Final Report

Submitted to the New Jersey Department of Environmental Protection, Division of Fish and Wildlife for the following project:

Project Title: A Pilot Trap Survey of Artificial Reefs in New Jersey for Monitoring of Black Sea Bass, Tautog, and Lobster

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Introduction

Three of the most important target species of commercial and recreational fisheries in New Jersey are structure-associated species that may not be sampled effectively by existing scientific trawl surveys. Black sea bass (*Centropristis striata*) are commonly targeted by commercial and recreational fisheries along the U.S. Atlantic coast. In 2015, black sea bass were the second most commonly caught target species by recreational anglers both along the entire Atlantic coast (13 million fish: NMFS, 2016) and in New Jersey (2.4 million fish: NMFS, 2017). Similarly, Tautog (*Tautoga onitis*) are also one of the most important target species of marine recreational fisheries in New Jersey (i.e., #5 by numbers: NMFS, 2017). American lobster (*Homerus americanus*) support a valuable commercial fishery in New Jersey, with the dockside value ranging from $2.2-$4 million in recent years (NMFS, 2017). While all three of these species are captured in trawl surveys, they are believed to primarily inhabit rocky reefs and wrecks, which are generally avoided by vessels fishing with bottom trawls. As a result, the reliability of scientific bottom trawl surveys for providing an index of relative abundance for these species is uncertain.

Black sea bass are a member of the family Serranidae (sea basses and groupers) and are found in estuaries (juveniles) and structured bottom habitat from the Gulf of Maine to the Gulf of Mexico (Drohan et al. 2007). In the Mid-Atlantic Bight, black sea bass undergo a seasonal migration in the fall from their inshore spring and summer habitat to deeper continental shelf waters (Musick and Mercer 1977, Moser and Shepherd 2009). Black sea bass is a protogynous hermaphrodite; individuals which begin life as females undergo sex change and become males later in life. The species supports important recreational and commercial fisheries throughout much of its range and is separated into two stocks in the Atlantic at Cape Hatteras, NC. The most recent stock assessment for the northern stock of black sea bass concluded that the stock is not overfished and overfishing is not occurring (NEFSC, 2017).

Several research priorities for black sea bass were identified in a previous stock assessment and an associated review (Miller et al. 2009), including (1) improving estimates of the natural mortality rate (M) and potential changes in M with age; (2) examining stock structure and the possible existence of sub-stocks; (3) development of a stock-wide trap survey; (4) understanding the impact of fishing on the sex ratio and the implications for fecundity and spawning success. This project focuses on item #3 from above, or the development of a trap survey. A previous tagging study (Provost et al., 2017), a population model (Robinson et al., 2017), and a review of stock assessment of hermaphroditic fishes (Provost and Jensen, 2015) by the PI and his research team have already addressed item #4 and provided useful preliminary data to aid in the development of a trap survey off New Jersey.

Tautog are a temperate wrasse (family Labridae) found in hard bottom habitat from South Carolina to Nova Scotia with the core range of the population from Massachusetts through Virginia (Steimle and Shaheen 1999). Like black sea bass, Tautog show seasonal onshore (in spring) and offshore (in fall) movements (Steimle and Shaheen 1999), though this seasonal migration is less pronounced than that of black sea bass and some individuals remain inshore over the winter (Arendt et al. 2001). Tautog are long-lived (maximum age > 30 years; ASMFC, 2015a) and thus potentially vulnerable to overfishing, though this may be somewhat offset by their early age at maturity (3-4 years, White et al. 2003). Growth rates and weight-at-age vary considerably throughout the species' range and samples from New York and New Jersey show substantially lower weight-at-age than those from other states (ASMFC, 2015a). A benchmark stock assessment conducted in 2014 (ASMFC, 2015a) concluded that tautog are overfished throughout the stock, but that overfishing is only occurring in the New England states (i.e., north of New York).

American lobster range from Newfoundland to Cape Hatteras, but are most abundant from Nova Scotia to Cape Cod. New Jersey is the southernmost state with a significant (i.e., over $1 million) lobster fishery. Because hard parts of lobster are shed during molting, aging is difficult and is most often based on analysis of lipofuscin concentration in neural tissue. A maximum age of approximately 100 years has been proposed (Cooper and Uzman 1980). The most recent stock assessment for the Southern New England (SNE) lobster stock, which includes New Jersey waters, concluded that the stock is "severely depleted", but that overfishing was not occurring (ASMFC 2015b). There is evidence of extremely low recruitment for the SNE stock in recent years. State surveys from New York through Massachusetts indicate that shell disease has become more prevalent in lobsters in this region beginning in the 1990s (ASMFC, 2015b); however, there are no consistent data on shell disease prevalence through time in New Jersey. There are two lobster conservation and management areas (LCMAs) off of New Jersey: LCMA 4 from roughly Barnegat Inlet north and LCMA 5 to the south. Both areas have instituted management measures to achieve a mandated 10% reduction in fishing effort in recent years, which included measures such as v-notching, release of all egg-bearing females, and seasonal closures.

In addition to the three target species, this trap survey also provides valuable information about stocks of several other species that are targeted by recreational or commercial fisheries. These species include scup (*Stenotomus chrysops*), Jonah crab (*Cancer borealis*), and rock crabs (*C. irroratus*). While scup have an accepted stock assessment, the two Cancer crab species do not. Growing fisheries and markets for these species, as well as legal mandates to assess all species targeted by fisheries in Federal waters, indicate that there will be a growing need for stock assessment of these crab species. The commercial and recreational fisheries for Jonah crab have been managed by the Atlantic States Marine Fisheries Commission since 2015. Given the lack of a fishery-independent trap survey in New Jersey waters, there will be very little data specific to our state that could be included in stock assessments for Cancer crabs.

Stock assessment scientists and fishery managers have long recognized the need for trap or other fixed-gear surveys to monitor structure-associated species, but there have been few attempts in the northeast to develop such a survey on broad temporal or spatial scales. The most recent attempt for a trap survey was the University of Rhode Island Ventless Trap Survey (hereafter "RI survey"), which used commercial fish traps fished at 16 stations within four zones from Massachusetts through Virginia, including New Jersey (Borden et al., 2013). A review of this survey by the Scientific and Statistical Committee of the Mid-Atlantic Fishery Management Council (Jones et al., 2014) concluded that "…the survey sampling design was problematic for allowing the use of the survey as a measure of abundance for black sea bass in stock assessments." Specifically, the review panel identified five issues with the survey design: "1) spatial distribution of the stations, 2) lack of comparison among captains, 3) lack of tests to determine if gear shows a saturation effect, 4) unbalanced sampling between regions, and 5) data analysis that doesn't account for sampling design." This SSC review was highly influential and any future fixed-gear surveys will need to address these concerns before they are likely to be used in stock assessment for black sea bass or other species.

An additional concern relevant to any fixed gear survey is the ability of that survey to provide a reliable index of relative abundance. That is, if the abundance of a target species in the greater vicinity of the survey doubles, the survey CPUE should also double. This should be true regardless of the absolute level of abundance. In other words, there should be a consistent linear relationship between the survey CPUE and actual abundance. In practice, survey indices show both random noise as well as some degree of non-linearity in their relationship to abundance (Harley et al. 2001). When the processes leading to noise and non-linearity are understood, the survey CPUE can be corrected for these effects. One source of both noise and non-linearity in trap surveys could be trap saturation or carrying capacity, whereas, a finite number of individuals would enter or can fit inside a trap. Another source is priority effects, whereby the presence of one organism in a trap alters the subsequent catch rate. Priority effects can be positive or negative depending upon the species involved. In summer 2013, we conducted a priority effects experiment on black sea bass at five wrecks on or near the Little Egg Inlet Reef. We compared the CPUE of traps seeded with either a male or a female black sea bass with unseeded control traps. We found that traps seeded with a female black sea bass had higher CPUE of both male and female black sea bass relative to the control (Kwityn et al. *In prep*). The effect was statistically significant and large; trap CPUE nearly doubled in the female seeded traps. Traps seeded with a male black sea bass showed either no difference relative to the control (for male CPUE) or a slight but significant decrease in CPUE (for female CPUE). There was no impact of the black sea bass seed on CPUE of tautog. The impact of seeding traps with tautog or lobster, both frequently captured in the traps, on CPUE of conspecifics or other species remains untested.

The relative lack of natural hard bottom off of New Jersey has driven the development and expansion of a large artificial reef program including 15 federally permitted reef sites containing more than 4,000 patch reefs (Figure 1; Resciniti et al., 2009). The program has been popular with recreational anglers who have provided much of the funds to purchase and deploy the materials used in creating these reefs either through donations or through the U.S. Fish and

Wildlife Sportfish Restoration Act, which includes funds from excise taxes on fishing gear and boat fuel. More than 75% of surveyed anglers have reported their fishing success on New Jersey's artificial reefs to be "good" or "excellent" (NJDEP 2010). Relative to the importance of these reefs to New Jersey's recreational fisheries and diving industry, there has been little in the way of scientific studies focused on understanding their ecology or evaluating their effectiveness at increasing productivity of target species. A 1998 NJDEP study found that the total biomass of marine organisms on artificial reefs was many times higher than that of natural sand bottom. Monitoring of artificial reefs in New Jersey has continued, though more extensive investigation is required to continue informing the activities of the NJDEP Artificial Reef Program.

As development of New Jersey's artificial reef network continues*, a key question is which materials provide the highest catch rates of target species*. While there are many different factors, including cost and durability, that determine which materials are best for artificial reefs, the ultimate goal is to enhance fishing opportunities. The two most widely utilized classes of artificial reef materials are concrete, including reef balls, castings, and demolition concrete, and primarily metal structures, including steel-hulled ships and tanks and stainless steel subway cars. There have been relatively obvious problems with the structural stability of some subway cars, but in general, the performance of different materials in attracting and retaining target species of commercial and recreational fisheries remains unexamined.

Project Objectives

The overall project goals are to: **(I)** characterize the seasonal and spatial variation in community composition and relative abundance of structure-associated species on artificial reefs off of New Jersey and **(II)** to provide the information necessary to design a statistically robust trap survey for New Jersey. The first goal provides immediate utility for New Jersey fishery managers through a characterization of seasonal changes in the fish and invertebrate communities inhabiting two artificial reefs. A comparison of fish and invertebrate abundance between different artificial reef materials also provides immediate utility for the NJDEP Artificial Reef Program. The second goal is a necessary step before a reliable and efficient trap survey can be developed that will stand up to the rigorous peer review process associated with stock assessment. The originally proposed project objectives were to:

1) Characterize seasonal changes in the fish and invertebrate communities of the Sea Girt and Little Egg Inlet reefs and differences between these two sites.
2) Evaluate possible differences in community composition and abundance between two of the most commonly used artificial reef materials: concrete-based structures (reef balls, castings, and demolition concrete) and primarily metal structures (tanks, ships & barges, and subway cars).
3) Characterize the statistical distribution of catch-per-unit-of-effort (CPUE) on hard and soft bottom for the three target species and any other species that are captured in sufficient numbers.
4) Assess spatial autocorrelation in trap CPUE for the three target species and any other species that are captured in sufficient numbers.
5) Assess the influence of soak time and priority effects on trap CPUE for the three target species and any other species that are captured in sufficient numbers.
6) Develop survey design recommendations for a long-term trap survey that can provide a statistically valid index of relative abundance for the three target species.

The research objectives were expanded while the project was in-progress. In 2017, the NJDEP Artificial Reef Program began construction of a new artificial reef, or the Manasquan Inlet Reef, which is located ~2 nautical miles east of the Manasquan Inlet. The construction of a new artificial reef provided an excellent research opportunity to collect baseline data before reef construction, and these data were of great interest to biologists working for the NJDEP Artificial Reef Program. Therefore, two additional project objectives were developed:

7) Characterize the seasonal variation in community composition and relative abundance of the three target species, and any other species that are captured in sufficient numbers, at the site of the new Manasquan Inlet Reef.

8) To provide a comparison of fish and invertebrate abundance at the Manasquan Inlet Reef site before and after deployment of the artificial reef materials or to provide a robust baseline for future before-after comparison if deployment of artificial reef materials is delayed beyond the period of this study.

Methods

Study Design – Locations and Times

The project focused on three artificial reefs off of New Jersey: Sea Girt, Little Egg reef, (Figure 1), and Manasquan Inlet Reef (Figure 4). As requested in the solicitation, one reef (Sea Girt) is north of Barnegat Inlet and one (Little Egg) is to the south.

To address objectives 1-3 above, 21 traps were deployed at the Sea Girt and Little Egg reefs for a total of 42 traps. An additional 6-12 traps were deployed at the Manasquan Inlet Reef site during different stages of reef construction. The total trap number at each reef was limited by the number of traps that a field crew can retrieve, process, and replace within a work day (daylight hours). Six traps were deployed on each of three bottom types (soft, concrete structure, metal structure) at each of the two reefs (Sea Girt and Little Egg). Initially, 12 traps were deployed on soft bottom. After construction, one trap was deployed on the new metal structure and two traps were deployed on the new concrete structures. Locations of the traps on the concrete and metal structures were randomly selected from published coordinates of different artificial patch reefs within the two sites (Resciniti et al. A guide to fishing and diving New Jersey reefs). Locations of the traps on soft bottom were randomly selected from within a buffer strip 1-3 km from the artificial reef boundary. The one km inner buffer was designed to prevent selection of soft bottom sites influenced by the nearby artificial reef. The three km outer buffer was designed to ensure that soft bottom sites represent the same local species pool and are easily accessible within the same sampling trip.

Two to four additional traps were deployed at each site to provide sufficient data for analysis of spatial autocorrelation (objective 4). The locations of these traps were determined after the other 18 trap locations were randomly selected. The locations of these spatial autocorrelation traps were selected to fill gaps within different distance bins of the variogram (a graph used to describe spatial autocorrelation). These non-randomly placed traps were excluded from analysis addressing objectives 1-3, where randomization was required for data analysis.

Traps were deployed for three survey periods: a Spring survey in March – April, a Summer survey in June – August, and a Fall Survey in October – November. A Winter survey was considered but rejected because of the logistical difficulties (e.g., ice cover in marinas and at boat ramps, frequent severe weather conditions on the roads and at sea) and because one of the main target species, BSB, migrates offshore to deeper water in the winter. The Spring and Fall surveys were timed to capture the arrival and departure, respectively, of BSB on New Jersey artificial reefs. Traps were deployed for four weeks, i.e., four retrievals, each season.

Protocol - Field and Laboratory Methods

To permit comparison with previous research conducted elsewhere in the mid-Atlantic, traps were identical to those used in the RI survey (which included stations in New Jersey and other mid-Atlantic states). Traps are made of marine grade vinyl coated wire. Outer dimensions of the traps are 43 ¾ L x 15 H x 22 ½ W and each trap is weighted with two four-pound metal bricks. Traps were purchased from Ketcham Supply Corp. in New Bedford, MA. This is the same company that built the traps for the RI survey. Traps were deployed on individual lines attached to a surface buoy. Buoys were marked with the words "Rutgers Research" and the phone number of the project PI to distinguish the traps from commercial fishing gear and to encourage concerned anglers or divers to contact the PI rather than disturbing the traps.

Trap deployment and final retrieval were conducted the R/V Roccus (27' center console), the R/V Resilience (25' pilot house), and the R/V Reef Bound (25' pilot house).

Trap retrievals occurred every 5 – 9 days with a target of 7 days and a two-day window on either side to allow for weather. This soak time is typical of soak times used in the commercial fish trap fishery in New Jersey and used by the PI on a previous project on Little Egg Reef. All fish and macroinvertebrates > 2 cm (maximum length) captured in the traps were identified and measured. Smaller individuals are rarely captured as they fall through the trap mesh. Sex was determined for all lobster via visual inspection of the pleopods. Sex was determined for black sea bass by manually expressing milt or eggs or, when necessary, via gonadal biopsy using a polypropylene cannula.

2016 Spring Seasonal Monitoring of Artificial Reefs

In March 2016, the deployment locations were selected for the seasonal (i.e., spring, summer, fall) monitoring of both the Sea Girt Reef (Figure 2) and the Little Egg Inlet Reef (Figure 3). There were 22 traps deployed on each reef, including six metal and concrete structures that were randomly selected from all of the NJDEP material deployments on each reef, six sand sites that were randomly selected within a 1-3 km buffer from each reef boundary, and four stations included to assess spatial autocorrelation in trap catch-per-unit-effort (CPUE) by filling gaps within different distance bins of a variogram.

Sea Girt Reef

All trips to the Sea Girt Reef were completed aboard the *R/V Roccus*. Following delays due to rough weather conditions, the 22 traps were deployed for the spring monitoring periods on the Sea Girt Reef on April 10. The traps deployed on the Sea Girt Reef were hauled on April 18, April 25, and May 1. The final trap hauls during the spring monitoring period on the Sea Girt Reef occurred on three separate dates (May 7, May 9, and May 12) due to weather and crew availability. The traps were brought on land after each of these trips and stored until redeployment for the summer. A total of three traps were lost on the Sea Girt Reef during the spring (April 18 – SG21 was missing; April 25 – SG17 was missing; SG2 was missing on May 7).

Little Egg Inlet Reef

The first attempt to deploy traps for the spring seasonal monitoring of the Little Egg Inlet Reef occurred on March 28 aboard the *R/V Reef Bound*. However, this trip was abandoned due to mechanical issues with the vessel's engines. All 22 traps were later successfully deployed on the Little Egg Inlet Reef on March 30 aboard the *R/V Reef Bound*. The traps deployed on the Little Egg Inlet Reef were hauled on four occasions, including April 6 aboard the *R/V Reef Bound*, April 20 aboard the *R/V Resilience*, April 28 aboard the *R/V Resilience*, and on May 7 aboard the *R/V Resilience*. An additional attempt was made to haul traps on the Little Egg Inlet Reef on April 13 aboard the *R/V Arabella*. However, this trip was abandoned during the steam out to the reef due to rough weather conditions. At the end of the trip on May 7, the gear was brought back on land and stored for deployment again during the summer. A total of two traps were lost on the Little Egg Inlet Reef during the spring (April 6 – LE18 was missing; May 7 – LE11 was missing).

2016 Summer Seasonal Monitoring of Artificial Reefs

Sea Girt Reef

All trips to the Sea Girt Reef were completed aboard the *R/V Roccus*. Following the last haul for the soak time experiment on June 21, the traps were shifted to the 22 seasonal monitoring locations (Figure 2) for the summer period. The traps deployed on the Sea Girt Reef were hauled on June 29, July 4, July 16, and July 25. A total of eight traps were lost on the Sea Girt Reef during the summer (June 29 - SG2 and SG11 were missing; July 4 - SG9 was missing; July 16 – SG11, SG12, SG20, and SG22 were missing; July 25 – SG7 was missing).

Manasquan Inlet Reef

Additional traps needed to be purchased in order to survey the Manasquan Inlet Reef (Figure 4). Another order of traps (n=20) was placed with Ketcham Traps and they were delivered in time for deployment during the same trip when traps were hauled on the Sea Girt Reef on July 16. A total of twelve traps were deployed on the Manasquan Inlet Reef at the same locations where scientists from the NJDEP Artificial Reef Program completed sediment sampling (Figure 5). These twelve traps were hauled on July 25, August 4, August 9, August 18, and August 24. Note that an additional trip was made out to the Manasquan Inlet Reef on August 1, but only one trap was hauled and the trip was then abandoned due to rough weather conditions. One trap was lost on the Manasquan Inlet Reef during the summer (MI4 was missing on August 4).

<u>Little Egg Inlet Reef</u>

On June 27, traps were deployed at the 22 sites for the summer seasonal monitoring period of the Little Egg Inlet Reef. These 22 traps were hauled on July 6, July 15, July 21, and July 27. All trips to the Little Egg Inlet Reef during the summer were completed aboard the *R/V Reef Bound*. One trap was missing on Little Egg Inlet Reef during the summer (July 15 – LE19 was missing).

2016 Fall Seasonal Monitoring of Artificial Reefs

<u>Sea Girt and Manasquan Inlet Reefs</u>

All trips to the Sea Girt and Manasquan Inlet Reefs were completed aboard the *R/V Roccus*. For the fall seasonal monitoring period, a total of 22 traps were deployed on the Sea Girt Reef and twelve traps were deployed on the Manasquan Inlet Reef. These traps were hauled on October 18, October 30, November 8, and November 18. A total of four traps were lost on the Sea Girt Reef during the fall (SG3 was missing on October 18; SG17 was missing on October 30; SG17 was missing on November 8; SG16 was missing on November 18). No traps were lost on the Manasquan Inlet Reef during the fall.

Little Egg Inlet Reef

The 22 traps for the fall seasonal monitoring period of Little Egg Inlet Reef were deployed on October 13 aboard the *R/V Resilience*. These traps were hauled on October 26, November 3, November 9, and November 16, all of which was completed aboard the *R/V Reef Bound*. One trap was lost on Little Egg Inlet Reef during the fall (LE3 was missing on November 3).

2017 Spring Seasonal Monitoring of Artificial Reefs

In April 2017, there were 22 traps deployed on Sea Girt Reef (Figure 2) and 22 traps deployed on Little Egg Inlet Reef (Figure 3). On each reef there were six metal and concrete structures that were randomly selected from all of the NJDEP material deployments on each reef, six sand sites that were randomly selected within a 1-3 km buffer from each reef boundary, and four stations included to assess spatial autocorrelation in trap catch-per-unit-effort (CPUE) by filling gaps within different distance bins of a variogram. In addition, 12 traps were deployed on the sand within the boundary of the planned Manasquan Inlet Reef (Figure 5).

Sea Girt Reef and Manasquan Inlet Reef

All trips to the Sea Girt Reef and the planned Manasquan Inlet Reef were completed together aboard the *R/V Roccus*. The 22 traps on the Sea Girt Reef and the 12 traps on the planned Manasquan Inlet Reef site were deployed for the spring monitoring period on April 3. The traps were hauled on April 14, April 20, April 30, and May 9. The traps were brought on land after the final trip and stored until redeployment for the summer. A total of eight traps were lost on the Sea Girt Reef during the spring (April 14 – SG8 was missing; April 20 – SG17 was missing; April 30 – SG13, SG20, and SG19 were missing; May 9 – SG4, SG11, and SG19 were missing). A total of four traps were lost on the planned Manasquan Inlet Reef site during the spring (April 14 – MI11 was missing; April 30 – MI1 was missing; May 9 – MI2 and MI1 were missing).

Little Egg Inlet Reef

The 22 seasonal monitoring traps were deployed on the Little Egg Inlet Reef on April 2 aboard the *R/V Resilience*. The traps deployed on the Little Egg Inlet Reef were hauled on four occasions, including April 12 aboard the *R/V Resilience*, April 18 aboard the *R/V Resilience*, April 27 aboard the *R/V Resilience*, and on May 4 aboard the *R/V Resilience*. At the end of the trip on May 4, the gear was brought back on land and stored for deployment again during the summer. A total of four traps were lost on the Little Egg Inlet Reef during the spring (April 18 – LE10 was missing; April 27 – LE4 was missing; and May 4 – LE3 and LE21 were missing).

2017 Summer Seasonal Monitoring of Artificial Reefs

Sea Girt Reef

All trips to the Sea Girt Reef were completed aboard the *R/V Roccus*. The 22 seasonal monitoring traps were deployed for the summer period on June 29. The traps deployed on the Sea Girt Reef were hauled on July 6, July 13, July 20, July 26, and August 1. A total of ten traps were lost on the Sea Girt Reef during the summer (July 6 – SG18, SG14, and SG7 were missing; July

13 – SG5 was missing; July 20 – SG2, SG3, and SG12 were missing; July 22 – SG2 was missing; and August 1 – SG14 and SG7 were missing).

Manasquan Inlet Reef

All trips to the Manasquan Inlet Reef were made in conjunction with the trips to Sea Girt Reef aboard the *R/V Roccus*. Initially only 6 traps (MI6, MI8, MI9, MI10, MI11, and MI12), half of the original 12 traps locations, were deployed on the Manasquan Inlet Reef on June 29 (Figure 6). The remaining six traps could not be deployed due to the planned material deployments on the reef site. The traps were hauled on July 6 and three additional traps (MI13, MI14, and MI15) were deployed on the coordinates of the new reef structure. The remaining hauls occurred on July 13, July 20, July 26, and August 1. A total of one trap was lost on Manasquan Inlet Reef during the summer (July 26 – MI15 was missing).

Little Egg Inlet Reef

On June 28, traps were deployed at the 22 sites for the summer seasonal monitoring period of the Little Egg Inlet Reef. These 22 traps were hauled on July 5 aboard the *R/V Resilience*, July 12 aboard the *R/V Reef Bound*, July 19 aboard the *R/V Reef Bound*, July 27 aboard the *R/V Resilience*, and August 3 aboard the *R/V Resilience*. A total of four traps were missing on Little Egg Inlet Reef during the summer (July 12 – LE9 was missing; July 27 – LE15 and LE2 were missing; and August 3 – LE19 was missing).

2017 Fall Seasonal Monitoring of Artificial Reefs

Sea Girt and Manasquan Inlet Reefs

All trips to the Sea Girt and Manasquan Inlet Reefs were completed aboard the *R/V Roccus*. For the fall seasonal monitoring period, a total of 22 traps were deployed on the Sea Girt Reef and nine traps were deployed on the Manasquan Inlet Reef on October 7. These traps were hauled on October 15, October 20, October 27, and November 2. A total of two traps were lost on the Sea Girt Reef during the fall (SG13 was missing on October 20; and SG19 was missing on November 2). One trap was lost on the Manasquan Inlet Reef during the fall (MI14 was missing on October 20).

Little Egg Inlet Reef

The 22 traps for the fall seasonal monitoring period of Little Egg Inlet Reef were deployed on October 6 aboard the *R/V Reef Bound*. These traps were hauled on October 19, October 27, November 3, and November 12. All of these trips were completed aboard the *R/V Reef Bound,* except for the final haul on November 12 which was completed aboard the *R/V Resilience*. Trips were attempted on October 17 aboard the *R/V Reef Bound* and on November 9 aboard the *R/V Resilience,* but were abandoned due to rough weather conditions. A total of seven traps were lost on Little Egg Inlet Reef during the fall (October 19 – LE8, LE6, and LE21 were missing; and October 27 – LE13, LE04, LE21, and LE17 were missing).

2018 Spring Seasonal Monitoring of Artificial Reefs

<u>Sea Girt Reef</u>

All trips to the Sea Girt Reef were completed aboard the *R/V Roccus*. The 22 traps on the Sea Girt Reef were deployed for the spring monitoring period on April 3. The traps were hauled on April 11, April 22, May 2, and May 14. The traps were brought on land after the final trip and stored until redeployment for the summer. A total of 12 traps were lost on the Sea Girt Reef during the spring (April 11 – SG7 and SG13 were missing; April 22 –SG14 and SG19 were missing; May 2 –SG14 was missing; May 14 –SG16 was missing).

<u>Manasquan Inlet Reef</u>

All trips to the Manasquan Inlet Reef were completed aboard the *R/V Roccus*. The 9 traps on the Sea Girt Reef were deployed for the spring monitoring period on April 3. The traps were hauled on April 11, April 22, May 2, and May 14. A total of 6 traps were lost on the Manasquan Inlet Reef during the spring (April 11 – MI13 was missing; April 22 – MI8 and MI13 were missing; May 2 – MI13 was missing, May 14 – MI3 was missing).

<u>Little Egg Inlet Reef</u>

All spring trips to the Little Egg Inlet Reef were completed aboard the *R/V Resilience*. The 22 seasonal monitoring traps were deployed on the Little Egg Inlet Reef on March 31 aboard the *R/V Resilience*. The traps deployed on the Little Egg Inlet Reef were hauled on April 9, April 21, May 1, and May 6. One trap was lost on the Little Egg Inlet Reef during the spring, LE3 on April 21.

2018 Summer Seasonal Monitoring of Artificial Reefs

Sea Girt Reef

All trips to the Sea Girt Reef were completed aboard the *R/V Roccus*. The 22 seasonal monitoring traps were deployed for the summer period on June 21. The traps deployed on the Sea Girt Reef were hauled on June 26, July 2, July 9, and July 16. A total of two traps were lost on the Sea Girt Reef during the summer (July 2 – SG5 was missing and July 9 – SG21 was missing).

Manasquan Inlet Reef

All trips to the Manasquan Inlet Reef were made in conjunction with the trips to Sea Girt Reef aboard the *R/V Roccus*. The traps were deployed on June 21 and hauled on June 26, July 2, July 9, and July 16. No traps were lost on Manasquan Inlet Reef during the summer.

Little Egg Inlet Reef

Traps were deployed at the 22 sites for the summer seasonal monitoring period of the Little Egg Inlet Reef on June 25 on the *R/V Resilience*. These traps were hauled aboard the *R/V Reef Bound* on July 3, July 10, July16, and July 28. One trap was missing on Little Egg Inlet Reef during the summer (LE1 on July 16).

2018 Fall Seasonal Monitoring of Artificial Reefs

Sea Girt

All trips to the Sea Girt Reef were completed aboard the *R/V Roccus*. The 22 traps on the Sea Girt Reef were deployed for the fall monitoring period on October 10. The traps were hauled on October 19, October 26, October 31 & November 4, and November 8. The third haul was split between October 31 and November 4 due to rough weather conditions and the fact that traps had moved significant distances in a preceding storm. A total of six traps were lost on the Sea Girt Reef during the fall (October 19 – SG6 was missing; October 26 – SG13 and SG 19 were missing; November 4 – SG17 was missing; November 8 – SG6 and SG15 were missing).

<u>Manasquan Inlet Reefs</u>

All trips to the Manasquan Inlet Reef were made in conjunction with the trips to Sea Girt Reef aboard the *R/V Roccus*. The traps were deployed on October 10 and hauled on October 19, October 26, November 4, and November 8. One trap was lost on Manasquan Inlet Reef during the fall (MI15 was missing on October 19).

<u>Little Egg Inlet Reef</u>

The 22 traps for the fall seasonal monitoring period of Little Egg Inlet Reef were deployed on October 9 aboard the *R/V Reef Bound*. These traps were hauled on October 16, October 22, October 30 & October 31, and November 8. The third haul was split between October 31 and November 4 due to rough weather conditions and the fact that traps had moved significant distances in a preceding storm. All of these trips were completed aboard the *R/V Reef Bound*. A total of three traps were lost on Little Egg Inlet Reef during the fall (October 22 – LE4 and LE5 were missing; October 30 – LE15 was missing).

Priority Effects Experiment on the Little Egg Inlet Reef

A priority effects experiment began on the Little Egg Inlet Reef on June 27, 2016, in order to evaluate whether seeding of traps with live lobster or tautog influences the CPUE of target and non-target species. As part of this experiment, 18 traps were deployed on concrete structures and they were divided into three groups to be deployed on patch reefs within the larger Little Egg Inlet Reef (Figure 7). Note that three traps also served as stations for the summer seasonal monitoring. On each patch reef, there were three traps deployed empty as controls, three traps that were seeded with live tautog (309–510 mm total length), and three traps that were seeded with live lobster (77–124 mm carapace length). The traps were redeployed after each haul, but the treatments on each patch reef were randomized before redeployment. These traps were hauled and redeployed on July 6, July 15, and July 21, and the final haul at the end of the experiment occurred on July 27.

The catch data from each trap haul was converted into CPUE data by dividing the number of individuals of a species caught by the soak time in days. Binomial generalized linear models were run on presence-absence data for each target species to assess differences between treatments.

Soak Time Experiment on Sea Girt Reef

A soak time experiment was completed from June 4, 2016, through June 21, 2016, on the Sea Girt Reef in order to determine if there is a saturation point at which trap catch-per-unit-effort (CPUE) remains constant. This experiment was originally proposed to occur on the Little Egg Inlet Reef, but was instead completed on the Sea Girt Reef because of the higher black sea bass catch rates observed on this reef during the spring and the lower costs for completing frequent trips to the northern reef site. This experiment consisted of 18 traps deployed on multiple substrates (i.e., metal structures, concrete structures, and sand) and split into three groups (Figure 8). Each group of traps was hauled at intervals of 1, 2, 3, 5, and 7 days over an 18-day study period (Figure 9).

The soak time experiment was carried out as outlined in the proposal, with slight modifications to the haul schedule for Group C due to rough weather on June 12 and June 13.

Shell Disease Monitoring

Data was collected on the presence and severity of shell disease for lobster, Jonah crabs, and rock crabs. Shell disease severity was classified by the system established by the Atlantic States Marine Fisheries Commission in 2000 and used in subsequent peer reviewed publications. This system consists of four severity categories defined by the percent of the body covered by lesions: disease free (0%), mild (1–10%), moderate (11–50%), and severe (51 – 100%) (Bethoney et al., 2011).

Binomial generalized linear models were run on the presence-absence data for each species to assess the influence of size and sex on disease prevalence.

BACI Study on Manasquan Inlet Reef

A before-after control-impact (BACI) design was used to investigate the impacts of structure deployments on the new Manasquan Inlet Reef.

