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The Colonization of a Multi-functional Artificial Reef Designed for the American Lobster, Homarus Americanus

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THE COLONIZATION OF A MULTIFUNCTIONAL ARTIFICIAL REEF DESIGNED FOR THE AMERICAN LOBSTER, *HOMARUS AMERICANUS*

By

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Thesis Advisor: Dr. Bob Bayer

An Abstract of the Thesis Presented
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Habitat loss and degradation caused by the installation of infrastructure related to coastal population increase removes vital habitat necessary in the lifecycles of benthic and epibenthic species. Of the species affected, the American lobster is the most commercially valuable specie in the Gulf of Maine, and it has been proposed that lack of suitable habitat could potentially limit lobster distribution and population. Granite block mooring systems (GNT) are essential in anchoring boats and equipment related to marine recreation and industry, the footprint of the GNT removes benthic habitat and does little to enhance epibenthic habitat. In an effort to support the sustainability of the lobster fishery, Habitat Mooring Systems™ designed a multifunctional artificial reef (HMS4000), which serves as both a marine mooring system and potential lobster habitat. A granite mooring system was compared to an HMS4000 at Seal Harbor, Mount Desert Island, ME and Sand Cove, South Bristol, ME, to understand the effectiveness of the HMS4000 to increase species richness, lobster abundance, lobster biomass, crab abundance, and fish abundance in, on or around the mooring. Data collection consisted of lobster counts, lobster carapace length, lobster sex, crab identification and count, fish identification and count, and all other invertebrates were identified and counted. Crabs were divided into two groups, 1) Jonah/rock crab, and 2) "Other crabs" where all other crabs were identified, counted and cataloged. Four dive surveys were performed at each location between July 26, 2012 and February 14, 2013.

The HMS4000 had a significantly higher species richness compared to the control groups at Seal Harbor, and higher lobster inhabitance compared to the GNT overall. The HMS4000 at both locations had similar lobster occupancy and calculated lobster biomass. Lobster carapace length on the HMS4000 was larger than other treatments, and the male to female lobster ratio was close to that of the control site, however there were no significant differences between treatments. Although Jonah/rock crab were found on the HMS4000, the GNT had significantly more, but, with less lobster abundance, the GNT had fewer resident predators and provided adequate shelter for this species group. No significant differences in fish prevalence were found, but fish had a greater tendency to use the artificial habitat over the GNT and control. Commercially valuable fish species, such as Atlantic cod and American eel, were exclusively surveyed on the HMS4000.

In conclusion the HMS4000 could alleviate habitat degradation through the mitigation of benthic habitat loss generated from a foot print of traditional granite mooring, by increasing overall species richness and providing suitable habitat that would support commercially and recreationally valuable species such as, the American lobster, Atlantic cod, Jonah crab, and American eel.

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INTRODUCTION

1.1. Background and Project Rational

The American lobster, *Homarus americanus* (H. Milne-Edwards, 1837), and the European lobster, *Homarus gammarus* (Linnaeus, 1758), have been the driving force of the lobster trapping industry of the North Atlantic for well over 100 years (Bannister & Addison, 1998). The Gulf of Maine fishery contributes the highest yield of lobster in the United States, making it the most valuable fishery in New England (Steneck & Wilson, 2001). The trend of lobster landings in Maine has shown an increase over the past decades. The 2019 preliminary lobster landings data for the Maine Department of Marine Resources, reports 45,688 metric tons, which translates to $485,405,036.00 USD (ANON, 2020c) making this fishery the most valuable in the state, and is accountable for 80% of all U.S. commercial landings (Holland, 2011; Incze et al., 2006; Steneck & Wilson, 2001).

Researchers have hypothesized several causes for this increase in population including: 1) the depletion of ground fish, through unsustainable fishing practices (Jackson et al., 2001), which may have reduced predation pressure and/or expanded lobster habitat (Steneck & Wilson, 2001), 2) the large amount of herring bait used to trap lobster has increased food abundance for lobsters (Grabowski et al., 2010), and/or 3) environmental factors such as inshore and offshore currents, effect larval settlement/recruitment (Incze et al., 2006). In any case, the survivability of the American lobster is reliant on appropriate shelter (Cobb, J., 1971), and it has been hypothesized that benthic shelter structure may be a limited resource for lobsters (Fogarty & Idoine, 1986) potentially restricting further population growth.

1.2. American Lobster Biology

The American lobster is a member of the kingdom *Animalia,* the phylum *Euarthropoda,* the subphylum *Crustacea,* the class *Malacostraca,* the order *Decapoda,* the family *Nephropidae,* the genus *Homarus,* and species *H. americanus.* This species is a negatively photo tactic, decapod, crustacean with bilateral symmetry. *H. americanus* basic anatomy consists of an exoskeleton including two chelipeds (one crusher and one pincher claw) and two maxillipeds for prey manipulation, four sets of pereiopods (walking legs) located on its thorax, and a modified abdominal tail (used for propulsion) with four uropods (tail flippers) and a telson (tail) on end (Figure 1.1.).

The American lobster is found in the North Atlantic waters of Labrador, Nova Scotia, Prince Edward Island, CA, and south along the North American continental shelf to North Carolina, and extends to the eastern edges of Georges Bank (ANON, 2020a; Cooper et al., 1971). Found in depths up to 700m, lobsters travel mostly in relation to seasonal changes in temperature. They move to shallow waters during the late spring and early summer, returning to deeper waters in fall and early winter seeking an optimal temperature ranging between 10° to 17.5°C (Cooper et al., 1971).

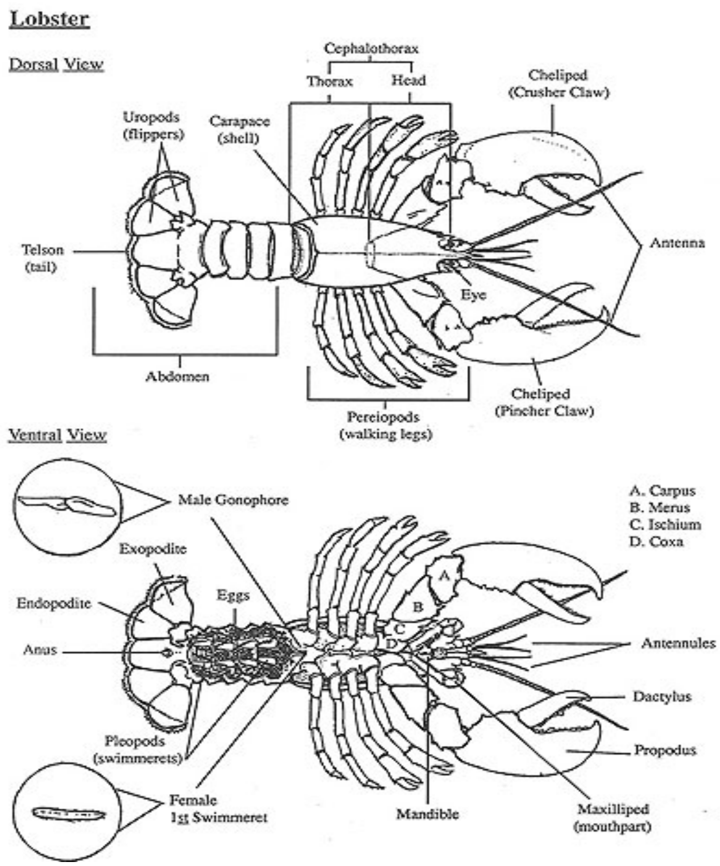

Figure 1.1. American Lobster Basic Anatomy (ANON, n.d.-c).

The early life stages of the American lobster are typical of decapod crustaceans. Once hatched, the larval lobster is entirely planktonic and will proceed to molt between its first 5 planktonic life stages (Figure 1.2.). After each molt, a distinct change in morphology, physiology, behavior and ecologic needs become apparent. The first three life stages of lobster are considered larval stages. During stage one, pereopods are present and used for swimming. Stage two, primitive pleopods, considered pleopod buds, are apparent on abdominal segments two through five, and during the third stage, the larvae develop thoracic exopodites and true pleopods on abdominal segments two through five, numerous setae are present, newly developed uropods, and the telson is present within a broad tail fan. Stage four, the individual takes on the appearance of the adult stage and pleopods start being used for swimming, antennae development is visible, and the uropods and telson become equal in length. Here the individual begins demonstrating settlement behavior (Scarratt, 1973). During this transition from pelagic to benthic, growth decreases as energy is redirected to finding appropriate substrate for settlement (Hudon, 1987).

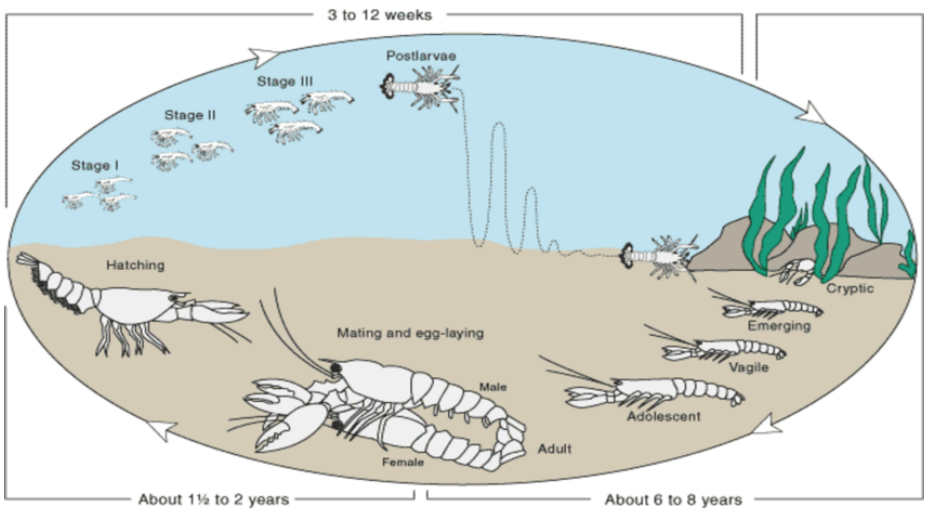

Figure 1.2. American Lobster Life Cycle (ANON, n.d.-b).

Predations of planktonic stages of lobster are incidentally consumed by planktivorous species (Hanson, 2009). The most common predators of the juvenile and small adult lobster in the Gulf of Maine are the striped bass, *Morone saxatilis* (Walbaum,1792), Atlantic cod, *Gadus morhua* (Linnaeus, 1758), sea raven, *Hemitripterus americanus* (T. N. Gill, 1872), and the short nose sculpin, *Myolocephalus octodecemspinosus* (Mitchill, 1814) (Hanson, 2009; cited in Wilkinson et al., 2015), where Wilkinson (2015) found juvenile lobsters to remain within shelters more often when Atlantic cod and sea ravens are present. Predator avoidance could possibly prolong settlement if suitable shelter, which includes materials such as cobbles and boulders (Cobb & Wahle, 1994), is not present (Cobb, 1968). Upon the completion of the fifth molt, lobster metamorphosis is complete and will permanently reside as benthic organisms (Hughes & Matthiessed, 1962). In warmer temperatures, the process can be completed in just a few weeks, but in cooler temperatures it could take several months (Hughes & Matthiessed, 1962). Once the individual settles, the lobster will continue to molt as growth occurs. Generally, lobsters will molt in early spring and late fall, and it is thought that favorable temperatures and food availably are correlating factors (Hughes & Matthiessed, 1962). The American lobster opportunistically feeds on mollusks, crustaceans, echinoderms, and polychaetes (Carter & Steele, 1981; Elner & Campbell, 1987).

A legally harvested lobster in the state of Maine must have a carapace length measuring between 8.26 cm and 12.7 cm. To reach this length, lobsters will molt approximately 25 to 27 times and are typically between five and seven years old. The adult phase is very long lived, where the oldest lobster on record was found in Nova Scotia, Canada, in 1977, and was thought to be around 100 years old and weighing 20.13 kg (ANON, 2009). Taking five to eight years to reach sexual maturity, an adult lobster can reproduce many times in a life span.

Seasonally, a female lobster will release pheromones to communicate reproductive readiness (ANON, 2012), and male lobsters will choose or create a shelter for mating and compete for the female. Soon after the female molts, the male will, by way of his first pair of pleopods, deposit a spermatophore in the female seminal receptacle (Figure 1.2.1.). The female may mate with multiple males within one mate season while males are know to mate with up to 54 different females in one season (Waddy et al., 2017). Females can store deposited sperm for several years before fertilizing eggs (Factor, 1995). The eggs are then extruded through the seminal receptacle, fertilized and attached to and carried by the pleopods of the abdominal segment. This extrusion process generally takes place in the summer or fall and the eggs will remain attached for seven to ten months. During this time the female oxygenates and keeps the eggs clean until spring. When ready, the female will release batches of eggs into favorable currents where they hatch and begin their planktonic life stages. For a more comprehensive understanding of the *H. americanus* biology or fisheries management, please refer to Factor, J. R. (ed)

1995: **Biology of the lobster *Homarus americanus***, or visit https://www.maine.gov/dmr/science-research/species/lobster/guide/index.html.

1.3. Shelter Needs of the American Lobster

American lobsters are less likely to occupy open areas (Wahle & Steneck, 1992), and it is thought that predation pressure drives shelter-seeking behavior (Cobb & Wahle, 1994). As they are unable to rapidly burrow in sand, or mud (Cobb & Wahle, 1994), lobsters, when given the opportunity, will typically choose against these substrates as habitat (Hudon et al., 1989). Preferred lobster shelter is more complex with cobble, boulders, and crevasses usable for predator protection (Cobb & Wahle, 1994). An ideal shelter would have two openings providing an entrance and escape exit with an optimum apertures sizes having a low profile where the height is half that of the width (Cobb, J., 1971). The carrying capacity and biomass of lobster habitat correlates to the quantity and size of available shelters. Applying these criteria to natural and artificial habitats could increase the survivability of juvenile lobsters and support a larger adult population (Hudon, 1987).

