Rutgers School of Environmental and Biological Sciences

Grant F. Walton Center for Remote Sensing and Spatial Analysis
Rutgers, The State University of New Jersey
14 College Farm Road
New Brunswick, New Jersey 08901-8551

http://crssa.rutgers.edu

Tel: 732-932-1582
Fax: 732-932-2587

Mapping the Critical Horseshoe Crab Spawning Habitats of Delaware Bay

Richard G. Lathrop Jr.
Larry Niles
Daniel Merchant
Timothy Farrell
Christopher Licitra

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EXECUTIVE SUMMARY

In 2005, the Rutgers Center for Remote Sensing & Spatial Analysis (CRSSA) undertook a systematic survey of Delaware Bayshore beaches to assess their suitability as horseshoe crab spawning habitat. Visual interpretation of high spatial resolution (1 meter or better) color/color infrared digital aerial photography acquired in 2002 was used to map five categories of horseshoe crab spawning habitat suitability: optimal, suitable, less suitable, avoided and disturbed. Given ongoing shoreline erosion in the Delaware Bay region, there was growing concern about the continued availability of prime horseshoe crab spawning habitat. Accordingly, an update with more recent aerial photography (i.e. from 2010-2011) and, in the immediate aftermath of the SuperStormSandy, aerial reconnaissance and sketch mapping was undertaken.

The resulting updated mapping did not reveal major changes in the horseshoe crab spawning suitability of the Delaware Bay shoreline of Delaware and New Jersey between 2002 and 2010. In both cases, approximately 70% of the shoreline did not show a change in habitat suitability. Of the 30% that exhibited a change, some areas showed a decline in mapped habitat suitability, while other areas showed increases in suitability. Overall, there was a slight decrease in mapped habitat suitability with a greater percentage of shoreline experiencing a decline in habitat suitability vs. an increase. Approximately 13% of the Delaware shoreline showing improvement and 18% showing degradation while approximately 11% of the New Jersey shoreline showing improvement and 18% showing

degradation. The post-SuperStorm Sandy mapping suggests that this “extreme” event had a greater negative impact on horseshoe crab spawning habitat than the prior 8 years of “normal” shoreline dynamics. Approximately 30% of the New Jersey Delaware Bay shoreline showed a decline in habitat suitability pre vs. post-Sandy as compared to 18% between 2002 and 2010. Portions of Cumberland and Cape May Countys’ shoreline appear to have been the most heavily impacted by the storm.

INTRODUCTION

Delaware Bay, on the United States Middle Atlantic seaboard, provides essential spawning habitat for horseshoe crabs, *Limulus polyphemus* (Atlantic States Marine Fisheries Commission, 1998). Delaware Bay also serves as critical stopover habitat for migrating shorebirds, especially during the spring migration when it supports some of the highest numbers recorded in the lower 48 states (Clark et al., 1993). Many of these migrants, including the red knot (*Calidris canutus*), rely heavily on the eggs of horseshoe crabs (Myers, 1986; Tsipoura and Burger, 1999; Niles et al., 2008). Because a significant proportion of the Western Hemisphere’s population of red knots, a species in decline and in consideration for protection as a US federally listed Threatened species, moves through Delaware Bay during the spring migration, this area is of international conservation concern.

Delaware Bay is fringed by extensive coastal marshes and mudflats that are typically fronted by a sandy barrier beach and backed by low dunes (Phillips, 1987). The sandy barrier beaches overlay marsh sediments (generally a fibrous peat formed by the root mat of the marsh plants) and vary in thickness from a thin veneer to about 2 m thick (Phillips, 1986). The Delaware Bay shoreline is very dynamic with active erosion and overwash (Phillips, 1986b). The intertidal portions of these sandy barrier beaches are of special significance as these are the locus of the horseshoe crab spawning activity and the shorebirds’ foraging activities. Beach areas that provide spawning habitat are considered essential habitats for adult horseshoe crabs. Horseshoe crabs appear to prefer beaches dominated by coarse sandy sediments and avoid beaches that have a high amount of peaty sediments or are adjacent to exposed peat banks (Botton et al., 1988). Based on some of these factors, Botton et al. (1988) developed a classification scheme that ranked beaches as either preferred or avoided habitat for horseshoe crab spawning. The Atlantic States Marine Fisheries Commission (1998) concluded that optimal spawning beaches may be a limiting reproductive factor for the horseshoe crab population.

