Restoration of Horseshoe Crab and Migratory Shorebird Habitat on Five Delaware Bay Beaches Damaged by Superstorm Sandy

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In late October of 2012, Superstorm Sandy battered the Delaware Bayshore. The storm raised the prospect of a catastrophic failure of horseshoe crab breeding and a further erosion of the Bay's migratory shorebird population. Surveys taken shortly after the storm revealed that 70% of New Jersey's horseshoe crab habitat had been wiped away by the fierce winds of Sandy. The future for the horseshoe crabs and the endangered shorebirds that rely on them looked bleak.

But we couldn't let decades of New Jersey-led global advocacy and research be swept away by that rising tide. Our only alternative was daunting: the first-ever restoration of horseshoe crab habitat, along over a mile of Delaware Bay beachfront, in fewer than four months. In short, it was the trifecta: a conservation challenge with a high price tag, an imminent deadline, and few precedents. Failure was a very real possibility.

But thanks to the leadership and passion of the individuals listed here, the beaches ravaged by Superstorm Sandy have not only been restored, but improved. Horseshoe crabs bred in surprisingly high densities this spring. Good numbers of shorebirds arrived in New Jersey from their wintering areas in South America, and left for the Arctic in excellent condition. Red knots, the endangered shorebird species most reliant on horseshoe crab eggs, used our newly restored beaches far more than any others. And the human residents of the Delaware Bayshore can now enjoy these improved beaches for recreation and to attract tourists to help their economies recover.

The shorebird and horseshoe crab season may be over in New Jersey, but our hard work goes on. Our assessments will continue to determine resiliency and to clarify what works best for crabs – ensuring we can do an even better job if and when disaster strikes again.

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Abstract

Superstorm Sandy made landfall in New Jersey on October 29, 2012 and devastated Atlantic Coast communities. This well-publicized catastrophic impact overshadowed the storm's equally damaging effects on the communities and wildlife habitat on Delaware Bay. Strong westerly winds caused a large storm surge that stripped sand from most of the beaches on the New Jersey side of the bay and washed it back into the adjacent marshes, exposing large sections of peat and rubble and leaving the sand well above the normal high tide line.

Surveys conducted immediately following the storm revealed over 70% of the optimal habitat for Atlantic Horseshoe Crabs (*Limulus polyphemus*), which rely on the sandy beaches of the Delaware Bay to lay eggs, had been destroyed. This loss was a potential catastrophe for the Atlantic flyway population of the Red Knot (*Calidris canutus rufa*), a threatened species whose numbers have been closely tied to the availability of horseshoe crab eggs at the Delaware Bay. As the habitat loss would result in a shortage of eggs, Red Knots and other shorebirds would be unable to gain the necessary weight to complete their migrations from wintering areas as far south as Tierra del Fuego to their breeding grounds in the Canadian Arctic. A similar loss of crab spawning in 2003, caused by bad weather, resulted in a dramatic decline in shorebird numbers that have yet to recover. Sandy's impact could have driven populations even lower.

> After Superstorm Sandy destroyed 70% of the horseshoe crab spawning habitat in New Jersey and left the migratory shorebirds that feed on horseshoe crab eggs in jeopardy, a team of scientists, conservation groups, and government agencies had just four months to repair the damage before the birds returned—and they managed to do just that.

To prevent this, a coalition of biologists, conservation groups, and government agencies led an initiative to restore the best beaches for birds and crabs, before the start of the spawning season in May. In less than five months, the team obtained permits, raised over $1.4 million, hired contractors and removed over 800 tons of debris and restored over 1.2 miles of beach with about 40,000 tons of sand. The five restored beaches were intensively monitored following restoration to assess success and to create a firm scientific basis for future restoration projects. The results of those studies form the body of this report.

Equally high abundances of spawning horseshoe crabs and foraging shorebirds were found at both the restored beaches and "control" beaches that had remained undamaged by Superstorm Sandy, while damaged beaches that were not restored featured minimal spawning and foraging. A count conducted near the peak of shorebird abundance on May 27, 2013 showed that significant proportions of three of the four primary species that feed on horseshoe crab eggs during stopover were found on the restored beaches. The abundance of horseshoe crab eggs on restored beaches was similar to that on control beaches at all depths sampled, and egg development rates were also comparable.

One month after construction ended, four of the five beaches had lost some sand, mostly to the mouths of adjacent small tidal creeks, adding sand to existing shoals. Although this loss of sand suggests the need for a better understanding of sand transport patterns to advise future restoration efforts, sand loss to creek mouth shoals still improves crab breeding conditions by expanding potential breeding area. These sub-tidal spawning habitats are vital to crabs and often support some of the highest densities of shorebirds on the bay.

Our project also included experiments using three different arrangements of racks with cultivated oysters to test their impact on wave action thus improving spawning conditions. One method yielded a statistically significant attenuating effect, but much more testing in real conditions are warranted before widespread application is possible.

Keywords: beach restoration, Delaware Bay, Red Knot, *Calidris canutus rufa*, Atlantic Horseshoe Crab, *Limulus polyphemus*

Introduction

Every spring, the Delaware Bay supports the world's largest concentration of breeding Atlantic Horseshoe Crabs (*Limulus polyphemus*). Between late April and early July, the beaches of the Bay will be teeming with these ancient creatures, which crawl onto the shore every night to spawn. An estimated population of 4 million female crabs will lay as many as 80,000 eggs each within the two month breeding period.

These eggs are a critical food resource for hundreds of thousands of migratory shorebirds, which arrive thin and spent after making days-long, nonstop flights from as far away as South America. These shorebirds—including Red Knots (*Calidris canutus*), Ruddy Turnstones (*Arenaria interpres*), and Semipalmated Sandpipers (*Calidris pusilla*)—have just a few short weeks to restore their fat reserves before continuing their migration north to their Arctic breeding grounds. In order to survive the migration and breed successfully, these birds rely on horseshoe crab eggs being plentiful.

> The largest concentration of horseshoe crabs anywhere in the world can be found in the Delaware Bay each spring. But overharvest greatly reduced their numbers in the 1990s, and since then the population has shown no signs of recovery, despite protective measures.

But this resource has dropped drastically in the last two decades. Starting in the 1990s, demand for horseshoe crabs rose dramatically as bait for conch and eel fishermen, and for bleeding for the pharmaceutical industry. The annual harvest of horseshoe crabs, which was fewer than 200,000 crabs in 1990, exploded to over 2 million by 1996. Harvest restrictions have been put in place in most states to stem population declines, but despite these efforts there has been no significant increase in the number of breeding adults in the last decade (Figure 1 and Figure 2).

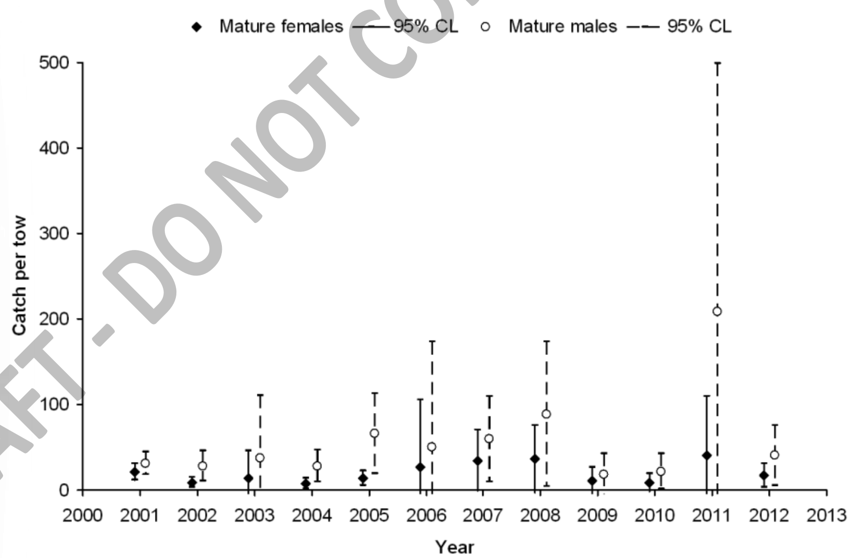

Figure 1. Results of Atlantic wintering areas of horseshoe crabs as estimated by a trawl done 0-3 nautical miles from shore. This area is the core wintering area of horseshoe crabs breeding on Delaware Bay. The graph clearly shows the lack of recovery of female crabs since their decline in the 1990's. A similar lack of recovery is evident in male surveys. Source: Hata and Hallerman 2013.

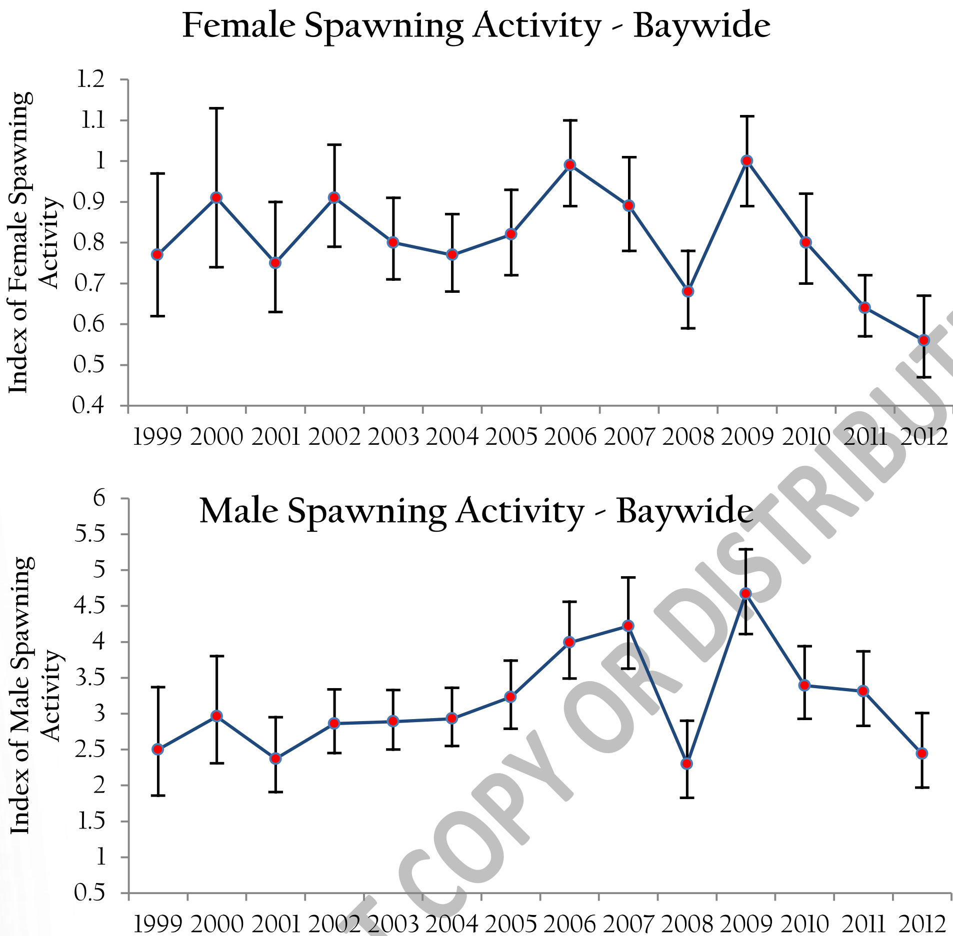

Figure 2. The index of female and male horseshoe crab spawning activity on Delaware Bay beaches for 1999 to 2012 shows no recovery in horseshoe crab numbers since the decline that took place in the 1990s. Error bars are 90% confidence intervals. Source: Zimmerman et al. 2013.

As the horseshoe crab population fell, so did the number of eggs that were available to migratory shorebirds, which depend on them for food. Unable to gain enough weight to successfully migrate, shorebird numbers fell dramatically, and now several species are in danger of extinction if the situation does not improve.

As the horseshoe crab population dwindled, the number of eggs available to shorebirds also fell. Without this critical food resource available, increasingly fewer shorebirds were able to reach the necessary weight before departing for the Arctic (Figure 3), and numbers plummeted. The Red Knot, once numbering close to 100,000 birds during the spring stopover in Delaware Bay, had fallen to a mere 13,000 birds by the mid-2000s (Figure 4). Other shorebird species were similarly affected. Like that of the horseshoe crab, the populations of these shorebirds appear to have stabilized but not increased. Unless horseshoe crab egg densities increase, it seems unlikely that shorebird populations will be able to recover.

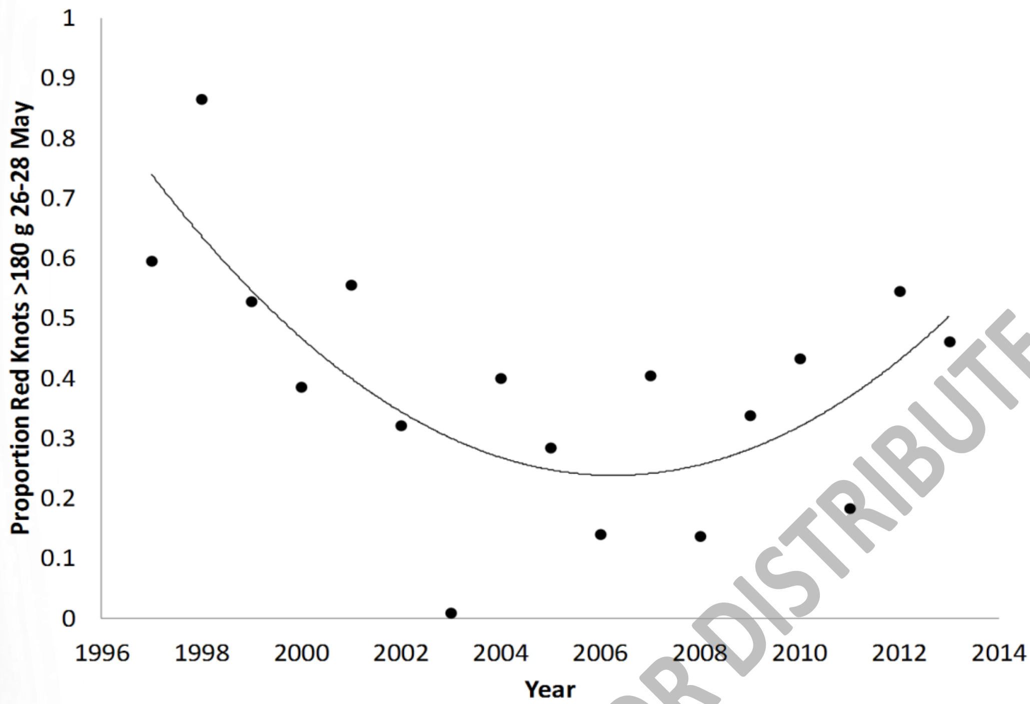

Figure 3. Red knots and other shorebirds depend on horseshoe crab eggs to obtain sufficient weight to fuel their long flight to the Arctic breeding grounds. This graph shows the proportion of Red Knots in the >180 g body-mass category in Delaware Bay during 26-28 May each year since 1996. The graph shows the decline in the proportion of birds making the threshold weight of 180 g until a low of less than 3% in 2003. The lack of recovery in crabs ultimately caused shorebirds numbers to fall until they were in equilibrium with the diminished egg resource. Source: Dey et al. 2013.