1.4. Marine Habitat Loss and Degradation

Global human population is increasing and, whether for economical or aesthetical purposes, coastal land mass is becoming more densely populated. As of 2014, approximately 2.6 billion people of the global population live within 100km of the oceans, accounting for an estimated 21% of continental landmass (cited in Patranella et al., 2017). Coastal development, commercial and residential fishing, and boating activities increase simultaneously with increasing coastal population. These activities are generating mechanical and chemical damages to our marine ecosystems resulting in the loss of vital ecological habitat, biodiversity and functionality (Bugnot et al., 2019; Duarte et al., 2013; Heery et al., 2017; Lee et al., 2006).

The development of the land-ocean interface necessary to support the influx of coastal population is known as “ocean sprawl” (Duarte et al., 2013). Ocean sprawl physically removes or degrades existing habitat by way of habitat alterations and artificial structure placement. When dredging is required for construction, fine sediment and any existing containments within the sediment are suspended, causing eye and gill damage to fish and hinder invertebrate filtration (cited in Knott et al., 2009). Also, the direct removal of benthic flora and fauna habitat related to the footprint of artificial structure is known as “placement loss” (Dugan et al., 2008; Heery et al., 2017). Ocean sprawl does not only displace flora and fauna through placement loss, but also alters the physical parameters of the related microenvironment. Artificial structure mass altars natural hydrology redirecting sediment and nutrient deposition, therefore changing food and benthic habitat availability (Heery et al., 2017).

Commercial and recreational fishing and boating activities that include dredging and trawling, mechanically damage marine benthic habitat. Commercial trawling and dredging for fish and shellfish remove much needed three-dimensional benthic habitat structure, which is an important resource of food, predator protection, nursery, or spawning needs that support the life cycle of both commercially and recreationally desirable species (cited in Turner et al., 1999). Also, recreational fishing activities have proven to be destructive to eelgrass habitat, as heavy boat traffic and anchor damage uproot large areas of eelgrass beds (Hastings et al., 1995; La Manna et al., 2015).

The pollutants associated with the urbanization of coastal regions include sewage effluents, heavy metals, pesticides, fertilizers, plastics, microplastics, automotive byproducts including lubricants, tire, and break dust, bitumen, paint, and corrosives from road and building construction, are concentrated through storm drainage systems. This urban runoff is transferred to fresh and marine aquatic ecosystems, and is responsible for major aquatic ecosystem habitat loss (cited in Bugnot et al., 2019; Lee et al., 2006). Alongside of urbanization, marinas and boatyards use antifouling paints to maintain unwanted biological growth on marine equipment and boat hulls. These paints introduce metallic pollutants such as copper, tributyl tin, and zinc (Bighiu et al., 2017). Urban runoff and marina pollution chemically degrade ecosystem functionality (cited in Bugnot et al., 2019). As a result of this contamination, basal food web organisms, such as copepods, are experiencing a decline in fecundity (Soroldoni et al., 2017), and benthic sediments bind to these toxins directly affecting in faunal invertebrates (cited in Knott et al., 2009). These chemical effects can have a considerably negative impact to survivability and the recruitment of invertebrates, including the American lobster (Heery et al., 2017; cited in Spanier, 1993).

Compounding the mechanical, hydrological, and chemical effects of ocean sprawl, the installation of causeways, marinas, wind and wave energy converters, including related pipelines and cables, oil and gas platforms, and aquaculture infrastructure, also introduces foreign habitable substrates. These new surfaces combined with the physical destruction of complex benthic habitat, and the loss of eelgrass beds provide vacant habitat, which can encourage the colonization of different or even invasive species (cited in Heery et al., 2017; cited in La Manna et al., 2015). The mechanical and chemical stressors generated by coastal development are in some ways irreversibly damaging benthic marine habitat, which has a direct impact on the biodiversity and functionality of our naturally occurring marine ecosystem.

1.5. Artificial Reefs

By definition, the European Artificial Reef Research Network characterizes an artificial reef as any man-made reef fixed, submerged, and designed to replicate attributes of natural reefs (Baine, 2001). Although incidental, the earliest records of artificial reefs and their use date back roughly 3,000 years to the beginning of the tuna fishery in the Mediterranean Sea. Here, fishermen would anchor tuna catch nets with large stones, and at the end of each tuna season, the lines would be cut and the stones were left behind. Over time these stones accumulated, creating habitat for other various species of fish. The colonization of smaller fish species encouraged by the rock piles created a new local fishery, which provided fish for market when tuna was no longer in season (Riggio et al., 2000).

Modern day uses of artificial reefs are a little more diversified and specific in purpose, serving as an aide to ecological research, environmental enhancement/restoration, illegal trawling prevention, breakwaters for habitat and coastal protection, water quality enhancement, and recreational diving (Baine, 2001; Becker et al., 2018; Fabi et al., 2011). With a wide variety of applications, the most extensively research and implemented artificial reef involves fish aggregate devices in respect to fisheries enhancement (Miller, 2002; Ponti et al., 2015).

In the past artificial reefs have most commonly been constructed with unwanted items such as old automobiles, tires, and scrap or even waste materials (Baine, 2001; cited in Becker et al., 2018; Bohnsack & Sutherland, 1985). Such poorly designed artificial reefs have proven to be ineffective or even destructive. One such example is the Osborne Reef project located off the coast of Fort Lauderdale, Florida. In the 1970s, over 2 million tires were haphazardly bound together with metal and nylon fasteners and sunk to form an artificial reef. This effort was thought to create recreational fish species habitat while repurposing waste materials. However, marine life found the toxic rubber difficult to colonize and eventually the fasteners failed allowing the tires to move with storm wave energy. This movement destroyed what little growth had occurred on the tires and began colliding with and damaging the natural coral reefs within the area. Eventually storm cycles spread thousands of tires over the Florida panhandle and as far as the beaches of North Carolina, resulting in major environmental destruction (ANON, 2020a). However, when properly implemented, Feigenbaum (1989) found in the Chesapeake Bay, Virginia, that tire reefs can increase catch rates of black sea bass, *Centropristis striata*

(Linnaeus, 1758), tautog, *Tautoga onitis* (Linnaeus, 1758), grey triggerfish, *Balisters capriscus* (J. F. Gmelin 1789), and oyster toad fish, *Opsanus tau* (Linnaeus 1766) (Feigenbaum et al., 1989).

Present day artificial reef design has shifted towards a multifunctional structure specifically crafted with marine grade concrete to replicate target specie shelter, while creating an inexpensive, long lived ecological service (Baine, 2001; Fabi et al., 2011; Feary et al., 2011; Pioch et al., 2011). Successful examples of these multifunctional designs include, "green marine" pipeline anchors used to mitigate coral reef damage (Pioch et al., 2011), illegal trawl prevention barricades (Relini et al., 2007), and the incorporation of habitat structure with wave turbine anchoring (Langhamer & Wilhelmsson, 2009).

Near the island of Mayotte (France, West Indian Ocean), "green marine" pipeline anchors for an underwater municipal water line were designed with various colors and textures to mimic the microenvironment in which they were installed. Researchers found these direct designed habitat anchors successful in the colonization of targeted species of fish and coral (Pioch et al., 2011).

Illegal trawl barriers designed as natural habitat were installed in the coastal waters of France and Italy (Relini et al., 2007; Tessier et al., 2015). These artificial reefs were successful in barricading trawlers from operating in protected regions of the Ligurian sea. These structures proved to be highly effective in conserving a fragile ecosystem, and increasing biodiversity and biomass of fish by providing shelter and nursery habitat. This resulted in local food production with an exportable resource (Relini et al., 2007).

Along the west coast of Sweden, the Lysekil Project is developing an offshore wave energy turbine. The system includes a surface buoy attached by a wire to a power generator on the seafloor, where wave energy is converted to electricity. This power generator is anchored by a marine grade concrete base design with 26 rectangular shelters 12cm x 15cm x 30cm in size (Langhamer &

Wilhelmsson, 2009). Langhamer (2009) found that these shelters significantly increase the quantity of the edible crab, *Cancer pagurus* (Linnaeus, 1758), when compared to control sites.

In general, some artificial reefs have worked as fish attractants, but are rarely successful in providing habitat for targeted species (Alevizon et al., 1985). Some research suggests that artificial reefs can actually redistribute biomass within a population, potentially concentrating commercial and/or recreational efforts, resulting in overexploitation (Grossman et al., 1997). In the general literature, most artificial reefs are typically presented with positive intent such as, increased bio-diversity or fish production, yet much related research lacks specific objectives (Becker et al., 2018), resulting in unclear and sometimes negative results (Baine, 2001). Artificial reefs placed in poorly understood micro-ecosystems could also unintentionally provide new habitat for non-indigenous species creating more of a problem than an environmental service (Perkol-Finkel et al., 2006; Sheehy & Vik, 2010). Conclusively, fishing demands are increasing, and marine habitat destruction continues. However, properly designed and located artificial reefs could provide an environmental service to both commercial and recreational activities in fisheries management and habitat restoration (Becker et al., 2017; Davis, 1985; Grossman et al., 1997).

1.6. Project Goals

On a global scale, the use of artificial reefs is on the rise and pelagic species interactions on these structures are well researched, but there is still much to be understood on epibenthic organisms and their usage (Ponti et al., 2015). However, artificial reefs placed in areas lacking suitable lobster habitat can increase population density of any size class (Jensen et al., 1993), therefore increase lobster prevalence within an area (Castro et al., 2001). When natural shelter is the only limiting factor, artificial reefs could support actively reproducing females, larger, marketable sized lobsters, increase catch per unit effort alleviating stress related to heavy fishing pressures, and possibly enhance or create local fisheries that do not provide adequate existing habitat (Jensen et al., 1993). In years past, artificial reef design lacked specific shelter needs (Alevizon et al., 1985) for targeted species, especially when considering the shelter attributes preferred by American lobster (Spanier, 1993).

The idea of a multifunctional artificial reef is slowly becoming of interest (Fabi et al., 2011), and the debate of whether or not the American lobster has reach maximum carrying capacity remains (Bannister & Addison, 1998). In response to the economic importance of the American lobster and the potential habitat limitation, Habitat Mooring Systems™ approached the University of Maine to design a multifunctional reef system. This artificial reef would support the increasing population of lobster by providing suitable shelter habitat, and serve as a reliable long-term, marine mooring system.

The primary objective of this research is to determine if the habitat mooring system encourages a more biologically diverse colonization of marine organisms in, on, or around the mooring in comparison to the traditional block style-mooring system, resulting in higher species richness. The more exclusive focus of this experiment is to determine if the habitat mooring system will encourage a higher colonization of lobster in, on, or around the mooring, when compared to a traditional block style-mooring system, concluding with increased lobster biomass.

CHAPTER 2

METHODS

2.1. Study Sites

This study was conducted at Seal Harbor, Mount Desert Island, ME, (Figure 2.1; 44°17’28 N, 68°14’ 17 W) and Sand Cove, South Bristol, ME (Figure 2.2; 43°50’25 N, 69°33’22 W). Seal Harbor is fairly unprotected from oceanic influences with a benthic habitat consisting of sand, ledge, cobblestone, and sparse macro-vegetation. The mean dive depth at Seal Harbor was 7.01 m (MLLW). In contrast, Sand Cove is an estuarine cove heavily protected by a sizable ledge running parallel to shore at the opening. The Sand Cove seafloor is comprised of sand with copious amounts of eelgrass, *Zostera marina* (L.). This area is a shallow sub tidal habitat and had a mean dive depth of 5.05 m.

This project surveyed a Habitat Mooring System mooring (HMS4000), a traditional granite block mooring (GNT), and a control plot (CON) at Seal Harbor and Sand Cove. The HMS4000 at Seal Harbor was deployed on July 28, 2010, two years prior to this study, and is currently being used for the “No Wake” buoy in the harbor. The HMS4000 at Sand Cove was deployed on July 16, 2012 for this project.

The HMS4000 is built from marine grade concrete, and is pyramidal with a flat top. This mooring is 1.32 m x 1.32 m at the base, 1.00 m x 1.00 m at the top, with a height of 0.60 m, and weights 1, 814.37 kg. Without the foot print of the base and including the 0.30 m x 0.30 m x 0.20 m recessed hitch bar compartment on the top of the mooring, the total epibenthic surface area of the HMS4000 is 4.12 m^2. The HMS4000 also has 12 hollow channels consisting of three different sizes and two different shapes (Figure 2.3). These channels run through the mooring creating an open passage through the entire unit. The dimensions of the four rectangular channels at the base of the HMS4000 are 7.62 cm x 15.24 cm area. The four channels through the middle of the HMS4000 are circular with a 7.62 cm aperture diameter. There are also four circular channels near the top of the mooring with a 5.08 cm aperture diameter (Figure 2.3).