Horseshoe crabs deposit most of their eggs 10-20cm deep in the sandy beach sediments (Botton et al., 1992); eggs are then redistributed to shallower depths by subsequent spawning and wave action where they are then available for shorebird foraging. Starting in 1999, systematic surveys were conducted to count intertidal (i.e., spawning) horseshoe crabs and their deposited eggs throughout Delaware Bay and quantified as an Index of Spawning Activity or ISA (Smith et al., 2002a; 2002b; Nichols, 2005). These surveys documented that horseshoe crab egg density varies by several orders of magnitude with densities sometimes exceeding 10^6/m of shoreline (Smith et al., 2002b). Smith et al.

(2002b) found that beach morphology and wave energy interacted with density of spawning females to explain variation in the density and distribution of eggs and larvae between the study beaches. Horseshoe crabs appeared to prefer narrow, low-energy (i.e., wave-protected) sandy beaches. While the surveys only sampled bay-front beaches, beaches along tidal creeks were also noted as being potential hotspots for horseshoe crab spawning and shorebird foraging. At a broader bay-wide scale, the use of intertidal beaches as horseshoe crab spawning habitat is limited in the north (i.e., Sea Breeze in NJ and Woodland Beach in DE) by low salinity and by ocean generated energy in the south (i.e., North Cape May, NJ and Broadkill, DE).

Not surprisingly, migratory shorebird abundance is spatially variable within the Delaware Bay estuary as a consequence of these larger bay-wide patterns of horseshoe crab abundance and spawning activity. In their study of site selection of migratory shorebirds in Delaware Bay, Botton et al. (1994) found that migrant shorebirds, including red knots, showed a strong preference for beaches with higher numbers of crab eggs. Shorebirds were recorded to aggregate near shoreline discontinuities, such as salt marsh creek deltas and jetties, that acted as concentration mechanisms for passively drifting eggs. Foraging and roosting shorebirds also react to human disturbance and are often displaced from prime foraging areas (Burger, 1986 Erwin, 1996). Thus near-shore development or high human use may lower a beach's value as optimal shorebird foraging habitat. These various studies suggest that a complex array of factors determine the optimality of particular Delaware Bay beaches as horseshoe crab spawning and shorebird foraging habitat.

A Fishery Management Plan (FMP) for Horseshoe Crab (*Limulus polyphemus*), was approved and adopted by the Atlantic States Marine Fisheries Commission on October 22, 1998. The goal of the FMP is to conserve and protect the horseshoe crab resource to maintain sustainable levels of spawning stock biomass to ensure its continued role in the ecology of coastal ecosystems, while providing for continued use over time. The FMP contains a monitoring program that includes continuing existing benthic sampling programs, establishing pilot programs to survey spawning horseshoe crabs and egg density, evaluating post-release mortality of horseshoe crabs used by the biomedical industry, and identifying potential horseshoe crab habitat in each state.

In 2005, the Rutgers Center for Remote Sensing & Spatial Analysis (CRSSA) in collaboration with the American Littoral Society initiated the Delaware Bayshore Horseshoe Crab Spawning Habitat Mapping Project (http://www.crssa.rutgers.edu/projects/coastal/hcrab/index.html. As part of this project CRSSA undertook a systematic survey of Delaware Bayshore beaches to assess their suitability as horseshoe crab spawning habitat (Lathrop et al., 2006). Visual interpretation of high spatial resolution (1 meter or better) color/color infrared digital aerial photography acquired in 2002 was used to map several categories of information that are relevant to the Bayshore's value as horseshoe crab spawning habitat: 1) beach type and width; 2) near-shore development; and 3) shoreline stabilization structures. Based on the remotely sensed assessment, the Bayshore's beaches were classified into five categories of horseshoe crab spawning habitat suitability: optimal, suitable, less suitable, avoided and disturbed. Approximately 45% and 21% of Delaware's and New Jersey's Delaware Bay shoreline, respectively, was classified as optimal or suitable spawning habitat.

Given ongoing shoreline erosion in the Delaware Bay region, there was growing concern about the continued availability of prime horseshoe crab spawning habitat. Accordingly, an update of the 2002 Delaware Bayshore Horseshoe Crab Spawning Habitat Mapping survey of horseshoe crab habitat with more recent aerial photography (i.e. from 2010-2011) was undertaken. In the interim SuperStorm Sandy hit the Delaware Bay region and further exacerbated coastal erosion and beach loss. In the immediate aftermath of the storm, aerial reconnaissance and sketch mapping was undertaken to assess the storm's damage. The objective of this report is to assess the change in the availability of horseshoe crab spawning habitat in the Delaware Bay region from the time period before and after SuperStorm Sandy.

MATERIALS and METHODS

Study Area

The Study Area included most of the Delaware Bay shoreline of Kent and Sussex counties on the Delaware side and Cumberland and Cape May counties on the New Jersey side (Figure 1).

