An Evaluation of Eelgrass Extent and Vessel Use Patterns Around Fishers Island, New York

Prepared by Matias Tong

February 28, 2019

The Nature Conservancy

Acknowledgements

The implementation of this project and the production of this report were made possible by the collaborative participation and broad support of the many people and organizations recognized below.

Aerial vessel survey project planning and management:
Chantal Collier, The Nature Conservancy in New York and Connecticut
David Gumbart, The Nature Conservancy in Connecticut
Stephen Lloyd, The Nature Conservancy in New York
Jonathan Milne, LightHawk Conservation Flying
Kyle Smith, Yale University

Aerial vessel survey data collection:
Chantal Collier, The Nature Conservancy in New York and Connecticut
Nicole Cooper, The Nature Conservancy in Connecticut
Joseph Fischetti, LightHawk Conservation Flying
David Gumbart, The Nature Conservancy in Connecticut
Robert Keller, LightHawk Conservation Flying
Steve Kent, LightHawk Conservation Flying
Tom LeCompte, LightHawk Conservation Flying
Stephen Lloyd, The Nature Conservancy in New York
Sally McGee, The Nature Conservancy in Rhode Island
Michael McNamara, LightHawk Conservation Flying
Liz Robinson, The Nature Conservancy in Connecticut

Benthic eelgrass survey project planning and management:
Chantal Collier, The Nature Conservancy in New York and Connecticut
Soren Dahl, New York State Department of Environmental Conservation
Stephen Lloyd, The Nature Conservancy in New York
Suzanne Paton, U.S. Fish and Wildlife Service
Adam Starke, The Nature Conservancy in New York

Benthic eelgrass survey data collection:
Chris Clapp, The Nature Conservancy in New York
Chantal Collier, The Nature Conservancy in New York and Connecticut
Soren Dahl, New York State Department of Environmental Conservation
Todd Glavin, New York State Department of Environmental Conservation
Carl Lobue, The Nature Conservancy in New York
Adam Starke, The Nature Conservancy in New York

Vessel and eelgrass survey data analyses, report preparation and presentation:
Matias Tong, Independent Contractor for The Nature Conservancy in New York

Funding and in-kind support provided by:
Fishers Island Yacht Club
LightHawk Conservation Flying
New York State Dept. of Environmental Conservation
The McCance Family
Scott M. Murphy
Seaview Scuba

Photo Credits (Front Page): Chantal Collier (Top, Center Right, Center Left), Adam Starke (Center)

Contents

EXECUTIVE SUMMARY

Globally and locally, seagrass meadows provide many crucial ecosystem services but face intense pressures from human activities and environmental stressors. In Long Island Sound, Fishers Island harbors most of the enduring eelgrass (*Zostera marina*) ecosystem in the New York waters of the Sound; and, of local concern are potential impacts to eelgrass from boating related sources.

During the annual boating season, the number of vessels in the Sound swells significantly, increasing pressures on sensitive eelgrass habitat from anchoring, mooring, propeller scarring, and boat wakes. To address these concerns, two surveys were conducted in 2017 around Fishers Island. One was a benthic survey, consisting of dives and underwater transects to characterize eelgrass condition and to groundtruth its extent, mapped in the U.S. Fish and Wildlife Service Long Island Sound Eelgrass Survey (Bradley & Paton, 2018). The second was an aerial survey, conducted aboard fixed wing aircraft to assess vessel use patterns around the island and to identify hotspots with greater threat to eelgrass habitat during the boating season.

The benthic eelgrass survey captured considerable variation in plant height, percent cover, and bed edges at different sites, underscoring the importance of site characteristics and environmental conditions in determining eelgrass distribution. A comparison of the inshore and offshore edges of eelgrass beds measured in our survey with those mapped in the USFWS survey showed that the edges were generally well aligned, except for a few areas where eelgrass extent recorded in the benthic survey deviated from the aerial survey results in shallower or deeper eelgrass habitat. During the benthic survey, some propeller scarring was found by the docks in East Harbor, suggesting that there are also dock related impacts that remain to be further investigated.

Analysis of the aerial survey data revealed most vessels observed were recreational boats, with the highest numbers recorded on weekend survey dates in July and August. Hotspots and areas of eelgrass habitat at greater risk from vessel activities include coastal waters adjacent to the Eighth Hole (at the Fishers Island Club golf course), Flat Hammock, East Harbor, West Harbor, and Hay Harbor. At these locations, impacts to eelgrass are associated with boats anchoring close to shore or directly over eelgrass, boats transiting in shallow waters, boat wakes, and to a lesser extent, the siting of moorings. In general, high vessel use in these areas reflects observations cited by local community members and demonstrates the value of including local knowledge in environmental problem identification and conservation management planning. Boat numbers reflect a conservative estimate of vessel activity given the frequency and duration of our survey flights and the likelihood of heavier use on holidays, which were not surveyed.

To protect eelgrass resources from potential boating-related impacts, different management options and examples are discussed – namely, boater education and outreach, zoning and designation of special management areas, and the use of conservation moorings. A combination of different strategies is likely needed with monitoring and adaptive management, which is essential to measuring and optimizing the success of any management plan. In addition, the baselines for vessel activity captured in this study are necessary for evaluating the effectiveness of future management strategies.

INTRODUCTION

Seagrass meadows are crucial to the long-term health of marine ecosystems and the well-being of communities around the world (Cullen-Unsworth et al., 2014). As underwater refuges, nurseries, and breeding and foraging grounds, seagrass meadows sustain diverse species of marine life, including many commercially and recreationally important fish and shellfish as well as threatened and endangered species like sea turtles, dugongs, and manatees (New York State Seagrass Task Force, 2009). Additionally, seagrass beds improve water quality by trapping fine suspended particles and reducing contaminants and pathogens that cause diseases in humans and marine life (Lamb et al., 2017). As highly productive ecosystems, seagrass meadows are important in the nutrient exchange of coastal waters and play key roles in the ocean's carbon cycle, where they serve as important carbon sinks (Duarte, Middelburg, & Caraco, 2004; Mcleod et al., 2011). Thus, they capture and store significant amounts of carbon as organic material in the ocean, reducing levels of atmospheric carbon dioxide, the primary driver of global warming and ocean acidification. Other ecosystem services provided by seagrass include wave attenuation and sediment stabilization, which help increase coastal resilience to storm surge and reduce coastal erosion (Fonseca & Fisher, 1986; Fonseca & Cahalan, 1992).

Given the ecological and socio-economic benefits of seagrasses, seagrass conservation is driven by a sense of urgency, because globally, seagrasses have declined at an accelerating rate (Waycott et al., 2009). Anthropogenic factors such as impaired water quality, climate change, coastal development and physical destruction have been implicated as the main drivers of decline (Waycott et al., 2009). With a 90 percent decrease in its historic extent, the loss of eelgrass (*Zostera marina*) in Long Island Sound, situated between the coastlines of Connecticut and Long Island, New York, is particularly acute (New York State Seagrass Task Force, 2009).

Since 2002, every three to five years, the U.S. Fish and Wildlife Service (USFWS) has used aerial imagery to delineate eelgrass beds in the Sound, where the remaining eelgrass is restricted to the eastern end of the estuary. The USFWS's most recent 2017 survey was based on aerial imagery taken in June and included field verification completed from September to October, via an underwater video camera lowered from a surface vessel (Bradley & Paton, 2018). Based on this survey, the waters around Fishers Island, New York, contain significant amounts of eelgrass, comprising 24% of the eelgrass extent in the Sound and 96% of the eelgrass extent in the New York portion of the Sound (Bradley & Paton, 2018). Consequently, Fishers Island has become the focus of conservation efforts directed at protecting its vital eelgrass resources.

Although eelgrass around Fishers Island is threatened by regional pressures similar to those impacting seagrasses worldwide (e.g. nitrogen pollution and climate change), of particular local concern are the physical impacts caused by boating activities (Collier, 2016). The waters around Fishers Island are popular for boating due to their quiet and undeveloped seascape, proximity to the Connecticut coast, and productive fishing grounds. Boaters use the areas for recreational and commercial purposes, engaging in activities ranging from fishing, aquaculture, and transportation to sailing, kayaking, and swimming. During the peak of the annual boating season, the number of vessels at popular island sites can surge dramatically, raising concerns about the potential impacts this increased pressure may have on eelgrass habitat (Collier, 2016). Examples of boating impacts on eelgrass include scarring and scouring from propellers (prop-scarring), anchors, conventional moorings and boat wakes.

Propeller scars, which have been documented in Hay Harbor (Fishers Island Conservancy Summer Sentinel, pers. obs.), result when a boat enters shallow water containing seagrass beds near the depth of its drafts. The boat's engine propeller cuts through the plants and excavates troughs in the meadow, stirring up sediment and creating scars barren of seagrass (Sargent, Leary, Crewz, & Kruer, 1995). Anchoring in seagrass habitat is also detrimental. The process of dropping, setting, and retrieving an anchor over seagrass directly crushes, scrapes, and uproots the plants, leaving depressions in the beds with the roots and rhizomes exposed (Collins, Suonpää, & Mallinson, 2010). Furthermore, conventional swing chain moorings, which consist of a buoy attached with a chain to an anchor, create circular scars in seagrass beds. To accommodate the tidal range, currents, wind and waves, this type of mooring has an extra length of chain that typically rests on the seafloor. When the tide, waves, or currents change, the chain is pulled up and down and drags along the seafloor as the surface buoy swings around its anchor, effectively scouring the area around the mooring of seagrass and leaving circular scars devoid of seagrass (Walker, Lukatelich, Bastyan, & McComb, 1989). Resuspension of sediments caused by the wake of motorboats may also scour seagrass plants and create turbidity, reducing the light they require for photosynthesis (Crawford, 2002). Although physical destruction and stress from propeller, moorings, anchor scars and boat wakes have been attributed as significant causes of seagrass habitat loss in different parts of the world, prior to this study, the level of risk associated with boating impacts at Fishers Island was unknown. This study was therefore motivated by the need to substantiate the condition and extent of eelgrass habitat around Fishers Island, to quantify the pressures it faces from boating sources, and to identify areas, opportunities and options for seagrass conservation.

Study Site

Fishers Island is located seven miles southeast of New London, Connecticut, at the eastern end of Long Island Sound. The island is about seven miles long and one mile wide at its widest point and according to the 2010 census, is home to 236 year-round residents, mostly on the western end of the island (U.S. Census Bureau, 2011). Politically, it is part of the Town of Southold, New York, although geographically, it is closer to Connecticut. Mass transportation access to the island is via ferry from New London, Connecticut. Although tourism is noticeably absent on the island, the number of residents swells during the summer, with the seasonal population reaching about 3000 people. The north side of Fishers Island is where the main harbors are located. West Harbor has the largest mooring and docking area and the other harbors are Silver Eel Cove, Hay Harbor, and East Harbor.

Esteemed for its natural coastal scenery and historical and cultural significance, Fishers island is home to diverse coastal habitats encompassing grasslands, coastal woodlands, sandy beaches, salt marshes, rocky shores, and eelgrass meadows (Collier, 2016). Dense beds of eelgrass can be seen exposed at the shoreline for several hours during lower low tides (**Figure 1**). Eelgrass distribution around Fishers Island is dynamic as shown in a comparison of its extent in 2012 and 2017, mapped in USFWS aerial surveys (**Figure 2**). Because of the island's importance as coastal habitat for protected and vulnerable species like grey seals, harbor seals, and ospreys and its significant eelgrass habitat, it was designated a *New York State Significant Coastal Fish and Wildlife Habitat* in 1987 and as a *Long Island Sound Study Stewardship Site* in 2005.

Figure 1: Eelgrass exposed during a very low tide at Fishers Island. (Photo: Justine Kibbe)

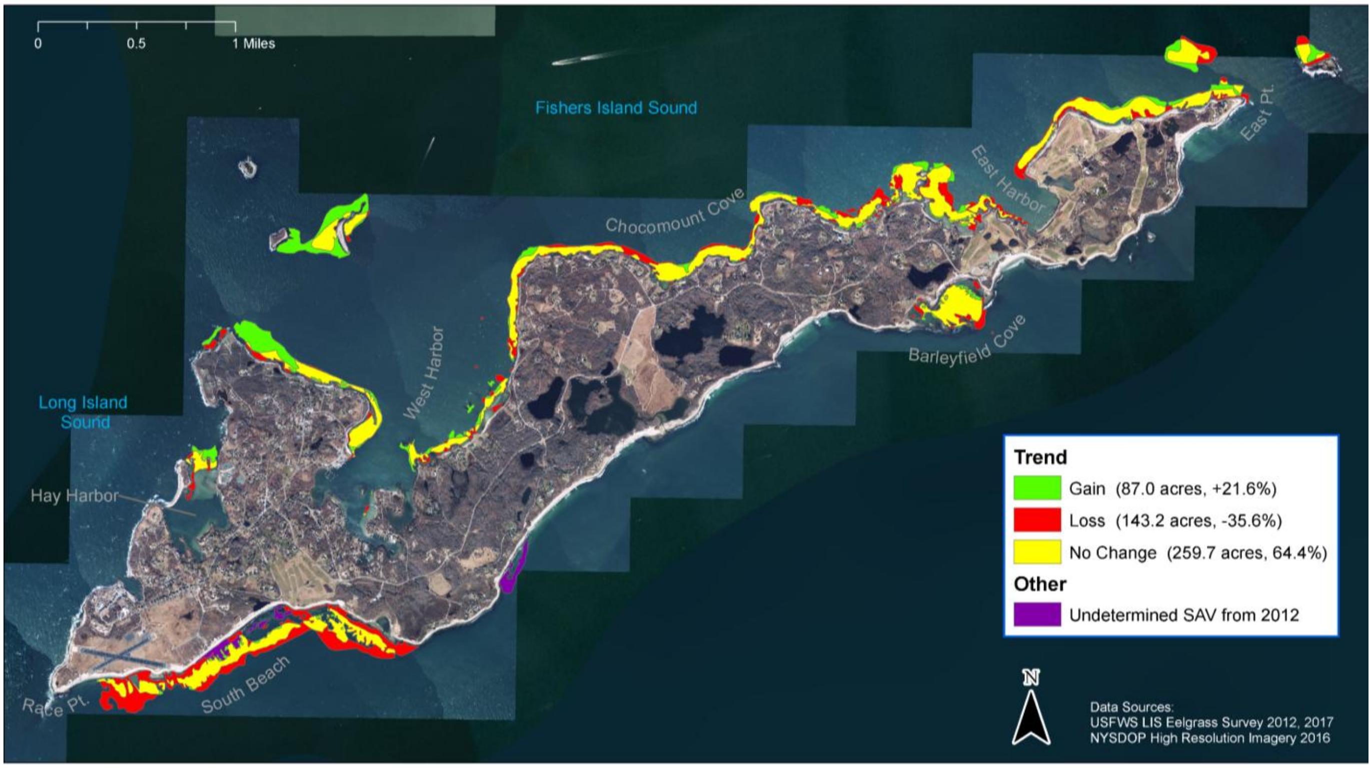


Figure 2: Changes in eelgrass distribution around Fishers Island from 2012 to 2017. The 2012 USFWS survey also delineated beds of undetermined submerged aquatic vegetation (SAV) where eelgrass could potentially exist but was not verified in the field.

METHODS

Objectives

To assess the status of eelgrass habitat around Fishers Island and the pressures created by vessel activities, two different surveys were conducted during the summer and fall of 2017. One was a benthic eelgrass survey with the main objectives to: (1) survey the extent and condition of eelgrass beds, and (2) supplement and groundtruth the 2017 extent determined by the USFWS aerial survey. The other was an aerial vessel survey conducted to: (1) assess patterns of vessel use around the island, (2) establish baselines for vessel activity, and, (3) identify eelgrass habitat at significant risk from boating related impacts.

Benthic Eelgrass Survey

Dive Transects

Transects were conducted by two divers equipped with SCUBA gear at thirteen pre-selected sites around Fishers Island and the adjacent islet of Flat Hammock from September 12, 2017 to October 11, 2017, during the peak of the perennial eelgrass growth cycle (**Figure 3**). The goal was to locate the offshore and inshore edges of the eelgrass beds, defined here as the points beyond which no eelgrass was sighted along the transect, and assess their condition and distribution by measuring percent cover and canopy height and recording eelgrass presence and absence within meadow areas. At each site, divers completed one to two transect surveys, each beginning and ending at the meadow edges (offshore and inshore), determined after swimming a sufficient distance beyond each edge to verify the bed limit had been reached. Above the divers, a surface buoy was towed containing a GPS unit, which was synchronized with the lead diver's watch at the beginning of each dive to track and record data collection points along the transect. The first transect was conducted inshore to offshore, along a compass heading perpendicular to the coastline. Once the offshore edge was reached, the divers swam 100 kicks parallel to the shoreline, against the direction of the prevailing current. After which, conditions permitting, the dive team conducted a second transect survey heading back towards the shore. Percent cover and canopy height were measured at the inshore edge, offshore edge, at 5 ft depth intervals, and at periodic intermediate intervals using a 0.5 m by 0.5 m quadrat and measuring tape, following standard seagrass monitoring protocols (Short, McKenzie, Coles, Vidler, & Gaeckle, 2006). Changes in presence and absence were visually determined along the transect. Transects were terminated at two sites before the offshore edge could be reached for safety reasons as the divers would have had to go too close to breakwaters or boat channels.

Site Checks

Based on island resident input, locations where eelgrass was thought to be located but not shown in the 2012 USFWS extent were checked by snorkel. Site checks consisted of three surface dives within 50 meters of each point to determine eelgrass absence or presence (**Figure 3**).

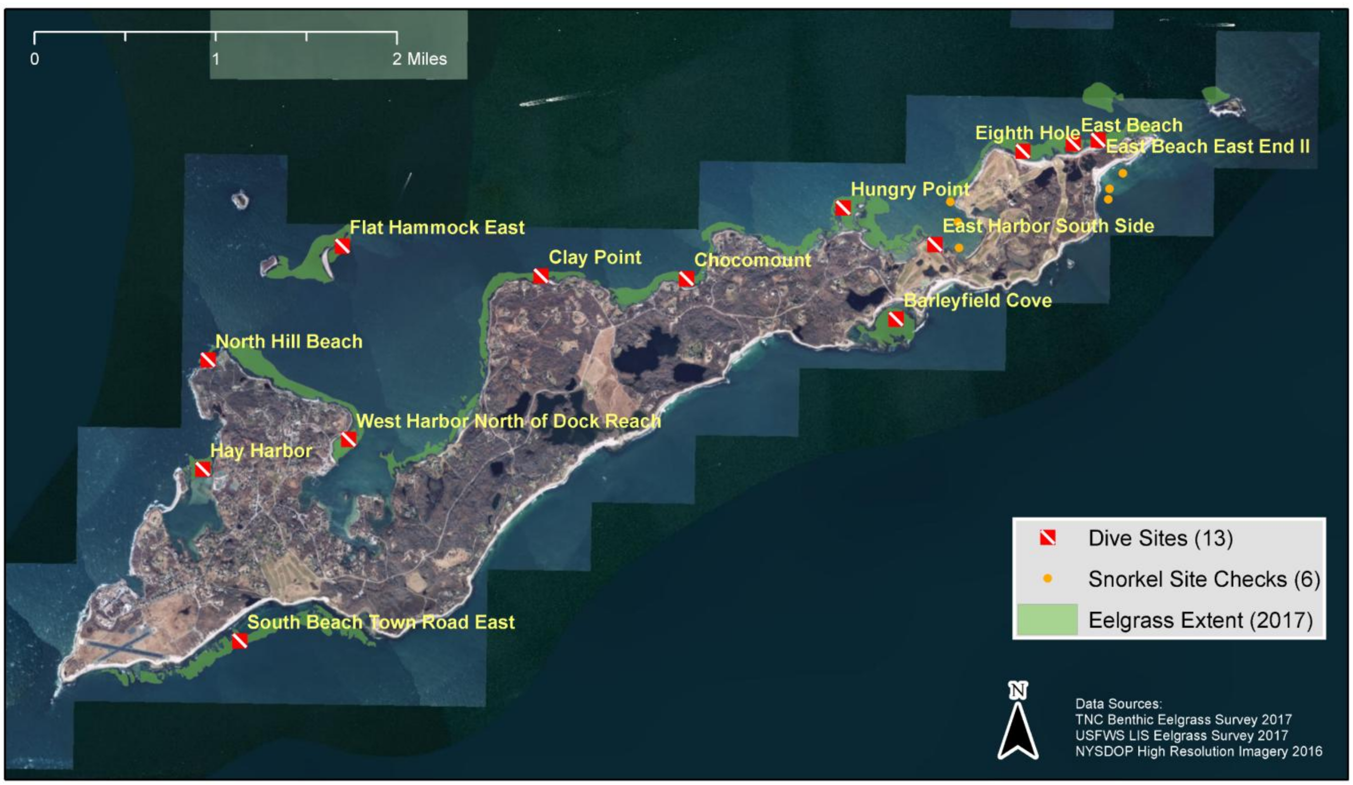


Figure 3: Sites chosen for dive transects and site checks overlaid on the 2017 USFWS eelgrass extent layer.

Analysis

Using the time recorded for each measurement or located bed feature, relevant GPS points were selected and imported from Garmin Homeport into ArcMap. The layer was projected to NAD 1983 State Plane Connecticut FIPS 0600 Feet**.** Because there were several GPS points associated with each data collection time record, which was measured to the minute, we took an 'average' of the locations; this was accomplished in ArcGIS by taking the centroid of the minimum bounding convex hull polygon representing the relevant points.

Transect lines and absence and presence line segments were later created from these points and added as two separate GIS layers. All the layers were then projected over the 2017 eelgrass extent from the USFWS survey. Water depths were adjusted for tide stage to the Mean Low Water (MLW) vertical datum using NOAA tide predictions for Silver Eel Pond, NY (station ID: 8510719) (NOAA, 2018). MLW tide predictions were obtained in minute intervals, and because all the relevant predictions were zero or above, they were subtracted from the corresponding survey depth measurements to yield depths adjusted to the MLW datum.

Aerial Vessel Survey

Flight and Image Acquisition

Fixed-wing and rotary-wing aircraft have successfully been employed in previous studies to gauge the impact of vessels on coral reefs and seagrass meadows (Behringer & Swett, 2010; Sargent, Leary, Crewz, & Kruer, 1995). This survey used fixed-wing aircraft to assess the composition and location of vessels and their status (anchored, moored, underway, etc.) relative to eelgrass extent around Fishers Island. A total of seven survey flights were conducted in 2017 during four weekend and three weekday dates, as follows:

- Saturday, May 27
- Saturday, June 10
- Monday, July 17
- Sunday, July 30
- Thursday, August 3
- Sunday, August 27
- Friday, September 29

Survey flights began at Race Point, the southwest point of Fishers Island, and progressed clockwise to capture vessel patterns around the island and adjacent islets, including Flat Hammock, North Dumpling and South Dumpling**.** Towards the end of each survey, a cross-island loop was flown to capture the inner reaches of West Harbor. Excluding transit flight time to and from the island, each flight took, on average, 27 minutes to complete and was flown at an altitude of about 400-600 m. To ensure photo quality, some flights included additional passes around the island, but no additional loops were made inside West Harbor. Aerial imagery was taken continuously, with overlapping frames, using a Ricoh G800SE digital camera with integrated GPS, pre-programmed to geotag each photo with the position and altitude it was taken from (Smith, 2017).

