Global Conservation Alliance

The Red Knot Survival Project 2009 Summary Report

Field-testing methods for increasing horseshoe crab (*Limulus polyphemus*) egg availability for imperiled red knot (*Calidris canutus* ssp. *rufa*) populations in Delaware Bay

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1.0 Problem Overview

North American populations of the '*rufa'* subspecies of the red knot are in danger of extinction. It is listed as endangered in Canada (COSEWIC 2007) and nominated for endangered species status in the US (Federal Register. 2006; 2009). The red knot's precipitous decline has paralleled a similar crash in horseshoe crab populations due to over-harvesting for the bait industry (Niles et al., 2009). Red knot populations have declined severely because they feed almost exclusively on depleted supplies of horseshoe crab eggs (Harrington 2001, Bottom et al. 2003, and Niles et al., 2009). Because most of the rufa red knots converge to Delaware Bay as their last stopover prior to departing to the Canadian Arctic to breed, their dependence on the bay has created a potential lethal bottleneck effect.

<u>Relevant Research</u>: Population trends of birds and crabs have been carefully monitored by Tsipoura and Burger (1999), Harrington (2001), Morrison et al., (2004) and Niles et al., (2009). Field investigations have documented what red knots eat (Haramis 2001, Karpanty et al. 2006), where they find it (Karpanty et al. 2006), and movements (Cohen et al., 2009. Thousands of birds have been cannon-netted and banded to determine arrival and departure weights and to track their movements in Delaware Bay (Karpanty et al. 2006, Gillings et al., 2007, Niles per. communication).

Accumulating adequate fat reserves at a rapid rate is vital for red knot survival. Research has shown that most red knots arriving in Delaware Bay in May remain for an average of 11 to 12 days during which time their weight nearly doubles, providing fuel for the final leg of their 10,000-mile trans-hemispheric flight from Tierra del Fuego at the southern tip of South America to their Canadian Arctic breeding grounds (Gillings et al., 2007). To reach a 'safe' departing weight (180 to 200 grams), birds must gain about 7.2 grams per day (Gillings et al., 2007). Baker and coworkers reported that the proportion of birds reaching this weight has decreased over the past two decades (Baker et al., 2004 in Karpanty et al. 2006). Moreover, birds arriving in late May must eat more eggs faster because their average stopover length is 8 to 10 days, two days shorter than most May arrivals. From a management perspective, increasing horseshoe crab egg availability should have maximum benefits for the latter cohort of birds.

<u>Potential Solution</u>: Although scientists have actively monitored population declines and extensively studied the ecology of red knots and horseshoe crabs, other than recent legislation in New Jersey mandating a moratorium on horseshoe crab harvesting and implementing harvest limits in nearby states (Niles et al., 2009), researchers and conservation biologists have not directly attempted to solve the immediate problem of reduced horseshoe crab egg availability in Delaware Bay. Because horseshoe crab egg abundance is limiting red knot fat deposition rates, we hypothesized that artificially increasing egg availability in the upper 5 cm of beach should result in heavier birds departing Delaware Bay (Famous et al., 2008). The concept of increasing egg availability is designed to provide a temporary 'life boat' to help red knot populations ride out present food shortages while horseshoe crab populations rebound, which is predicted to take a minimum of 8-12 years (Federal Register 2006).

The Red Knot Survival Project was established by GCA in 2008 to develop methods for increasing food availability for red knots and other shorebirds. Funded by the Marine Conservation Action Fund of the New England Aquarium in 2008 (Famous et al., 2008), we tested using a commercial aquaculture fish food as a supplemental provision. Although most shorebirds preferred horseshoe crab eggs to fish food (Photo 1), laughing gulls, an important competitor for horseshoe crab eggs in Delaware Bay, were attracted in very large numbers to 1 by 1.4 m test plots (Photo 2). Two plots at opposite ends of a one-kilometer long beach attracted all laughing gulls away from prime shorebird feeding areas, thus indirectly increasing egg availability for shorebirds.

The present study evaluated two manual methods for turning over beach sediments to bring eggs to the beach surface where red knots feed, including the upper five centimeters. We sampled egg densities before and after turning sediments over. Next, we asked the question: Are there sufficient eggs remaining in beach sediments to warrant a second digging or ‘harvest’ the following day? We resampled our plots and compared post-dig egg count data collected the previous day. Finally, because disturbing horseshoe crab egg masses over large areas (e.g., several acres per beach) has the potential to reduce horseshoe crab productivity, we assessed the relative numbers of eggs remaining within the incubation zone the day after digging as an indirect indicator.

Goals and Objectives

The goal of Global Conservation Alliance’s (GCA) Red Knot Survival Project is to increase horseshoe crab egg availability so that birds can eat more eggs faster and leave Delaware Bay for their Canadian Arctic breeding grounds at weights adequate for their survival. The additional fat reserves should increase year-to-year survivalship and annual productivity by buffering the energy-demanding costs of unpredictable Arctic weather and the high cost of early breeding season activities, including egg production (Morrison and Hobson 2004).

Objectives:

1) to field test hand-operated methods for bringing horseshoe crab eggs into the upper 5 cm of beach where birds feed,
2) to determine if egg densities remaining in the sediment are high enough to harvest again the following day,
3) to qualitatively assess bird response to increased egg densities, and
4) to evaluate the use of artificial food to attract laughing gulls away from shorebird feeding habitat leaving more food for shorebirds.

Photo 1 Semipalmated sandpipers eating artificial fish food on Reed's Beach

Photo 2 Laughing gulls feeding on artificial fish food developed for the marine aquaculture industry

3.0 Methods

Study Area

The study area was comprised of four New Jersey beaches located on the northeast corner of Delaware Bay: Moore's, Gandy's, Reed's and Cook's Beaches. The high intertidal zone was sampled at all beaches. Two intertidal sections of Moore's Beach were sampled with the upper intertidal sampling area labeled as Upper Moore's Beach and the lower intertidal sampling area labeled as Lower Moore's Beach. All were west facing and beach substrates were comprised of coarse well-drained sand. Raised sand berms and low sand dunes separated beaches from contiguous saltmarsh vegetation that was dominated by *Spartina patens* and *S. alterniflora*. A band of coarse dead plant debris and anthropogenic junk lined the tops of the beaches.

Statistical Analysis

We utilized an Analysis of Variance (ANOVA) Repeated Measures design with two dependant variables: treatment and beach. Nine plots were established at Moore's Beach and Gandy's Beach. Surfaces samples were collected prior to digging (pre-dig) and immediately after digging (post-dig) on day one. Plots were resampled the next day before (pre-redig) and after digging (post-redig) to determine if enough eggs remained in sediments to provide a second supplemental feeding.

