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Nekton Usage of High Marsh Habitats in Connecticut Salt Marshes, with Emphasis on the Genus Fundulus

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NEKTON USAGE OF HIGH MARSH HABITATS IN CONNECTICUT SALT MARSHES, WITH EMPHASIS ON THE GENUS *FUNDULUS*

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NEKTON USAGE OF HIGH MARSH HABITATS IN CONNECTICUT SALT MARSHES, WITH EMPHASIS ON THE GENUS *FUNDULUS*

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ABSTRACT

Large scale habitat use patterns of salt marsh nekton are fairly well understood, but small-scale patterns within marsh habitats are not as well known, including the genus *Fundulus,* an important salt marsh species. This is an area of study that needs more research, particularly in light of increases in salt marshes loss within the last several decades. Salt marshes are a primary habitat for *Fundulus* species. Sea level rise and urbanization have been major contributors to salt marsh loss and alteration.

Salt marshes are highly variable habitats both spatially and temporally due to tidal cycles, high and low marsh areas and vegetation differences relative to their distances from sub-creeks/ mosquito ditches and main creeks. Changes in *Fundulus* abundance was assessed from 2015 to 2018 during summer and fall. In this study, nets and underwater cameras were used to collect samples of nekton in high, low and sub-tidal creek habitats within the salt marshes in Branford, Connecticut. Nekton abundances and specifically *Fundulus* abundance were assessed relative to season, depth of water, vegetation coverage, and spatial differences from sub-tidal creeks/ mosquito ditches and main creeks. *Fundulus* size was also compared to the above variables.

Nekton, and specifically *Fundulus* abundance, varied considerable both spatially and temporally. Nekton and *Fundulus* abundances were greatest in the fall across the marshes sampled. Nekton and *Fundulus* abundances were significantly higher in high marsh areas, which were 30 cm and greater in water depth during high tide, as well as a significantly lower in abundance at 9.9 cm and below. *Fundulus* were larger during the fall compared to summer. *Fundulus* 3.15 cm or less in length was more abundant on the high marsh further from sub-creeks (41 m). Smaller fish (below 3.15 cm) also were found greater abundances in areas of higher vegetation coverage.

Assessing how nekton is responding to salt marsh change due to sea level rise and other global change phenomena. Nekton, like *Fundulus*, are critical components of Atlantic Coast salt marshes and as such we need to understand their dynamics in the face of such changes in order to assess what conservation and mitigation approaches might be best to preserve their populations and ecosystem functions.

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CHAPTER I

INTRODUCTION

Salt marshes are critical coastal habitats throughout the world. They are areas of coastal grassland that are regularly flooded. Salt marshes create a constantly changing habitat for nekton, due to tidal cycles (Adamowicz and Roman 2005). Salt marshes are made up of many unique habitat types including areas of high and low marsh with different vegetation types, bare patches, pools and creeks. Areas of low marsh are located along the seaward edge of the salt marsh and usually flooded at every tide and exposed during low tide. High marsh areas fall between landward edges of the low marsh to the upland border, generally coinciding with the mean spring tide high water mark. Tidal inundation generally decreases and elevation increases from the seaward end of the high marsh to the upland transition, creating variety of potential sub-habitats.

Salt marshes are generally characterized by changing zonation of plants reflecting changing levels of tidal inundation. In Connecticut, S*partina alterniflora* typically occupies low marsh areas and areas of a high marsh are dominated by *Spartina patens, Distichlis spieata,* and *Juncus gerardii.* Over the past several decades, the vegetation of high marsh areas in Connecticut, and throughout southern New England, has changed from being dominated by *S. patens* to being dominated by short *S. alterniflora* (Warren and Neiring 1993). Bare patches with no vegetation can also be found on the high marsh. Pools that generally stay inundated permanently can be spread throughout salt marshes and on average are 10 cm deep in the Long Island Sound area (Zajac, unpublished data). Salt marshes have intertidal creeks that connect to permanently flooded waterways (main creeks); these areas are flooded during times of high tide and normally are clear of standing water during low tide (Allen et al. 2007). Salt marshes can also have subtidal creeks that connect to permanently flooded waterways (main creeks), but are always flooded (Able et al. 2006). Nekton are able to occupy these different habitats in salt marshes.

Salt marshes are extremely productive and support a variety of nekton (Rozas and Minello 1997), for reproduction, feeding, growth and predator refuge (Rountree and Able 2007). Salt marshes are made up of a mosaic of many different habitats with varying levels of connectivity, which makes the study of nekton communities and their population dynamics challenging. Even though there have been numerous studies of salt marsh nekton (e.g. Hettler 1989; Raposa et al. 2003), it is still largely unknown how nekton may be responding to current changes in salt marsh ecology due to sea level rise and other impacts.

This thesis focuses on assessing patterns of nekton use of salt marsh habitats in Connecticut salt marshes that are changing in their overall character, and in particular species of the common salt marsh fish genus *Fundulus.* Below, I present an overview of the biology and ecology of *Fundulus*, followed by an overview of how salt marshes are changing and the potential impacts on nekton use of these habitats.

Fundulus Biology and Ecology

The genus *Fundulus* has forty different types of species within the genus (Myers et al. 2019). The three species that are found within Connecticut are F. *heteroclitus*, F. *luciae*, and F. *majalis.* The most abundant species in Connecticut is F. *heteroclitus.* F. *heteroclitus* geological range is along the Atlantic Coast, from the Gulf of St. Lawrence to Northeast Florida (U.S Fish & Wildlife Service 2017).

Fundulus can grow up to 15 cm in length, with an average adult length of 8.9 cm (U.S Fish & Wildlife Service 2017). There is a broad range of sizes for each *Fundulus* species: F.

heteroclitus is 1cm to 8 cm, F. *luciae* 0.9cm to 3.7cm, and F. *majalis* 4.9 to 7.6cm, based on studies throughout the New York and New Jersey coast (Yozzo and Ottman 2003).

Fundulus live three to four years. Spawning occurs in estuaries and salt marshes from April to August. They lay eggs on mollusk shells or dead vegetation while tides are highest during new and full moons. Eggs are exposed to air when tides recede, and will not hatch until covered with water during the next month's highest tide (Chesapeake Bay Program 2016; U.S Fish & Wildlife Service 2017). *Fundulus* abundance in tidal marshes is lowest during the winter but can still be present even at freezing temperatures, and highest in the summer. High abundances in the summer correlate with the time that reproduction occurs, which indicates salt marshes are an area for reproduction (Halpin 1997; Raposa & Roman 2001).

Fundulus abundance can change significantly among seasons in different sub-habitats. Annually, the average *F. heteroclitus* abundance is significantly higher in sub-creeks versus main creeks that connect to coastal waters and mudflat habitats. However, abundances in mudflats are equal or exceed creeks in warm-water months (Halpin 1997).

Fritz & Garside (1974) and Halpin (1997) showed abiotic factors that can affect *Fundulus* abundance. Salinity preference for *F. heteroclitus* is between 8‰ - 20‰, with a higher preference for 20‰ (Fritz & Garside 1974). Abundances are highest when water temperatures average 28.5°C ± 1.11°C (Halpin 1997).

Fundulus use salt marshes at different times of a tidal cycle, depending on size and species. Adult *F. heteroclitus* (> 3 cm in length) will only use salt marshes when flooded, while young (≤ 3 cm in length) will use salt marshes at all times of a tidal cycle (U.S Fish & Wildlife Service, 2017; Kneib and Wanger 1994). Both age classes of *F. heteroclitus* are more abundant during slack high tide in vegetated intertidal marsh sites (25 to 90 m from the nearest sub-creek). (Kneib and Wanger 1994). The patterns of *F. lauciae* show all age classes are significantly more abundant at ebb tide in vegetated intertidal marsh sites. However, juvenile sizes (≤ 2 cm) of *F. lauciae* tend to be more abundant at slack high tide (Kneib and Wanger 1994). Overall, most nekton are significantly more abundant during slack high tide (Kneib and Wanger 1994).

Fundulus are more abundant during daytime high tides than those at night, yet higher tides generally occur at night (Fell et al. 2003; Halpin 1997). Individuals feed opportunistically at high tide during the day on various invertebrates, algae and detritus. *Fundulus* are visual feeders and are more effective in eating during the day when they can see food, which could be a reason for *Fundulus* to be more abundant during day high tides (U.S Fish & Wildlife Service 2017; Chesapeake Bay Program 2016). *Fundulus* are preyed upon by many fishes, wading birds and blue crab (*Callinectes sapidus*) (U.S Fish & Wildlife Service 2017).

There are differences in habitat usage of *F. heteroclitus* depending on fish size, and differences in the type and amount of vegetation present (Figure 1). *F. heteroclitus* at one year of age (~1.5 cm to 4.0 cm in total length) are abundant in shallow habitats (marsh surface pools and intertidal creeks) rather than deep habitats (sub-tidal marsh edges and sub-tidal creeks). Fish older than one year (≥ 4.0 cm in total length) are more abundant in deeper locations than young fish; however, both age classes are collectively more abundant in shallower depth locations (Figure 1) (Able et al. 2006). Able et al. (2012) found *Fundulus* density varied among habitats with higher abundances within marsh pools and intertidal creeks compared to sub-tidal creeks, the marsh perimeter and boat basin habitats (boat basin was closest to the ocean, about 3 m deep at mean low water). *Fundulus* are most abundant in sub-creeks at times of low flow and low tide (Allen et al. 2007). *F. heteroclitus* density is significantly higher in upper creeks versus lower creek habitats when both areas of the creek are 30-40 cm deep and the marsh surface is not flooded at sampling time (Corman and Roman 2011; Haplin 1997). In mudflats, *F. heteroclitus* abundance is lower in deeper depths (Halpin 1997). *F. lauciae* is more prevalent after rain events, as salt marshes are inundated for longer periods of time (Yozzo & Ottman 2003).

Fundulus are significantly higher in abundance in habitats with a high percentage of vegetation cover versus bare areas, likely in order to avoid predators and because there is less food (Rountree and Able 2007; Able et al. 2012). Juvenile and small adult fish species use habitats with emergent vegetation (Hettler 1989). *Fundulus* inhabit vegetated areas of *Spartina* in large quantities and move greater distances than when in *Phragmites* (Able et al. 2006). *F. heteroclitus* has lower levels of triacylglycerols and fatty acids when present in *Phragmites australis* patches versus *Spartina* patches. Lipids are important for reproduction, migrations and overwintering survival (Weinstein at al. 2009). When *Phragmites australis* becomes dominant in an area, there can be a loss of *F. luciae* populations which are not easily re-introduced even when native *Spartina* is restored (Able et al. 2006). Other studies have shown that there is no significant difference in nekton species richness or abundance between marsh areas dominated by *Phragmites australis* compared to those dominated by *Typha angustifolia* (Fell et al. 2003).

Movement patterns in *Fundulus* are still not well understood. Able et al. (2006) found larger *Fundulus* travel longer distances within a marsh. On average, *Fundulus* traveled 29 m away from a release site, and 76% of fish traveled <30 m away from a release site (Able et al. 2006). *Fundulus* are significantly more abundant 30 m away from a river or creek bed compared to 10 m away (Fell et al. 2003).

F. heteroclitus is one of the most abundant and productive fish species in salt marshes around the Northwest Atlantic Coast, including Connecticut salt marshes (Gotto & Wallace, 2010; Yozzo and Ottman 2003). In a study by Kneib and Wagner (1994), *F. hetercolitus* was caught 90.2% of the time and Roposa & Roman (2001) found that *F. hetercolitus* made up 86.16% of the nekton population. *F. luciae* and *F. majalis* are present in the same salt marshes as *F. heteroclitus*, but at much lower abundances.

Fundulus is among the most important fishes in Connecticut salt marshes (Fell et al. 2003). The genus connects different trophic levels by being both a predator and a prey species (Kneib 1986). Ecosystem functions in coastal environments depend on trophic connectivity within salt marshes and coastal food webs (Figure 2). An emphasis on salt marsh fish species is especially relevant because marshes are being eliminated, altered, created and restored, yet the scientific community does not fully understand what factors influence the population dynamics of *Fundulus* (Able et al. 2006). Limited knowledge on the wide variation of nekton creates a barrier to understand what changes in behavior, growth and survival of *Fundulus* are caused by human influence and/or natural changes in salt marshes (Rountree & Able 2007).

Alteration of Salt Marsh Habitats due to Sea Level Rise and Urbanization and Potential Impacts on Nekton

Salt marshes are changing on a global scale. The amount of coastal salt marshes has decreased significantly because of sea level rise (SLR). Historically, coastal salt marshes have been seen to push further back into the landscape when sea level rises. Now there is human infrastructure obstructing salt marshes from retreating inland (Webb et al. 2013). Also, SLR is happening much faster, which does not allow for salt marshes to adapt.

SLR is happening much faster due to the increase of global temperature rise. Due to many anthropogenic activities temperature is rising at an accelerated rate. Marine vegetated areas occupy 0.2% of the oceans surfaces but contribute to 50% of the carbon burial in marine areas. If these vegetated areas are lost, carbon dioxide will be released. This will increase global warming, which will increase SLR (Duarte et al. 2013).

Global SLR has risen 10 to 20 mm per year for the past 100 years and is expected to keep increasing. The Intergovernmental Panel on Climate Change (IPCC) modeled (under the assumption that temperature will continue to rise) by 2030, global-mean SLR will be 8-29 cm higher than today, with a best-estimate of 18 cm. By 2070, the global sea level rise will be 21-70 cm, with a best-estimate of 44 cm. (IPCC 2013). According to National Oceanic and Atmospheric Administration (NOAA), global SLR will be even higher than the IPCC report, with a 250 cm increase by 2100 (NOAA 2017). The IPCC has modeled Connecticut to have a SLR of 25 cm by 2050 and a SLR of 50 cm by 2100 (Figure 3; Connecticut Institute for Resilience & Climate Adaption 2018). Craft et al. (2009) modeled a decline in salt marshes of 20 to 45 percent by 2100, based on the IPCC mean and maximum SLR data.

SLR will affect each marsh location differently. A key determinant of salt marsh vulnerability to SLR is whether the surface elevation in the intertidal zone can keep up with rising sea level (Webb et al. 2013). If a salt marsh cannot keep up with changing sea levels, vegetation will decrease due to constant submergence of plants with higher tide levels. Tidal vegetation cannot survive complete inundation and marshes will be lost.

SLR will likely have varied effects on different organisms. Impacts will be based on usage patterns of their current habitat and is a reason why nekton habitat patterns need to be studied in this regard. *Fundulus* is thought to be more resistant to SLR than other species because of its ability to live in a wide range of habitats (Able et al. 2012; Ruiz 2016). A moderate SLR (less than 60 cm) may benefit salt marsh organisms by expanding the habitat and its complexity. However, rapid SLR (a minimum of 60 cm within the next century) will result in smaller and more dispersed marshes with simpler patches and edges, which creates less area for forage and refuge spaces for nekton (Torio & Chmura, 2013). Nekton habitat use patterns during high tide are important to understand to more accurately predict what ecosystem functions could be altered and/or lost due to SLR.

SLR will not only affect *Fundulus* and other marsh nekton, but also the ecosystem services provided by salt marshes, such as waste treatment, biological productivity, sediment stabilization and buffer zones (Craft et al. 2009). Coastal squeeze will exacerbate the affects of SLR, leading to decreases in marsh area. Ideally, salt marshes would grow vertically and push horizontally towards land as sea level rises. Impermeable surfaces and barriers prevent marshes from expanding horizontally inland, which causes coastal squeeze (Torio & Chmura 2013; Sound Health 2008).

Not only can SLR negatively affect nekton, urbanization can also affect nekton and their habitats. Coastal development can degrade terrestrial-aquatic linkages, reduce shallow water habitats and impair ecosystem services. Urbanization negatively impacts salt marshes potentially resulting in loss of diversity, increased dominance of tolerant taxa, changes in species traits and the proliferation of invasive species (Yates and Bailey 2010).

Fish abundance is reduced in areas of urbanization (when salt marshes are within 200 to 1000 meters of human activity) and unnatural shorelines, compared to upland areas of minimal development and natural coastline (Bilkovic & Roggero 2008). Each nekton responds to urbanization differently. Size, weight and diet can change in species that are in urbanized areas compared to less urban areas. For example, blue crabs and brown shrimp length and weight did not change with increase in urbanization, but *Fundulus grandis* were found to be significantly smaller when exposed to urban areas (Lowe and Peterson 2015). Also, *F. grandis* had empty stomachs and different diets when in an urbanized areas (ate large brown shrimp) compared to non-urbanized areas (ate small grass-shrimp and fish) (Lowe and Peterson 2015). Altered physiochemical properties of urbanized habitats can result in considerable shifts in biological assemblages, especially trophic connecting species like the *Fundulus* genus. (Gotto & Wallace 2010).

An emphasis on salt marsh fish species is especially relevant because marshes are being eliminated, altered, created and restored, yet the scientific community does not fully understand what factors influence the population dynamics of nekton (Able et al. 2006). Limited knowledge about the wide variation of nekton creates a barrier to understanding what changes in behavior, growth and survival of nekton are caused by human influence and/or natural changes in salt-water marshes (Rountree and Able 2007). SLR and coastal development pose an impact to nekton, to what extent is unknown. The usage of salt marsh habitat by nekton is important to understand so insightful mitigation and conservation efforts can be utilized moving forward.