Mapping

Using on-screen visual interpretation of high spatial resolution color infrared digital aerial photography acquired in 2010, several categories of information that are relevant to the Bayshore's value as horseshoe crab spawning habitat were mapped: 1) beach type and width; 2) near-shore development; and 3) shoreline stabilization structures. All mapping was performed in ArcGIS 10.1 through on-screen editing, at a scale of 1:1000. Delaware imagery consisted of springtime 2007 aerial color ortho-photography in MrSid format with a ground cell resolution of 0.25 meters (http://datamil.delaware.gov/wmsconnector/com.esri.wms.Esrimap/DE_aerial07?). New Jersey imagery was summer-time 2010 aerial color ortho-photography in MrSid format, with a ground cell resolution of 1 meter (http://njwebmap.state.nj.us/njimagery). A majority of the mapping was undertaken by two photo-interpreters: one for New Jersey and one for Delaware. The results were then quality controlled by a third photo-interpreter to ensure consistency between the Delaware and New Jersey results.

Three main land cover categories were recorded into separate fields in the attribute table: 1) Shoreline land cover, 2) Interior-beach land cover, and 3) Adjacent area land cover. The compositions of these three categories dictated the placement of polygons during the digitizing process. When large rivers or inlets were encountered, digitizing proceeded approximately 200 meters upstream on either side. Interior shorelines of major harbors, such as Mispillion Harbor, were not mapped. Back-beach and shoreline beach armor