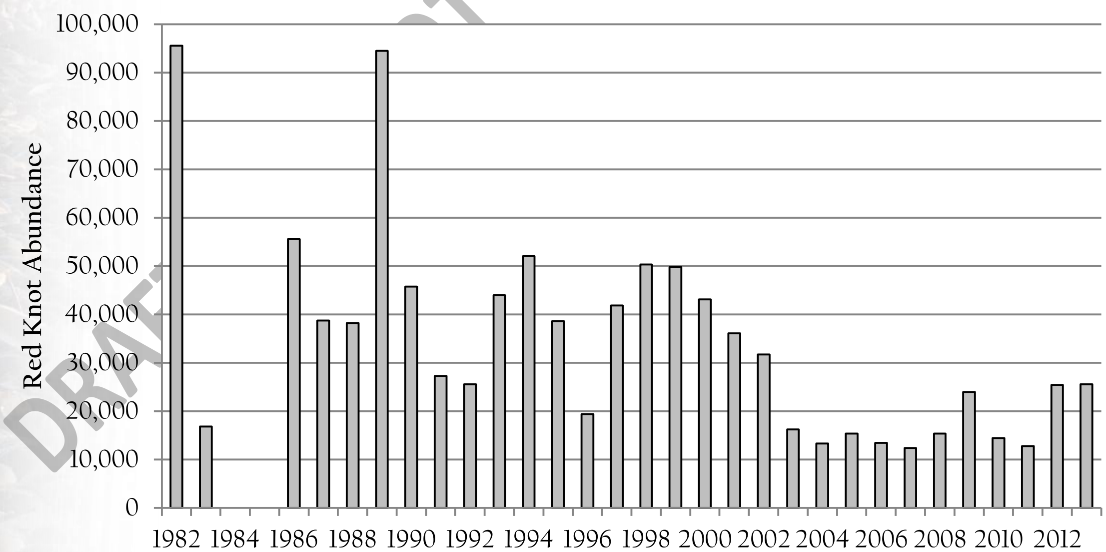

Figure 4. Peak aerial count of Red Knots in Delaware Bay during spring stopover, 1982-2013. Counts in 1982 and 1983 were conducted by New Jersey Audubon; counts from 1986 on were conducted by New Jersey Division of Fish & Wildlife and Delaware Division of Fish & Wildlife. No aerial counts were conducted during the years 1984-1985 or 2009; the value for 2009 is a peak ground count. Sources: Niles et al. 2010 (1982-2006) and Dey et al. 2013 (2007-2013).

Superstorm Sandy and the Aftermath

On October 29, 2012, Superstorm Sandy ravaged the coast of New Jersey. Sandy's tidal surge and waves caused extensive beach erosion along the Delaware Bay shoreline. Sand was stripped from beaches and carried inland onto the adjacent marshes. In many places, the resulting shoreline was severely starved of sand, leaving large salt marsh ledges and blocks protruding from the remaining sand.

This loss of sand on beaches translated to major degradation of horseshoe crab spawning habitat. Inventories of horseshoe crab habitat in the Delaware Bay in 2002 (Figure 5) and again in 2010 indicated that the habitat had changed very little over this time period (Figure 6). However, surveys immediately after Superstorm Sandy (Figure 7) revealed a significant loss of habitat, including an estimated 70 percent decrease in optimal habitat and greater than 20 percent decrease in suitable and less suitable habitat classes. This decline in habitat quality was due to the loss of sand from beaches as a result of Superstorm Sandy and left several prime horseshoe crab spawning beaches in very poor condition.

During the 2000s, the suitability of Delaware Bay's beaches for horseshoe crab breeding remained unchanged, with most prime spawning beaches remaining intact. But Superstorm Sandy destroyed most of the available habitat, causing severe erosion and pushing much of the sand into the adjacent marshes, exposing layers of peat and rubble.

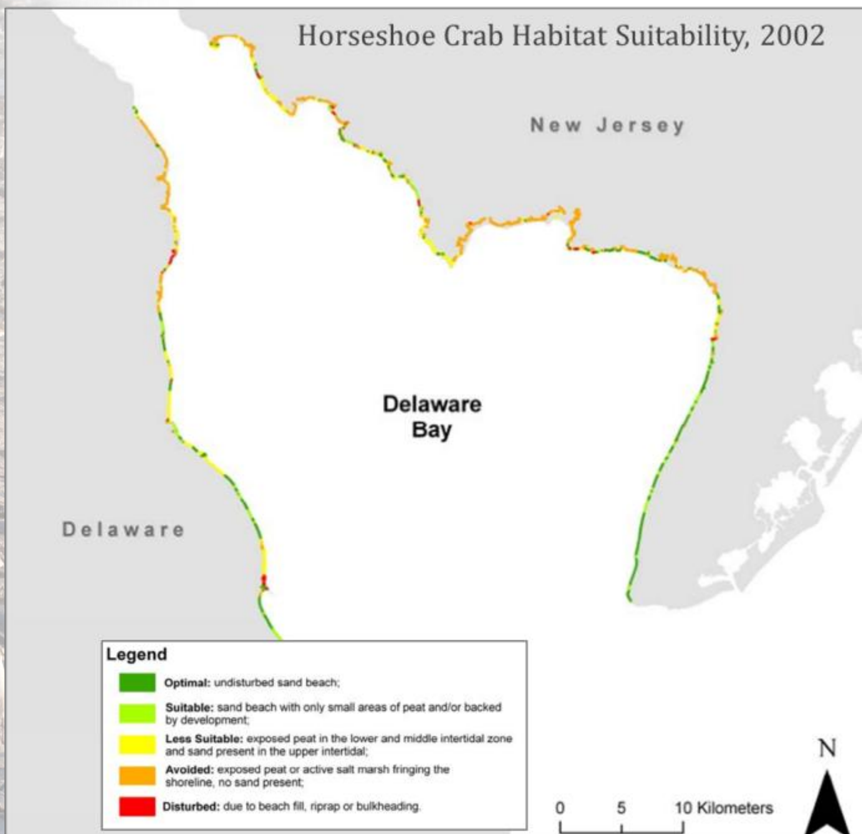

Figure 5. Suitability of habitat for horseshoe crabs in Delaware Bay, 2002.

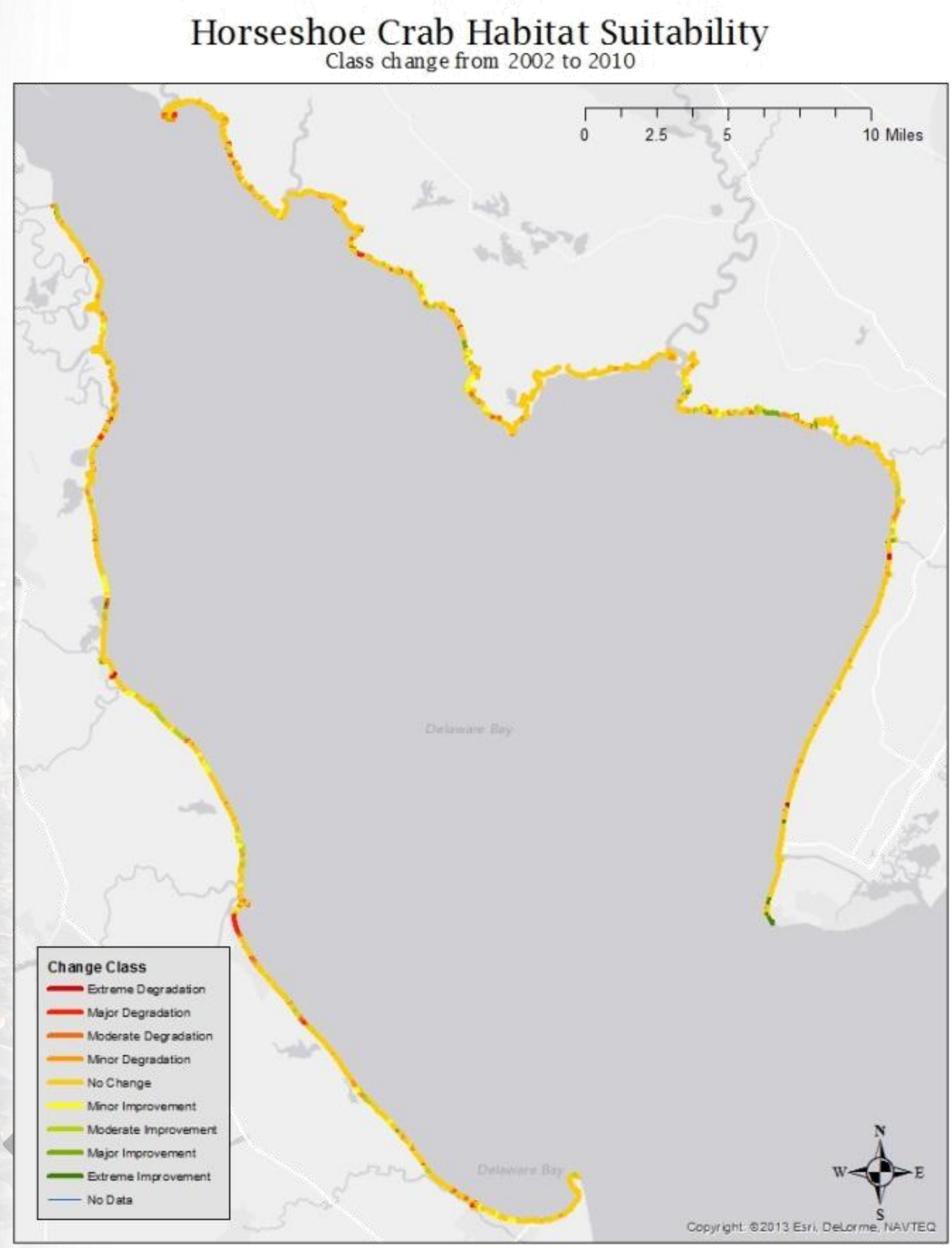

Figure 6. Horseshoe crab habitat suitability class change between 2002 and 2010. Minor change represents the movement of one class (e.g., from Optimal to Suitable), moderate: 2 classes, major: 3 classes and severe: 4 classes (e.g., from Optimal to Avoided)

