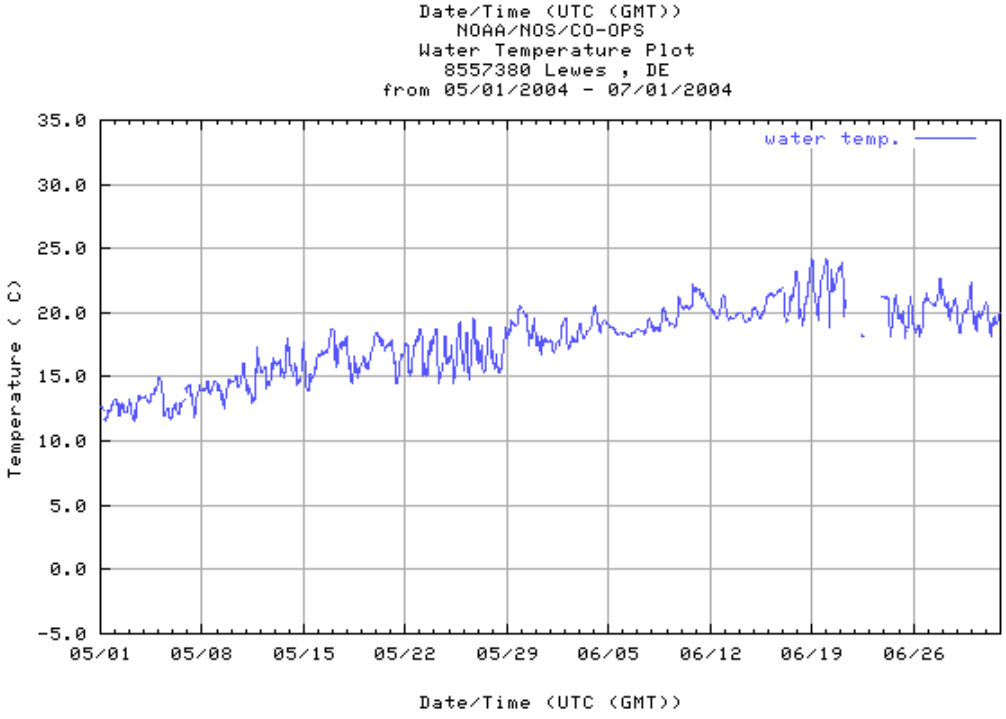
NOAA/NOS/CO-OPS
Water Temperature Plot
8557380 Lewes , DE
from 05/01/2004 - 07/01/2004
water temp.
Temperature (C)
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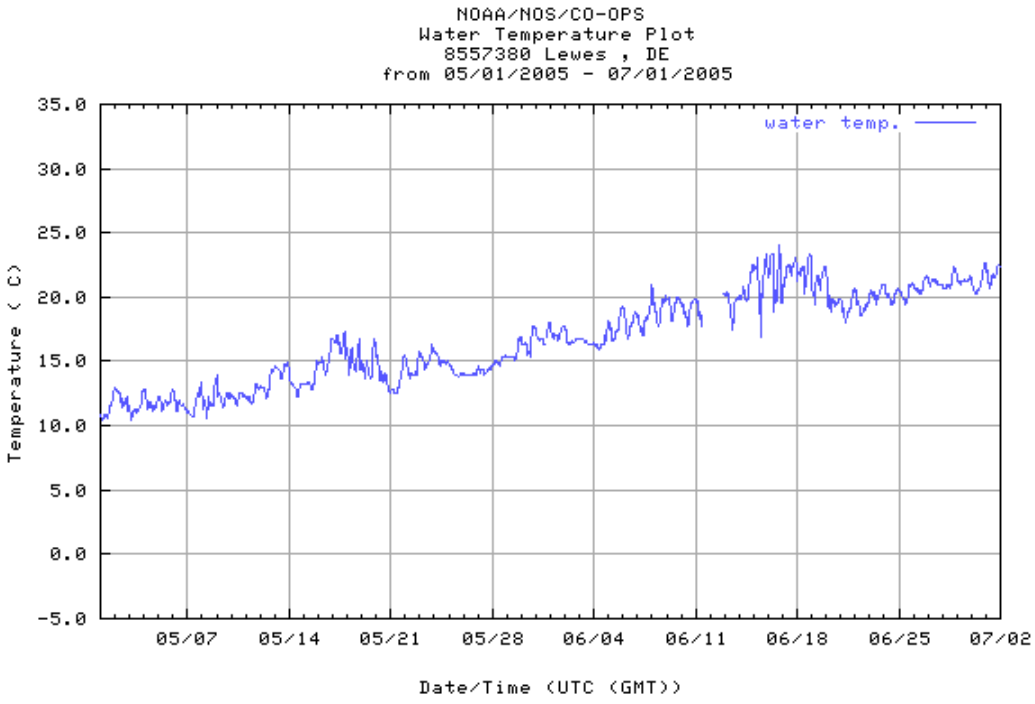
0.0
-5.0
05/01
05/08
05/15
05/22
05/29
06/05
06/12
06/19
06/26
Date/Time (UTC (GMT))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from 05/01/2005 - 07/01/2005
water temp.
Temperature (C)
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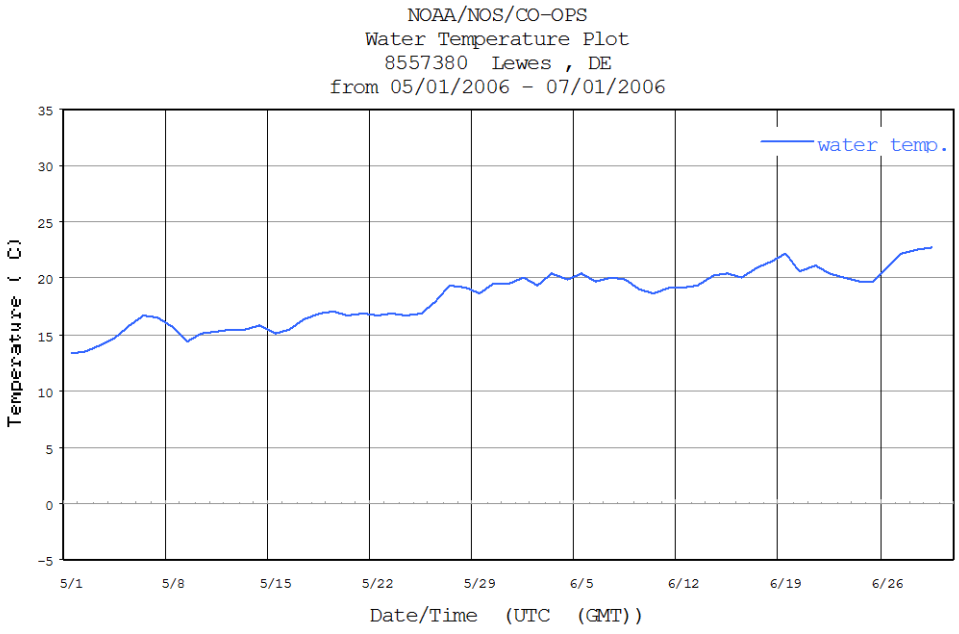
30.0
25.0
20.0
15.0
10.0
5.0
0.0
-5.0
05/07
05/14
05/21
05/28
06/04
06/11
06/18
06/25
07/02