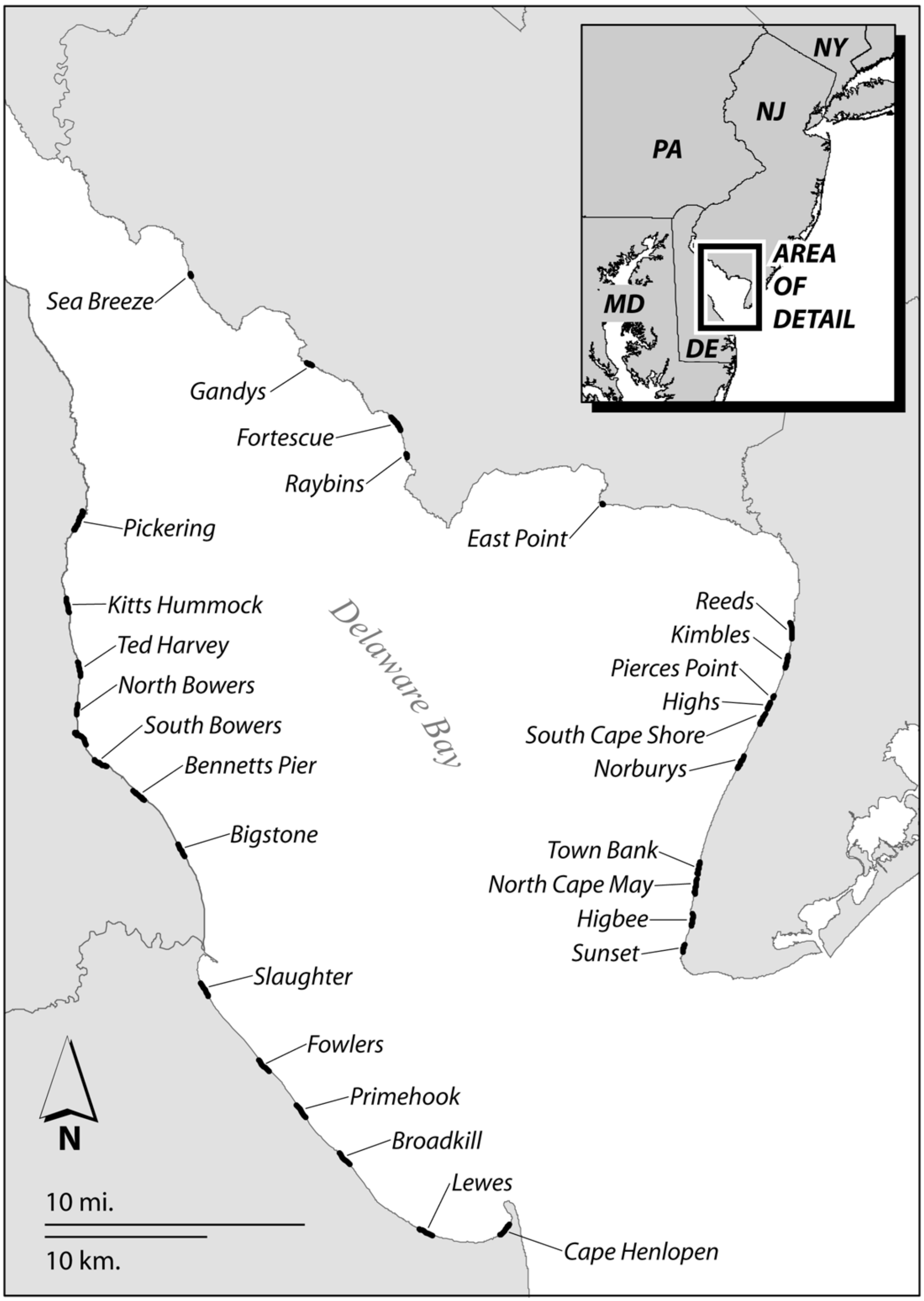

Figure 1. Location of study area with selected beaches as reference.

were delineated separately. Back-beach armor was defined as a hard, immovable structure located directly behind a beach, and shoreline armor as a similar structure located directly against the water. When a pier or jetty was encountered, the armor line was drawn across the base of the structure rather than around its perimeter to prevent exaggeration.

Using the mapped shoreline GIS data, we classified the Delaware Bay shoreline into five categories of horseshoe crab spawning suitability based on criteria proposed by Botton et al. (1988). The five categories were:

1) Optimal: undisturbed sand beach;
2) Suitable: sand beach with only small areas of peat and/or backed by development
3) Less Suitable habitat with exposed peat in the lower and middle intertidal zone and sand present in the upper intertidal (Botton et al's Avoided AB category);
4) Avoided habitat with exposed peat or active salt marsh fringing the shoreline, no sand present (Botton et al's Avoided C category); and
5) Disturbed due to riprap, bulkheading or other beach armoring (Botton et al's Avoided D category).

The 2010 spawning suitability GIS map was then cross-tabulated with the 2002 mapping to characterize the changes. This was accomplished in ArcGIS using the following steps:

- Converted 2010 shoreline file to points (Data Management Tools\Features\Feature Vertices to Points);
- Generated Thiessen polygons from point file (Analysis Tools\Proximity\Create Thiessen Polygons);
- Dissolve Thiessen polygons based on habitat type (Data Management Tools\Generalization\Dissolve);
- Intersect Thiessen polygons with 2002 shoreline polyline files (Analysis Tools\Overlay\Intersect).

The Post-Sandy assessment was taken by aerial reconnaissance. Using the same five categories of spawning suitability habitats (see above) and a global positioning system (GPS) to record geographic coordinate locations, the spotters mapped the start and stop of different habitats along the shoreline. These coordinate locations were then mapped as "bounding box" polygons in ArcGIS. The 2010 spawning suitability GIS data was cross-tabulated with the Post-Sandy GIS data to assess changes related to the storm damage.

RESULTS

Between 2002 and 2010, the percent of horseshoe crab spawning habitat mapped as Optimal and Suitable remained reasonably consistent along the Delaware portion of the Delaware Bay shoreline (when combined, 46.2% vs. 48.7% in 2002 vs. 2010 respectively), while the amount of Less Suitable habitat declined from 32.0 to 20.3%, (Table 1). The Optimal class also showed a lot of loss and gain differences with approximately 27% of the area mapped as Optimal in 2002 mapped as a different class in 2010 (Table 2). This loss was nearly balanced by other areas previously mapped as Less Suitable or Suitable in 2002 which were mapped as Optimal in 2010 (i.e. 72% of the gain was from the 2002 Less Suitable class and 26% from the 2002 Suitable class) (Table 2). The amount of Disturbed and Avoided habitat increased in Delaware (when combined, 21.8% vs. 31.0% in 2002 vs. 2010 respectively) (Table 1). Examination of the change matrix (Table 2) shows that those areas mapped as Avoided or Disturbed in 2002 predominantly stayed as such and the increase in these categories is largely due to the approximately 20% of the Less Suitable class switching to Avoided. Looking at this another way, over 68% of the shoreline did not show a change in habitat suitability, while approximately 13% showed improvement and 18% showed degradation (Table 4). Examination of Figure 2 shows that the areas of improvement and degradation were scattered along the shoreline. One notable area mapped as declining in spawning habitat suitability is in the vicinity of Slaughter Beach.