Construction of the new Manasquan Inlet Reef began in the June 2017. Traps were deployed on 12 sand sites spread across the new reef area for several monitoring seasons preceding deployment (Figure 5). After the material deployments in June 2017, traps were placed on the new structure sites on Manasquan Inlet Reef, one on metal and two on concrete (Figure 6). Traps were deployed within one week of material deployment and monitored through the rest of 2017 and all of 2018. Concurrently, traps were monitored on the neighboring Sea Girt Reef both before and after the Manasquan Inlet Reef construction, providing a control group for comparison (Figure 4).

Difference in difference (DID = (mean value after treatment – mean value before treatment) – (mean value after control – mean before control)) was used to evaluate the influence of reef construction on target species abundance, target species size distribution, and community diversity.

Results

The following are results from the data collected during seasonal monitoring and experiments on Little Egg Inlet Reef, Sea Girt Reef, and Manasquan Inlet Reef from 2016-2018.

Seasonal Monitoring

The catch of black sea bass, tautog, and lobster varied spatially. Overall, black sea bass catch was significantly higher on Sea Girt Reef than on either Little Egg Inlet Reef or Manasquan Inlet reef ($p<0.0001$). There was no significant difference in catch between Little Egg Inlet Reef and Manasquan Inlet Reef ($p=0.0775$). Tautog catch was highest on Sea Girt Reef, intermediate on Little Egg Inlet Reef, and lowest on Manasquan Inlet Reef ($p<0.0001$). The catch of lobster was highest on Manasquan Inlet Reef, intermediate on Little Egg Inlet Reef, and lowest on Sea Girt Reef ($p<0.0001$) (Figure 11).

Separating mean CPUE by year demonstrates similar general seasonal trends each year, with some interannual variation. Black sea bass CPUE peaked in the summer and was relatively low in both spring and fall across both reefs and all three years. Lobster CPUE was lowest in the spring and high in the summer for both reefs across all three years, however there was variation in lobster CPUE in the fall. Tautog CPUE showed the greatest amount of inter-reef and inter-annual variation. At Sea Girt Reef, Tautog CPUE was lowest in the spring and similar in the summer and fall, except in 2018 when fall tautog CPUE was higher than summer. At Little Egg Inlet Reef, tautog CPUE in 2016 and 2017 was low in both spring and summer and peaked in the fall. In 2018, tautog CPUE on Little Egg Inlet Reef was low in both spring and fall and peaked in the summer (Figure 13).

The catch of black sea bass, tautog, and lobster varied temporally. Black sea bass catch was highest in the summer season on all three reefs ($p<0.0001$). On Little Egg Inlet Reef and Manasquan Inlet Reef, catch of black sea bass was intermediate in the fall and lowest in the spring ($p<0.0001$). In contrast, on Sea Girt Reef, black sea bass catch was intermediate in the spring and lowest in the fall ($p<0.0001$). Tautog catch was highest in the fall season on all three reefs ($p<0.0001$). On Little Egg Inlet Reef and Manasquan Inlet Reef, there was no significant difference in the catch of tautog between spring and summer ($p=0.95$). On Sea Girt Reef, tautog catch was significantly higher in the summer than in the spring ($p<0.05$). Lobster catch was lowest in the spring on both Little Egg Inlet Reef ($p<0.0001$) and Sea Girt Reef ($p<0.05$). There was no significant difference in lobster catch between summer and fall on either Little Egg Inlet Reef ($p=0.66$) or Sea Girt Reef ($p=0.12$). On Manasquan Inlet Reef, lobster catch was highest in the summer ($p<0.0001$) and there was no difference in lobster catch between spring and fall ($p=0.06$) (Figure 12).

The catch of black sea bass, tautog, and lobster was variable among the different substrate types (metal, concrete, and sand). There was no consistent pattern in the black sea bass catch rates between the three reefs. Black sea bass catch was highest on concrete on Little Egg Inlet Reef ($p<0.0001$), sand on Sea Girt Reef ($p<0.0001$), and metal on Manasquan Inlet Reef

($p<0.001$). Black sea bass catch was lowest on sand on both Little Egg Inlet Reef and Manasquan Inlet Reef ($p<0.001$) and lowest on metal on Sea Girt Reef ($p<0.0001$) (Figure 14).

The mean tautog CPUE was consistently higher on the structure (metal and concrete) sites than on sand sites at all three reefs ($p<0.0001$), with the exception of Manasquan Inlet Reef where there was no difference between tautog catch on metal and sand ($p=0.153$). There was no consistency in which structure type (metal vs. concrete) had the highest tautog catch. On Little Egg Inlet Reef, tautog catch was highest on metal structure ($p<0.0001$). On Sea Girt Reef, there was no significant difference between tautog catch on metal and concrete sites. On Manasquan Inlet Reef, tautog catch was highest on concrete structure ($p<0.05$) (Figure 14).

There was no consistent pattern in the catch of lobster of different substrates across reefs. Lobster catch was lowest on sand sites on Little Egg Inlet Reef ($p<0.0001$), equivalent across all substrate types on Sea Girt Reef ($p>0.1$), and highest on sand sites on Manasquan Inlet Reef ($p<0.005$). There was no significant difference between lobster catch on metal or concrete sites on any of the reefs ($p>0.4$) (Figure 14).

Priority Effects Experiment on the Little Egg Inlet Reef

Trap CPUE data exhibited evidence of priority effects; the presence of some species in the trap influenced the catch of other species. Lobster seeded traps caught significantly more lobsters ($p<0.0001$) and significantly fewer Jonah crabs *Cancer borealis* ($p<0.001$) than either control or tautog seeded traps. Both seeded treatments caught fewer black sea bass than the control traps, but the difference was not statistically significant ($p>0.1$). Tautog catches were very low in all treatments and no significant differences between treatments were detected (Figure 15).

To further tease apart the influence of lobster seeded traps, the lobster seeded traps were divided into traps seeded with male and female lobsters. Traps seeded with female or male lobsters caught more lobster than the control traps, regardless of the sex of the seed lobster ($p<0.01$). Traps seeded with male lobster caught significantly fewer Jonah crabs ($p<0.01$), however Jonah crab catch in traps seeded with female lobsters was not significantly different from control traps ($p>0.05$). Neither black sea bass nor tautog showed a significant difference in CPUE between male lobster seeded, female lobster seeded, and control traps (Figure 16).

Soak Time Experiment on Sea Girt Reef

Three traps were missing during the soak time experiment (SG23 and SG39 on June 14; SG27 on June 15). There were no issues with any other trap deployments during this experiment. Traps were deployed for 1 day (n=17), 2 days (n=18), 3 days (n=12), 5 days (n=18), or 7 days (n=17). The mean number of black sea bass in the catch increased from 1 day to 5 days soak time, with a reduction in the mean catch during 7 days soak times (Figure 17). Based on these results, a 5 day soak time appears optimal for black sea bass.

The catches of tautog (n=15) and lobster (n=14) were both very low during the soak time experiment, which makes it difficult to draw definitive conclusions from these results. For tautog, catches were highest during 5 days and 7 days soak times, but there was no evidence of a trap saturation point (Figure 18). No lobsters were caught during 1 day or 2 days soak times and there was an increase in catch for the longer soak times with traps soaking for 7 days having the highest catches (Figure 19). However, no pattern or saturation point was observed.

Shell Disease Monitoring

The prevalence of shell disease varied spatially, temporally, and between species. Overall, Jonah crabs had the highest level of shell disease prevalence (68.5%), while rock crabs had the lowest level (10.4%). No overarching temporal or spatial trend in shell disease prevalence was observed.

Shell disease prevalence increased with size for both males and females of all three species ($p < .05$). Female Jonah crabs have a lower prevalence of shell disease than male ($p < .05$). There was not a significant difference in prevalence of shell disease between sexes in American lobsters. There was no significant difference in shell disease prevalence between sexes in rock crabs (Figure 20).

BACI Study on Manasquan Inlet Reef

Construction of Manasquan Inlet Reef had some impact on the marine community. There was a significant increase in black sea bass CPUE after the construction of Manasquan Inlet Reef. Comparing catch before and after the construction of the Manasquan Inlet Reef, the control traps (Sea Girt Reef) had a significant increase in mean CPUE of 0.52 black sea bass per trap per day ($p<0.001$), and the treatment traps (Manasquan Inlet Reef) had a significant increase in mean CPUE of 1.59 black sea bass per trap per day. Therefore, the net increase in mean black sea bass CPUE attributed to the deployment of reef materials was 1.07 black sea bass per trap per day (Figure 21). In contrast, lobster CPUE decreased. The control traps had a significant increase in mean lobster CPUE of 0.05 ($p < .001$). The treatment traps had a significant decrease in mean CPUE of 0.23 ($p < .001$). Therefore, the net decrease in mean lobster CPUE was 0.28 lobster per trap per day (Figure 23).

There was no significant difference in the mean size of black sea bass caught before and after reef construction (Figure 22). The traps are size selective, catching fish large enough to not fit through the trap mesh, but small enough to enter the trap funnel; therefore, a change in the abundance of very small or very large fish would not be detected in the trap survey data. The construction of the Manasquan Inlet Reef had no detectable influence on community diversity (Figure 24).

Conclusions

Seasonal Monitoring

The trap survey seasonal monitoring captured spatial and temporal variation in abundance and community composition, providing useful supplementary information to trawl surveys specifically about the population dynamics within reef areas (Figures 11-14). Catch rate, both within and between species, varied by reef, season, and substrate, indicating that broad geographic and temporal sampling is necessary for a complete understanding of population dynamics on and around artificial reefs; one site or season is not representative of the others.

Tautog catch was consistently higher on structure sites than sand sites on all three reefs. However, the type of structure (metal or concrete) yielding peak catch varied between reefs. Furthermore, for black sea bass and lobster there was no consistent substrate preference between reefs (Figure 14). The variation in substrate preference between species at a given reef suggests that a combination of reef materials is needed to support the most diverse and abundant reef community. The variation in substrate preference between reefs within a given species might indicate that substrate material alone (metal, concrete, sand) does not sufficiently to capture the characteristics that determine the suitability of a substrate as habitat. For example, structure height, area, or complexity might be more important than material.

The consistently low tautog catch on sand sites compared to structure sites indicates that tautog may be particularly structure-associated. Therefore, developing fixed-gear surveys capable of sampling directly on reef structure is particularly important for assessing the population of this species.

<u>Priority Effects Experiment on the Little Egg Inlet Reef</u>

The priority effects experiment demonstrated that priority effects influence the relationship between trap CPUE and true abundance, meaning that trap CPUE may not be linearly related to abundance (Figures 15 and 16). Therefore, priority effects are a potential source of bias in trap survey data that could result in hyper-stability or hyper-depletion of the survey index and should be taken into consideration when interpreting survey data.

Additional information is needed to identify priority effects in the general seasonal monitoring dataset. Patchiness – overdispersion of CPUE – is insufficient to infer priority effects, as at least two other processes can also result in overdispersion: (1) schooling behavior; (2) shared habitat associations. More continuous information than is provided by weekly trap hauls is needed to connect survey data to hyper-stability or hyper-depletion, for example, daily catch instead of terminal catch.

The priority effects observed in this experiment may be different in different regions or different species assemblages. For example, our results demonstrating that lobster seeded traps caught significantly more lobster differ from the results of Richards et al 1983 and Addison 1995, which found that the presence of lobster in traps reduced the CPUE of other lobster. This discrepancy could result from a number of variables that differed between studies, such as location, season, population density, and the number of seed animals in the trap. Further experimentation to understand the impact of these variables would enhance the application of this study to other regions and improve the interpretation of trap survey data on a larger geographic scale.

Understanding factors, such as priority effects, that influence the relationship between trap catch and actual abundance is an important step towards informing the development of statistically-robust trap surveys that can be used to monitor spatial and temporal trends in marine community composition and inform fishery management. A manuscript is in preparation to further analyze the data from this priority effects experiment and consider the implications for broader-scale implementation of trap surveys (Berglund et al., *In prep.*).

Soak Time Experiment on Sea Girt Reef

The soak time experiment demonstrated that soak time affects the relationship between trap CPUE and true abundance. The shape of this relationship varies between species (Figures 17-19). The saturation point was observed for black sea bass, but additional experimentation including longer soak times may improve our understanding of the saturation curve for lobster and tautog. Understanding the shape of this relationship is important for improving the interpretation of trap survey data beyond dividing catch by days of soak time, a method which assumes a linear relationship between soak time and catch.

Shell Disease Monitoring

The results of the shell disease monitoring support existing literature that shell disease prevalence increases with size. This relationship is thought to be caused by the reduced frequency of molting as size increases (Castro et al., 2010). In contrast, these results do not support the existing hypothesis that, after sexual maturity, females will have higher prevalence of shell disease than males due to the lack of molting when they are egg-bearing (Figure 20).

Shell disease increases mortality and decreases reproduction and therefore presents a serious threat to the profitable crustacean fisheries of the Northwest Atlantic. Understanding the potential predictors of shell disease prevalence, such as size and sex, is important for identifying vulnerable populations and designing management measures. The trap survey shell disease monitoring has expanded the spatial extend and resolution of shell disease monitoring for Jonah crabs and American lobster and has provided some of the first shell disease monitoring for rock crabs. Continued monitoring is needed to better understand and predict shell disease prevalence and severity.

BACI Study on Manasquan Inlet Reef

From the current data, is it unclear what impact Manasquan Inlet Reef construction has had on the marine community (slight increase in black sea bass mean CPUE, slight decrease in mean lobster CPUE, no detectable impact on diversity) (Figures 21-24). The existing data spans seventeen months after initial reef construction; changes in diversity and abundance of the reef community may occur on longer time scales. In addition, the future deployment of additional materials in the reef area will provide increased sample size for structure sites. Continuing to survey Manasquan Inlet Reef in the future will provide a more complete understanding of the impacts of reef construction on the marine community.

Project Outreach and Education

At the beginning of this project, efforts were made to reach out to recreational and commercial fishermen to inform them of the project goals and notify them where traps would be deployed to reduce the risk of gear conflicts. The following links include postings about the project and additional postings will be made when final project results are available:

http://www.njfishandwildlife.com/news/2016/reeftrapsurvey.htm

http://www.njfishing.com/forums/showthread.php?t=87308

http://www.thebassbarn.com/forum/66-inshore-fishing-forum/734465-trap-survey-little-egg-sea-girt-reefs.html#post7221161

With the Rutgers' *R/V Roccus* tied up at Ken's Landing in Point Pleasant, NJ for the season there were many other opportunities to engage in dialogue about the project with members of the recreational fishery. D. Zemeckis frequently discussed the project goals and preliminary results with interested anglers in the marina, which helped to spread the word about the project and NJDEP Artificial Reef Program, including the new Manasquan Inlet Reef.

On October 7, 2016, P. Clarke and D. Zemeckis delivered presentations to the monthly meeting of the Sunrise Rod and Gun Club in Red Bank, NJ. Their presentations included an overview of the NJDEP Artificial Reef Program and the present trap survey project, respectively. The presentation of D. Zemeckis was entitled "Conducting a Pilot Trap Survey on New Jersey's

Artificial Reefs". Plans have been discussed to continue with similar presentations throughout New Jersey during the winter and spring of 2017.

On October 10, 2016, D. Zemeckis delivered a seminar presentation at the Department of Marine and Coastal Sciences at Rutgers University. The presentation was entitled "Informing the assessment and management of fishery resources through collaborative research" and half of the talk was focused on the present trap survey project.

Mattea Berglund, an undergraduate student from Brown University at the time, worked with the research team for the summer of 2016 as part of the Rutgers University Research Internships in Ocean Sciences (RIOS), which is funded through the National Science Foundation. M. Berglund assisted with all aspects of the project, including field sampling during the summer, data entry and analysis, lab work, and preparation of presentations. As part of her summer research project, M. Berglund analyzed the data from the priority effects experiment on Little Egg Inlet Reef. She continued her work on this project as an independent study for course credit through Brown University during the Fall 2016 and Spring 2017 semesters under co-supervision of D. Zemeckis and O. Jensen. The goal of her independent study was to publish an article on the priority effects experiment in a peer-reviewed journal. The current reference for the article in preparation is:

Berglund, M.K., Zemeckis, D.R., Jensen, O.P., and Clarke, P.A. *In prep*. Priority effects in fish traps in the Mid-Atlantic. Planned Journal: North American Journal of Fisheries Management.