Area of Interest

Prior to digitizing vessels from the aerial surveys, we defined an ‘area of interest' spatial layer to help determine which boats from the aerial survey images to include in the digitization process. This was largely because many of the aerial photographs included boat locations that were well beyond a reasonable distance from Fishers Island to likely have an impact to eelgrass. Being far from the coast also made the location of these boats more difficult to determine as there were fewer points of reference. Therefore, we only considered offshore areas up to 40 feet in depth and within 1 mile of Fishers island. While seagrass has not been documented deeper than 24 feet in the area, the generous 40 feet threshold was intended to account for some error that would be involved in geolocating boats, particularly in areas where the depth drops over short distances. In addition, this allowed for a single depth contour area that would also include North Dumpling Island when defining the area of interest. The area of interest layer was created in ArcMap by intersecting areas less than 40 feet in depth and 1 mile in distance away from Fishers Island. The resulting layer included adjacent islets and, for simplification purposes, a few deeper areas inside the resulting polygon layer. This layer was imported into Google Earth as a reference layer.

Digitization

Using aerial photos to geolocate vessels in Google Earth

The geotagged photos from the survey flights were converted to points inside ArcMap and then exported as a KMZ file for viewing in Google Earth. Using the position and altitude the photos were taken from and features of the coastline, the view in Google Earth was oriented to align with each aerial photo. Then, in Google Earth, vessel positions were manually located as points and added to a new point layer (**Figure 4**). Only boats in physical contact with seawater and within the area of interest were located and kept in the point layer. This methodology was selected as a reasonably accurate and reliable approach based on the findings in Smith (2017), which compared different methods of geolocating boats around Fishers Island aboard fixed-wing aircraft.

Figure 4: Method of geolocating boats from aerial photos in Google Earth.

Recording and identifying vessels

Each geolocated point corresponded to a record in the survey table, with each boat categorized by vessel class, type, and status (**Table 1**).

Vessel Category	Definition	Options
Class	What is the vessel's purpose?	Commercial Recreational Unknown
Type	How is the vessel operated?	Power boat Sailboat Paddle craft Unknown
Status	How is the vessel secured?	Anchored Docked Moored Stationary Underway

Table 1: Categories used to characterize vessels.

Boats were categorized as “unknown" for vessel class and type if they were too distant to identify and were absent of tell-tale features, such as boat wakes or sails. For vessel status, boats were determined to be “anchored” if they had a visible anchor line or in some cases, if their positions relative the shoreline or other boats necessitated it being so. Boats lacking a visible wake were classified as “stationary” for vessel status if they did not have an anchor line or adjacent mooring clearly visible. Thus, “stationary” vessels were boats that were adrift or possibly anchored or moored (likely, if near a mooring field) with the anchor line or mooring buoy not discernible from the aerial photos. During the survey, it was common to see smaller boats, such as rigid inflatable boats towed behind larger vessels like sailboats; these boats were still counted as separate boats but were not recorded as anchored even if the towing boat was anchored. In addition, boats rafted together were counted separately.

Incorporating vessels from additional passes in survey flights

For surveys with multiple passes, vessels from additional passes were only recorded if the boats were underway or not previously found in a location. In some cases, photos from additional passes were substituted for some areas in the first pass because of better image quality. While the number of new boats recorded in the additional passes did not make up a significant proportion of boats, they were excluded from the numerical portion of the analysis (i.e. vessel counts and other charts). They were however still included in the spatial analysis in the maps because their spatial extent provides useful information for natural resource management planning.

Analysis

The point layer for each survey was exported from Google Earth into ArcMap and then the layers were combined and joined to a table with the vessel information. This final layer was used for the spatial analysis. Charts were created using Microsoft Excel and R. In making charts and counting vessels, the number of distinct vessels was determined from the number of unique Boat IDs. As a result, the charts represent the actual number of vessels captured in our survey sample. The maps, on the other hand, emphasize the relative locations of these vessels because a vessel may have been recorded in more than one location in a survey (such as for boats underway or boats found in a different location in a later pass).

RESULTS

Benthic Eelgrass Survey

Overview

Along our dive transects, eelgrass was documented at depths of 0 to 17 ft below MLW with the offshore edge located at depths varying between 3 to 17 ft below MLW and the inshore edge, 0 to 6 ft below MLW (**Figure 5**). Eelgrass grew to a maximum height of 150 cm which was recorded at 3 ft below MLW in Barleyfield Cove (**Figure 3**). **Figure 6** shows the site by site variation in percent cover. All sites surveyed, except Clay Point and East Harbor, featured areas with 50% or greater percent cover at depths ranging from 1 to 12 ft below MLW. See **Appendix A** for additional charts related to variation in plant height and depth by dive site.

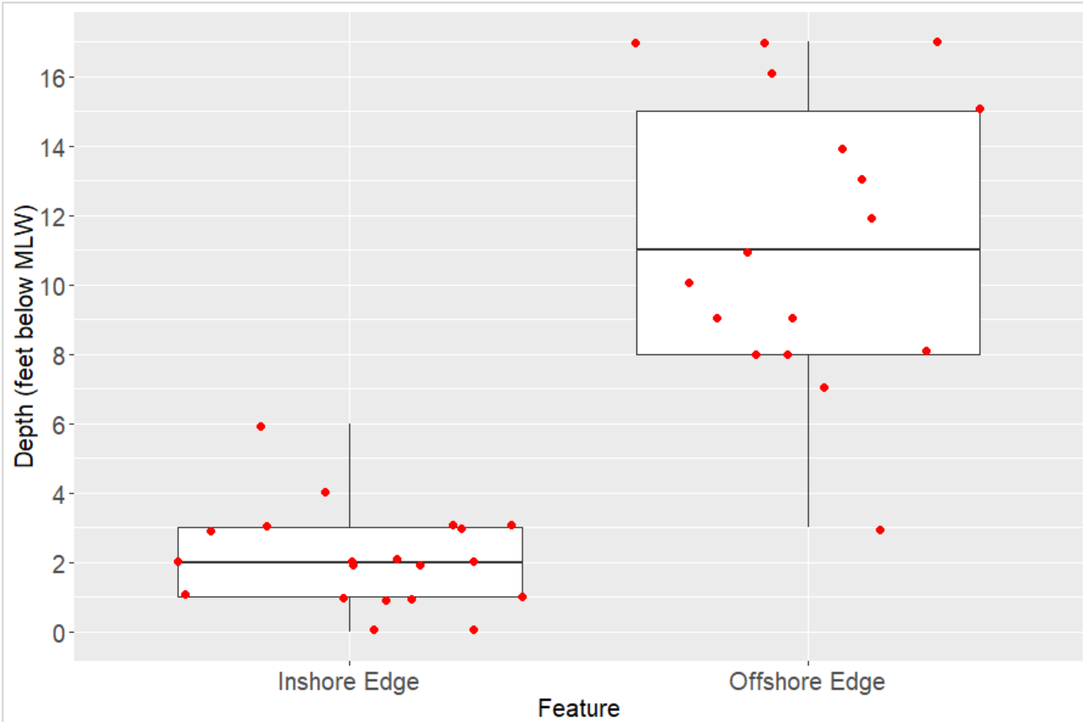


Figure 5: Depths of the inshore (n = 20) and offshore (n=17) edges along dive transects at different sites.

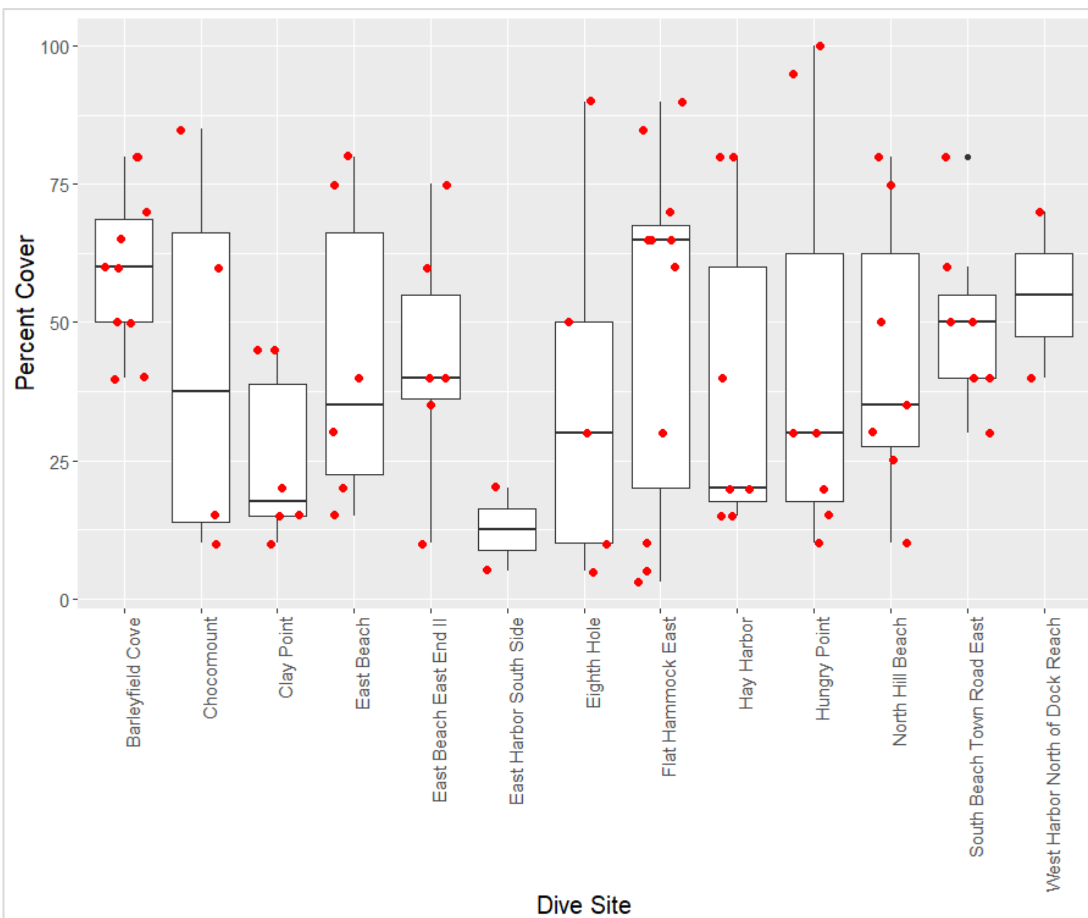


Figure 6: Variation in percent cover by dive site.

During the benthic surveys, divers observed eelgrass covered with extensive epiphytes throughout the cove off Dock Beach in West Harbor and some areas were completely overgrown. Eelgrass meadows at other sites like South Beach, Clay Point, and East Harbor were patchy in distribution. For sites checked by snorkel, eelgrass was observed interspersed with macroalgae growth in East Harbor on the west side and propeller scars were found by the docks on the east side of the harbor (**Figure 7**). Propeller scars were also observed along dive transects at Eighth Hole, at depths up to 7 ft below MLW.

Mapping Eelgrass Condition and Extent

The results of all the site checks can be seen in **Figure 7.** For the dive transects, detailed maps of each site showing transect and absence/presence lines, percent cover measurements, and bed features are displayed in the following figures and in **Appendix B**. Charts of plant height by depth for each transect and dive site are in **Appendix C**.

At Flat Hammock, percent cover exceeded 60% in several areas and decreased to 5% or less at the offshore edge (**Figure 8**). At Hungry Point, there was a more gradual decrease in percent cover as the offshore edge was reached (**Figure 9**). Here, the measured inshore edge corresponded well with the edge mapped in the 2017 USFWS aerial eelgrass survey, while the measured offshore edge extended a distance farther than that mapped. At North Hill Beach, there was a more marked difference between the measured inshore edge and that mapped in the USFWS survey (**Figure 10**). Diver surveys also revealed an offshore edge at South Beach, which significantly exceeded the USFWS aerial survey mapped edge. Aside from these exceptions, dives sites generally had measured edges falling within or close to the 2017 USFWS mapped extent.

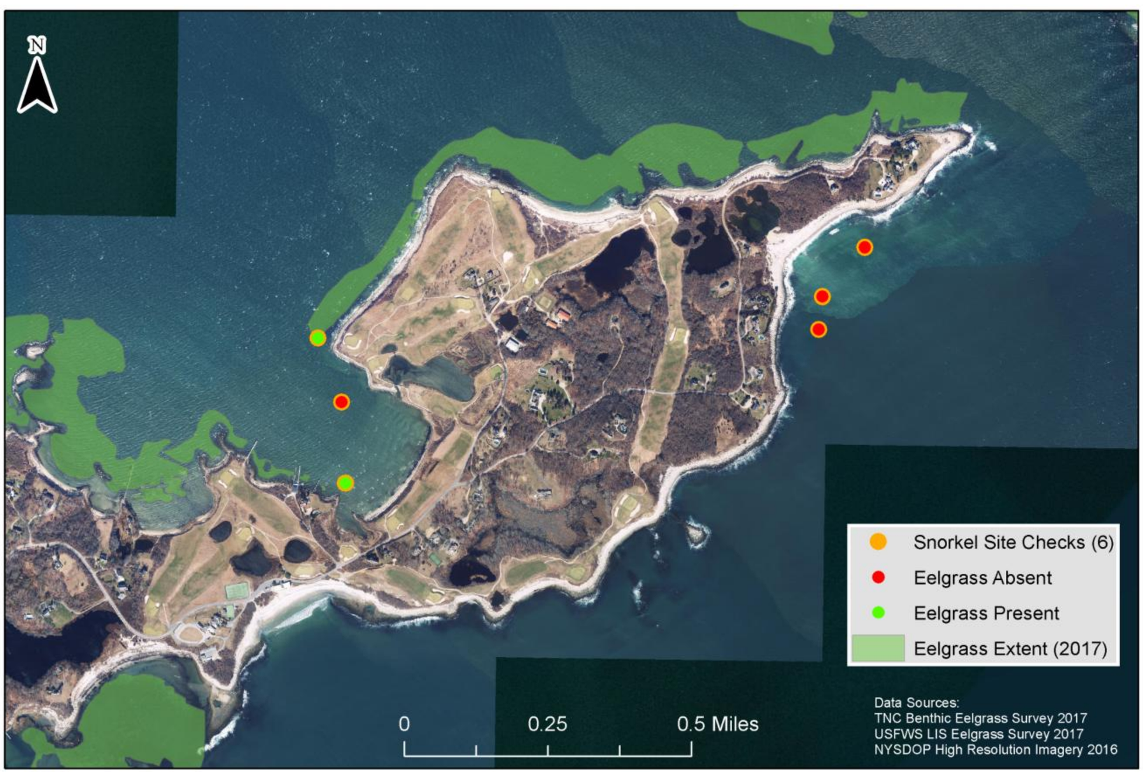


Figure 7: Sites checked for eelgrass by snorkel at the eastern end of Fishers Island.

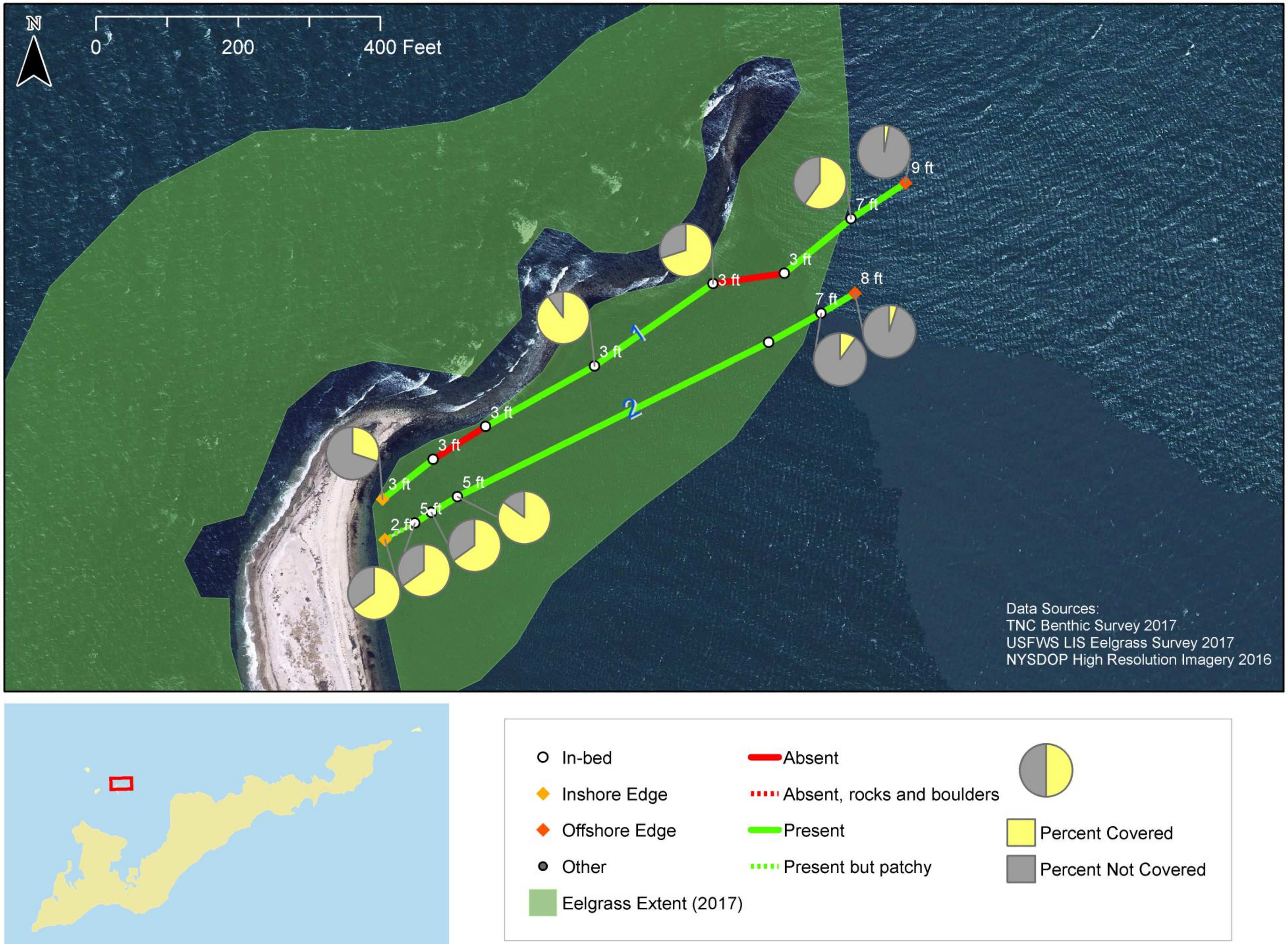


Figure 8: Flat Hammock

*Depth in feet below MLW

Figure 9: Hungry Point

*Depth in feet below MLW

Figure 10: North Hill Beach

*Depth in feet below MLW

Aerial Vessel Survey

Overview

A total of 1432 boats were recorded from all seven surveys combined. Most of these boats were recreational powerboats (70.9%) followed by sailboats (16%), which suggests the prevalence of recreational activity around the island. Commercial powerboats made up 3.2% of all the boats surveyed (**Figure 11**) and included commercial fishing and aquaculture boats, ferries, law enforcement, and ambulatory vessels. Small business driven recreational boats, such as charter boats, were not distinguished from other recreational boats because they could not be easily identified from the aerial images. More than half of the boats were docked (51.1%) and a significant portion was moored (14.3%) (**Figure 12**). Combining the percentages of stationary (19.7%) and underway boats (10.1%) shows that almost a third of all the boats surveyed were likely in use.

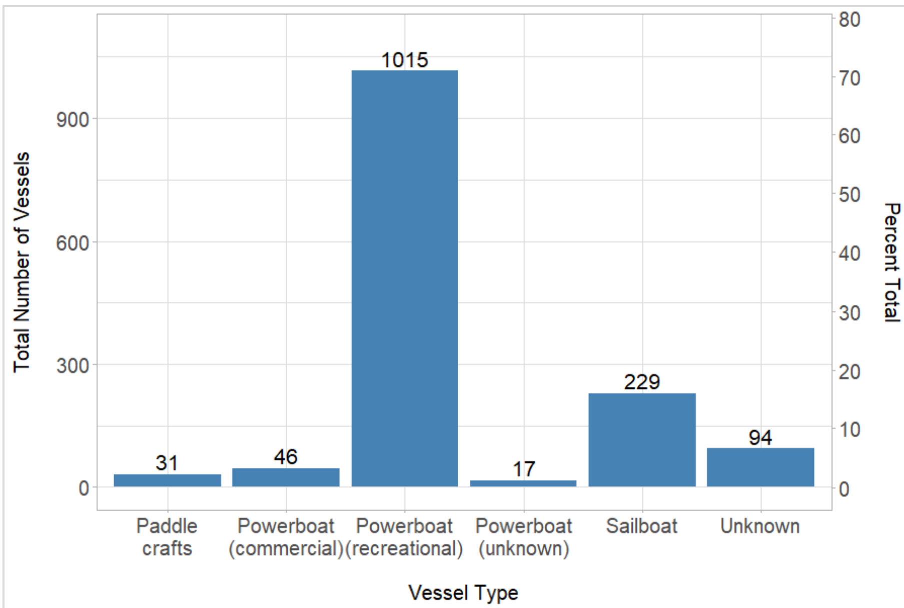


Figure 11: Total number of vessels by type.