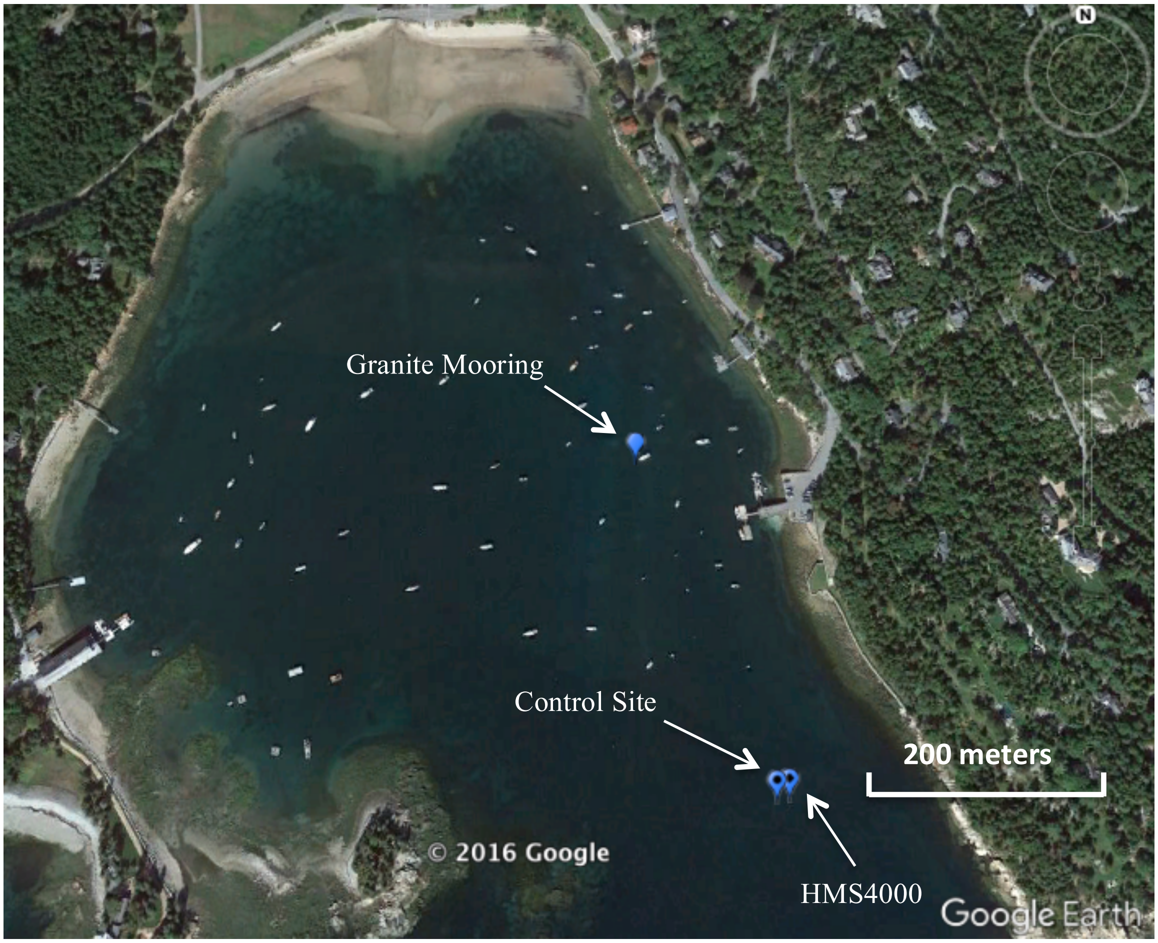

Figure 2.1. Map of Seal Harbor Study Site. The Google Earth image from Seal Harbor, Mount Desert Island, ME, shows the approximate location of the HMS4000 mooring, the granite mooring, and the control site used in this study.

Figure 2.2. Map of Sand Cove Study Site. The Google Earth image from Sand Cove, South Bristol ME, shows the approximate location of the HMS4000 mooring, the granite mooring, and the control site used in this study.

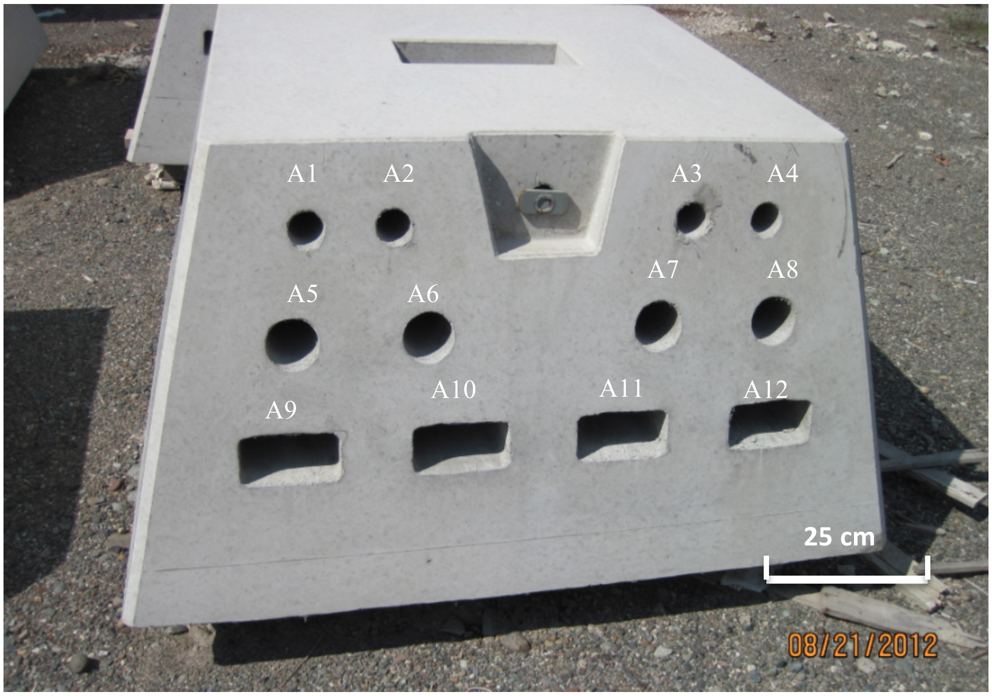

Figure 2.3. Photograph of the Habitat Mooring System. The HMS4000 is a marine grade concrete mooring designed with 12 aperture holes to provide habitat for benthic, marine species. The aperture labels used in this study are indicated above each channel.

At each location, a preexisting, traditional granite block mooring system was chosen for comparison. The granite mooring observed at Sand Cove was rectangular with a footprint of 1.25 m x 0.80 m and a height of 0.30 m giving a total surface area of 2.23 m^2. The granite mooring observed at Seal Harbor had a convex, irregular, pentagonal shape with sides measuring 0.46 m, 1.15 m, 0.55 m 1.00 m, and 1.25 m, with a height of 0.60 m, and a total surface area of 3.81 m^2.

The control sites were chosen at each location to represent the benthic habitat surrounding the HMS4000 and granite moorings, and to evaluate the natural diversity of the area. The 10.2 m^2 area of the control site was determined by combining the surface area of the 1 meter perimeters with the actual surface area of the HMS4000. The center of the control site was marked with a rebar sand screw painted fluorescent yellow, which remained in place for the duration of the study. The perimeter of the control site was measured during each dive using a 0.64 cm rope fashioned with a loop at one end and a 1.9 cm x 31 cm polyvinyl chloride (PVC) pipe as a handle on the opposite end, for a total length of 1.80 m. The rope was attached to the sand screw then fully extended. Next, keeping the rope fully extended, the diver slowly swam in a circle. The area outlined by the rope was the 10.2 m^2 surveyed for this treatment.

For each mooring at both sites, the sides were labeled arbitrarily to keep track of data for the duration of the project. Side 1 was selected on the initial dives and, while facing Side 1, its compass bearing was recorded for future reference. For the HMS4000, Side 1 included openings of one end of the channels. Sides 2, 3, and 4 were labeled in a clockwise pattern, and the top side was simply labeled 'Top'. On the HMS4000, the channels were labeled A1 through A12, beginning at the top left to the bottom right (Figure 2.3).

At Seal Harbor Side, 1 of the HMS4000 had a bearing of 90 °E, while the granite mooring had a bearing of 30 °NE. The Granite mooring was approximately 170 m and 350 °NW from the HMS4000. The sand screw at the control site was located 10 m away from the HMS at 270 °W (Figure 2.1). The convex portion of the GNT was surveyed as a single side. At Sand Cove, Side 1 of HMS4000 had a bearing of 150 °SE, and the granite mooring was 12 m away from the HMS4000 at 295 °NW with a Side 1 bearing of 60 °ENE. The control site was 10 m away from the granite mooring at 330 °NW (Figure 2.2).

2.2. Data Collection and Equipment

All field data was collected via self-contained underwater breathing apparatus (SCUBA) between July 26, 2012 and February 28, 2013. A total of five dives were completed at intervals no less than two weeks apart. The first dive at these locations, referred to as Dive 0, consisted of mooring orientation, scraping the moorings clean from all encrusting species, and determining and marking the appropriate control sites. The following four dives were for data collection. All information on invertebrate and vertebrate species observed at each site during the dives was recorded using premade data collection sheets on waterproof paper attached to a writing cylinder. Each species was identified and the number of individuals within each specie group was recorded. We also visually determined the sex and measured the carapace length of the American lobster using a Hondbay mini double scale vernier caliper. Data were collected from all five surfaces and from within the 1 m perimeter surrounding the base of both the HMS4000 and granite moorings. The contents of internal chambers in the HMS4000 were also surveyed and recorded. To establish the 1 m perimeter for each dive on both mooring types, a 1.6 m piece of 1.9 cm diameter PVC pipe marked at 1.0 m was used by holding the pipe at 90° from the base with the marker farthest away from the mooring. Using the marker on the PVC pipe, we moved it along each side of the mooring to outline the 1.0 m perimeter. In addition, we emptied each channel on the HMS4000 by placing a mesh catch bag over each aperture and pushing the pipe through the opposite end of the channel, forcing out any inhabitants. At the control site we recorded species type, abundance, and carapace length and sex of lobster.

To record vegetative colonization, we used an underwater Cannon PowerShot D10 waterproof camera for photographic record. Before each picture, a 1.9 cm diameter PVC quadrat with a 50 mm wire grid was placed over each side of the mooring for a reference of scale (Figure 2.4). Two dials positioned on the side of the quadrat were used to indicate photo location. A second 83 cm by 56 cm quadrat was used to lay down eelgrass during photography. This quadrat was made with 1.9 cm diameter PVC pipe, with an interior 7.6 cm grid made with masonry string. Photos were downloaded to a computer for further analysis.

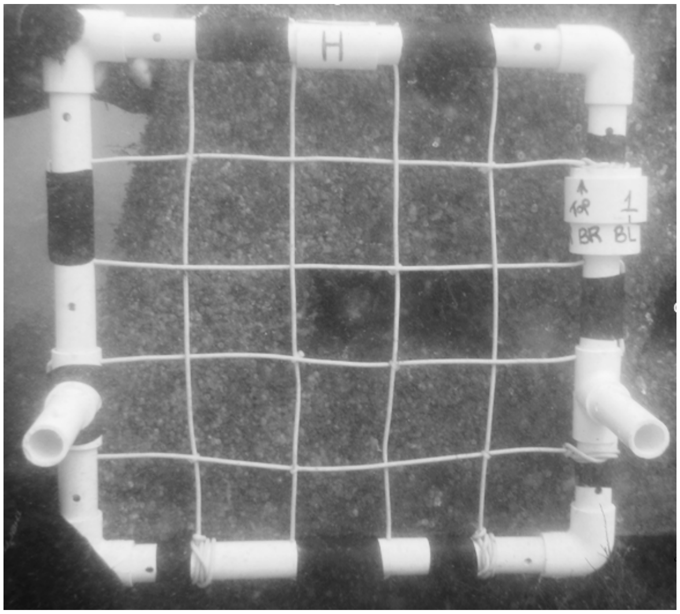

Figure 2.4. Photograph of Quadrat with Identification Dials. Quadrat is constructed of 1.9 cm diameter polyvinyl chloride (PVC) pipe with a 50 mm wire grid. The location indicator dials are at the top center and left center of the quadrat. The left center dial is divided into an upper and lower dial. The top indicator dial identifies mooring type: HMS4000 (H), granite block mooring (G); Center left upper indicator dial identifies side of mooring: side 1 (1), side 2 (2), side 3 (3), side 4 (4), and top side (TOP); Center left lower indicator dial identifies location on side of mooring: top left (TL), top right (TR), bottom left (BL), and bottom right (BR).

A minimum of two scientific divers, referred to in the following as Diver 1 or Diver 2, assisted in data collection. Both divers slowly approached each unit and began recording the number and location of each species they observe fleeing upon their advancement. At the mooring sites, Diver 1 held the 1.6 m PVC pipe just above the sea floor with one end at 90° to the mooring. While Diver 1 moved along each side of the mooring marking the edge of the 1.0 m perimeter, Diver 2 recorded their observations from within the 1.0 m area. Then, Diver 2 recorded data on the Top, Sides 1 and 2 while Diver 1 recorded data from Sides 3 and 4. On the HMS4000, Diver 2 positioned a mesh catch bag at each channel opening while Diver 1 vacated the channel using the PVC pipe previously described. Captured species were identified, counted, and measured from within each channel. For the HMS4000 and the granite moorings, we then photographed vegetation on the moorings. Diver 1 placed the quadrat on each corner of the Top, Sides 1, 2, 3, 4, and updated the picture identification dials to correspond with the location (Figure 2.4), while Diver 2 took photographs of each quadrat placement. At the Sand Cove HMS4000, the second quadrat was placed alongside the mooring side surface and laid down to temporally pushed back the eelgrass for better visibility. At the control site, Diver 1 attached the rope to the sand screw, extended it, and, while keeping the rope taught, slowly swam around the sand screw until returning to the start point of the circle. Diver 2 swam inside of Diver 1 and recorded all observations within the circle. When possible, all lobsters were captured, measured, and sexed before being released. More information on the bottom times and depths of each dive can be found in Appendix A, Table A. 1.

2.3. Data Analysis

Species identification was accomplished by referencing the Marine Life of the North Atlantic guide (A. J. Martinez, 2010). Species richness was the calculated mean number of species present during the four surveys at each treatment. Species richness was compared between treatments among study sites. Key species were then categorized into four groups: (1) American lobster. (2) Jonah and rock crab, *Cancer borealis* (Stimpson, 1859)/*Cancer irroratus* (Say, 1817); (3) “Other Crabs” which consisted of any crabs other than Jonah and rock crab, and (4) Fishes, *Teleost* which included all fish species surveyed. The mean number of individuals within each category was compared as abundance. Abundance for each category was compared by treatments among study sites.

For lobster analysis, the mean carapace was used to compare the size of lobster found at each study site. The mean carapace length of lobsters found inhabiting the HMS4000 shelters was also compared to the aperture size in which they were found to evaluate the relationship of lobster size to aperture sizes. The estimated mean weight of a lobster was calculated by inputting the measured carapace length into the regression equation developed by Krouse (1973):

$$\log W = -2.9052 + 2.9013 \log L$$

where W is the estimated weight of the lobster (in g) and L is the measured carapace length (in mm). Biomass was calculated in meters squared (in $g \cdot m^{-2}$), by dividing the mean estimated weight of lobster found at each study site by the surface area of that treatment (± S.E.; n = 4).