An additional nine plots were established at the north end of Reed's Beach as a third test beach and to assess inter-beach effects. Six plots were actively treated while three served as untreated control plots. All plots were sampled before digging while the six treatment plots were sampled immediately after digging. Because of time constraints, the actively treated plots were not redug the following day.

Separate ANOVA tests were conducted:

- Dig and redig experiments at Gandy's and Moore's Beaches;
- Comparison of Upper Moore's Beach to Lower Moore's Beach;
- Dig-only treatment at Reed's, Upper Moore's and Gandy's Beaches, and
- Comparison of the nine untreated control plots to the 18 dig-only plots at Reed's, Moore's and Gandy's Beaches.

Separate ANOVAs were conducted, three using transformed egg count means and one using untransformed data. We present the log-transformed ANOVA in this report as it provided the highest P values. We also present count summaries using untransformed count data.

No statistical analysis was conducted on the trenching experiment for which no egg samples were collected.

Test Plot and Trench Sampling Methods

Test Plots: Fifty-four test plots were established on Moore's, Gandy's and Reed's Beaches (Table 1) along the New Jersey shore of Delaware Bay. Using a clam rake, we turned over and mixed the upper 20 cm of beach surface in each plot (Photo 3). Four sediment core samples were collected from each plot before digging (labeled Pre-dig in tables) and immediately after digging (Post-dig) at all beaches (Photo 4). Plots were resampled the next day before digging (Pre-redig) and after digging (Post-redig) to determine if enough eggs remained in sediments to provide a second supplemental feeding. Three hundred and sixty horseshoe crab egg samples were extracted from four 10 cm diameter by 5 cm deep sediment cores using a coffee can (Table 1). The four-sample mean from each plot was used for our statistical analysis.

Dug in the morning, plots were placed about a meter below the previous high tide strand line. Plots were organized into three groups of three at each beach: two treatment plots and one control or undisturbed plot. Plots were separated by two meters while each group of three plots was separated by five meters. Table 1 summarizes the number of plots and horseshoe crab egg samples collected at each beach.

Samples were individually bagged then placed in coolers. Eggs were extracted within two days using the floatation method, after which they were counted either visually when numbering less than 150 eggs (approximately) per sample, or estimated volumetrically for samples exceeding 150 eggs. Developmental differences in egg size among samples were not evaluated because sampling was conducted within several days following a spring tide, a peak laying period for horseshoe crabs. Visual inspection of egg surface features did not reveal characteristics of advanced development, which indicates recent egg deposition.

Table 1 Summary of horseshoe crab egg samples collected by beach

		Sub-sample Numbers			
		Dig-only		Re-dig	
Beach	Plots	Pre-dig	Post-dig	Pre-redig	Post Re-dig
Gandy's Beach	9	36	24	36	24
Moore's Beach (Upper)	9	36	24	36	24
Moore's Beach (Lower)	9	36	24		
Reed's Beach	9	36	24		
Total Sub-samples		360 samples			

Photo 3 Turning over the upper 20 cm of beach in 2 by 3 m plots
Vertical poles mark plot edges.

Photo 4 Collecting 10 cm by 5 cm deep subsamples (4 per plot)

Trenches: Five shallow trenches, approximately 17 to 20 m long, were dug perpendicular to the shoreline at Gandy's and Cook's Beaches. Trenches started about 2 meters below the previous high tide strand line and extended downslope into partially saturated wet sand. Trenches were about 60 to 70 cm wide as measured from the top of the sloping sides. The sand-egg mixture removed from the trenches was spread over the adjacent 2 m of beach surface on the left sides of the trench, as shown in Photo 5. Photograph 5 shows newly dug trenches prior to the arrival of birds.

Due to time restraints, no egg samples were collected to measure the level of increased egg availability. Rather, we used the relative number of birds feeding in and adjacent to trenches compared to adjacent untrenched sections of beach as an indirect measure of food availability. Although observations were qualitative, general conclusions can be drawn to guide future studies.

Photo 5 Trenches dug perpendicular to Gandy's Beach, approximately 17-20 m long. The sand-egg mixture was spread over a 2 m wide strip on the left side of the trench as shown in the photograph.

4.0 Results

4.1 Plot Experiments

We evaluated the effects of turning beach sediments over in plots as a means for increasing egg availability for red knots and other spring migrating shorebirds. We performed four analyses using three sets of transformed data, including square root, natural log and 4th root; and untransformed count data. All analyses yielded highly significant increases in the number of eggs transported to the red knot feeding zone (upper 5 cm of beach), with $p=<0.0001$ values for all three sets of transformed data and, $p=0.0002$ for untransformed counts. Table 2 presents the results of the ANOVA using log-transformed counts. Although the Treatment *X* Beach interaction term was significant, it was consistent over all beaches.

There were two potential outliers with the log-transformed data: Gandy's Plot 15 Pre-redig Count=1,956.25 and Gandy's Plot 18 Post-redig Count=15.5. We conducted a log-transformed analysis without the outliers and arrived at similar highly significant p values. There were no outliers in ANOVAs using untransformed count and square root and forth root transformed counts.

Table 2 ANOVA Repeated Measures Design Table (Log-transformation)

	Numerator DF	Den DF	F-value	p-value
Treat	3	28	33.8545	<0.0001
Beach	1	10	2.2042	0.1685
Treatment x Beach	3	28	5.1349	0.0059

Figures 1 and 2 present horseshoe crab egg counts by plot showing pre-dig, post-dig, pre-redig (next day) and post-redig for non-transformed and log transformed counts for Gandy's Beach. Figures 3 and 4 plot the same count information for Moore's Beach. Figures 5 and 6 present combined summaries for both beaches for untransformed and log-transformed counts, respectively. Note that graphs presenting log-transformed data tend to visually inflate changes in low count values, which accounts for the apparent differences between same-beach graphs. The trends in both, however, are similar.

Tables 3 to 6 present the effect means for each treatment type. Note that the means for pre-dig and post-dig for Reed's Beach were the lowest among beaches, which indicates there was a lower density of horseshoe crab egg masses in the upper beach zone. Upper Moore's beach had the lowest pre-redig counts and the highest post-redig values, suggesting a higher density of egg masses at Upper Moore's Beach.

As expected, there was a sharp increase in egg availability after each digging. We were surprised to find a return to low egg availability the morning following the first dig. We concluded that the overnight depletition of eggs within the upper five cm of sediment was caused by a combination of predation by birds, fish, and invertebrates and winnowing by wave action. The major cause of egg depletion in the upper five cm (near surface) was likely caused by wave action occurring as sediments were inundated during which time the eggs were ‘floated’ or washed out of the sand by the incoming and outgoing tidal front passing over sediments. This process was similar to ‘floating’ the eggs (lower specific gravity) out of sediment samples.