Date/Time (UTC (GMT))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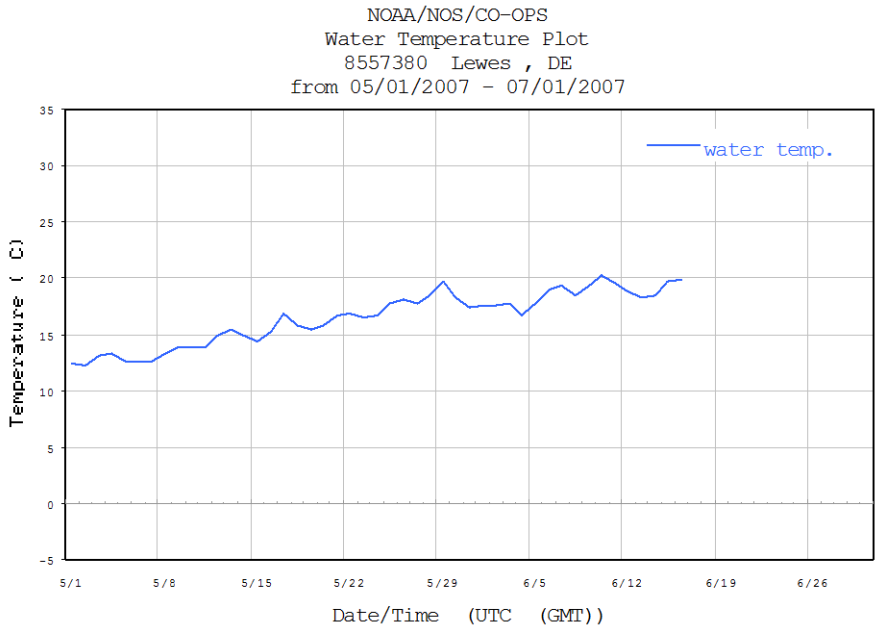
Water Temperature Plot
8557380 Lewes , DE
from 05/01/2006 - 07/01/2006
water temp.
Temperature (C)
35
30
25
20
15
10
5
0
-5
5/1
5/8
5/15
5/22
5/29
6/5
6/12
6/19
6/26
Date/Time (UTC (GMT))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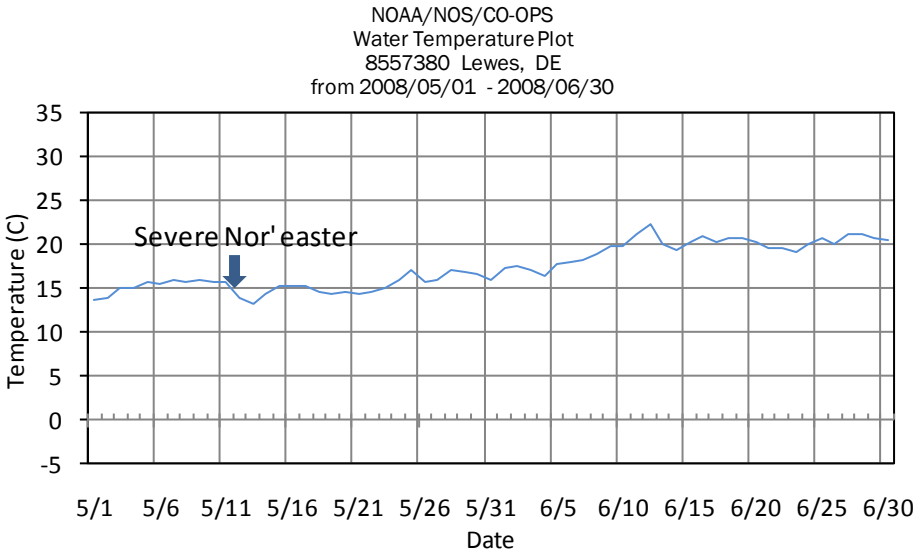