A Univariate Analysis of Variance (ANOVA) test with Fisher's Least Significant Difference (LSD) post-hoc analysis was run to test for significant differences in species richness, lobster abundance, mean lobster carapace length, and lobster biomass (± S.E.; n = 4) between the mooring types and control plots for each location. An ANOVA was applied to evaluate the effects between aperture size on the lobster carapace length of the individuals observed within the shelters of the HMS4000 and shelter size (± S.E.; n = 4). The differences in these factors between the Seal Harbor and Sand Cove study sites were not evaluated; all comparisons were made between the HMS4000, the granite mooring and the control plots within each site.

Unfortunately, a second HMS 4000 could not be deployed at Seal Harbor, Mount Desert Island, ME, due to budgetary constraints. However, a second HMS4000 was deployed at Sand Cove, South Bristol, ME, much closer to the University of Maine dive facility. As it was not possible to make direct comparisons by means of repeated measures with exact replicates within one location, the four dives from each location were "loosely" treated as replicates to provide a general understanding of the mooring colonization by the local fauna and flora.

The mean occupancy of the HMS4000 at each site was calculated, at both locations, as the mean percentage of shelters occupied by lobster only and by all species, with lobster included (± S.E.; n = 4).

Significant differences between the mean male and female lobster abundance, and significant differences between the mean carapace length of male and female lobster were calculated using the Students T-Test. All statistical analyses were conducted using SPSS Statistical Software, Version 22 (IBM Corporation), and significant differences were calculated with $p = 0.05$.

CHAPTER 3

RESULTS

3.1. Species Richness

Combining data from Seal Harbor and Sand Cove, a total of 33 species were identified throughout this project. Overall, lobster, Jonah/rock crab, “Other crabs”, and fish were more abundant at Sand Cove compared to Seal Harbor. The newly deployed HMS 4000 was the only mooring system that produced any substantial vegetative growth, that being hair algae, *Enteromortha sp and/or Bryopsis sp.* No other vegetation repopulated in measurable amounts at either site resulting in the removal of all vegetative species from comparisons. The total number of species recorded at Seal Harbor and Sand Cove were higher at the HMS4000 and the GNT than their respective CON groups (Table A. 2.; Table A. 3.). Mean species richness of the HMS4000 and the GNT was significantly higher than their respective controls at Seal Harbor ($p = 0.00$) and Sand Cove ($p = 0.002$) (Figure 3.1). However, there were no significant differences in species richness between the HMS4000 and the GNT at either location.

3.2. American Lobster, Jonah/Rock Crab, and “Other Crabs” Abundance

There were significantly more lobsters observed at the HMS4000 than other treatments in Seal Harbor ($p = 0.00$), as there were no lobsters surveyed on the GNT or CON. Although the GNT at Sand Cove had relatively fewer lobsters observed than the HMS4000 and CON, no other significant differences were found in relation to lobster abundance (Figure 3.2). When comparing crab abundance to treatments, no Jonah/rock crabs there were significantly more Jonah/rock crabs at the Sand Cove GNT compared to other treatments at this site ($p = 0.002$). No other significant differences were found between Jonah and rock crab in any other comparison (Figure 3.3). The species that composed the “Other crab” group were the decorator crab, *Majoidea spp.* (Samouelle, 1819), green crab, *Carcinus* maenas (Linnaeus 1758), hermit crab, *Pafurus spp.* (Latreille, 1802), and the Asian shore crab, *Hemigrapsus sanguineus* (Milne-edwards, 1853). No significant differences were found between the "Other crabs" group and any treatment at either location.

3.3. Fish Species Abundance

Fish species during this study were, American eel, *Anguilla rostrata* (Lesueur, 1821), Atlantic cod, cunner, *Tautogolabrus adsqerus* (Walbaum 1792)*,* flounder, *Platichthys spp* (Girard 1858), hake *Merluccius bilinearis* (T. N. Gill 1884), rock gunnel, *Pholis gunnelius* (Linnaeus 1758), sculpin, *Cottoidea spp.,* and all unidentified fishes were labeled "*Teleost"*. The highest abundance of fish was on the Sand Cove HMS4000 and the lowest abundance of fish was on the control site at both Seal Harbor and Sand Cove, but there were no significant differences between treatments at either location (Figure 3.4).

3.4. Mean American Lobster Carapace and Mean Biomass

No mean lobster carapace length or mean lobster biomass comparisons could be made at Seal Harbor, as there were no lobsters observed at the GNT or CON. Although more lobsters were surveyed at the Sand Cove study site, there were no significant differences in mean lobster carapace lengths between treatments (Figure 3.5). Again there was no significant difference in the mean lobster carapace length to the HMS4000 aperture selection (Figure 3.6). In general, Sand Cove had a higher mean lobster biomass and the CON was highest of all study sites at this location, but there were no significant differences between treatments (± S.E.; n = 4; Figure 3.7).

3.5. Mean Percent Occupancy in HMS4000 Shelter Space

The mean percent occupancy of lobsters in the HMS4000 shelters at Seal Harbor and Sand Cover were coequal with 27.1% occupancy per dive (Figure 3.8). The mean percent occupancy of shelter space in the HMS4000 at Seal Harbor, in respect to all species, was slightly lower at Seal Harbor. Atlantic cod, cunner, flounder, sculpin, one unidentified fish, and American lobster were surveyed occupying the shelters within the Seal Harbor HMS4000 on 46.0 ± 11.0% of the dives. The HMS4000 at Sand Cove had a mean shelter occupancy of 50.0 ± 6.0% per dive which included, the American eel, cunner, flounder, hake, sculpin, and the American lobster (Figure 3.9). For a comprehensive listing regarding species and specific shelter use refer to Appendix A, Table A. 4.

3.6. Mean Carapace Length and Abundance of Male and Female American Lobsters

Although there were more male lobsters at the Sand Cove control site than any other treatment, there were no significant differences between the abundance of male lobster compared to female lobster at either location (figure 3.10). The mean carapace length of male lobster was slightly larger than the female at the HMS4000 at both locations, but not significantly different from other study sites (Figure 3.11).

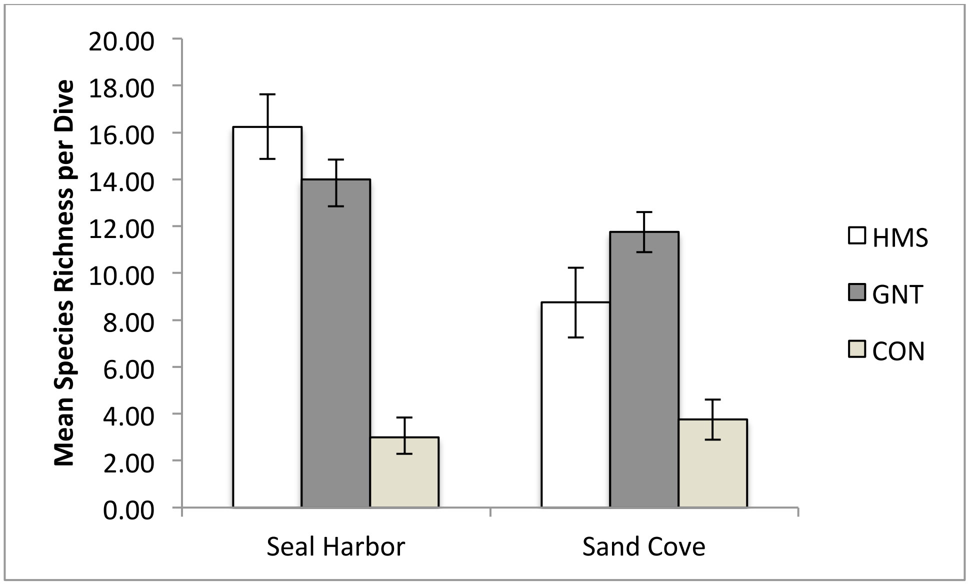

Figure 3.1. Comparing Mean Species Richness between Experimental Groups. The mean species richness (± S.E.; n = 4) was significantly higher at the HMS4000 (white bar) and the granite ($p = 0.002$; grey bar) moorings relative to their respective control (CON; tan bars) groups for both Seal Harbor (left) and Sand Cove (right). No comparisons were conducted between study sites.

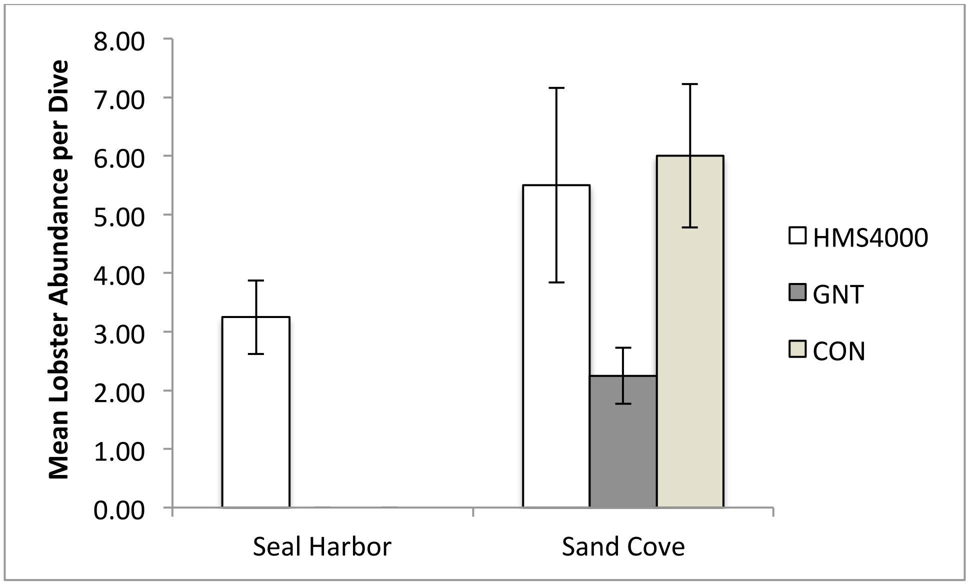

Figure 3.2. American Lobster Mean Abundance Compared between Experimental Groups. At Sand Cove (right), lobsters were present at the HMS4000 (white bars) and the granite (GNT; grey bars) moorings as well as the control (CON; tan bar) site, with the fewest observed at the GNT, however no significant differences were found. The lobsters surveyed at Seal Harbor (left) were significantly higher at the HMS4000 than the GNT and CON ($p = 0.00$; ± S.E.; $n = 4$). Study sites were compared separately.

a b

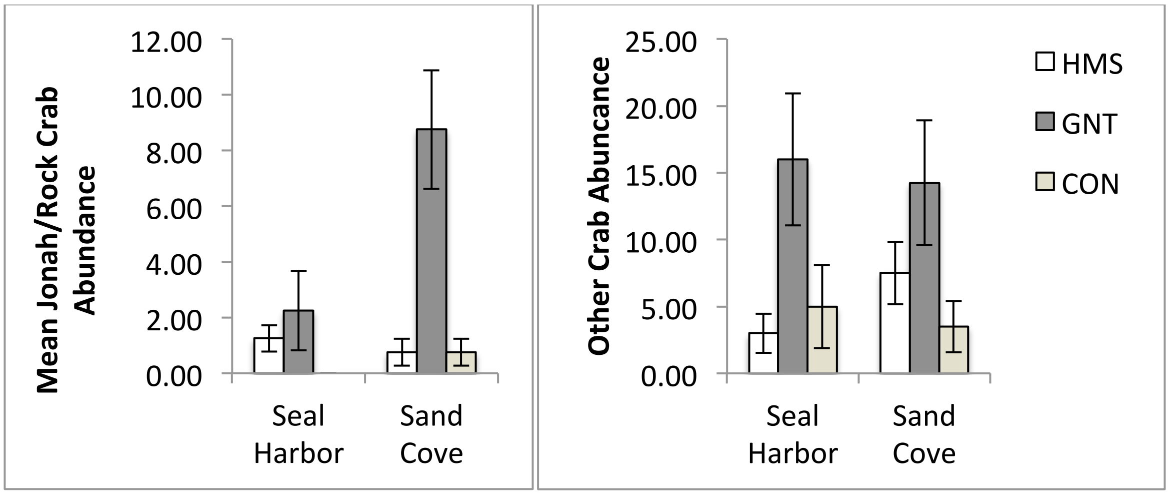

Figure 3.3. Comparisons of Crab between Experimental Groups. Jonah and rock crab, (graph a) as one group and "Other crabs", including the decorator crab, green crab, hermit crab, and Asian shore crab, (graph b) as a second group between mooring types. No Jonah/rock crabs were surveyed at the control site (CON; tan bars series) at Seal Harbor (left bar series). There were significantly more Jonah/rock crabs (graph a) at the Sand Cove (right bar series) granite (GNT; grey bar series) mooring than the HMS4000 (white bar series) and the CON (tan bar series) at this location ($p = 0.002$; ± S.E.; $n = 4$). Study sites were compared separately.