Photos 6 to 8 (Pages 16 and 17) show semipalmated sandpipers feeding in plots on Reed’s Beach. Note that birds did not discover the plots until the incoming high tide pushed them to within ten feet of the plot prior to detection.

Table 3 Effect means for pre-dig treatments at each beach

Beach	N	Count
Gandy’s Beach	6	109.66667
Reed’s Beach	6	116.50000
Upper Moore’s Beach	6	33.62500
Overall	18	86.59722

Table 4 Effect means for post-dig treatments at each beach

Beach	N	Count
Gandy’s Beach	6	1364.2500
Reed’s Beach	6	673.5417
Upper Moore’s Beach	6	4766.2500
Overall	18	2268.0139

Table 5 Effect means for pre-redig treatments at each beach

Beach	N	Count
Gandy’s Beach	6	351.9167
Upper Moore’s Beach	6	166.0000
Overall	12	258.9583

Table 6 Effect means for post-redig treatments at each beach

Beach	N	Count
Gandy’s Beach	6	1371.833
Upper Moore’s Beach	6	2606.292
Overall	12	1989.062|

Figure 1 Gandy’s Beach average egg count per plot for dig and redig treatments

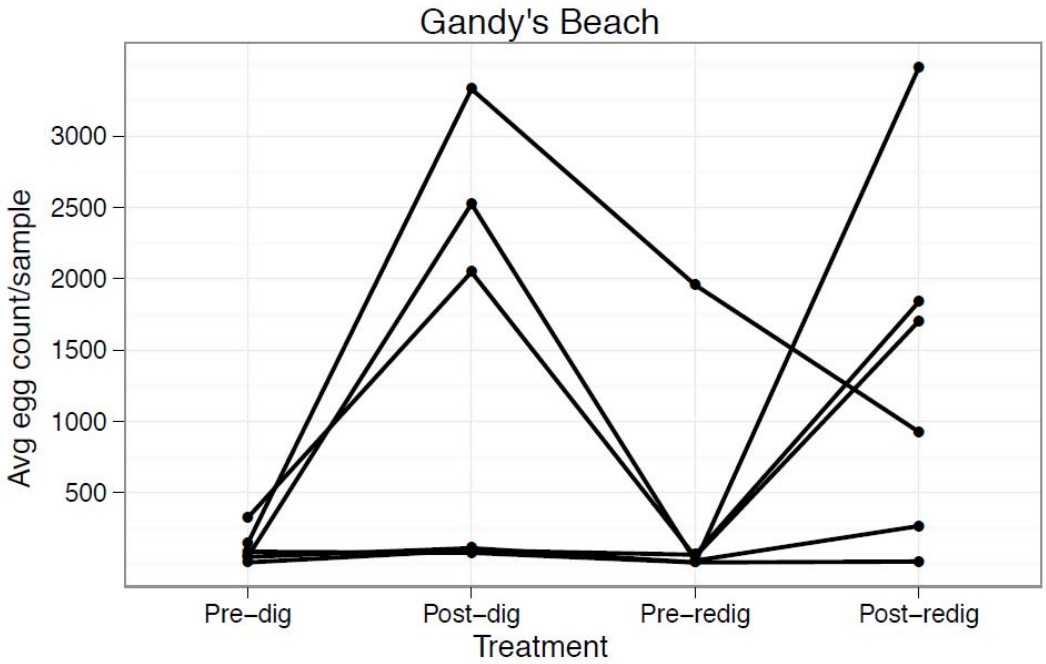


Figure 2 Gandy’s Beach log-transformed egg count per plot for dig and redig treatments

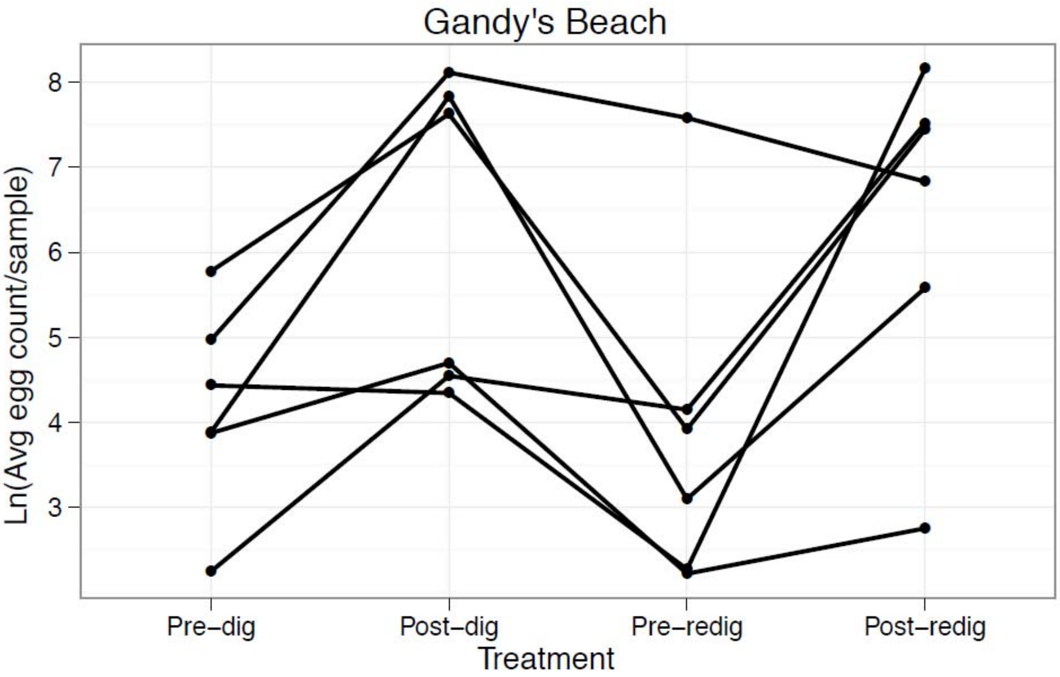


Figure 3 Upper Moore's Beach average egg count per plot for dig and redig treatments

Figure 4 Upper Moore's Beach log-transformed average egg count per plot for dig and redig treatments

