EFFECTS OF MARSH CHANNELIZATION ON FISH AND INVERTEBRATE COMMUNITIES AT LITTLE SAINT SIMONS ISLAND, GEORGIA

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ABSTRACT

I used effective number of species (ENS) linear models, Morisita's index of similarity, and generalized linear models to compare seasonal fish and invertebrate species diversity and assemblage differences in reference salt marshes to those altered by parallel grid ditching on Little Saint Simons Island, GA. Bag seines were deployed to capture fish and invertebrates from 6 sites over 6 sampling campaigns. I captured 20,861 sub-adult fishes representing 43 species, 23 families and 12 orders. ENS of fish and invertebrate species were not different between altered and unaltered marshes. The fall campaigns had very similar assemblages of fishes between altered and unaltered marshes, and assemblages captured during summer campaigns were either dissimilar or moderately similar. GLM models predicted that mummichog, sailfin molly, white mullet, and spot were more likely to inhabit altered marshes year-round and Atlantic silverside, bay anchovy and striped mullet were more likely to inhabit unaltered marshes year-round.

INDEX WORDS: Parallel grid ditch, Channelization, Salt marsh, Marine fishes, Marine invertebrates, Effective Number of Species, Morisita's, Assemblages, Water Quality, Barrier island, Georgia, Little Saint Simons Island

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DEDICATION

To my favorite ladies in the world:
My bride Katelyn
My mom Suzette

You are both everything to me. I miss you mom and wish you could have read this. You probably would not have let me get this close to alligators and rattlesnakes. I love you Katelyn with all my heart.

To my son, Henry Boone, who was born 7/28/2020:

Follow your dreams, listen to your heart, and follow the beat of your own drum.

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CHAPTER 1

LITERATURE REVIEW

Restoration Efforts

As a consequence of altering salt marshes over the last century, channelized salt marsh may be affected and the ecosystem may become less biodiverse than unaltered habitats (Talbot et al., 1986; Kuhn et al., 1999; Partyka & Peterson, 2008; C. Talbot et al., 2018). Fish assemblages, particularly the absence or presence of key estuarine or marine species, provide a metric of marsh health. Studies to monitor a specific migratory species such as striped bass and herring throughout its life stages, as it travels through corridors from a marsh to a larger system to complete their life stages have been performed repeatedly (Able et al., 2007). Within salt marsh systems, connectivity of subtidal and intertidal creeks with marsh pools is imperative for reproductive cycles of estuarine and diadromous fish species (Able et al., 2012). Salt marshes in Georgia often lack the permanent marsh pools found in New England marshes; therefore, marsh creek connectivity and sinuosity are imperative for estuarine and diadromous fishes of the Southern Atlantic coast to complete their life stages (Kneib, 1994). Losses in the productivity of a salt marsh system linked with breaks in connectivity downstream results in a significant reduction in richness and diversity of residential estuarine fishes (Rudershausen et al., 2016).

In an effort to improve the functionality of an altered salt marsh, a restoration technique called structural marsh management (SMM) was implemented to a preexisting altered salt marsh habitat by excavating a small pond over the site (Kuhn et al., 1999). This allowed the restoration team to enclose a marsh area and construct flood gates to manage the water level as a means of reducing tidal scouring or erosion. However, SMM was not recommended as it increases accretion rates and leads to overall wetland loss (Kuhn et al., 1999).

Restoration of natural function of marshes altered for human purposes have been ongoing for decades, all with varying degrees of success. For example, a new technique called Open Marsh Water Management (OMWM), created in the 1960's, involved installing several small pond excavations that were connected by curved ditches (Lesser, 2007). This technique allowed tidal exchange to occur, removing stagnant water suitable for mosquito breeding. Plugging parallel grid ditches with peat or plywood to prevent the draining of water from the high marsh has been a common procedure in OMWM (Riepe, 2018). OMWM have been extremely successful in many cases and were utilized to restore a New Jersey salt marsh site that now contains fish densities and tidal flows similar to an untouched reference salt marsh site (Talbot et al., 2018). Care should be used in restoration projects in the salt marsh when refilling an altered site with oceanic tides, as potential nutrient loading can alter the biogeochemistry and ecological function of the system (Portnoy, 1999).

Species Diversity

Ecologists often use indices, such as the Shannon Diversity Index (H') to measure the biological diversity of a system, by taking into account the number of species and the proportion of each species in a sampling site; these data can then be used to compare diversity among sites. H' is often used to generate statistics by using diversity as a metric of habitat health and function, especially in community studies. While accepted in the scientific literature, there are issues that arise from the inherent nonlinear relationship of H' and diversity. Indices are not a true indicator of diversity; rather a measure of entropy (Chao, 2004). For example, a toxin that enters a lake containing 500 equally common species and kills 50% of the population would yield a 6.227 H’ before the spill and 5.544 after (10% decrease).

Effective number of species (ENS) is the exponent of H’ and allows a true estimate of species diversity to be calculated on a linear scale, whereas H’ is calculated on a non-linear scale (Chao, 2004). ENS has been used in many projects interested in observing species diversity (e.g., H’) and community structure.

Managed wetlands in the southeastern United States have been designated for waterfowl habitat, specifically for attracting game species of North American duck. Within these compounds, tidal flow is altered and controlled with flood gates to maintain higher water levels during the avian migration in the fall and winter. However, this management approach for waterfowl may not be beneficial for fishes. For example, more larval and subadult fishes (as indicated by ENS), occurred in two wetlands managed for fishes in coastal regions of South Carolina compared with two similarly sized adjacent wetlands managed for waterfowl (Carswell et al., 2015). Further, species diversity in fish managed wetlands was higher than in waterfowl managed wetlands (Carswell et al., 2015); they suggested that frequent tidal exchange is vital for larval fish survival and presence.

Similarity Indices

Similarity indices are used to compare community data with other data sets or between treatment groups. Robinson and Jennings (2014) used a Morisita’s index of similarity to compare assemblages of fishes captured in a South Carolina impoundment to those from 12 other impoundments and reference marsh locations in North Carolina and South Carolina. This index has values that range from 0 for assemblages that are completely dissimilar to 1 for assemblages that are identical. Robinson and Jennings (2014) assigned their assemblages to classes based on the following criteria for Morisita's Index: a score of 0.25 meant assemblages were somewhat similar, 0.50 were moderately similar, and 0.75 were very similar. They found 53% of the impoundments were moderately similar, while only 7% of impoundments-reference sites were moderately similar. They noted that the similarity index score decreased by 63% when the tidal influence differed between the assemblages.

Community Structure

Fish assemblage data are often collected to evaluate the health of an aquatic system's community structure and ecological function. Analyzing fish populations that may be affected by some sort of perturbation are often sorted into functional groups, or guilds (Nordlie, 2003; Robinson & Jennings, 2014). Organisms are often assigned to a guild based on its life stage, migratory pattern, trophic level, phylogenetic category, or some other categorical group. Migratory guilds are used to categorize fishes utilizing a specific function within a marine or brackish system.

Hierarchical linear models (HLM) have been used to analyze data in a multitude of ecological studies to address questions about the assemblages of organisms (Vierheller, 2014). HLM is an extension of a generalized linear model (GLM) that uses beta parameters to estimate the slope of a regression; this information can be used to test a large matrix of categorical and continuous data to test for relationships between response and explanatory variables (Chao, 2004). This type of data analysis was first used in sociological studies and has become a common data analysis tool for environmental and experimental research designs. HLM are used for a nested design analysis; ecological data sets often contain factorial nested measurements such as site, sample, month, season, and year. A HLM or GLM can be a useful tool to interpret ecological data by incorporating the effects of variables such as water quality, habitat types, community structure, population dynamics, temporal and spatial data.

Using a hierarchical linear model (HLM), Carswell (2015) found differences in fish assemblages between wetlands managed for fish and those managed for waterfowl. He concluded that a consistent and complete tidal exchange is imperative to maintain a diverse sub-adult fish assemblage in marsh impoundments.

Using migratory guilds as a monitoring unit, Robinson and Jennings (2011) determined that a reduction in connectivity and amplitude of tides in a Southeastern Atlantic salt marsh habitat can significantly lower the diversity of marine migrant fishes within the system. A similar pattern was observed in Florida (Harrington & Harrington, 1982). They concluded that the lower numbers were directly related to reduction in food items after the implementation of an impoundment. The impoundment experienced a decrease in vegetation supplying vascular tissue and shelter for herbivorous fishes. This relationship was seen in managed salt marshes in Louisiana that yielded lower productivity due to a restriction in migration patterns for larval estuarine fishes (Hoese, 2007).

Field Site: Little Saint Simons Island

Anthropogenic History on Little Saint Simons Island

Records as early as 2000 B.C.E. show anthropogenic activity from Guale indigenous people on LSSI (Thompson & Worth, 2011). “Middens” were formed when the Guale people harvested oysters and left a massive pile of shells to form a small hammock. The indigenous people utilized the salt marshes of the Southeastern US for its steady supply of fish, mammals, and shellfish. The Guale people were chased away from their homeland with the settlement of

Europeans in the 15th century. Guale middens still exist on the North end of the island, with several extant bridges and dikes running throughout.

LSSI was later offered to Swiss colonist Samuel Ougspourger via king grant in 1760 AD (Sullivan, 2002a). A few years later the island was later purchased by English Loyalist brothers John and James Graham who intended to convert the salt marsh into viable agriculture land. LSSI was later bought by Major Pierce Butler in 1774, along with a large area of Saint Simons, Hampton Point, and Butler’s Island. Butler used enslaved African people to run a massive agricultural operation in harsh conditions to produce cotton and rice. LSSI remained in the ownership of the Butler family until descendant Francis Butler Leigh sold the island for $12,500 to Eagle Pencil Company owner O.F. Chichester in 1908. With intentions to clear cut Eastern Red Cedar for pencil production, Chichester realized that the trees were twisted from the saltwater and wind and would not work for pencil production. He removed several trees, then sold the island to Philip Berolzheimer at the end of 1908. The Berolzheimer family imported several nonnative animals including red deer, sika deer, fallow deer, elk, turkey, and bobwhite quail onto the island (Morse, 2008). They built several blinds and towers on the island for duck and deer hunting. During their ownership of the island, the Civilian Conservation Corps (CCC) installed the parallel grid ditches to create increased habitat for insectivorous fishes for mosquito control (Coleman et al., 2018). The Berolzheimer family opened up the Lodge on Little Saint Simons Island in 1978 as a means of generating income and inviting guests to visit the private island (Sullivan, 2002b). The family retained ownership of the island until former Secretary of the Treasury and C.E.O of Goldman Sachs Hank Paulson obtained full island ownership in 2014.

CHAPTER 2

INTRODUCTION

Salt marshes provide vital habitat for an array of estuarine and marine organisms. With a large food supply and shelter from predation, estuarine and marine fish populations use salt marsh creeks for spawning and nursery habitats (Kneib, 1984). Diadromous fishes that utilize salt marshes and estuaries for nursery habitat depend on a corridor to the ocean to complete their life stages and forage for food in different locations (Dobson & Frid, 2009; Able et al., 2012). Salt marsh creek hydrology is highly variable; changes in water depth, sinuosity, substrate composition, turbidity, salinity, and temperature can greatly influence the community structure within these systems. While estuarine and marine organisms are resilient to fluctuations in these variables, deviations from average conditions may affect an organism's migration. On the macro-scale, seasonal changes of water quality are the mechanisms that drive fish migration towards suitable habitat (Dobson & Frid, 2009; Robinson & Jennings, 2014).

Tide cycles can also alter the community structure of a salt marsh creek. Tides vary daily between incoming (flood) and outgoing (ebb) cycles. Tidal flow is affected by the distance of the moon in relation to the Earth, and new moons and full moons will increase the tidal surge between tide cycles (Dobson & Frid, 2009). The flooding tidal surge provides nourishment for vegetation in riparian buffers and floodplain zones. This vegetation provides food and shelter for invertebrates like periwinkle snails, fiddler crabs, and residential estuarine fishes (Kneib, 1994; Luk & Zajac, 2013; Moffett & Gorelick, 2016).

The salt marshes in Georgia contain approximately 378,000 acres of habitat that have been identified as “one of the most extensive and productive marshland systems in the United States” (GADNR, 2020). This accounts for nearly 1/3 of all salt marshes in the eastern coast of the United States.

While salt marshes are a naturally dynamic and stochastic system, anthropogenic alterations have induced unpredictable and inconsistent tide cycles. Most alteration projects were constructed for farming or pest control—mainly to reduce mosquito and invasive species populations (Talbot et al., 1986). Early alterations of salt marshes began with rice cultivation circa 1760-1860 along the Eastern seaboard of the United States. Installing flood gates in a salt marsh creek allowed a farmer to control the level of water and salinity in a given area based on the fluctuation of tidal creek water and freshwater from rain or Floridan artesian wells (Sullivan, 2002a; Cotton, 2004; Seabrook, 2012).

Little Saint Simons Island (LSSI), a small barrier island of the Georgia (USA) coast, contains several hundred acres of parallel grid ditching installed by the CCC in the 1930’s. Except for the changes in the hydrology from marsh alteration, LSSI has very little anthropogenic influence (Sullivan, 2002a). LSSI is an ecologically intact Holocene era island that has hosted an array of scientific studies for several decades. Many of these projects include analysis of salt marsh and beach habitats to study populations of shorebirds, songbirds, reptiles, mammals, invertebrates, and plant communities (Morse, 2008; Colbert, 2016; Sterling, 2017). Nearly 8,000 acres on LSSI is classified as Southern Atlantic Coastal Plain Salt and Brackish Tidal Marsh, while the additional 3,000 acres comprises of upland habitats of maritime live oak hammocks (upland marsh islands), oak-cedar-palmetto marsh hammocks, maritime pine upland flatwoods, sweet grass-wax myrtle interdune meadows, and Atlantic Ocean beach habitat (Coleman et al., 2018).

The channelized areas from the 1930's are still present in the salt marshes of LSSI today and there is visual evidence of unsuccessful connectivity to a large water source based on lack of tidal flooding, high sedimentation rates, and marsh plant dieback from previous surveys. The lack of flooding tidal water in this area has changed much of the landscape in the floodplain and has led to large-scale die-off of plants like wax myrtle (*Myrica* sp.) and smooth cordgrass (*Spartina alterniflora*) during periods of drought. Several altered sites have lower water levels at high tide relative to other unaltered habitats of similar stream width and elevation. A contemporary analysis of water quality and diversity of fishes captured at altered and unaltered sites will answer the question whether channelized sites are in fact impeding the production and success of the salt marsh.

Despite knowledge of fish dependence on intact salt marshes, few studies have analyzed fish populations in smaller tidal creeks along the Southeastern Atlantic Coast, perhaps due to complex tidal cycles exhibiting the highest production rates and greatest tidal amplitude on the east coast of the United States. Given that many salt marsh creeks along the eastern seaboard have been modified, evaluating the species compositions of fishes and invertebrates present in salt marshes containing parallel grid ditches compared to reference marshes, as well as baseline studies of water quality variation between altered and unaltered salt marshes is critical to test for anthropomorphic effects.

In this study, I undertake a previously unavailable analysis of salt marsh fish assemblages and connectivity within reference (unaltered) streams and parallel grid ditched (altered) sections of the Little Saint Simons Island marsh system. The results of my analysis will be used for decision support to evaluate potential management actions, as necessary, to return altered salt marsh habitats to a natural state on LSSI and other southeastern marshes. Further, my approach can be used to evaluate similar marshes in southeastern US. A return to natural habitats may increase the biomass of resident and migratory fishes thereby improving foraging habitat for wading birds, mammals, reptiles, and other estuarine organisms (Harrington & Harrington, 1982).

The goal of this project was to determine whether parallel grid ditches affect assemblages of fishes and invertebrates on a barrier island in Georgia. My specific objectives were as follows:

a. Compare water quality variables (temperature and salinity) between altered and unaltered marshes on LSSI
b. Compare effective number of fish and invertebrate species between altered and unaltered marshes on LSSI
c. Compare similarities of fish assemblages between altered and unaltered marshes on LSSI
d. Investigate probabilities of occurrence in altered or unaltered marshes for prevalent fishes captured on LSSI

CHAPTER 3

METHODS

Materials and Methods

Six sites were identified on Little Saint Simons Island to compare overall fish and invertebrate communities in altered and unaltered marshes (Figure 2). The six sites were comprised of three altered sites < 5 meters from a parallel grid ditch, and three unaltered sites > 50 meters from a parallel grid ditch to attempt to avoid extraneous effects of bridges or other infrastructure (Appendix I). Selected streams were all wadable; 3-5m wide, ~ 4m deep, with similar elevation and sandy substrates. I sampled these locations over three summer campaigns and three fall campaigns (Appendix H).

Following methods described in Jennings & Weyers (2002), I used a seine net fitted with an internal bag seine to capture fishes from each site. These 0.63-cm mesh seines were 9.1m long x 2.4m high and contained a 2.4 x 2.4 x 2.4-m bag. I used four PVC pipes (1.5m) to anchor the net to the banks. At slack high tide, my field technicians and I deployed the seine net across the tidal creek, so the lead line was taut (Appendix D & E). We then fastened each end of the float line to the opposite stream banks by looping them around the other two PVC pipes, opening the net for fish capture and allowing the net to enclose on itself as the tide dropped (Jennings & Weyers, 2002). I measured water quality variables with a YSI multiprobe at the peak high tide when nets were deployed. Water quality variables included temperature (ºC) and salinity (parts per thousand). I deployed nets for 4 hours to ensure the bag seines closed and avoid any loss of fishes from a change in the tide cycle. We pulled the nets onto the shoreline and immediately placed all specimens in a labeled jar containing 95% ethanol. Any blue crabs captured at these sites were transferred on ice to a freezer on LSSI.

Once all six sites were sampled each season, all fishes and invertebrates were taken to the Aquatic Biology and Ecotoxicology Laboratory (ABEL) at the University of Georgia; all fish were identified to species and 30 individuals from each species were measured for total length (mm) and weight (g). For species with more than 30 individuals, the remaining individuals were weighted, and their total weight divided by the mean weight of the first 30 individuals to estimate abundance. All data were entered into a Microsoft Excel spreadsheet and analyzed in R (R Studio Team, 2018)**.**

Statistical Analysis

Water Quality Data

After averaging the three water readings from each site during each campaign, I used a t-test to test for differences in temperature (ºC) and salinity (ppt) between altered and unaltered marshes during each of the six campaigns.

Fish and Invertebrate Effective Number of Species

I used Shannon's Diversity Index (H') and the exponent from this index to calculate assemblage diversity and to estimate true diversity of fishes (effective number of species (ENS)) on a linear scale (Chao, 2004; Carswell et al., 2015). To calculate H', I first took the proportion of individuals (p_i) captured from the i^{th} species at the j^{h} site among the k^{th} sample. I then multiplied

p_i to the natural log of p_i and summed all values to produce the H’ from each site during the six samples (n=36).

$$H'(sample\ k) = \sum_{i=1}^{site\,j} p_i * |\ln p_i|$$

Using the H’ from each sample in all sites, I calculated the ENS by taking the exponent of the H’ value from both conditions in each sample:

$$ENS = e^{H'}$$

I averaged the ENS from sites into marsh condition when the tests showed no statistical difference between sites. I utilized a linear model to evaluate differences in mean ENS in response to continuous covariates (water temperature and salinity) (n=36).

Morisita’s Index of Similarity

Using the raw data of fishes collected on Little Saint Simons Island between 2018-2019, I used a 12x12 matrix to investigate the similarity among pooled samples of fishes captured in altered and unaltered marshes during each of the six. Following the methods of Robinson and Jennings (2014), I used a Morisita’s index of similarity (MIS) to obtain correlation coefficients between assemblages of fishes captured in altered or unaltered marshes between the 6 sample campaigns. A MIS correlation coefficient of 0 is equivalent to completely dissimilar assemblages, 0.25-0.49 is somewhat similar, 0.50-0.74 is moderately similar, and 0.75-1 is very similar. A MIS allowed me to determine if fish assemblages were similar or dissimilar between altered and unaltered marshes during each campaign.

Fish Occurrence Generalized Linear Models

To gain additional insight into the assemblages of prevalent fishes captured on LSSI, I used general linear models to investigate the effect of marsh condition on abundance of individual fish species. The fishes assessed in the models were: Atlantic silverside (*Menidia menidia*), bay anchovy (*Anchoa mitchelli*), mummichog (*Fundulus heteroclitus*), sailfin molly (*Cyprinodon variegatus*), striped mullet (*Mugil cephalus*), white mullet (*Mugil curema*), and spot (*Leiostomus xanthurus*).

After plotting my count data, I found they were not distributed normally. I used a generalized linear model (GLM) with a Poisson distribution to assess the effect of predictor variables on count values of the prevalent fishes.

For this analysis, I used marsh condition and values of salinity (ppt) and temperature (°C) obtained from the altered and unaltered marshes on LSSI as predictor variables in the models. I used an 85% confidence interval to calculate upper and lower limits for each of the variables in my models, as Arnold (2010) claims that a lower confidence interval of 85% would show that "model-selection and parameter-evaluation would be more congruent". Parameter estimates whose intervals did not contain zero were judged to be strong predictors of fish abundance.

I used Akaike's Information Criteria (AIC_c) with small sample size adjustment (Hurvich & Tsai, 1989) to select among a group of candidate models for each species to identify the best fitting model. AIC_c is an entropy-based measure of fit for the best model and generates an Akaike weight (ωi) to show the weight of support for a model that supports the data with the least parameters. All models were generated in R.

CHAPTER 4

RESULTS

Water Quality

During summer campaigns, mean water temperature was 29.3±1.1 °C (SE) in altered marshes (n=3) and 28.7±0.6 °C in unaltered marshes (n=3) (Figure 3; Table 1). Altered marshes in the summer had mean salinity readings of 30.2±2.5 (SE) ppt and 30.6±1.7 ppt in unaltered marshes during summer seasons.

In fall campaigns, mean water temperature was 19.9±1.5 °C (SE) in altered marshes (n=3) and 19.9±1.2 °C in unaltered marshes (n=3). Altered marshes in the fall had mean salinity readings of 30.9±1.4 (SE) ppt and 31.5±0.9 ppt in unaltered marshes during summer seasons.

Using separate t-tests to compare readings from altered and unaltered sites in each campaign, I found significantly different water temperatures among conditions during the first summer campaign in July 2018 (*p*-value= <0.001), and first fall campaign (*p*-value= 0.03). All other comparative analyses showed that temperature did not vary significantly between altered and unaltered marshes in the other four campaigns. The t-tests comparing salinity readings from pooled sites in the same condition among each campaign did not show any significant differences.

Invertebrate Effective Number of Species

I captured 9,802 invertebrate organisms representing six species from six families (Tables 2 & 3). Of these invertebrates, 83% were grass shrimp (*Palaemonetes pugio*) and 14% were white or brown shrimp (*Litopenaeus* sp.). The linear models showed the response of ENS to condition (p=0.50), water temperature (p=0.27), and salinity (p=0.15) (Figures 4 & 5). None of these interactions were statistically significant.

Fish Effective Number of Species

Between 2018 and 2019, I captured a total of 20,861 sub-adult fishes representing 43 species, 23 families, and 13 orders over the two-year study (Tables 4 & 5). The linear models showed the response of ENS to condition did not have a significant response to ENS (p=0.72), while the response of ENS to water temperature (p=7.9E-4) and salinity (0.01) did (Figures 6 & 7).

Morisita's Index of Similarity

The results of similarity analysis indicated that fish assemblages were either dissimilar or moderately similar between altered and unaltered marshes during summer campaigns and virtually identical during the fall campaigns (Figure 8). The Morisita's index for fish assemblages in altered and unaltered marshes during the first summer campaign in July 2018 was 0.06, closer to the range of complete dissimilarity. In 2019, fish assemblages were moderately similar in early and late July, with Morisita's index values of 0.65 and 0.55, respectively. Fall samples were virtually identical during all three campaigns, with values of 0.99 in November 2018 and October 2019 and 1.00 in November 2019.

Fish Occurrence Using Generalized Linear Models

The global model containing the variables condition, temperature, salinity, and the interaction of condition and water temperature was the best fitted model with the strongest effects on the occurrences of Atlantic silverside, bay anchovy, and striped mullet, respectively. The global model for each had an Akaike weight of 1.

For mummichog, the best model showed that condition, water temperature, and salinity predictor variables had the strongest effects on abundance. This model was 2.35 times more likely than the next strongest model that included the interaction of condition and salinity. The best model, which removed all interaction terms had an Akaike weight of 0.61. The next best model had an Akaike weight of 0.26.

The best sailfin molly model showed that condition, water temperature, and salinity predictor variables had the strongest effects on abundance of these fishes. This model was 47.00 times more likely than the next strongest model that included the interaction of condition and salinity. The best model, which removed all interaction terms, had the lowest AIC_c and had an Akaike weight of 0.94.

White mullet models showed that condition, water temperature, salinity, and the interaction of condition and water temperature predictor variables had the strongest effects on the distribution of these fishes. This model was 22.75 times more likely than the next strongest model that removed all interaction terms. The best model had the lowest AIC_c and had an Akaike weight of 0.91.

The best spot model showed that condition and water temperature predictor variables had the strongest effects on their occurrence. This model was 15.17 times more likely than the next strongest model that included salinity only. The best model had the lowest AIC_c and had an Akaike weight of 0.91.

CHAPTER 5

DISCUSSION

Summary of Research Findings

The findings from this study will help inform land management decisions concerning marsh restoration on LSSI. While hydrological function is likely impaired within altered sites, my metric of species diversity (ENS) was not different between altered and unaltered marshes, which may indicate that altered marshes have sufficient tidal exchange to support fish migratory pathways. This led me to consider additional analysis into the data set by evaluating the similarities of the assemblages of fish in altered and unaltered marshes. Using Morisita's index of similarity, I determined that altered and reference marshes support very similar assemblages of fishes during fall months, and moderately similar or nearly dissimilar assemblages during summer months.

Lastly, I found that assemblages of Atlantic silversides, bay anchovies, and striped mullet are more likely to inhabit reference marshes throughout the year while assemblages of mummichog, sailfin molly, white mullet, and spot were more likely to inhabit parallel grid ditches throughout the year (Figures 9-15). These models illustrate that the most prevalent fishes in altered marsh conditions were euryhaline and more tolerant of extreme thermal and oxygen levels while the unaltered marshes supported more highly migratory fishes on LSSI. Ecologically and economically important fishes are utilizing both altered and unaltered marshes in high densities throughout the observed temperature range (14-35°C) during this study.

Water Quality

Consistent water quality variables are a driving factor that influence biotic assemblages of organisms seeking quality habitat. