Horseshoe Crab Spawning Activity in Delaware Bay: 5 years of a standardized and statistically-robust survey

Report to the ASMFC Horseshoe Crab Management Board

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Summary

- 2003 marks the fifth consecutive year that the Delaware Bay Horseshoe Crab Spawning Survey was implemented in a standardized manner throughout Delaware Bay and throughout May and June. Over the past 5 years numerous volunteers and coordinators have worked very hard to implement this survey in a rigorous manner.
- Estimates of spawning activity from this survey have been precise. Coefficient of variation has been below 14% over the past 5 years and below 10% over the past two years.
- Spawning has tended to peak in late-May, although there has been considerable year-to-year variation in the timing of spawning activity. In some years spawning activity has been more uniformly distributed (2000 and 2001), and in other years spawning activity has been more sharply peaked (1999 and 2002).
- Peak spawning in 2003 occurred later and the percent of spawning in May was lower than in previous years. In 2003, there was very little spawning until the end of May, which might have been due to unusually low water temperatures.
- The overall conclusions remain unchanged from last year's report. We conclude that spawning activity in Delaware Bay over the past 5 years has been either stable or declining at a rate less than 8% per year. Spawning activity appears more stable in New Jersey than in Delaware. Patterns of decline in spawning activity on Delaware beaches show up when examining data from beaches individually and when data are summarized statewide.

Introduction

The Atlantic State Marine Fisheries Commission (ASMFC) sponsored a workshop on horseshoe crab surveys in January 1999. The workshop resulted in recommendations for the design and implementation of a statistically valid survey of spawning horseshoe crabs in the mid-Atlantic region. In Delaware Bay, the recommendations were used to redesign the volunteer-based spawning survey that began in 1990. Funds were awarded from the USGS State Partnership Program in 1999, the U.S. Fish and Wildlife Service in 2000, and the Delaware Division of Fish and Wildlife in 2001—2003 to implement the Delaware Bay Horseshoe Crab Spawning Survey. During those years, Ms. Benjie Swan (Limuli Labs) and Dr. Bill Hall (Univ. of Delaware) have been contracted to coordinate the survey.

The Delaware Bay Horseshoe Crab Spawning Survey was designed to accomplish 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 production of *Limulus* amoebocyte lysate (LAL).

With this report, we continue an annual series of statistical reports on the survey. A detailed description and evaluation of the spawning survey design was presented in Smith et al. (2002).

This and previous reports are intended to complement the ongoing series of reports that have been issued by the survey coordinators, Ms. Swan and Dr. Hall in cooperation with Dr. Carl Shuster.

Data availability

Data presented in this report (summarized to the beach level) and the spreadsheets, which show calculations, are available on internet at http://www.lsc.usgs.gov/AEB/2065/ISA_data.asp.

Data from 2003 are still undergoing error checking so analyses based on these data should be considered preliminary.

Summary results

In 2003, 23 beaches were surveyed on as many as 15 tides from April 29th through July 1st. Thirteen of the beaches were in Delaware and 10 were in New Jersey. The number of tides per beach sampled ranged from 9 to 15 (median = 14), and the total number of tides sampled for all beaches was 302.

During the first lunar period April 29th through May 3rd, there was virtually no spawning. There is reason to believe this was due to unseasonably cold water temperatures. Thus, the spawning index was based on the next 4 lunar periods: May 14-18, May 29 – June 2, June 14-18, and June 27 – July 1).

The index of spawning activity calculated for each beach surveyed from 1999 to 2003 is shown in the Appendix I.

Beach-specific spawning activity – Power to detect trends is lowest for beach-specific results. However, based on linear regression there were two beaches where the regression slope was significantly different from zero – that occurred at Woodland beach and Cape Shore Lab where the slopes indicated declines (Figure 1 and Appendix II). The majority of the slopes among Delaware beaches (9 out of 11) were negative (Appendix II). Half of the slopes among New Jersey beaches (5 out of 10) were negative (Appendix II).