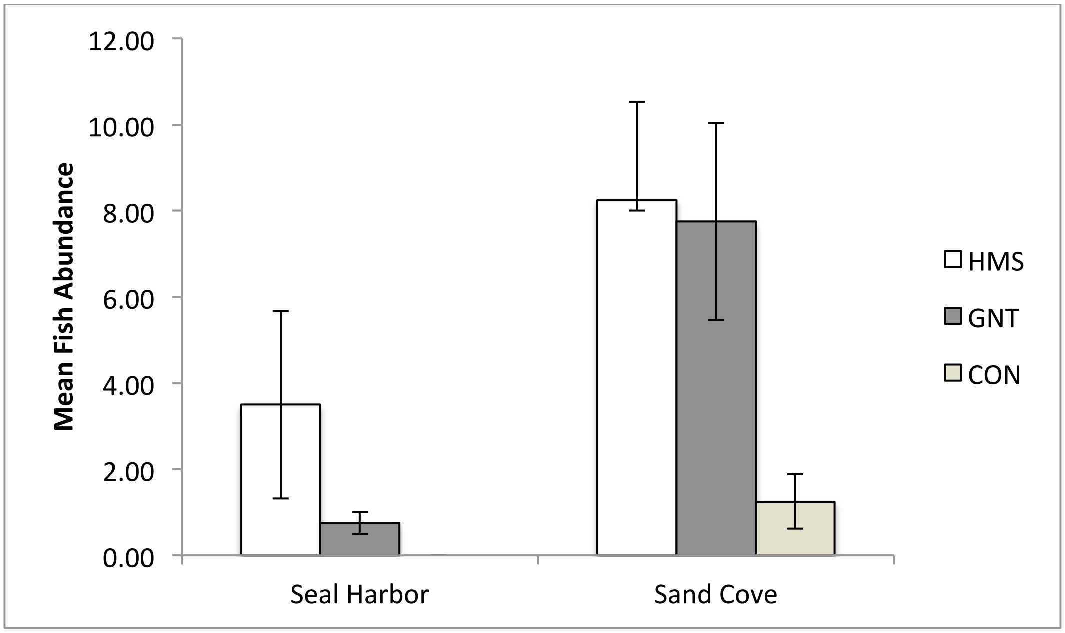

Figure 3.4. Fish Abundance between Experimental Groups. The group of fishes observed at Seal Harbor (left) and Sand Cove (right) include the American eel, Atlantic cod, cunner, flounder, hake, rock gunnel, and unidentified fishes. Overall there were more fish surveyed at Sand Cove, no fish observed at the control (CON) site at Seal Harbor, no but significant differences calculated between treatments at either study site (± S.E.; n = 4). Study site were compared separately.

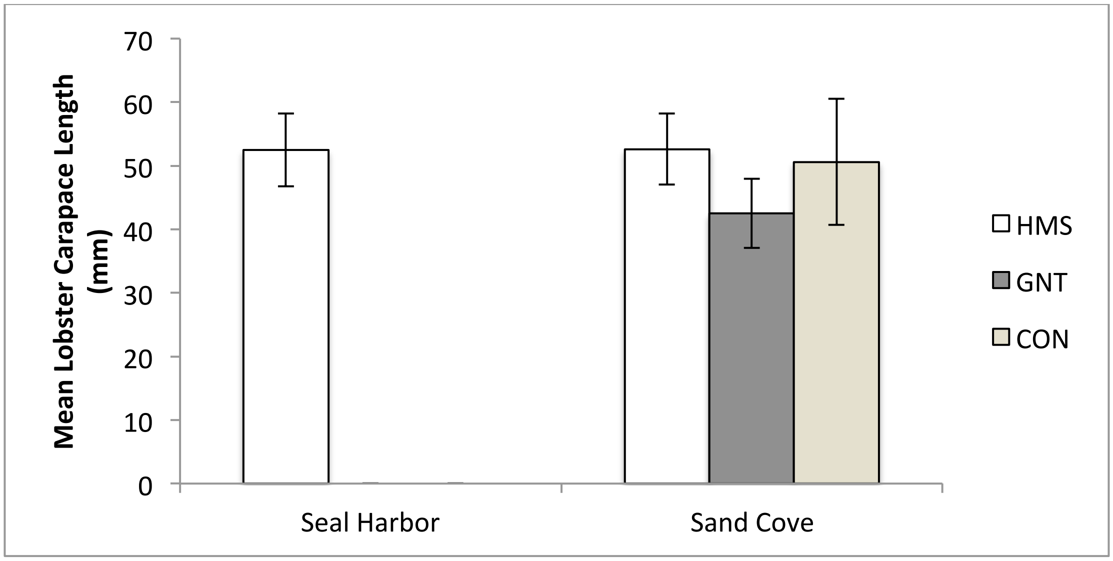

Figure 3.5. Comparing Mean American Lobster Carapace Length between Experimental Groups. The mean American lobster*,* carapace length (mm ± S.E.; n = 4) is shown for the HMS4000 (white bar), granite mooring (GNT; grey bar), and control site (CON; tan bar) at both Seal Harbor (left) and Sand Cove (right). No significant differences between moorings. Study sites were compared separately.

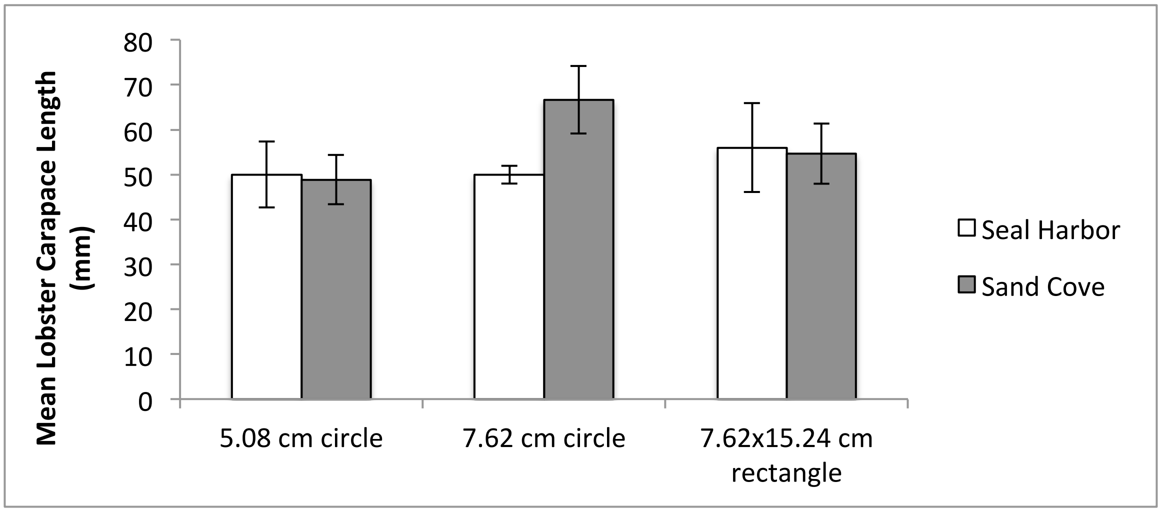

Figure 3.6. Mean American Lobster Carapace Length Compared to HMS4000 Shelter Aperture Selection. The mean American lobster, carapace length from Seal Harbor (white bar) and Sand Cove (grey bar) were grouped according to aperture size (5.08 cm and 7.62 cm circles and 7.62x15.24 cm rectangle). Conclusively, there were no significant differences between aperture size and carapace length (± S.E.; n = 4).

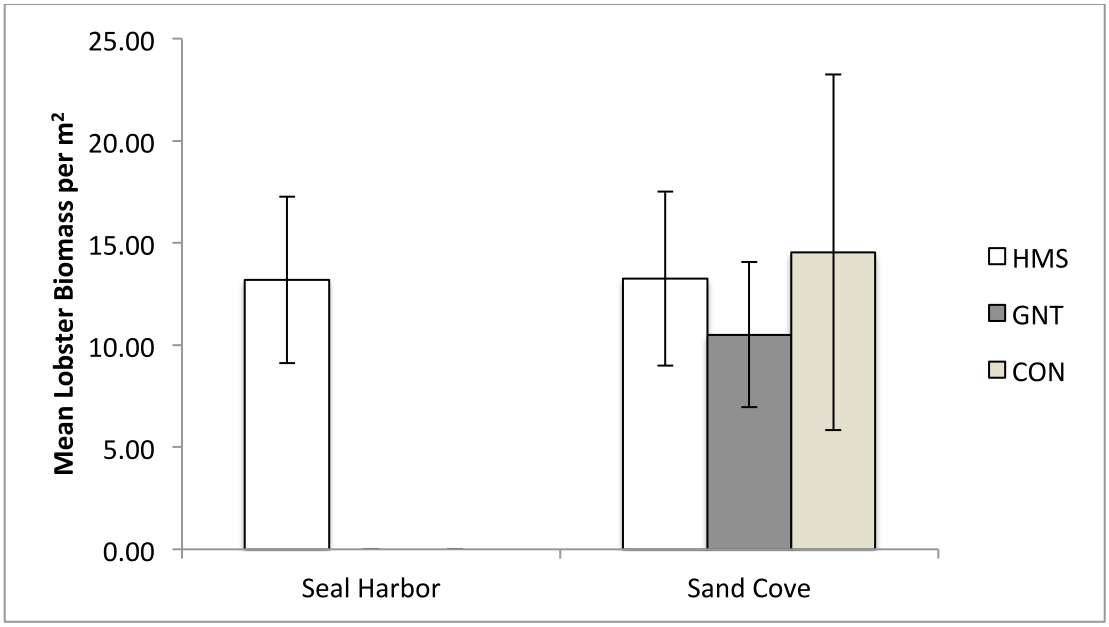

Figure 3.7. Comparing Calculated Mean American Lobster Biomass between Experimental Groups. The calculated mean lobster biomass at the Seal Harbor (left) HMS4000 (white bar) was 13.19 g per m^2 with no lobster observed at the GNT (grey bar) or CON (tan bars). At Sand Cove (right), the calculated mean lobster biomass at the HMS4000, GNT, and CON were 13.26, 10.51, and 14.55 g per m^2, respectively. Sand Cove had a relatively higher mean lobster biomass, however there were no significant differences between experimental groups (± S.E.; n = 4). Study sites were compared separately.

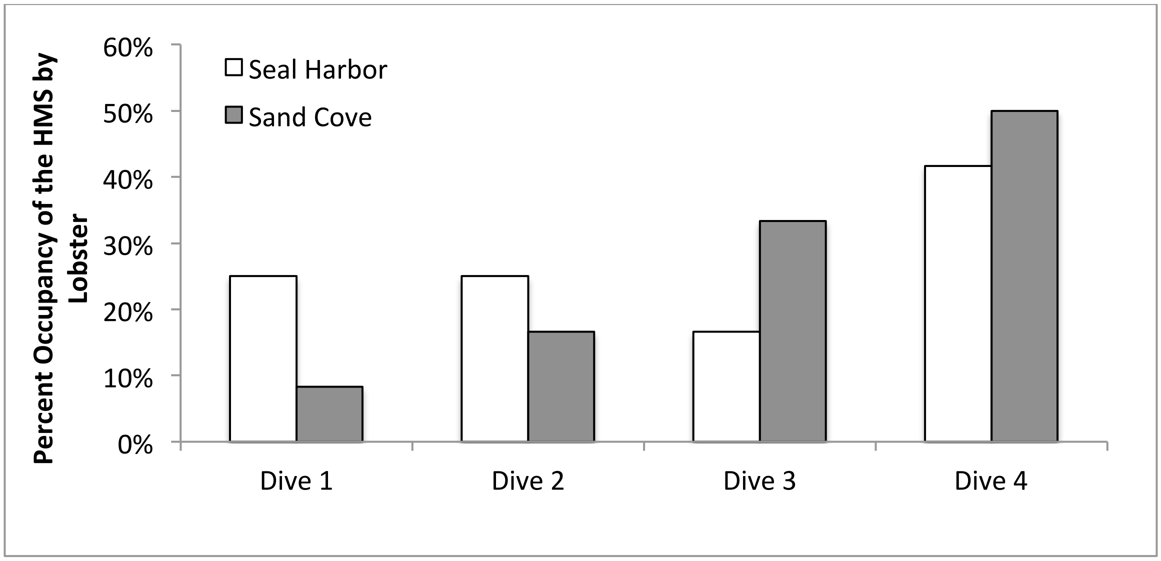

Figure 3.8. Percent Occupancy of the American Lobster Inhabiting the HMS4000 Shelters at Seal Harbor and Sand Cove over Four Surveys. The Seal Harbor (white bar) and Sand Cove (grey bar) had a calculated percent occupancy were 27.1 ± 5.0% and 27.1 ± 4.0% respectively.

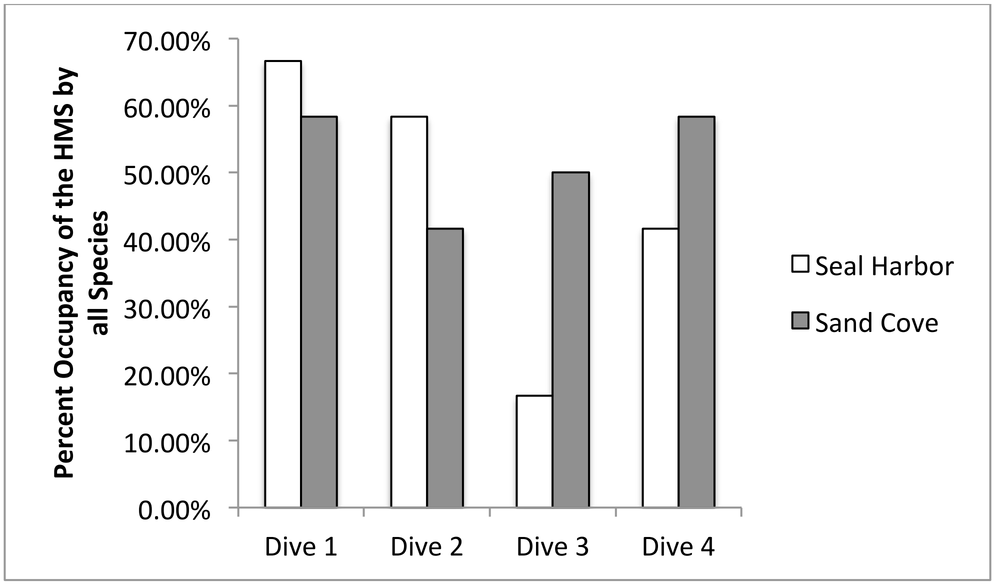

Figure 3.9. Percent Occupancy of all Species, Including the American Lobster, Inhabiting the HMS4000 Shelters at Seal Harbor and Sand Cove over Four Surveys. The mean occupancy of all species at the Seal Harbor (white bar) HMS4000 was 46 ± 11.0%., and 50 ± 6.0% at the HMS4000 at Sand Cove (grey bar).