The percent of horseshoe crab spawning habitat mapped as Optimal and Suitable increased slightly along the New Jersey portion of the Delaware Bay shoreline between 2002 and 2010 (when combined, 20.8% vs. 24.5% in 2002 vs. 2010 respectively), while the amount of Less Suitable habitat declined from 33.8 to 17.9%, (Table 1). The Optimal class showed loss and gain differences with approximately 18% of the area mapped as Optimal in 2002 mapped as a different class in 2010 (Table 3). This loss was more than balanced by other areas previously mapped as Less Suitable or Avoided in 2002 were mapped as Optimal in 2010 (i.e., 61% of the gain was from the 2002 Less Suitable class and 28% from the 2002 Avoided class) (Table 3). The amount of Avoided habitat along the New Jersey shoreline increased greatly (39.8% in 2002 vs. 51.7% in 2010 respectively) (Table 1). Examination of the change matrix (Table 3) shows that those areas mapped Disturbed in 2002 predominantly stayed as such. There was switching of small but significant area from Avoided to a Less Suitable and Optimal class (approximately 9% of the 2002 Avoided area). The Less Suitable class showed the greatest differences with approximately 56% of the mapped 2002 area switching classes in 2010 (Table 3). Approximately 39% of the 2002 Less Suitable class was classed in the Avoided category in 2010. Looking at this another way, over 72% of the shoreline did not show a change in habitat suitability, while approximately 11% showed improvement and 18% showed degradation (Table 4). Examination of Figure 2 shows that the areas of improvement and degradation were scattered along the shoreline. One notable area of improvement in New Jersey is at the southern tip of Cape May and is associated with a major beach replenishment project that was undertaken there.

A reconnaissance survey undertaken in the immediate aftermath of SuperStorm Sandy showed a decline in shoreline area classed as Optimal or Suitable (from over 24% pre-Sandy to approximately 9% post-Sandy) and increase in areas mapped as Less Suitable or Disturbed (from approximately 23% pre-Sandy to 36% post-Sandy) (Table 1). While the overall amount of Avoided area remained relatively unchanged, Table 5 reveals both gain and loss differences. In particular, areas mapped as Less Suitable in 2010 went to Avoided Post Sandy as well as vice versa (Table 5). Approximately 58% of the New

Jersey shoreline did not show a change in mapped category while approximately 11% showed improvement and 30% showed a decline in mapped habitat suitability (Table 6). Examination of Figure 3 shows that a major hotspot of declining spawning habitat suitability was in the along the eastern Cumberland County shoreline (east of East Point) and along the north-central Cape May shoreline (i.e., Reed's Beach to Norburys).

Table 1. Length of Delaware Bay shoreline classed into horseshoe crab spawning habitat suitability for 2002, 2010 and Post-Sandy 2013. Shoreline measured as km and % of individual state total.

	Delaware				New Jersey					
Habitat	2002 (km & %)		2010 (km & %)		2002 (km & %)		2010 (km & %)		Post Sandy (km & %)	
Avoided	16.78	18.39%	22.20	23.81%	58.84	39.82%	85.72	51.67%	88.59	54.92%
Disturbed	3.08	3.40%	6.67	7.15%	8.28	5.60%	9.90	5.97%	17.96	11.13%
Less Suitable	28.98	32.01%	18.93	20.30%	49.88	33.76%	29.69	17.90%	40.21	24.92%
Suitable	10.56	11.66%	12.95	13.89%	5.07	3.43%	9.92	5.98%	5.48	3.40%
Optimal	31.28	34.54%	32.48	34.84%	25.69	17.39%	30.86	18.48%	9.09	5.64%
Total	90.68		93.23		147.76		168.09		161.33	

Table 2. Results of the 2002 vs. 2010 cross-tabulation of shoreline change for Delaware. Note that these figures represent areas mapped in both 2002 and 2010, there was an additional 2.56 km of shoreline mapped in 2010 (not mapped in 2002).

Delaware

(km of shoreline)

		2010 Habitat					
		Avoided	Disturbed	Less Suitable	Suitable	Optimal	**Total**
2002 Habitat	Avoided	14.56	0.27	1.61	0.16	0.17	16.77
	Disturbed	0.35	2.47	0.06	0.18	0.02	3.08
	Less Suitable	6.01	0.85	14.74	1.90	5.48	28.98
	Suitable	0.00	0.78	0.15	7.67	1.96	10.56
	Optimal	1.64	0.14	3.32	3.46	22.73	31.29
	Total	22.56	4.51	19.88	13.37	30.36	**90.68**

Table 3. Results of the 2002 vs. 2010 cross-tabulation of shoreline change for New Jersey. Note that these figures represent areas mapped in both 2002 and 2010, there was an additional 18.09 km of shoreline mapped in 2010 (not mapped in 2002).