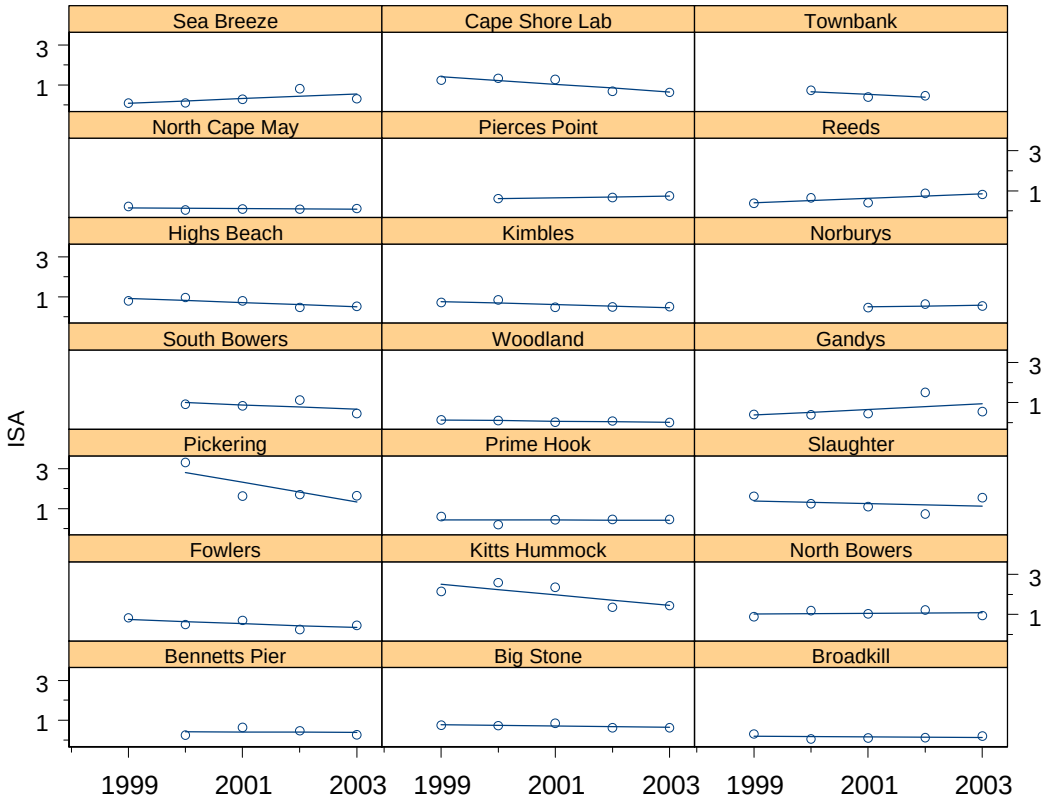

Figure 1. Beach-specific index of spawning activity (ISA) for the 17 beaches that have been surveyed at least 3 years within 1999 to 2003. Line represents results from beach-specific linear regressions. Linear regression results are summarized in Appendix II.

Temporal distribution of spawning

The timing of spawning is important because it affects the forage available to migratory shorebirds. Timing could also affect survival of egg, larvae, and juvenile stages.

In 2003, there was very little spawning during early and mid-May (lunar period 1), peak spawning activity during late May/early June (lunar period 2), and generally higher spawning activity in DE than in NJ (Figure 2 and 3). Peak spawning occurred after May 29th, which was later than in previous years (Table 1). In 1999 and 2002, peak spawning occurred after May 28th in Delaware, but in those years there had been considerable spawning in New Jersey by mid-May (Table 1). In 2001 and 2003, over 50% of the spawning in Delaware occurred in June.

Spawning tends to start earlier in New Jersey than in Delaware, and percent of spawning that occurs in May has been consistently higher in New Jersey than in Delaware (Table 1). However, cumulative spawning through the season tends to be higher in Delaware than in New Jersey. In 4 out of 5 years, the amount of spawning and egg deposition has been higher in Delaware than in New Jersey (Figure 3).