Furthermore, M. Berglund has delivered presentations on her research:

Berglund, M., Zemeckis, D.R., Jensen, O.P., and Clarke, P. 2016. Priority effects in fish traps seeded with American lobster or tautog. Rutgers University Research Internship for Ocean Sciences – Poster Session, New Brunswick, NJ, August 12, 2016. (Poster)

In September 2016, trap catch data from this project were shared with Jeffrey Brust (NJDEP) who included preliminary analysis of these data in a working paper for the 2016 Black Sea Bass Stock Assessment Working Group entitled “Investigating the utility of inshore trawl surveys for developing black sea bass abundance indices”. Therefore, preliminary results from this project have already been considered in the stock assessment and management of black sea bass.

Stephanie Arsenault, an undergraduate student from Eckerd College at the time, worked with the research team for the summer of 2017 as part of the Rutgers University Research Internships in Ocean Sciences (RIOS), which is funded through the National Science Foundation. S. Arsenault assisted with all aspects of the project, including field sampling during the summer, data entry and analysis, lab work, and preparation of presentations. As part of her summer research project, S. Arsenault analyzed year one trap survey data from Little Egg Inlet Reef and Sea Girt Reef to explore community composition. She continued her work on this project as her senior thesis through Eckerd College, during the Fall 2017 and Spring 2018 semesters under co-supervision of D. Zemeckis and O. Jensen.

On February 28, 2017, M. Berglund delivered a presentation at the Association for the Society of Limnology and Oceanography 2017 Aquatic Sciences Meeting in Honolulu, HI. The presentation was titled “Priority effects in fish traps used to survey community composition at artificial reefs.”

On August 11, 2017, S. Arsenault presented a poster at the Rutgers University Research Internships in Ocean Sciences (RIOS) Poster Session. The poster was titled “Describing Community Composition of Artificial Reefs off New Jersey.”

On August 23, 2017, D. Zemeckis and M. Berglund delivered presentations in the Artificial Reef Symposium of the American Fisheries Society Annual Meeting in Tampa, FL. Their presentations included an overview of the trap survey project and an analysis of the priority effects conducted in the summer of 2016, respectively. The presentation of D. Zemeckis was titled "Conducting a Pilot Trap Survey to Inform the Development and Fishery Management of New Jersey's Artificial Reefs." M. Berglund's presentation was titled "Priority Effects in Commercial Fish Traps Used to Survey New Jersey's Artificial Reefs." The symposium was streamed via Facebook Live on the Florida Artificial Reef Facebook Page.

On September 16, 2017, M. Berglund ran an exhibit about the trap survey project at the Rutgers University Marine Field Station Annual Open House and gave rolling presentations as visitors moved through the exhibits. A total of 509 people attended the open house.

On October 17, 2017, D. Zemeckis delivered a presentation at the ReClam the Bay Shellfish Gardener Program in Toms River, NJ. The presentation was titled, "Conducting a Pilot Trap Survey to Inform the Development and Fishery Management of New Jersey's Artificial Reefs." Several members of the audience subsequently contacted M. Berglund and D. Zemeckis about volunteering for the trap survey project.

On October 26, 2017, M. Berglund delivered a presentation of at the Mid-Atlantic Chapter of the American Fisheries Society Annual Meeting in Dover, DE. The presentation was titled "Insights into Community Composition and Reef Development from a Pilot Trap Survey of New Jersey Artificial Reefs."

Maura Glovins, an undergraduate student from the University of South Carolina, worked with the research team for the summer of 2018 as part of the Rutgers University Research Internships in Ocean Sciences (RIOS), which is funded through the National Science

Foundation. M. Glovins assisted with all aspects of the project, including field sampling during the summer, data entry and analysis, lab work, and preparation of presentations. As part of her summer research project, M. Glovins analyzed before and after trap survey data on the new Manasquan Inlet Reef to explore impacts of the reef construction.

Therese Apuzzo, an undergraduate from Rutgers University, worked with the research team for the summer of 2018 as part of the Rutgers University Aresty Summer Science Program. T. Apuzzo assisted with all aspects of the project including field sampling during the summer, data entry and analysis, lab work, and preparation of presentations. For her research project, T. Apuzzo compared the length distribution and sex ratio of black sea bass caught in the trap survey and in the trawl survey in the same regions.

Anali Berrocal, an undergraduate from Rutgers University, worked with the research team February-July of 2018 as part of the Douglas College SUPER Program. A. Berrocal assisted with all aspects of the project including field sampling during the summer, data entry and analysis, lab work, and preparation of presentations. For her research project A. Berrocal analyzed the influenced of size and sex on shell disease susceptibility in American lobster, Jonah crabs, and rock crabs.

Kiernan Bates, an undergraduate from Rutgers University, worked with the research team September 2018 – April 2019 as a work study student. K. Bates assisted with all aspects of the project including field sampling, lab processing of samples, and data entry.

In January 2018, M. Berglund presented about the trap survey at the Staten Island School of Civic Leadership College and Career Fair in Staten Island, NY.

On July 11, 2018, D. Zemeckis conducted a workshop about the trap survey for the 4-H Connects Camp in New Brunswick, NJ. M. Berglund assisted with demonstrations.

In July, 2018, M. Berglund presented about the trap survey to Watershed Institute Summer Science Program in New Brunswick, NJ.

On August 2, 2018, T. Apuzzo presented a poster at the Aresty Summer Science Program Research Symposium in New Brunswick, NJ. The poster was titled, “To Trap or to Trawl? That is the Question.”

On August 10, 2018, M. Glovins presented a poster at the RIOS Poster Session in New Brunswick, NJ, and won second place in the best poster contest. The poster was titled “It’s a Trap: A Look at Ecological Succession After the Construction of an Artificial Reef.”

On August 21, 2018, O. Jensen delivered a presentation about the trap survey in the Fisheries Independent Surveys session of the American Fisheries Society Annual Meeting in Atlantic City, NJ. The presentation was titled “Trap Survey Development for Mid-Atlantic Artificial Reefs: Investigating Bias and Filling Data Gaps.” A. Berrocal’s poster, “Shedding New Light on Epizootic Shell Disease” was also presented by members of the research team at the conference.

On September 26, 2018, M. Glovins presented a poster at the University of South Carolina Sustainability Showcase in Columbia, SC. The poster was titled “It’s a Trap: A Look at Ecological Succession After the Construction of an Artificial Reef.”

On October 5, 2018, A. Berrocal presented a poster at the Douglas College Poster Session in New Brunswick, NJ. The poster was titled, “Shedding New Light on Epizootic Shell Disease.”

On April 26, 2019, M. Glovins presented a poster Discover University of South Carolina, in Columbia, SC. The poster was titled “It’s a Trap: A Look at Ecological Succession After the

Construction of an Artificial Reef." M. Glovins was awarded second place in the poster competition.

Throughout this project, many graduate students (Christopher Free, Christien Laber, Emily Slesinger, Zoë Kitchel, Abigail Golden), undergraduate students (Wes Bowlby, Brendan Campbell, Jenelle Estrada, Shawn Hazlett, Naomi Jainarine, Thomas Johnson, Rachael Young, Ria Kobernuss, Laura Wiltsee, Therese Apuzzo, Kiernan Bates, Sneha Sivaram, Isabella Betancourt, Anali Berrocal, Joe Bavaro), and community members (Joe Guastella, Amy Kamarainen, Richard Knowles, and Nico Preston) volunteered to help with field sampling and lab work. The involvement of these students and community members in the research contributed to the educational outreach and cost-effectiveness of this project.

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References

Addison, J. T. 1995. Influence of behavioral interactions on lobster distribution and abundance as inferred from pot-caught samples. In ICES Marine Science Symposia (Vol. 199, pp. 294-300). Copenhagen, Denmark: International Council for the Exploration of the Sea.

Arendt, M., J. Lucy, and T. Munroe. 2001. Seasonal occurrence and site-utilization patterns of adult tautog, *Tautoga onitis* (Labridae), at manmade and natural structures in Chesapeake Bay. Fish Bull. 99:519-527.

ASMFC (Atlantic States Marine Fisheries Commission) 2015a. Tautog Benchmark Stock Assessment and Peer Review Reports.

ASMFC (Atlantic States Marine Fisheries Commission). 2015b. American Lobster Benchmark Stock Assessment and Peer Review Report. Prepared by the ASMFC American Lobsters Stock Assessment Review Panel. Accepted for management used August 2015.

Bethoney ND, Stokesbury KDE, Stevens BG, Altabet MA (2011) Bait and the susceptibility of American lobsters *Homarus americanus* to epizootic shell disease. Dis Aquat Org 95:1-8.

Castro, K. M., Cobb, J., Gomez-Chiarri, M., & Tlusty, M. (2012). Epizootic shell disease in American lobsters Homarus americanus in southern New England: Past, present and future. *Diseases of Aquatic Organisms,100*(2), 149-158. doi:10.3354/dao02507

Cooper, R. A. and Uzmann, J.R. 1980. Ecology of juvenile and adult *Homarus. In* The biology and management of lobster. Vol. 2. Edited by Cobb, J. S. and Phillips, R. Academic Press, New York. pps. 97-141.

Borden, C., Skrobe, L., Cadrin, S.X. 2013. Industry Based Survey on Black Sea Bass Utilizing Ventless Traps. Final Report to the NOAA Northeast Fisheries Science Center, NOAA Grant No. NA12NMF4540018.

Drohan, A.F., Manderson, J.P., and D.B. Packer. 2007. Essential fish habitat source document: black sea bass, *Centropristis striata*, life history and habitat characteristics 2nd Ed. NOAA Tech. Memo. NMFS-NE-200.

Harley, S., Myers, R.A., and A. Dunn. 2001. Is catch-per-unit-effort proportional to abundance? Canadian Journal of Fisheries and Aquatic Science. 58:1760-1772.

Miller, T.J., Muller, R., O'Boyle, B., and A. Rosenberg. 2009. Report by the peer review panel for the Northeast data poor stocks working group. 34pp.

Moser, J., and Shepherd, G.R. 2009. Seasonal distribution and movement of black sea bass (*Centropristis striata*) in the Northwest Atlantic as determined from a mark-recapture experiment. J. Northwest Atl. Fish. Sci. **40**: 17-28.

Musick, J. A., and L. P. Mercer. 1977. Seasonal distribution of black sea bass, *Centropristis striata*, in the Mid-Atlantic Bight with comments on the ecology and fisheries of the species. Transactions American Fisheries Society 106:12-25.

Northeast Fisheries Science Center. 2017. 62nd Northeast Regional Stock Assessment Workshop (62nd SAW) Assessment Report. US Dept. Commer., Northeast Fish Sci Cent Ref Doc. 17-03; 822 p. Available from: National Marine Fisheries Service, 166 Water Street, Woods Hole, MA 02543-1026.

NMFS (National Marine Fisheries Service) 2013. Fisheries of the United States 2013. https://www.st.nmfs.noaa.gov/commercial-fisheries/fus/fus13/index

Provost, M.M. and O.P. Jensen. 2015. The impacts of fishing on hermaphroditic species and treatment of sex change in stock assessments. Fisheries, 40(11): 536-545.

Provost, M.M., O.P. Jensen, and D. Berlinsky. In review. Influence of size, age, and season on sex change in Black Sea Bass. Marine and Coastal Fisheries.

Resciniti, J., C. Handel, C. FitzSimmons, and H. Carberry. 2009. A guide to fishing and diving New Jersey reefs. New Jersey Department of Environmental Protection, Division of Fish and Wildlife, Bureau of Marine Fisheries, Reef Program. 70 p.

Richards, R.A., J.S. Cobb, and M.J. Fogarty. 1983. Effects of behavioral interactions on the catchability of American lobster, *Homarus americanus*, and two species of Cancer crab. Fishery Bulletin, 81(1): 51-60.

Robinson, O.J., Jensen, O.P., Provost, M.M., Huang, S., Fefferman, N.H., Kebir, A., and J.L. Lockwood. 2017. Evaluating the impacts of fishing on sex-changing fish: A game theoretic approach. ICES Journal of Marine Science: doi:10.1093/icesjms/fsw222.

Steimle, F. W. and P. A. Shaheen. 1999. Tautog (*Tautoga onitis*) life history and habitat requirements. NOAA Technical Memorandum NMFS-NE-118.

White, G.G., T.A. Munroe, and H.M. Austin. 2003. Reproductive seasonality, fecundity, and spawning frequency of tautog (*Tautoga onitis*) in the lower Chesapeake Bay and coastal waters of Virginia. Fisheries Bulletin 101: 424-442

Figures

Figure 1 – Map of New Jersey's Artificial Reef Network (form Resciniti et al., 2009). Traps for this project were deployed on the Sea Girt Reef by sailing out of the Manasquan River Inlet and on the Little Egg Inlet Reef by sailing out of the Little Egg Inlet. Traps were also deployed on the Manasquan Inlet Reef, which is a new reef site for which deployments will begin in 2017.

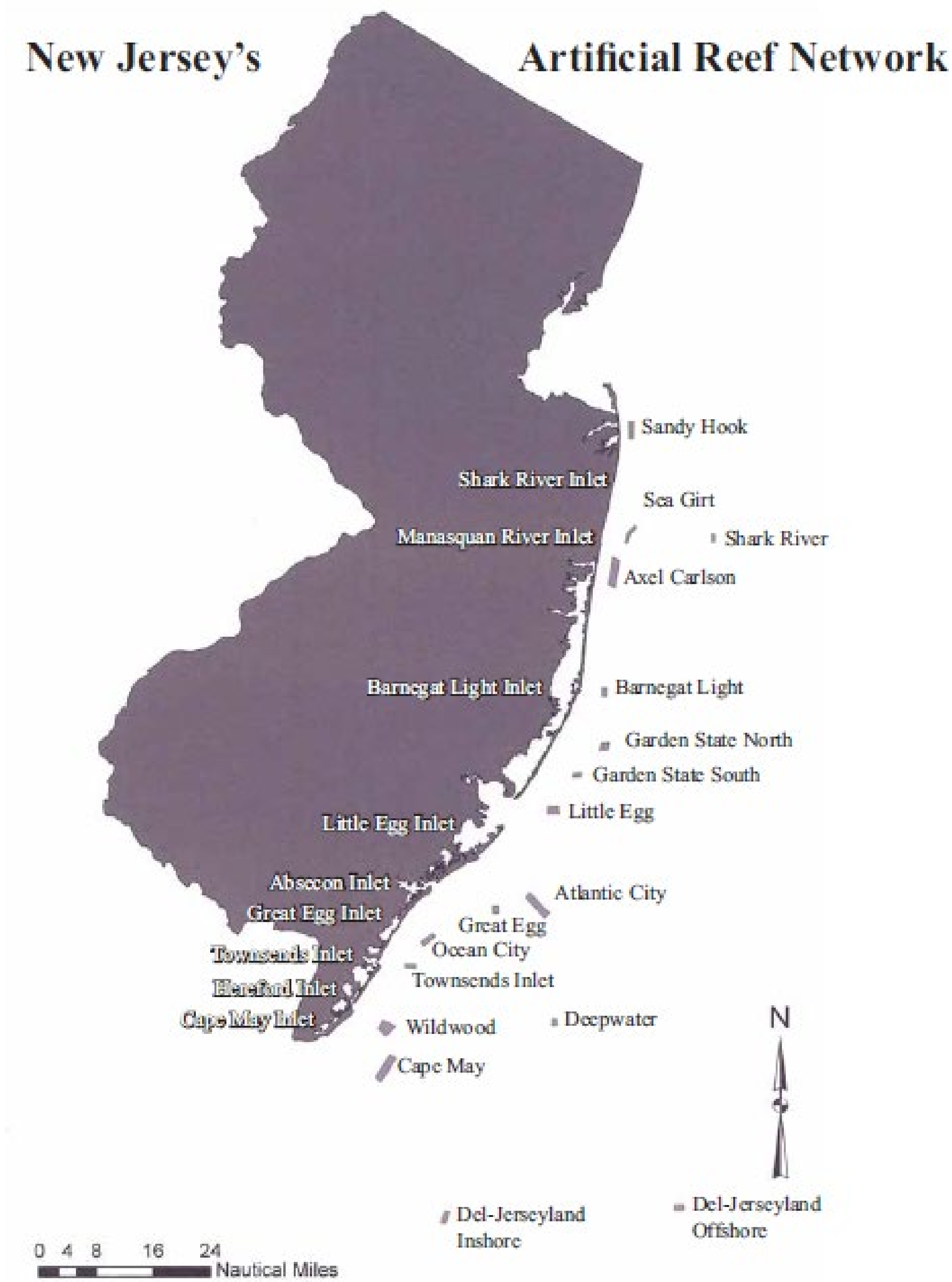

Figure 2 – Map of trap deployment locations on the Sea Girt Reef. Locations marked with an X represent metal structures, * are concrete structures, squares are sand sites, and triangles are spatial autocorrelation sites. The solid line represents the reef boundary and the dashed line represents a 1-3 km buffer around the reef boundary.