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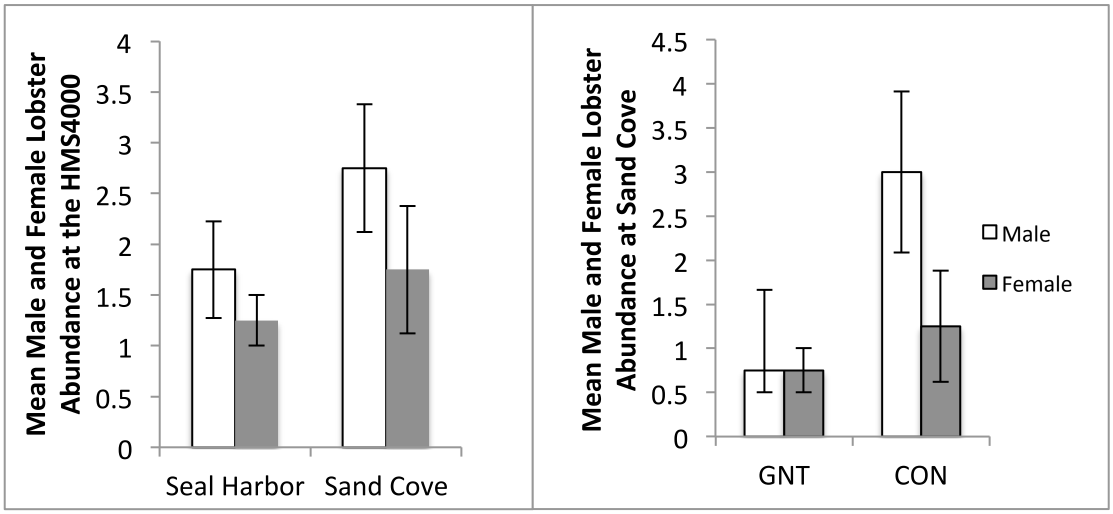

Figure 3.10. Comparing Mean Male and Female American Lobster Abundance between Experimental Groups. The trend of the mean number of male lobster (graph a; white bar series) when compared to female lobster abundance was highest at the control site in Sand Cove (graph b; CON) and higher on both HMS4000 treatments (graph a; white bar series) compared to the granite study site (graph b; GNT), however there were not significant differences among study groups.

a b

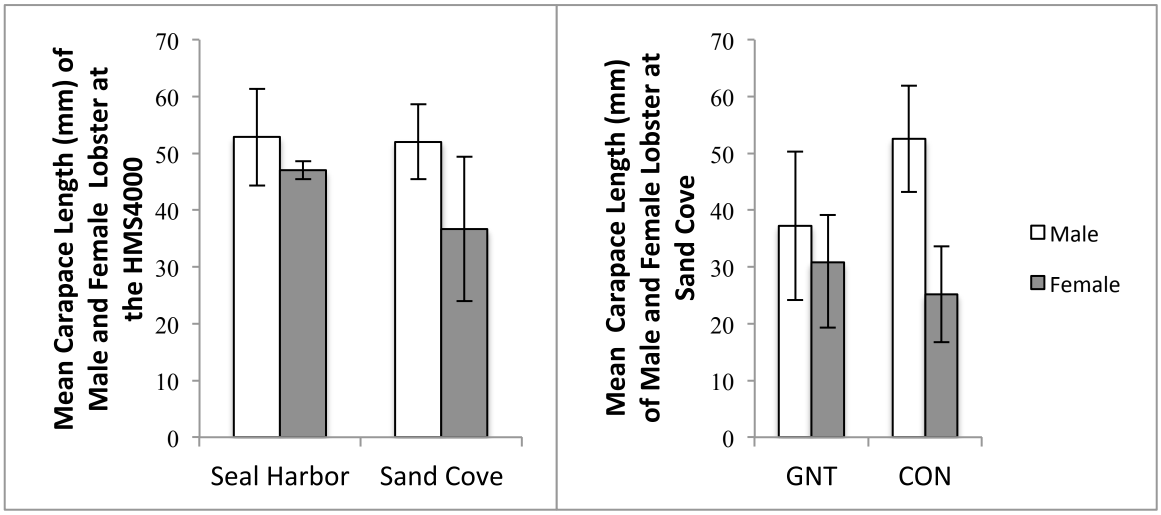

Figure 3.11. Comparing the Mean Carapace Length of Male and Female American Lobsters between Experimental Groups. Although the there was a trend of larger males at each treatment, there were no significant differences between male and female carapace lengths (± S.E.; n = 4).

CHAPTER 4

DISCUSSION

Seal Harbor and Sand Cove have very different benthic habitat with a slightly different species composition. Sand Cove, having a well-protected estuarine influence, a copious amount of eelgrass, and sandy substrate, had a trend of higher overall abundance of species in the categories of American lobster, Jonah/rock crab, “Other crabs”, and fish. Conversely, Seal Harbor had a deeper mean dive depth, a greater exposure to open ocean elements, and a less structured habitat consisting of ledge, gravel, and some cobble, yet had a trend of higher species richness by 67% (Table A. 2.; Table A. 3.). In general, Sand Cove had a higher abundance and biomass of lobster, while Seal Harbor had a slightly larger mean carapace length of male lobster. Combining all lobster data from both locations, the male to female ratio of the 29 lobsters surveyed was 71% female, which is higher than the expected ratio of 1:1 found in this region of the Atlantic by previous research (Cooper et al., 1975; Krouse, 1973), however these researchers had sample sizes much larger than that analyzed in this project.

The specie richness of the HMS4000 and the GNT was significantly higher at Seal Harbor ($p = 0.00$) and Sand Cove ($p = 0.02$) compared to their respective control groups (Fig. 3. 1.). This was of no surprise as other artificial reef research suggests structured habitat would provide shelter for more species than areas with no structure (Patranella et al., 2017). However, the trend of the HMS4000 at Seal Harbor had a higher species richness compared to all treatments from both groups. The HMS4000 at Seal Harbor was deployed approximately two years prior to the HMS4000 at Sand Cove. Species richness increases over time as species such as the northern rock barnacle, *Semibalanus balanoides* (Linnaeus 1767), begin to colonize and provide food for sea stars, *Asteroidea*, (Blainville 1830), sea star grazing creates habitat for macro algae, which attracts more invertebrates, such as crab and lobster, and ultimately fish that prey on the invertebrates (Buckley & Hueckel, 1985). The northern rock barnacle and sea star were present on the older more seasoned HMS4000 and GNT in Seal Harbor. Rock barnacles were also on the GNT in Sand Cove. Over time, it is likely, the progression of colonization on the HMS4000 at Sand Cove would surpass the GNT in species richness like the more seasoned example surveyed in Seal Harbor.

Similar to the findings of Jensen (1993), lobster had inhabited the artificial reef within the first few weeks of deployment. Lobster abundance was significantly greater at the HMS4000 as there were no lobsters in the other treatments at Seal Harbor. Overall, the trend of lobster abundance at Sand Cove was higher at the CON compared to other treatments and again higher at the HMS4000 over the GNT (Fig. 3. 2.). Unlike Seal Harbor, the Sand Cove CON was particularly dense with eelgrass, and sea grasses has been shown to provide complex habitat that can reduce predation risk on decapods (Heck & Thoman, 1984). Also, lobsters are negatively phototactic (Cobb, J., 1971), which may encourage the use of eelgrass as a form of shade shelter. Generally, lobsters at Sand Cove were found at higher densities, which also promotes movement (Hovel & Wahle, 2010). Given there was no structured shelter within the control plot, it would be difficult to establish if these lobsters were actually residing here or just transiently using the habitat.

An artificial reef study conducted by Scarratt (1968) found lobster carapace length to be uniform throughout the structure. Concurrently the mean carapace lengths of lobster surveyed within each HMS4000 treatment at both locations were approximately 53 mm (Scarratt, 1968). The trend of the mean carapace length on both HMS4000 treatments was slightly larger than lobsters surveyed at the Sand Cove GNT and CON (Fig. 3. 5.). The shelters within the HMS4000 at Seal Harbor and Sand Cove were consistent with a mean lobster occupancy of 27% (Fig. 3. 8.). Occupancy consisted of only one lobster per shelter at a time, which concurs with the findings of lobsters on natural sheltering habitat (Ennis, 1984). Interestingly, the Sand Cove HMS4000 mean carapace length of lobsters using the 7.63 cm circular shelter was 67 mm. This was at least 10 mm larger than lobsters surveyed in any other shelter size or shape in the HMS4000, at either location (Fig. 3. 6.). Cobb (1971) found lobsters with a carapace length between 51 cm and 70 cm to prefer a shelter opening area size and shape more closely related to that of the lower 7.62 cm x 15.24 cm channel. However, Cobb (1971) only investigated square and rectangular openings with a minimum aperture of 8.89 cm x 12.7 cm, rather than the smaller circular ones used in this project. It is possible that there was a higher population of this particular size class in need of suitable shelter, and this specific shelter shape and size was more favorable than other available options.

Using rock to form a 2740 m^2 artificial reef, Scarratt (1968) found that mean lobster density was higher closer to the edges of the structure, and less dense towards the interior, therefore calculating a mean lobster biomass range of 4.3 to 13.1 g per m^2. The HMS4000 at Sand Cove and Seal Harbor both had a calculated mean lobster biomass of 13 g per m^2, which was higher than the GNT treatment (Fig. 3. 7.) and corresponds to the higher density biomass found by Scarratt (1968). Although the trend of the mean lobster biomass on the HMS4000 was higher than the GNT, it was less than the 14.55 g per m^2 surveyed at CON in Sand Cove.

The GNT at Sand Cove had equal amounts of male and female lobster present, which does reflect the 1:1 ratio of similar size class (<81 mm) lobsters found by Krouse (1973). In contrast, the trend of the CON at Sand Cove and the HMS4000 in both study groups had a higher mean male lobster over female lobster abundance (Fig. 3. 10.). Also, the trend of the mean male carapace length of the lobster on both HMS4000 treatments and the CON at Sand Cove was larger than the female. Generally speaking, the HMS4000 had a trend of larger female lobsters and a higher number of larger male lobsters seeking refuge over the GNT (Fig. 3. 10). Comparably, Jensen (1993) found lobsters on an artificial reef to be larger on average compared to those surveyed in adjacent natural habitat. In Sand

Cove, on two sequential dives, one female per dive was very close in length and surveyed within a similar shelter location in the HMS4000. On the second dive, the female lobster was found having recently molted. Jensen (1993) also suggests that reproductively active lobsters may use artificial reefs more frequently as a secure habitat in areas of heavy fishing activity. Unfortunately this female was not tagged in this study, so it is not possible to say if this individual was the same female from the previous dive. In any case, the second female surveyed was certainly using this artificial reef as shelter for molt recovery and could have potentially mated within or near the structure.

The mean Jonah/rock crab abundance was significantly higher at the GNT treatment in Sand Cove (Fig. 3. 3.; P=0.002), which was also the trend at Seal Harbor but not significantly different than the respective treatments. Although Jonah/rock crabs may not be in direct shelter competition with lobster, their shelter habitats do overlap, and lobster feed extensively on the rock crab (Richards & Cobb, 1986; Scarratt & Lowe, 1972), which could explain the lower prevalence on the HMS4000. The GNT at Sand Cove is a granite block mooring system that was actively in use. The movement of the mooring chain removed all eelgrass within the surrounding area of the mooring. This left a fine gravel substrate in a large radius of the GNT. The GNT in Seal Harbor was in a naturally open, sandy area. In contrast, the HMS4000 at Sand Cove was deployed specifically for this study and not mechanically operating as a boat mooring, therefore the dense eelgrass surrounding this treatment was undisturbed from anchor chains. As Jonah/rock crab occupies open sandy area (Scarratt & Lowe, 1972), the GNT provided suitable habitat. This suitable habitat combined with lower predation pressure could explain the higher abundance of Jonah/rock crabs at the GNT study sites.

The mean abundance of the “Other crab” category was comprised mostly of green crab and hermit crab. As green crabs are typically found in higher abundance in shallow waters (Donahue et al., 2009), they were only found at the Sand Cove study site. Prior to one dive at Sand Cove, maintenance staff lowered the mooring chain on the granite mooring system for winter storage. The chain was stacked inside the 1 m perimeter of the GNT, which provided much new shelter space. Numerous green crabs rapidly exploited this new habitat. After this surveyed, the chain was stretched out to reduce the extra shelter space and avoid further data bias. Naturally this increased the green crab count on the GNT, but the overall trend of green crab abundance was still higher at the HMS4000. Jonah/Rock crabs are predators of the green crab and they were present on the GNT significantly more than the other treatments, however Jonah/crabs were also surveyed on the HMS4000 along with a higher mean number of lobsters, which equally consume green crab (League-Pike & Shulman, 2009; Sungail et al., 2013; Williams et al., 2009). Williams (2009) suggests green crab are a potential competitor of prey and are more effective in finding and consuming prey before lobster, depending on size class of both the lobster and green crab. The research conducted and cited by Williams and MacSween (2009) investigated adult green crab prey competition against three size classes of lobster ranging from 28 mm to 80 mm (Williams et al., 2006, 2009). They found green crab and lobster show aggression to attain prey items, but once either individual gains possession, the other immediately retreats. Also, as the size increases in lobster carapace, the lobster becomes more successful in prey acquisition. The green crabs present in this study were not all adult sizes, therefor it is hard to determine any similarities in agonistic behavior, but it is very possible similar interactions are taking place. Green crabs have also been observed climbing kelp fronds to avoid lobster predation (League-Pike & Shulman, 2009) and could be using the eelgrass surrounding the HMS4000 in a similar manner, although not directly observed during the surveys. The combination of HMS4000 and the dense eelgrass could be allowing cohabitation for this size class of both species, which offers beneficial prey competition and favorable shelter for the green crab verses the predation risk on the GNT.