Objectives

The goal of this study was to understand current nekton use of specifically high marsh habitats in two Connecticut salt marshes. This research addressed a set of general questions and specific hypotheses regarding the ecology of nekton, and *Fundulus* in particular. These include:

How does nekton use of high marsh habitats differ with respect to tidal patterns relative to season, depth of tide, and vegetation coverage.

What spatial differences are there in nekton occupation of different marsh habitats *Fundulus*?

If there are differences in *Fundulus* abundances throughout the above variables will size of *Fundulus* differ?

Specific null hypotheses tested included:

a) Nekton, and more specifically *Fundulus*, will not show significant differences in abundance and habitat use between seasons, depth of tide, or vegetation coverage within high to low marsh areas or in sub-tidal creeks.

b) There will be no significant spatial differences (distance from mosquito/ sub-tidal creeks or main creek locations) in abundance of nekton and specifically *Fundulus* over the study period.

c) Size of *Fundulus* will not differ throughout season, depth of tide, vegetation or distance from mosquito ditches and sub-creeks.

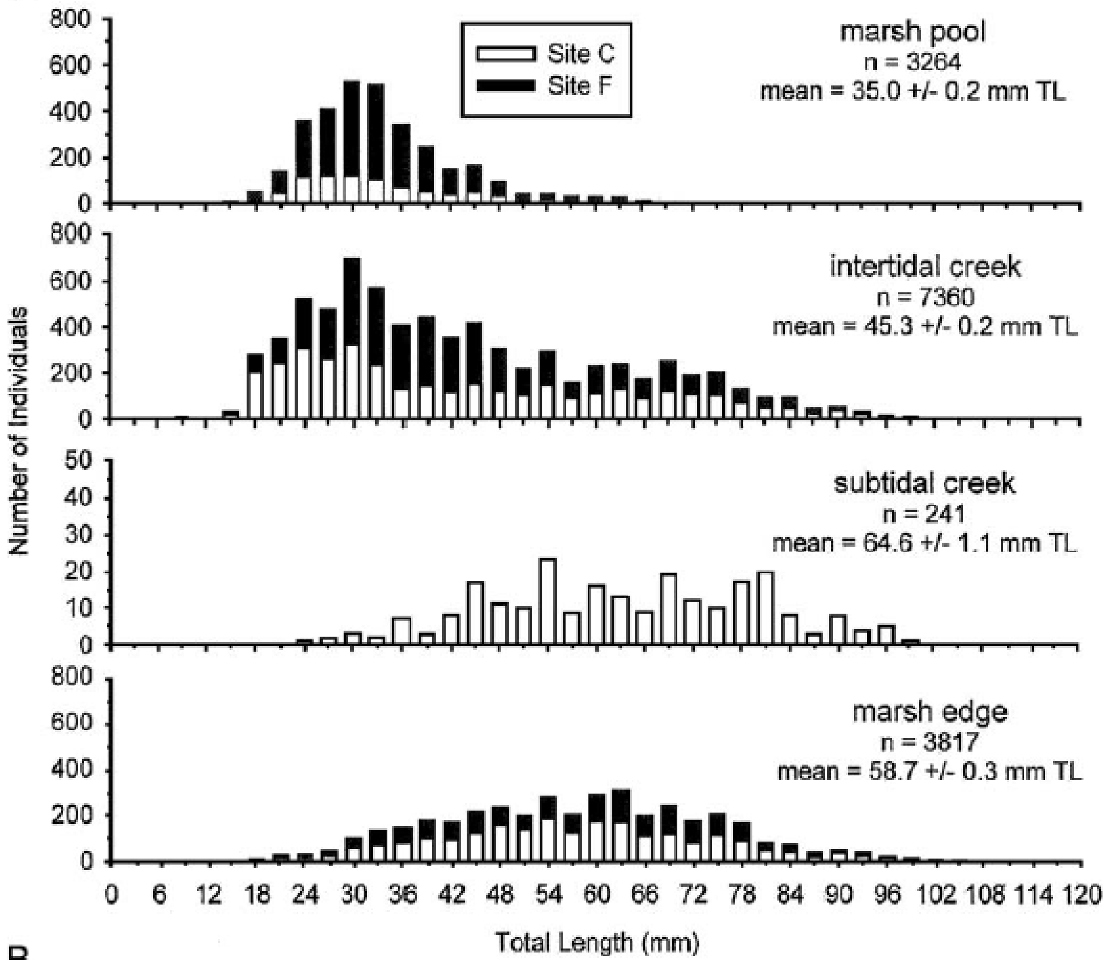

Figure 1. *Fundulus heteroclitus* size distributions in reference to different habitats (Able et al. 2006).

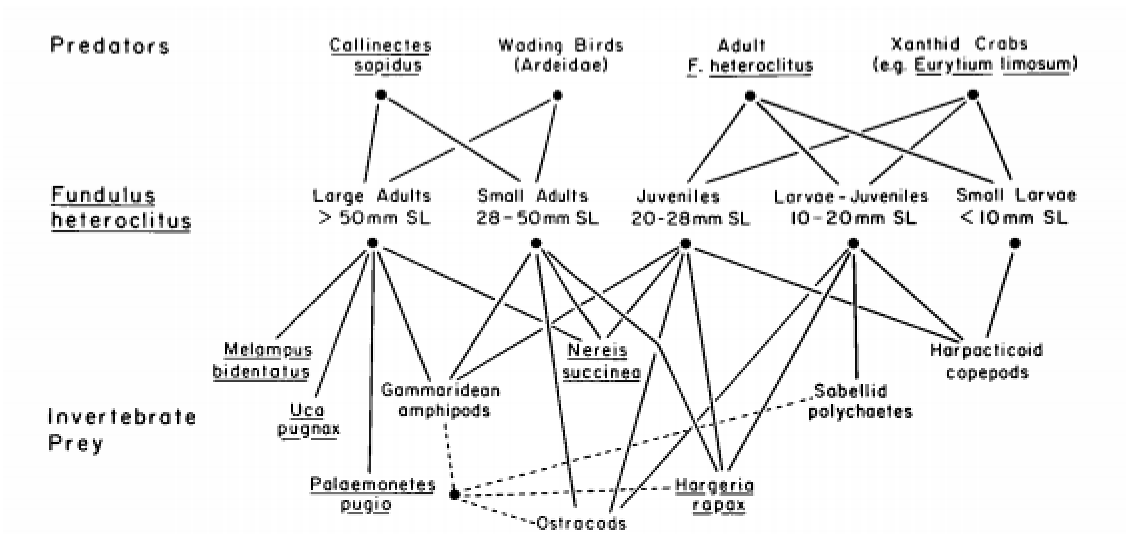

Figure 2. Summary of the trophic relationships involving different size (age) classes of *Fundulus heteroclitus* in tidal marshes. Dashed lines indicate pathways by which *Fundulus* predation may indirectly affect salt marsh benthic invertebrates (Knieb 1986).

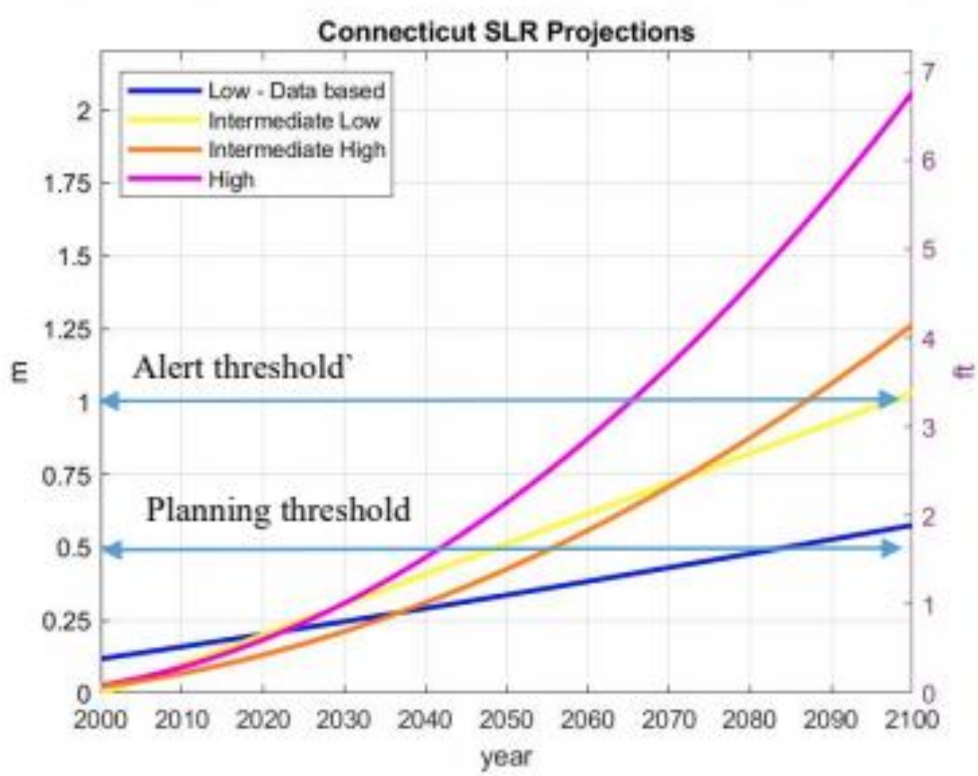

Figure 3. Sea level rise projections for Connecticut based on local tide gage observations (blue), the IPCC (2013) model simulations near Long Island Sound (yellow line), the semi-empirical models (orange line) and ice budgets (magenta line). (IPCC 2013).

CHAPTER II

METHODS

Field Work

Sampling was conducted at two Branford, CT salt marshes (Figures 4 and 5) during times of the day closest to highest predicted spring high tides between June and October 2018. Data from previous studies (Zajac, unpublished) conducted throughout 2015-2017 were also incorporated into this study.

Samples were taken on the rising tide in different habitat types including small creeks, mosquito ditches, low to high marsh transitions and also on the high marsh. Different techniques were used in these habitats to sample nekton. Underwater cameras (GoPro©) were used in tidal creeks and mosquito ditches (Figure 6). Three cameras were deployed on each sampling day at different distances away from the main tidal creek in the marsh. Cameras were deployed after the flood tide had inundated the sub-creek or mosquito ditch to a depth of approximately 25 to 30 cm. Each camera was attached to a PVC pipe that was then put into the marsh sediments. Cameras were left in place most of flood tide, all of slack tide and a small amount of time into the ebb tide, collecting about 45 to 60 minutes of video. The location of each camera was recorded using GPS so distances to the main creek's centerline could be measured later.

Rigid throw nets were used to capture nekton on high marsh areas. The nets were 1 m^2 and made out of PVC pipe with a 0.4 cm mesh netting (Figure 7). A minimum of three samples were taken each sampling day at high to low marsh transitions and in high marsh areas at several positions along random transects. Dip nets were used to collect all nekton within the net. Once dip netting yielded no nekton after 10 swipes the throw net would be moved to another random sample location.

The abundance of all nekton in each sample was recorded and the lengths of *Fundulus heteroclitus, Fundulus luciae*, and *Fundulus majalis* were measured using a fish board. The sizes of any *Fundulus* that escaped while being measured were estimated. At each sample location, the percent vegetation coverage was determined by visual approximation and water depth was measured. GPS point coordinates were taken at each sample location.

Data Analysis

Data collected in the field was uploaded to Excel files. NCSS statistical software (Hintze 2019), was used to test differences in the abundance of nekton (from video and net data), specifically *Fundulus* and *Palaemonetes* (from only net data), among habitat and sampling site variables and dates. Analysis of Variance (ANOVA) or two Sample t-tests were used to test for differences.

Video Analysis

To analyze videos, each individual fish was counted when going into the video frame, similar to the approach used in other studies (James-Pirri et al. 2010; Ellis and Bell 2008). No attempt was made to determine if individuals had been counted previously in the video. Mean nekton abundance per minute was calculated by dividing the total number of nekton counted in the video by the number of minutes per video record. NCSS software was used to test differences in nekton abundance at different distances from the main creek using Analysis of Variance.

Geographic Information Systems (GIS)

To determine spatial differences within nekton abundance samples, all variables measured in the field (species richness, total abundance, length of *Fundulus*, water depth, percent vegetation coverage) were joined to the merged point samples (GPS recorded) that were collected in the field (Figure 8). The net data were separated into groups based on spatial location of specific habitats including high to low marsh transitions and distance from sub-tidal creeks/ mosquito ditches. The camera data were separated into groups based on distance from the centerline of the main creek to compare nekton abundance per minute over different distances. The near analysis tool in ArcGIS was used to calculate distance from the net samples to the sub-tidal creeks/ mosquito ditches and the camera samples to the main creek's centerline (Figure 9). Distance to the main creek's centerline was used because the edges of the main creeks are variable in aerial imagery due to different tidal heights at the time the imagery was obtained. Analysis of Variance was used to determine if there was a differences in nekton and *Fundulus* abundance due to distance from a main creek' or mosquito ditches. .

Models

Fundulus Population Densities

The Geo-statistical Analyst Wizard in ArcGIS was used to extrapolate population densities of total *Fundulus* abundance across the spatial extent of study sites (Figure 10). The kriging semivariogram/ covariance model was used to show the relationship between sample net points.

Sea Level Rise

A model was created to understand how SLR in Branford, CT may affect *Fundulus* density in the near future (50 to 100 years from now). Elevation data were used to determine current marsh boundaries (greater than zero feet) and to predict SLR (Figure 11). The raster calculator in ArcGIS was used to select elevation data (CT ECO 2017) at 0.5, 1 and 2 feet to model changes in flooding heights on the study marshes. Each elevation raster represented SLR of different magnitudes. These are expected SLR predictions for Connecticut, as a 1 foot SLR is predicted by 2050 and a 2 foot rise is predicted by 2100 (NOAA 2017; IPCC 2013). The elevation data were clipped to the marsh boundaries to show predictions of areas of the marsh that will be permanently inundated. The current elevation of zero (with *Fundulus* abundance data attached) was then subtracted from each SLR polygons to adjust for areas that are always inundated currently and not considered marsh habitat. This was then used to predict how many *Fundulus* would be displaced and would be pushed further into the marsh (Figure 12). This would answer the question if there would be an increase in *Fundulus* density within the salt marshes with predicted SLR.

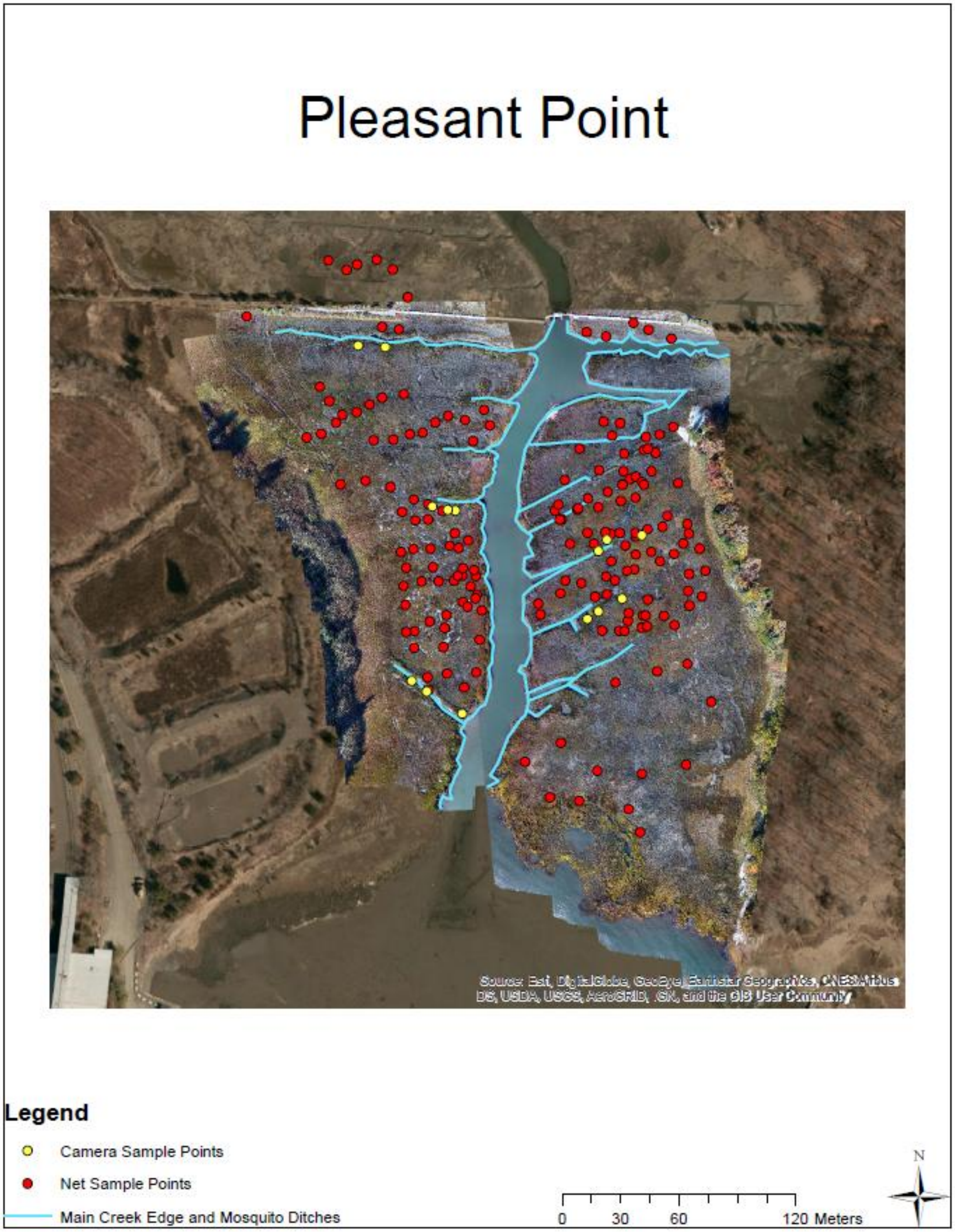

Figure 4. Camera and net sample points in Pleasant Point in Branford, CT

Figure 5. Camera and net sample points in Banca in Branford, CT

Figure 6. Go-Pro© connected to a PVC pole that is in salt marsh sediments.