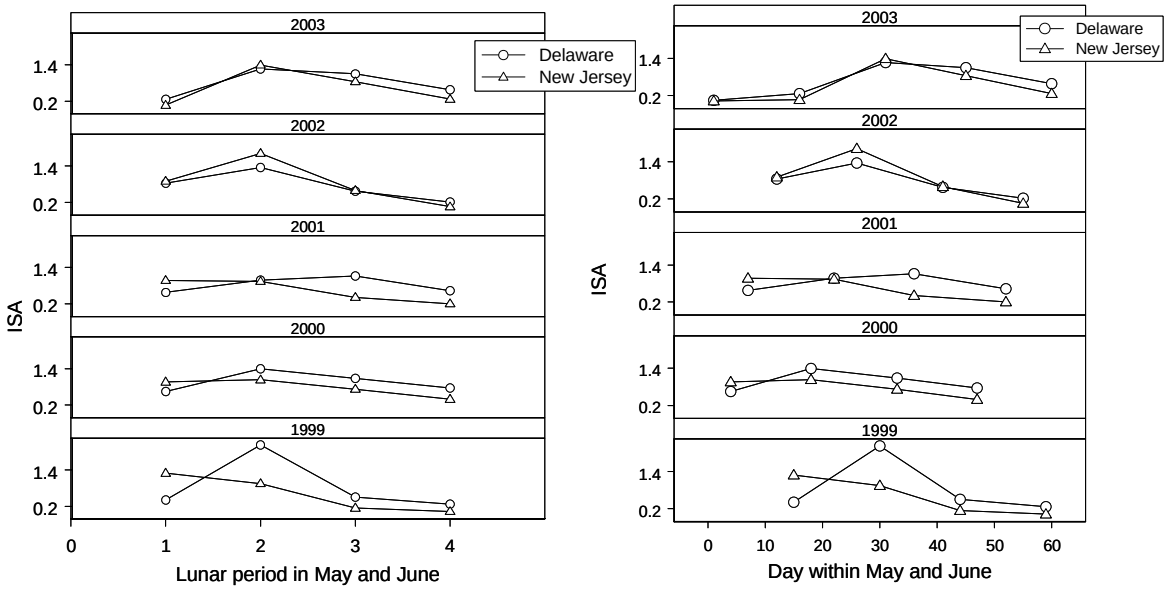

Figure 2. Index of spawning activity for Delaware Bay in May and June for 1999 to 2003. The left graph shows spawning by lunar period: lunar periods 1 and 2 are in May, and lunar periods 3 and 4 are in June. The right graph shows spawning by day within May and June. The index is the number of spawning females within 1 m of high tide line on beach index sites. Surveys were conducted within 3 days of the new or full moons, and these periods were termed 'lunar periods'. The index is shown separately for beaches in Delaware (circles) and New Jersey (triangles).

Table 1. Summary statistics reflecting the timing of horseshoe crab spawning in New Jersey and Delaware. Cumulative spawning is an estimate of the number of nests per 100 m of shoreline.

	New Jersey			Delaware		
	Dates of peak spawning	% of spawning in May	Cumulative spawning by May 31st	Dates of peak spawning	% of spawning in May	Cumulative spawning by May 31st
1999	May 13—17	93	1120	May 28—June 1	77	1316
2000	May 16—18	64	995	May 16—18	53	1021
2001	May 5—9	76	955	June 3—7	47	774
2002	May 24—28	81	1361	May 24—28	73	1092
2003	May 29—June 2	60	742	May 29—June 2	47	796

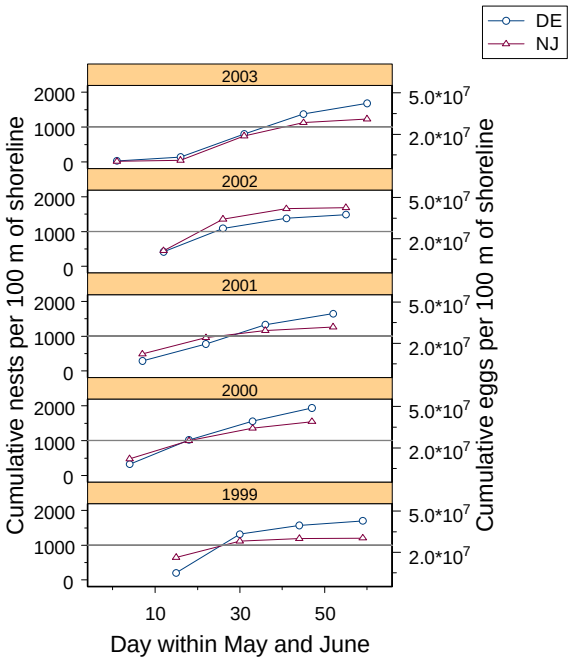

Figure 3. Cumulative amount of spawning across May and June for 1999—2003. A nest represents the spawning activity of one female on one high tide. Cumulative nests represent the accumulation of spawning activity up to a day within May and June. The calculation of 'cumulative eggs' assumes that a female deposits 26,000 eggs per spawn based on 88,000 eggs per female from Shuster and Botton (1985) and on average 3 spawning events per female from Brousseau et al. (in review). Day 10 refers to May 10th, Day 30 refers to May 30th, Day 50 refers to June 19th, and so on.