Hermit crabs were more commonly surveyed at the GNT at both locations. These crabs form a part of the American lobster diet, and are a preferred prey item for the specific size class surveyed on the HMS4000 (Fig. 3.5.) (Hanson, 2009). This could explain the lower abundance of hermit crabs at these sites, and increased abundance on the GNT where fewer lobster was surveyed. The Seal Harbor GNT had no lobster present and the hermit crab was surveyed three times more at this treatment than any other study sites. As a whole, the trend of the “Other crab” category was more intense at the GNT at Sand Cove and Seal Harbor than other treatments, but the green crab seemingly preferred the HMS4000, and the hermit crab, potentially by way of predator avoidance, preferred the GNT.

Langhamer (2009) found fish species to rapidly occupy a newly deployed artificial reef habitat. Similarly, in this study fish were present at the HMS4000 on the first survey, three weeks after the reef was deployed in Sand Cove. Although there was no significant difference between treatments, fish were observed more often on the HMS4000 at both locations than other treatments. All fish species, apart from sculpin and flounder at Sand Cove, where found to be exclusive to or present by at least twice the amount on the HMS4000 over any other treatment (Table A.5). The observed trend of flounder was higher on the GNT at Sand Cove, however the flounder abundance on the HMS4000 reflected that of the CON. The sculpin observed in Sand Cove were in greater numbers at the GNT, and there were slightly more present on the HMS4000 over the CON, yet no significant differences were found. The juvenile flounder surveyed during this project were not identified by specific specie, however the Maine Department of Marine Resources (DMR) states the winter flounder, *Pleuronectes americanus*, (Walbaum 1792), to be the most common flounder along the Maine coastline (ANON, n.d.-a). Estuarine eelgrass beds are highly productive as winter flounder nurseries and depending on the density of juveniles during a particular year, they will either inhabit the eelgrass areas (low density years) or use adjacent bare bottoms areas (high density years) as habitat (Lazzari, 2008). The Sand Cove study site would be an example of this suitable nursery habitat, and juvenile flounder were surveyed here three times more than Seal Harbor, indicating the possibility these were winter flounder. If in fact these were winter flounder, it would be possible to conclude we were experiencing a high population density year, as they were most commonly observed at the exposed sandy bottom associated with the GNT, adjacent to the dense eelgrass present at the other treatments.

Seal Harbor and Sand Cove where drastically different in environmental characteristics and in lobster density, yet the HMS4000 still supported the same biomass of larger lobster, and the overall percent occupancy was very similar (Seal Harbor: 46%; Sand Cove: 50%; Fig. 3. 8.). The HMS4000 had significantly higher species richness, and trended towards a higher average male lobster abundance, lobsters with larger mean carapace length, and a higher lobster biomass when compared to a traditional block style mooring system. Throughout this project, the HMS4000 provided shelter for Jonah crab, rock crab, flounder, and a variety of commercially important fish species unique to the HMS4000 such as, Atlantic cod, and the American eel. The Jonah crab is an up and coming fishery in New England with a landings increase of over 650% since the early 2000s and a reported landing of 9,162.57 metric tons in 2018 (ANON, 2020d). Rock crab is highly beneficial to the American lobster diet as they are high in proteins that support growth, molt and fecundity (Gendron et al., 2001; Scarratt & Lowe, 1972). The Atlantic cod population, as stated by the Maine DMR, is vulnerable, unstable, and on the decline (ANON, 2015b). As a result, in 2019, the state of Maine landings for Atlantic cod was 40 metric tons, reduced from approximately 3,000 metric tons in 1950 (ANON, 2020b). Likewise, the American eel annual allowable catch has greatly reduced as the population is rapidly declining due to overfishing, habitat degradation and habitat loss (ANON, 2015a, 2019).

Increased species richness can support the food web of exploited commercial species while inhabiting species in secondary fisheries (Worm et al., 2006). Where the HMS4000 was not expressing enhancement, in comparison to the GNT, it scored more favorably than or equal to the control group in categorizes such as, lobster abundance, Jonah/rock crab abundance, fish abundance, mean lobster biomass, and mean lobster carapace length. The HMS4000 had a significantly higher species richness and was providing habitat for exploited species such as, Atlantic cod, and American eel, and included prey items that benefit lobster growth and reproduction, while supporting a secondary Jonah crab fishery. Appropriate food availability provided through strong species richness would encourage long term colonization of lobster, resulting in an increase of lobster biomass rather than simply redistributing existing populations, potentially expanding the fishery (Jensen 1993).

At Seal Harbor, a sunken boat was observed within the vicinity of the HMS4000. This structure was busy with lobster activity. At least on one occasion, a lobster was observed traveling between the HMS4000 and the boat. Void of complex structure, the control site was just 10 m away from the HMS4000 yet did not shelter any lobsters during the surveys of this project. Areas lacking in suitable shelter prohibit greater distribution of all size lobster (Cobb, J., 1971), but if suitable habitat is present, lobsters will frequent the same shelter between daily foraging (cited in Spanier, 1993). Artificial reefs designed with suitable lobster habit could support populations in area that habitat is limited (Jensen et al., 1993). If other Habitat Moorings Systems were in use in Seal Harbor it is possible that the lobsters would continue to occupy more area within the harbor similar to what was observed between the HMS4000 and the sunken boat. For example, if the increased species richness and mean lobster biomass of 13 g per m^2 of the HMS4000 were consistent across the replacement of the 195 permitted mooring in Seal Harbor, it would vastly increase species richness and potentially support a total lobster biomass of 2,340 kg, while benefiting other valuable fisheries such as Atlantic cod, and the Jonah crab.

With an increasing coastal population (cited in Patranella et al., 2017) and inevitable development of the land-ocean interface, habitat loss and degradation associated with commercial and recreational activities could be mitigated through structural habitat enhancements (Becker et al., 2017; Davis, 1985; Grossman et al., 1997), such as the HMS4000.

In this study, the HMS4000 displayed an overall ability to increase species richness, while expressing trends leading to an increased number of larger lobsters and an increased abundance of fish. Larger lobsters selecting the HMS4000 over other treatments suggest a possible shortage of suitable habitat for this size class, particularly in Sand Cove. In general, lobster and fishes inhabited this artificial reef quite rapidly and consistently between the two sites, however significant findings were restricted by too few replicates. Considering the duration of this project, the trend in lobster usage of this artificial reef could only suggest the redistribution of lobster from an area with less or no suitable habitat, rather than an increase in lobster biomass or population size. An initial survey of lobster population, lobster biomass, Jonah crab, rock crab, and fish abundance within the study site, prior to the deployment of more habitat mooring systems, would allow for a better understand of the full ecological impact these structures have on the local biota. A longer research period, within one study location would prove advantageous in determining significant trends, and provide clarity on seasonal influences related to fauna movement and flora lifecycles (Buckley & Hueckel, 1985). Artificial reefs have the potential to greatly improve fishery resources (Buckley & Hueckel, 1985), and the trends found in this study suggest the HMS4000 would be an effective approach to alleviate the pressures induced from specie exploitation and habitat loss. The HMS4000 could provide an environmental service through the mitigation of placement loss related to granite moorings, by increasing overall species richness and providing suitable habitat that would support commercially and recreationally valuable species such as the American lobster, Jonah crab, Atlantic cod, and American eel.

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APPENDIX A: Supplemental Material

Figure A.1. Dive Information. Seal Harbor (left) and Sand Cove (right) dive dates, actual bottom time (A.B.T.), and actual depth (A.D.) by dive.

Seal Harbor, Mount Desert Island, Maine			
Dive #	Date	A.B.T. min.	A. D. meters
0	07/30/2012	48	8.84
0	07/30/2012	52	6.1
0	07/30/2012	30	7.32
1	10/11/2012	47	7.92
1	10/11/2012	30	6.4
2	12/07/2012	41	7.01
2	12/07/2012	24	6.1
3	12/20/2012	39	7.01
3	12/20/2012	25	6.1
3	12/20/2012	14	6.4
4	02/14/2013	41	8.53
4	02/14/2013	17	6.4

Sand Cove Beach, South Bristol, Maine			
Dive #	Date	A.B.T. min.	A. D. meters
0	07/26/2012	52	3.05
0	07/26/2012	37	3.66
1	08/09/2012	79	3.66
1	08/09/2012	61	8.84
2	08/23/2012	102	3.05
3	10/03/2012	79	5.18
3	10/03/2012	35	8.23
4	10/17/2012	71	5.5
4	10/17/2012	38	4.3

Figure A.2. Complete List of Species Present on HMS4000 (HMS), Granite (GNT) Mooring, and Control (CON) Site at Seal Harbor. A value of 1 indicates presence of the species, while 0 means it was not observed at that treatment.

SEAL HARBOR SPECIES CATALOG							
SPECIES	**HMS**	**GNT**	**CON**	**SPECIES**	**HMS**	**GNT**	**CON**
Porifera				**Arthropoda, cont.**			
Sponges, *Porifera*, (Grant, 1836)	1	1	0	Hermit/Other Crabs, *Pagurus spp*.	1	1	1
Cnidaria				Jonah/Rock Crabs, *Cancer: borealis/irroratus*	1	1	0
Sea Anemone, *Actiniaria spp*.	1	1	0	All Other Crabs, *Cancer spp.*	0	1	0
Gastropoda				Nothern Rock Barnacle, *Semibalanus balanoides*	1	1	0
Limpets, *Patellogastropoda*, (Lindberg, 1986)	1	1	0	**Echinodermata**			
Periwinkles, *Littorinidae*	1	1	0	Green Sea Urchin, *Strongylocentrotus Droebachiensis*, (Muller, 1776)	1	1	0
Whelks, *Buccinidae*, (Linnaeus, 1758)	0	1	1	Sand Dollar, Common, *Echinarachnius parma*, (Lamarck, 1816)	1	1	1
All Other Snails, *Gastropoda,* (Cuvier, 1795)	0	1	0	Sea Cucumber, *Holothuroidea*, (Blainville, 1834)	1	0	0
Sea Slugs, *Nudibranch*, (Cuvier, 1817)	1	1	0	Sea Stars, Asteroidea	1	1	0
Bivalvia				**Tunicata**			
Blue Mussel, *Mytilus edulis*, (Linnaeus, 1758)	1	1	0	All Tunicates, *Ascidiacea*, (Blainville, 1824)	1	1	0
Horse Mussel, *Modiolus modiolus*, (Linnaeus, 1758)	1	0	0	**Osteicthyes**			
Clams, *Veneroida*, (Gray, 1854)	0	0	0	American Eel, *Anguilla rostrata*	0	0	0

Figure A.2. Continued

Annelida				Atlantic Cod, *Gadus morhua*	1	0	0
Segmented Worms, *Annelida*, (Lamarch, 1809)	1	0	1	Cunner, *Tautogolabrus adsperus*	1	0	0
Arthropoda				Flounder, *Platichthys ssp.*			
American Lobster, *Homarus americanus*	1	0	0	Hake, *Merluccius bilinearis*	0	0	0
Sand Shrimp, *Crangon septemspinosa*	0	0	0	Rock Gunnel, *Pholis gunnelius*	0	0	0
All Other Amphipods, *Amphipoda*, (Latreille, 1816)	1	1	1	Sculpin, *Cottoidea spp.*	1	1	0
Decorator Crab, *Majoidea*	0	1	0	Unidentified Fish, *Teleost*	1	0	0
Green Crab, *Carcinus maenas*	0	0	0				
				TOTAL SPECIES PRESENT	**23**	**20**	**5**

Figure A.3. Complete List of Species Present on HMS4000 (HMS), Granite (GNT) Mooring, and Control (CON) Site at Sand Cove. A value of 1 indicates presence of the species, while 0 means it was not observed at that that treatment.

SAND COVE SPECIES CATALOG							
SPECIES	**HMS**	**GNT**	**CON**	**SPECIES**	**HMS**	**GNT**	**CON**
Porifera				**Arthropoda, cont.**			
Sponges, *Porifera*	1	0	0	Hermit/Other Crabs, *Pagurus spp.*	1	1	0
Cnidaria				Jonah/Rock Crabs, *Cancer: borealis/irroratus*	1	1	1
Sea Anemone, *Actiniaria spp*.	0	0	0	All Other Crabs, *Cancer spp.*	0	1	1
Gastropoda				Northern Rock Barnacle, *Semibalanus alanoides*	0	1	0
Limpets, *Patellogastropoda*	1	1	1	**Echinodermata**			
Periwinkles, *Littorinidae*	1	1	0	Green Sea Urchin, *Strongylocentrotus droebachiensis*	0	0	0

Figure A.3. Continued.

Whelks, *Buccinidae*	0	0	0	Sand Dollar, Common, *Echinarachinius parma*	0	0	0
All Other Snails, *Gastropoda*	0	0	0	Sea Cucumber, *Holothuroidea*	0	0	0
Sea Slugs, *Nudibranch*	0	0	0	Sea Stars, *Asteroidea*	0	0	0
Bivalvia				**Tunicata**			
Blue Mussel, *Mytilus edulis*	1	1	0	All Tunicates, *Ascidiacea*	1	1	0
Horse Mussel, *Modiolus modiolu*	1	1	0	**Osteichthyes**			
Clams, *Veneroida*	1	1	0	American Eel, *Anguilla rostrata*	1	0	0
Annelida				Atlantic Cod, *Gadus morhua*	0	0	0
Segmented Worms, *Annelida*	0	0	0	Cunner, *Tautogolabrus adsperus*	1	1	1
Arthropoda				Flounder, *Platichthys* spp.	1	1	1
American Lobster, *Homarus americanus*	1	1	1	Hake, *Merluccius bilinearis*	1	0	0
Sand Shrimp, *Crangon septemspinosa*	0	0	0	Rock Gunnel, *Pholis gunnelius*	0	0	0
All Other Amphipods, *Amphipoda*	0	0	0	Sculpin, *Cottoidea* spp.	1	1	0
Decorator Crab, Majoidea	0	0	0	Unidentified Fish, *Teleost*	0	0	0
Green Crab, *Carcinus maenas*	1	1	1				
				TOTAL SPECIES PRESENT	**16**	**15**	**8**

Figure A.4. Occupancy of HMS4000 Shelters. AC = Atlantic Cod, AE = American Eel, AL = American Lobster, CF = Cunner Fish, HF = Hake Fish, SF =Sculpin Fish, UF = Unidentified Fish.