Figure 7. Mesh net (m^{-2} area with 0.4 cm mesh size) used in random quadrate sampling.

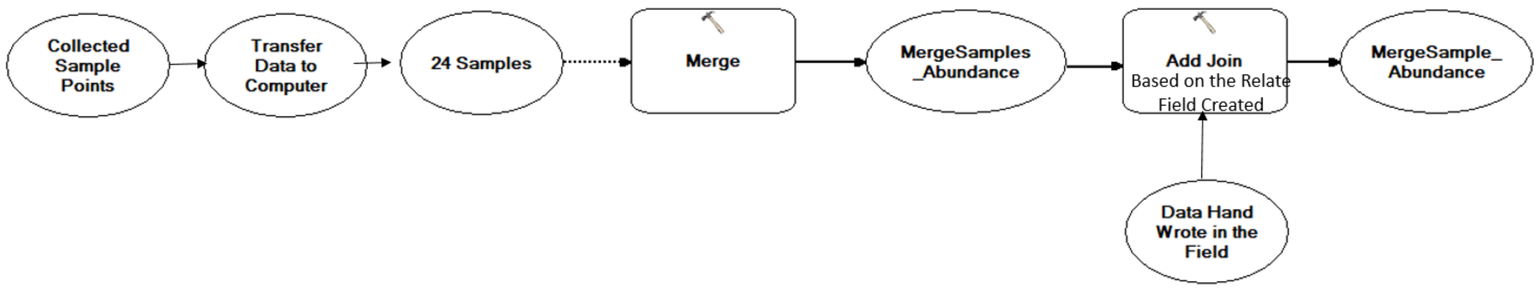

Figure 8. Steps taken to analyze net sample points in ArcGIS.

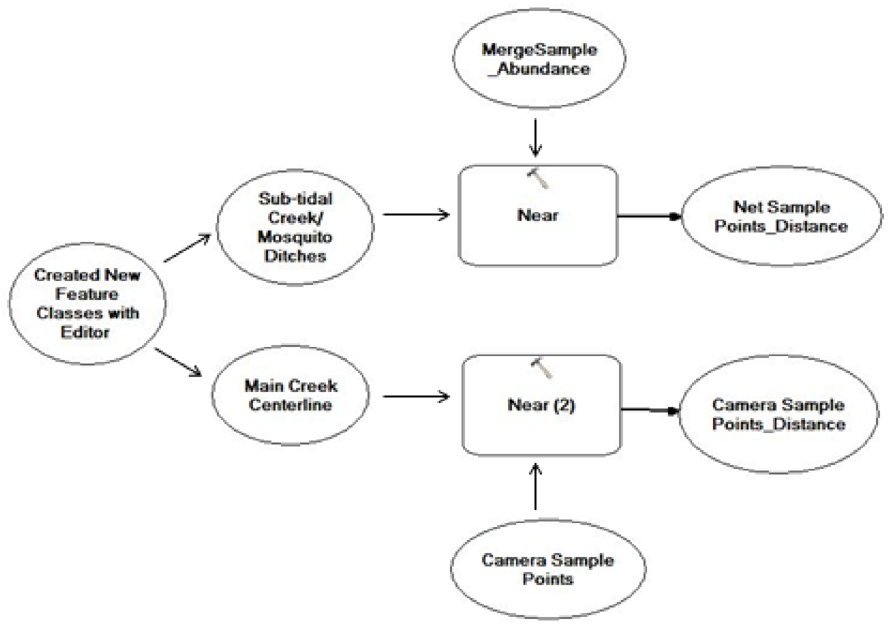

Figure 9. Steps taken to determine the distance from each sample point from the nearest mosquito ditch (for net sample points) or centerline of the main creek (for camera sample points).

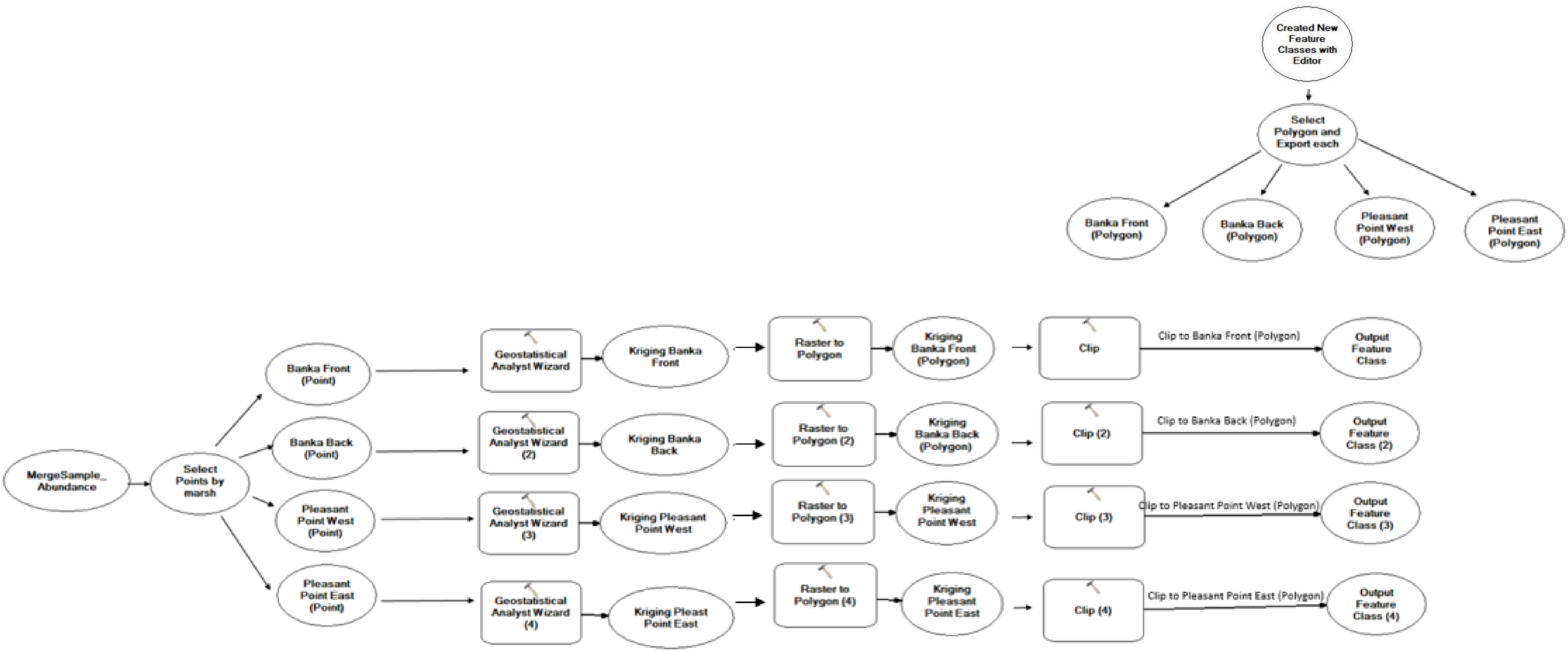

Figure 10. Steps taken to estimate population densities of *Fundulus* from calculations made in Figure 9.

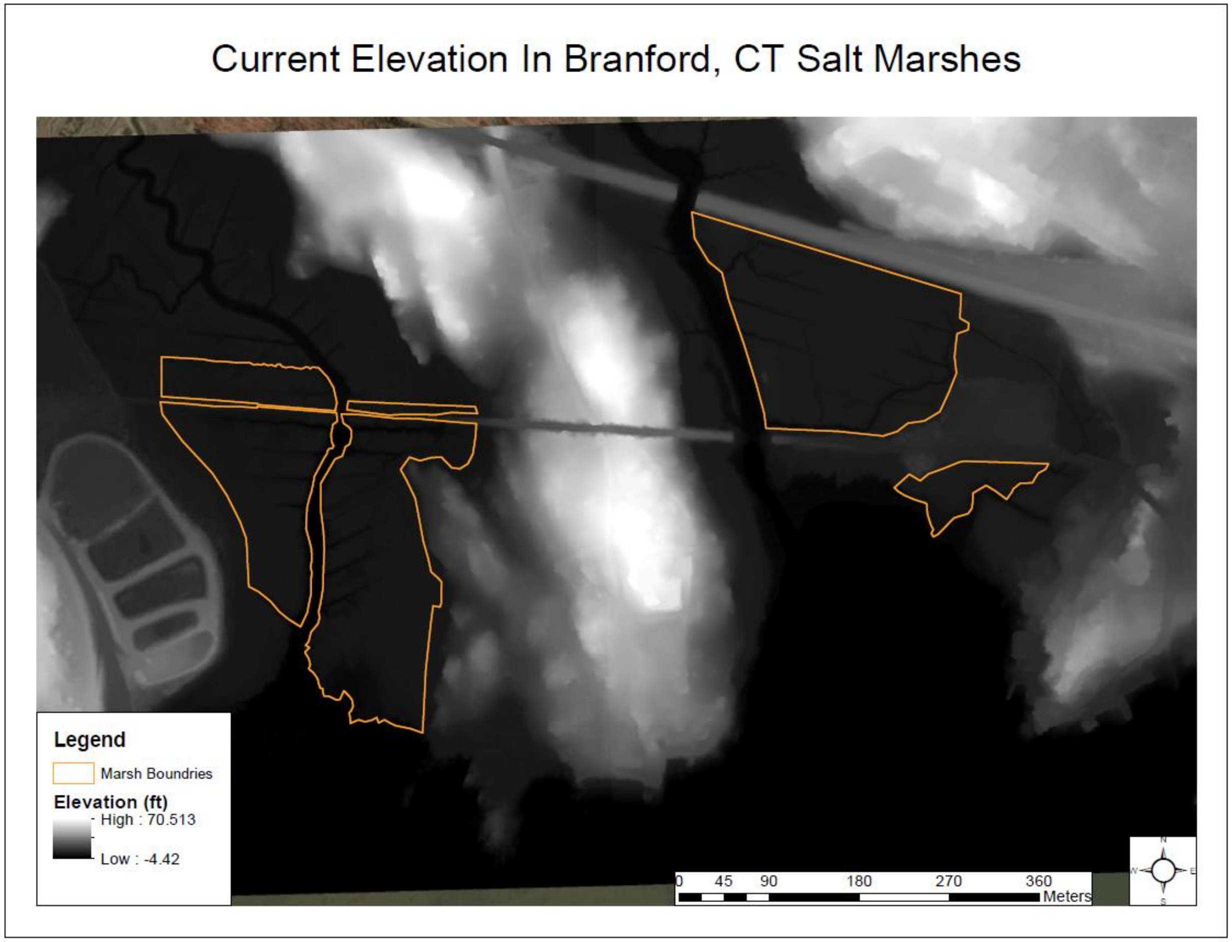

Figure 11. Elevation in the area of the Branford, CT salt marsh study site (CT ECO 2017) show very small changes but were used for data analayses below; orange lines represent marsh boundaries of the study area.

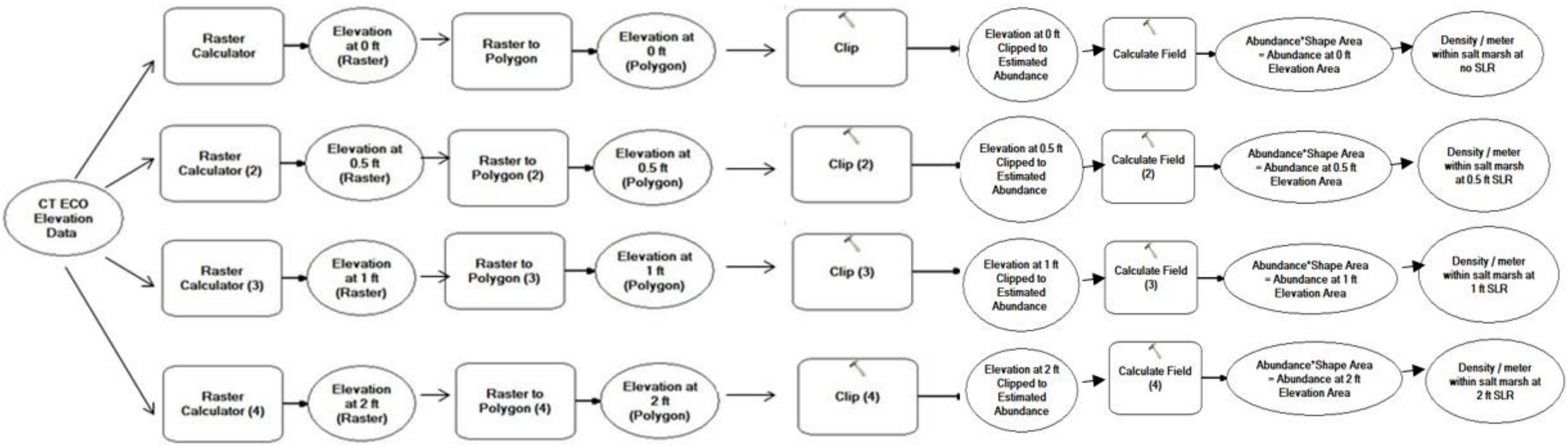

Figure 12. The steps taken to show the increase in *Fundulus* density within all marshes in Branford, CT if there were a 0.5, 1 or 2 foot sea level rise.

CHAPTER III

RESULTS

There were a total of 299 net sample points collected between May and October in 2015 to 2018. There were a total of 5,459 nekton individuals sampled: 1,496 *Fundulus*, 2,174 *Palaemonetes* and many other nekton were caught throughout the duration of the study. The genus *Fundulus* made up 34% of all nekton found throughout the Branford, CT study period (Figure 13). The *Fundulus* genus accounted for 97% of the total fish population (Figure 14).

Net Data: Differences in Abundance

Mean nekton abundance was higher in the fall of 2018 and during one sample day in September 2015 compared to all other samples dates (Figure 15). In the fall 2018 nekton net samples were more variable than that found in any other year. *Fundulus* and *Palaemonetes* abundance varied throughout 2015 to 2018 (Figure 16; Figure 17). Mean *Fundulus* abundance was 5 m^{-2} with two outliers of 122 and 335 individuals. Mean *Palaemonetes* abundance was 11 m^{-2} throughout the duration of the study. There was a large abundance of both *Fundulus* and *Palaemonetes* throughout September and October (Figure 16; Figure 17).

Considering all sites and dates, there were significantly more nekton in fall versus summer per net sample (Figure 18, Two Sample t-Test: p= 0.0000). There were significantly more *Fundulus* caught per net sample in the fall compared to the summer (Figure 19, Two Sample t-Test: p = 0.00304; n=297). Two outliers were taken out, as the abundance was very high on two separate fall sample days. Although, when outliers were accounted for, there still was a significantly higher abundance of *Fundulus* in the fall versus the summer per net sample (Two Sample t-Test: p= 0.01623, n = 299). There were significantly more *Palaemonetes* caught per net sample in the fall compared to the summer (Figure 20, Two Sample t-Test: p = 0.00000, n=289). There were ten sample sites that *Palaemonetes* were not accounted for (due to human error when sampling) and were not included into the results.

Nekton were marginally significantly more abundant in depths greater than 30cm compared to shallower depths per net sample (less than 9.9 cm) (Figure 21, ANOVA: p= 0.06638, n= 277). *Fundulus* abundance was significantly smaller in shallower depths (less than 9.9cm) compared to deeper depths (>30cm) within all habitat locations and tidal cycles per net sample (Figure 22, ANOVA: p= 0.01996, n=275). With outliers included (122 and 335 *Fundulus* abundances) there was not a significant difference within different water depths per net sample (Figure 23, ANOVA: p=0.42299, n = 277). *Palaemonetes* mean abundance was also significantly smaller in shallower depths (0 – 9 and 15 - 19.9cm) compared to deeper depths (>30cm) within all habitat locations and tidal cycles per net sample (Figure 24, ANOVA: p= 0.02333, n=267). There were some samples that did not have depths (cm) documented (human error in the field), so some n values are less than the total amount of samples recorded.