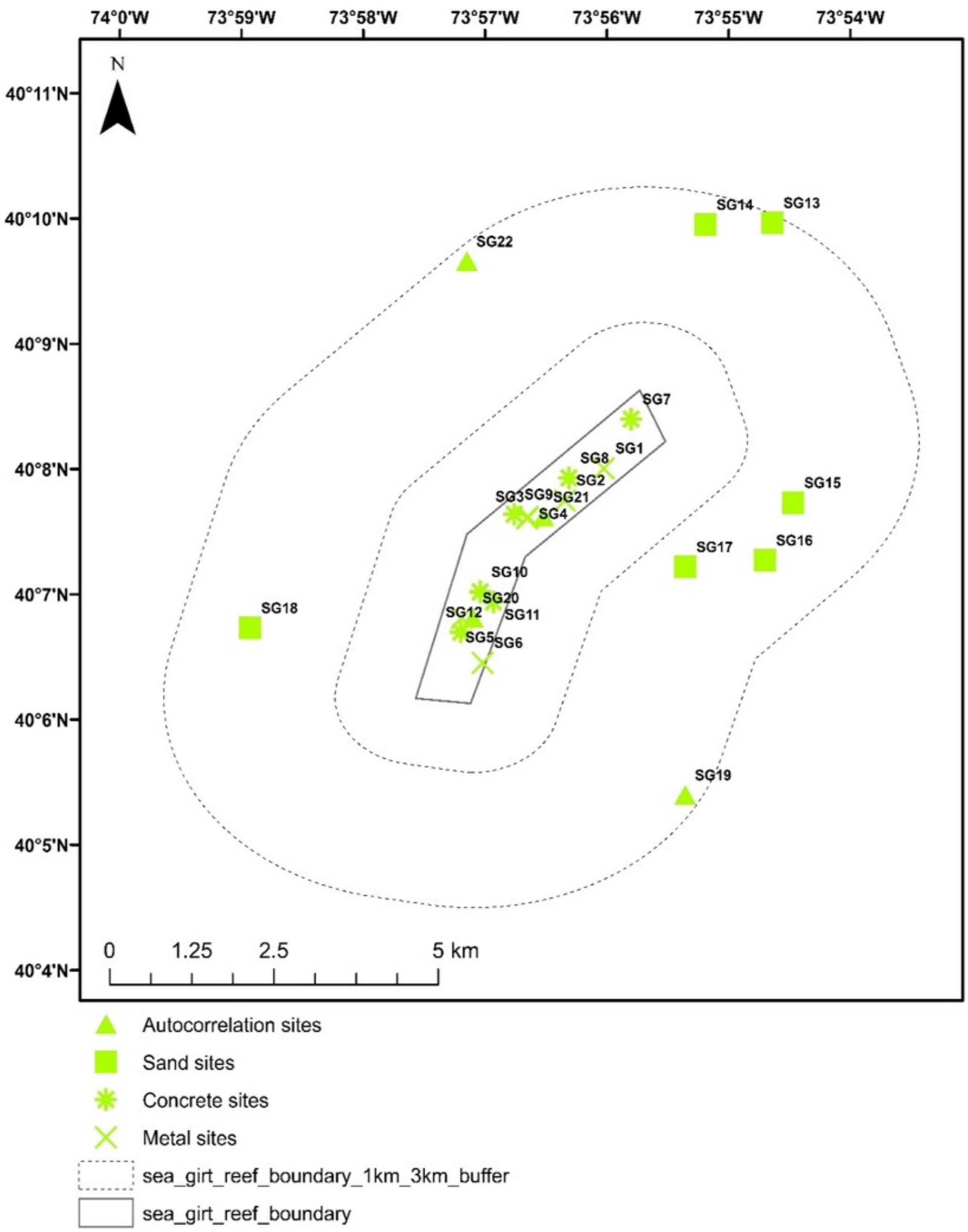

Figure 3 – Map of trap deployment locations on the Little Egg Inlet Reef. Locations marked with an X represent metal structures, * are concrete structures, squares are sand sites, and triangles are spatial autocorrelation sites. The solid line represents the reef boundary and the dashed line represents a 1-3 km buffer around the reef boundary.

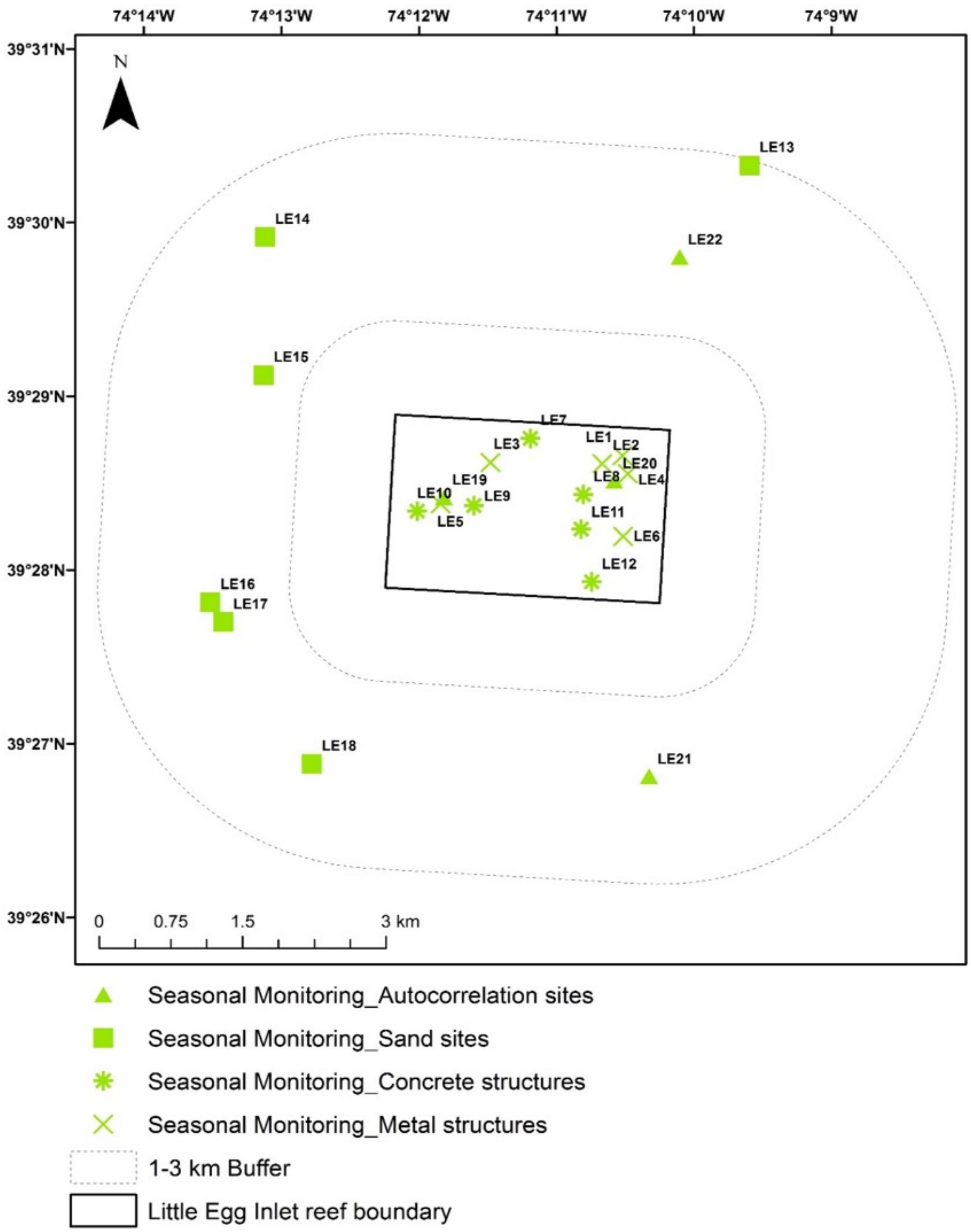

Figure 4 – Map depicting the location of the new Manasquan Inlet Reef in relation to the Manasquan Inlet and Sea Girt Reef.

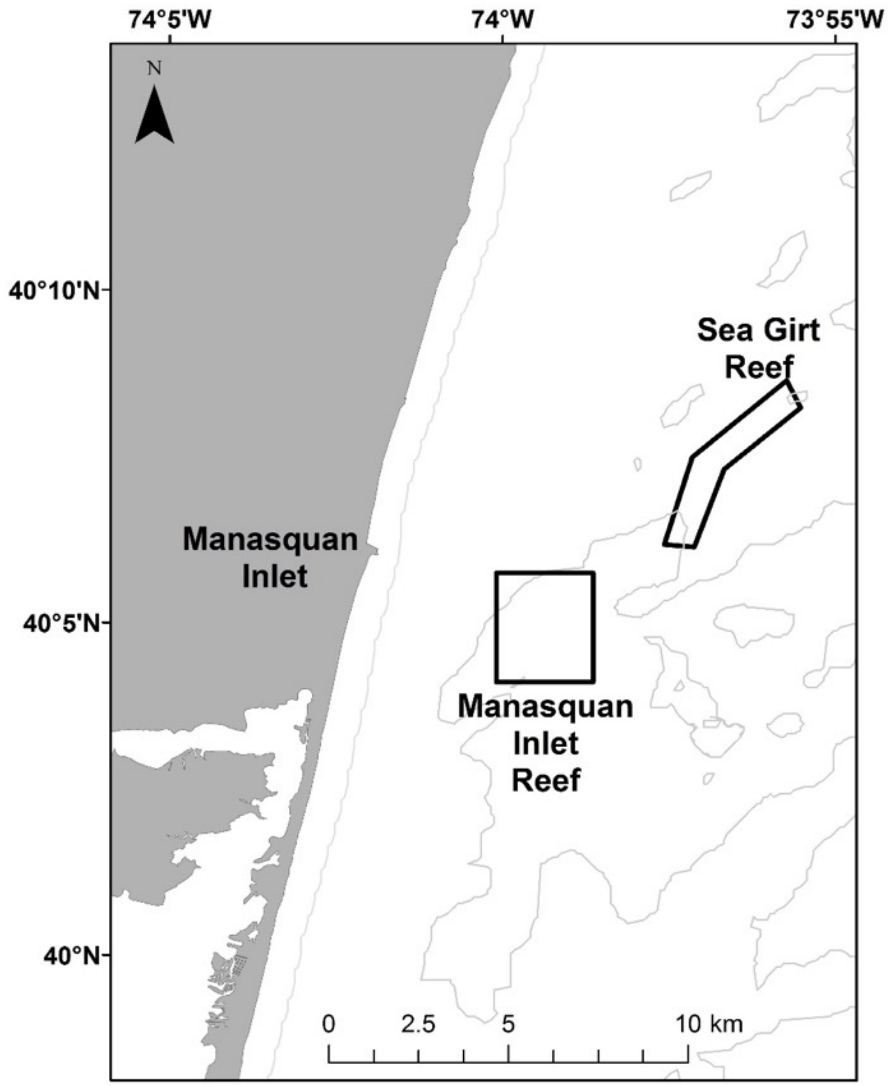

Figure 5 – Map of the twelve deployment locations on the site of the planned Manasquan Inlet reef before reef construction began.

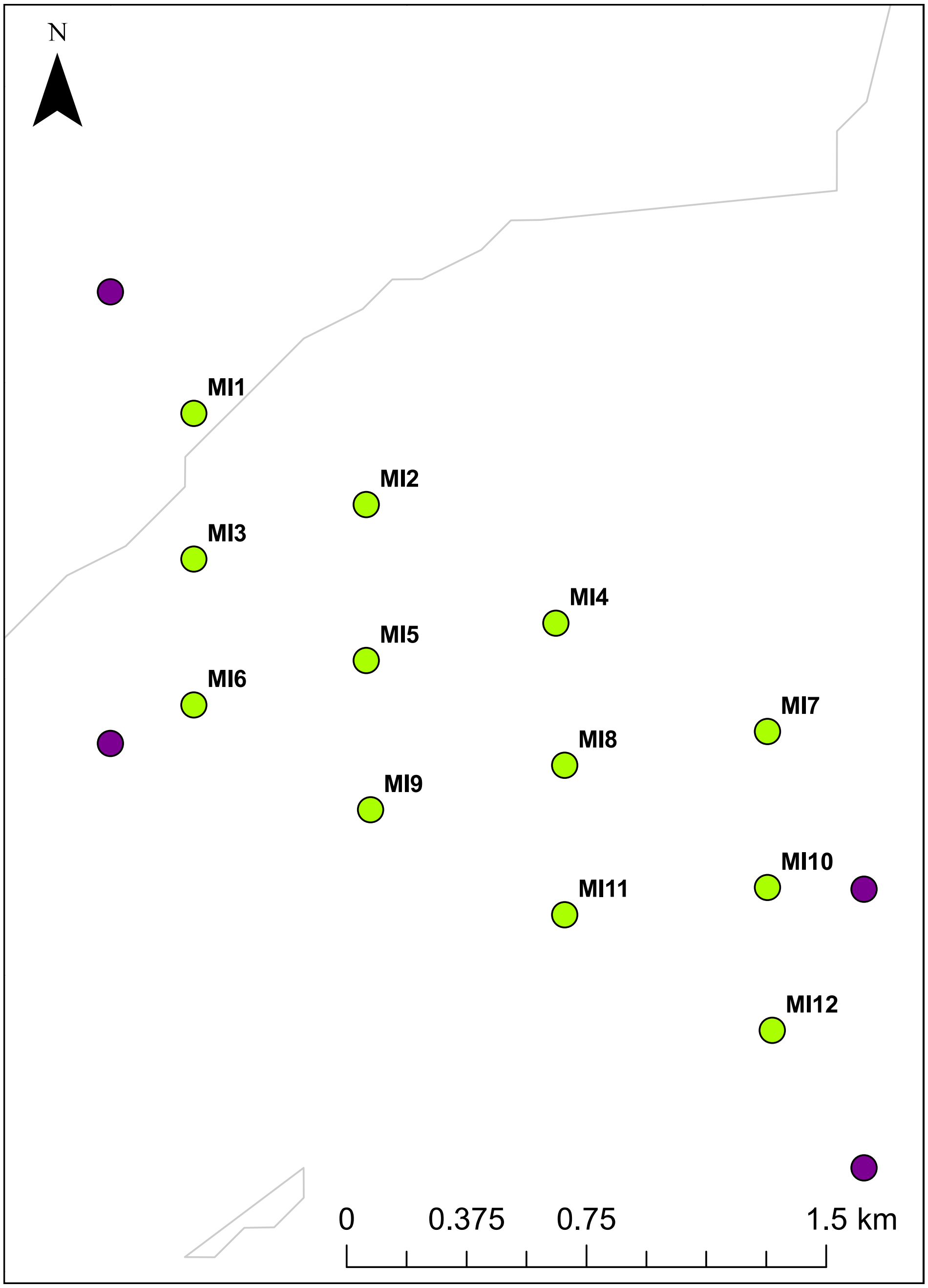

Figure 6 – Map of the nine trap deployment locations on the site of the new Manasquan Inlet Reef after reef construction began. Traps MI13, MI14, and MI15 are on the structure deployed in the summer of 2017.

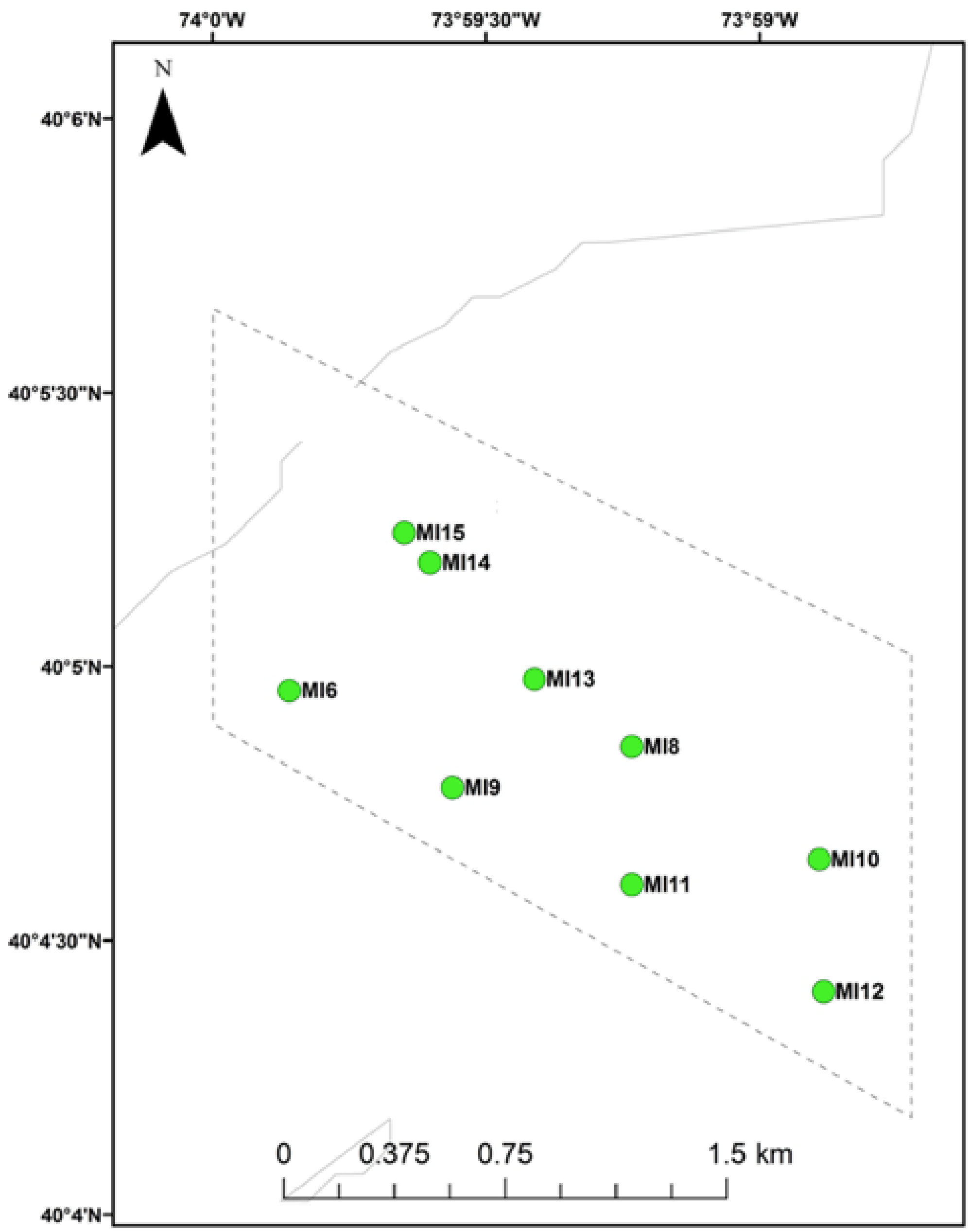

Figure 7– Map of the trap deployments for the priority effects experiment conducted on the Little Egg Inlet Reef during the summer of 2016. Dotted circles represent the traps grouped on each of the tree patch reefs within the greater reef boundary.

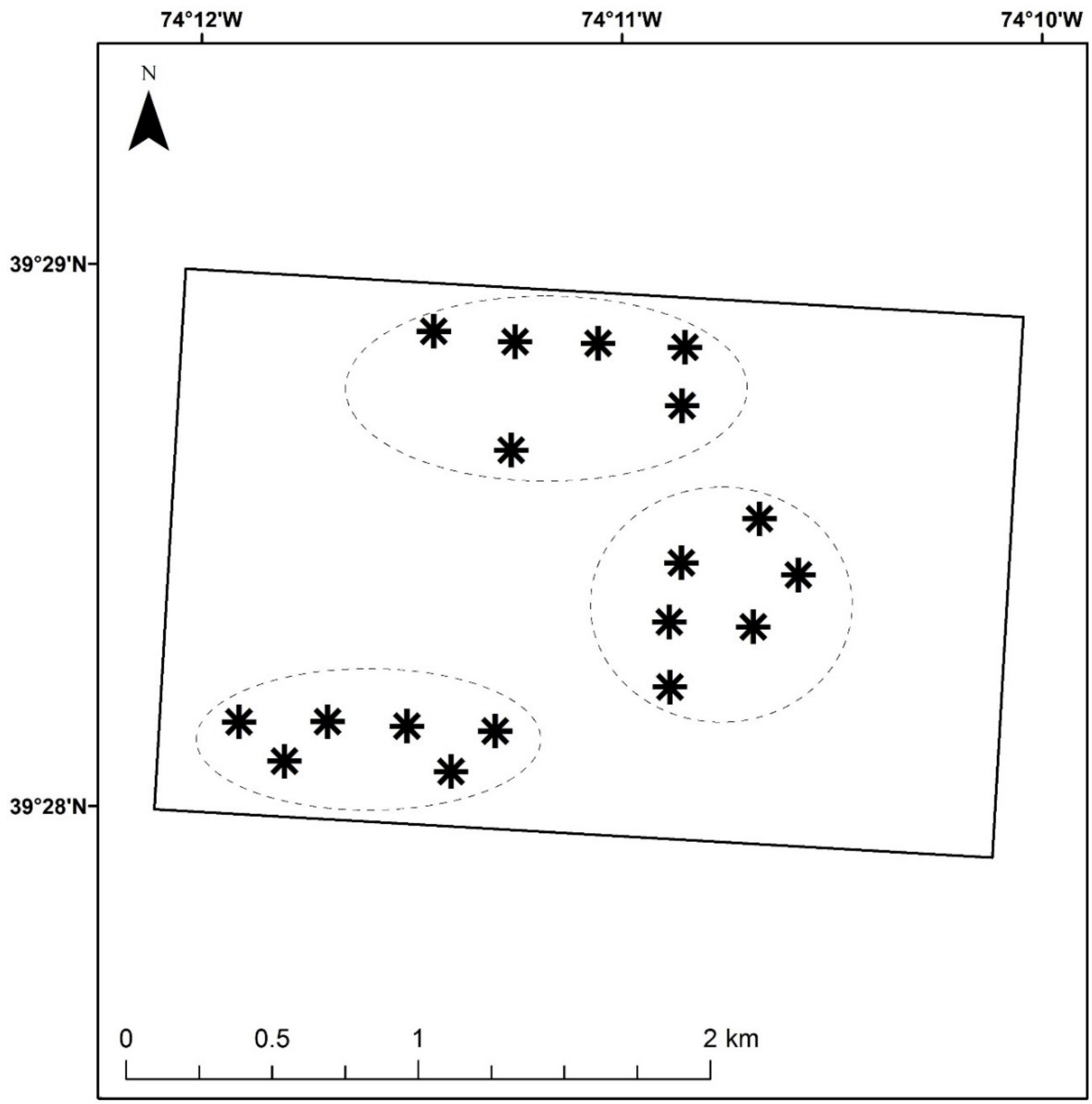

Figure 8 – Map of the 18 trap deployment positions on the Sea Girt Reef for the soak time experiment. The traps were randomly assigned to three groups and hauled at intervals of 1, 2, 3, 5, and 7 days over an 18-day study period.

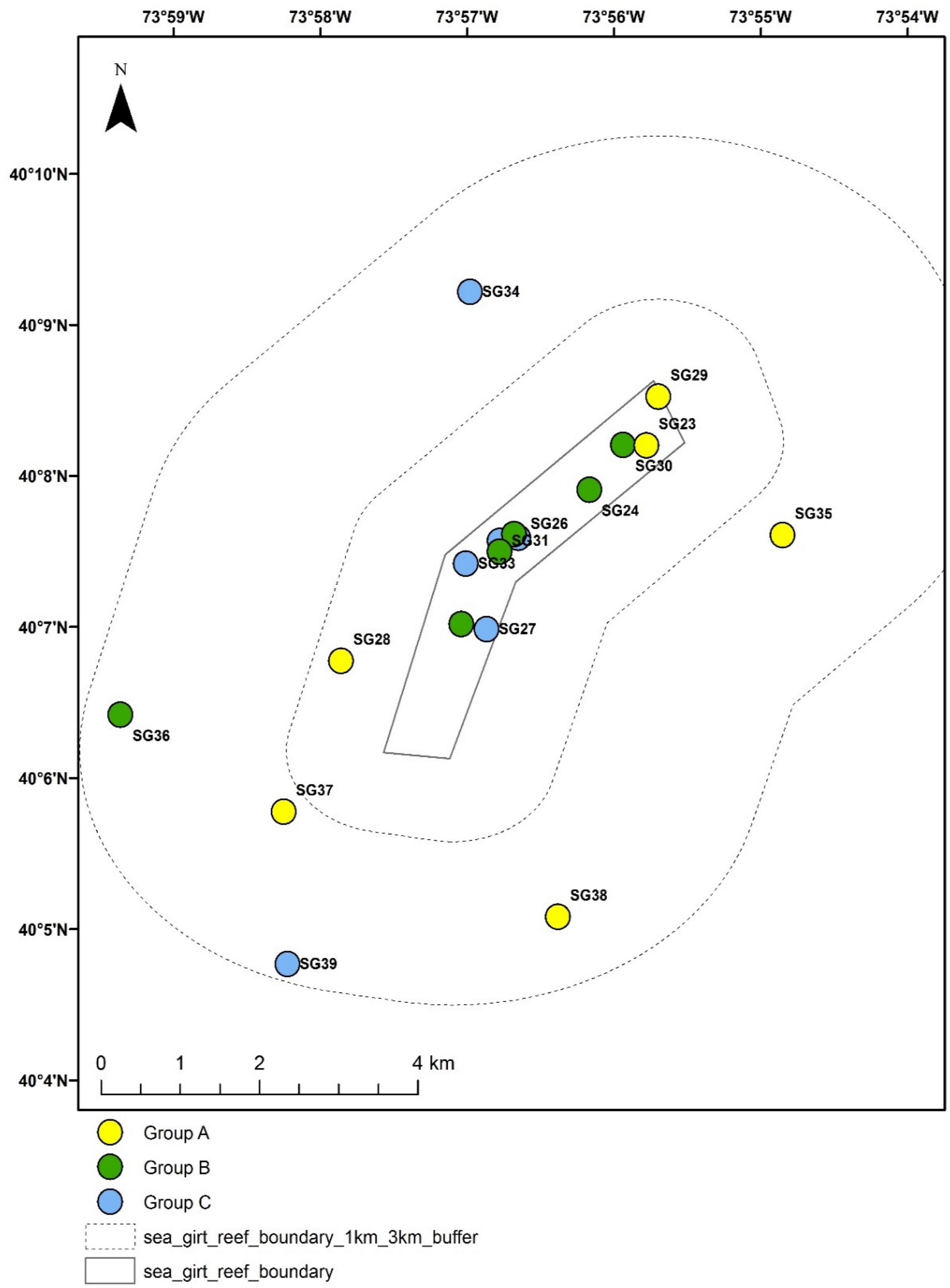

Figure 9 – Completed trap retrieval scheme for the three groups of six traps that were deployed as part of the soak time experiment on the Sea Girt Reef. All traps were deployed on June 4, which is represented by an ‘X’. The numbers in each box represent the soak time for a given group of traps hauled on a particular day.

Study Day and Date	(0) 6/4	(1) 6/5	(2) 6/6	(3) 6/7	(4) 6/8	(5) 6/9	(6) 6/10	(7) 6/11	(8) 6/12	(9) 6/13	(10) 6/14	(11) 6/15	(12) 6/16	(13) 6/17	(14) 6/18	(15) 6/19	(16) 6/20	(17) 6/21
Group A - SG23, SG28, SG29, SG35, SG37, SG38	**X**	**1**		**2**							**7**		**2**					**5**
Group B - SG24, SG25, SG30, SG32, SG10, SG36	**X**		**2**					**5**			**3**							**7**
Group C - SG26, SG27, SG31, SG33, SG34, SG39	**X**			**3**							**7**	**1**					**5**	**1**

Figure 10 – Conceptual diagram of the before-after control-impact design study on Manasquan Inlet Reef.

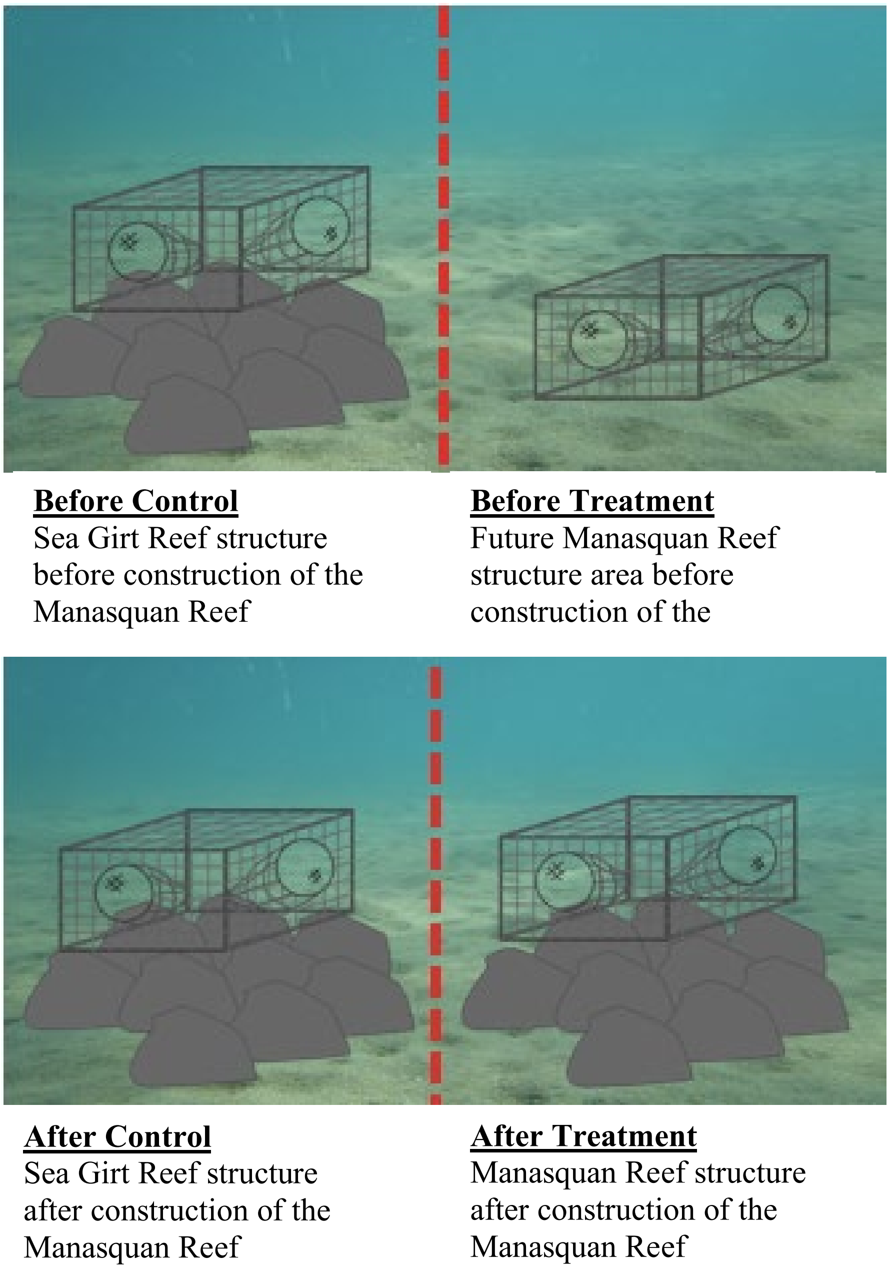

Figure 11 – Mean catch per trap of the three target species (black sea bass, American lobster, and tautog) on each reef (Little Egg Inlet, Sea Girt, and Manasquan Inlet) over all three years of sampling.