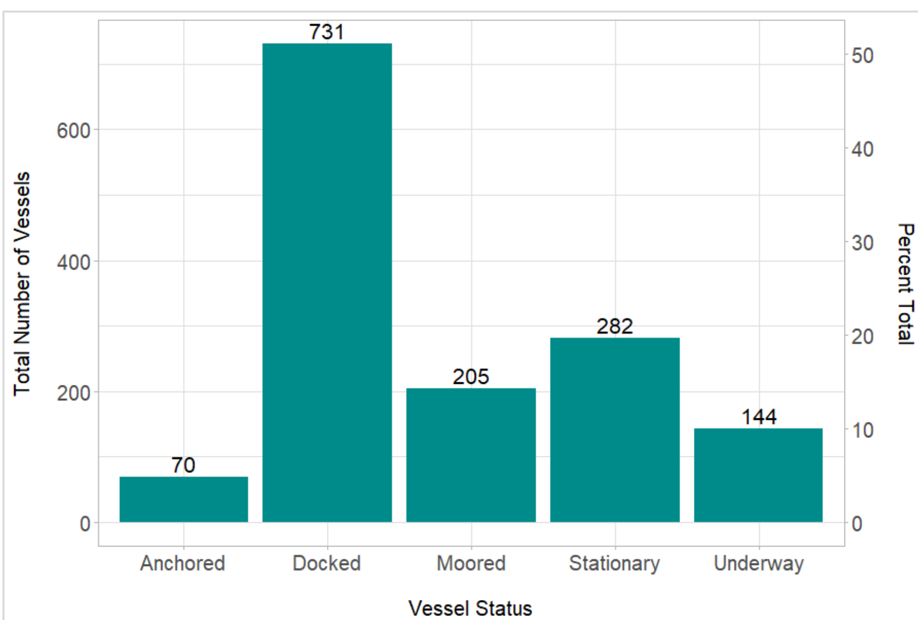


Figure 12: Total number of vessels by status.

Based on survey dates, the busiest boating days were July 30 (27.2%) and August 27 (24.7%), both Sundays (**Figure 13**). The fewest boats were recorded near the beginning and end of the boating season, May 27 (7.3%), June 10 (7.2%), both Saturdays, and September 29 (7.5%), a Friday. Weekday and weekend differences are shown in **Figure 14**. An accompanying map showing the locations of these vessels by survey date can be seen in **Figure 15**.

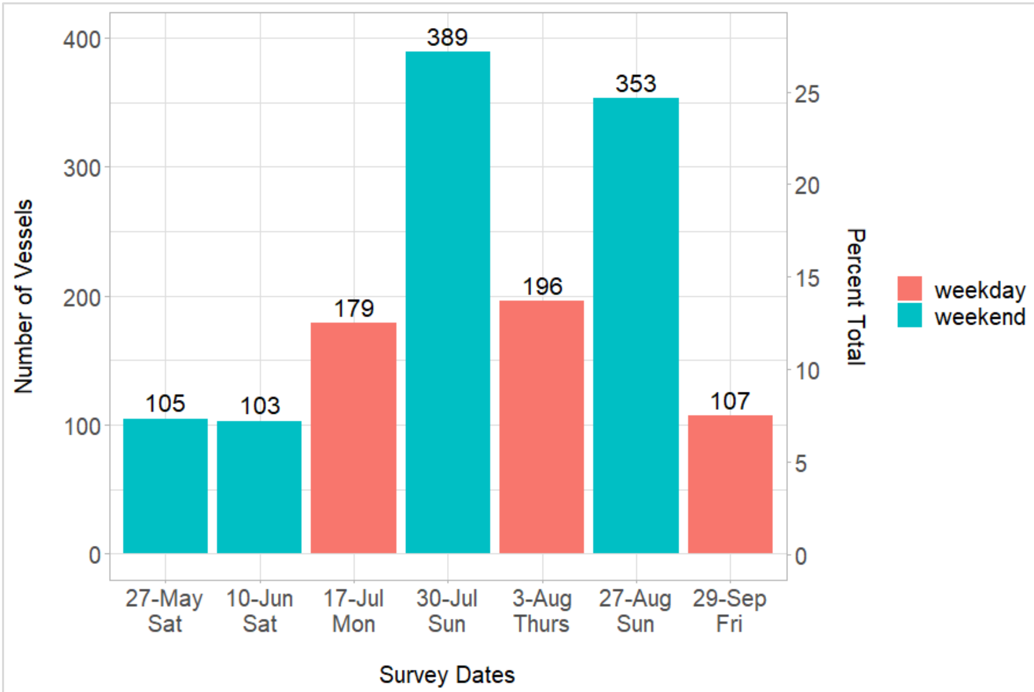


Figure 13: Number of vessels by survey dates and use level.

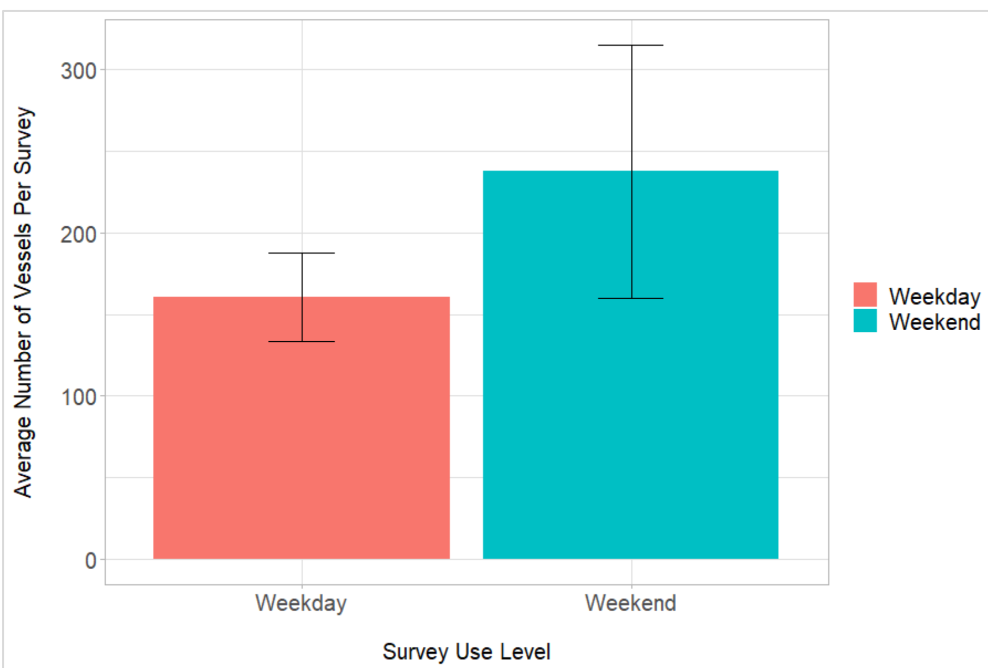


Figure 14: Average number of vessels per survey for each use level. Error bars indicate standard error.

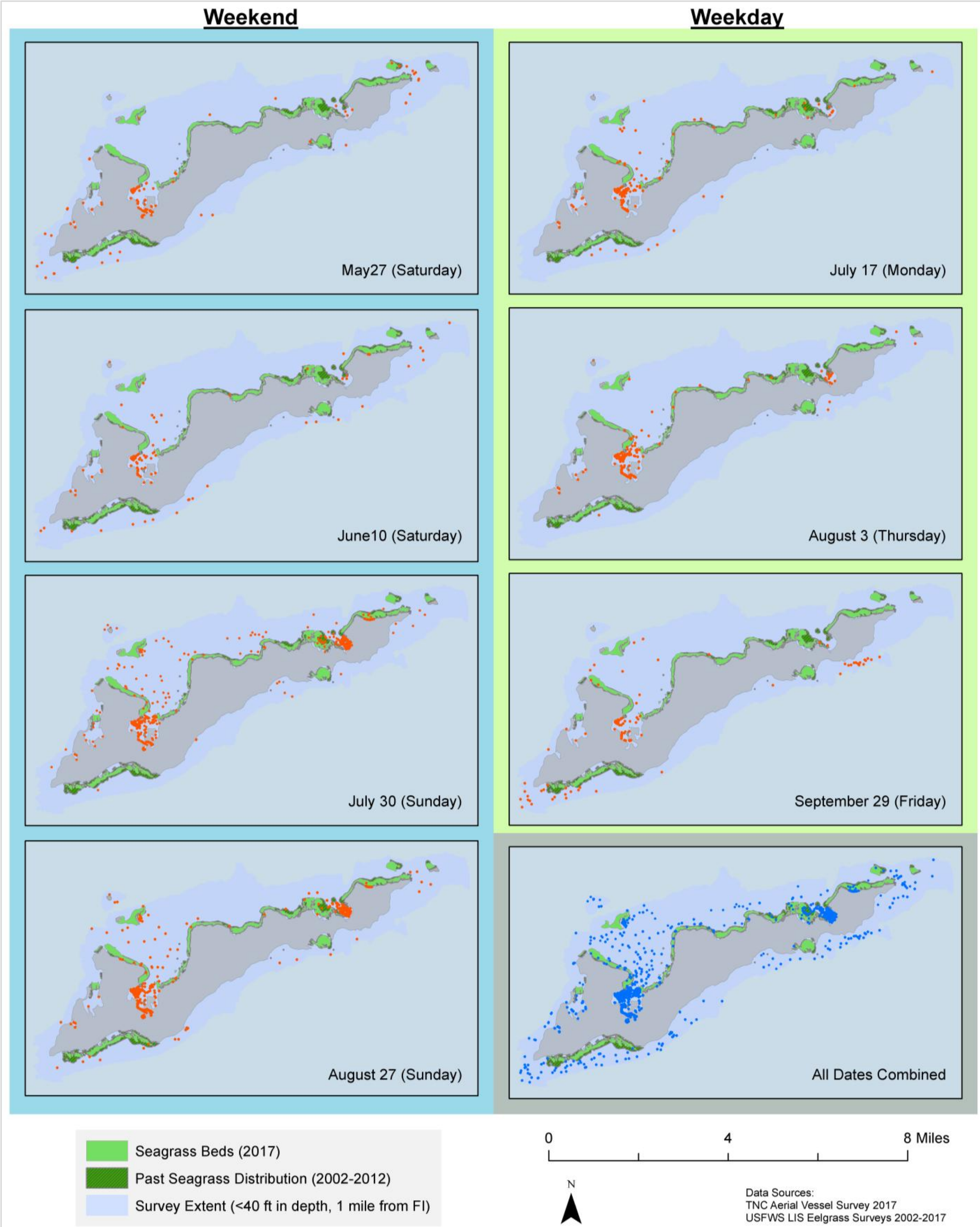


Figure 15: Vessel locations by survey date and use level

Vessel Locations by Type

The busiest survey dates (July 30 and August 27) recorded a two to threefold increase in the number of recreational powerboats and an increase in the number of sailboats within the study area of interest (**Figure 16**). There were some weekend and weekday differences, most notably in the average number of powerboats per survey use level (**Figure 17**). The map in **Figure 18** shows the locations of vessels from all the surveys combined, sorted by type. Sailboat activity was concentrated on the north side of Fishers Island with only one sailboat recorded on the south side. Clusters of mostly powerboats but also sailboats were found in and around eelgrass habitat in sheltered bays and coves on the north side of the island.

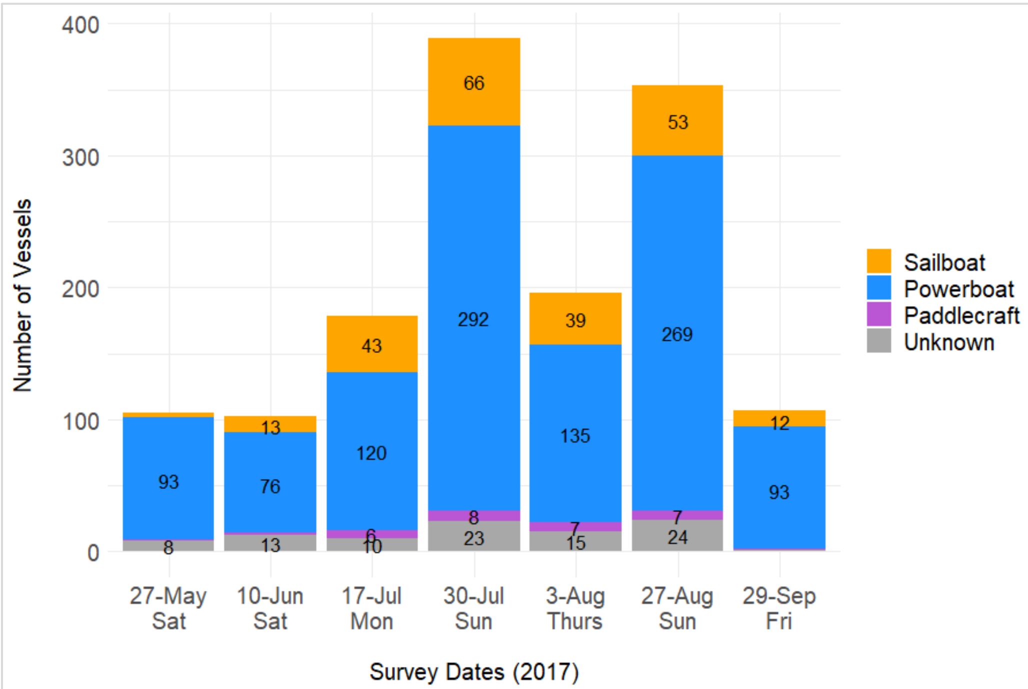


Figure 16: Number of vessels by survey date and boat type

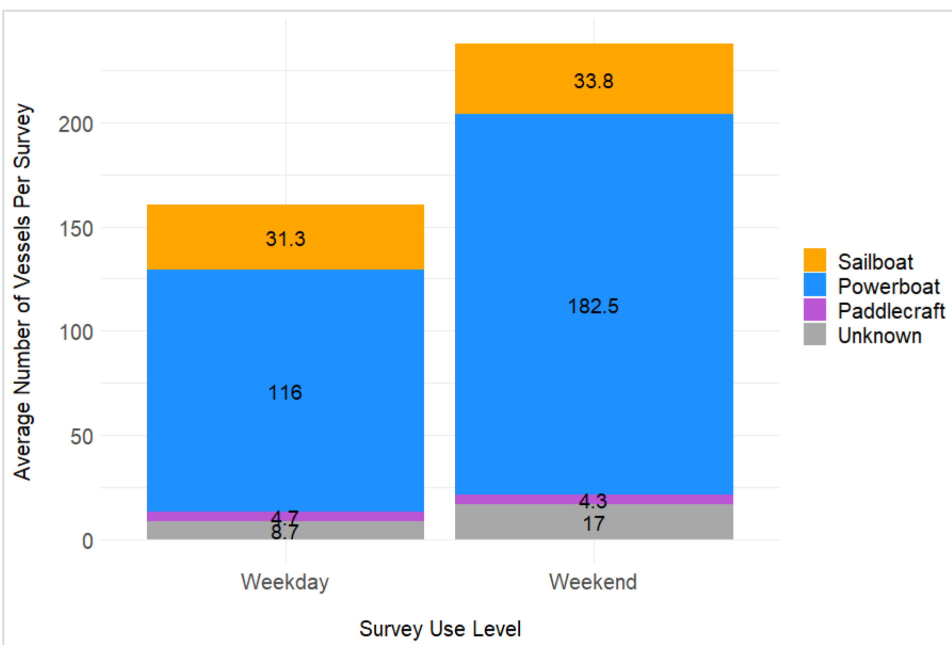


Figure 17: Average number of vessels by use level and boat type

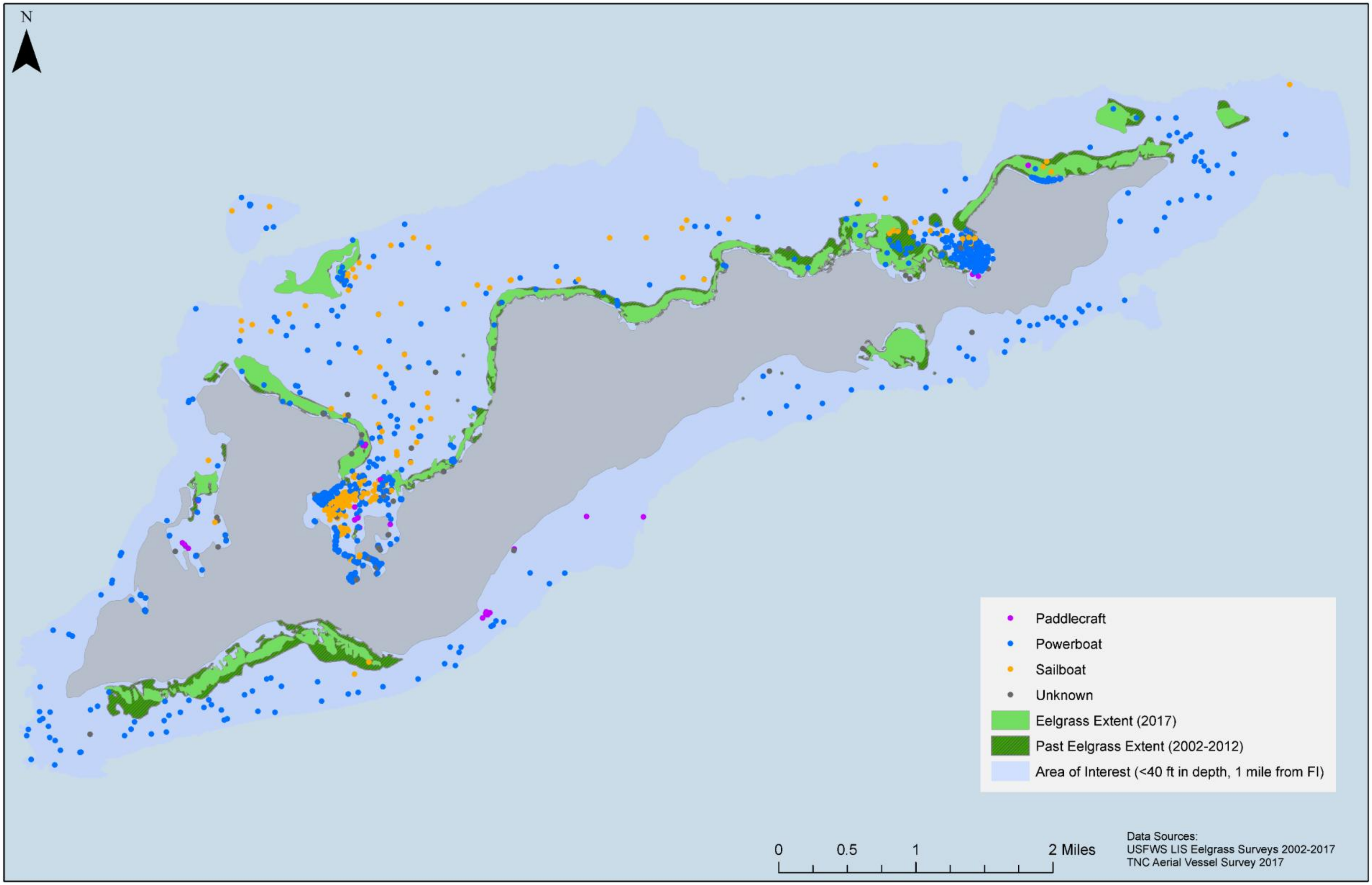


Figure 18: Vessel locations sorted by boat type

Vessel Locations by Status

The busiest survey dates also presented a substantial increase in the proportion of boats that were anchored and stationary. At the peak of the boating season, the number of docked boats nearly doubled, and the number of moored boats also increased (**Figure 19**). Weekday and weekend differences can be seen in **Figure 20**. The highest number of anchored and stationary boats were observed during the July 30 and August 27 surveys and mainly found in East Harbor, Eighth Hole, and Flat Hammock. **Figure 21** shows a map of vessel locations sorted by status. Some boats were found in the vicinity of eelgrass and areas of high dock use can also be seen as well. **Figure 22** shows the locations of these vessels relative to the known eelgrass extent from 2002-2017.

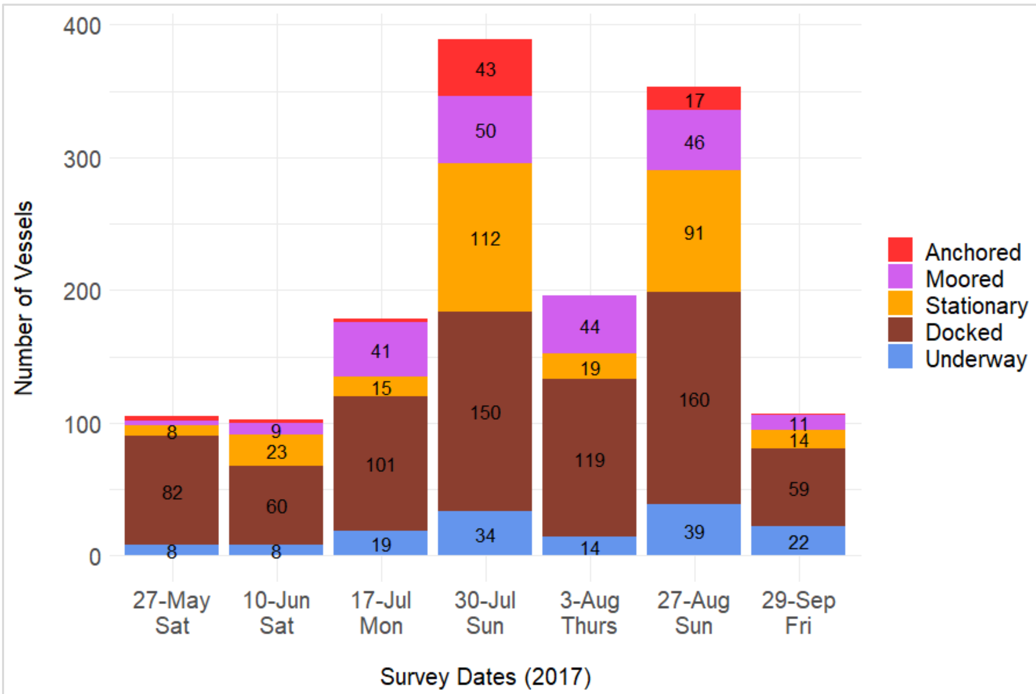


Figure 19: Number of vessels by survey dates and boat status.

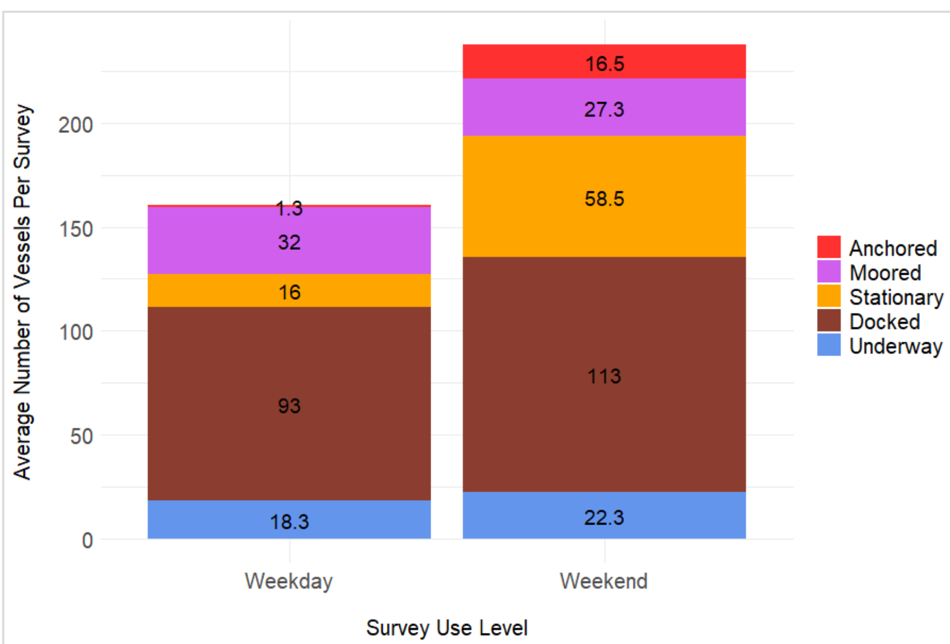


Figure 20: Average number of vessels by use level and boat status.