Nekton abundance did not show any significant difference within vegetation cover per net sample (Figure 25, ANOVA: p= 0.47690; n= 232). *Fundulus* mean abundance had no significant difference within different vegetation coverage per net sample (Figure 26, ANOVA: p = 0.87878, n=230). With outliers present (122 and 335 *Fundulus* abundances) there still were no significant differences in *Fundulus* abundance compared to vegetation coverage (p=0.48341, n = 232). *Palaemonetes* mean abundance did not show a significant difference in vegetation coverage per net sample (Figure 27, ANOVA: p= 0.36485, n=222). There were some samples that did not have vegetation coverage documented (human error in the field), so some n values are less than the total amount of samples recorded.

Total nekton mean abundance increased significantly when greater than 41 meters away from a sub-creek or mosquito ditch per net sample (Figure 28, ANOVA: p= 0.03083, n= 258). *Fundulus* mean abundance had a marginal significant difference when 41 meters or greater away from a mosquito ditch or sub-creeks in Branford, CT salt marshes (Figure 29, ANOVA: p = 0.09597, n = 256). With outliers present there were no significant difference in *Fundulus* abundance compared to distance from mosquito ditches per net sample (ANOVA: p=0.37166, n = 258). *Palaemonetes* mean abundance did show a significant increase in abundance when 41 meters or greater away from a mosquito ditch or sub-creek per net sample (Figure 30, ANOVA: p = 0.00814, n = 248). There were some samples that were not GPS to calculate sample distance from mosquito ditches (human error in the field), so some n values are less than the total amount of samples recorded.

High to low transitions and high marsh zones were identified and mapped (per net sample) to assess *Fundulus* abundance differences between habitat location (Figure 31; Figure 32). *Fundulus* abundance had no significant difference in high marsh locations compared to high to low marsh transition areas (Figure 33, Two Sample t-Test: p = 0.93936, n= 236). However, with outliers (122 and 335 abundances of Fundulus in specific sample locations on different days) included (122 and 335 *Fundulus* abundances) there was a marginally lower significant abundance in high marsh locations compared to high to low marsh transition areas (Figure 34, Two Sample t-Test: p = 0.09638, n= 238). There was a large standard error within the high to low marsh transition due to including both low marsh and transitions zones together. Also, some samples were not GPS (human error in the field), so some n values are less than the total amount of samples recorded.

Fundulus abundance was estimated for each marsh and was approximated to have highest *Fundulus* density (m^{-2}) in Banca Back and least *Fundulus* density in Banca front (Figure 35,

Table 1, n=259). There was a higher standard error within *Fundulus* abundance in Pleasant Point East than any other marsh in Branford, CT (Figure 36).

Net Data: Fundulus Size

Mean *Fundulus* size (cm) ranged from 1 to 10 cm throughout 2015 to 2018 (n = 855). The average size for *Fundulus* through 2015 to 2018 was 3.14 cm in Branford, CT salt marshes (Figure 37, n=855). In Banca Back the average length of *Fundulus* was 2.93 cm (n=456), 3.4 cm in Pleasant Point East (n=289), and 3.28 cm in Pleasant Point West (n= 108).

Fundulus did not have a significant size difference in fall versus the summer in the net samples (Figure 38, Two Sample t-Test: p=0.37058, n=855). Mean *Fundulus* size (average 2.83 cm) was significantly smaller in deeper depths (> 30cm water depth) compared to shallower depths per net sample. Mean *Fundulus* size greater than 3.03 cm were found in water depths less than 30 cm (Figure 39, ANOVA: p=0.00003; n= 810). Mean *Fundulus* size (cm) was larger (≥ 3.4 cm in less vegetated areas (21-60% vegetation coverage) and smaller (≤ 3.02 cm) in more vegetated areas (61-100% vegetation coverage) (Figure 40, ANOVA: p=0.0000 n= 639). Mean *Fundulus* size was significant different relative to distances from mosquito ditches (Figure 41, ANOVA: p=0.03202, n=640). There was no distance from sub-creeks that had a significantly larger *Fundulus* size, but the overall trend showed mean *Fundulus* size decreased when further from subtidal creeks (30 m away) and increased when > 41 m away from sub-creeks.

Video Data

Mean nekton abundance was measured with Go-Pro© cameras in July to September in 2018 to measure difference in nekton abundance throughout sub-creeks and mosquito ditches in Branford, CT salt marshes (Figure 42, n=16). There was no significant difference in mean abundance per minute compared to distance from the main creek's centerline (Figure 43, ANOVA: $p=0.13279$, $n= 16$), but there was a trend that showed more nekton abundance per minute when the camera was 41 to 60 meters away from the centerline of the main creek.

Sea Level Rise

The sea level modeling that was done suggests that SLR may increase the density of *Fundulus* m^{-2} (Figure 44; Table 2). At Pleasant Point East, *Fundulus* density in the model increased the most out of all four marsh sections, based on the current study's estimated *Fundulus* population (Figure 35). Each marsh did not have the entire *Fundulus* population estimated because samples were not taken close enough to the shoreline in Banca Front and Pleasant Point West to make accurate population estimations (Figure 44).

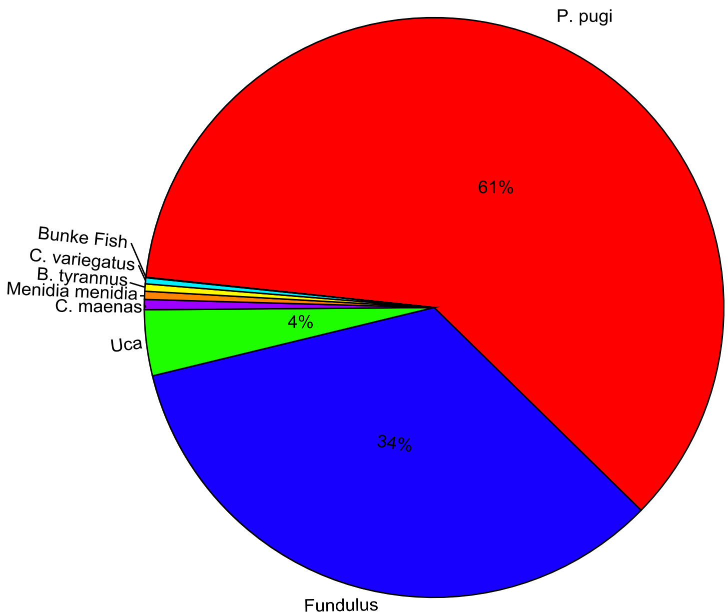

Figure 13. The percent of nekton species within Branford, CT salt marshes.

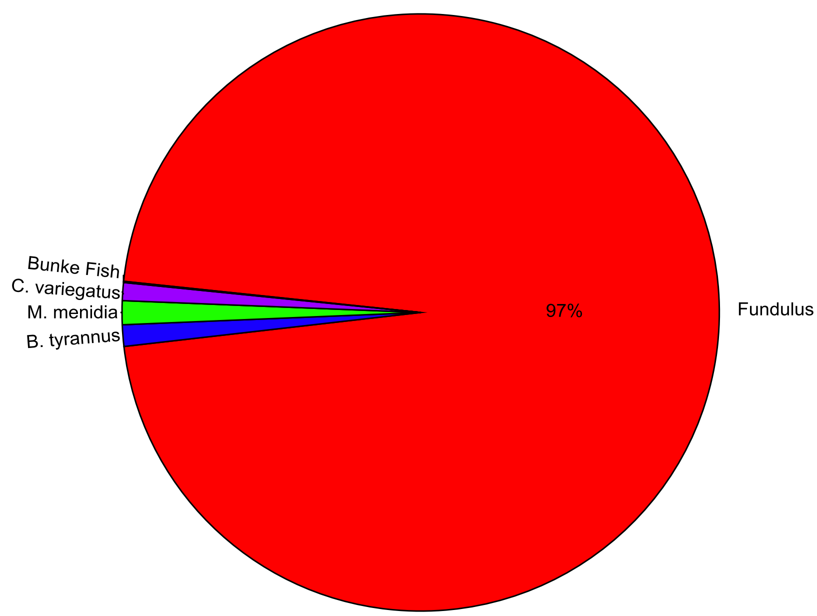

Figure 14. The percent of fish species within Branford, CT salt marshes.

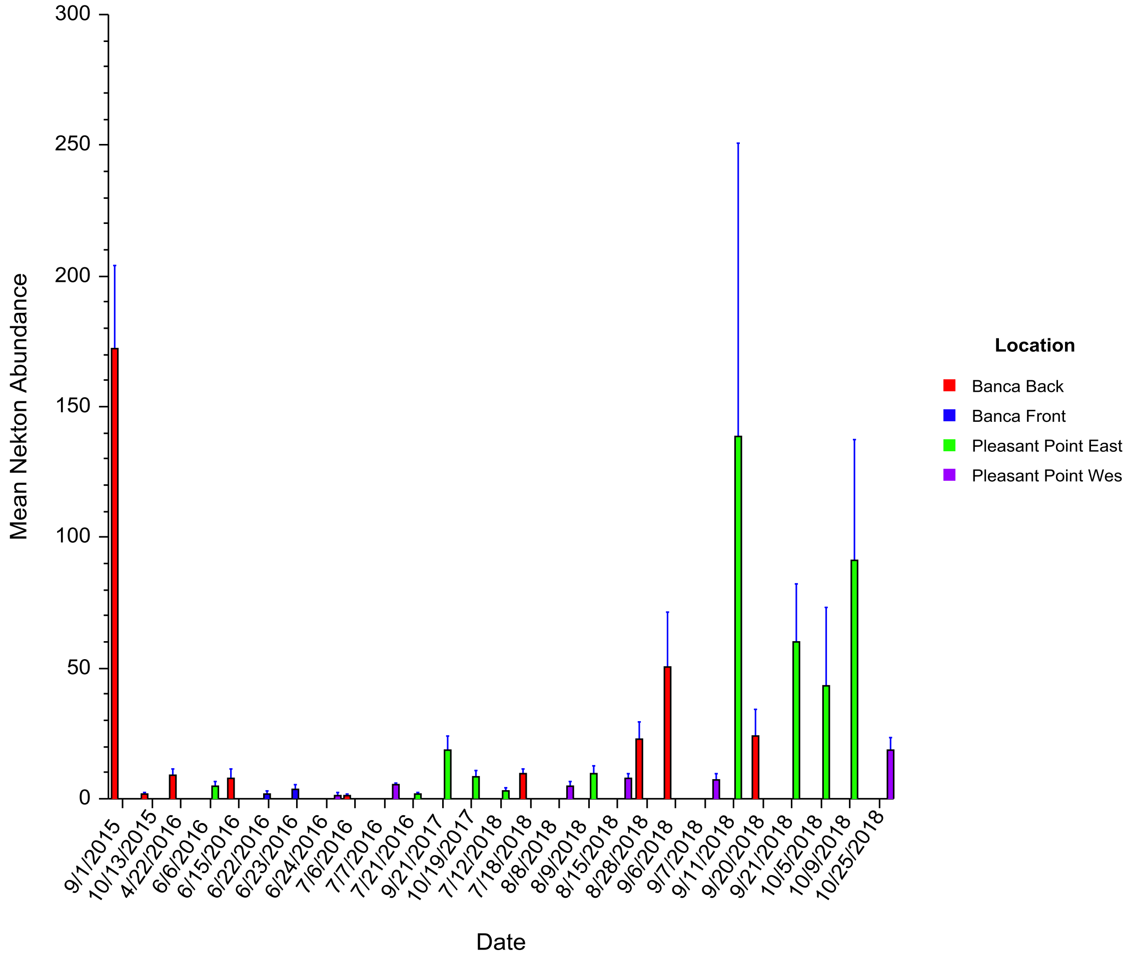

Figure 15. Nekton mean abundance between 2015 and 2018, where each date represents one marsh that was sampled in Branford, CT.

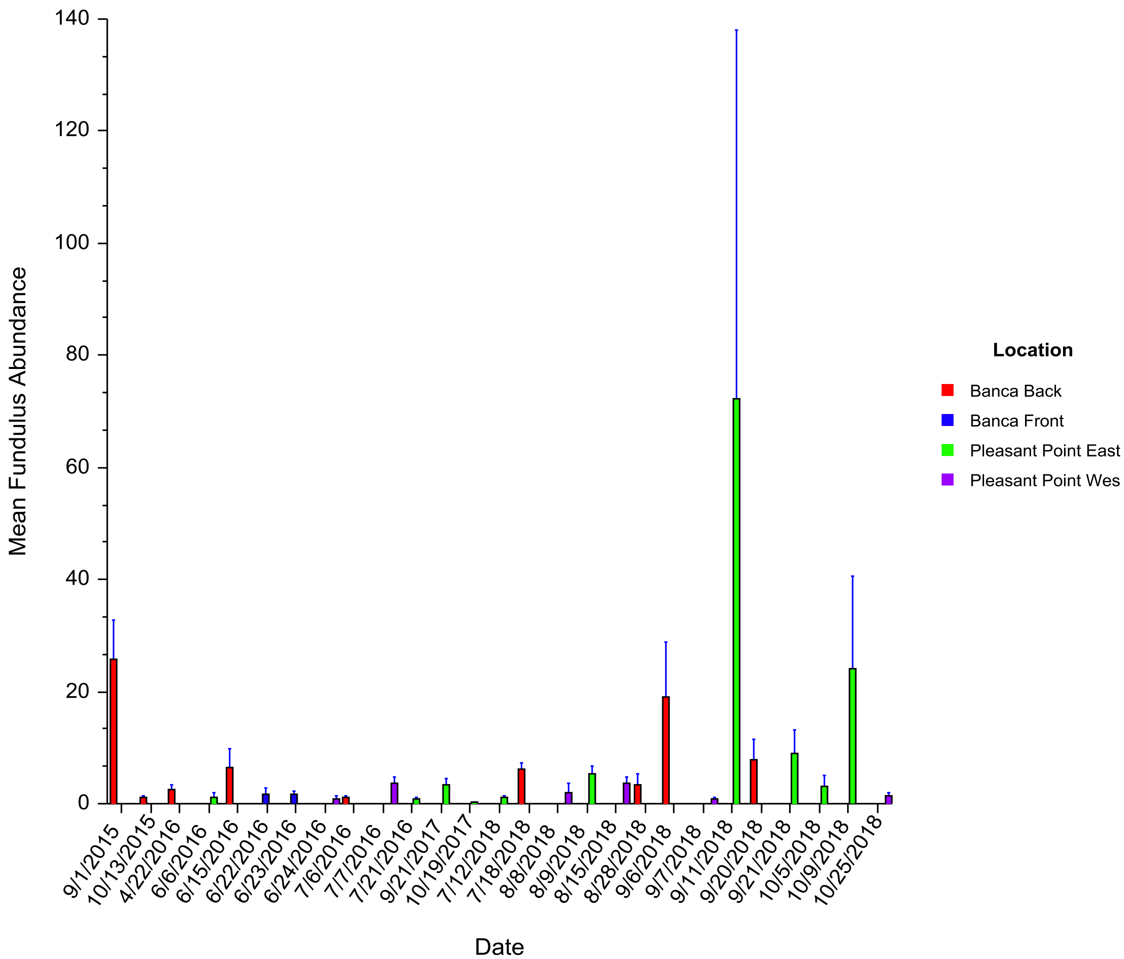

Figure 16. *Fundulus* mean abundance throughout 2015 to 2018, where each date represents one marsh that was sampled in Branford, CT.

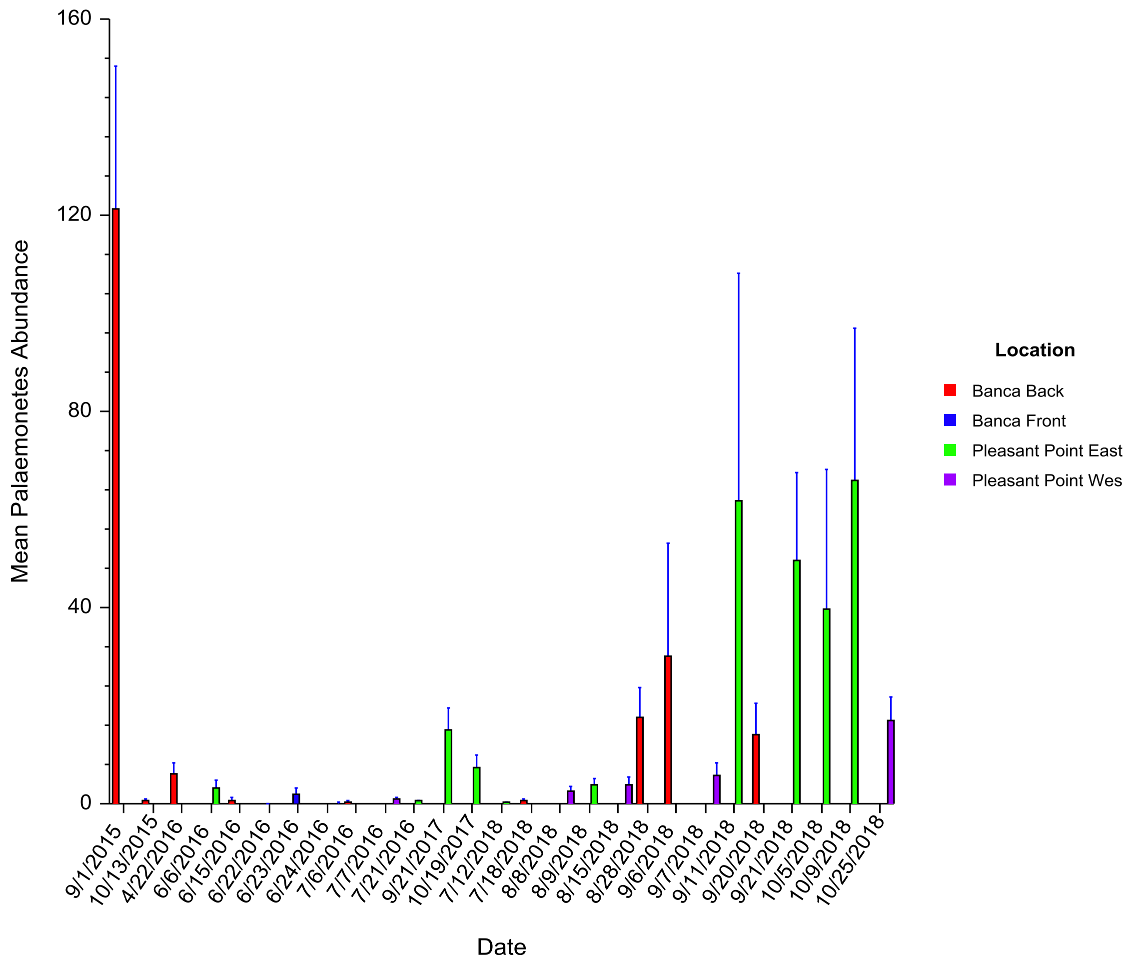

Figure 17. *Palaemonetes* mean abundance throughout 2015 to 2018, where each date represents one marsh that was sampled in Branford, CT.

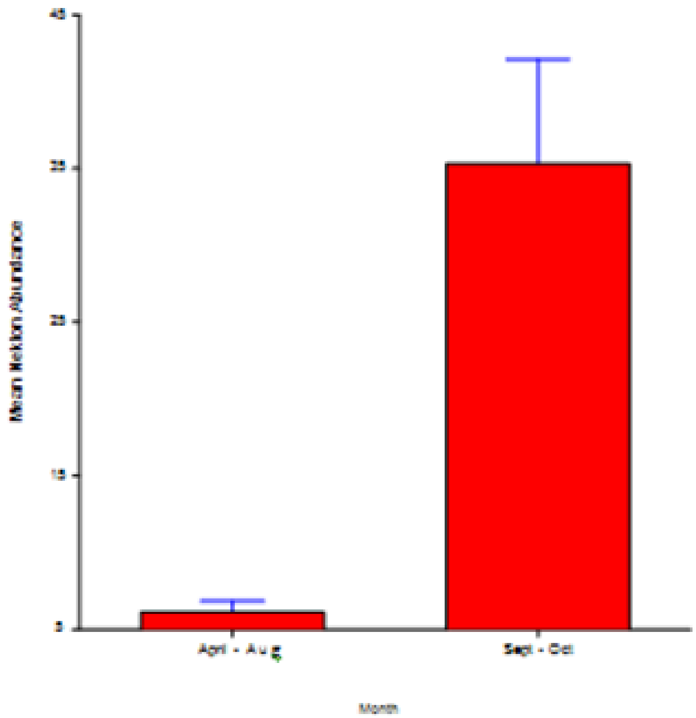

Figure 18. Nekton mean abundance per net sample in summer compared to fall, in Branford, CT salt marshes.

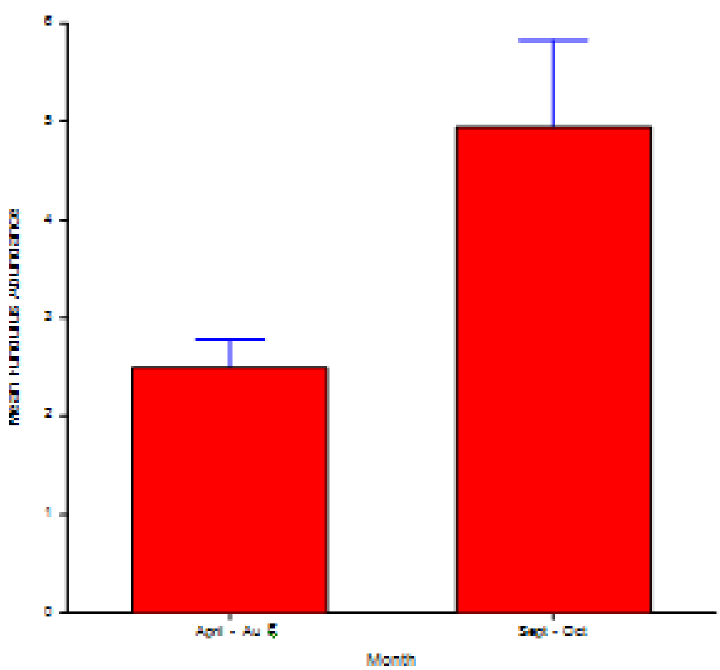

Figure 19. *Fundulus* mean abundance per net sample in summer compared to fall, in Branford, CT salt marshes.

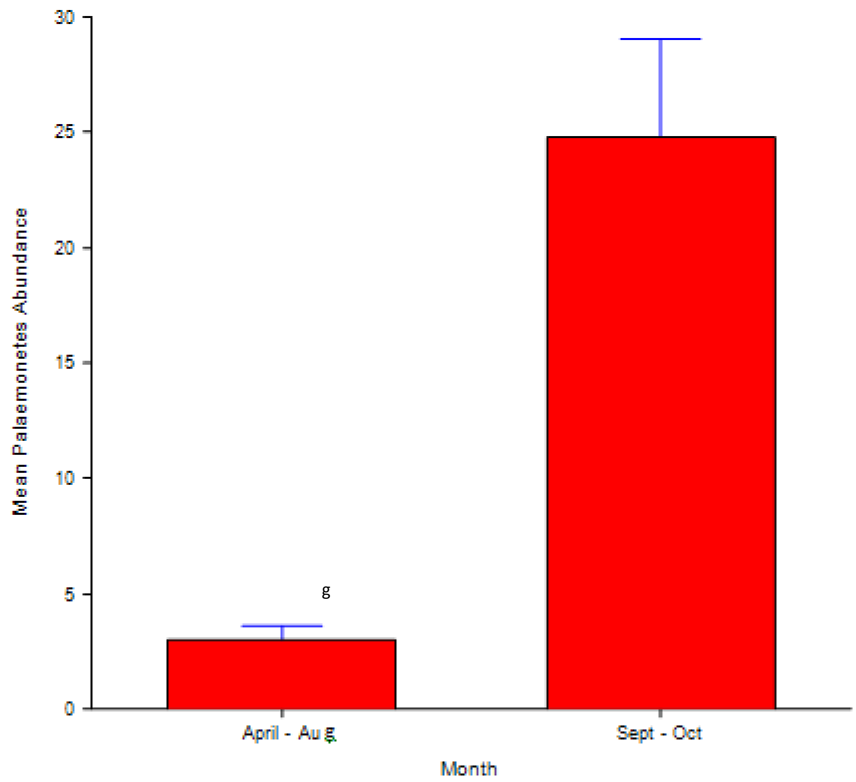

Figure 20. *Palaemonetes* mean abundance per net sample in summer compared to fall, in Branford, CT salt marshes.

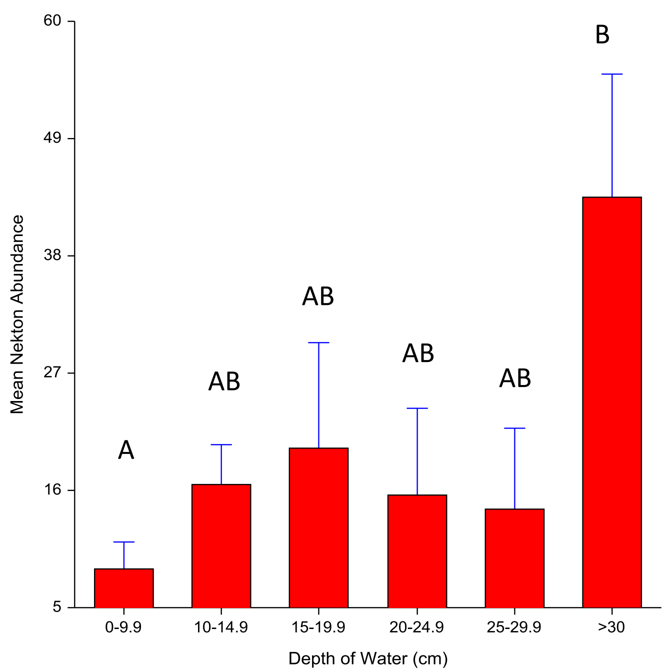

Figure 21. Nekton mean abundance per net sample in different depths (cm) in Branford, CT salt marshes.

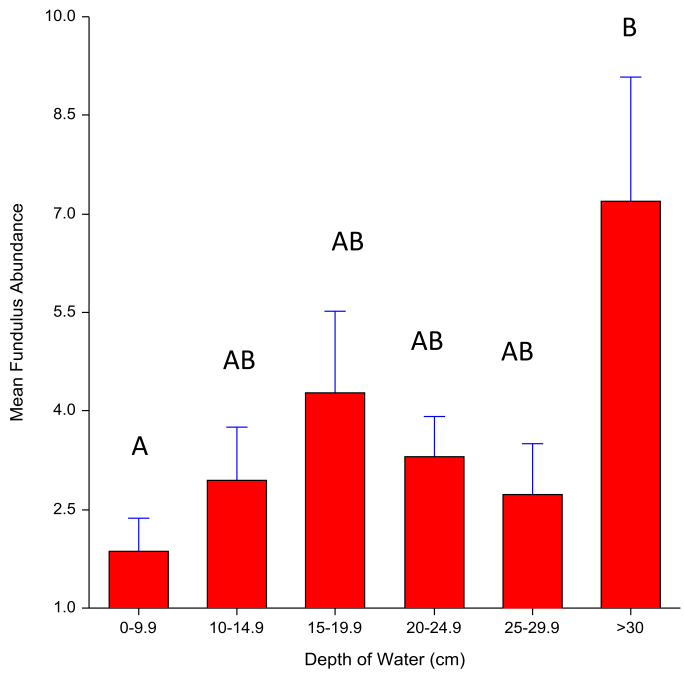

Figure 22. *Fundulus* mean abundance per net sample in different depths (cm) in Branford, CT salt marshes without outliers (122 and 335 mean total abundance for two sample sites).

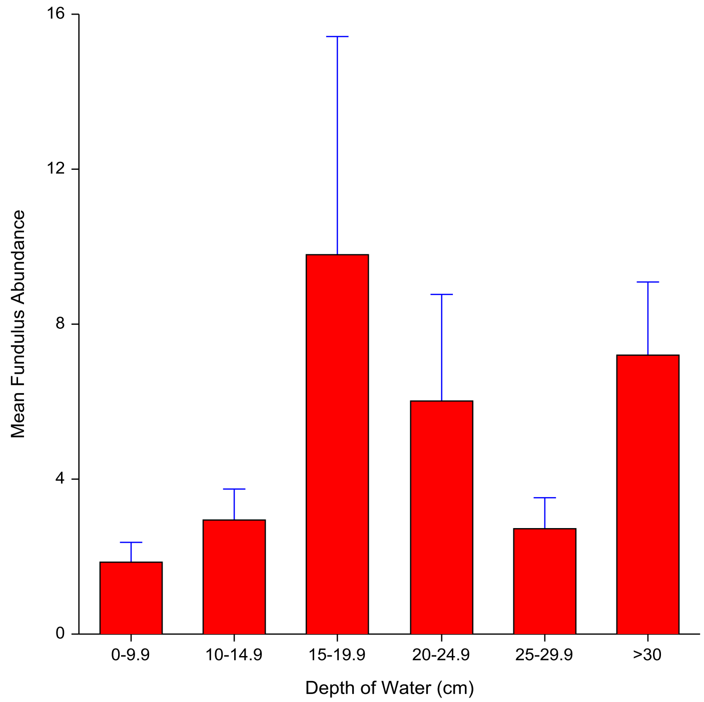

Figure 23. *Fundulus* mean abundance per net sample in different depths (cm) in Branford, CT salt marshes with outliers.

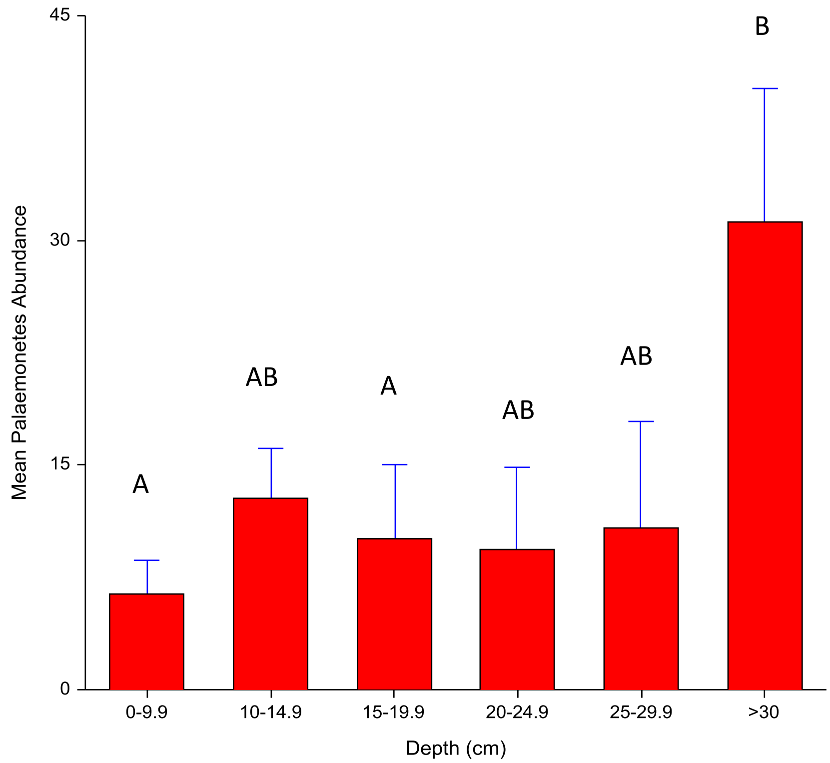

Figure 24. *Palaemonetes* mean abundance per net sample in different depths (cm) in Branford, CT salt marshes.

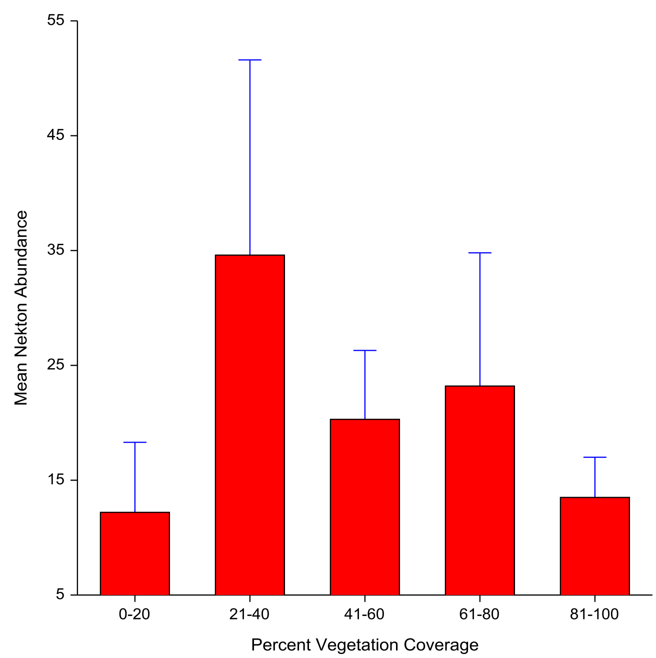

Figure 25. Nekton mean abundance per net sample in different vegetation coverage (%) in Branford, CT salt marshes.

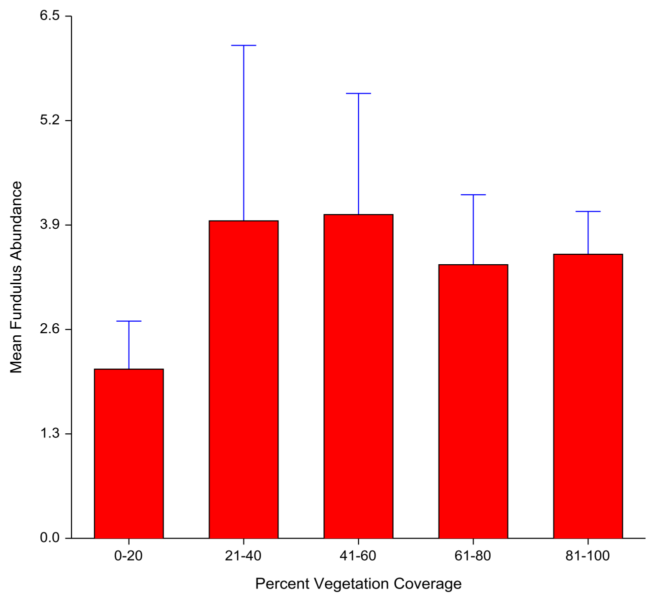

Figure 26. *Fundulus* mean abundance per net sample in different vegetation coverage (%) in Branford, CT salt marshes.