State-specific spawning activity – Trends in spawning activity over 1999—2003 at the state-level show relative stability in spawning activity and seem somewhat offsetting (Figure 4 and Table 2). Change in spawning activity in New Jersey is slight and positive, although not significantly so (slope = 0.02, SE = 0.040, P = 0.73), and in Delaware the change is negative, although again not significantly so (slope = -0.06, SE = 0.025, P = 0.12).

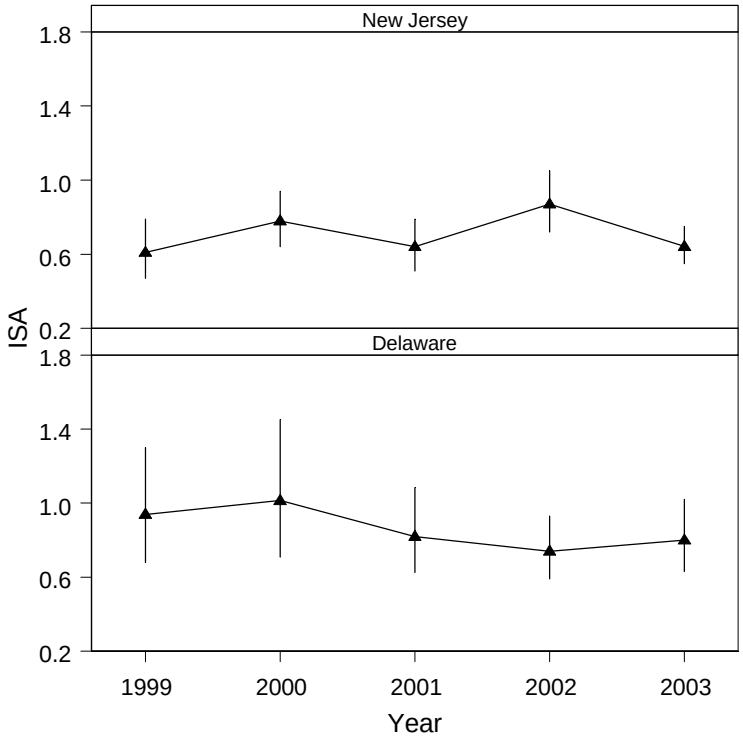

Figure 4. State-specific index of spawning activity (ISA) for New Jersey and Delaware from 1999 to 2003. Vertical bars show 90% confidence intervals.

Table 2. Index of spawning activity (ISA) computed separately for Delaware and New Jersey from 1999 to 2003.

	Delaware			New Jersey		
Year	ISA	90% CI	Beaches surveyed	ISA	90% CI	Beaches surveyed
1999	0.94	0.68, 1.30	8	0.61	0.47, 0.79	9
2000	1.01	0.71, 1.45	11	0.78	0.64, 0.94	11
2001	0.82	0.63, 1.08	12	0.64	0.51, 0.79	10
2002	0.74	0.59, 0.93	13	0.87	0.72, 1.05	10
2003	0.80	0.62, 1.02	13	0.64	0.55, 0.75	10

Baywide spawning activity – The data do not indicate a change in spawning activity at the baywide scale (Figure 5 and Table 3). The regression slope shown in Figure 4B is close to zero (slope = –0.02, SE = 0.023, 90% confidence interval = -0.06 to 0.02). We can be reasonably certain that the slope is not less than –0.06 or greater than 0.02, which are the limits of the 90% confidence interval. On average, the index was 0.8 females per m of shoreline on each night of the survey. Equivalently, on 1 km of shoreline there were, on average, 800 females per night. Based on baywide spawning activity over the past 5 years we can rule out annual declines in excess of 60 females per night along 1 km beach. Another way to express this is that we can rule out changes in excess of 7 to 8% per year or in excess of a 30% decline over 5 years. Because the confidence intervals overlap zero, an increase up to 2.5% per year or 13% over 5 years are is also plausible.