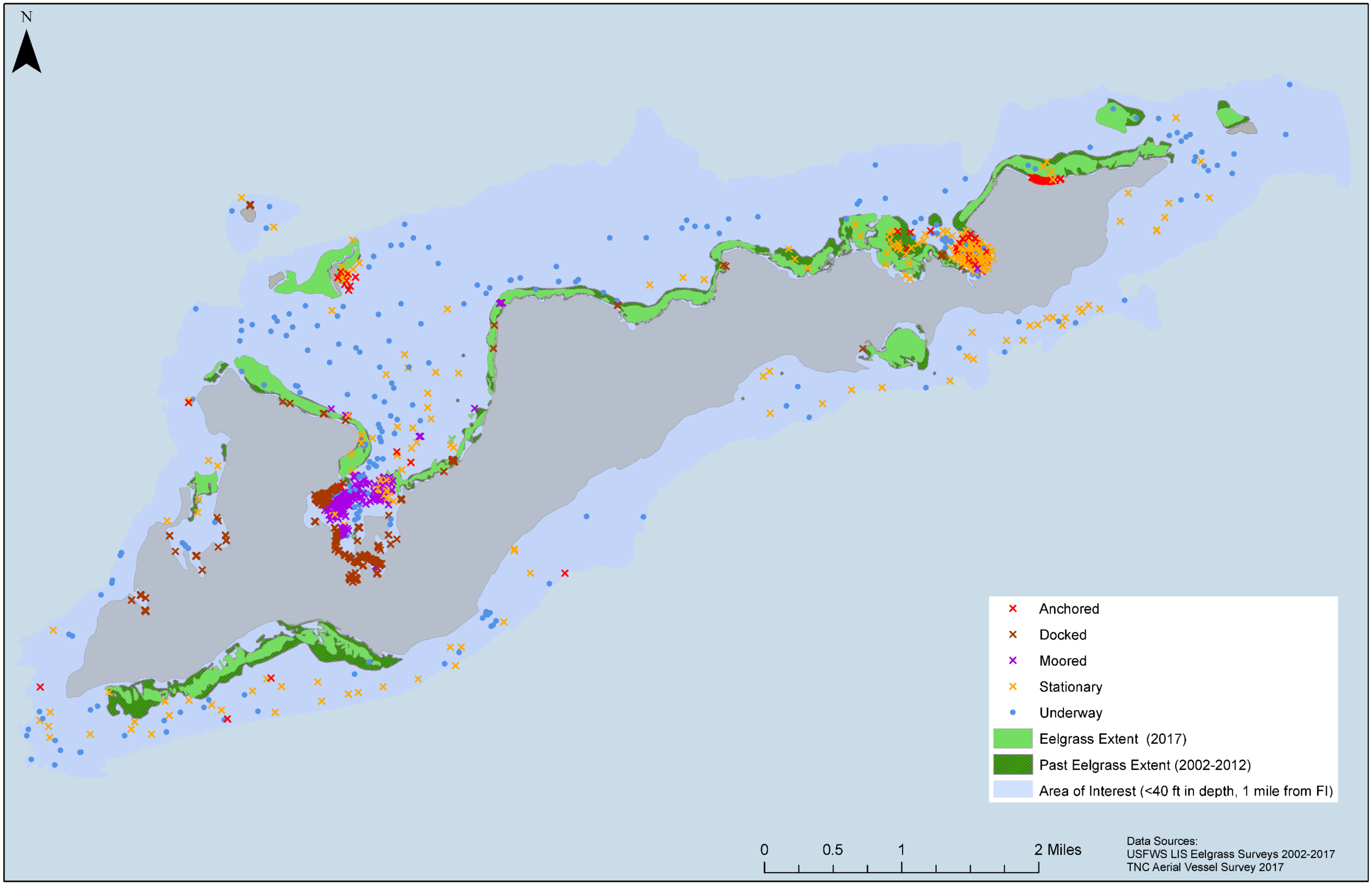


Figure 21: Vessel locations sorted by status

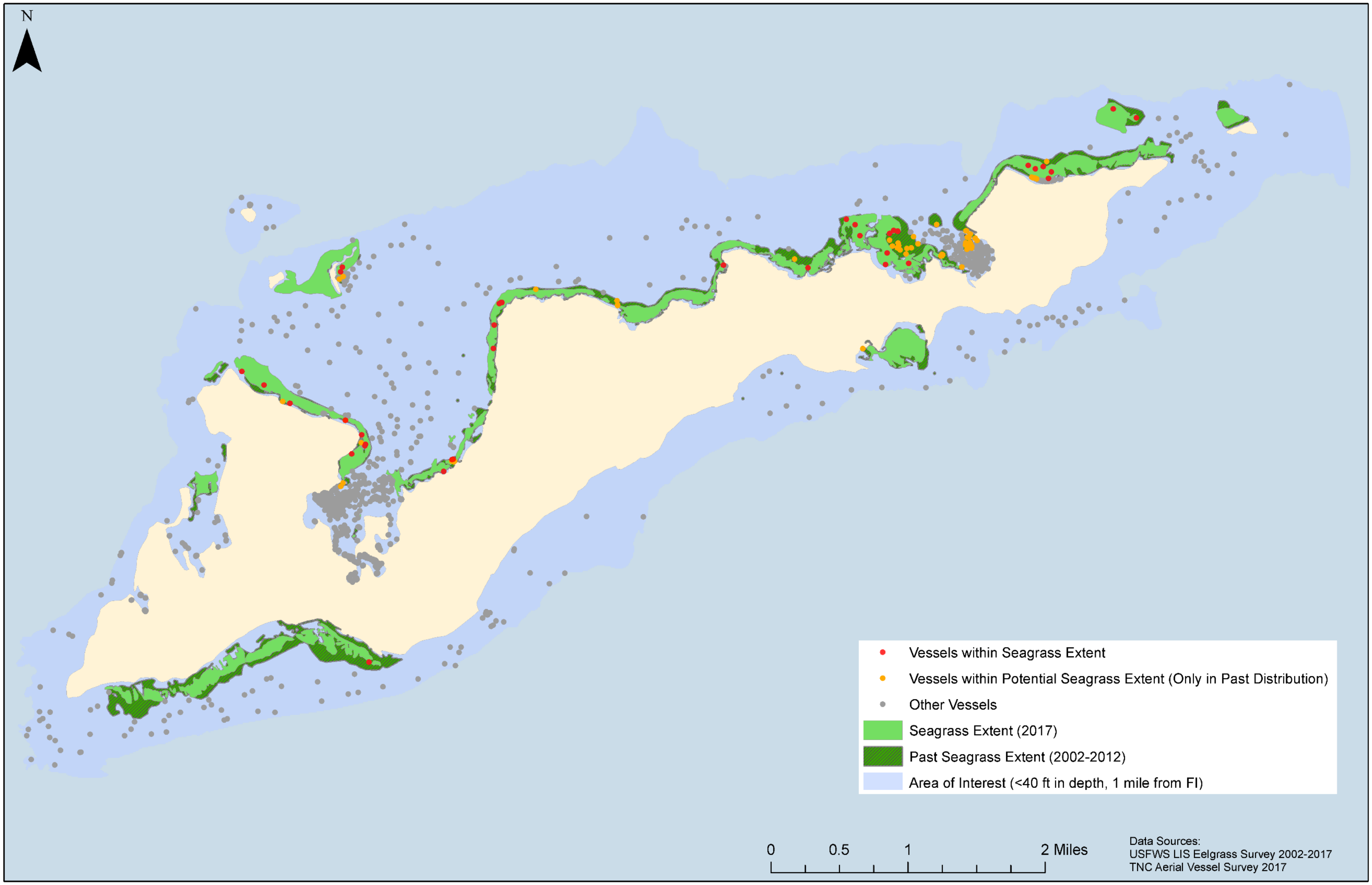


Figure 22: Vessel locations relative to seagrass extent

Hotspots of Vessel Activity in the Vicinity of Eelgrass

Figure 23 outlines five hotspots of vessel activity in or around eelgrass habitat, which are shown in greater detail in subsequent figures. Inferring from the maps presented earlier in this report, these sites contain areas of eelgrass where our survey revealed greater propeller scarring, mooring, and anchoring pressures. It includes parts of East Harbor, Eighth Hole, Flat Hammock, West Harbor, and Hay Harbor. Most of these are sheltered bays or coves with calmer waters and access to the beach.

At East Harbor (**Figure 24**), many boats were stationary or anchored in the harbor on high use survey dates with some boats venturing away from congested parts of the harbor, into shallow adjacent areas where more eelgrass is found. At Eighth Hole (**Figure 25**), most boats were shore anchored with two anchors, one extending onto the beach from the stern and the other into the water from the bow. Most of these boats weren't located directly over eelgrass, however, their bow anchors had impacts on the adjacent eelgrass beds. In addition, these powerboats had to move through shallow water over eelgrass to access the shore. Propeller scars were observed in eelgrass during the benthic survey at this site. At Flat Hammock (**Figure 26**), powerboats and sailboats were anchored close to shore, with some anchoring directly over eelgrass. At West Harbor (**Figure 27**), the majority of moored and docked boats were not located over eelgrass habitat. However, eelgrass habitat in the harbor is at risk of higher stress from frequent boat traffic and associated impacts such as anchoring, propeller scarring and boat wakes, which suspend sediments and reduce water clarity. Moreover, the benthic survey documented the extensive eelgrass beds north of the Dock Beach were covered with macroalgae, which may be indicative of an environment with greater disturbances. Hay Harbor (**Figure 28**), is a good example of an area where boats were not sighted in eelgrass habitat in the survey, but because of the location of eelgrass inside the shallow entrance channel to the harbor, the eelgrass is more vulnerable to boater impacts like propeller scarring.