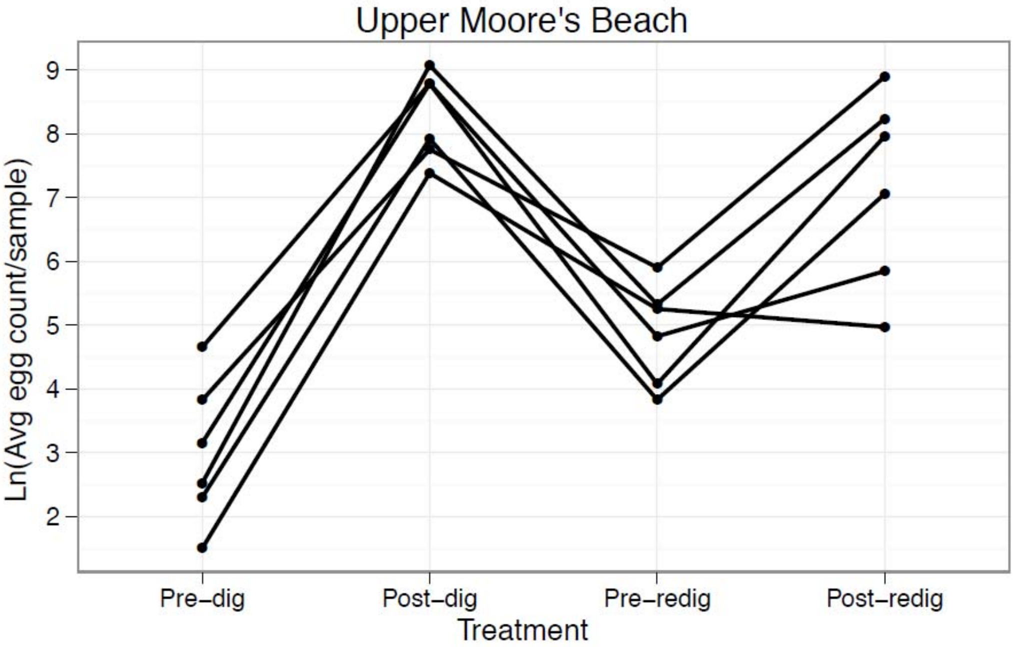


Figure 5 Moore’s and Gandy’s Beaches average egg count per plot for dig and redig treatments

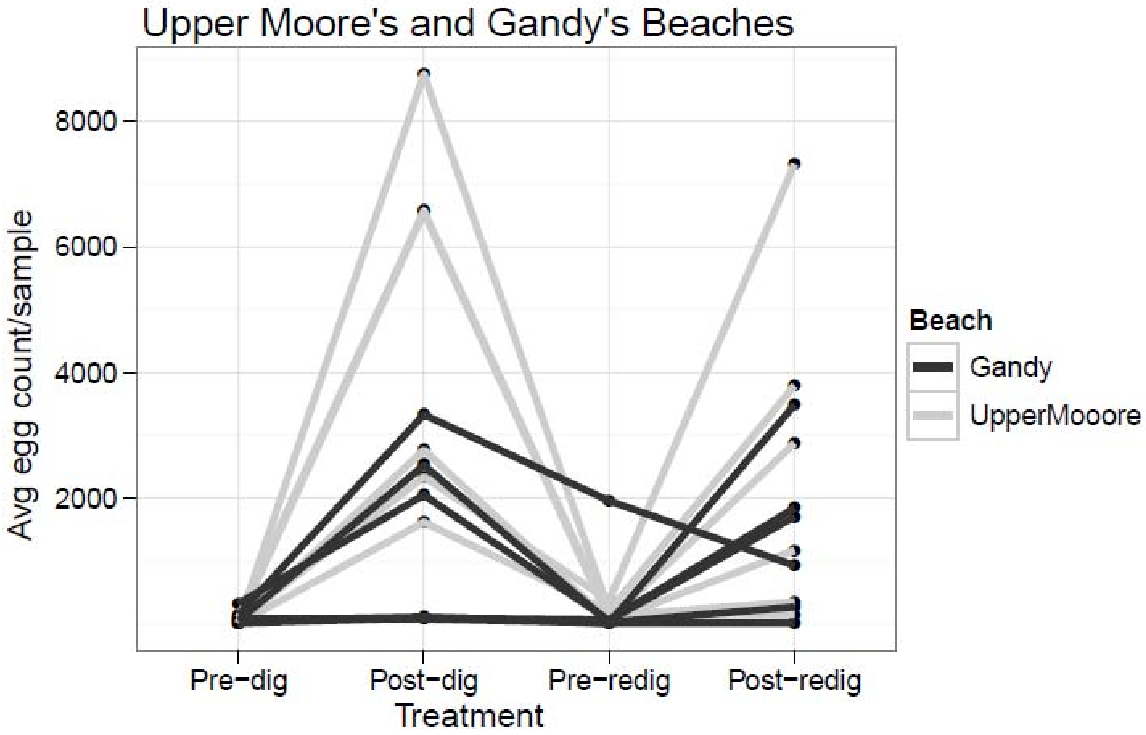


Figure 6 Moore’s and Gandy’s Beaches log-transformed average egg count per plot for dig and redig treatments

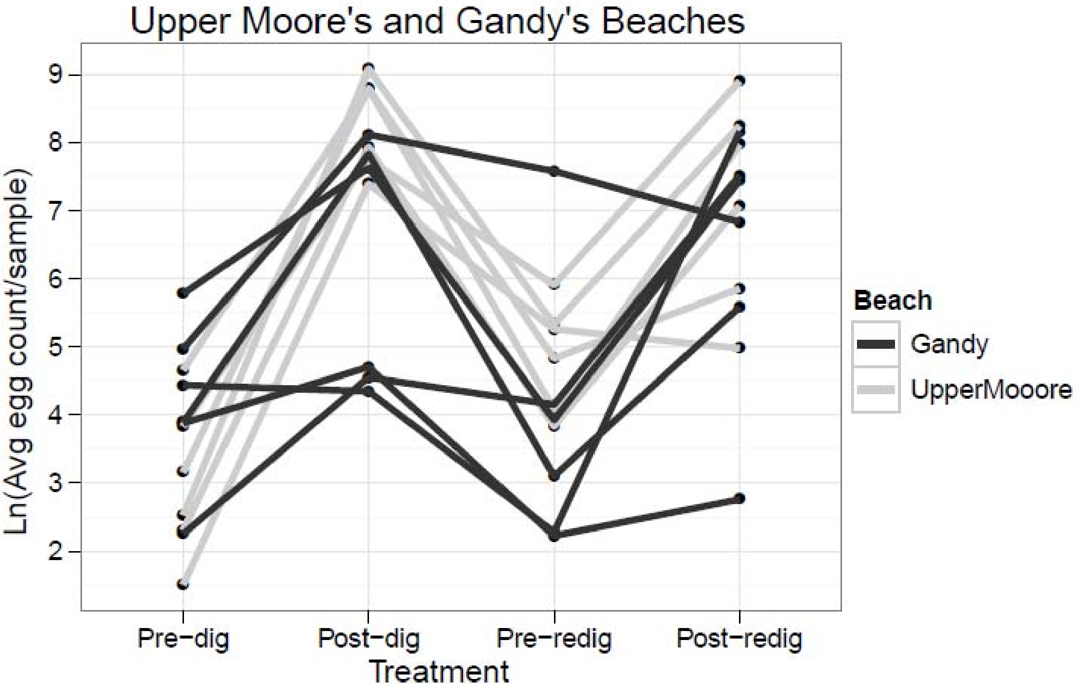


Photo 6 Shorebirds feeding on horseshoe crab eggs in test plot at Reed's Beach Plot was partially inundated (note upper beach debris in foreground)