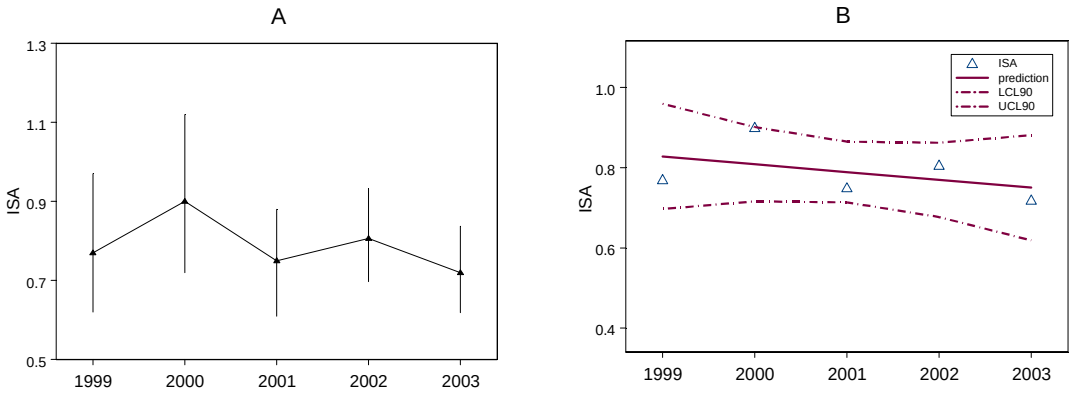

Figure 5. A) Baywide index of spawning activity (ISA) from 1999 to 2003. Vertical bars show 90% confidence intervals. B) Baywide ISA shown as triangles with a fitted regression line (solid line) and 90% confidence intervals (dashed lines).

Table 3. Index of spawning activity (ISA) for the Delaware Bay from 1999 to 2003. Standard error (SE) and 90% confidence intervals are also presented.

Year	ISA	SE	CV (%)	90% CI
1999	0.77	0.105	13.6	0.62, 0.97
2000	0.90	0.119	13.3	0.72, 1.12
2001	0.73	0.081	11.1	0.61, 0.88
2002	0.81	0.071	8.8	0.70, 0.93
2003	0.72	0.067	9.2	0.62, 0.84

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Shuster, Jr., C. N. and M. L. Botton. 1985. A contribution to the biology of the horseshoe crab, *Limulus polyphemus*, in Delaware Bay. Esutaries 4:363-372.

Smith, D. R., P. S. Pooler, B. L. Swan, S. Michels, W. R. Hall, P. 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.

Appendix I. Index of spawning activity (ISA), standard error (SE), and number of tides sampled (n) for beaches surveyed in the Delaware Bay Horseshoe Crab Spawning Survey from 1999 to 2003.

		1999			2000			2001			2002			2003		
State	Beach	ISA	SE	n	ISA	SE	n	ISA	SE	n	ISA	SE	n	ISA	SE	n
DE	Bennetts Pier	.	.	.	0.2515	0.0655	6	0.6399	0.1534	11	0.4713	0.0828	11	0.2754	0.1101	10
	Big Stone	0.7463	0.1635	7	0.7290	0.1633	9	0.8563	0.2085	11	0.6265	0.1873	11	0.6299	0.1362	12
	Broadkill	0.3197	0.0394	12	0.0638	0.0215	11	0.1170	0.0262	11	0.1347	0.0495	11	0.2075	0.0871	10
	Cape Henlopen										0.0857	0.0259	9	0.1816	0.0362	10
	Fowlers	0.828	0.1611	9	0.4933	0.1878	11	0.7033	0.2341	10	0.2370	0.0938	10	0.4487	0.1527	9
	Kitts Hummock	2.1510	0.1887	12	2.5830	0.2164	8	2.3545	0.6702	10	1.3558	0.3885	12	1.4387	0.2824	12
	Lewes	.	.	.	.	.	.	0.0838	0.0748	8						
	North Bowers	0.8806	0.1813	4	1.1819	0.1302	11	1.0383	0.0835	11	1.2225	0.0779	12	0.9448	0.1876	11
	Pickering	.	.	.	3.3047	0.5451	10	1.6244	0.2718	11	1.6992	0.2009	11	1.6417	0.3114	12
	Prime Hook	0.5984	0.0718	6	0.1872	0.0904	8	0.4446	0.1523	11	0.4504	0.1091	11	0.4542	0.1186	12
	Slaughter	1.6190	0.1097	3	1.2338	0.2873	12	1.0963	0.2842	11	0.7270	0.1634	11	1.5533	0.4688	10
	South Bowers	.	.	.	0.9196	0.1214	8	0.8433	0.3693	9	1.1265	0.1071	12	0.4589	0.0973	10
	Ted Harvey										1.4446	0.2408	11	1.9852	0.3369	12
	Woodland	0.1368	0.0494	10	0.1033	0.0339	12	0.0292	0.0124	12	0.0783	0.0327	12	0.0075	0.0120	12
NJ	East Point	.	.	.	0.3458	0.1260	10	.	.	.						
	Fortescue	0.2473	0.0352	11	.	.	.	.	.	.				0.4062	0.0614	12
	Gandys	0.4014	0.0846	11	0.3922	0.1182	12	0.4521	0.141	11	1.5122	0.4343	10	0.5498	0.0963	10
	Higbees	.	.	.	0.0361	0.0159	11	.	.	.						
	Highs Beach	0.7892	0.0884	12	0.9594	0.2162	11	0.7950	0.2616	11	0.4685	0.1595	11	0.5275	0.0845	12
	Kimbles	0.7063	0.0813	11	0.8521	0.1992	9	0.4773	0.0741	11	0.4932	0.0896	11	0.4970	0.0727	11
	Norburys	.	.	.	.	.	.	0.4600	0.1626	10	0.6242	0.4961	10	0.5363	0.0464	6
	North Cape May	0.2250	0.0438	12	0.0500	0.0317	10	0.0904	0.0287	10	0.0845	0.0385	10	0.1233	0.0399	10
	Pierces Point	.	.	.	0.6128	0.1301	8	.	.	.	0.6747	0.2583	10	0.7450	0.2796	10
	Raybins	0.0259	0.0095	9	.	.	.	.	.	.						
	Reeds	0.3808	0.0974	12	0.6468	0.1362	11	0.4049	0.2171	10	0.8768	0.2299	10	0.8225	0.2165	9
	Sea Breeze	0.0947	0.0071	4	0.1039	0.0175	9	0.2842	0.2001	4	0.8142	0.1305	6	0.3100	0.0800	12
	Cape Shore Lab	1.2452	0.1578	12	1.3311	0.2251	12	1.2775	0.1896	12	0.6850	0.1711	11	0.6283	0.0919	12
	Sunset	.	.	.	.	.	.	0.1139	0.0197	11						
	Townbank	.	.	.	0.7363	0.2146	11	0.3958	0.1268	9	0.4589	0.1648	10			

Appendix II. Results from beach-specific linear regression of spawning activity versus year. Only beaches surveyed at least 3 years were included.

State	Beach	Slope	SE	P-value
DE	Bennetts Pier	-0.01	0.0997	0.93
	Big Stone	-0.03	0.0288	0.33
	Broadkill	-0.02	0.0350	0.69
	Fowlers	-0.10	0.0603	0.19
	Kitts Hummock	-0.26	0.1310	0.14
	North Bowers	0.02	0.0530	0.77
	Pickering	-0.49	0.2890	0.23
	Prime Hook	0.00	0.0543	0.97
	Slaughter	-0.06	0.1267	0.65
	South Bowers	-0.11	0.1316	0.49
	Woodland	-0.03	0.0103	0.07
NJ	Cape Shore Lab	-0.19	0.0646	0.06
	Gandys	0.14	0.1548	0.43
	Highs	-0.10	0.0463	0.12
	Kimbles	-0.08	0.0414	0.16
	Norburys	0.04	0.0728	0.69
	North Cape May	-0.02	0.0224	0.50
	Pierces Point	0.04	0.0097	0.14
	Reeds	0.11	0.0538	0.13
	Sea Breeze	0.23	0.0833	0.11
	Townbank	-0.14	0.1165	0.45