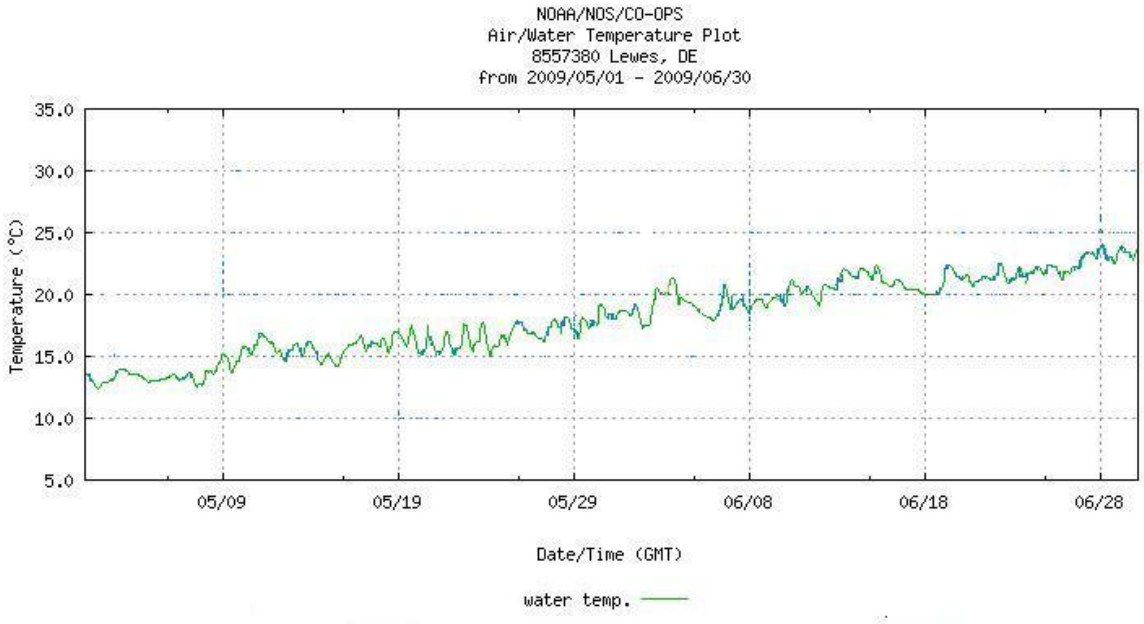
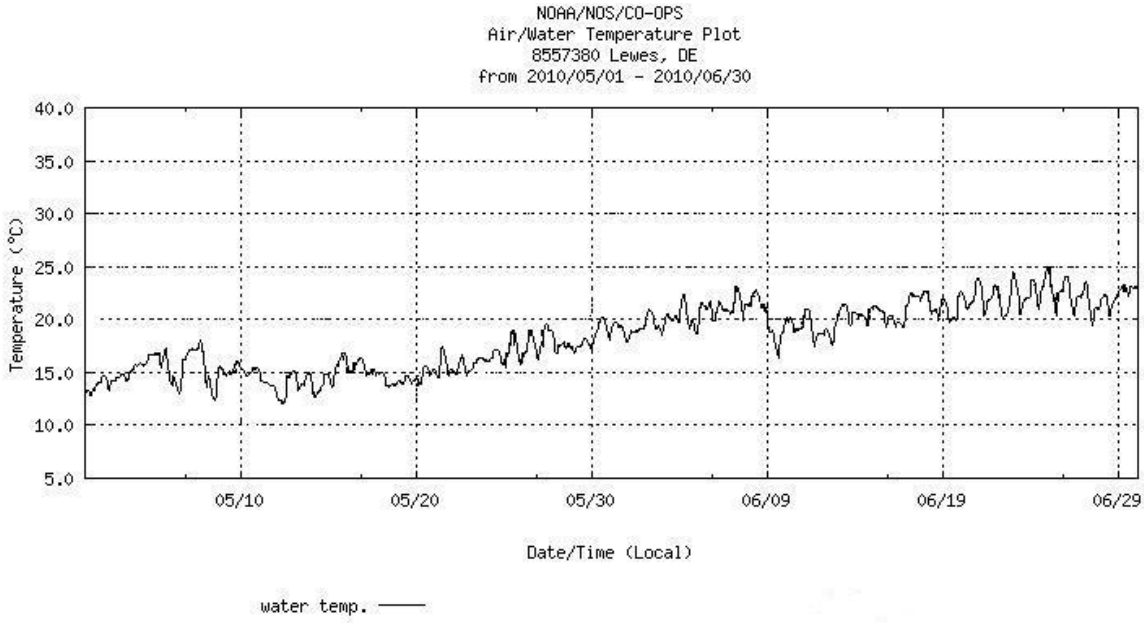
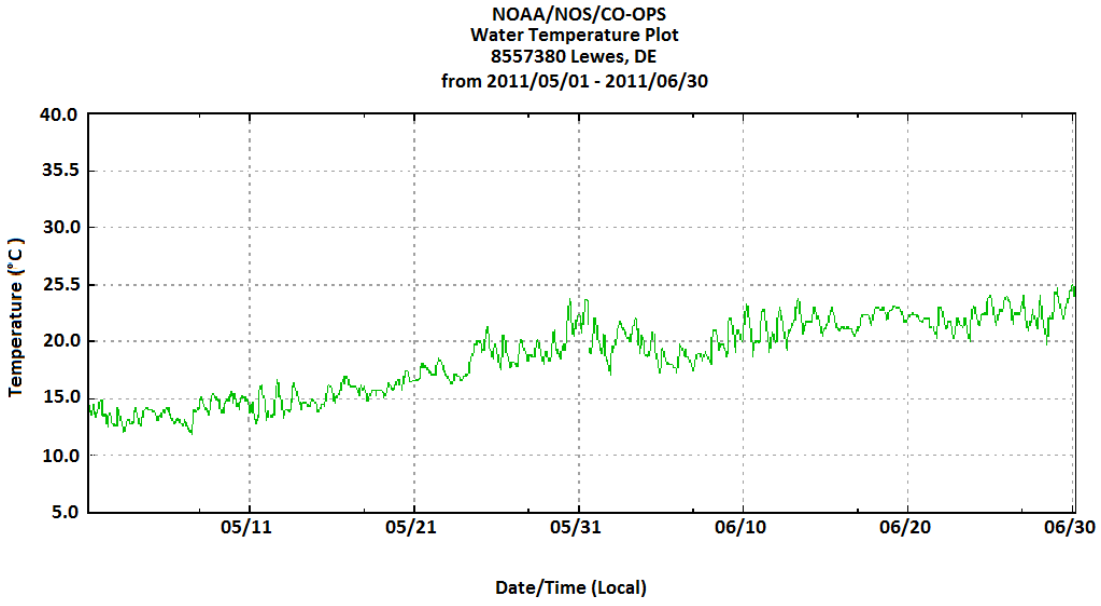
Water Temperature Plot
8557380 Lewes , DE
from 05/01/2007 - 07/01/2007
water temp.
Temperature (C)
35
30
25
20
15
10
5
0
-5
5/1
5/8
5/15
5/22
5/29
6/5
6/12
6/19
6/26
Date/Time (UTC (GMT))