Photo 7 Semipalmated sandpipers feeding in unflooded portion of plot

Photo 8	Laughing gulls feeding in test plot at Moore’s Beach. Note, no birds are feeding in the undisturbed control plot in foreground

To increase beach sample size for the pre-treatment (pre-dig) vs. post treatment (post-dig) analysis, we conducted a separate ANOVA using log-transformed egg counts from Reed's, Gandy's, and Moore's Beaches (Table 7). Like the two-beach ANOVA (Table 2), the increase in egg counts was highly significant (P=<0.001). The combined pre-treatment and post-treatment plot means for the three beaches are presented in Figures 7 and 8, showing untransformed and log-transformed counts, respectively. The plot means for Reed's Beach are presented for untransformed and log-transformed counts in Figure 9 and Figure 10, respectively. Similarly, the plot means for Gandy's Beach were presented in Figures 1 and 2, while plot means for Upper Moore's Beach were presented in Figures 3 and 4.

With the exception of two plots at Moore's Beach and one at Reed's Beach, egg counts increased by one or more orders of magnitude. A low increase in egg counts probably reflects a low number or lack of egg masses as horseshoe crab nests are not evenly spaced (Fraser et al., 2010). Likewise, within-plot distribution of egg masses was uneven, as both high and low increases in within-plot egg counts were not uncommon.

Table 7 ANOVA Comparing pre-treatment (pre-dig) to post-treatment (post-dig) for Gandy's, Moore's and Reed's Beaches

	Numerator DF	Den DF	F-value	p-value
Treatment	1	15	102.7496	<0.0001
Beach	2	15	0.3931	0.6817
Treatment x Beach	2	15	15.9424	0.0002

Figure 7 Gandy’s Moore’s and Reed’s Beach pre-treatment (pre-dig) vs. post-treatment (post-dig) untransformed egg counts per plot

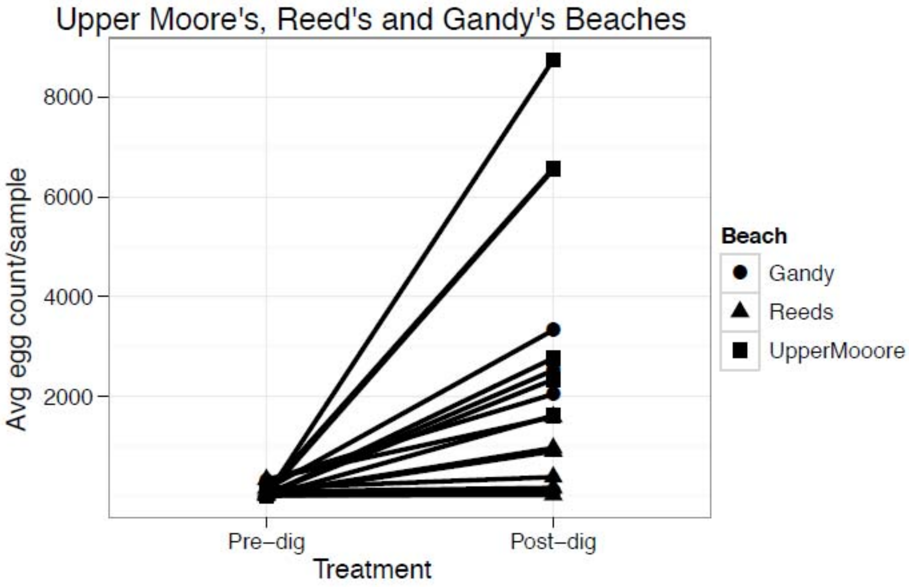


Figure 8 Gandy’s Moore’s and Reed’s Beach pre-treatment (pre-dig) vs. post-treatment (post-dig) log-transformed egg counts per plot

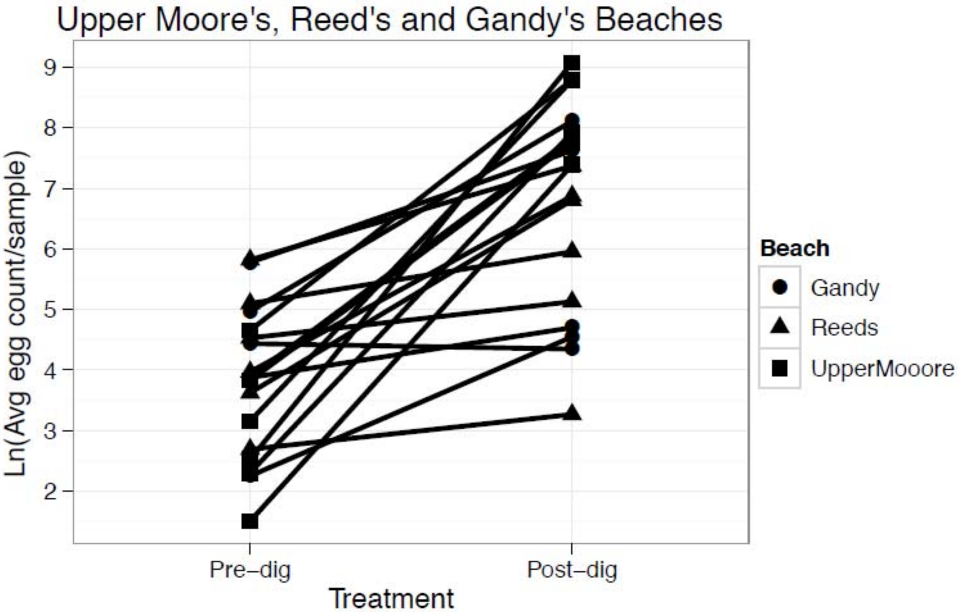


Figure 9 Reed’s Beach pre-treatment (pre-dig) vs. post-treatment (post-dig) untransformed egg counts per plot