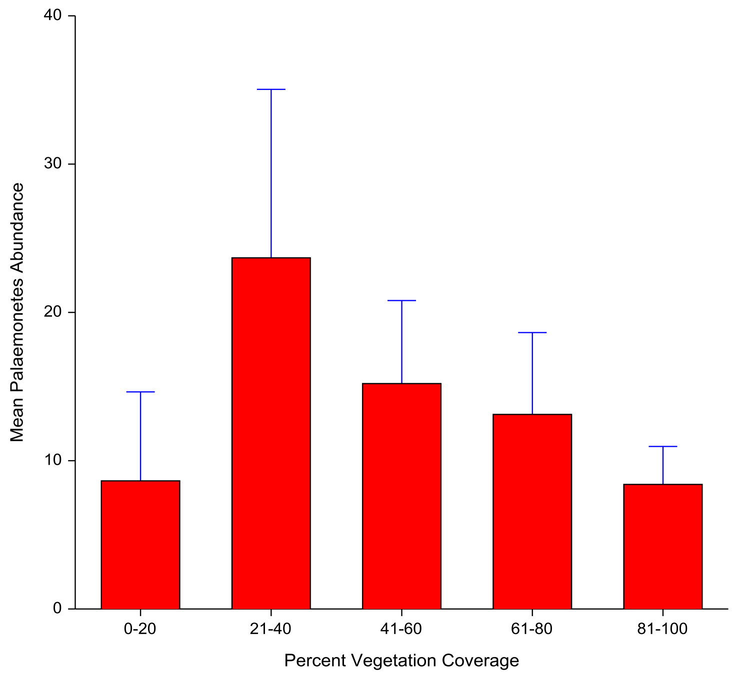

Figure 27. *Palaemonetes* mean abundance per sample in different vegetation coverage (%) in Branford, CT salt marshes.

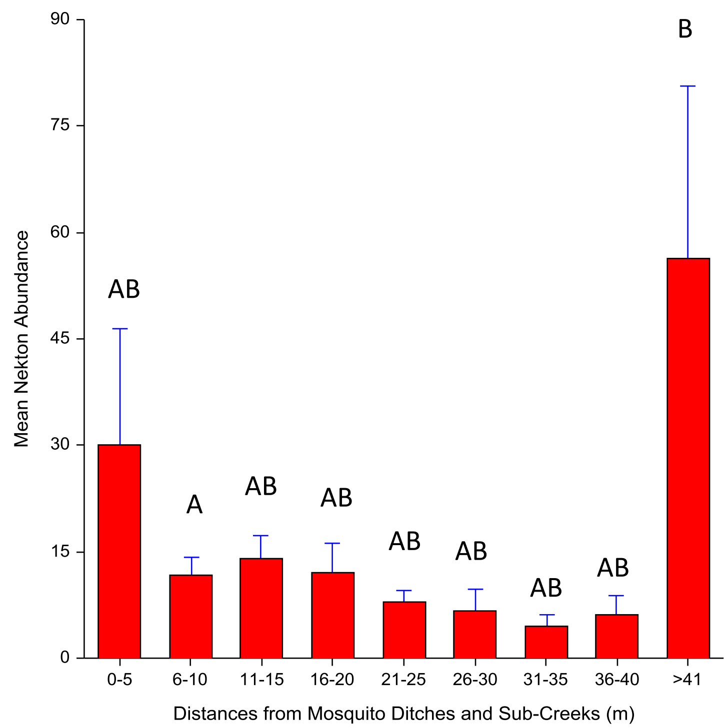

Figure 28. Nekton mean abundance per net sample from different distances of high marsh to mosquito ditches and sub-creeks in Branford, CT salt marshes.

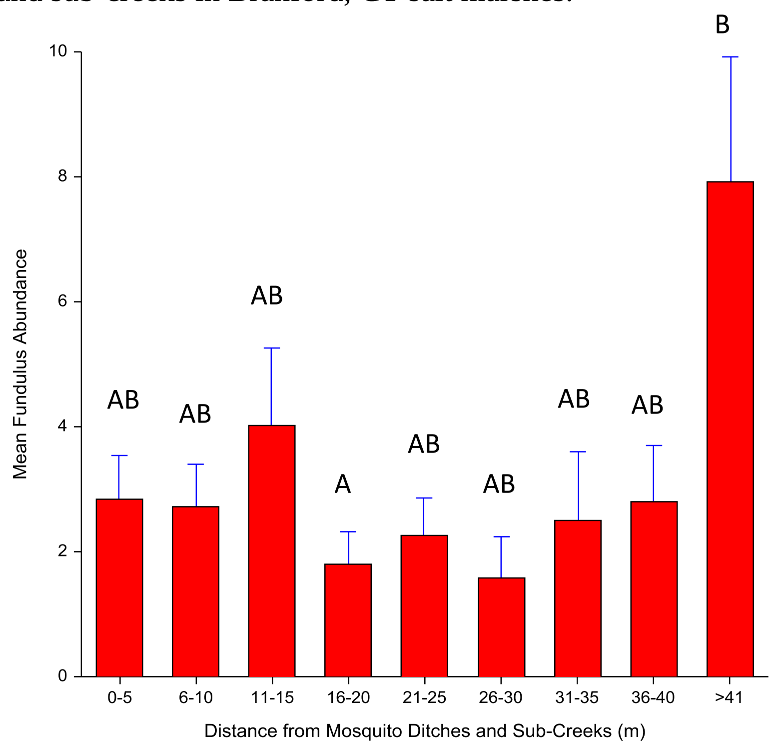

Figure 29. *Fundulus* mean abundance per net sample from different distances of high marsh to mosquito ditches and sub-creeks in Branford, CT salt marshes.

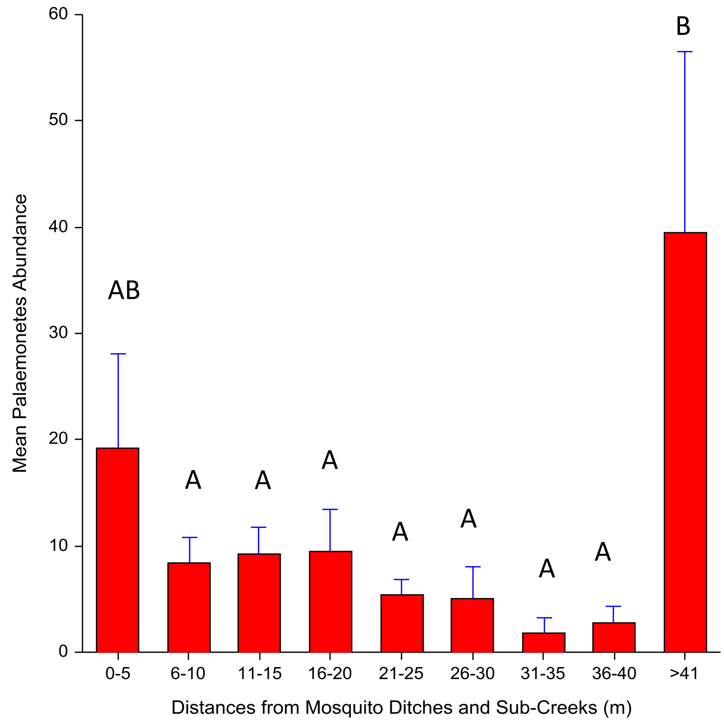

Figure 30. *Palaemonetes* mean abundance per net sample from different distances of high marsh to mosquito ditches and sub-creeks in Branford, CT salt marshes.

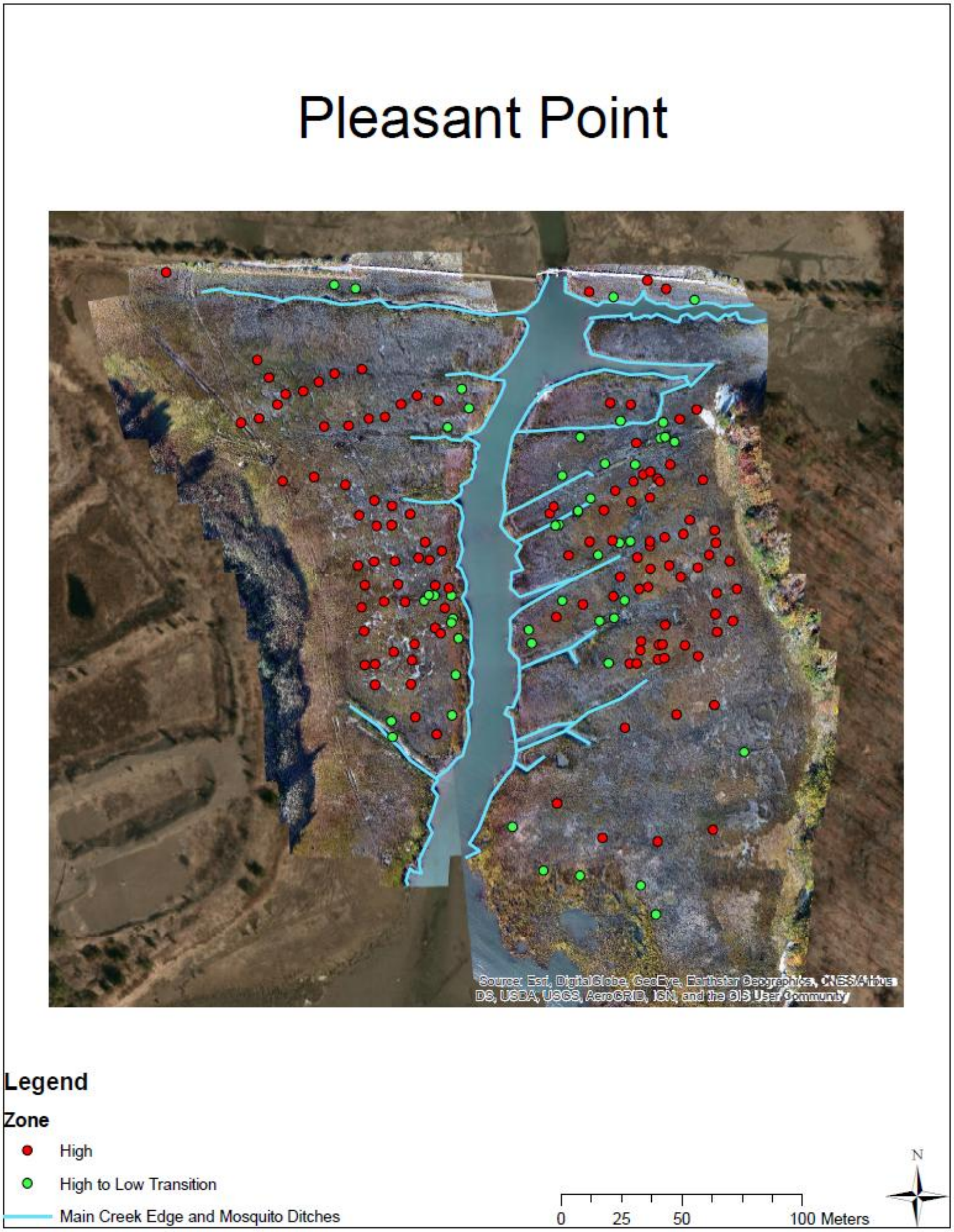

Figure 31. Identification of sample points in high and high to low transition zones within Pleasant Point salt marsh.

Figure 32. Identification of sample points in high and high to low transition zones within Banca Back salt marsh.

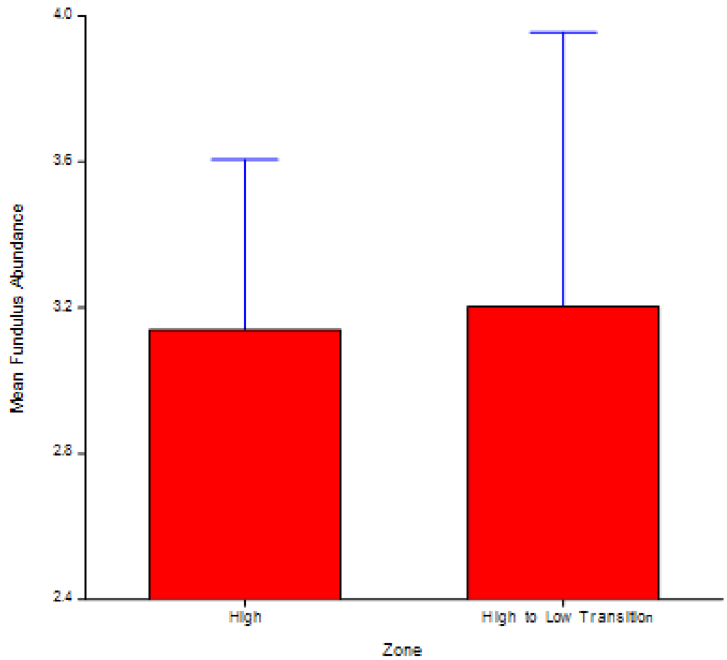

Figure 33. High and high to low marsh transition zones compared to *Fundulus* abundance without outliers (122 and 335 mean total abundance for two sample sites).

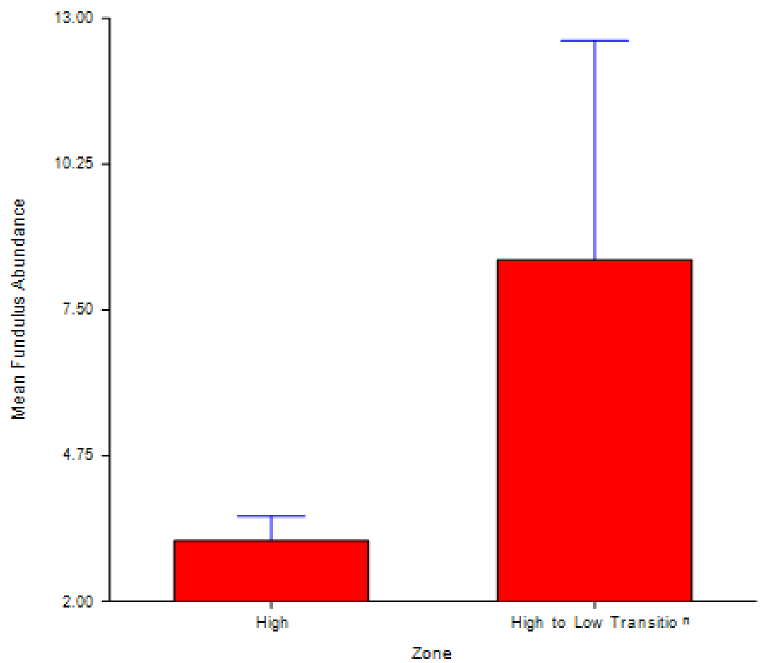

Figure 34. High and high to low marsh transition zones compared to *Fundulus* abundance with outliers (122 and 335 mean total abundance for two sample sites).

Fundulus Abundance

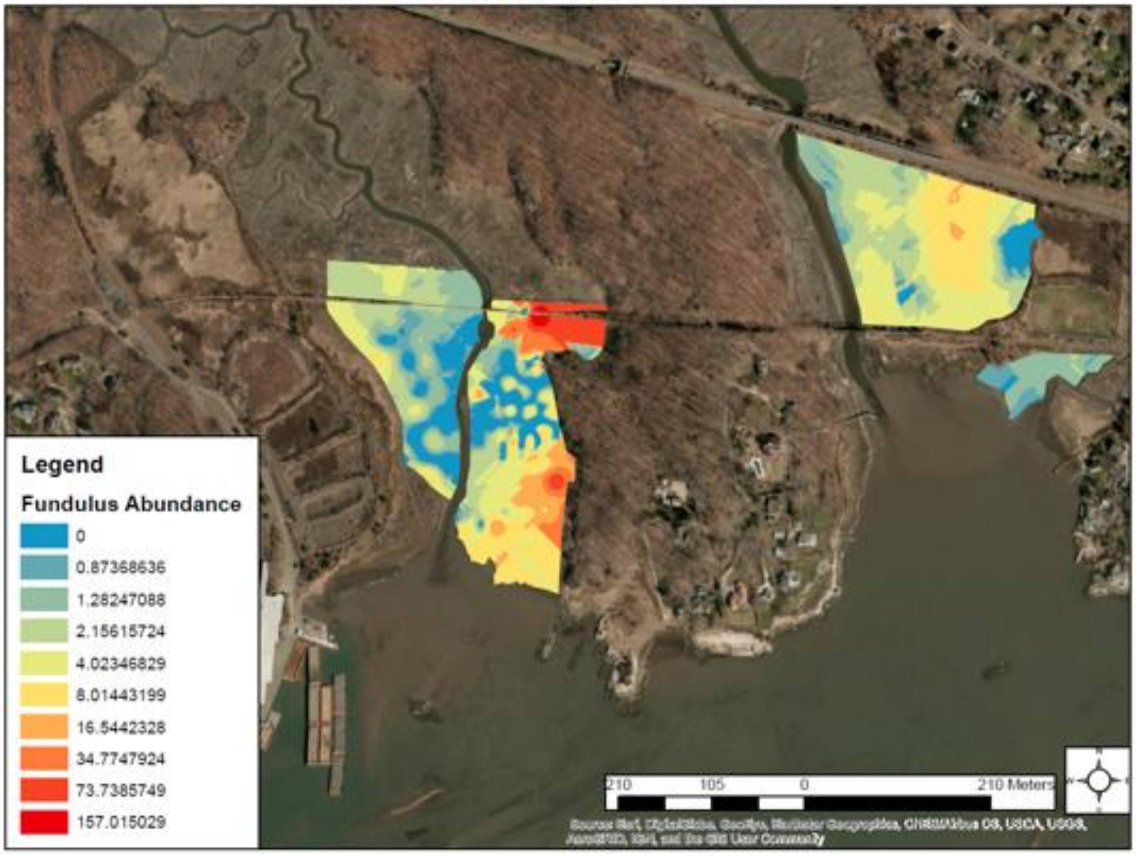

Figure 35. *Fundulus* abundance throughout Branford, CT salt marshes, where all data collected through 2015 to 2018 was used.