NOAA/NOS/CO-OPS
Water Temperature Plot
8557380 Lewes, DE
from 2008/05/01 - 2008/06/30
Severe Nor'easter
Temperature (C)
35
30
25
20
15
10
5
0
-5
5/1
5/6
5/11
5/16
5/21
5/26
5/31
6/5
6/10
6/15
6/20
6/25
6/30
Date


NOAA/NOS/CO-OPS
Air/Water Temperature Plot
8557380 Lewes, DE
from 2009/05/01 - 2009/06/30
35.0
30.0
25.0
20.0
15.0
10.0
5.0
Temperature (°C)
05/09
05/19
05/29
06/08
06/18
06/28
Date/Time (GMT)
water temp.


NOAA/NOS/CO-OPS
Air/Water Temperature Plot
8557380 Lewes, DE
from 2010/05/01 - 2010/06/30
40.0
35.0
30.0
25.0
20.0
15.0
10.0
5.0
Temperature (°C)
05/10
05/20
05/30
06/09
06/19
06/29
Date/Time (Local)
water temp.


NOAA/NOS/CO-OPS
Water Temperature Plot
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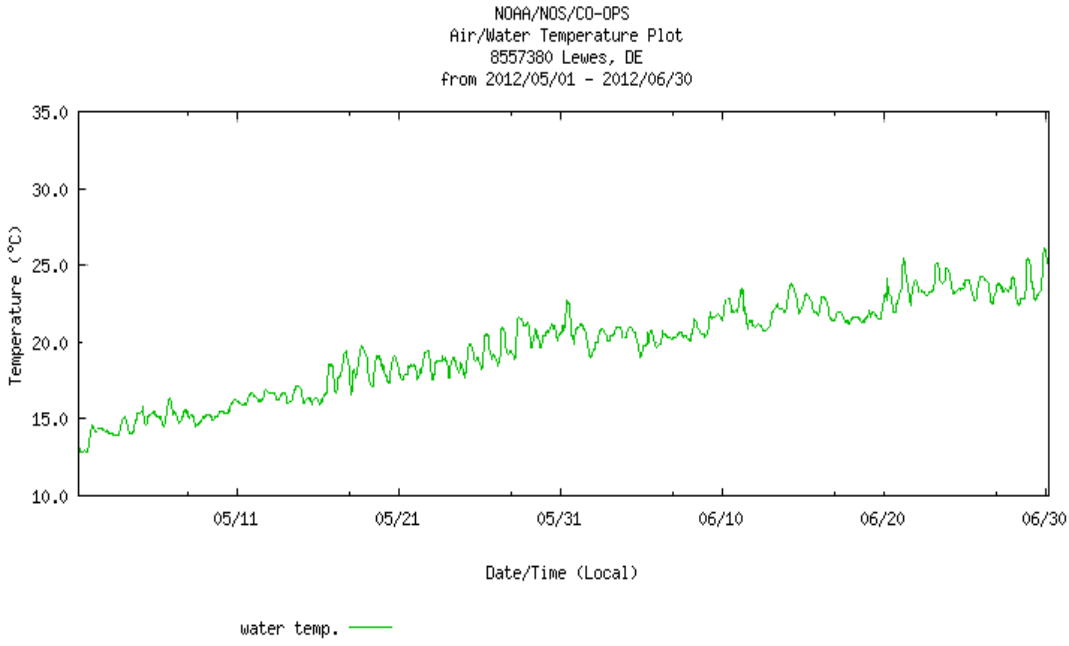
from 2011/05/01 - 2011/06/30
Temperature (°C)
40.0
35.5
30.0
25.5
20.0
15.0
10.0
5.0
05/11
05/21
05/31
06/10
06/20
06/30
Date/Time (Local)
water temp.


NOAA/NOS/CO-OPS
Air/Water Temperature Plot
8557380 Lewes, DE
from 2012/05/01 - 2012/06/30
Temperature (°C)
35.0
30.0
25.0
20.0
15.0
10.0
05/11
05/21
05/31
06/10
06/20
06/30
Date/Time (Local)
water temp.

APPENDIX II. 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 2012.

State	Beach	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
DE	Bennetts Pier		0.22	0.64	0.47	0.28	0.55	0.70	0.61	0.55	0.37	0.64	0.22	0.28	0.32
DE	Big Stone	0.75	0.73	0.86	0.63	0.64	0.76	0.81	1.09	1.35	0.71	0.79	0.67	0.86	0.54
DE	Broadkill	0.32	0.06	0.12	0.13	0.21	0.17	0.19	0.12	0.18	0.55	0.23	0.49	0.57	0.22
DE	Cape Henlopen				0.09	0.18	0.13	0.27	0.10	0.06	0.30	0.26	0.32	0.42	0.30
DE	Fowlers	0.78	0.49	0.70	0.24	0.45	0.61	0.21	0.41	0.50	0.53	0.21	0.42	0.13	0.06
DE	Kitts Hummock	2.15	2.58	2.35	1.47	1.55	1.24	1.42	1.72	1.44	1.23	1.48	1.30	1.27	0.85
DE	Lewes				0.08										
DE	North Bowers	0.88	1.18	1.04	1.21	0.98	0.50	0.60	0.75	1.11	0.36	0.69	0.75	0.49	0.43
DE	Pickering		3.30	1.62	1.70	1.64	1.64	1.47	1.49	1.64	1.99	1.67	1.87	1.14	1.42
DE	Prime Hook	0.60	0.19	0.44	0.59	0.47	0.76	0.65	0.73	1.11	0.92	0.61	0.92	1.03	0.26
DE	Slaughter	1.62	1.33	1.10	0.73	1.65	1.52	0.68	1.04	1.24	1.10	0.72	0.75	1.14	0.47
DE	South Bowers		0.92	0.84	1.13	0.47	0.48	0.63	0.72	1.30	0.57	1.02	0.50	0.58	0.54
DE	Ted Harvey				1.44	1.99	1.52	0.82	1.46	1.93	1.47	1.19	1.34	1.35	1.23
DE	Woodland	0.14	0.10	0.03	0.08	0.01	0.00	0.01	0.27	0.03	0.00	0.02	0.16	0.01	0.08
NJ	East Point		0.35												
NJ	Fortescue	0.25				0.42	0.54	0.58	0.65	0.16	0.33	0.44	0.34	0.34	0.73
NJ	Gandys	0.40	0.39	0.45	1.41	0.55	0.82	0.88	1.17	0.83	0.30	1.31	1.24	0.25	1.50
NJ	Higbees		0.04					0.14			0.03	0.14		0.42	0.06
NJ	Highs Beach	0.79	0.96	0.80	0.47	0.53	0.70	0.76	0.69	0.75	0.46	0.73	0.56	0.61	0.68
NJ	Kimbles	0.71	0.85	0.48	0.50	0.50	0.41					0.82	0.51	0.33	0.93
NJ	Norburys			0.46	0.62	0.54	0.67	0.94	0.69	0.43	0.41	1.14	0.68	0.71	0.78
NJ	North Cape May	0.23	0.05	0.09	0.08	0.12	0.02	0.12	0.02	0.04	0.03	0.08	0.02	0.24	0.03
NJ	Pierces Point		0.61		0.67	0.73	0.96	0.83	0.74	0.94	0.71	1.27	1.11	0.96	1.13
NJ	Raybins	0.03													
NJ	Reeds	0.38	0.65	0.40	0.88	0.82	0.42	0.24	0.97	0.31	0.34	1.07	0.57	0.82	0.86
NJ	Sea Breeze	0.09	0.11	0.30	1.63	0.39	0.43	0.21	0.85	0.93	0.67	0.77	1.02		
NJ	Cape Shore Lab	1.25	1.33	1.28	0.69	0.63	0.90	1.17	0.82	1.26	0.39	1.11	0.79	0.80	1.19
NJ	Sunset			0.11					0.01	0.00	0.01	0.16			
NJ	Townbank			0.74	0.40	0.46	0.20			0.29			0.31	0.39	0.24
NJ	Villas							0.71	0.48		0.34	0.64	0.41	0.53	0.24