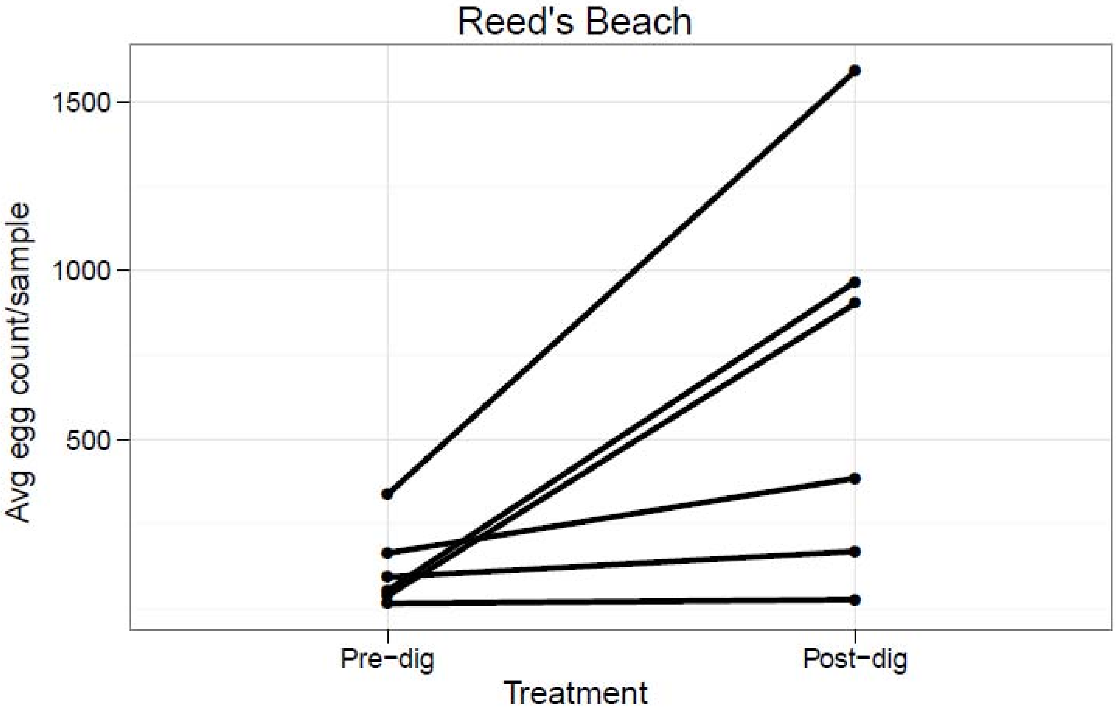
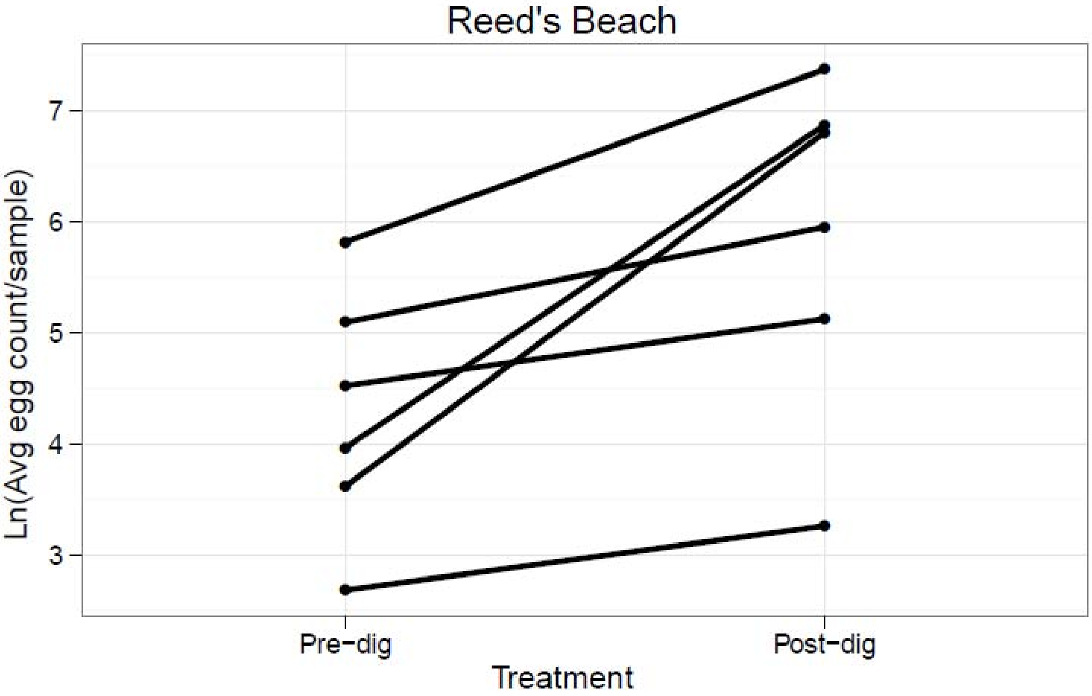


Figure 10 Reed’s Beach pre-treatment (pre-dig) vs. post-treatment (post-dig) log-transformed egg counts per plot



Control vs. Pre-dig averaged over Upper Moore's, Gandy's and Reed's Beaches

We compared egg count data from nine control plots to 18 treatment plots on Reed's, Gandy's and Upper Moore's Beaches to confirm that pre-dig treatment 'control' counts in the two treatment-two beach (Gandy's and Upper Moore's Beach) ANOVA were valid controls. There were no significant differences in egg counts between the undisturbed control plots and adjacent pre-dig treatment plots, as shown in ANOVA table (Table 8). Table 9 presents the average egg counts for control vs. pre-dig samples. In general, the egg counts in control plots averaged about 20% lower than treatment plots (63.8 vs. 86.6, respectively).

Table 8 ANOVA table comparing control egg counts to pre-dig counts at Reed's, Gandy's and Upper Moore's Beaches[1]

	Df	Sum Sq	Mean Sq	F value	Pr (>F)
Beach	2	6888	3443.8	0.4861	0.6218
Treatment: Beach	2	25171	12585.7	1.7765	0.1937
Residuals	21	148774	7084.5		

[1] The ANOVA analysis was conducted using untransformed count data.

Table 9 Control plot and pre-dig treatment plot mean egg counts at Reed's, Gandy's and Upper Moore's Beaches

Treatment	N	Egg Count Mean
Control Plots	9	63.83333
Pre-dig Plots	18	86.59722
All Plots	27	79.00926

ANOVA comparing Upper Moore’s Beach to Lower Moore’s Beach

Because sampling effort was limiting, we sampled both the upper and lower intertidal zones of Moore’s Beach to determine if sampling two sections of one beach out-weighed the value of sampling one section of a greater number of beaches. Based on an on-site examination of the data, we assessed that egg densities appeared insufficient to warrant a re-dig treatment. We then focused our remaining sampling effort on the upper intertidal zone at Gandy’s, Reed’s and Cook’s Beaches.