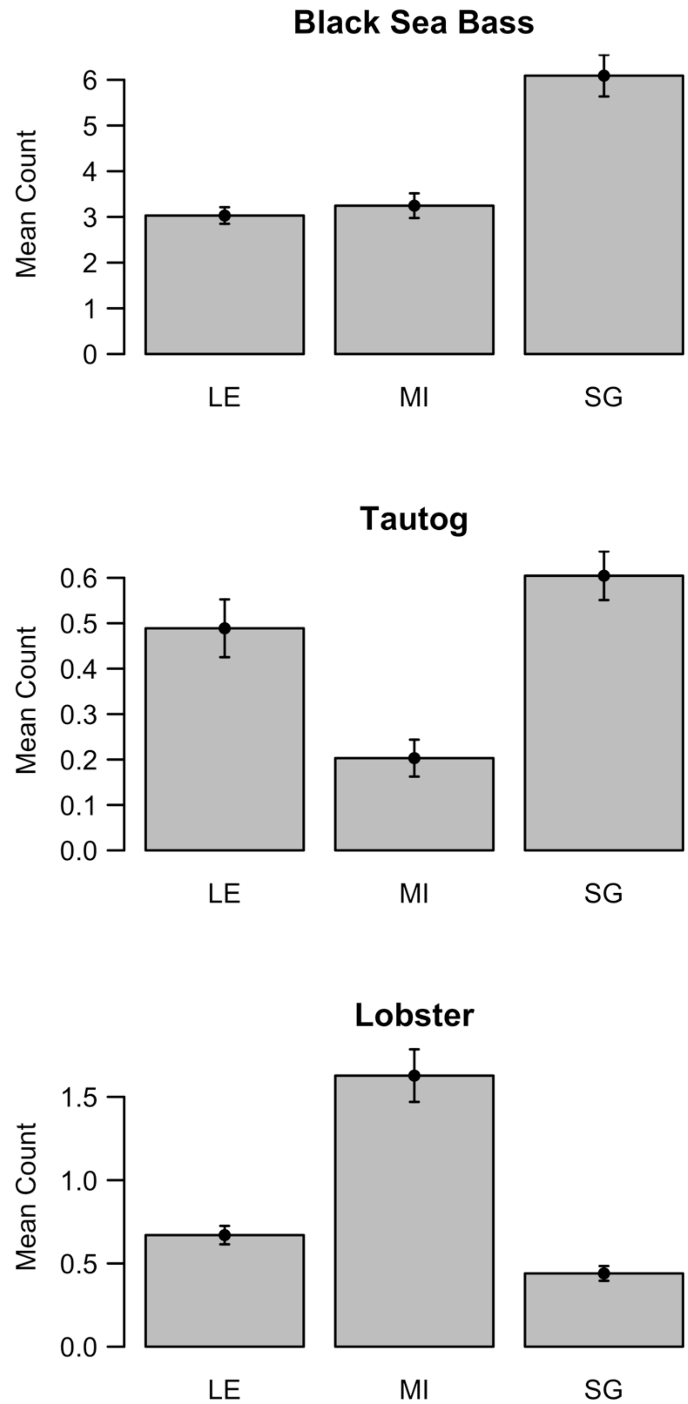

Figure 12 – Mean catch per trap of the three target species (black sea bass, American lobster, and tautog) for each season (spring, summer, fall) on each reef (Little Egg Inlet, Sea Girt, and Manasquan Inlet) over all three years of sampling.

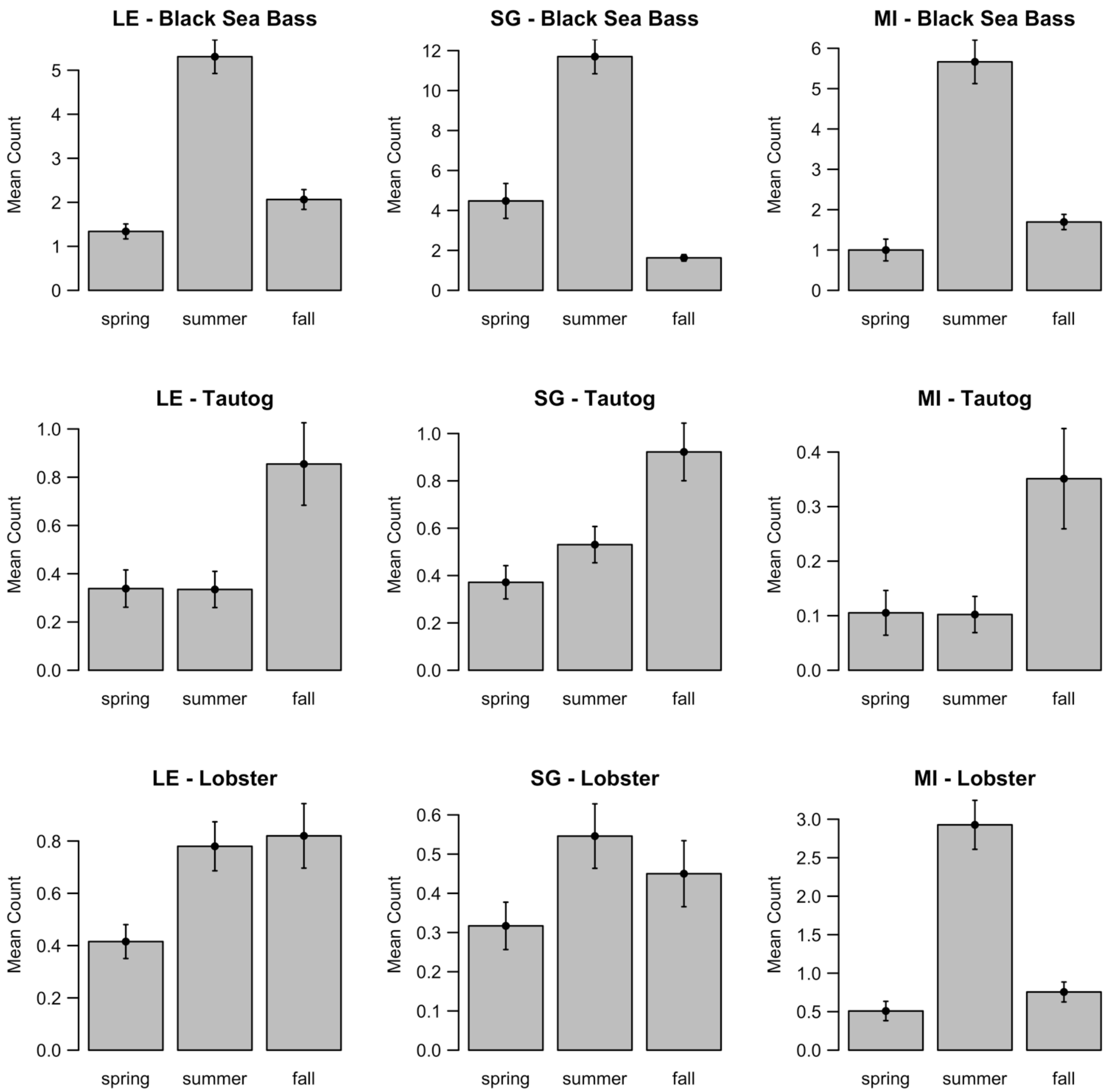

Figure 13 – Mean catch-per-unit-effort (CPUE) of the three target species (black sea bass, American lobster, and tautog) for each season (spring, summer, fall) of each year (2016, 2017, 2018) on each reef (Little Egg Inlet and Sea Girt).

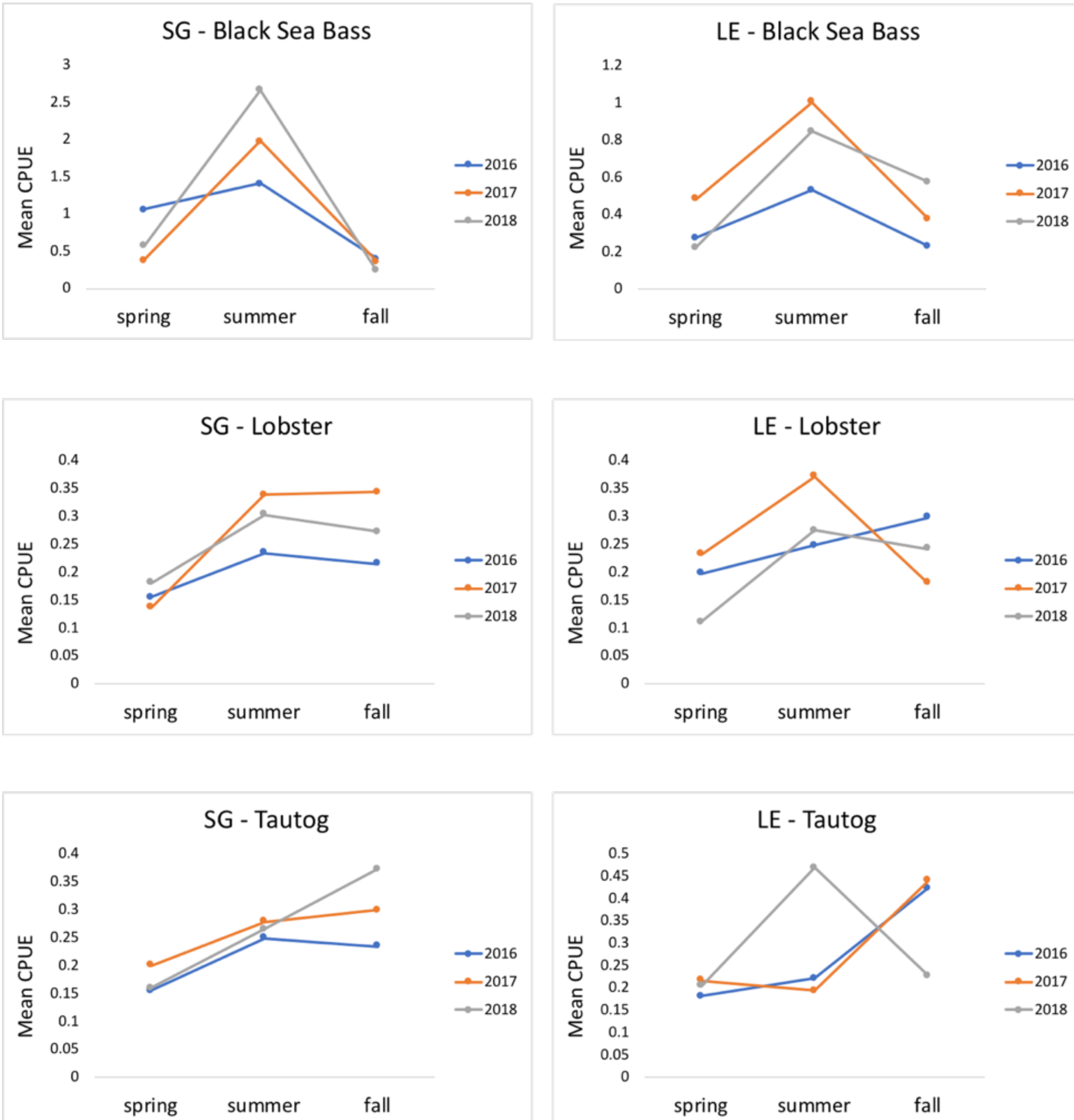

Figure 14 – Mean catch per trap of black sea bass, tautog, and lobster for each substrate type on the Sea Girt Reef and Little Egg Inlet Reef averaged over all seasons and years. Error bars represent standard error of the mean.

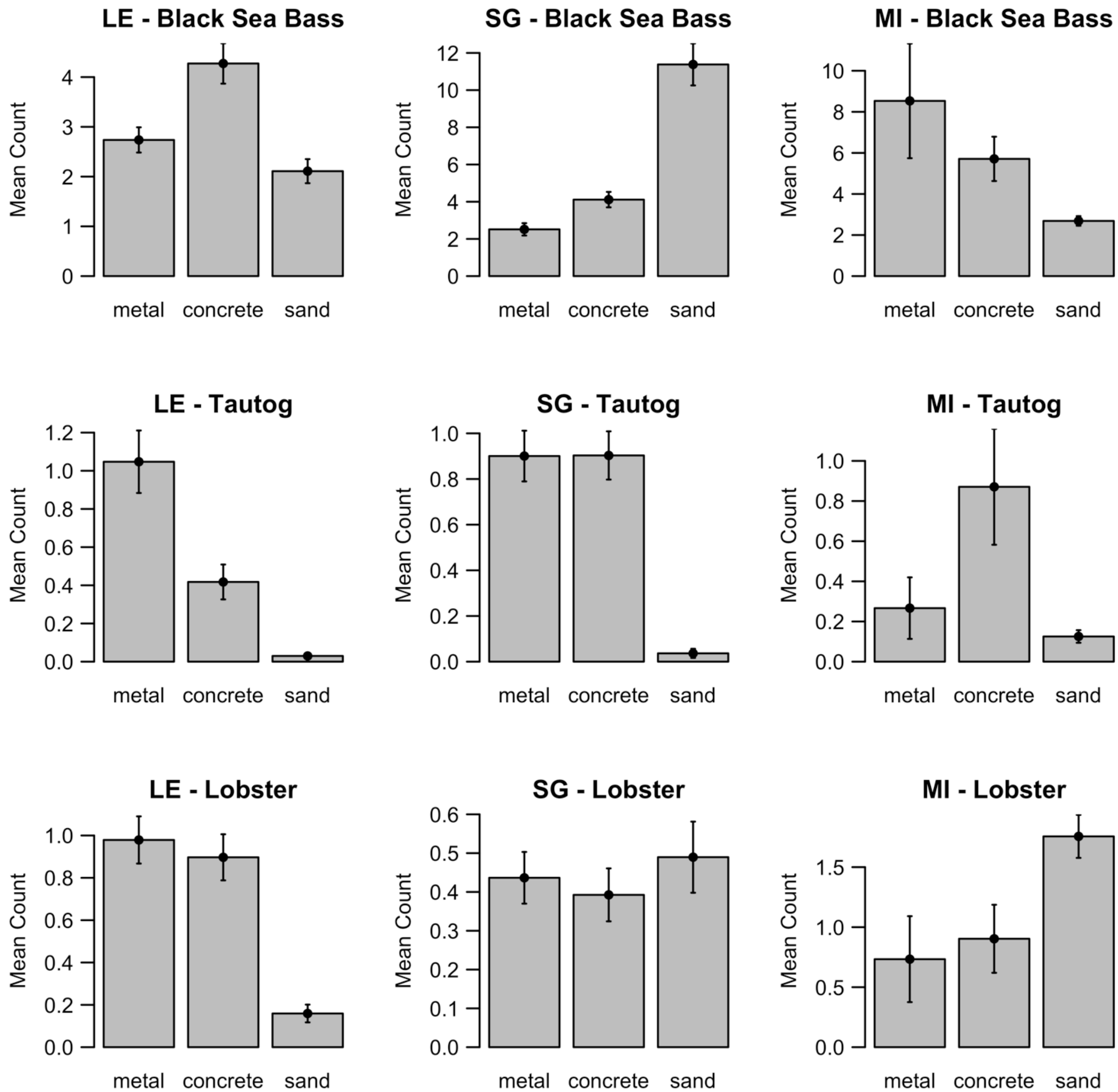

Figure 15 – Probability of capture in control, lobster seeded, and tautog seeded traps for four commercially important fish and invertebrate species. Error bars represent the standard error of the coefficient.

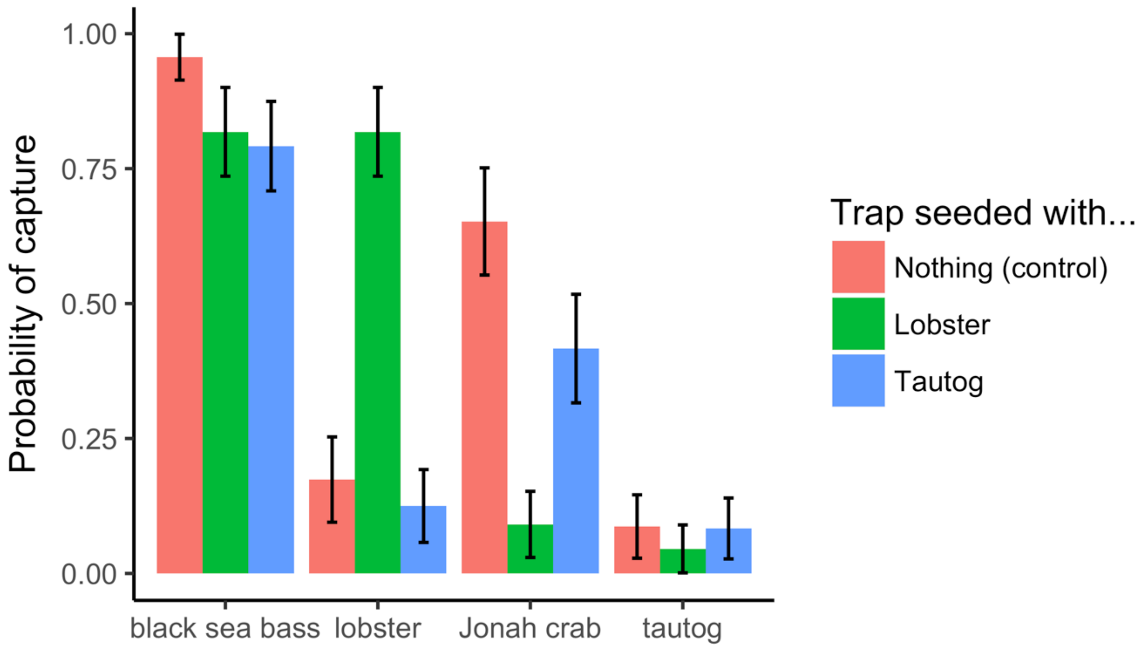

Figure 16 – Probability of capture in control, male lobster seeded, and female lobster seeded traps for four commercially important fish and invertebrate species. Error bars represent the standard error of the coefficient.