New Jersey

(km of shoreline)

		2010 Habitat					
		Avoided	Disturbed	Less Suitable	Suitable	Optimal	**Total**
2002 Habitat	Avoided	53.16	0.42	2.57	0.14	2.55	58.84
	Disturbed	0.31	6.35	0.57	0.65	0.39	8.28
	Less Suitable	19.47	0.40	21.78	2.75	5.48	49.88
	Suitable	0.02	1.09	0.05	3.41	0.51	5.07
	Optimal	0.59	0.66	1.05	2.28	21.12	25.69
	Total	73.55	8.91	26.01	9.23	30.06	**147.76**

Table 4. Compilation of the observed changes between 2002 and 2010 into a relative scale of degrading (declining) and improving (increasing) horseshoe crab spawning habitat suitability. Note that minor change represents the movement of one class, moderate: 2 classes, major: 3 classes and extreme: 4 classes (e.g., from Optimal to Avoided).

Class Changes

(2002 to 2010)

	Delaware		New Jersey	
Change	**Km**	**%**	**Km**	**%**
Extreme Degradation	0.14	0.15	0.66	0.44
Major Degradation	2.42	2.66	1.67	1.13
Moderate Degradation	4.17	4.60	1.47	0.99
Minor Degradation	9.89	10.90	22.22	15.04
No Change	62.18	68.57	105.82	71.61
Minor Improvement	5.82	6.42	6.14	4.15
Moderate Improvement	5.70	6.29	6.19	4.19
Major Improvement	0.35	0.39	3.21	2.17
Extreme Improvement	0.02	0.02	0.39	0.27
Total	90.68		147.76	

Table 5. Results of the 2010 vs. Post-Sandy cross-tabulation of shoreline change for New Jersey. Note that these figures represent areas mapped in both 2010 and 2012, there was an additional 4.55 km of shoreline mapped in 2010 (not mapped in 2012).

New Jersey

(km of shoreline)

		Post Sandy (2012) Habitat					
		Avoided	Disturbed	Less Suitable	Suitable	Optimal	**Total**
2010 Habitat	Avoided	68.82	6.20	9.61	0.60	0.49	85.72
	Disturbed	2.64	4.31	1.29	0.01	0.94	9.19
	Less Suitable	12.13	2.62	13.59	1.11	0.23	29.68
	Suitable	1.49	1.99	4.54	1.04	0.86	9.92
	Optimal	3.51	2.83	11.18	2.72	6.56	26.80
	Total	88.59	17.95	40.21	5.48	9.08	**161.31**

Table 6. Compilation of the observed changes between 2010 and Post-Sandy into a relative scale of degrading (declining) and improving (increasing) horseshoe crab spawning habitat suitability. Note that minor change represents the movement of one class, moderate: 2 classes, major: 3 classes and extreme: 4 classes (e.g., from Optimal to Avoided).

Class Changes

(2010 to Post Sandy 2012)

New Jersey

Change	Km	%
Extreme Degradation	2.83	1.76
Major Degradation	5.50	3.41
Moderate Degradation	15.29	9.48
Minor Degradation	25.59	15.86
No Change	94.32	58.47
Minor Improvement	14.22	8.81
Moderate Improvement	2.12	1.32
Major Improvement	0.51	0.31
Extreme Improvement	0.94	0.58
Total	161.33	