The ANOVA analysis found that post-dig or treatment effects were highly significant in both the upper and lower intertidal zones as shown in Table 10. There was also a less significant difference in post-dig egg counts between the upper and lower intertidal zones.

Table 11 presents egg counts averaged over pre-dig and post-dig treatments, pre-dig treatment, and post-dig treatment. Pre-dig egg counts were similar for both the upper and lower intertidal zones. The increase in egg counts after digging in the lower intertidal zone was more than 50% less than post-dig counts in the upper intertidal (upper beach), the primary egg laying zone for horseshoe crabs.

Table 10 ANOVA table comparing log-transformed egg counts (post-dig counts) between the high (upper) intertidal and lower intertidal zones at Moore’s Beach

	Num DF	denDF	F-value	p-value
Treatment	1	10	113.6341	<0.0001
Intertidal	1	10	3.1194	0.1078
Treatment: Intertidal	1	10	2.7398	0.1289

Table 11 Comparison of plot means for treatment egg counts between the upper intertidal and the lower intertidal sections of Moore's Beach

Treatment and Effect	N	Egg Count Mean
Effect averaged over Pre- and Post-dig		
Upper Intertidal Zone	12	2,399.9375
Lower Intertidal Zone	12	971.2292
All Plots	24	1,685.5833
Effect when Treatment = Pre-dig		
Upper Intertidal Zone	6	33.62500
Lower Intertidal Zone	6	25.41667
All Plots	12	29.52083
Effect when Treatment = Post-dig		
Upper Intertidal Zone	6	4,766.250
Lower Intertidal Zone	6	1,917.042
All Plots	12	3,341.646

Figure 11 Moore’s Beach High Intertidal (upper beach) vs. Low Intertidal (lower Beach) pre-dig vs. post-dig average egg count per plot

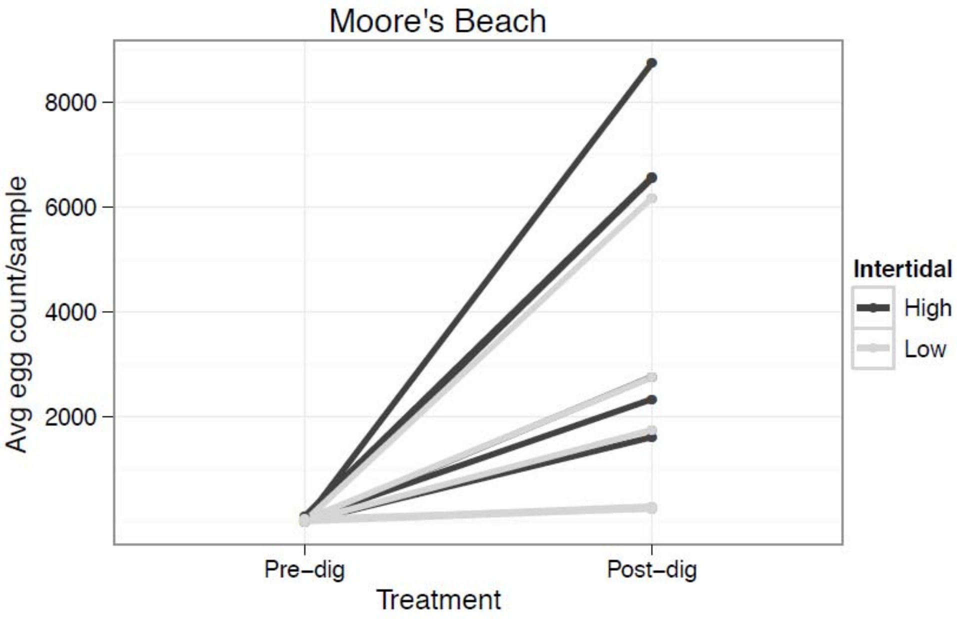
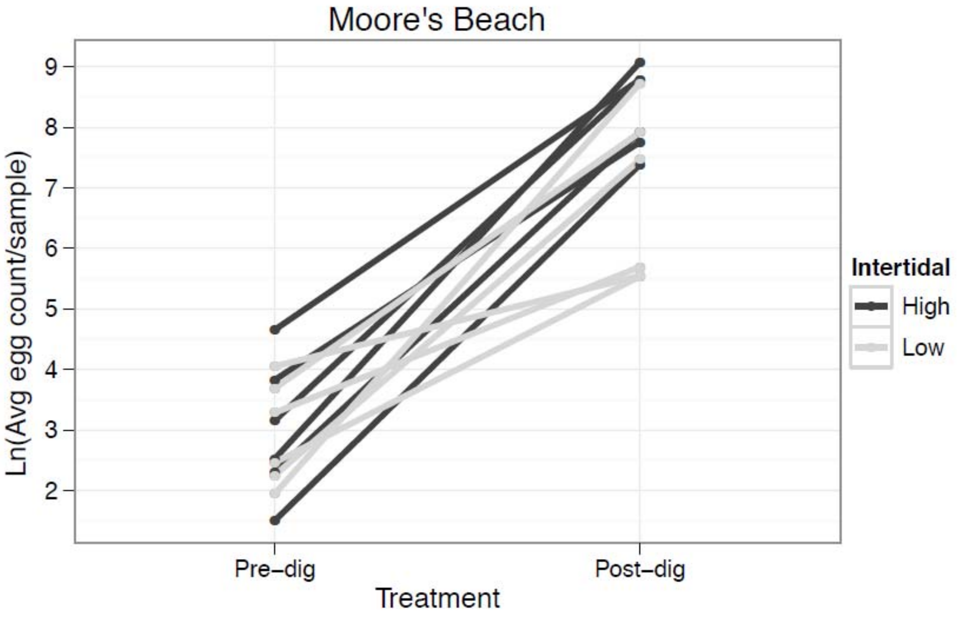


Figure 12 Moore’s Beach High Intertidal (upper beach) vs. Low Intertidal (lower Beach) pre-dig vs. post-dig log transformed average egg count per



plot

4.2 Trenching experiment

No quantitative egg count data were taken during the trenching experiments at Gandy's and Cook's Beaches. Increased bird usage was photographically documented. We assumed that there was an increase in egg availability based on the higher number of shorebirds foraging on surfaces receiving sand-egg sediments derived from ditches.

Photos 9 and 10 show feeding birds concentrated inside the trench and within 2 m wide strips on the left side of the trenches where the sand-egg mixture was spread as shown in the photos. The trenches were an effective method for luring birds up the beach away from the incoming tide-front to egg-enhanced sand, which in turn, increases foraging time on substrate with higher egg densities. It is essential that they detect egg-enhanced surfaces quickly to maximize their benefits. Comparing detection rates between the trenched beaches vs. beaches turned over with a clam rake, shorebirds detected the trenched beach surfaces faster, in greater numbers and had more time to forage than on beach surfaces turned over with clam rakes. Scattering thin layers of egg-enhanced sediments over greater areas of beach provides a larger footprint of egg-enhanced beach surface. The trenches extended far into the intertidal zone allowing shorebirds to find egg-enhanced surfaces sooner, which in turn guided them up the beach. In addition, trench digging is less labor intensive and disturbs less horseshoe crab breeding habitat than turning the beach over without spreading.