HMS4000 Shelter Occupancy per Dive: Seal Harbor				
Channel	Dive 1	Dive 2	Dive 3	Dive 4
A1	CF	AC/SF	AL	AL
A2	-	-	-	AL
A3	-	-	-	AL
A4	AL	AL	AL	-
A5	CF	SF	-	AL
A6	AC	-	-	-
A7	SF	AL	-	-
A8	-	AL	-	-
A9	AL	-	-	-
A10	SF	-	-	-
A11	-	SF	-	-
A12	AL	UF	-	AL
% Occupancy	66.7	66.7	16.7	41.7
Mean % Occupancy	**47.9**			
HMS Shelter Occupancy per Dive: Sand Cove				
Channel	Dive 1	Dive 2	Dive 3	Dive 4
A1	CF	CF	Al	AL
A2	-	-	Al	-
A3	AL	-	-	-
A4	CF	-	-	AL
A5	CF	AL	CF	-
A6	CF	-	-	AL
A7	CF	-	-	AL
A8	-	-	AE	HF
A9	-	-	-	-
A10	-	-	AL	AL
A11	-	HF/HF	-	-
A12	CF	AL	AL	AL
% Occupancy	58.3	41.7	50	58.3
Mean % Occupancy	**52.1**			

Figure A.5. A Comprehensive List of all Species Cataloged at Seal Harbor.

Species Catalog: Seal Harbor						
Species	**Experimental Group**	**Dive #**				**Total**
		10/11/12	**12/07/12**	**12/20/12**	**02/14/13**	
Porifera						
Sponges, *Porifera*	HMS	9	4	1	1	15
	GNT	-	4	2	2	8
	CON	-	-	-	-	0
Cnidaria						
Sea Anemone, *Actiniaria spp.*	HMS	2	6	4	7	19
	GNT	10	6	5	4	25
	CON	-	-	-	-	0
Gastropods						
Limpets, *Patellogastropoda*	HMS	104	303	2	1	410
	GNT	400	-	-	-	400
	CON	-	-	-	-	0
Periwinkles, *Littorinidae*	HMS	100	-	-	-	100
	GNT	2	-	6	11	19
	CON	-	-	-	-	0
Whelks, *Buccinidae*	HMS	-	-	-	-	0
	GNT	-	-	-	1	1
	CON	-	-	1	-	1
All Other Snails, *Gastropoda*	HMS	-	-	-	-	0
	GNT	-	-	-	1	1
	CON	-	-	-	-	0
Sea Slugs, *Nudibranch*	HMS	-	7	2	3	12
	GNT	6	14	6	4	30
	CON	-	-	-	-	0

Figure A.5. Continued.

Species	Experimental Group	Dive # 10/11/12	12/07/12	12/20/ Species 12	02/14/13	Total
Bivalves						
Blue Mussel, *Mytilus edulis*	HMS	1	1	2	2	6
	GNT	-	11	-	-	11
	CON	-	-	-	-	0
Horse Mussel, *Modiolus modiolus*	HMS	-	1	2	-	3
	GNT	-	-	-	-	0
	CON	-	-	-	-	0
Clams, *Veneroida*	HMS	-	-	-	-	0
	GNT	-	-	-	-	0
	CON	-	-	-	-	0
Annelida						
Segmented Worms, *Anelida*	HMS	-	-	-	1	1
	GNT	-	-	-	-	0
	CON	-	-	1	-	1
Arthropod						
American Lobster, *Homarus americanus*	HMS	3	3	2	5	13
	GNT	-	-	-	-	0
	CON	-	-	-	-	0
Sand Shrimp, *Crangon septemspinosa*	HMS	-	-	-	-	0
	GNT	-	-	-	-	0
	CON	-	-	-	-	0
All Other Amphipods, *Amphipoda*	HMS	-	1	-	2	3
	GNT	5	6	-	5	16
	CON	-	4	1	1	6
Decorator Crab, *Majoidea*	HMS	-	-	-	-	0
	GNT	1	-	1	1	3
	CON	-	-	-	-	0
Green Crab, *Carcinus maenas*	HMS	-	-	-	-	0
	GNT	-	-	-	-	0
	CON	-	-	-	-	0

Figure A.5. Continued.

Species	Experimental Group	Dive # 08/09/12	08/23/12	10/03/12	10/17/12	Total
Arthropod, cont.						
Hermit Crab, *Pagurus spp.*	HMS	5	6	1	-	12
	GNT	22	9	24	5	60
	CON	2	4	14	-	20
Jonah/Rock Crabs *Cancer borealis/irroratus*	HMS	2	2	1	-	5
	GNT	6	3	-	-	9
	CON	-	-	-	-	0
Asian Shore Crab, *Hemigrapsus sanguineus*	HMS	-	-	-	-	0
	GNT	1	-	-	-	1
	CON	-	-	-	-	0
Nothern Rock Barnacle, *Semibalanus alanoides*	HMS	-	300	305	87	692
	GNT	18	1	400	109	528
	CON	-	-	-	-	0
Echinoids						
Green Sea Urchin, *Strongylocentrotus droebachiensis*	HMS	1	2	-	4	5
	GNT	5	1	-	-	6
	CON	-	-		-	0
Sand Dollar, Common, *Echinarachnius parma*	HMS	15	4	-	100	119
	GNT	100	100	100	100	400
	CON	100	100	100	100	400
Sea Cucumber, *Holothuroidea*	HMS	3	1	3	3	10
	GNT	-	-	-	-	0
	CON	-	-	-		0
Sea Stars, *Asteroidea*	HMS	-	9	13	11	33
	GNT	2	25	27	16	70
	CON	-	-	-	-	0
Chordata-Tunicates						
All Tunicates, *Ascidiacea*	HMS	1	1	3	5	10
	GNT	1	-	4	4	9
	CON	-	-	-	-	0

Figure A.5. Continued.

Species	Experimental Group	Dive #				Total
		10/11/12	12/07/12	12/20/12	02/14/13	
Osteichthyes						
American Eel, *Anguilla rostrata*	HMS	-	-	-	-	0
	GNT	-	-	-	-	0
	CON	-	-	-	-	0
Atlantic Cod, *Gadus morhua*	HMS	1	1	-	-	2
	GNT	-	-	-	-	0
	CON	-	-	-	-	0
Cunner, *Tautogolabrus adsperus*	HMS	3	-	-	-	3
	GNT	-	-	-	-	0
	CON	-	-	-	-	0
Flounder, *Platichthys spp.*	HMS	3	-	-	-	3
	GNT	1	-	-	-	1
	CON	-	-	-	-	0
Hake, *Merluccius bilinearis*	HMS	-	-	-	-	0
	GNT	-	-	-	-	0
	CON	-	-	-	-	0
Rock Gunnel, *Pholis gunnelius*	HMS	-	-	-	-	0
	GNT	-	-	-	-	0
	CON	-	-	-	-	0
Sculpin, *Cottoidea spp.*	HMS	2	3	-	-	5
	GNT	-	-	1	1	2
	CON	-	-	-	-	0
Unidentified Fish, *Teleost*	HMS	-	1	-	-	1
	GNT	-	-	-	-	0
	CON	-	-	-	-	0

Figure A.6. A Comprehensive List of all Species Cataloged at Sand Cove.

Species Catalog: Sand Cove						
Species	**Experimental Group**	**Dive #**				**Total**
		08/09/12	**08/23/12**	**10/03/12**	**10/17/12**	
Porifera						
Sponges, *Porifera*	HMS	-	-	-	1	1
	GNT	-	-	-	-	0
	CON	-	-	-	-	0
Cnidaria						
Sea Anemone, *Actiniaria spp.*	HMS	-	-	-	-	0
	GNT	-	-	-	-	0
	CON	-	-	-	-	0
Gastropods						
Limpets, *Patellogastropoda*	HMS	-	1	45	19	65
	GNT	1	-	2	-	3
	CON	-	-	-	6	6
Periwinkles, *Littorinidae*	HMS	3	6	18	19	46
	GNT	9	3	9	7	28
	CON	-	-	-	-	0
Whelks, *Buccinidae*	HMS	-	-	-	-	0
	GNT	-	-	-	-	0
	CON	-	-	-	-	0
All Other Snails, *Gastropoda*	HMS	-	-	-	-	0
	GNT	-	-	-	-	0
	CON	-	-	-	-	0
Sea Slugs, *Nudibranch*	HMS	-	-	-	-	0
	GNT	-	-	-	-	0
	CON	-	-	-	-	0

Figure A.6. Continued.

Species	Experimental Group	Dive #				Total
		08/09/12	08/23/12	10/03/12	10/17/12	
Bivalves						
Blue Mussel, *Mytilus edulis*	HMS	-	-	-	-	0
	GNT	-	6	1	1	8
	CON	-	-	-	-	0
Horse Mussel, *Modiolus modiolus*	HMS	-	-	1	3	4
	GNT	4	3	1	1	9
	CON	-	-	-	-	0
Clams, *Veneroida*	HMS	-	-	-	1	1
	GNT	1	1	-	-	2
	CON	-	-	-	-	0
Annelida						
Segmented Worms, *Anelida*	HMS	-	-	-	-	0
	GNT	-	-	-	-	0
	CON	-	-	-	-	0
Arthropod						
American Lobster, *Homarus americanus*	HMS	1	9	6	6	22
	GNT	3	3	1	2	9
	CON	3	5	8	8	24
Sand Shrimp, *Crangon septemspinosa*	HMS	-	-	-	-	0
	GNT	-	-	-	-	0
	CON	-	-	-	-	0
All Other Amphipods, *Amphipoda*	HMS	-	-	-	-	0
	GNT	-	-	-	-	0
	CON	-	-	-	-	0
Decorator Crab, *Majoidea*	HMS	-	-	-	-	0
	GNT	-	-	-	-	0
	CON	-	-	-	-	0
Green Crab, *Carcinus maenas*	HMS	3	3	8	9	23
	GNT	2	6	11	2	21
	CON	-	2	3	8	13

Figure A.6. Continued.

Species	Experimental Group	Dive # 08/09/12	08/23/12	10/03/12	10/17/12	Total
Arthropod, Continued.						
Hermit Crab, *Pagurus spp.*	HMS	-	1	4	2	7
	GNT	-	6	11	16	33
	CON	-	-	-	-	0
Jonah/Rock Crabs *Cancer borealis/irroratus*	HMS	1	2	-	-	3
	GNT	10	7	14	4	35
	CON	2	-	-	1	3
Asian Shore Crab, *Hemigrapsus sanguineus*	HMS	-	-	-	-	0
	GNT	-	-	-	3	3
	CON	-	-	-	1	1
Nothern Rock Barnacle, *Semibalanus alanoides*	HMS	-	-	-	-	0
	GNT	6	1	1	5	13
	CON	-	-	-	-	0
Echinoids						
Green Sea Urchin, *Strongylocentrotus droebachiensis*	HMS	-	-	-	-	0
	GNT	-	-	-	-	0
	CON	-	-	-	-	0
Sand Dollar, Common, *Echinarachnius parma*	HMS	-	-	-	-	0
	GNT	-	-	-	-	0
	CON	-	-	-	-	0
Sea Cucumber, *Holothuroidea*	HMS	-	-	-	-	0
	GNT	-	-	-	-	0
	CON	-	-	-	-	0
Sea Stars, *Asteroidea*	HMS	-	-	-	-	0
	GNT	-	-	-	-	0
	CON	-	-	-	-	0
Chordata-Tunicates						
All Tunicates, *Ascidiacea*	HMS	-	-	4	-	4
	GNT	-	-	1	-	1
	CON	-	-	-	-	0

Figure A.6. Continued.

Species	Experimental Group	Dive # 08/09/12	08/23/12	10/03/12	10/17/12	Total
Osteichthyes						
American Eel, *Anguilla rostrata*	HMS	-	-	1	-	1
	GNT	-	-	-	-	0
	CON	-	-	-	-	0
Atlantic Cod, *Gadus morhua*	HMS	-	-	-	-	0
	GNT	-	-	-	-	0
	CON	-	-	-	-	0
Cunner, *Tautogolabrus adsperus*	HMS	9	1	8	6	24
	GNT	-	2	6	2	10
	CON	-	-	1	-	1
Flounder, *Platichthys spp.*	HMS	-	-	4	-	4
	GNT	1	2	3	-	6
	CON	1	-	2	1	4
Hake, *Merluccius bilinearis*	HMS	-	2	-	1	3
	GNT	-	-	-	-	0
	CON	-	-	-	-	0
Rock Gunnel, *Pholis gunnelius*	HMS	-	-	-	-	0
	GNT	-	-	-	-	0
	CON	-	-	-	-	0
Sculpin, *Cottoidea spp.*	HMS	-	-	1	-	1
	GNT	4	6	4	1	15
	CON	-	-	-	-	0
Unidentified Fish, *Teleost*	HMS	-	-	-	-	0
	GNT	-	-	-	-	0
	CON	-	-	-	-	0

BIOGRAPHY OF THE AUTHOR

Christopher Roy was born in Lewiston, Maine on June 17, 1977. He graduated from Lewiston High School in 1996. He attended the University of Maine in Augusta receiving an Associate's of Art in Liberal Studies in 2006, and then carried on to complete a Bachelor's of Science in Marine Sciences with a concentration in Aquaculture at the University of Maine in 2010. Since Christopher began at the University of Maine in 2006, he worked at the University of Maine Aquaculture Research Center, the UMaine Center for Cooperative Aquaculture Research, and managed/remolded the aquatic systems at the Maine State Aquarium. He also had the opportunity to assist in the research of cold-water corals in the Drake's Passage, Antarctica. Christopher is a candidate for the Master of Science degree in Animal Science from the University of Maine in May of 2020.