Horseshoe Crab Habitat Suitability
Class change from 2002 to 2010

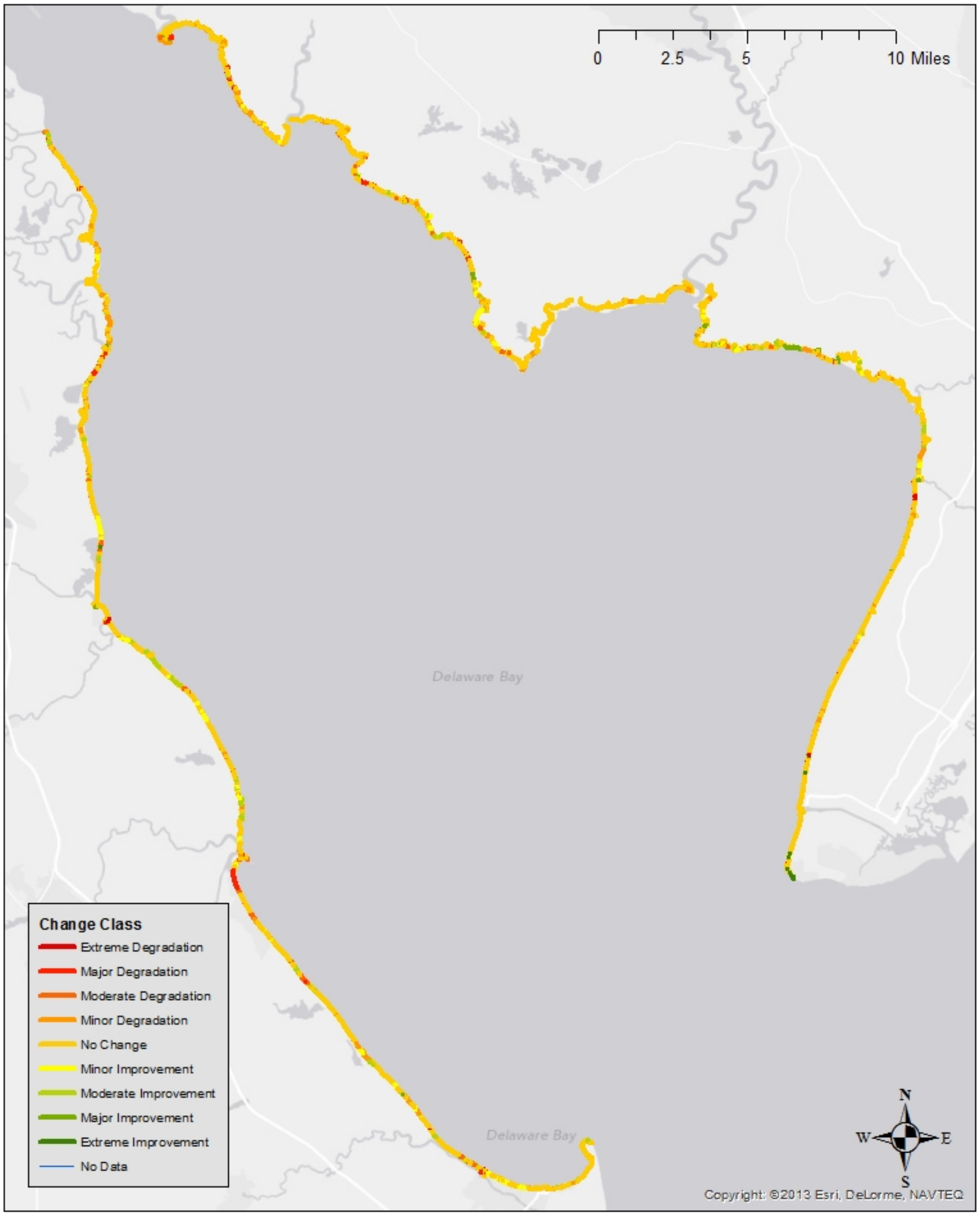

Figure 2. Map of change in horseshoe crab spawning habitat suitability between 2002 and 2010. Note that minor change represents the movement of one class, moderate: 2 classes, major: 3 classes and extreme: 4 classes (e.g., from Optimal to Avoided).