Photo 9 Freshly dug trenches at Gandy's Beach. Birds populated the trenched section of beach within 20 minutes of digging as shown in the next photograph.

Photo 9 Broad view of Gandy''s Beach trenches with feeding birds. This photograph was taken 20 minutes after the trenches were excavated (see above photograph).

Photo 10 Close-up of shorebirds feeding on horseshoe crab eggs in a shallow trench and on the sand-egg mixture tossed to the left side. Note the darker colored sand on the left slope of the ditch. The darker coloration was created by thousands of shorebird probe holes, which are clearly visible under magnification. Shorebirds included red knot, semipalmated sandpiper, ruddy turnstone, sanderling, and white-rumped sandpiper.

Laughing Gull Distraction Experiments

We placed the artificial fish food Aquamax in test plots to attract laughing gulls away from shorebird feeding areas. Aquamax is approximately the same size as horseshoe crab eggs, although their size approximately doubles after inundation by seawater. In 2008, we demonstrated that two 1 by 1.4 m plots of Aquamax placed in the upper beach zone attracted over 1,300 laughing gulls away from a kilometer of prime shorebird feeding habitat at Reed’s Beach for five hours, leaving more crab eggs for shorebird consumption (Famous et al., 2008). These experiments were conducted during a year when the numbers of horseshoe crab eggs were very low.

In 2009, we established test plots containing Aquamax at the north end of Reed’s Beach. In contrast with 2008, horseshoe crab eggs were abundant along New Jersey Bay beaches in late May (Photos 11 and 12. Under these conditions, laughing gulls were not attracted to our Aquamax plots. Most gulls foraged along the incoming tide front where horseshoe crab eggs were clearly visible or they rested in small groups along the water/beach interphase.

In addition to the plots, we spread Aquamax in parallel lines and in small patches along Reed’s Beach and monitored shorebird and laughing gull behavior during the incoming tide front as it inundated the chow. Shorebirds including semipalmated sandpipers

(90% of the shorebirds present at Reed's Beach), dunlin, sanderlings, ruddy turnstones and white-rumped sandpipers, typically foraged within a meter of the wave-wash zone along the incoming tide front, traveling in lines parallel to the beach. Semipalmated sandpipers and sanderlings passing through patches of Aquamax, typically paused for 30 to 45 seconds to feed, whereas birds typically continued to move through sections of beach without Aquamax as they foraged parallel to the beach following the in-and-out motion of the waves. After encountering an Aquamax deposit, semipalmated sandpipers typically foraged within the deposit as the incoming tide front reached the food (Photos 2 and 13). Birds were not, however, attracted to patches of Aquamax greater than a meter above the wave wash zone.

Although we did not conduct controlled food selection studies within a statistical framework, shorebirds appeared to consume Aquamax as encountered rather than being attracted to it. Laughing gulls may not have been attracted to Aquamax in 2009 because horseshoe crab eggs were in adequate supply. During years or portions of May when horseshoe crab eggs are limiting, small-sized artificial foods such as Aquamax should be an effective tool for luring laughing gulls away from shorebird feeding habitat, effectively leaving more eggs for red knots and other shorebirds.

Photo 11 Horseshoe crab eggs formed dark dull grey lines parallel to ripple marks over many acres at High's Beach

Photo 12 Incoming tide flooding horseshoe crab egg deposits along the shore at High's Beach. Four parallel sets of high tide horseshoe crab egg strand lines were present along the upper beach, indicating an abundant laying.

Photo 13 Semipalmated sandpiper feeding on Aquamax at Reed's Beach

Summary and Conclusions

The long-term objective of the Red Knot Survival Project is to have heavier birds leaving Delaware Bay each spring. Our short-term objective for 2009 was to document that turning over beach sediments to increase horseshoe crab egg availability was a viable, ecologically sound method for increasing egg densities for red knots and other shorebirds. Using simple tools, we demonstrated statistically significant ($p=0.001$) increases in egg availability within the upper 5 cm of shorebird feeding habitat. The concept of increasing egg availability is designed to provide a temporary 'life boat' to help red knot populations ride out present food shortages while horseshoe crab populations rebound, which is predicted to take a minimum of 8-12 years (Federal Register 2006). Assuming a moderate horseshoe crab population recovery, our food-enhancement methods can be applied on any suitable beach where horseshoe crabs nest during years or specific portions of the spring migration when egg availability is insufficient.

Our most relevant findings are presented below,

- Turning over beach surfaces with clam rakes and shovels resulted in a highly significant increase in horseshoe crab egg availability for red knots and other shorebirds.
- Turning over the same beach surface the following day resulted in a highly significant increase in egg availability.
- The high level of eggs remaining within egg-incubation habitat (e.g., proper moisture and temperature regimes) after digging suggests that many displaced eggs may remain viable.
- Shorebirds were attracted in high numbers to sections of beach with enhanced egg densities.
- Trenched portions of beaches attracted greater numbers of shorebirds than beach turned over by clam rakes.
- Spreading sand-egg mixtures over adjacent beach surfaces is more efficient than turning over and not spreading the sand-egg mixture (e.g., using a clam rake) in terms of square meters of 'donor' beach needed to provide an equal surface area of enhanced egg availability, thus fewer egg masses are disturbed.
- Early detection by shorebirds of egg enhanced beach surfaces will provide longer foraging time and more efficient use of disturbed horseshoe crab egg masses. Trenches directly led shorebirds up the beach to egg-enhanced feeding habitat ahead of the incoming tidal front, providing more foraging time on egg enhanced beach surfaces.

- Egg mass distribution on beaches was not evenly spaced, confirming other studies (Fraser et al., 2010).

- Egg mass distribution within plots was also uneven, as both low and high (highly significant) increases in within-plot egg counts were not uncommon.

- Turning sediments over in both the upper and middle to lower intertidal zones at Moore’s Beach yielded a highly significant increase in egg counts compared to undisturbed substrate.

- The increase in egg number per sample in the middle to lower intertidal zone was less than increase in egg counts in the upper intertidal zone, reflecting expected lower nest densities away from the upper beach.

- Pre-treatment (pre-dig) egg counts in the middle to lower intertidal zone was similar to pre-treatment counts in the upper intertidal, which is likely related to wave action flooding or floating eggs out of the mineral substrate, which is comprised of heavier particles.

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