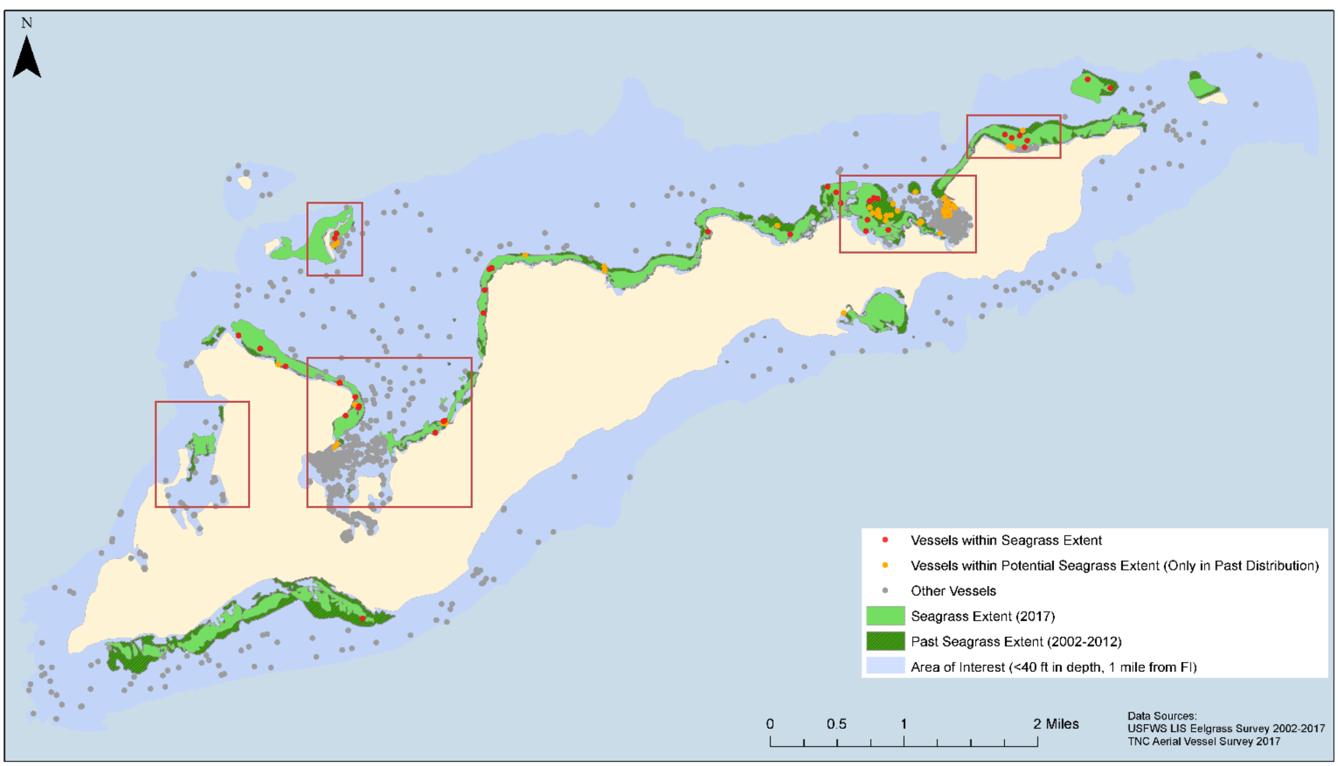


Figure 23: Hotspots of vessel activity and eelgrass habitat at greater risk

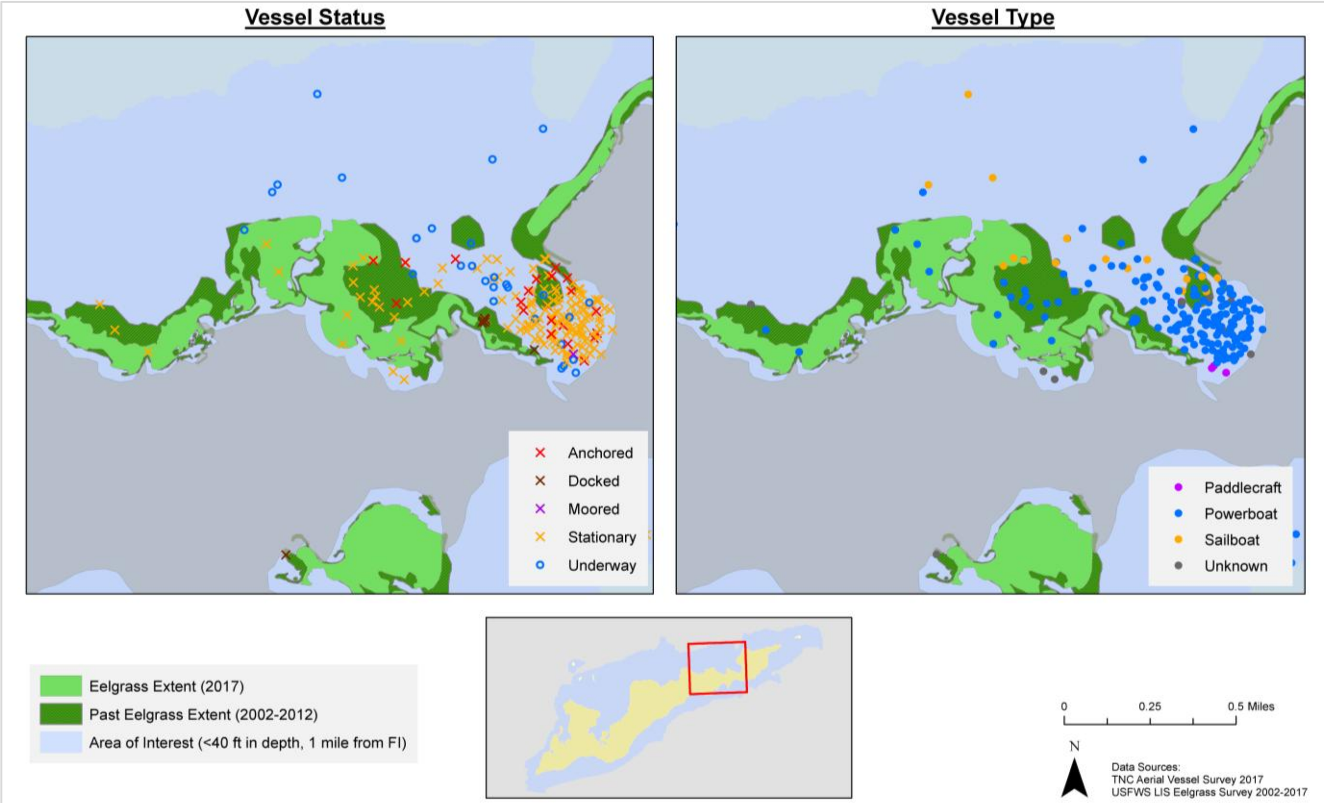


Figure 24: East Harbor Area

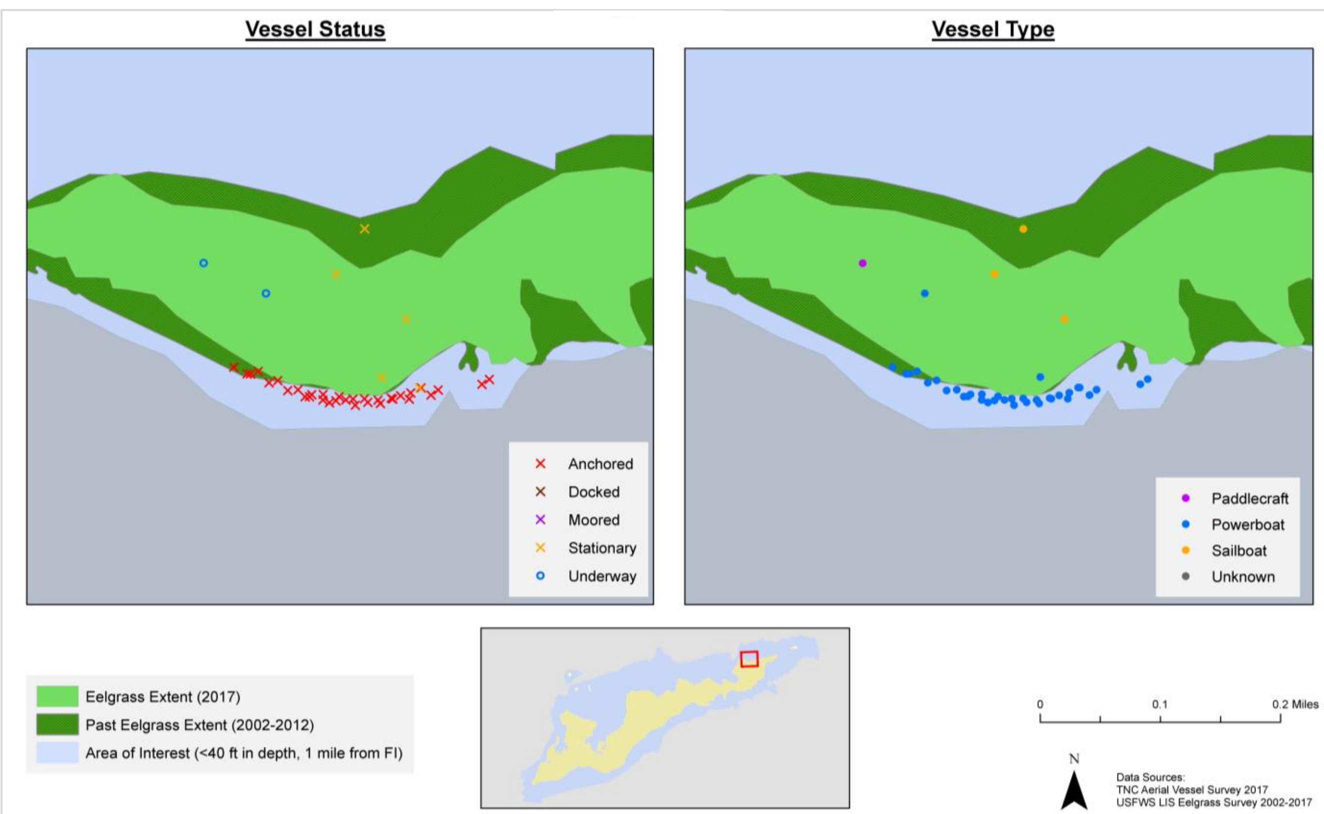


Figure 25: Eighth Hole

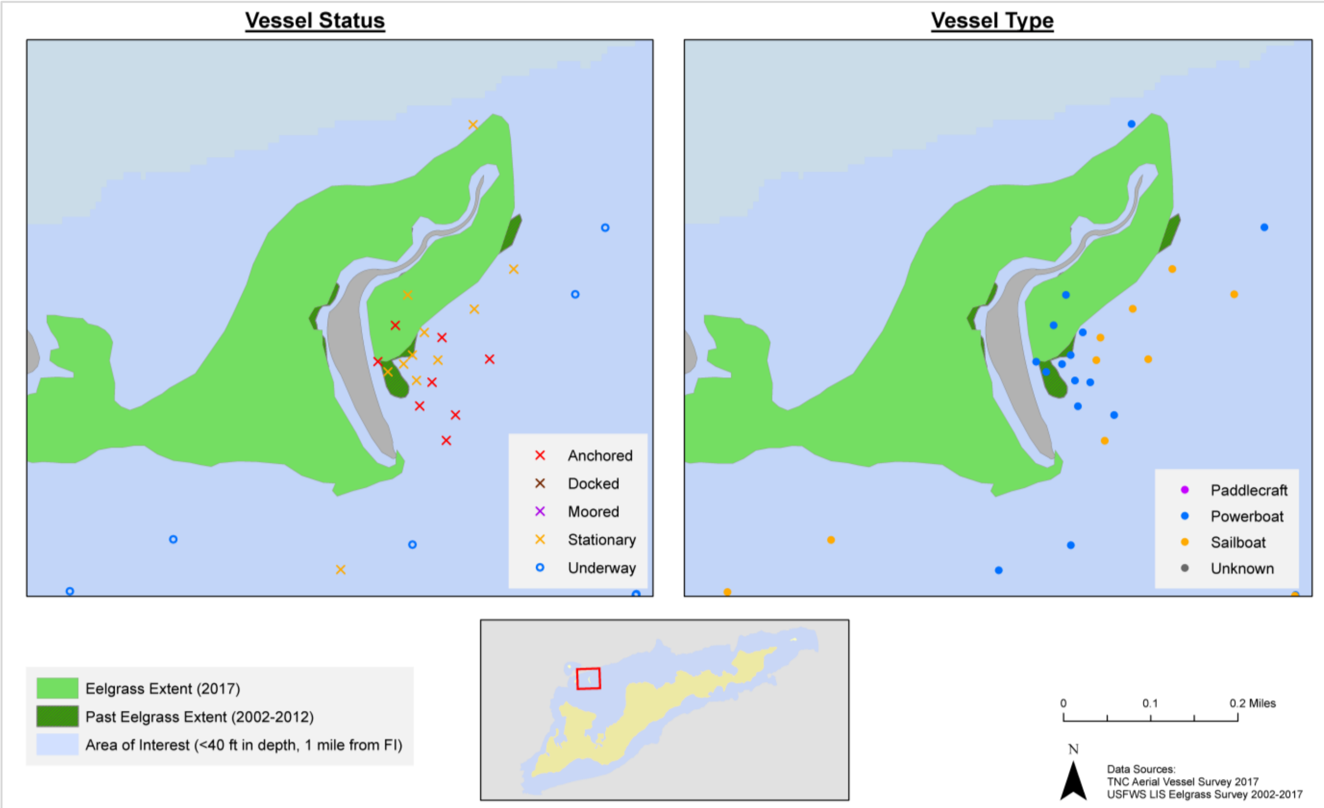


Figure 26: Flat Hammock

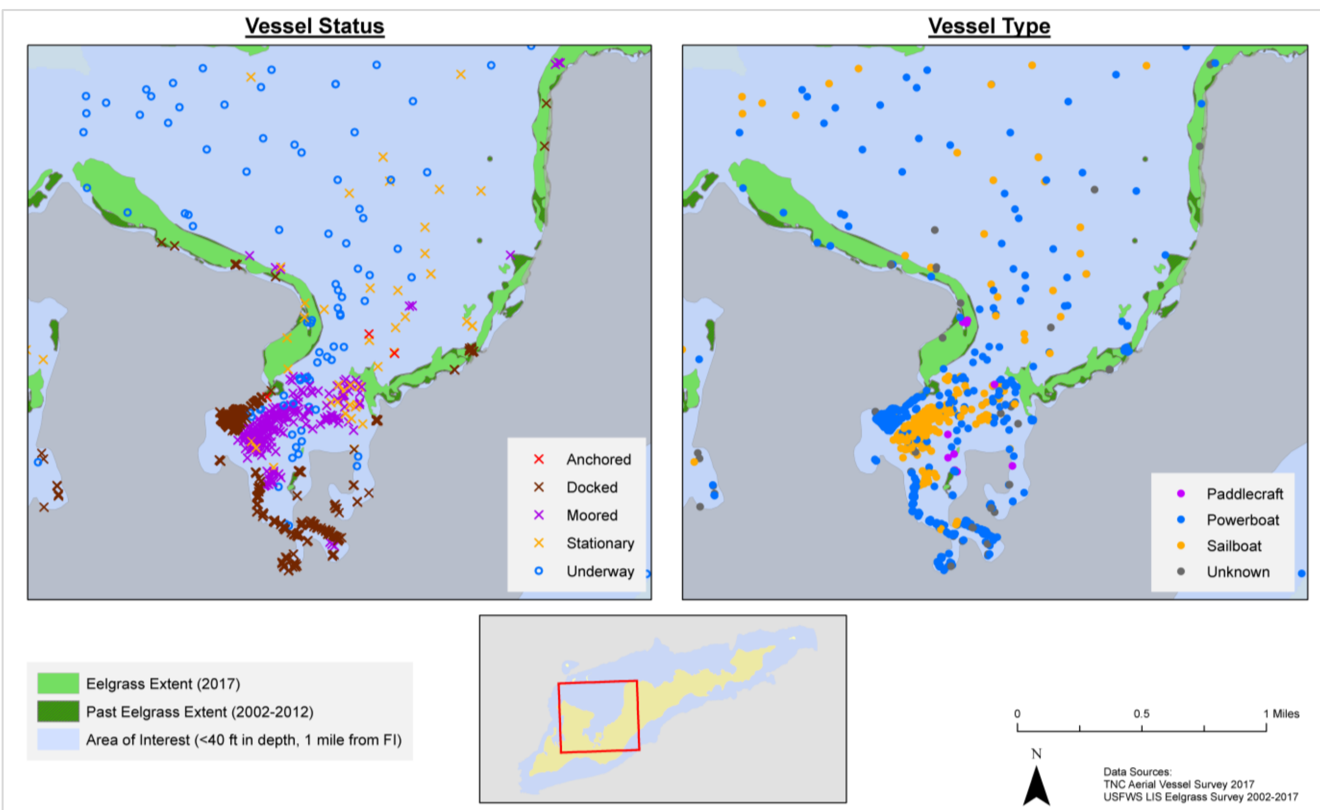


Figure 27: West Harbor

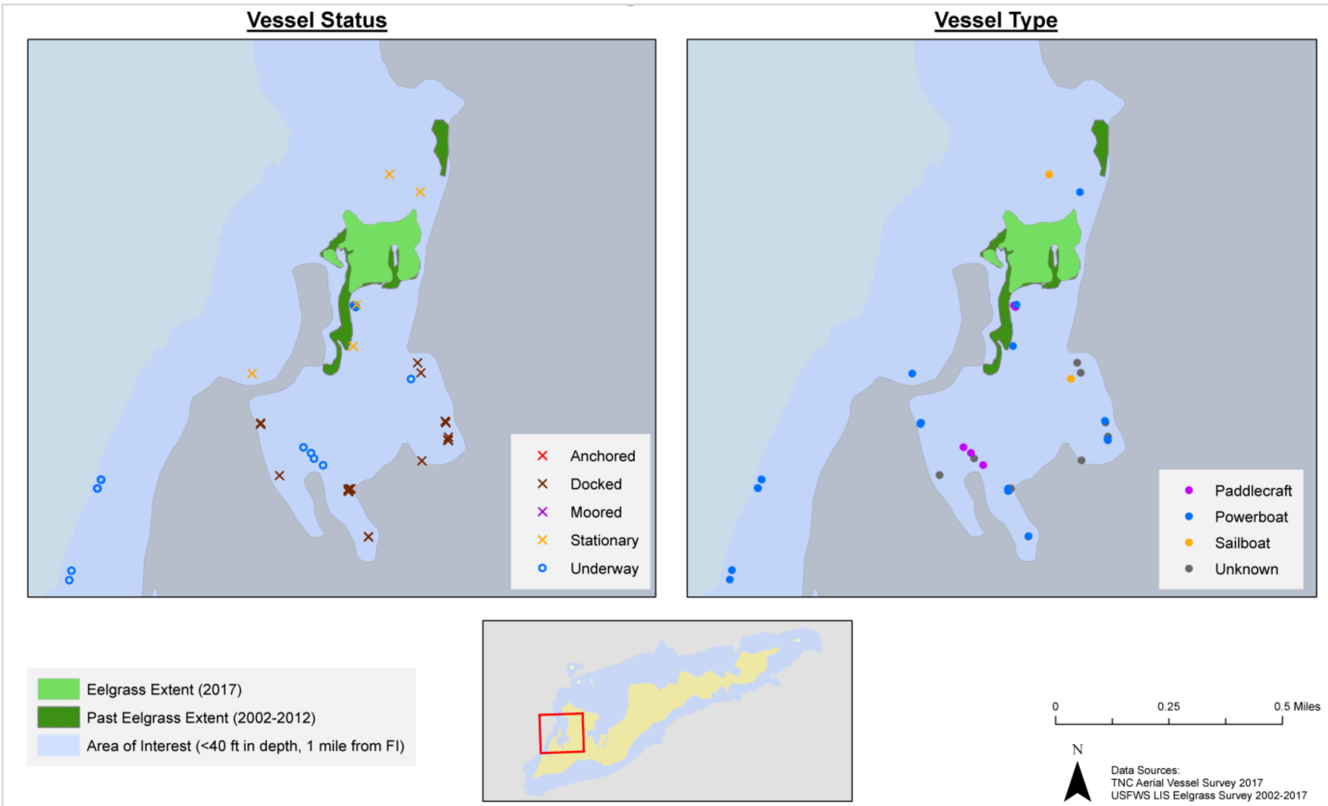


Figure 28: Hay Harbor

DISCUSSION

Groundtruthing Eelgrass Extent

One of the main goals of the underwater benthic survey was to use *in situ* transect data to verify the eelgrass extent around Fishers Island, delineated in the 2017 USFWS survey. A secondary goal was to validate the presence or absence of eelgrass at historic sites identified by the island community, but undocumented in the previous USFWS survey (2012). Before making a comparison, however, it is important to consider differences in the projects' methodologies. For example, the USFWS survey (2017) used aerial images to delineate eelgrass beds on a large scale (1:1500). These images were taken in June, showing an eelgrass extent earlier in the perennial growth cycle than that captured in our benthic survey, during September and October. For some areas, the USFWS survey (2017) did use field verification, completed around the same time as this survey, to adjust eelgrass extent. Additionally, edges in the USFWS survey (2017) were defined as when eelgrass cover dropped to 5%, whereas our definition was when eelgrass was absent (M. Bradley, personal communication).

Despite these differences, the offshore and inshore edges recorded in our benthic survey generally corresponded well with the edges mapped by the 2017 USFWS survey. At most of our dive sites, the measured edges were close to the edges mapped by USFWS and differences were generally within the margin of error. In a few cases, our measured offshore edge was closer to shore than that which they mapped. At two of these sites, West Harbor and Barleyfield Cove, proximity of the offshore edge to an active vessel channel and a breakwater, respectively, and safety protocols prevented the dive team from reaching the offshore edge. At Eighth Hole, we suspect the actual outer edge was not reached even though the divers traveled a reasonable distance beyond the measured edge to verify eelgrass absence beyond that point. At three sites, our measured inshore or offshore edge extended significantly farther than the edges mapped by USFWS (a difference of about 35-75 ft for the offshore edges at

Hungry Point, North Hill Beach and South Beach, and about 150 ft for the inshore edge at North Hill Beach). These results illustrate that some areas of deeper or shallower eelgrass were not fully captured in the USFWS survey, which could be due to a variety of reasons including factors affecting the aerial image quality for the particular date and location conditions like water clarity. Notably, these edge differences occurred in locations where field verifications were not performed as part of the USFWS survey.

Despite a few limitations, our dives at selected sites demonstrate the reliability of the 2017 USFWS eelgrass extent around Fisher's Island. For local project planning and permitting purposes (e.g. siting moorings, docks, aquaculture and submerged infrastructure, such as communication cables), the USFWS eelgrass extent map is a good starting point, but for local management purposes, higher resolution information is needed. Small differences in the actual and mapped edges of eelgrass could have significant implications for conservation and management of the resource. Ideally multiple tiered studies including dive transects would resolve these differences and provide data at a finer resolution (Neckles, Kopp, Peterson, & Pooler, 2012). Given limitations in resources and funding, however, one management strategy for local project decision-making is to consider eelgrass extent in the context of potential eelgrass habitat. This could be done by including past eelgrass distribution as part of the project area or including a buffer around known eelgrass extent to avoid and minimize direct and indirect impacts to eelgrass associated with local projects.

Variability in Eelgrass Beds

As shown in the benthic survey, there can be considerable variation in eelgrass abundance and distribution even within an eelgrass meadow. This is because eelgrass growth is determined by a suite of environmental variables such as light availability which varies with depth and water clarity, temperature, type of substrate, nutrient concentrations (dissolved oxygen and carbon), presence of toxic sulphides and the degree of physical exposure from tides, waves and currents. Eelgrass distribution is also regulated by biotic factors such as competition, disease, herbivory (Greve & Binzer, 2004), and their location relative to an eelgrass patch.

As a result, eelgrass distribution and condition can vary greatly due to site-specific characteristics. For example, eelgrass was recorded as growing particularly tall in Barleyfield Cove which is much more sheltered from wave action and currents compared to other sites. Besides spatial variation, eelgrass biomass can fluctuate greatly temporally. In the temperate regions where it is found, eelgrass exhibits seasonal growth patterns that are strongly influenced by water temperature. In Long Island Sound, for instance, eelgrass growth peaks in September and experiences diebacks and senescence during the winter months. Eelgrass biomass also fluctuates interannually in response to climatic changes, such as storms or phenomenon such as El Niño and La Niña, and coastal processes that gradually shape the coastline through erosion and deposition of sediment. So, when considering eelgrass extent, it is also important to consider intrinsic variability inside eelgrass beds and the dynamic nature of eelgrass growth and expansion.

Aerial Survey Highlights and Implications

The aerial survey revealed areas where boating activity was particularly concentrated and where the greatest potential impacts to eelgrass are likely to occur, mainly from recreational boat activity. Hotspots like parts of East Harbor, Flat Hammock, and Eighth Hole were popular recreational boating destinations, especially during days of peak use, with some boats seen anchored directly over eelgrass. Other places like West Harbor and Hay Harbor have channels with frequent boat traffic making eelgrass beds in the vicinity more vulnerable to impacts such as propeller scarring or increased turbidity related to wakes. Overall, our findings corroborated observations by local community members, underscoring the value of local knowledge in place-based resource conservation and management (Reid, Berkes, Wilbanks & Capistrano, 2006; Mackinson & Nottestad, 1998)

At the Eighth Hole, another concern our study revealed was boats that were seen anchored close to shore with their bow anchor lines extended offshore into the eelgrass (**Figure 29**). While these boats may not be directly over eelgrass, local reports and anecdotal evidence suggest that their anchors do fall in eelgrass beds because during retrieval, boaters have been observed removing entangled eelgrass from their anchors. Moreover, to reach the beach, these vessels had to transit shallow waters, which might be one cause of the propeller scarring observed there.

Figure 29: Eighth Hole, July 30 (Photo: Chantal Collier)

In addition, scarring observed by the docks during dives in East Harbor and docked boats found in or near eelgrass from the aerial survey suggest that there are dock related boating impacts as well. As boats travel to and from the docks, propeller scarring can occur, especially during low tide. Shading by docks and docked vessels are also important eelgrass management issues in these areas. The biggest potential impact noted in the survey is scarring from propellers and anchors as opposed to that from moorings because not many moored boats were sighted in or near eelgrass. The moored boats in the main mooring field in West Harbor, for example, were not sighted over known eelgrass extent. There are a few moorings in West Harbor and elsewhere along the north shore, however, that are in or near eelgrass so the impact from moorings cannot be ruled out.

Our analysis represents a conservative estimate of vessel activity around Fishers Island in our survey area of interest. Although our survey included flights throughout the boating season, the level of boat activity is likely greater. There are likely locations with high levels of boating activity not fully captured in our survey and absolute numbers of boats are based on totals from the seven survey dates (each flight about half an hour in length). For example, due to constraints in scheduling and resources, it was not possible to conduct any survey flights on major holidays when there is potentially greater boat activity.

Management Options

To address boating impacts on seagrass habitat around Fishers Island, several management options are available. The options detailed here are education and outreach, designation of special management areas or zones, and alternatives to conventional moorings, such as conservation moorings. Based on our findings, management strategies at Fishers Island should prioritize reaching recreational boaters, including powerboat and sailboat users, during days of peak use to have greatest impact. For some issues like boats anchoring close to shore, boater outreach and education may be the most effective strategy, whereas for frequent boat anchoring, propeller scarring, and boat wakes in seagrass areas, a combination of different management options may be appropriate.

Boater Education and Outreach

Raising awareness and public support through boater education is essential to any long-term focused seagrass conservation and management plan. With proper knowledge and active boater involvement, scarring in seagrass is preventable. Simple steps like being mindful of seagrass extent, tide levels, and the depth of a boat's draft relative to water depth; and, knowing what to do if a boat enters a shallow seagrass area (lift, drift, pole, or troll) and when propeller scarring is occurring (when the propeller wash turns brown), can go a long way toward minimizing boat-related impacts on seagrass (Texas Parks and Wildlife, 2006). Boater education can also encourage cooperation through boater to boater communication, which is an efficient and effective channel for spreading seagrass awareness and best practices for boating. Given the wide geographic origin of boaters who use waters around Fishers Island, the task of outreach is not without its challenges and may require collaboration across state boundaries.

Education comes in many different forms including conducting boater surveys to understand public perceptions of seagrass and to identify gaps in knowledge, distributing boaters' guides with maps showing sensitive seagrass habitat locations and alternatives to transiting and anchoring in those areas, setting up educational signage in marinas, boat launches, and yacht clubs, and stickers with navigational aids and tips on avoiding anchoring and propeller scarring in seagrass. In general, Smith and Hellmund (1993) recommend educational strategies that: (1) make boaters aware of the link between detrimental boating behavior and scarring in seagrass habitat, (2) clearly demonstrate ways of boating responsibly, and (3) foster a sense of stewardship and connection to the health of the seagrass ecosystem.

One innovative example of on-the-water boater education and outreach successfully employed in the Florida Keys National Marine Sanctuary and Rookery Bay National Estuarine Research Reserve is Team OCEAN (Ocean Conservation Education Action Network). Part of the program involves assigning trained volunteers to sanctuary and reserve boats in heavily visited reef and seagrass sites, where they go from boat to boat acquainting visitors with general information about the sanctuary or reserve and its protective zones and provide tips on boating safely. Team OCEAN volunteers distribute informational packets containing boater charts, sanctuary information, and helpful navigation tips that enhance the visitor experience and promote responsible and safe boating. By being physically present at different sites, they help prevent boaters from potentially grounding in and damaging shallow reef and seagrass areas by signaling errant boaters to move away. (Florida Keys National Marine Sanctuary, 2015). Building a personal connection with boaters in this way and attaching a face to the message is a powerful means of motivating boaters to care about and protect sensitive seagrass habitat.

Zoning and Special Management Areas

Zoning and special management areas are another option available to protect seagrass habitat around Fishers Island. Zones can be created to restrict certain activities, such as no anchor, no motor, no wake, or restricted mooring zones. Others can be established to have a more cautionary role such as reminding boaters to proceed with care in areas with seagrass. These zones can be mandatory as part of local, state or federal regulations, with or without enforcement and penalties, or may be completely voluntary, with cooperation encouraged through boater education and community watch programs.

For example, in Port Townsend, WA, along the busy downtown waterfront, voluntary no anchor zones, along with a heavy focus on education and outreach, was successful in reducing the number of boats anchoring inside seagrass. The number of boats seen inside seagrass dropped from a pre-project level of 20 percent in 2003 to less than 1 percent in subsequent years. Similar to some areas around Fishers Island, like East Harbor and Flat Hammock, boats in Port Townsend only needed to anchor a short distance further offshore to avoid seagrass areas (Pearson & D'Amore, 2005; Jefferson County Marine Resources Committee, 2010).

At Fort DeSoto Park in Pinellas County, FL, a coalition of government and citizen representatives, concerned with propeller scarring, helped create and adopt an ordinance that separated the management area into zones. These included no motor exclusion zones, also called pole and troll zones that allowed boaters to use long poles or smaller trolling motors instead of conventional motors, and caution zones with penalties for seagrass damage. As a result of these management actions, the rate of propeller scarring was significantly reduced compared to areas with no protection (Stowers, Fehrmann, & Squires, 2000). In another example, in the Redfish Bay State Scientific Area, TX, voluntary propeller-up zones were not effective in reducing propeller scarring during the five years they were implemented. Only after adopting and enforcing regulations that made it unlawful to uproot seagrass with submerged propellers and substantial boater outreach and education did propeller scarring decrease (Texas Parks & Wildlife, n.d.). For more information regarding these and other examples see **Table 2**.

For Fishers Island, the possibility of protecting seagrass habitat by designating special management areas is afforded by the Seagrass Protection Act, passed in 2012 by the New York Legislature in response to recommendations by the Seagrass Task Force, established in 2006. More specifically, the law requires the New York State Department of Environmental Conservation (DEC) to protect existing seagrass habitat and regulate coastal and marine activities that threaten seagrass habitat or restoration efforts by: 1) designating seagrass management areas (SMA), 2) developing and adopting a management plan for each SMA, and 3) consulting with local governments, recreational boaters, marine industries, fishermen, affected property owners and other stakeholders so as to effectively manage, protect and restore seagrass. The management plan adopted for each SMA helps guide the DEC in the development of any rules and regulations needed to protect seagrass habitat and at the same time, seeks to preserve traditional recreational activities, such as boating and marina operations, as well as shellfishing and finfishing (New York Legislature, 2012). Because of its extensive seagrass habitat and the proactive involvement of local community members, Fishers Island would be an ideal candidate for a SMA designation.

Conservation Moorings

Conservation or “seagrass friendly” moorings are another viable management option to: (1) create mooring fields with minimal impacts on seagrass, (2) replace conventional swing chain moorings and allow recovery of mooring scars, or (3) to relieve anchoring pressure on seagrass in high-use areas. One kind of conservation mooring has an elastic rod that minimizes contact with the seafloor and prevents scouring caused by heavy chains used in conventional moorings. This type of mooring also has a helical screw-in anchor with a smaller footprint than a conventional block or mushroom anchor. One consideration for setting up conservation moorings is the cost of purchasing, installing, and maintaining them. Funding from grants or partnerships or fees generated from boater use can help alleviate these costs.

CONCLUSION

A combination of different management options may be suitable for protecting the eelgrass ecosystem at Fishers Island from boating and other impacts. Our surveys establish baselines for eelgrass condition and extent and vessel use around the island, by which the success of different management strategies can be measured, and identify areas where management is needed most. Because of the variability inside eelgrass beds, the dynamic nature of eelgrass growth and expansion, and likely changes to boating patterns over time, management strategies need to be adaptive and managers will need to respond accordingly to new circumstances. Therefore, crucial to the development of a long-term management plan is the establishment of a monitoring program and active collaboration among local community, government and non-governmental partners; the aim is to track the location and types of marine and coastal activities occurring in and adjacent to seagrass meadows and to assess the health of the enduring seagrass ecosystem at Fishers Island, so that it can be protected for many generations to come.