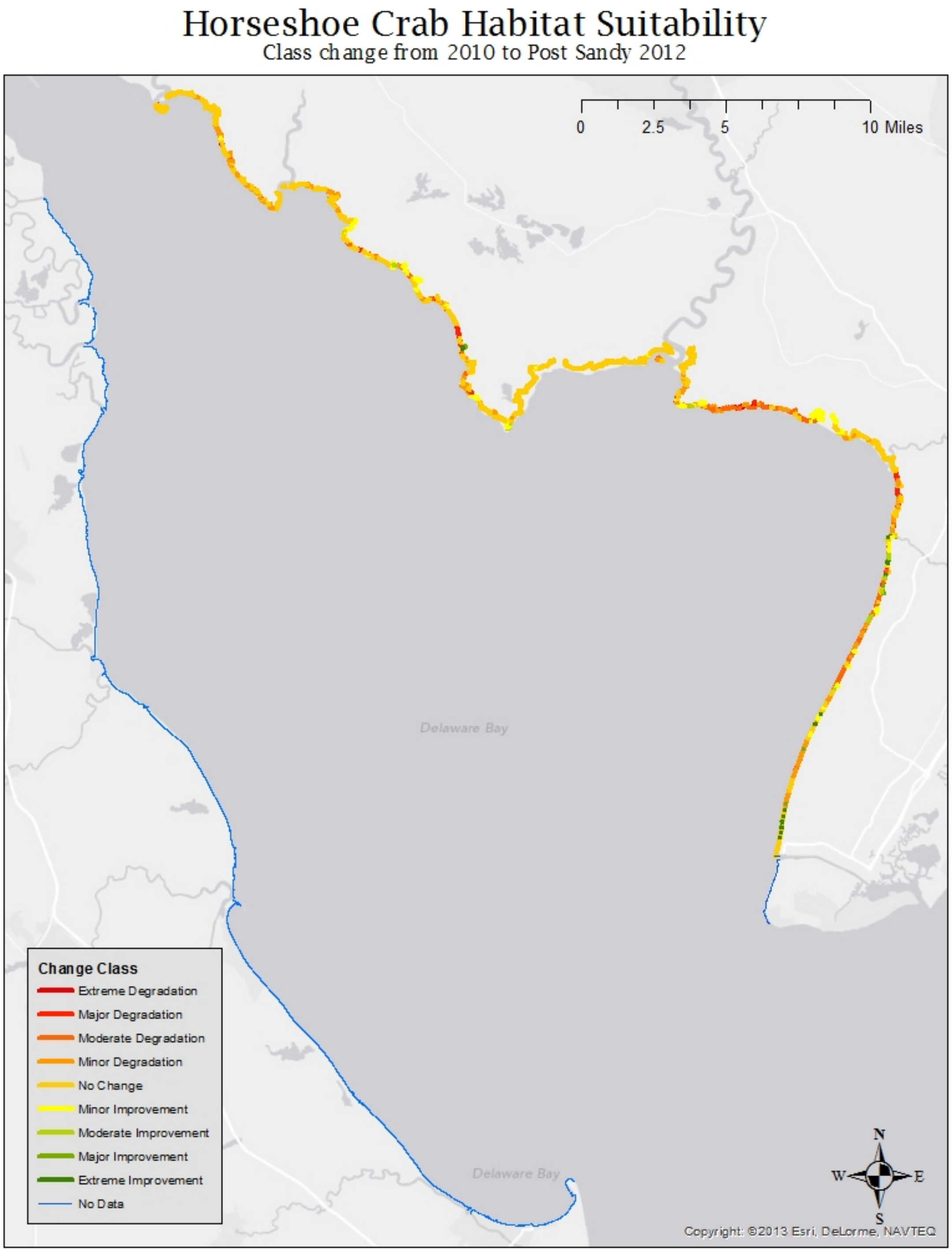

Figure 3. Map of change in horseshoe crab spawning habitat suitability between 2010 (pre-Sandy) and 2012 (post-Sandy). Note that minor change represents the movement of one class, moderate: 2 classes, major: 3 classes and extreme: 4 classes (e.g., from Optimal to Avoided).

DISCUSSION AND CONCLUSIONS

This study did not reveal major changes in the horseshoe crab spawning suitability of the Delaware Bay shoreline of Delaware and New Jersey between 2002 and 2010. In both cases, approximately 70% of the shoreline did not show a change in habitat suitability (Table 4). Of the 30% that exhibited a change, some areas showed a decline in mapped habitat suitability, while other areas showed increases in suitability. Overall, there was a slight decrease in mapped habitat suitability with a greater percentage of shoreline experiencing a decline in habitat suitability vs. an increase. Approximately 13% of the Delaware shoreline showing improvement and 18% showing degradation while approximately 11% of the New Jersey shoreline showing improvement and 18% showing degradation (Table 4).

Direct comparison of the 2002 and 2010 aerial photography shows that many sections of shoreline experienced significant landward erosion (i.e., on the order of meters) and overwash. This was especially true of exposed marsh areas. Delta areas near tidal creek mouths also showed many changes with sand bars eroding, shifting and forming. Some of the new sand bars and spits may serve as highly suitable horseshoe crab spawning habitat, as well as serve as hotspots for shorebird foraging activities. Some known hotspot areas of horseshoe crab spawning (e.g., Mispillion Harbor) were not mapped either in 2002 or 2010 as these occur in “interior” waters.

The post-SuperStorm Sandy mapping suggests that this “extreme” event had a greater negative impact on horseshoe crab spawning habitat than the prior 8 years of “normal” shoreline dynamics. Approximately 30% of the New Jersey Delaware Bay shoreline showed a decline in habitat suitability pre vs. post-Sandy (Table 6) as compared to 18% between 2002 and 2010 (Table 4). Portions of Cumberland and Cape May Countys’ shoreline appear to have been especially heavily impacted (Figure 3). In response to SuperStorm Sandy, during the spring of 2013 an emergency beach replenishment effort was undertaken to restore several key horseshoe crab spawning beaches on the New Jersey Cape May shoreline (Niles, Per. Comm.). Approximately 1500 meters of shoreline between Reed’s Beach and Pierce’s Point and 650 meters at Moore’s Beach were subject to replenishment with tons of trucked-in sand.

While efforts were made to ensure a consistency in the mapping methodology between 2002 and 2010, inevitably some of the observed changes in area may be more an artifact of a change in methodology or photo-interpreter error, rather than a true change on the ground. The amount of potential error was not quantified. It should also be noted that the post-Sandy mapping was more cursory in nature (i.e., recorded by an observer during an aircraft overflight rather than digitized onscreen from rectified aerial photography.

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