Error! Reference source not found.. Estimated total population of the *Fundulus* present in a given amount of salt marsh.

Pleasant Point West		Pleasant Point East		Banca Back		Banca Front	
Fish	Area (m^2)	Fish	Area (m^2)	Fish	Area (m^2)	Fish	Area(m^2)
64,607	25,897	792,429	33,403.26	218,108	37,423.06	7,745	4,865

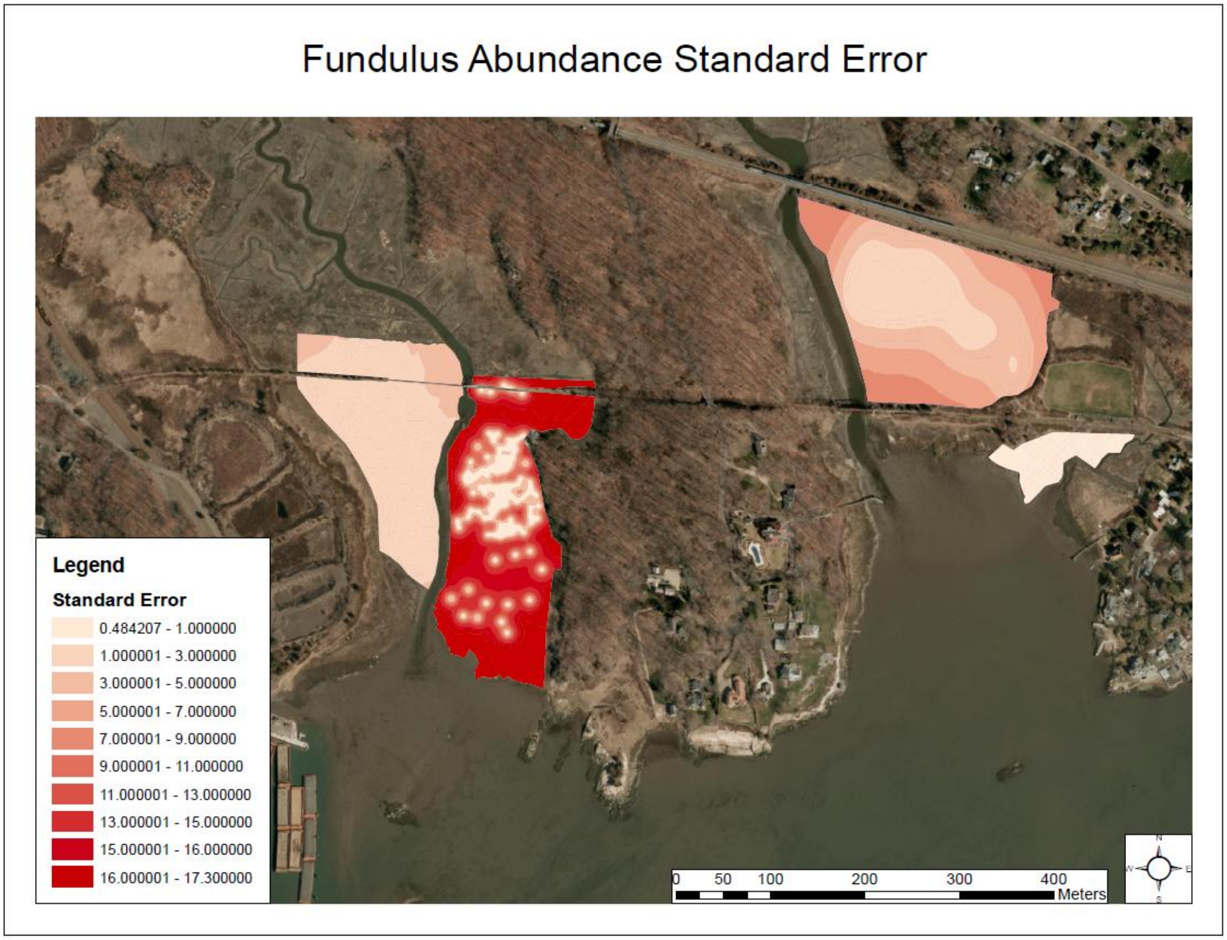

Figure 36. Standard error within estimation of *Fundulus* abundance based on sample points collected.

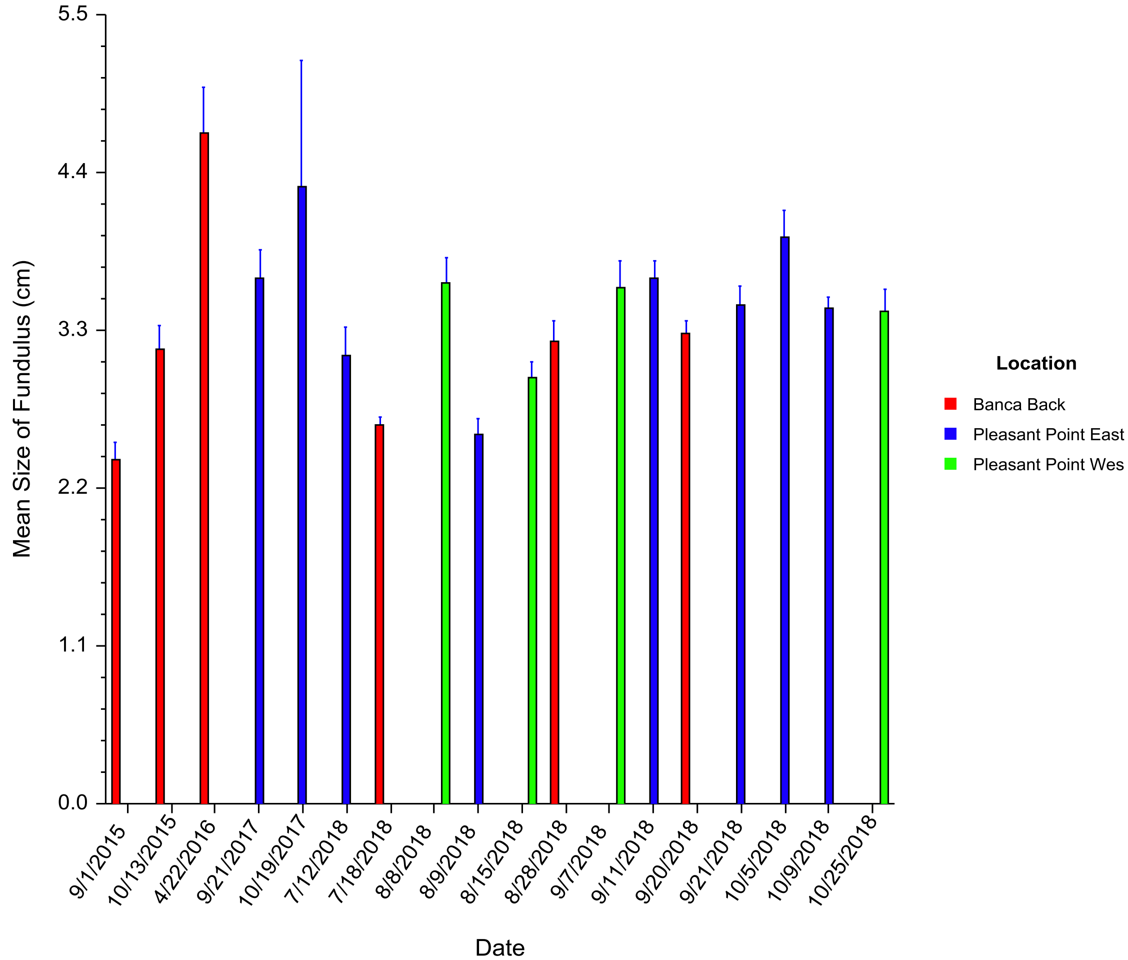

Figure 37. Mean *Fundulus* size throughout 2015 to 2018, where each date represents one marsh that was sampled in Branford, CT.

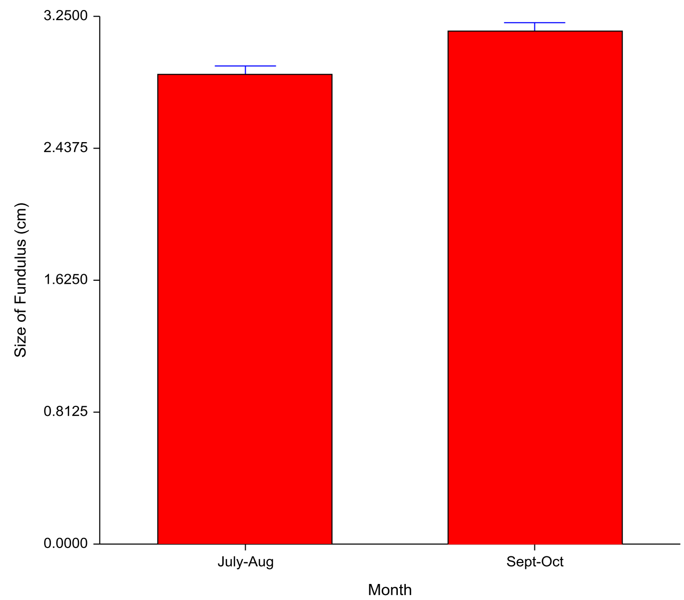

Figure 38. *Fundulus* mean size (cm) per net sample in summer compared to fall, in Branford, CT salt marshes.

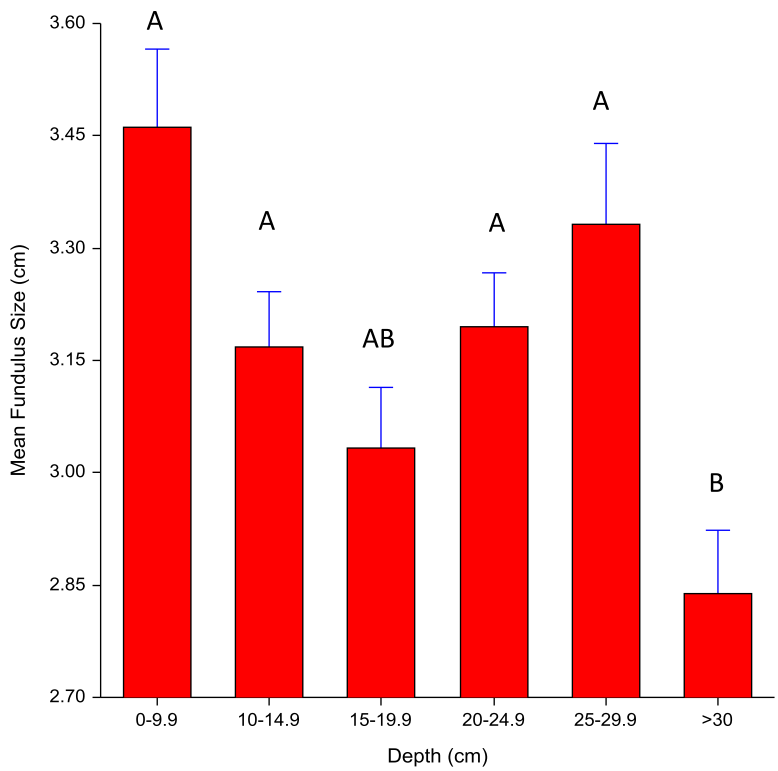

Figure 39. *Fundulus* mean size (cm) presence per net sample in different water depths in Branford, CT salt marshes.

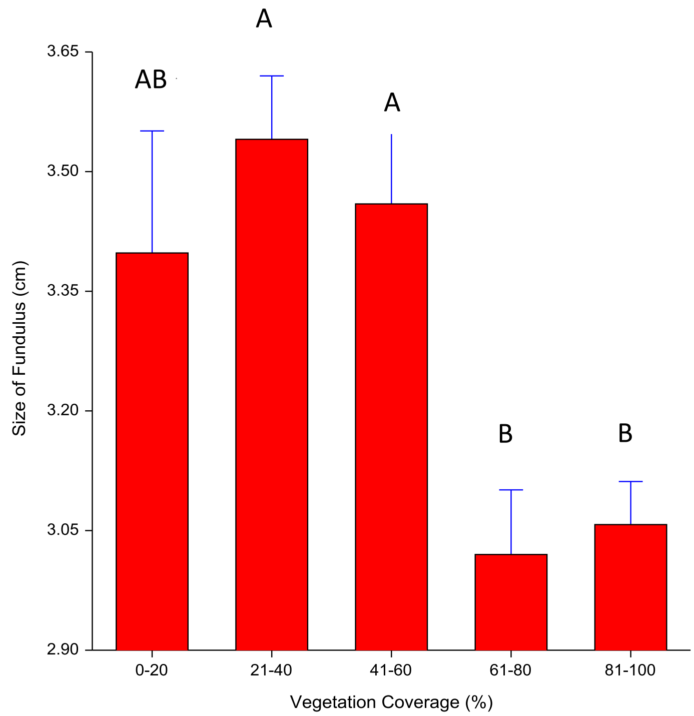

Figure 40. *Fundulus* mean size (cm) presence per net sample in different vegetation coverage (%) in Branford, CT salt marshes.

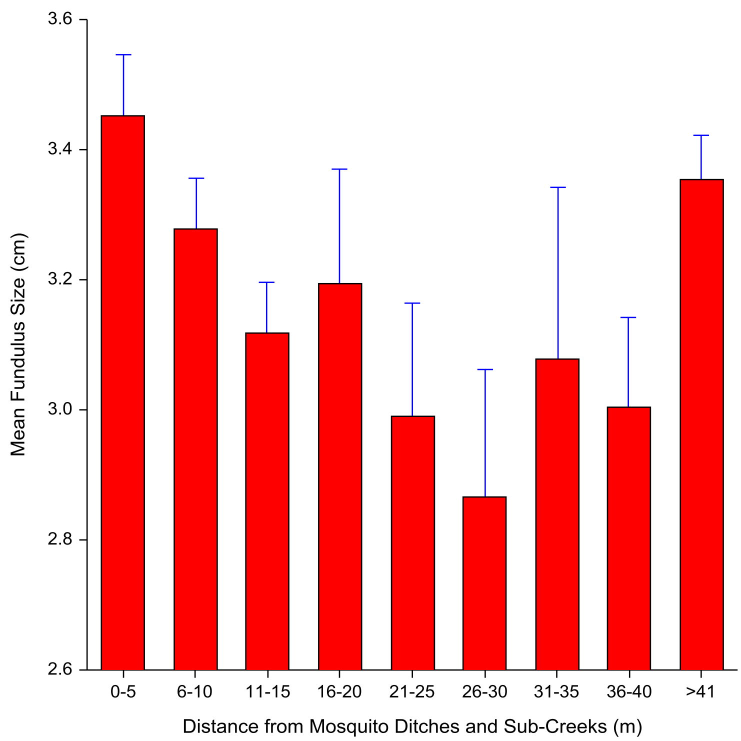

Figure 41. *Fundulus* mean size (cm) presence per net sample from different distances of high marsh to mosquito ditches and sub-creeks in Branford, CT salt marshes.