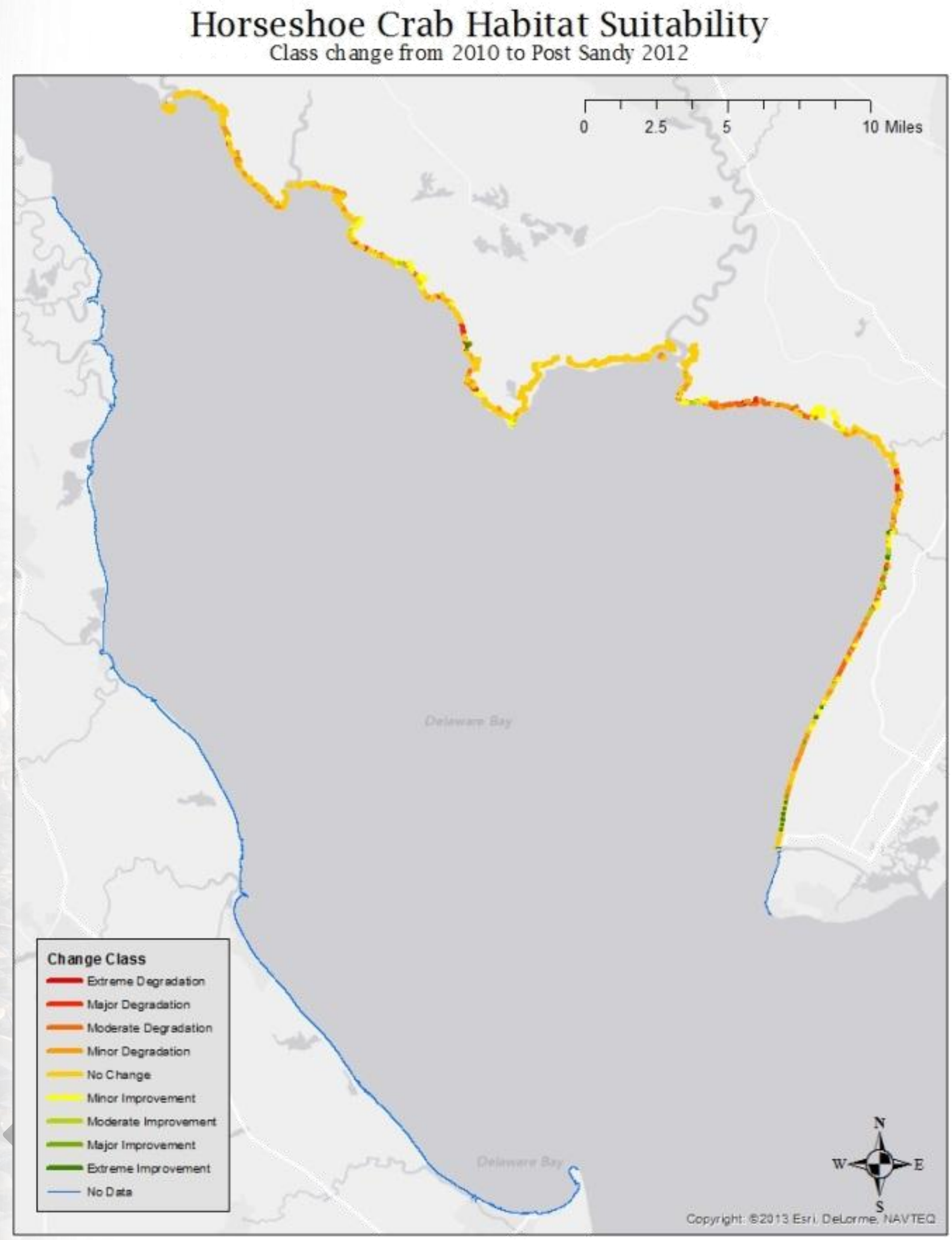

Figure 7. Horseshoe crab habitat suitability class change between 2010 and 2012 after Superstorm Sandy. Minor change represents the movement of one class (e.g., from Optimal to Suitable), moderate: 2 classes, major: 3 classes and severe: 4 classes (e.g., from Optimal to Avoided)

This could have had catastrophic effects on the already-stressed shorebird populations. In 2003, a combination of increased harvest and poor spawning conditions resulted in the greatest single-season drop in red knot numbers, with the number counted in Delaware Bay just slightly more than half of the previous year's count (see Figure 3). It was feared that the reduction in available eggs as a result of Sandy's destruction of the key spawning beaches would have similarly deleterious effects. The shorebirds would be unable to rebuild their weight and would either fail to breed or succumb to the hostile arctic weather. This could have been the final blow to species like the red knot, which is currently endangered in New Jersey, as well as a candidate for listing in the United States and already listed as a threatened species in Canada and other countries.

> Superstorm Sandy's effects meant a potential ecological catastrophe for horseshoe crabs and the shorebirds that rely on them. To repair the damage before the start of the May spawn, the restoration team had just a few months to produce cost estimates, create detailed engineering diagrams, secure the necessary permits, raise funding, hire heavy equipment operators, and finally, rebuild the beaches.

With a potential ecological disaster looming just six months away, a coalition of scientists and consultants from the New Jersey Division of Fish & Wildlife, the American Littoral Society, the Conserve Wildlife Foundation of New Jersey, The Wetlands Institute, and other organizations set out to reconstruct five of the highest-used beaches before the beginning of spawning season the next May. An existing Army Corps of Engineers plan to for an ecological restoration of four of the five target beaches had existed for about ten years but had stalled due to a lack of funding; this proposal formed the backbone of the new proposal. Several New Jersey Department of Environmental Protection bureaus were consulted on information about the proper sand grain size, the potential for contaminants, to locate a source for the new sand that would be required, and to secure permission from the fisherman who had leased oyster fishing rights in the waters adjacent to the target beaches.

With the horseshoe crab spawn only months away the team presented their preliminary restoration plan including beach profiles, detailed material estimates, landowner contacts and other materials necessary for permitting to a meeting of state and federal regulators. By mid-March the project permitting was granted and trucks bearing sand began offloading on Kimbles Beach, the first target for restoration.

The Restoration Process

In order to restore the amount of horseshoe crab habitat destroyed by Superstorm Sandy, rubble and other impingement hazards were removed from several sites and nearly 40,000 tons of sand imported to five New Jersey beaches.

At the completion of the project just prior to the 2013 spawning season, 1.5 miles of Delaware Bay coastline had been restored to optimal habitat conditions for horseshoe crabs. Restoration activities included repairing public access roads as well as removing rubble, pilings, and bulkheads that previously interfered with horseshoe crab spawning activity. Lastly, 1,517 truckloads of sand totaling approximately 40,000 tons were imported and sculpted into the proper beach profile (Table 1). We monitored the response of horseshoe crabs and shorebirds to the restored beaches by counting spawning horseshoe crabs, shorebirds, and horseshoe crab eggs, and by tracking crab egg development. To assess beach stability we measured beach profiles before and immediately after project completion, and again one month after project completion.

Restored Site	Sand Volumes (tons)	Sand Volumes (cubic yards)	Debris Removed (tons)	Area of Beach Habitat Restored (linear ft.)	Public Access Road Repair Material (tons)
Pierce's Point	7,975.58	6,135.06	14.11 (timber)	1,165	-
Kimbles Beach	13,196.01	10,150.78	-	1,560	64.4 (asphalt)
Cooks Beach	4,334.76	3,334.43	-	1,140	150.3 (asphalt)
South Reeds Beach	5,663.88	4,356.83	48.21*	1,160	-
Moore's Beach	7,737.32	5,951.78	760.00**	900	3,047.6 (concrete)
TOTALS	**38,907.55 Tons**	**29,928.88 Cubic Yards**	**822.32 Tons**	**5,925 Linear Ft.**	**3,262.3 Tons**

* 48.21 total tons of debris and rubble removed (38.77 tons concrete & 9.44 tons timbers)

** Concrete material was crushed and recycled on-site for use on an adjacent New Jersey Department of Environmental Protection flood control project.

Table 1. Totals from beach restoration at Moore's Beach and Pierce's Point to South Reeds sections of the Delaware Bayshore, spring 2013.

In order to offset the amount of horseshoe crab habitat destroyed by Superstorm Sandy, five damaged New Jersey beaches extending a total of over one mile were reconstructed. Over 800 tons of rubble and other debris that could potentially trap horseshoe crabs were removed from several sites, and nearly 40,000 tons of sand were imported. In addition, over 3,000 tons of asphalt and crushed concrete were used to repair three public access roads.

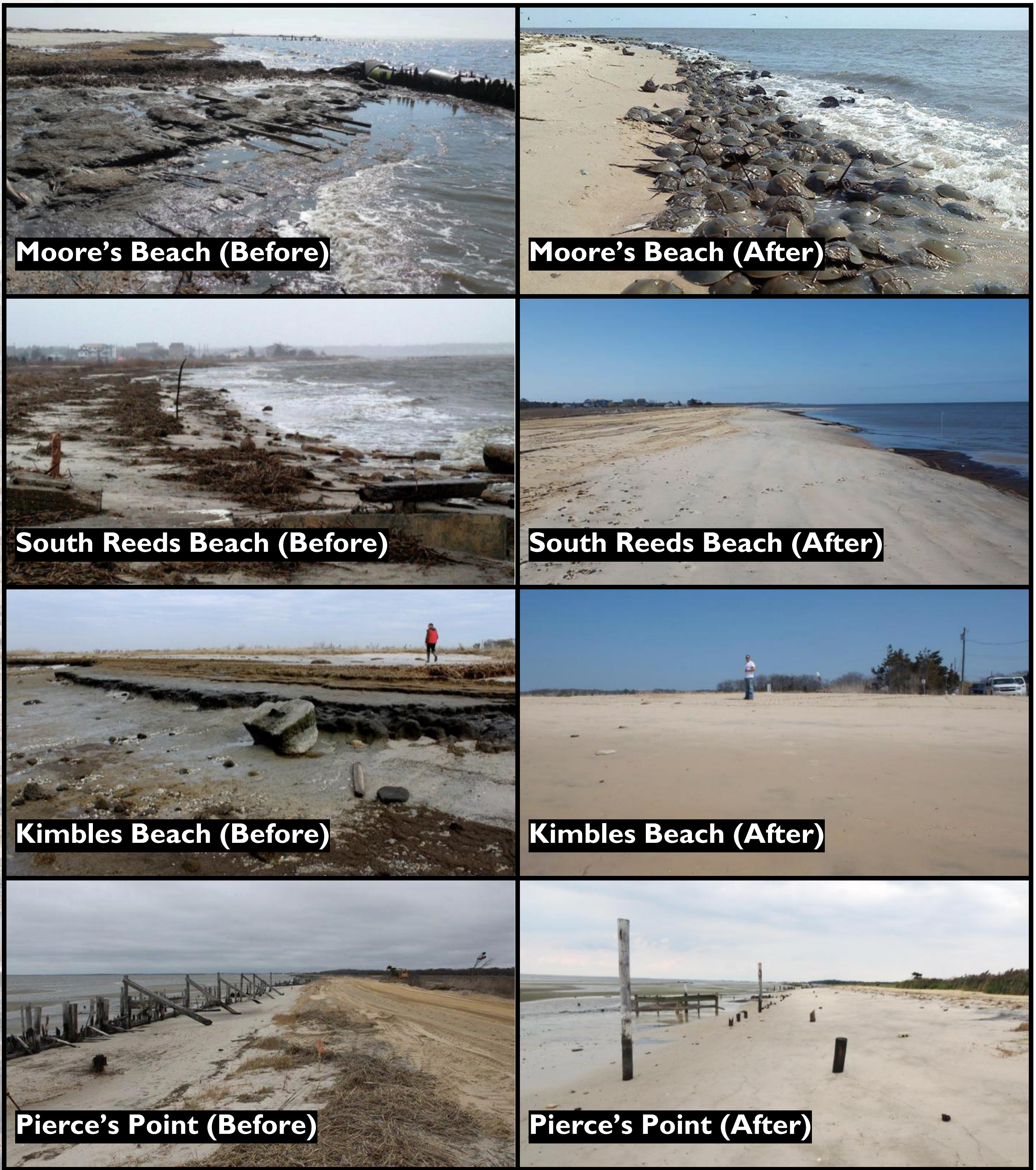

Figure 8. Conditions before and after restoration at restored New Jersey beaches. Cooks Beach was also restored, but is not pictured; its pre-restoration condition was very similar to that of Kimbles Beach.

Horseshoe Crab and Shorebird Use of Restored Beaches

The restoration succeeded in creating horseshoe crab habitat that was used by both spawning horseshoe crabs and shorebirds feeding on horseshoe crab eggs. We compared the abundance of horseshoe crabs and shorebirds on restored beaches to abundances on two beaches that were not restored, but still maintained optimal spawning habitat despite the storm (control beaches). Restored beaches had equally high abundance of both horseshoe crabs and shorebirds when compared to the control beaches (see Figure 9 and Figure 10). We also made counts on unrestored beaches with degraded horseshoe crab spawning habitat similar to the condition of restored beaches prior to restoration. These unrestored beaches had negligible horseshoe crab spawning and shorebird use of these beaches was generally limited to roosting (not feeding).

The numbers of horseshoe crabs and shorebirds using the restored beaches were comparable to the numbers found on beaches that were not damaged by Superstorm Sandy, and significantly higher than the numbers of birds and crabs using storm-damaged beaches that were not restored.

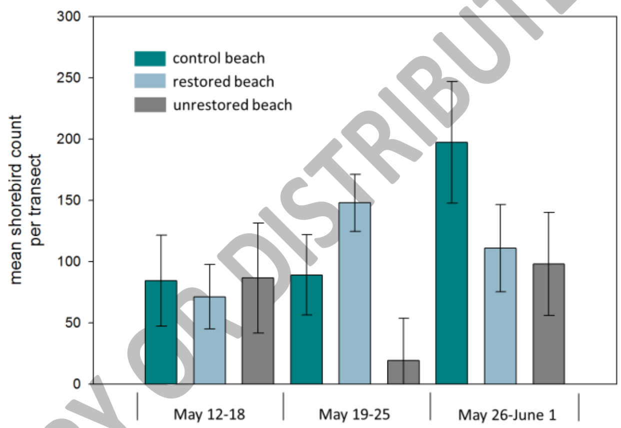

Figure 9. Shorebird foraging activity on restored vs. control and undamaged beaches.

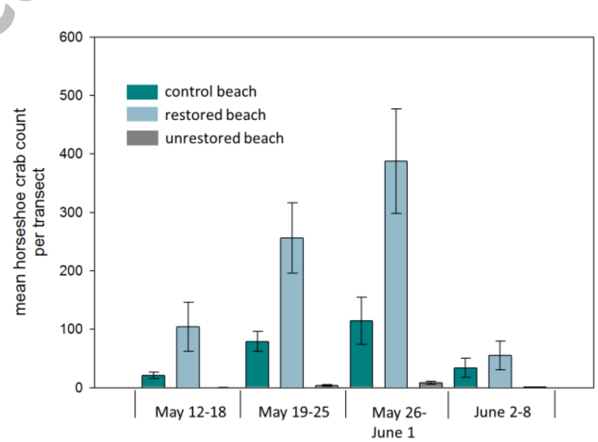

Figure 10. Horseshoe crab spawning activity on restored vs. control and undamaged beaches.

Delaware Bay Shorebird Distribution: the Role of Restored Beaches

Baywide counts of shorebirds indicated that the restored beaches hosted a significant proportion of three of the four primary species that feed on horseshoe crab eggs during stopover. The stretch of restored beaches from Pierces Point north to South Reeds Beach harbored 24 percent of all the Red Knots present in the Delaware Bay, including both the New Jersey and Delaware coastlines, near the peak of shorebird abundance on May 27, 2013. The restoration sites also harbored 18 percent of Ruddy Turnstones, 1 percent of Sanderlings, and 10 percent Semipalmated Sandpipers present in the Bay at that time. The other major center of shorebird abundance was the western shore of Egg Island Point, which had 57 percent of Red Knots, 19 percent of Ruddy Turnstones, 94 percent of Sanderlings, and 32 percent of Semipalmated Sandpipers present in the Bay during the May 27 survey. Overall the New Jersey coastline of the Delaware Bay harbored 94 percent of Red Knots (Figure 11), 49 percent of Ruddy Turnstones (Figure 12), 49 percent of Semipalmated Sandpipers (Figure 13), and 99 percent of Sanderlings (Figure 14).

> **A** count taken near the peak of shorebird abundance in 2013 found that significant proportion of the shorebirds that feed on horseshoe crab eggs in Delaware Bay were using the restored beaches.

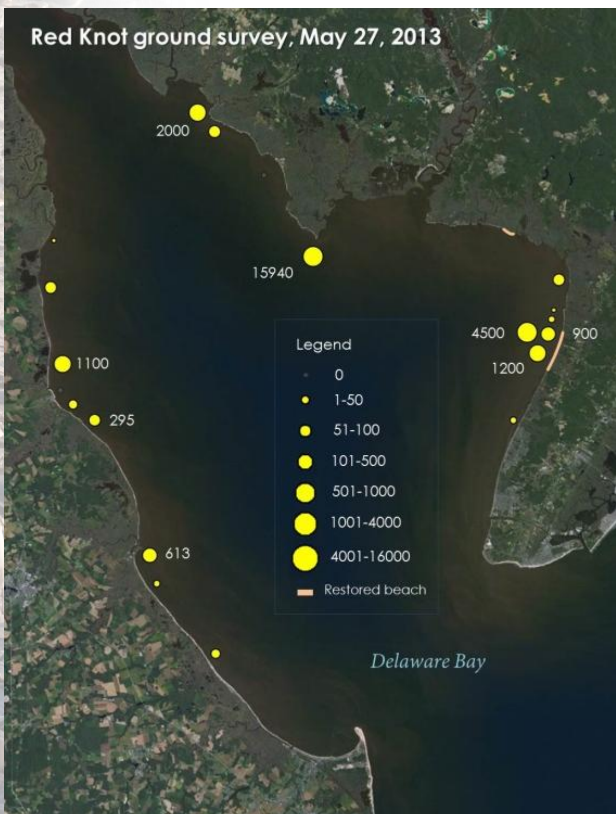

Figure 11. Location of Red Knots within Delaware Bay during peak abundance, 2013

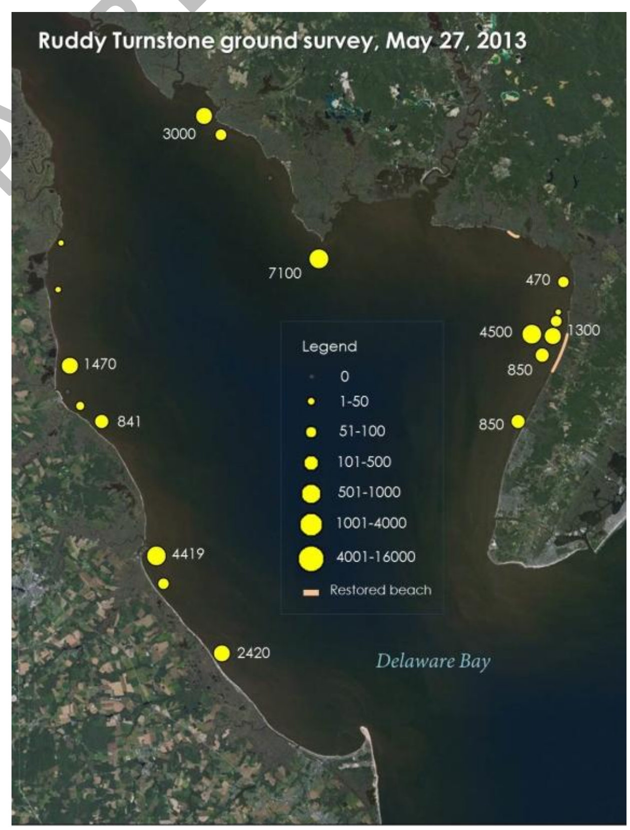

Figure 12. Location of Ruddy Turnstones within Delaware Bay during peak abundance, 2013

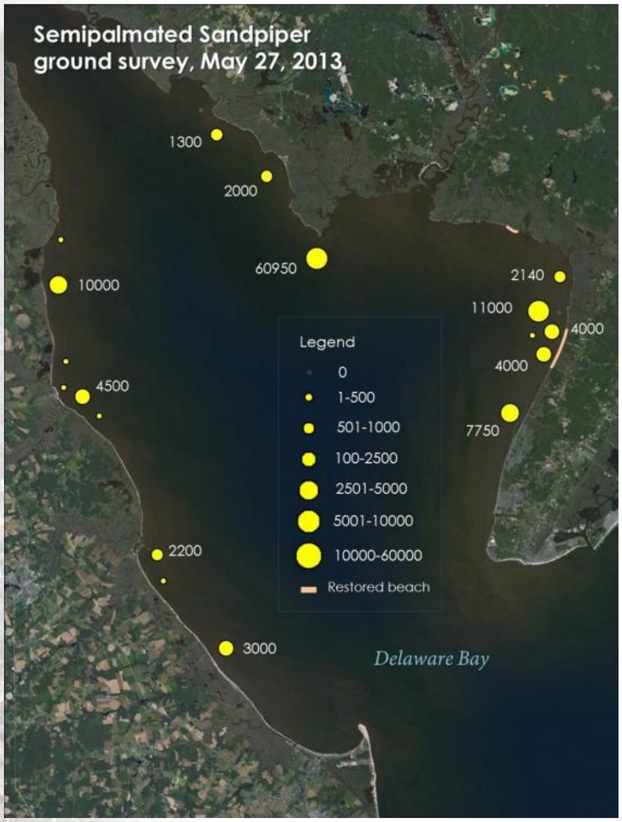

Figure 13. Location of Semipalmated Sandpipers within Delaware Bay during peak abundance, 2013.

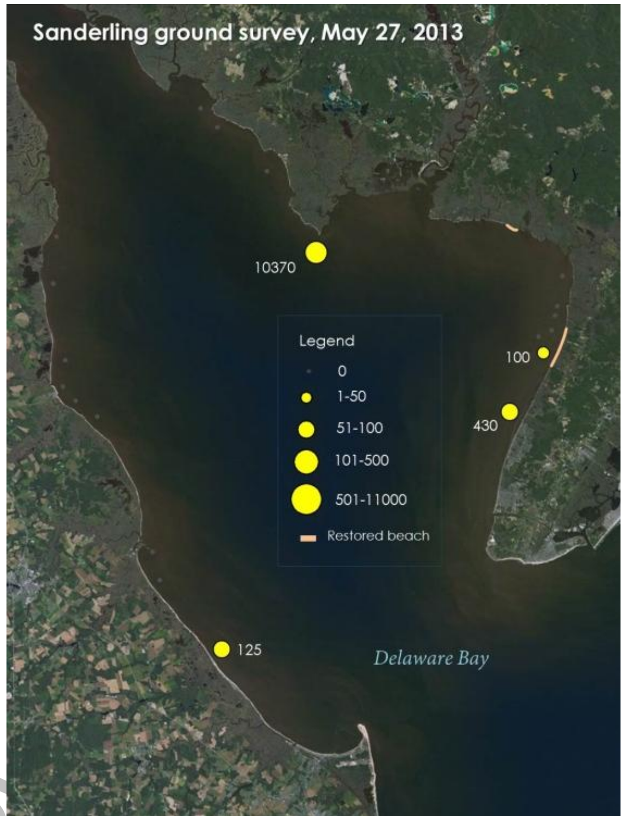

Figure 14. Location of Sanderlings within Delaware Bay during peak abundance, 2013.

Horseshoe Crab Egg Abundance on Restored Beaches

We measured egg abundance in both the upper 5 cm of sand (Figure 15) as well as at a deeper depth of 20 cm (Figure 16). The shallow samples represent eggs available to feeding shorebirds, while the deep samples represent egg abundance at the preferred laying depth of horseshoe crabs. At both depths, the abundance of eggs on restored beaches was similar to the egg abundance on control beaches that were still considered optimal spawning habitat after Superstorm Sandy.

> The abundance of horseshoe crab eggs found both at shallow and deeper depths on the restored beaches was similar to the abundance found at beaches that were left relatively undamaged by Superstorm Sandy.

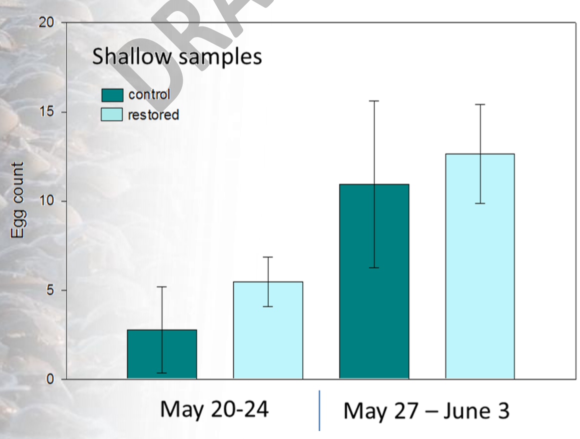

Figure 15. Average count of horseshoe crab eggs found in shallow samples (> 5 cm of sand)

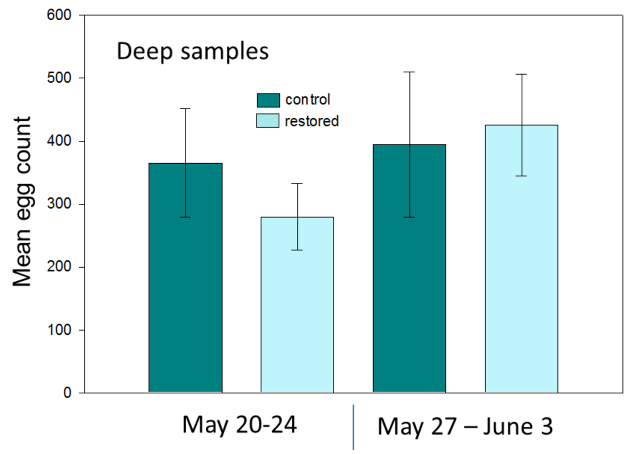

Figure 16. Average count of horseshoe crab eggs found in deep samples (< 20 cm of sand)

Horseshoe Crab Egg Development on Restored Beaches

We measured horseshoe crab egg development on restored and control beaches by burying samples of eggs in individual mesh bags which were then anchored in the sand. We observed consistent egg development rates across restored and control beaches (Figure 17). The primary variable influencing egg development to the larval stage was sand depth. A greater proportion of eggs reached maturity at sand depths greater than 40 cm (Figure 18). It may be important to have a minimum of 20 cm sand buffer between horseshoe crab eggs and the underlying peat because the peat creates low oxygen conditions that affect egg survival.

> **The development of horseshoe crab eggs was similar at both the restored beaches and at beaches undamaged by Superstorm Sandy.**

Sampling locations with sand depths greater than 41 cm were scattered across restored and control beaches. The one exception was North Reeds Beach (an unrestored control beach in optimal condition) which had consistently deep sand. The uniformly deep sand at this site may be due to the effect of the adjacent jetty which is driving sand accumulation on this beach.

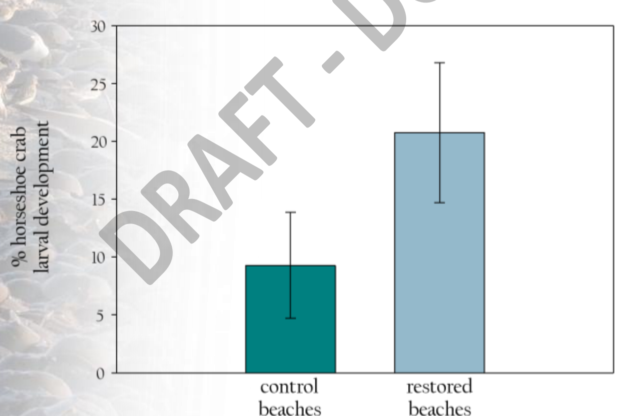

Figure 17. Horseshoe crab larval development at restored vs. control beaches.

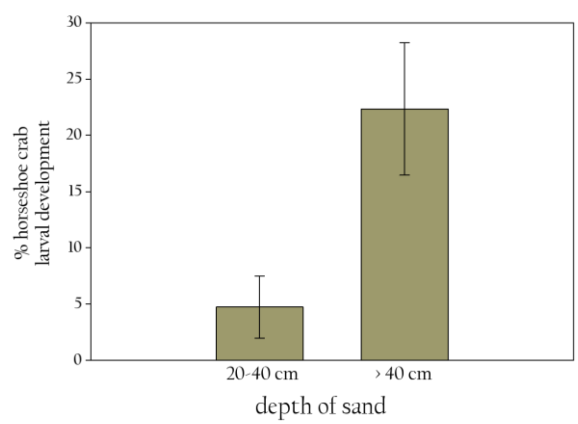

Figure 18. Horseshoe Crab larval development by depth of eggs.

Condition of Restored Beaches One Month after Restoration

The Richard Stockton College Coastal Research Center monitored beach profiles before, immediately after, and one month after sand replenishment on all restored beaches. By the one-month post-construction measurements, all beaches except Pierce's Point had lost sand (see Figure 19 and Figure 20). Generally sand was lost at the end of the restored parts of beaches. Although sand movement beyond the restoration site was not tracked, it is likely that it moved from restoration beaches via longshore drift and was subsequently deposited on adjacent unrestored beaches and tidal creek shoals. Although ideally all sand would stay in place, sand movement to other beaches and creek shoals is a generally positive outcome. Creek shoals in particular provide natural protection from wave action and these areas are important spawning habitat for horseshoe crabs, particularly during periods of high wave action. The loss of sand was exacerbated by unusual northwest winds that created erosional conditions. A key need for Delaware Bay restoration efforts is a clear understanding of sand transport patterns at different locations and under a range of weather scenarios.

> **Measurements taken one month after restoration concluded revealed that all but one of the restored beaches had lost sand. However, it is likely that this sand moved to adjacent areas of horseshoe crab spawning habitat, such as unrestored beaches or creek shoals.**

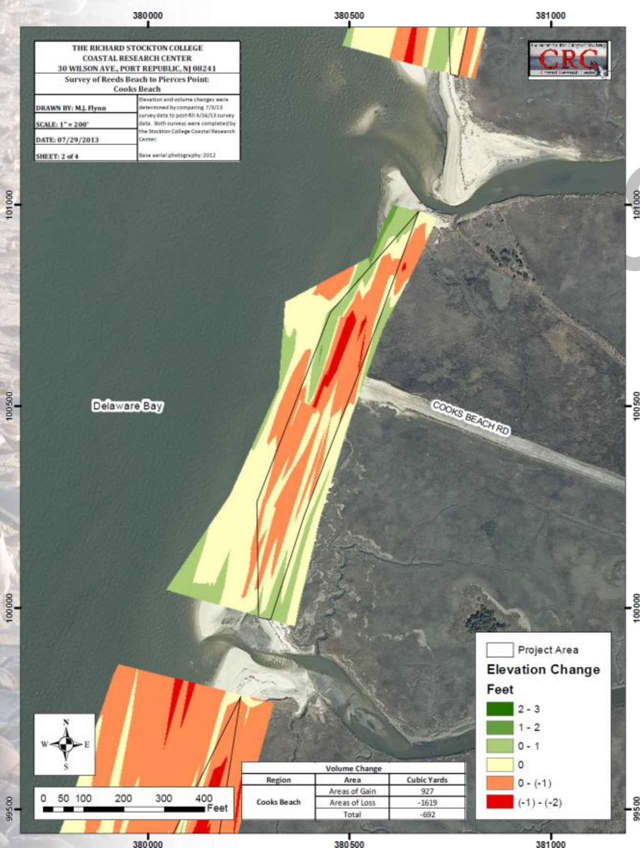

Figure 19. Erosion at Cooks Beach one month after restoration.