Appendix III. Expansion of spawning survey to the April 21st lunar event for 2012. Recommendation by the ASMFC Delaware Bay Ecosystem Technical Committee.

Female horseshoe crab spawning has been correlated with water temperature in Delaware Bay with initiation of spawning beginning when water temperatures reach 15° C (Smith and Michels 2006). Early scouting of beaches by state biologists and volunteers in previous years suggested significant spawning events occur during lunar events in late April when water temperatures approach 15° C. In 2012, average daily water temperature in Delaware Bay increased to 15°C by April 15th and remained consistently above thereafter (Figure 1), suggesting spawning would occur before the start of the annual survey (May 3).

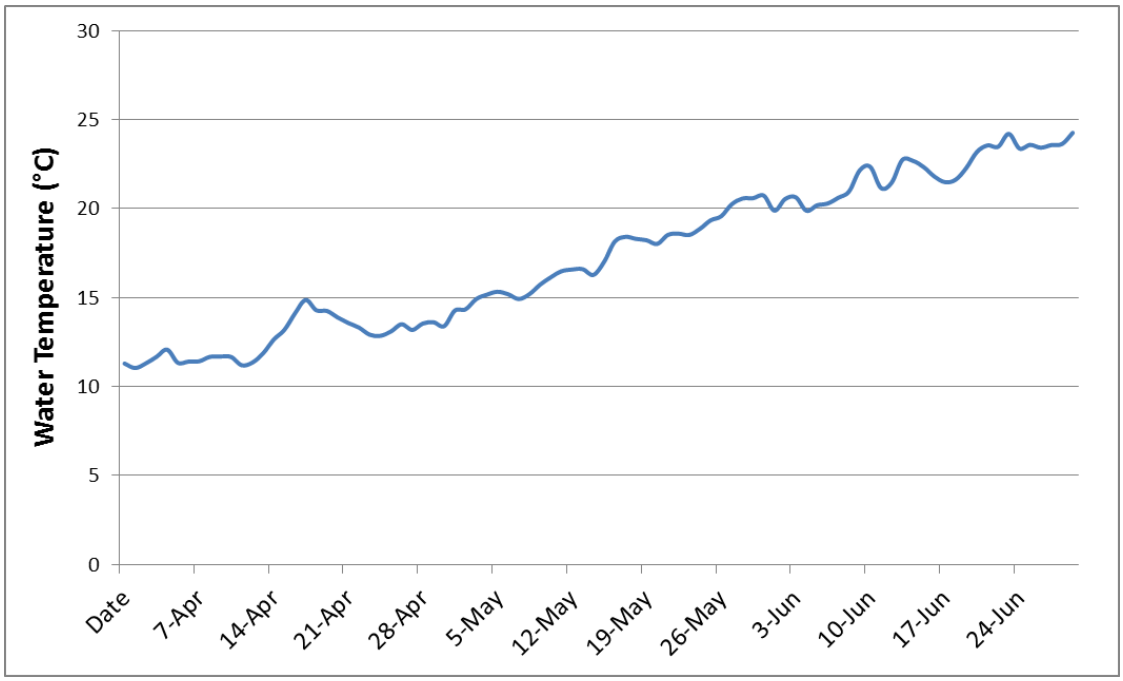


Figure 1. Water temperatures, as recorded by the National Ocean Service at Lewes, DE Station ID 8557380, for 2009-2012 from January 1 to June 10.