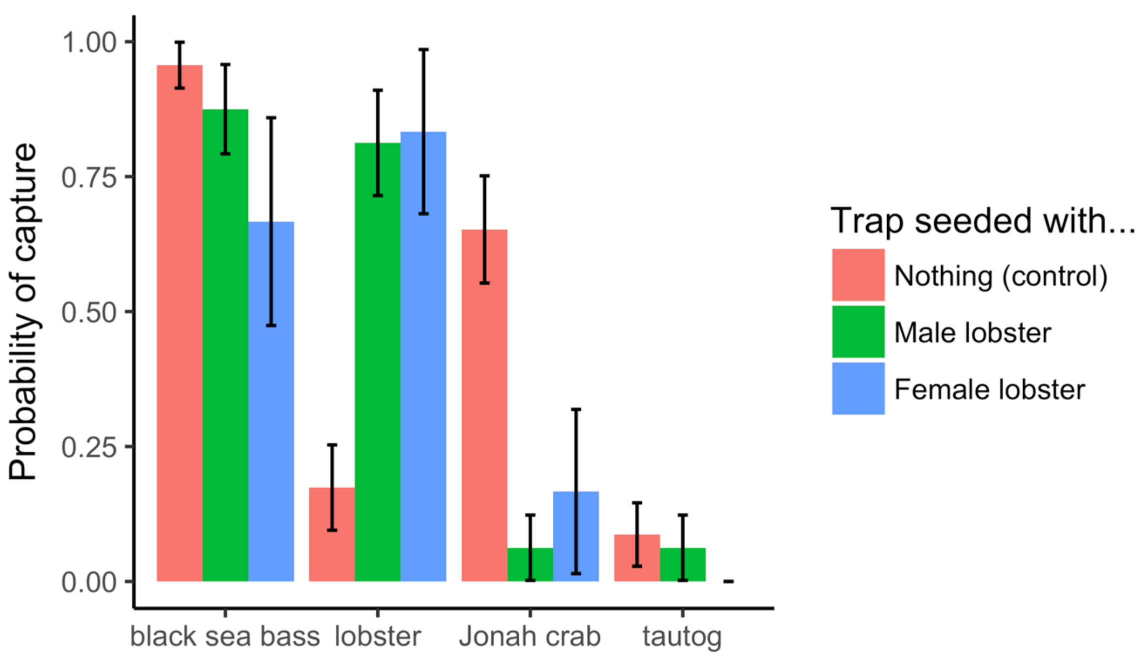

Figure 17 – Results from the soak time experiment conducted on the Sea Girt Reef in June 2016. Mean catch of black sea bass is plotted for each time interval upon which traps were hauled during the experiment (1, 2, 3, 5, and 7 days). Error bars represent standard error of the mean.

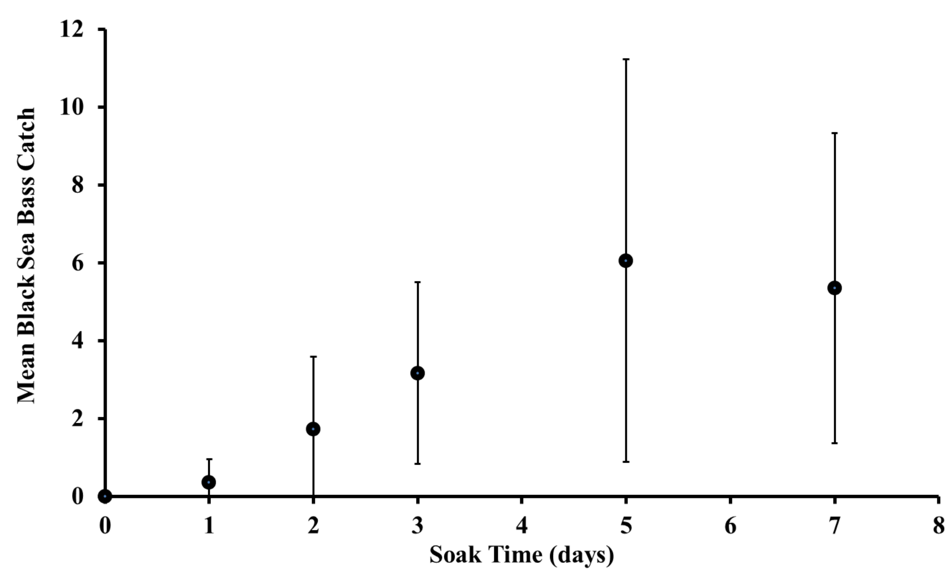

Figure 18 – Results from the soak time experiment conducted on the Sea Girt Reef in June 2016. Mean catch of tautog is plotted for each time interval upon which traps were hauled during the experiment (1, 2, 3, 5, and 7 days). Error bars represent standard error of the mean.

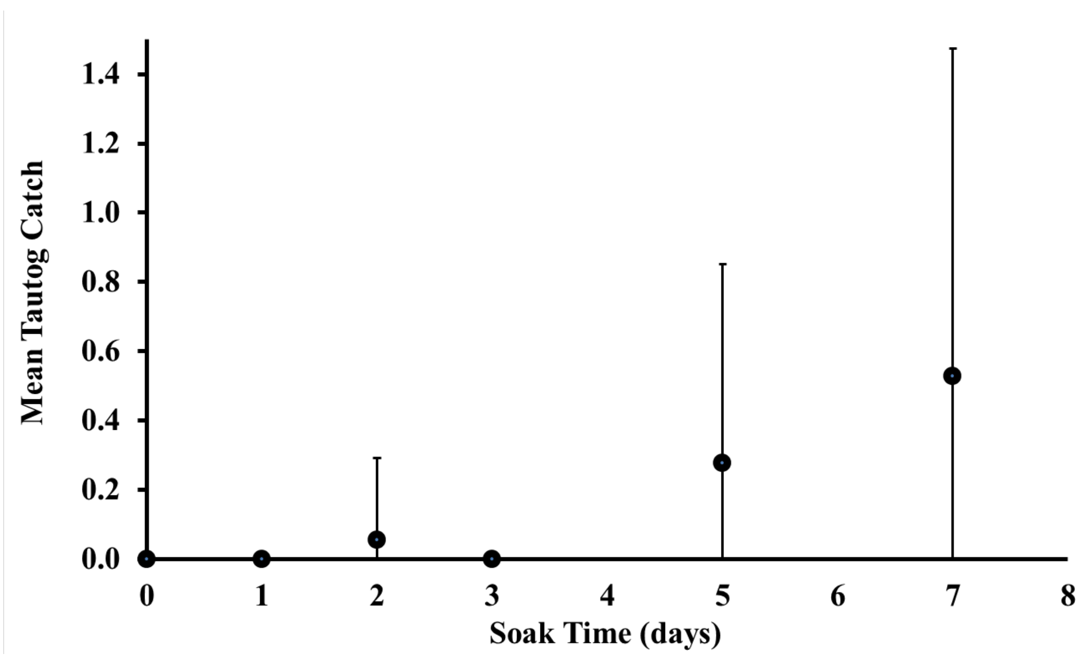

Figure 19 - Results from the soak time experiment conducted on the Sea Girt Reef in June 2016. Mean catch of lobster is plotted for each time interval upon which traps were hauled during the experiment (1, 2, 3, 5, and 7 days). Error bars represent standard error of the mean.

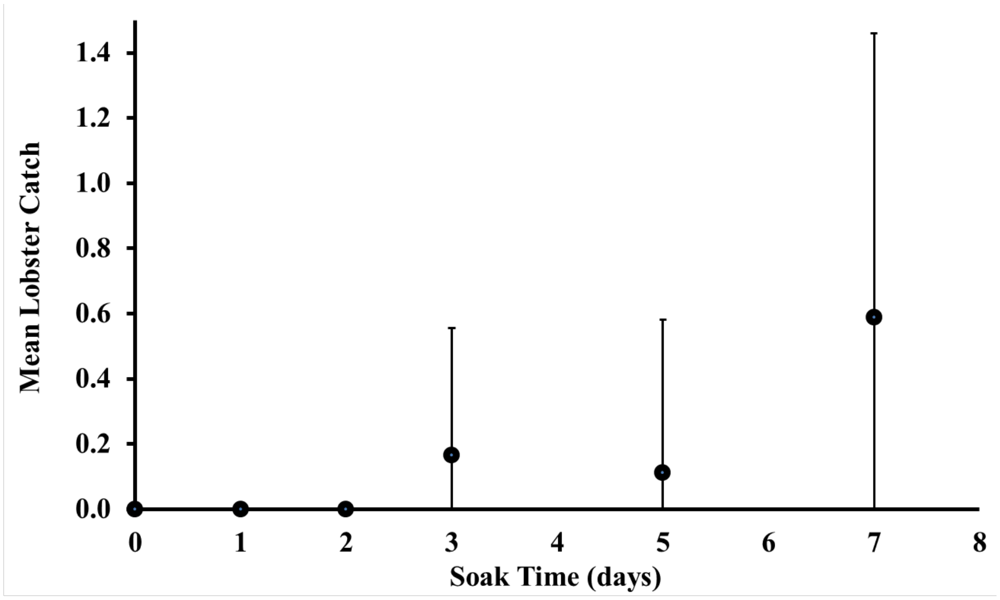

Figure 20 – Generalized linear models of shell disease presence in male and female Jonah crabs, American lobster, and rock crabs. Shaded region represents the confidence interval.

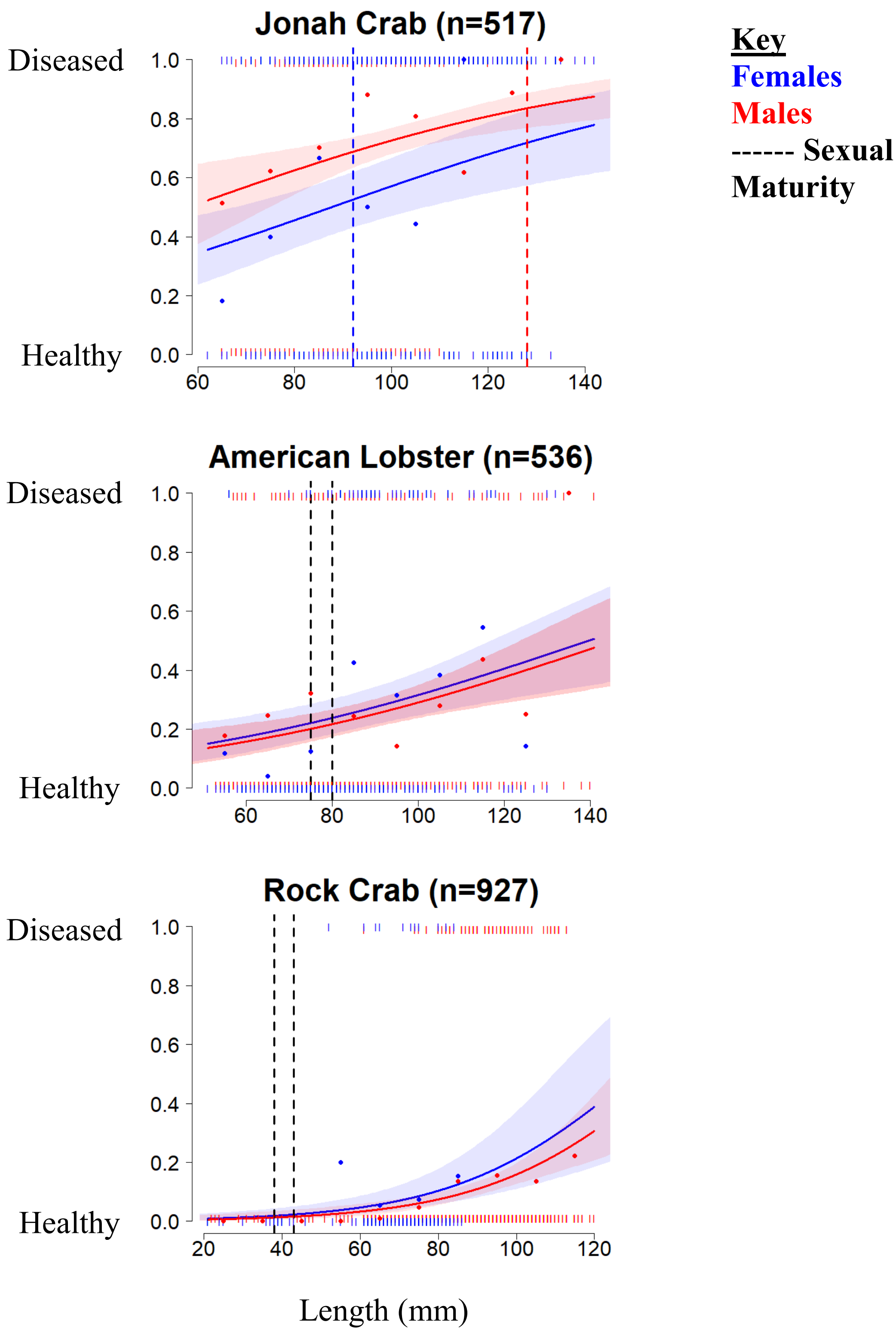

Figure 21 – Mean CPUE of black sea bass in each BACI group (before-control, after-contorl, before-treatment, after-treatment). Error bars represent standard error of the mean.

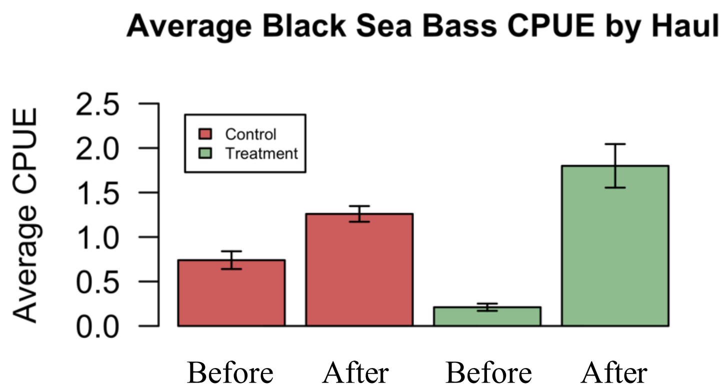

Figure 22 – Mean size of black sea bass in each BACI group (before-control, after-contorl, before-treatment, after-treatment). Error bars represent standard error of the mean.

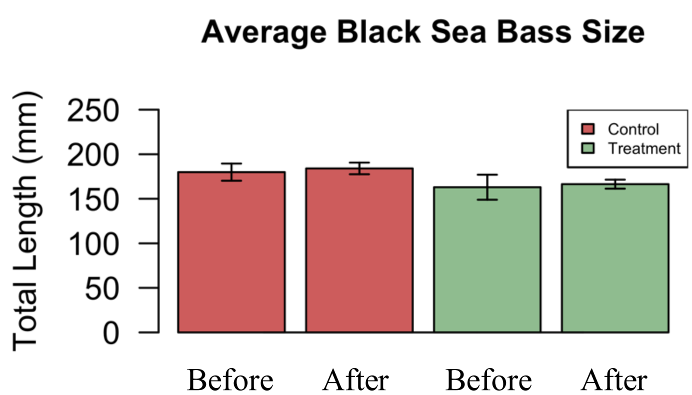

Figure 23 – Mean CPUE of lobster in each BACI group (before-control, after-contorl, before-treatment, after-treatment). Error bars represent standard error of the mean.

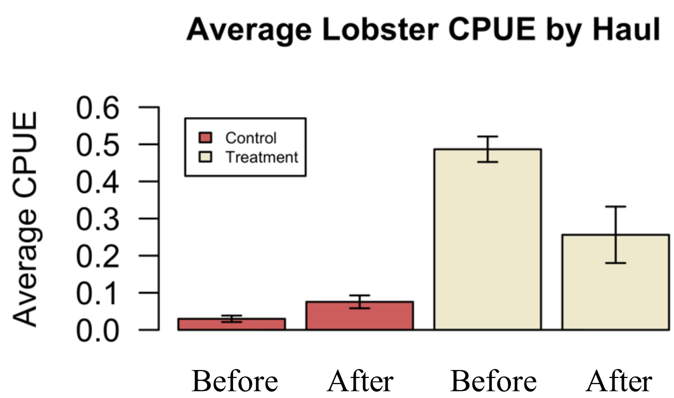

Figure 24 – Mean diversity (using Shannons Diversity Index) in each BACI group (before-control, after-contorl, before-treatment, after-treatment). Error bars represent standard error of the mean.