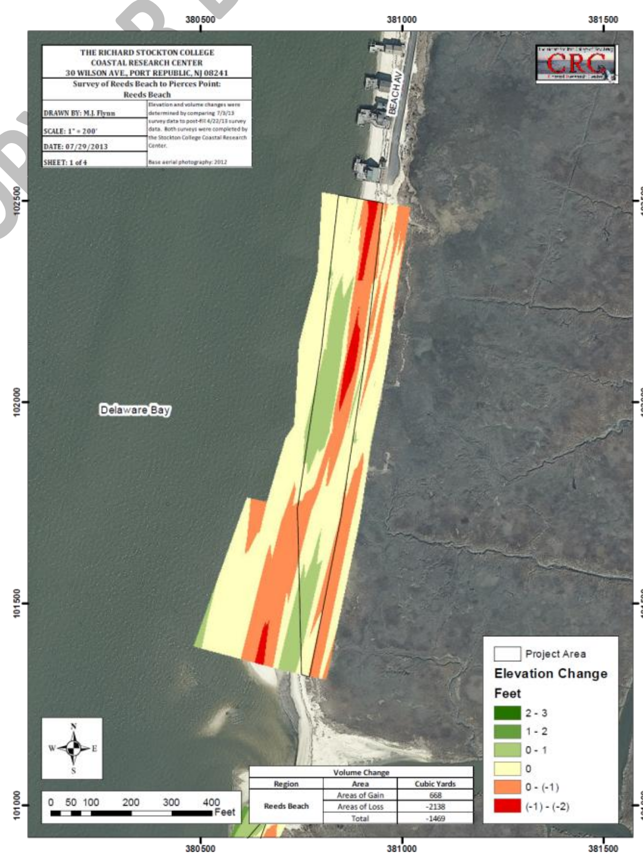

Figure 20. Erosion at South Reeds Beach one month after restoration.

Effectiveness of Oyster Aquaculture for Wave Attenuation

We deployed several configurations of cultivated oysters offshore of South Reeds Beach to test their effectiveness for attenuating wave action. Attenuating wave action can both protect beaches from wave-induced erosion and provide calm water for horseshoe crabs during rough wave conditions. We tested a double row of rectangular oyster racks, a single row of racks, and a series of oyster cultivation baskets suspended from a floating longline parallel to the shore. We examined wave attenuation effects by installing a wave gauge in the intertidal area between the oysters and the beach (see Figure 21). We installed a second wave gauge in an adjacent beach segment with no oysters for comparison. Our results indicate that the double row of oyster racks had a statistically significant wave attenuating effect during periods of rougher wave conditions (Figure 22). The single row of oysters and the baskets on floating longline had no discernible wave-attenuating effect. These results are encouraging, although the magnitude of attenuation was relatively small. More designs need to be tested as we move toward a goal of creating wave attenuation levels that can protect the shorelines and create calm spawning habitat under rough wave conditions. Wave-attenuating structures could be an essential component of a comprehensive restoration strategy that can help protect restoration investments by easing wave action on beaches and reducing the potential for erosion.

> Experiments using configurations of cultivated oysters indicate the possibility of using them to dampen waves, which would provide calm spawning areas for horseshoe crabs during rough wave conditions and protect the beach from erosion.

Figure 21. A double row of oyster racks proved the most effective method of wave-attenuation tested.

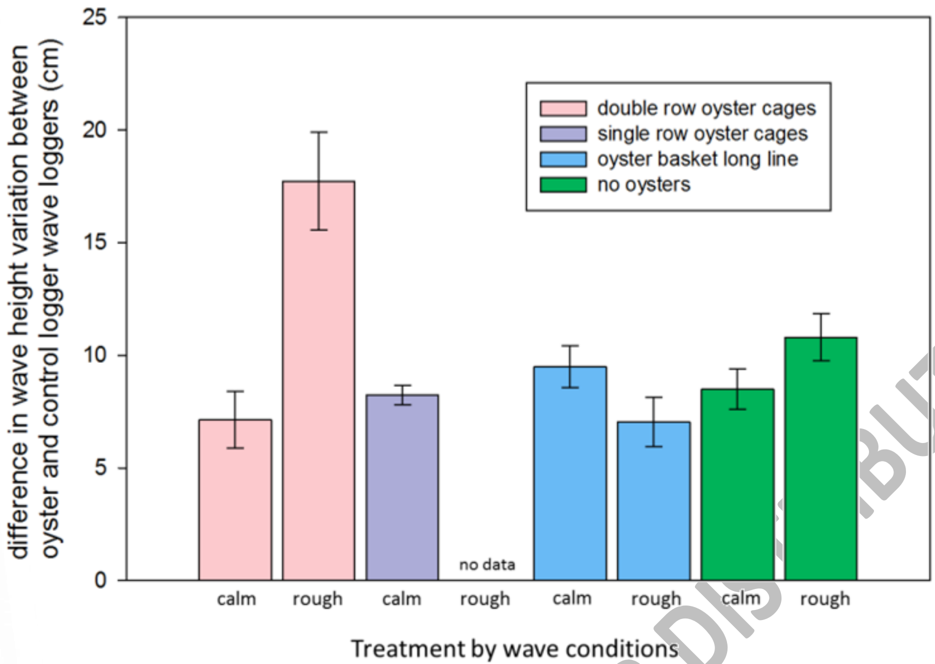

Figure 22. Wave-attenuation effect of three arrangements of oyster cultivation racks and baskets.

Conclusion

The primary goal of the restoration project was to recreate habitat suitable for both horseshoe crab breeding and shorebird foraging that had been destroyed by Superstorm Sandy, and to do so in the five months before the return of horseshoe crab spawning season. The time restriction was certainly met, as rubble removal and reconstruction were completed by early May on five New Jersey beaches. Data taken clearly revealed that more horseshoe crabs and shorebirds utilized these beaches than similarly damaged beaches that went unrestored. A baywide count of shorebirds echoed this finding, reporting that significant proportions of three of the four main shorebird species that feed on horseshoe crab eggs in the Delaware Bay were found on the restored beaches. Additional comparisons were made to beaches that were left undamaged by Superstorm Sandy, and both the abundance and development of horseshoe crab eggs at all sampled depths were comparable at both the restored beaches and these undamaged beaches. In this sense, it certainly appears that the primary goal of the restoration project was accomplished.

A secondary and less quantifiable goal was the gathering of data that could be used to improve similar restoration efforts in the future. Measurements taken approximately one month after the completion of restoration revealed that sand had been lost from four of the five restored beaches; however, where the sand was lost to is unknown. It is quite possible that the sand simply migrated to nearby unrestored beaches or to other areas of importance to horseshoe crabs such as protective creek shoals. If this is the case, consistent losses at restoration sites may not be the detriment it originally appears to be. Conducting further study to determine the movement of sand around these Delaware Bay sites has been identified as an important direction for future research. Additional experiments tested a preliminary method of reducing wave-induced erosion using cultivated oysters produced limited but successful results. This too seems a direction for future research.

Beach restoration efforts on the Delaware Bay in the spring of 2013 were effective in producing both short- and long-term results. Frequent horseshoe crab spawning and shorebird foraging on beaches that had been decimated by Superstorm Sandy revealed that the restoration efforts had successfully repaired the beaches and prevented the feared ecological catastrophe, and information gathered during and after the project have provided valuable information that will maximize the success of future restoration projects – both on the Delaware Bay and beyond.

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