Proportion of crabs spawning in May is a key parameter of the Adaptive Resource Management Framework, recently approved for horseshoe crab management for 2013. Migratory shorebirds access eggs on the beach present during their stopover season (generally May). Eggs become available to feeding shorebirds through wave action and disturbance by subsequent spawning horseshoe crabs. To capture this action within the ARM Framework, proportion of the crab population spawning during the migration (month of May) is included as a parameter (McGowan et al. 2011). This value is provided by the annual beach spawning survey. The accuracy of this parameter depends upon sampling the full spawning season and assumes April spawning in negligible.

However, in years when water temperature reaches 15°C in April, it is conceivable that a moderate proportion of the spawning population is not quantified. In such cases, the estimated proportion of female horseshoe crabs spawning in May does not adequately characterize egg resources available to migratory shorebirds, as

females typically deliver their entire annual reproductive output over the course of one lunar period (D. Smith pers. comm.) and would, therefore, not be accounted for in the May sampling.

In an attempt to mitigate this potentially confounding factor, the ASMFC's Delaware Bay Ecosystem Technical Committee suggested expanding the annual spawning survey to include the second lunar period in April at a few select sites in Delaware and New Jersey. Seven beaches in Delaware and 4 in New Jersey were sampled 3 nights in April during the new moon lunar phase (April 19, 21, 23). Twenty-seven of a total of 33 tides were sampled (18 in Delaware, 9 in New Jersey) with 2 cancelled due to no surveyors and 4 cancelled due to weather conditions. Despite the small sample size, appreciable spawning was documented at 5 of the 7 beaches on one or more nights. Pickering beach counts on April 21st summed to 207 female crabs, or an average of 2.07 females per quadrant. The index of bay-wide female spawning activity was calculated as 0.18 for the first lunar period of the 2012 survey (April) which is a higher value than the first lunar period sampled in the years 2003 (0.04) and 2005 (0.12) and the last lunar period (June) in the years 1999 (0.15), 2002 (0.14), 2006 (0.11), 2010 (0.06), and 2012 (0.14) (Table 1).

Table 1. 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 2012. Lunar period 0 denotes the second lunar period in April.

Year	0	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	
2009		0.67	1.84	0.96	0.48	
2010		1.26	1.52	0.42	0.06	
2011		0.46	0.92	1.00	0.21	
2012	0.18	0.71	1.02	0.43	0.14	

When April counts are included in the 2012 analysis, the proportion of female horseshoe crabs spawning during the months of April and May in Delaware and New Jersey is 67 and 93 percent, respectively. However, when April counts are excluded, these proportions drop to 64 and 92 percent (Table 2).

Table 2. Summary statistics reflecting the timing of female horseshoe crab spawning in Delaware and New Jersey and average May water temperatures. Water temperatures were recorded at the National Ocean Service station at Lewes, DE.

	Delaware		New Jersey		
	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	26	15.2
2009	22 May - 26 May	59	22 May - 26 May	66	15.5
2010	12 May - 16 May	82	25 May - 29 May	88	15.6
2011	30 May - 3 June	52	30 May - 3 June	44	16.0
2012	2June - 6 June	64	18 May - 22 May	92	17.8
2012 w/April	2June - 6 June	67	19 May - 22 May	93	17.8

Horseshoe crab spawning varies both temporally and spatially within, and between, years due to abundance and abiotic factors such as water temperature, lunar phase, tide height, wave height, and salinity. The annual horseshoe crab spawning survey in Delaware Bay offers the benefit of being statistically robust as it encompasses a large area and has been conducted over a long time period (14 years). Weather patterns and specific weather events can accelerate or delay spawning activity in any given year, shifting spawning outside of the sampled time frame. It is therefore important to understand these effects when viewing data from a single year.