Table 2: Examples of Management Options

Management Example	Type of Impact	Description	Strategies
Florida Keys National Marine Sanctuary and Rookery Bay National Estuarine Research Reserve, FL	Vessel Groundings and Anchor Scars in Seagrass and Coral Reefs	An integral component of Team OCEAN (Ocean Conservation Education Action Network) is on-the-water boater outreach and education. In areas and on days of high use, such as holidays, trained volunteers go boat to boat, talking to boaters and distributing informational packets to encourage stewardship and responsible boating. In the Florida Keys National Marine Sanctuary, their presence directly prevents groundings by making boaters wary of shallow reef and seagrass areas. Program staff members also visit local businesses such as marinas and dive/snorkel shops to disseminate brochures and hear concerns from local business owners. The program has enjoyed great success and the model for on-the-water outreach and education has been replicated in other places like the Rookery Bay National Estuarine Reserve.	• On-the-water boater outreach and education • Informational packets with boater charts, sanctuary information, and navigation tips which enhance the visitor experience and promote boater safety • Outreach at events and festivals • Informational stickers showing what to do if a boat becomes grounded, distributed at marine boat rental facilities. • Connections with local businesses to help raise awareness and adapt strategies in response to feedback **For more information:** https://floridakeys.noaa.gov/volunteer_opportunities/teamocean.html
Port Townsend, WA	Anchor Damage to Seagrass	In 2003, the initiative of creating voluntary no anchor zones began with public scoping followed by a trial run during a popular festival in the fall. Seasonal marker buoys were deployed along a half mile stretch of the downtown waterfront to delineate the offshore edge of seagrass beds. The buoys read "Anchor Out for Safety and For Salmon," emphasizing that boating outside of seagrass not only protects vital salmon habitat but also protects boaters because anchors do not hold well in seagrass. Additionally, there was also substantial boater outreach and education including signage placed in marinas. Before the project, around 20 percent of boats were inside seagrass extent. After installation of the buoys, monitoring showing that the percentage dropped to 1.4 percent in the 2004 boating season to less than one percent in subsequent years.	• Community input and approval • Seasonal marker buoys • Brochures and outreach to popular boating and tourism publications and visitor guide • Videos shown in educational venues, at a yacht club, and in an environmental film festival. • Information booths during festivals • Seagrass protection pledges • Monitoring of boater compliance **For more information:** http://depts.washington.edu/uwconf/2005psgb/2005proceedings/papers/B9_PEARS.pdf http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.173.4721&rep=rep1&type=pdf http://www.nwstraits.org/media/2275/jef-2016-noanchorzone.pdf

Fort DeSoto Park/ Tampa Bay, FL	Propeller Scarring in Seagrass and Manatee Strikes	In 1990 in Pinellas County, meetings were held by a coalition of government and citizen representatives, including those representing commercial and fishing interests, to agree on plans to protect seagrass. In 1992, because of their efforts, an ordinance was passed that separated the management area into different zones. Exclusion/restriction zones prohibited the use of internal combustion engines and caution zones allowed motor use, but boaters incurred penalties for seagrass damage. Other areas required boats to travel at slow speed or had no restrictions. Because of these management efforts, significant reductions in scarring were seen from aerial images in both exclusion and caution zones. Components essential to the success include documenting the problem, involving all users and addressing their concerns, avoiding assigning blame, providing feedback and adapting the management program to new findings.	• Boat restriction/exclusion zones (no motor/poll or troll) • Seagrass caution zones • Slow / minimum wake zones • Signs at boat ramps and marinas showing regulatory areas. • Enforcement and monitoring • Public information campaign • Sign maintenance program • Monitoring of boater compliance **For more information:** https://www.researchgate.net/publication/225873454_Decadal_Changes_in_Seagrass_Distribution_and_Abundance_in_Florida_Bay (pp. 58-66) https://www.tbeptech.org/TBEP_TECH_PUBS/2018/2012-2017_TBEP_PE_FINAL.pdf (pp. 234-235)
Redfish Bay Scientific Study Area (RBSSA), TX	Propeller Scarring in Seagrass	In 2000, after research found extensive propeller scarring in seagrass at Redfish Bay (RB), a premier fishing destination, the Texas Parks and Wildlife Commission designated the bay as a State Scientific Area (SSA) for education, research and conservation purposes. Initially, voluntary "propeller-up" zones, outlined with posts and signs, were created. However, during the five years they were implemented, the voluntary zones proved ineffective at reducing propeller scarring. As a result, in 2006, mandatory "no uprooting" rules were brought into effect for the whole RBSSA, which meant the bay was still accessible to boaters, but it became unlawful to uproot and excavate seagrass with submerged propellers; rules were enforced, and offenders were subject to fines. Anchoring and transiting with troll motors in seagrass was allowed. After four years of enforcement and active education and outreach, monitoring found significant reductions in propeller scarring.	• Mandatory "no uprooting" zone • Signs marking the boundary of the State Scientific Area and striped PVC posts to mark access lanes • Maps showing cut points that can be used to access the area safely • Boat ramp signs describing the regulatory area and rules • Signs at marinas and boat launches showing techniques to minimize seagrass damage (lift, drift, poll, and troll) • Ads in Fishing Magazine and billboards, in donated ad spaces • Outreach events • Monitoring and enforcement **For more information:** https://tpwd.texas.gov/publications/pwdpubs/media/pwd_br_v3400_1101.pdf https://tpwd.texas.gov/landwater/water/habitats/seagrass/redfish-bay

REFERENCES

Behringer, D. C., & Swett, R. A. (2010). *Determining vessel use patterns in the southeast Florida region*. Miami Beach, FL. Pp 88. Retrieved September 10, 2018, from https://floridadep.gov/sites/default/files/FDOU_33A_0.pdf

Bradley, M., & Paton, S. (2018). *Tier 1 2017 mapping of Zostera marina in Long Island Sound and change analysis*. Hadley, MA: U.S. Fish and Wildlife Service. Retrieved September 10, 2018, from http://longislandsoundstudy.net/wp-content/uploads/2018/08/LIS_2017_report2_wAppendix_REVISED-FINAL.pdf

Collier, C. (2016). *Comanagement of U.S. marine protected areas: current efforts and their potential implications for seagrass management at Fishers Island, New York* (Master's project). Duke University. Retrieved September 10, 2018, from http://hdl.handle.net/10161/11884

Collins, K. J., Suonpää, A. M., & Mallinson, J. J. (2010). The impacts of anchoring and mooring in seagrass, Studland Bay, Dorset, UK. *Underwater Technology*, *29*(3), 117–123.

Crawford, R. E. (2002). Secondary wake turbidity from small boat operation in a shallow sandy bay. Journal of Coastal Research, 50–65.

Cullen-Unsworth, L. C., Nordlund, L. M., Paddock, J., Baker, S., McKenzie, L. J., & Unsworth, R. K. (2014). Seagrass meadows globally as a coupled social–ecological system: Implications for human wellbeing. *Marine Pollution Bulletin*, *83*(2), 387–397.

Duarte, C. M., Middelburg, J. J., & Caraco, N. (2004). Major role of marine vegetation on the oceanic carbon cycle. *Biogeosciences Discussions*, *1*(1), 659–679.

Florida Keys National Marine Sanctuary. (2015). Team OCEAN. Retrieved January 1, 2019, from https://floridakeys.noaa.gov/volunteer_opportunities/teamocean.html

Fonseca, M. S., & Cahalan, J. A. (1992). A preliminary evaluation of wave attenuation by four species of seagrass. *Estuarine, Coastal and Shelf Science*, *35*(6), 565–576.

Fonseca, M. S., & Fisher, J. S. (1986). A comparison of canopy friction and sediment movement between four species of seagrass with reference to their ecology and restoration. *Marine Ecology Progress Series*, *29*(1).

Greve, T. M., & Binzer, T. (2004). Which factors regulate seagrass growth and distribution? (Chapter 4). *European Seagrasses: An Introduction To Monitoring and Management*, 19–23.

Jefferson County Marine Resources Committee. (2010). *Voluntary No Anchor Eelgrass Protection Zone* (Progress Report). Retrieved January 2, 2019, from http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.173.4721&rep=rep1&type=pdf

Lamb, J. B., Van De Water, J. A., Bourne, D. G., Altier, C., Hein, M. Y., Fiorenza, E. A., … Harvell, C. D. (2017). Seagrass ecosystems reduce exposure to bacterial pathogens of humans, fishes, and invertebrates. *Science*, *355*(6326), 731–733.

Mackinson, S., & Nottestad, L. (1998). Points of View: Combining Local and Scientific Knowledge. *Reviews in Fish Biology and Fisheries*, *8*(4), 481–490. Retrieved January 20, 2019, from https://doi.org/10.1023/A:1008847106984

Mcleod, E., Chmura, G. L., Bouillon, S., Salm, R., Björk, M., Duarte, C. M., … Silliman, B. R. (2011). A blueprint for blue carbon: toward an improved understanding of the role of vegetated coastal habitats in sequestering CO2. *Frontiers in Ecology and the Environment*, *9*(10), 552–560.

Neckles, H. A., Kopp, B. S., Peterson, B. J., & Pooler, P. S. (2012). Integrating scales of seagrass monitoring to meet conservation needs. *Estuaries and Coasts*, *35*(1), 23–46.

New York Legislature. (2012). New York Seagrass Protection Act. NY ECL Article 13, §§ 13-0701 – 13-0705. Retrieved February 20, 2019, from: http://nyw.law.streaver.net/ENV/html

New York State Seagrass Task Force. (2009). *Final report of the New York State Seagrass Task Force: recommendations to the New York State governor and legislature*. State of New York. Retrieved September 10, 2018, from https://www.dec.ny.gov/docs/fish_marine_pdf/finalseagrassreport.pdf

NOAA. (2018). Tides and Currents. Retrieved January 10, 2019, from https://tidesandcurrents.noaa.gov/tide_predictions.html

Pearson, P., & D'Amore, J. (2005). Community Involvement in Eelgrass Protection, Port Townsend, Washington. In *Proceedings of the 2005 Puget Sound Georgia Basin Research Conference*. Retrieved January 10, 2019, from http://depts.washington.edu/uwconf/2005psgb/2005proceedings/papers/B9_PEARS.pdf

Reid, W. V., Berkes, F., Wilbanks, T. J., Capistrano, D., & eds. (2006). *Bridging scales and knowledge systems: concepts and applications in ecosystem assessment*. Island Press, Washington, D.C., USA. Retrieved January 10, 2019 from https://www.cifor.org/library/2179/

Sargent, F. J., Leary, T. J., Crewz, D. W., & Kruer, C. R. (1995). Scarring of Florida's seagrasses: assessment and management options.

Short, F., McKenzie, L. J., Coles, R. G., Vidler, K. P., & Gaeckle, J. L. (2006). *SeagrassNet Manual for Scientific Monitoring of Seagrass Habitat, Worldwide edition* (University of New Hampshire Publication) (p. Pp 75).

Smith, D. S., & Hellmund, P. C. (1993). *Ecology of greenways: design and function of linear conservation areas*. University of Minnesota Press. Retrieved January 10, 2019, from https://www.fs.fed.us/rm/pubs_other/rmrs_1993_cole_d001.pdf

Smith, K. (2017). *Aerial survey of vessel activity in seagrass (Zostera marina) near Fishers Island, NY – data collection methods trial*. Yale School of Forestry and Environmental Studies.

Stowers, J. F., Fehrmann, E., & Squires, A. (2000). Seagrass Scarring in Tampa Bay: Impact Analysis and Management Options (pp. 47–54). Presented at the Seagrass Management: It's not Just Nutrients!, St. Petersburg, Florida. Retrieved January 10, 2019, from https://www.researchgate.net/publication/225873454_Decadal_Changes_in_Seagrass_Distribution_and_Abundance_in_Florida_Bay

Texas Parks & Wildlife Department. (2006). Redfish Bay State Scientific Area. Retrieved January 10, 2019, from https://tpwd.texas.gov/publications/pwdpubs/media/pwd_br_v3400_1101.pdf

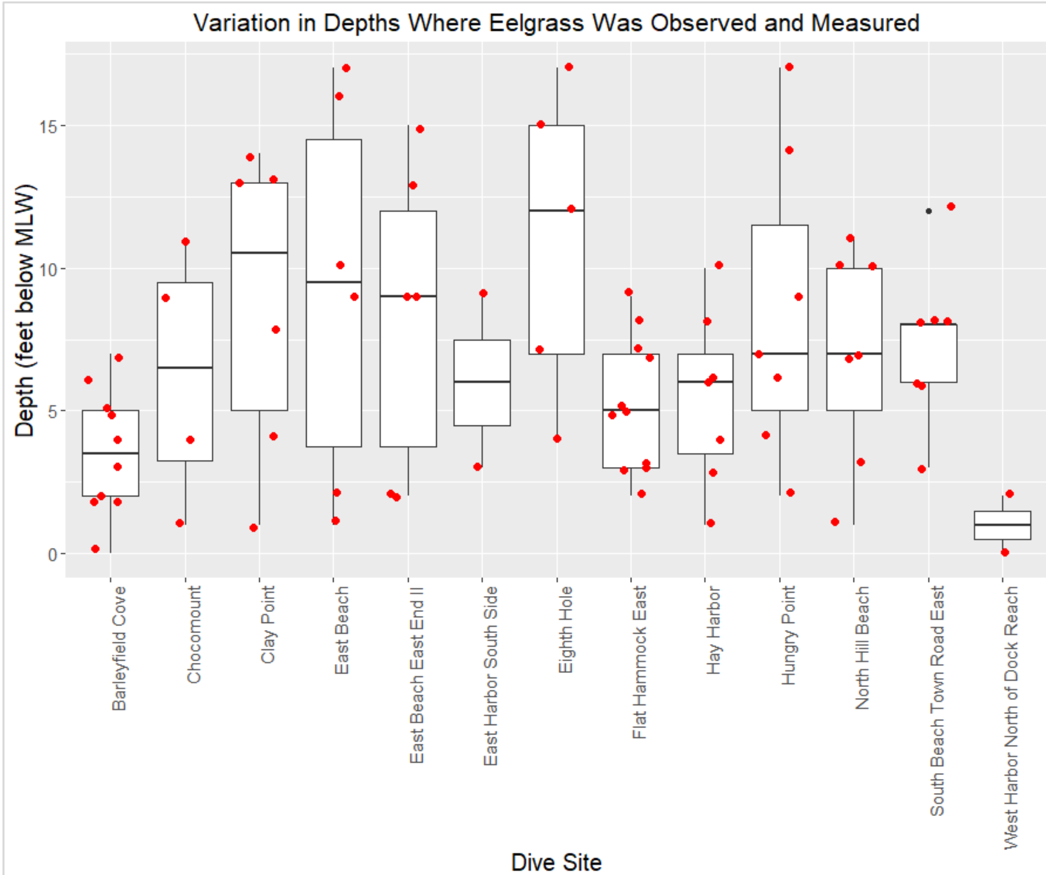
Texas Parks & Wildlife Department. (n.d.). Seagrass Protection. Retrieved January 28, 2019, from https://tpwd.texas.gov/landwater/water/habitats/seagrass/redfish-bay

U.S. Census Bureau. (2011). *2010 demographic profile*. Retrieved October 10, 2018, from https://factfinder.census.gov/faces/nav/jsf/pages/community_facts.xhtml?src=bkmk

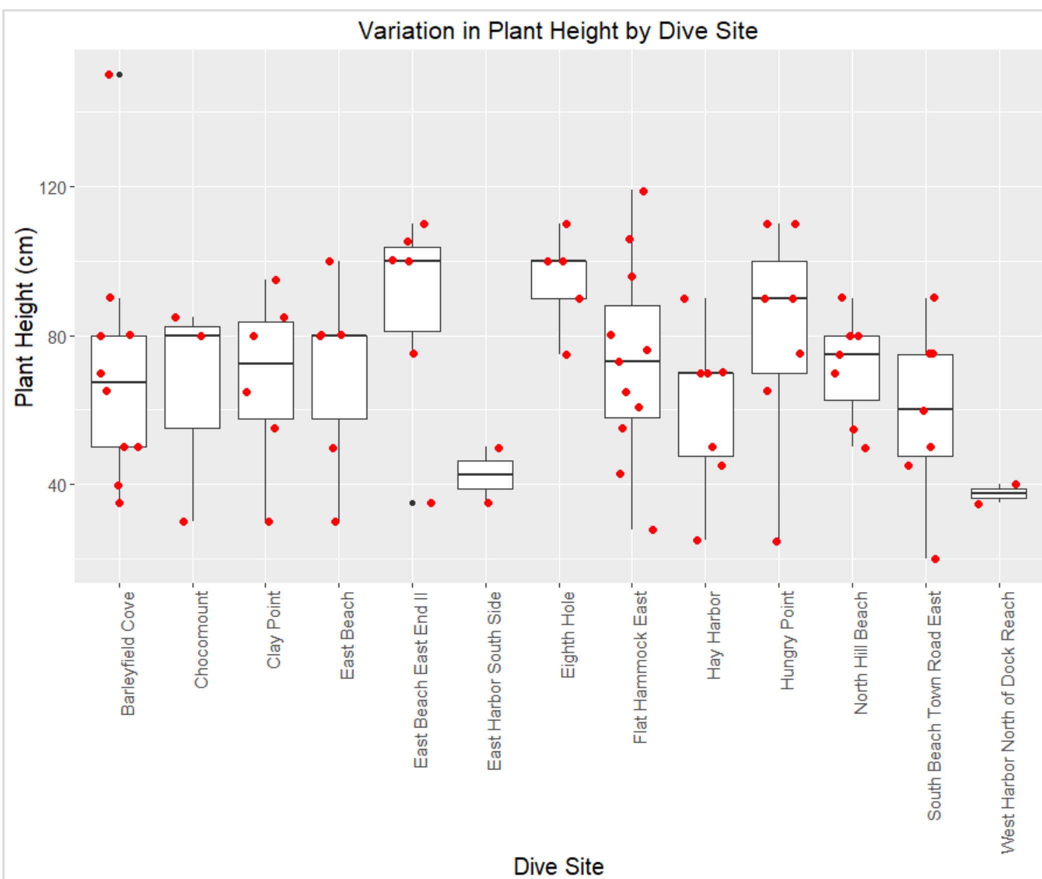
Walker, D. I., Lukatelich, R. J., Bastyan, G., & McComb, A. J. (1989). Effect of boat moorings on seagrass beds near Perth, Western Australia. *Aquatic Botany*, *36*(1), 69–77.

Waycott, M., Duarte, C. M., Carruthers, T. J., Orth, R. J., Dennison, W. C., Olyarnik, S., … Hughes, A. R. (2009). Accelerating loss of seagrasses across the globe threatens coastal ecosystems. *Proceedings of the National Academy of Sciences*, *106*(30), 12377–12381.

Appendix A: Variation in Depth and Plant Height by Dive Site



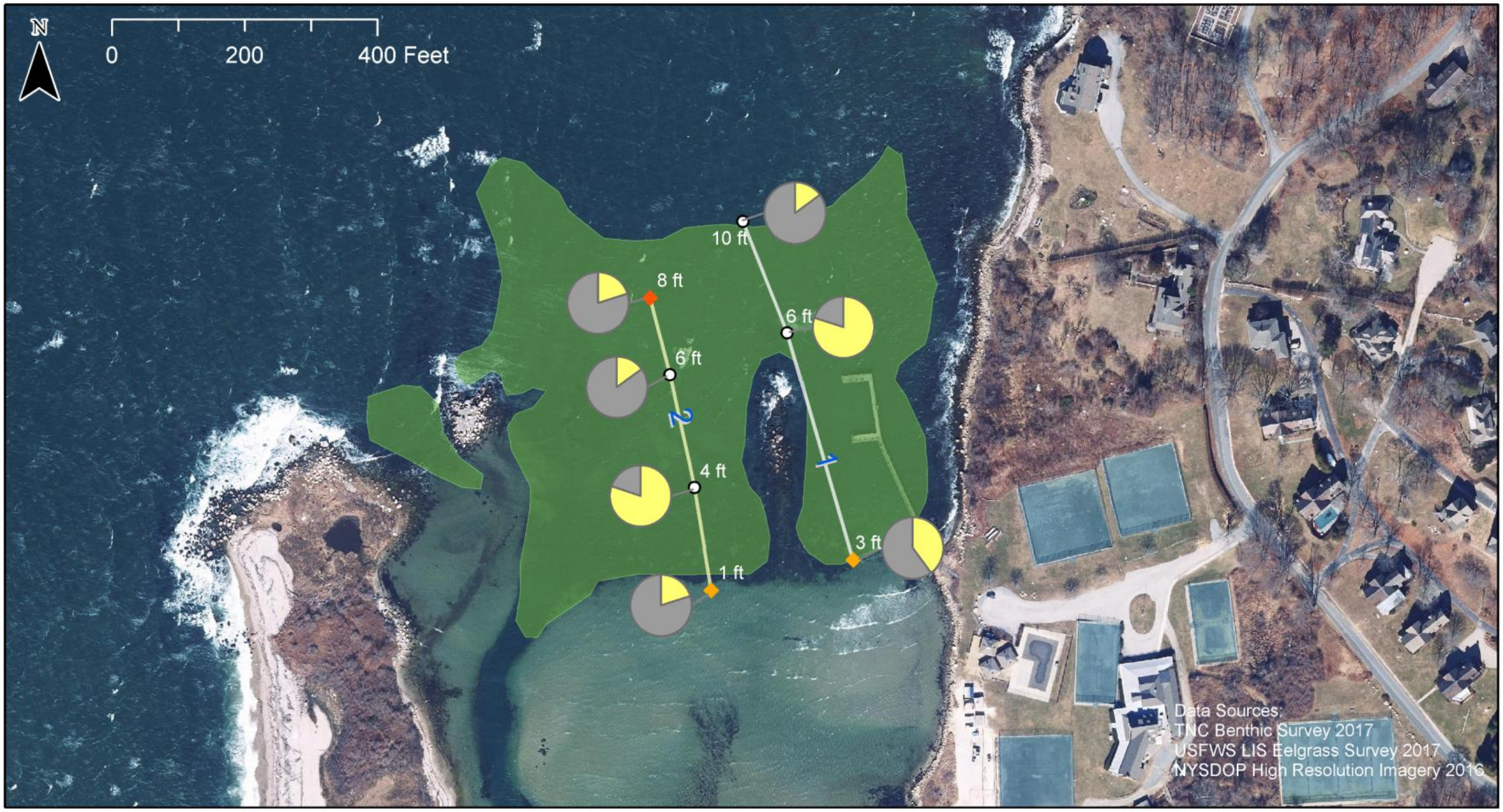
Variation in Depths Where Eelgrass Was Observed and Measured
Depth (feet below MLW)
0
5
10
15
Barleyfield Cove
Chocomount
Clay Point
East Beach
East Beach East End II
East Harbor South Side
Eighth Hole
Flat Hammock East
Hay Harbor
Hungry Point
North Hill Beach
South Beach Town Road East
West Harbor North of Dock Reach
Dive Site

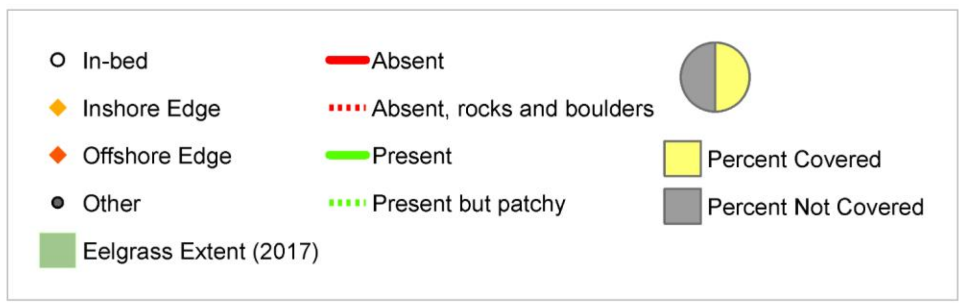


Variation in Plant Height by Dive Site
Plant Height (cm)
40
80
120
Barleyfield Cove
Chocomount
Clay Point
East Beach
East Beach East End II
East Harbor South Side
Eighth Hole
Flat Hammock East
Hay Harbor
Hungry Point
North Hill Beach
South Beach Town Road East
West Harbor North of Dock Reach
Dive Site

Appendix B: Additional Dive Transect Survey Maps

Hay Harbor

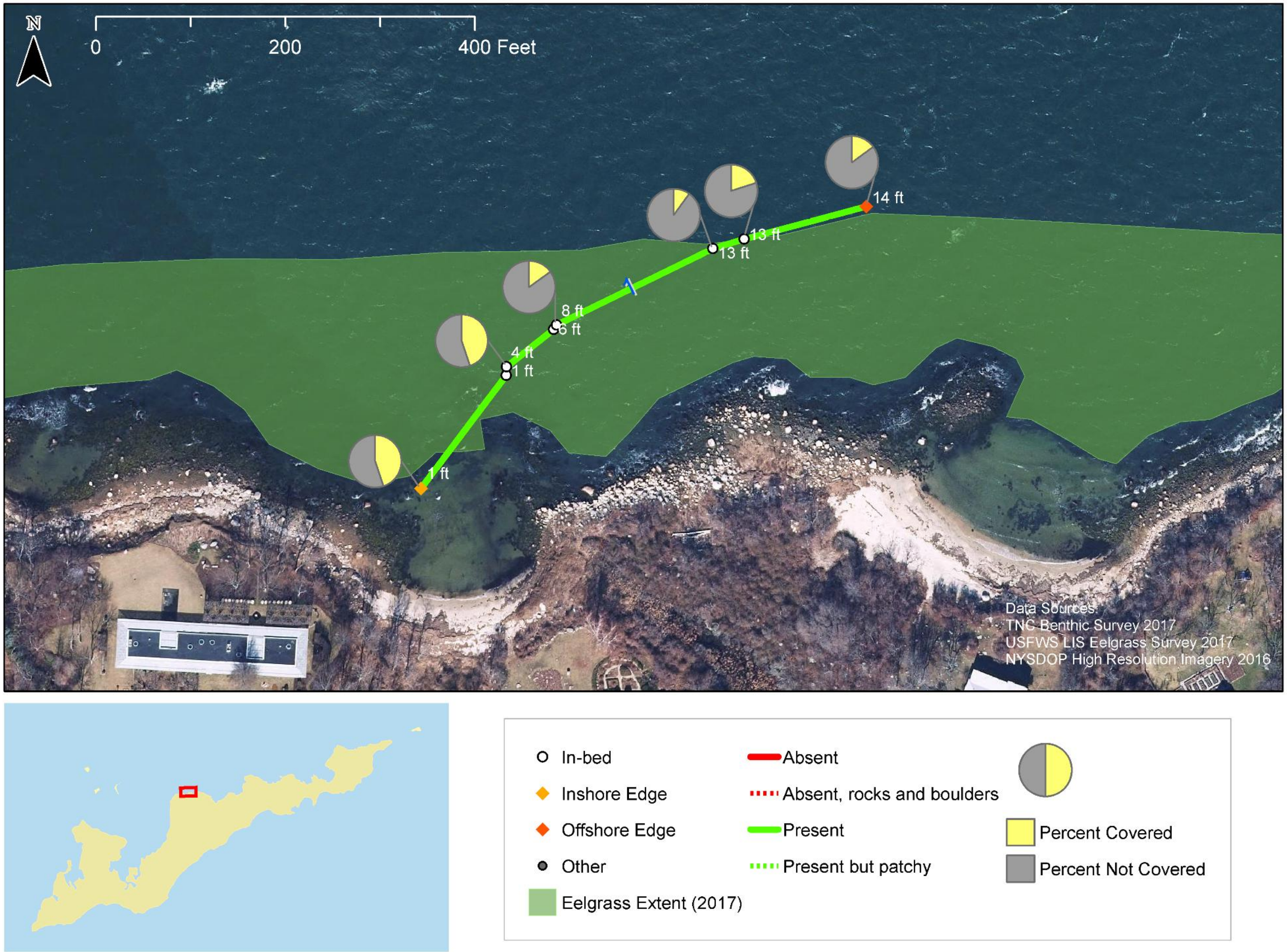




*Depth in feet below MLW

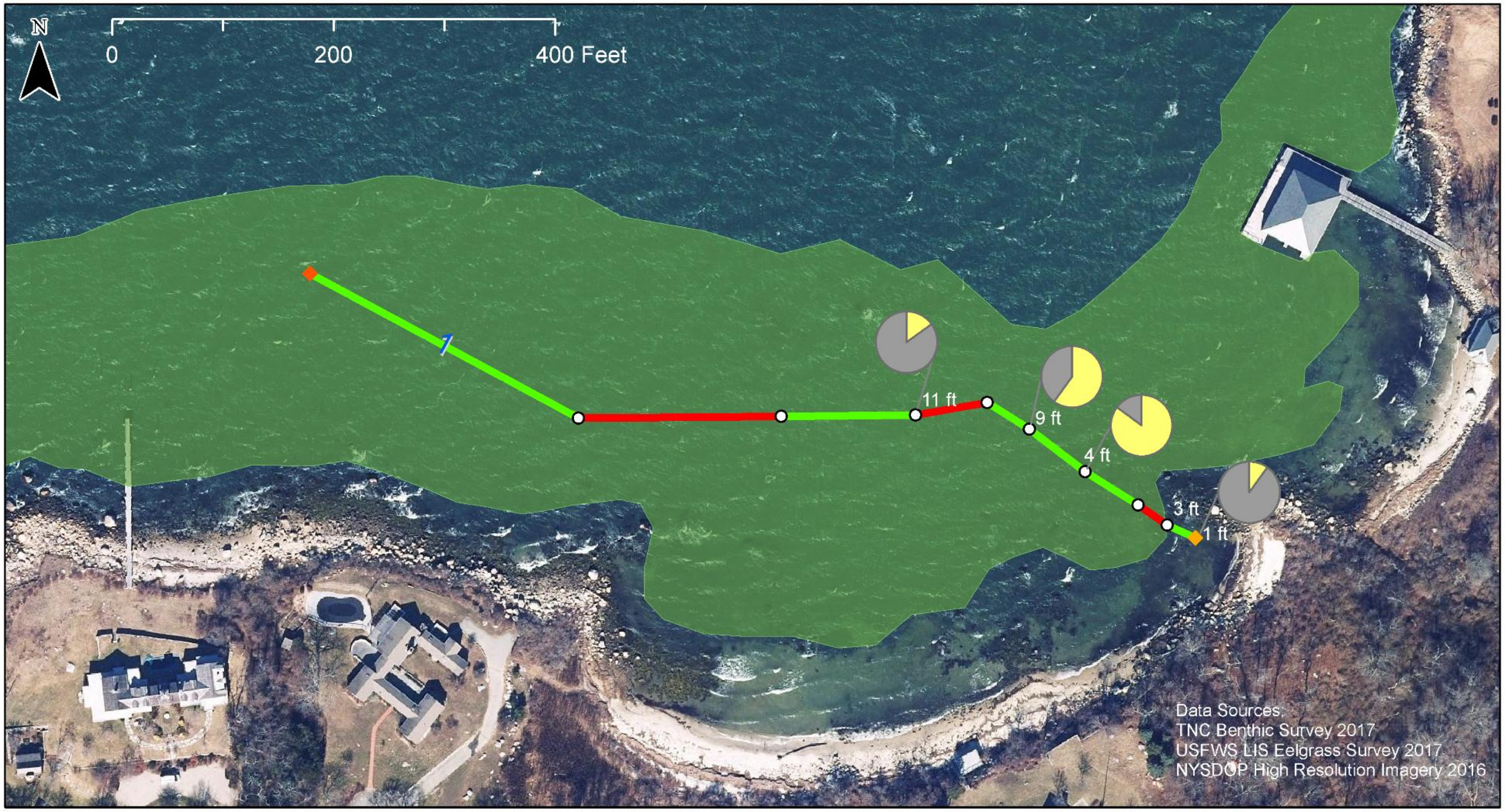

West Harbor North of Dock Reach
N
0 ft
1
2 ft
0
200
400 Feet
Data Sources:
TNC Benthic Survey 2017
USFWS LIS Eelgrass Survey 2017
NYSDOP High Resolution Imagery 2016
In-bed
Inshore Edge
Offshore Edge
Other
Eelgrass Extent (2017)
Absent
Absent, rocks and boulders
Present
Present but patchy
Percent Covered
Percent Not Covered
*Depth in feet below MLW

Clay Point



*Depth in feet below MLW

Chocomount



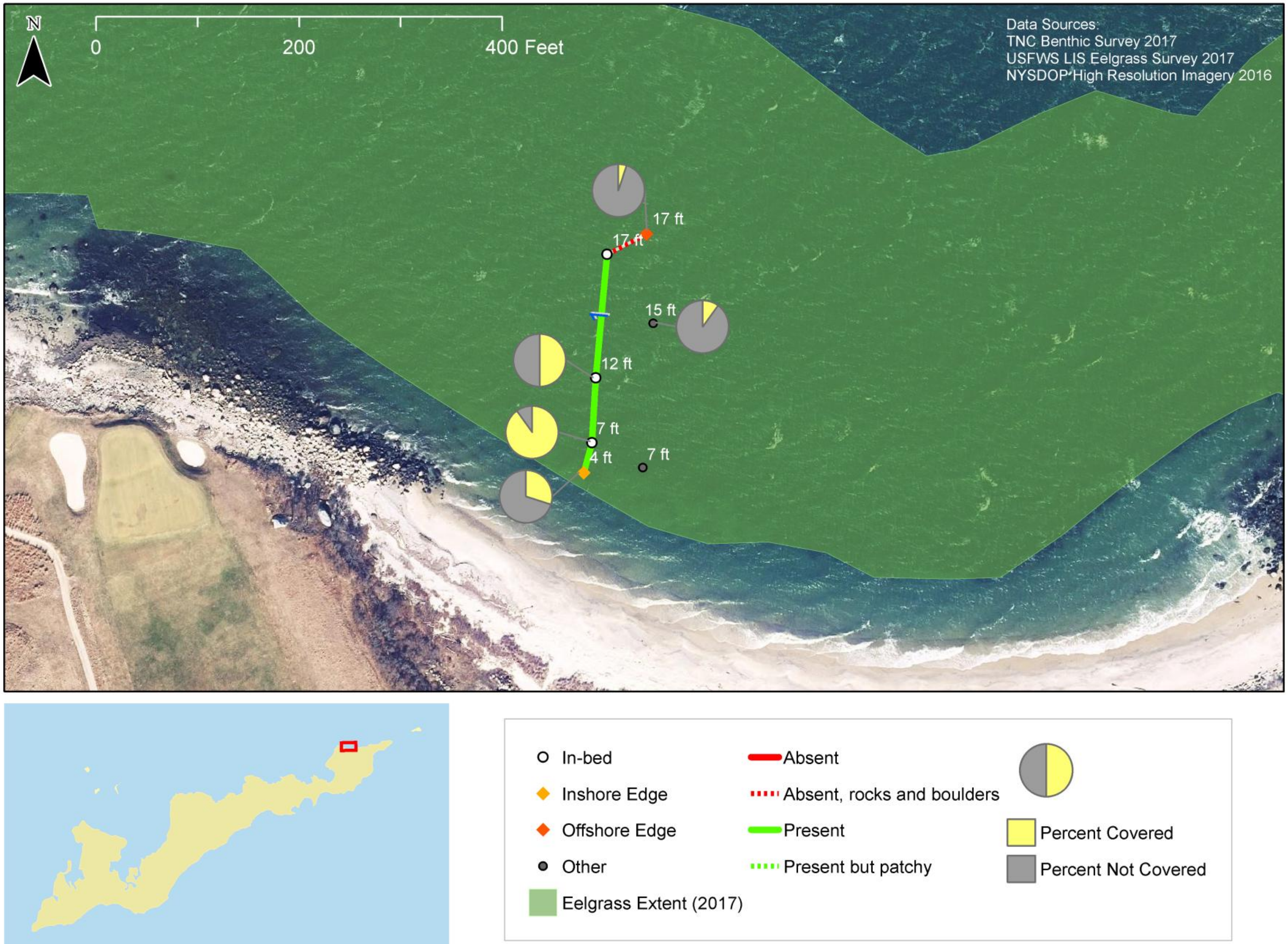
In-bed
Inshore Edge
Offshore Edge
Other
Eelgrass Extent (2017)
Absent
Absent, rocks and boulders
Present
Present but patchy
Percent Covered
Percent Not Covered

*Depth in feet below MLW

East Harbor South Side

*Depth in feet below MLW

Eighth Hole

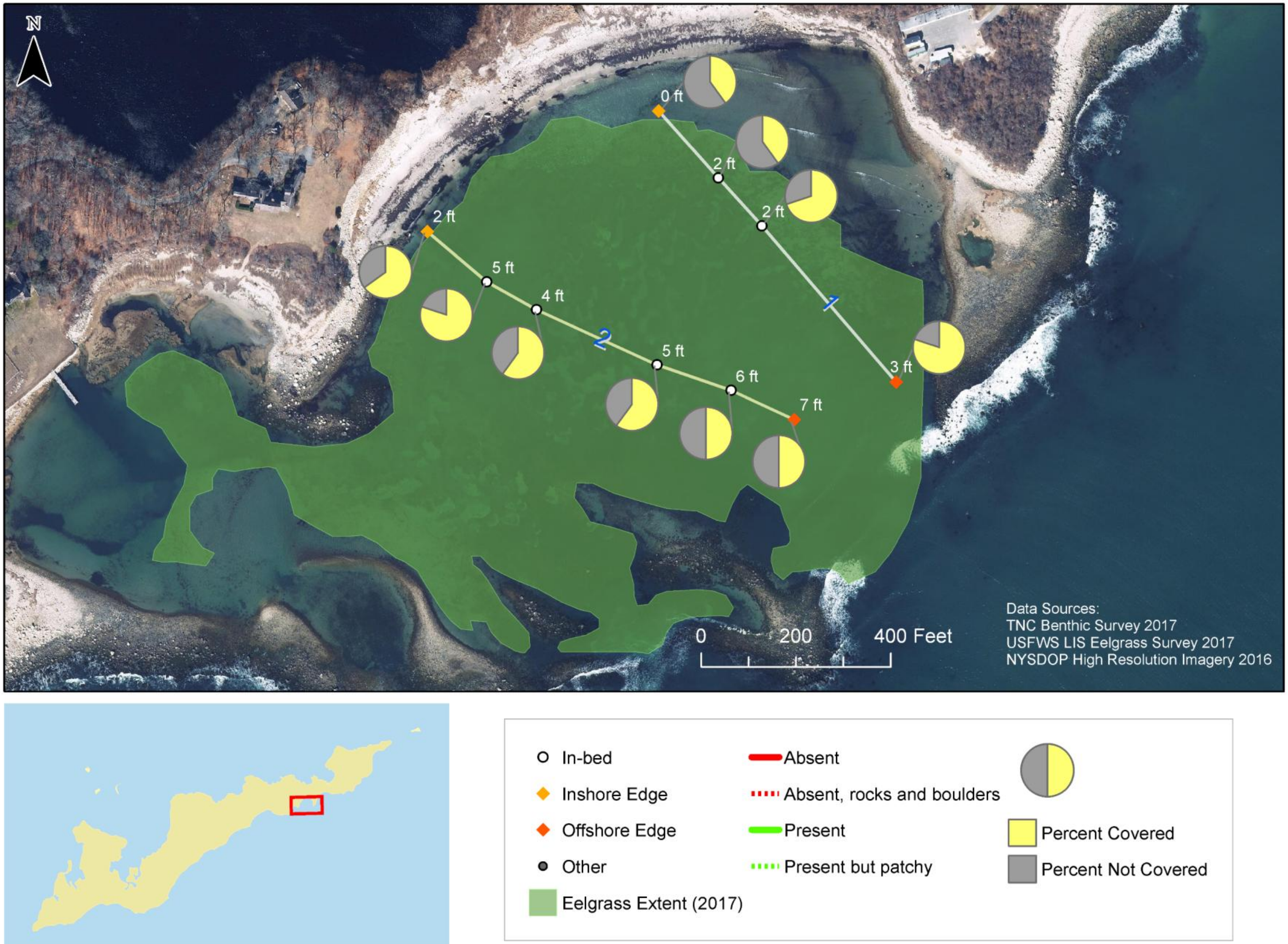


*Depth in feet below MLW

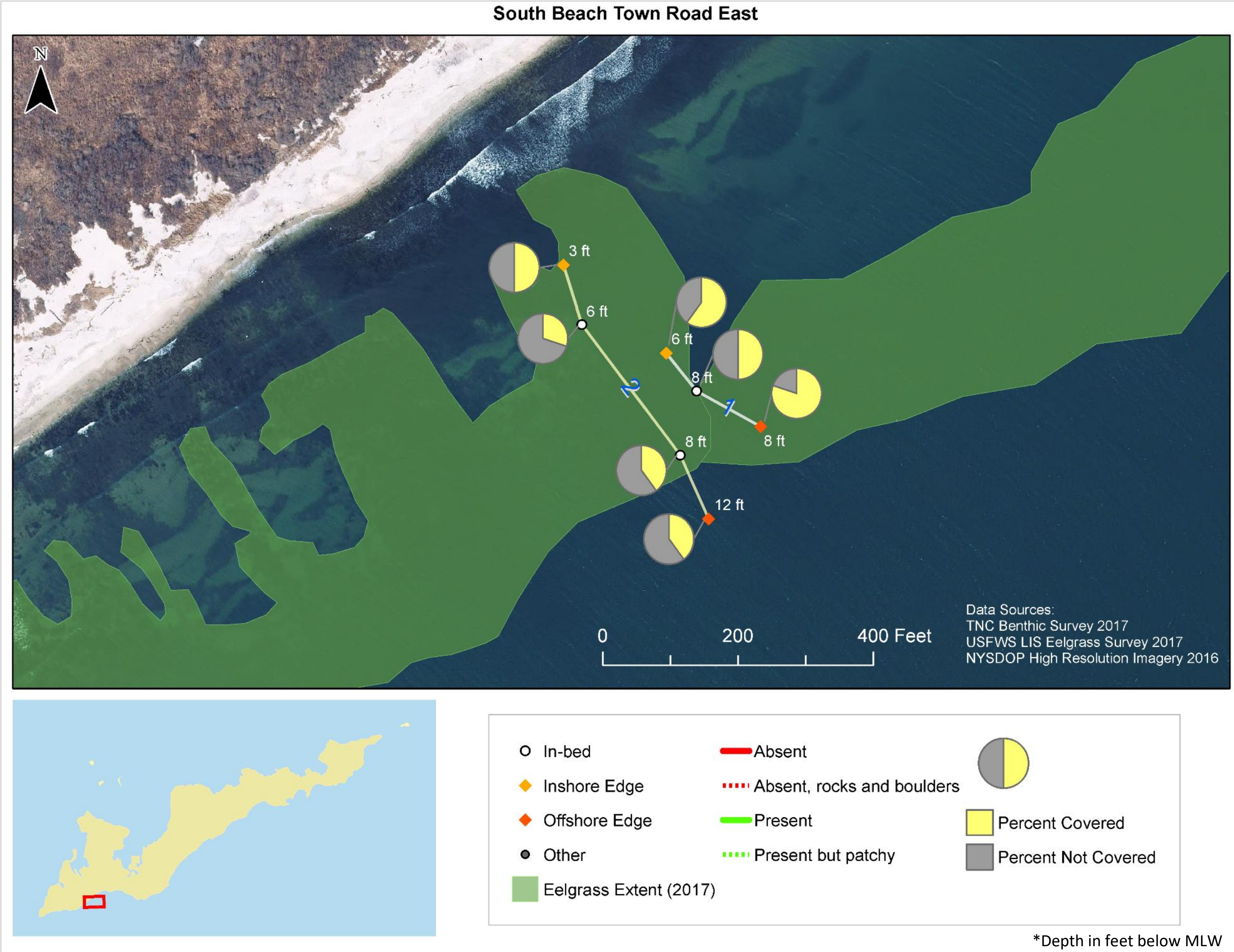
East Beach

*Depth in feet below MLW

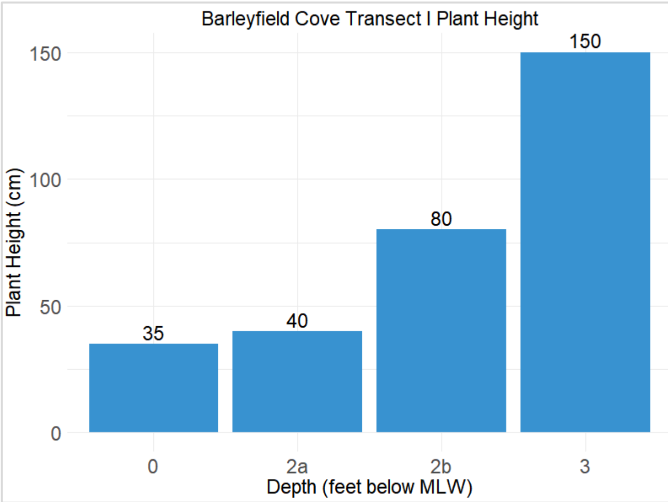
Barleyfield Cove

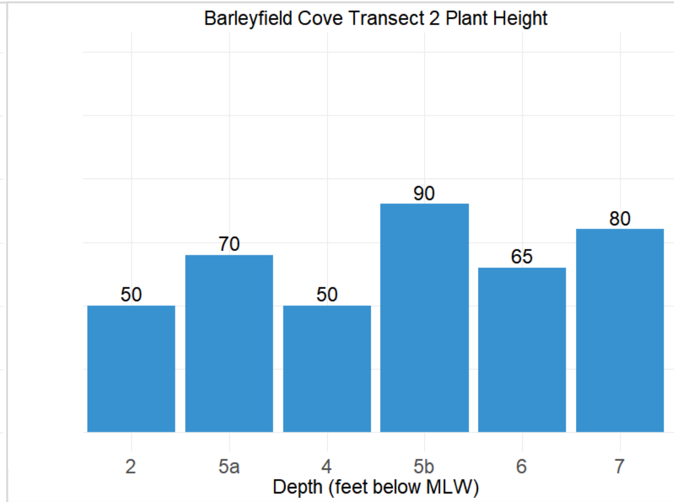


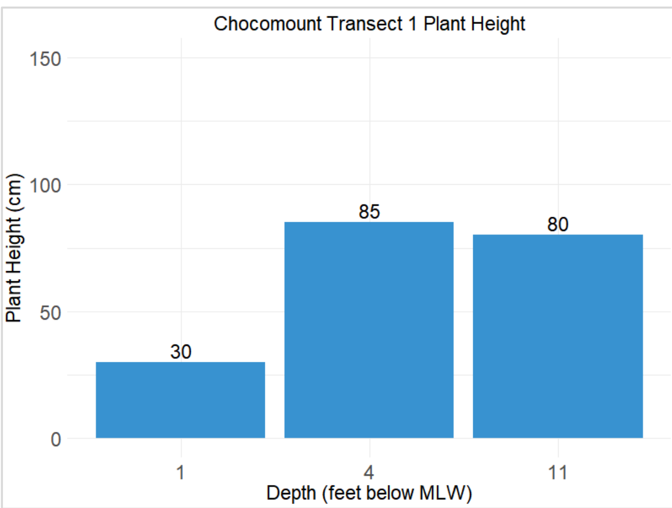
*Depth in feet below MLW

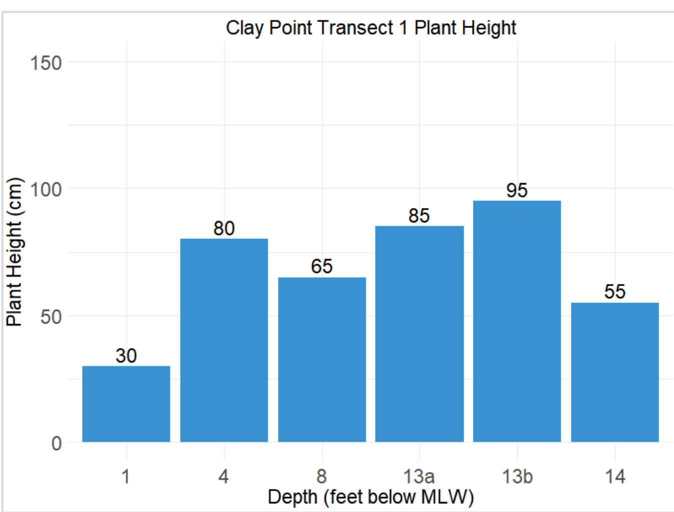

South Beach Town Road East
N
3 ft
6 ft
6 ft
8 ft
2
1
8 ft
8 ft
12 ft
0
200
400 Feet
Data Sources:
TNC Benthic Survey 2017
USFWS LIS Eelgrass Survey 2017
NYSDOP High Resolution Imagery 2016
In-bed
Inshore Edge
Offshore Edge
Other
Eelgrass Extent (2017)
Absent
Absent, rocks and boulders
Present
Present but patchy
Percent Covered
Percent Not Covered
*Depth in feet below MLW

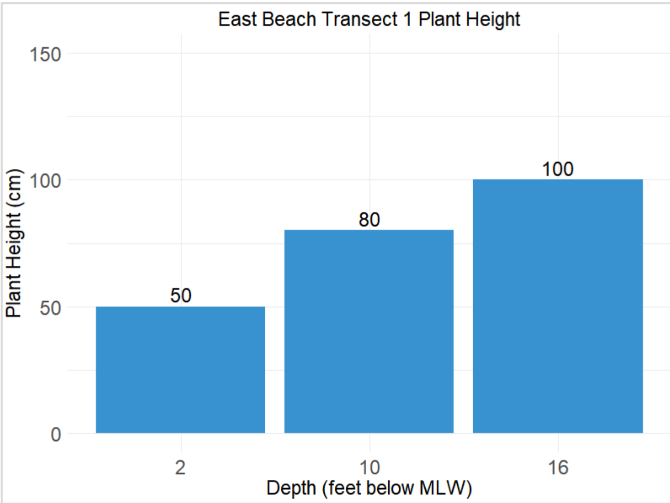
Appendix C: Changes in Plant Height with Depth by Transect

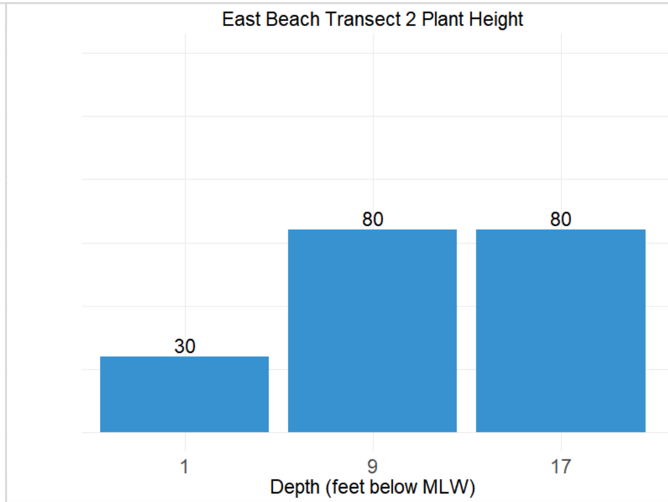


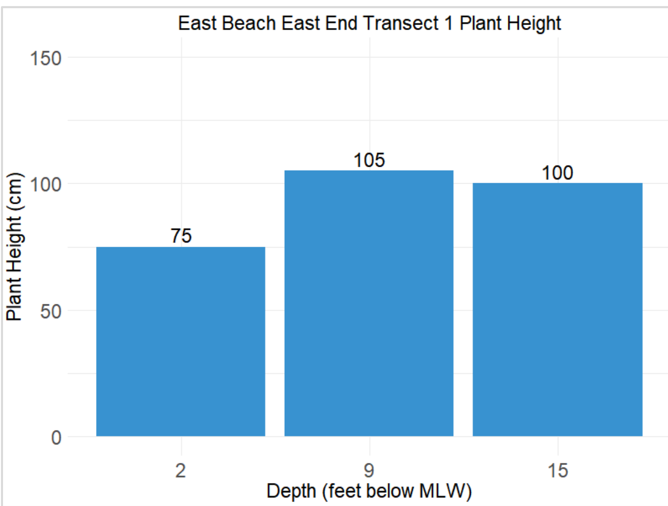


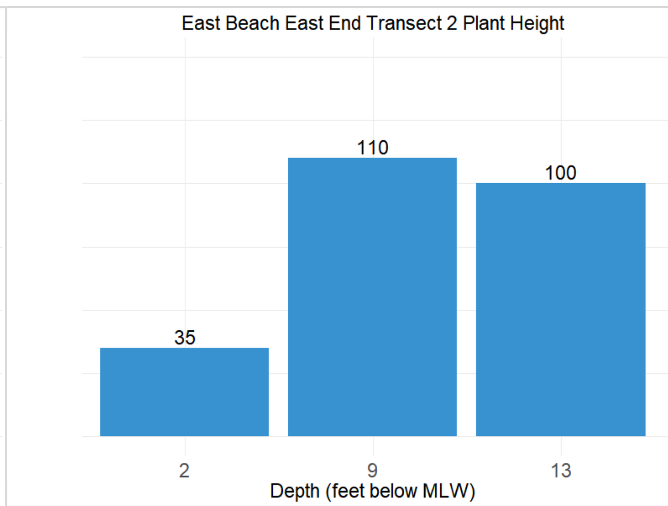


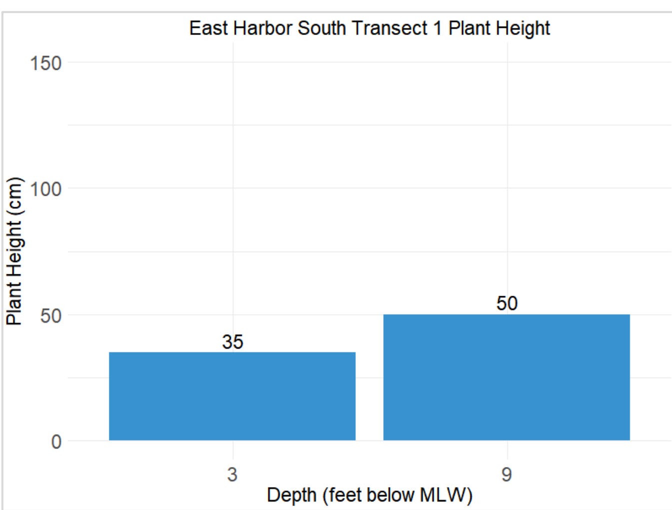


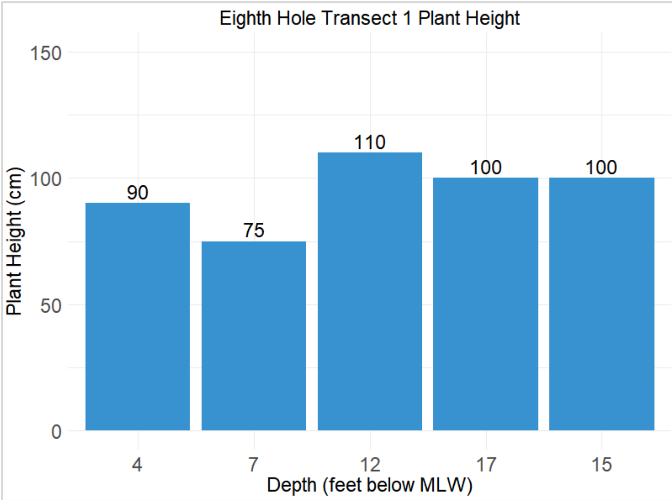

East Beach Transect 1 Plant Height
Plant Height (cm)
150
100
50
0
50
80
100
2
10
16
Depth (feet below MLW)

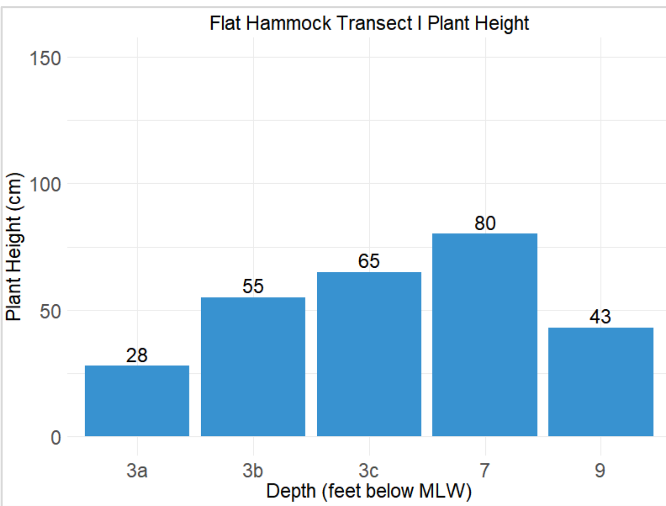

East Beach Transect 2 Plant Height
30
80
80
1
9
17
Depth (feet below MLW)

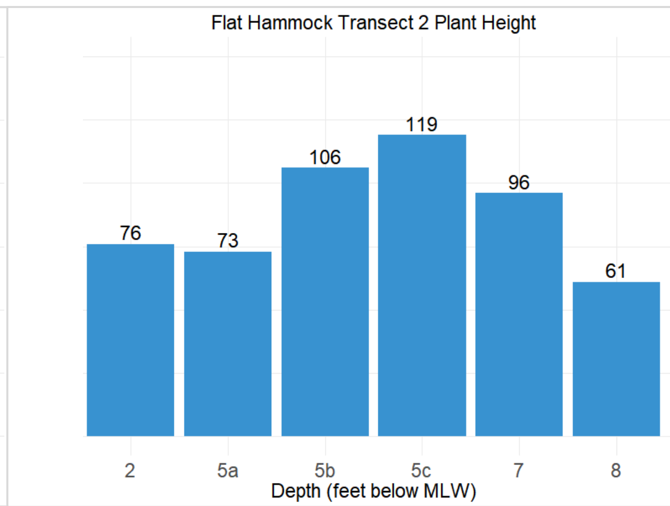

East Beach East End Transect 1 Plant Height
Plant Height (cm)
150
100
50
0
75
105
100
2
9
15
Depth (feet below MLW)

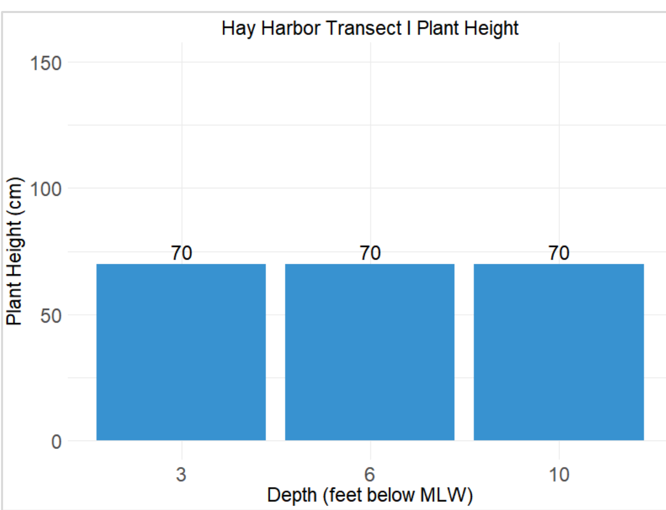

East Beach East End Transect 2 Plant Height
35
110
100
2
9
13
Depth (feet below MLW)

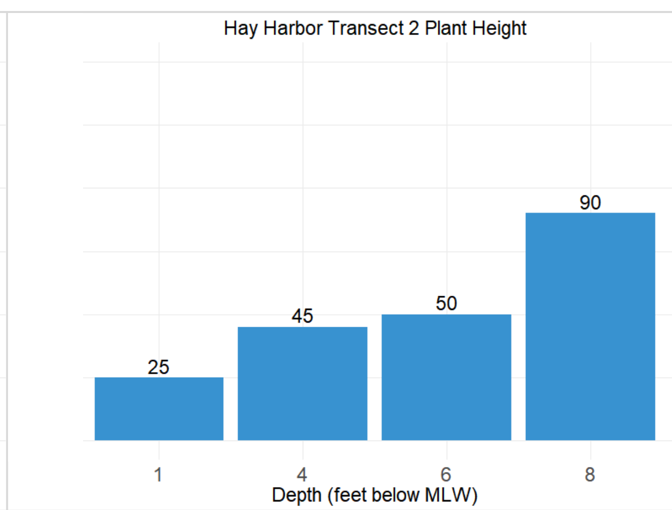

East Harbor South Transect 1 Plant Height
Plant Height (cm)
150
100
50
0
35
50
3
9
Depth (feet below MLW)

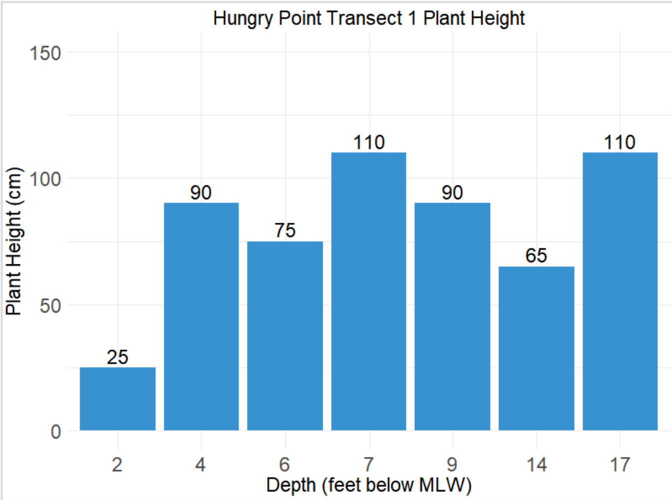

Eighth Hole Transect 1 Plant Height
Plant Height (cm)
150
100
50
0
90
75
110
100
100
4
7
12
17
15
Depth (feet below MLW)

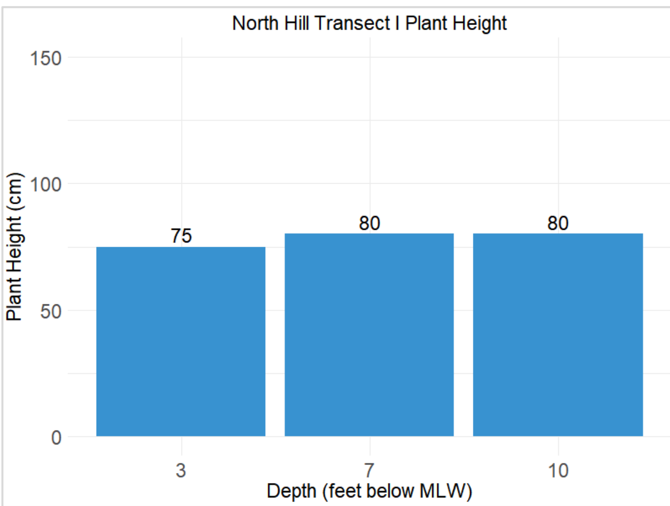

Flat Hammock Transect I Plant Height
Plant Height (cm)
150
100
50
0
28
55
65
80
43
3a
3b
3c
7
9
Depth (feet below MLW)

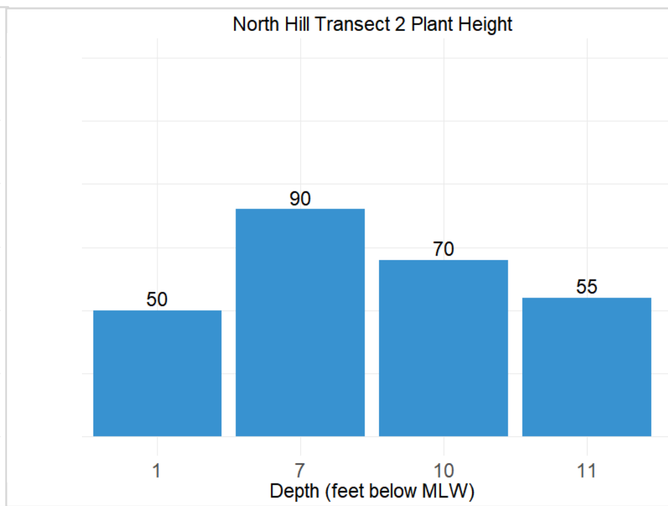

Flat Hammock Transect 2 Plant Height
76
73
106
119
96
61
2
5a
5b
5c
7
8
Depth (feet below MLW)

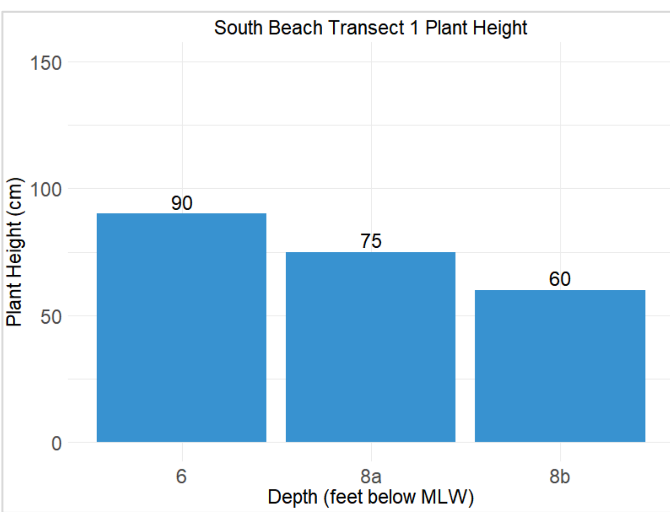

Hay Harbor Transect I Plant Height
Plant Height (cm)
150
100
50
0
70
70
70
3
6
10
Depth (feet below MLW)

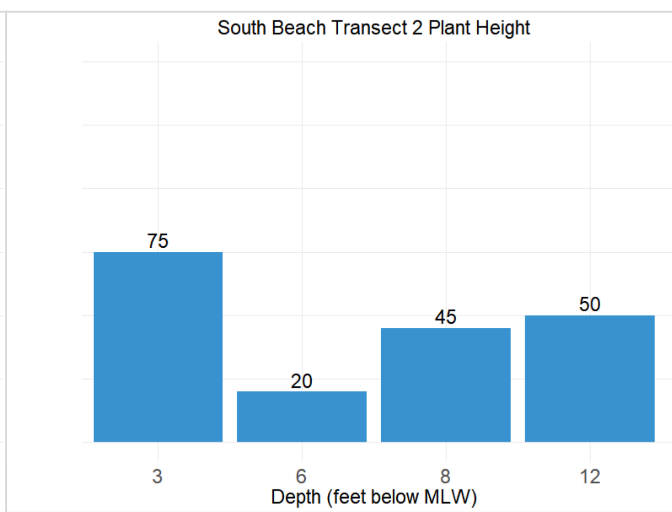

Hay Harbor Transect 2 Plant Height
25
45
50
90
1
4
6
8
Depth (feet below MLW)

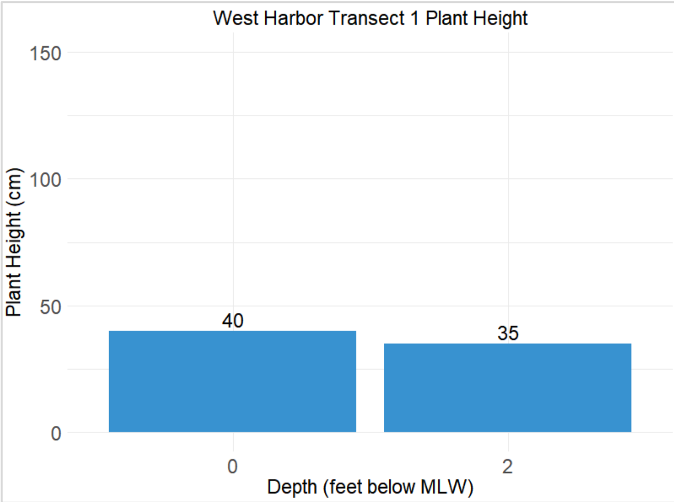

Hungry Point Transect 1 Plant Height
Plant Height (cm)
150
100
50
0
25
90
75
110
90
65
110
2
4
6
7
9
14
17
Depth (feet below MLW)


North Hill Transect I Plant Height
Plant Height (cm)
150
100
50
0
75
80
80
3
7
10
Depth (feet below MLW)


North Hill Transect 2 Plant Height
50
90
70
55
1
7
10
11
Depth (feet below MLW)


South Beach Transect 1 Plant Height
Plant Height (cm)
150
100
50
0
90
75
60
6
8a
8b
Depth (feet below MLW)


South Beach Transect 2 Plant Height
75
20
45
50
3
6
8
12
Depth (feet below MLW)


West Harbor Transect 1 Plant Height
150
100
50
0
Plant Height (cm)
40
35
0
2
Depth (feet below MLW)