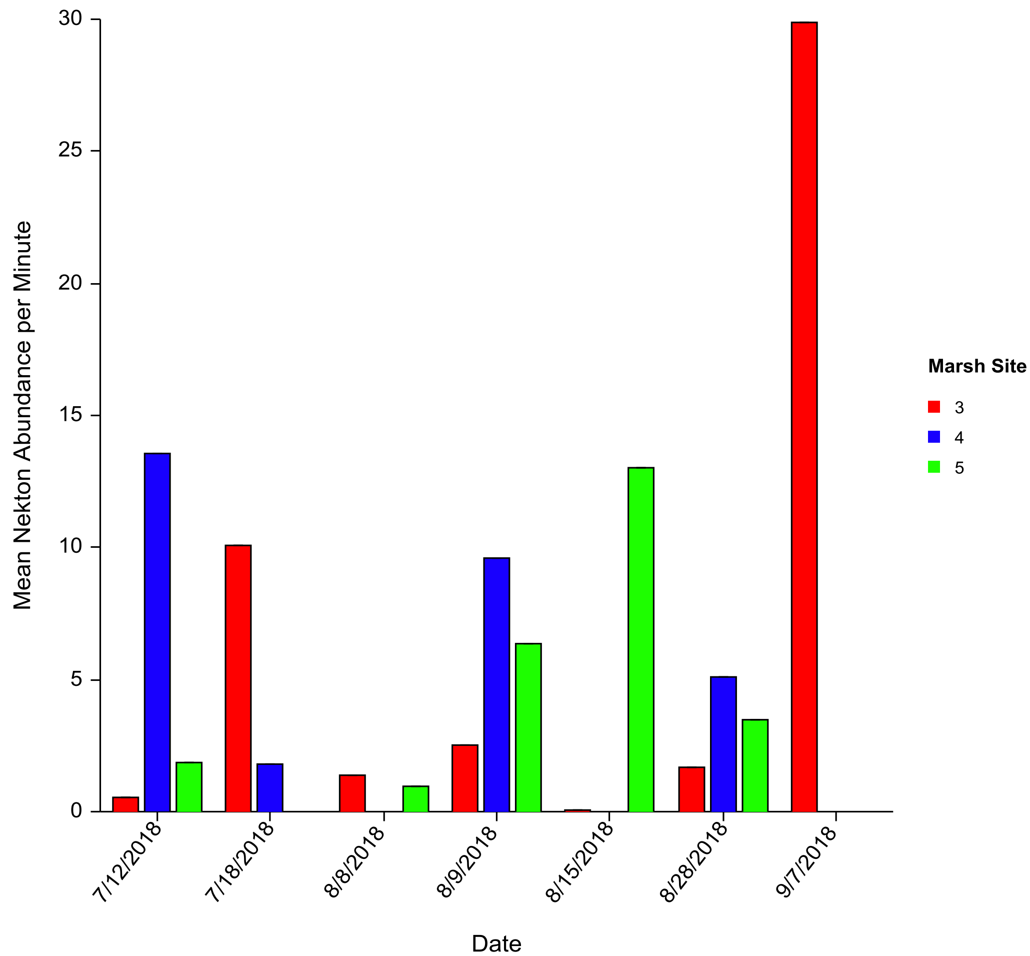

Figure 42. Mean nekton abundance per minute of Go-Pro© video analysis on each sample date throughout July to September of 2018, where 7/18/2018 camera 5, 8/8/2018 camera 4, 8/9/2018 camera 5, 8/15/2018 camera 4, and 9/7/2018 camera 4 and 5 are missing due to lack of clarity in video.

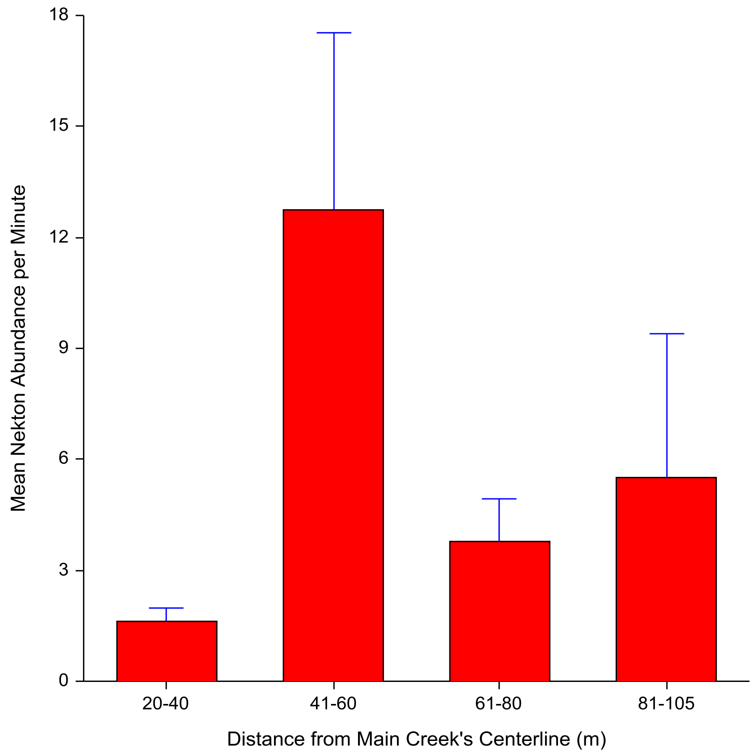

Figure 43. Mean nekton abundance per minute of Go-Pro© video analysis at different distances from the centerline of a main creek in Branford, CT salt marshes.

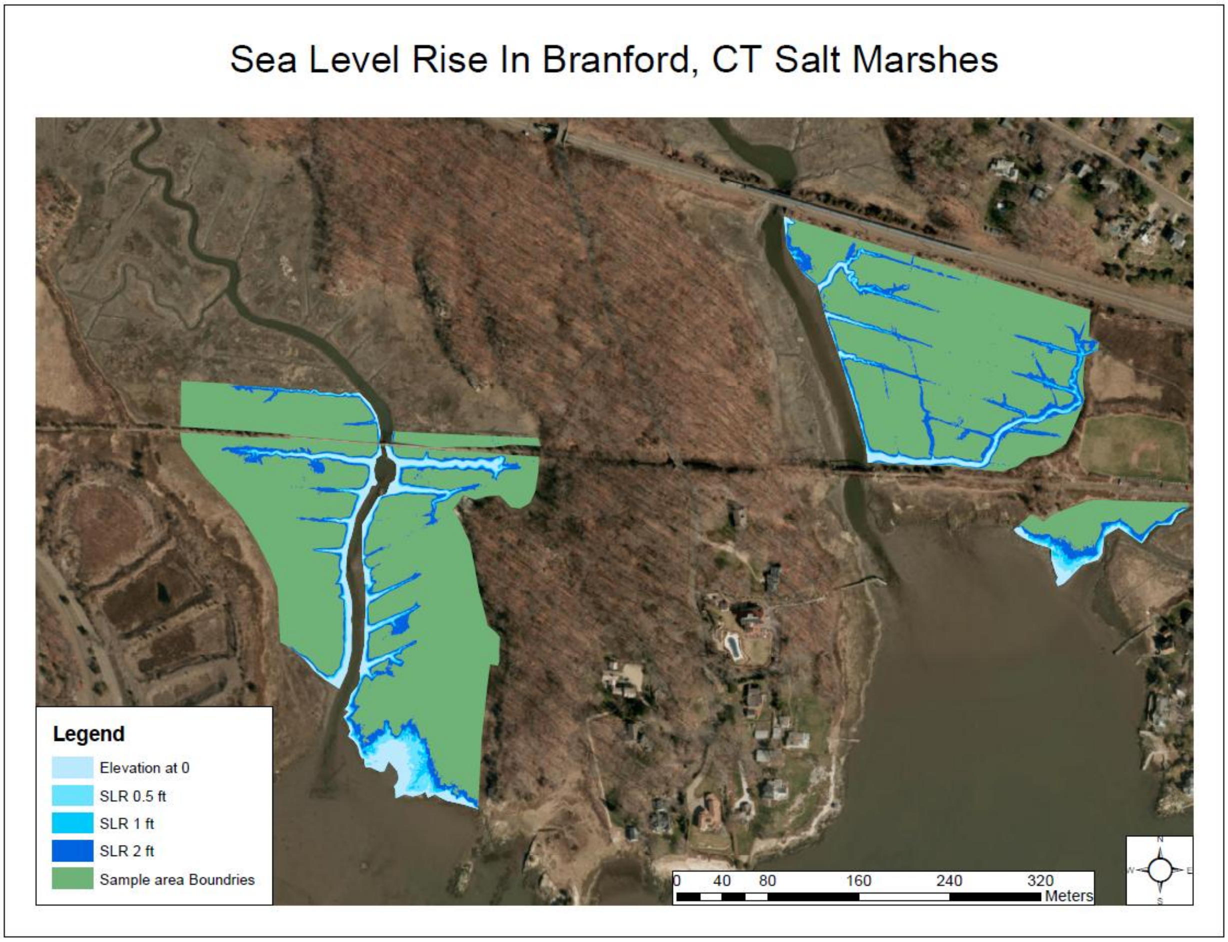

Figure 44. Predicted sea level rise in Branford, CT salt marshes.

Table 1. Increase of *Fundulus* density with increase in sea level rise.

	Pleasant Point East	Pleasant Point West	Banca Back	Banca Front
Current Population within Sample Boundary	24 fish / meter^2	2 fish / meter^2	6 fish / meter^2	2 fish / meter^2
With 0.5 foot Sea Level Rise	26 fish / meter^2	3 fish / meter^2	6 fish / meter^2	2 fish / meter^2
With 1 foot Sea Level Rise	27 fish / meter^2	3 fish / meter^2	6 fish / meter^2	2 fish / meter^2
With 2 feet Sea Level Rise	30 fish / meter^2	3 fish / meter^2	7 fish / meter^2	2 fish / meter^2

CHAPTER VI

DISCUSSION

The genus *Fundulus* made up 34% of all nekton found throughout the study, which is comparable to another study (Fell et al. 2003). In the study, *Fundulus* made up 97% of the total fish caught, which is comparable to other salt marsh studies (Kneib & Wagner 1994; Fell et al. 2003).

Net Data: Abundance

The null hypothesis for this study that there would be no difference in total nekton and *Fundulus* abundance between season and water depth was rejected. The null hypothesis that nekton and *Fundulus* abundance would not be different among varying levels of vegetation cover was supported.

In this study, nekton and more specifically *Fundulus* have higher abundance in the fall compared to the summer. Raposa and Roman (2001) found abundance to be higher in the fall compared to the summer for nekton and *Fundulus.* Depth was expected to be the leading cause of abundance change between seasons, as average water depth was expected to be significantly lower in the summer (Ruiz et al. 2003). Water depth varied throughout both seasons, leading to a small average (2.5cm) change between seasons. The difference in abundance between seasons could be due to predator presence, rather than water depth. For example, *Lagodon rhomboids* (pinfish) is a predator of *Fundulus* and can be almost three times more abundant in the summer compared to the fall (Meyer & Posey 2014). *Lagadon rhomboids* is found in higher abundances in the summer in Long Island Sound (CT DEEP 2013). *Fundulus* abundance was higher in the fall at the study sites, which may be related to lower abundance of their predators at this time of the year.

Nekton and specifically *Fundulus* abundance was significantly higher when water depth was > 30 cm and significantly lower when water depth was < 9.9 cm. Corman and Roman (2011) found *F. heteroclitus* density to increase in areas that had a water depth between 30-40 cm, but started to decrease in abundance at depths > 70 cm (Corman and Roman 2011). Water depth on the high marsh was never > 42 cm when sampling occurred at the study site.

Both nekton and *Fundulus* abundance did not vary to any great extent relative to differences in vegetation cover. Nekton and *Fundulus* abundance has been shown to increase in highly vegetated and deeper areas, as these may provide a predator refuge (Ruiz et al 1993; Minello et al. 2003). In this study, there was little correlation between high abundance and high vegetation coverage, but generally *Fundulus* abundance was lower when there was 0 to 20 % vegetation cover.

Net Data: Spatial Differences

Nekton and *Fundulus* abundance varied spatially across high marsh habitats. There were more fish in low marsh to high marsh transition areas compared to further distances on the high marsh. However, in some cases abundances increased at distances > 41 m away from the mosquito ditches, suggesting that nekton used these high marsh habitats during high tide. Similarly, Fell et al. (2003) found that *Fundulus* abundance increased as distance (10, 20 and 30 m) away from sub-tidal creeks increased. Another study showed that as the area of low marsh increased across the entire salt marsh, *Fundulus* abundance increased overall, even though the area of high marsh was larger (Meyer and Posey 2014).

Video Data: Spatial Differences

There was no significant difference in nekton abundance in videos as distance into mosquito ditches and sub-creeks increased from the main creek centerline. However, higher abundances of nekton were seen when cameras were located 41 to 60 meters away from the centerline of the main creek. In another study (Corman and Roman 2011), nekton abundance showed two distinct communities in upper versus lower ditches; richness was higher in lower ditches (11 taxa) than upper ditches (4 taxa). *F. heteroclitus* was more abundant in lower ditches (average 28.2) than upper ditches (average 8.5). *F. luciae* was also more abundant in upper ditches (average 2.7) than lower ditches (average 1.1) (Corman and Roman 2011). In this study, only abundance of nekton was counted and total abundance did not show differences in upper versus lower creek areas.

Differences in Abundances Relative to Fundulus Size

In this study, the average length of *Fundulus* was 3.14 cm and ranged from 1 to 10 cm. A majority of the fish collected were juvenile *Fundulus* (1 to 4 cm); 37% of the *Fundulus* total population caught were above 4 cm (nominal adult size) but only 5% of the total population caught were greater than 5 cm, showing a lack of large adult fish. Other studies showed a higher average length of *F. heteroclitus* (about 6 cm) (Bushbaum et al. 2006; Fell et al. 2003) and smaller ranges of *F. heteroclitus* (from 1 to 8 cm) throughout salt marshes (Yozzo and Ottman 2003).

There was no difference in size of *Fundulus* between fall and summer. In another study that compared pools to creeks, there were no large size changes when comparing seasons (Raposa and Roman 2001). Both the current study and Raposa and Roman (2001) had, on average, many juvenile fish and minimal numbers of adults. Also, samples were taken only between May through October. Raposa and Roman (2001) did a study year round, and found that there were no *Fundulus* present in the winter. However, another study found that adult *Fundulus* (≥ 4 cm in total length) increase in length from July to December (Able et al. 2006), which may be correlated with spawning.

Fundulus < 3 cm is size were more abundant at depths > 30 cm and between 15 to 19.9 cm. However, Ruiz et al. (1993) found that *F. heteroclitus* above 3 cm were more abundant at greater depths (35 cm) and fish below 3 cm were more abundant at shallow depths (1 to 18 cm). Predation in salt marshes is minimal on juvenile fish as depth decreases, which is thought to be the reason for smaller fish to be in shallow waters (Ruiz et al. 1993). The absence of a wider range of fish sizes in this study, particularly larger fish, reflects that the focus of this thesis was on the high marsh where it is likely that larger fish would not occupy due to potential exposure to predators or other conditions. *Fundulus* less than or equal to 3.1 cm were significantly more abundant in highly vegetated areas, and *Fundulus* greater than 3.4 cm in low vegetated areas. Juvenile and small adult nekton fish species, including *Fundulus,* use habitats with emergent vegetation more abundantly than adults for predator refuge (Hettler 1989).

Fundulus size also decreased as distance from mosquito ditches increased from 0 to 30 m, but size increased at distances ≥ 31 m from mosquito ditches. Most of the fish sampled were juveniles (1 to 4 cm), so it was interesting to find that even within juvenile fish there would be the spatial differences. Another study found a general increase in abundance of *Fundulus* when 30 meters away from mosquito ditches and had similar *Fundulus* sizes as this study (Fell et al. 2003).

Video Data: Limitations

Video samples were recorded from June to October 2018, but there were some limitations that did affect the analyses. First, turbidity was an issue for some video records, as some videos were not used when the water was too turbid, which was classified when vegetation could not be seen in the video. Becker et al. (2010) and Mueller et al. (2006) provided standards of turbidity levels for accuracy in underwater video collection. However, Kimball and Able (2012) had higher turbidity (5.1 NTU in 2005 and 14.1 NTU in 2006) and still were able to use their data. I did not measure turbidity directly, but in future studies this variable should be measured to provide information on environmental conditions that affected the quality of the video and the usefulness for assessing fish communities on the marsh. It is possible that a white backdrop for contrast could be used in front of the camera to help with species identification in future studies as well as was done by Kimball and Able (2012). However, this backdrop could block the travel path of fish, which may alter fish migration patterns. The backdrop could allow for *Palaemonetes pugio* to be seen better as well. James-Pirri et al. (2010) excluded shrimp from the dataset as they could not identify this species often on camera. *Palaemonetes pugio* was only seen when water was relatively clear or when they were close to the camera lens.

Future Studies

As sea level rise is predicted to on the order of 1 foot by 2050 and 2 feet by 2100 (IPCC 2013), salt marshes are projected to be inundated and their area will decrease. The abundance of *Fundulus* is affected by water depth. The preferred depth shown throughout the literature and in the study is around 30 cm for *Fundulus.* As water depth increases across the entire areal extent of salt marshes, and there are fewer shallow water habitats as associated with high tide conditions on the high marsh, densities of *Fundulus* may decrease. This may be particularly critical for small fish that use these high marsh habitats for feeding during high tide. Ruiz et al. (1993) found that water depths above 31 cm were correlated with significantly lower *Fundulus* densities. The increase in water depth may also lead to conversion of salt marsh areas to intertidal mud flats, further decreasing the amount of critical marsh for *Fundulus*. The GIS analyses conducted in this study suggest that as sea level rise increases, the density of *Fundulus* in certain marsh habitats will increase which may increase competition.

Future studies should compare salt marshes of different sizes to understand how habitat loss may affect nekton densities and differences in habitat use, and how this may affect overall population dynamics and indeed salt marsh food webs and ecosystem dynamics. Other studies should model different remediation practices to help hinder salt marsh loss due to sea level rise, and potentially assess if such remediation's can maintain nekton populations on salt marshes. Overall, salt marsh mitigation plans should be developed and assessed whether they will be able to preserve salt marsh species and ecosystems into the future (Corman and Roman 2011).

CHAPTER V

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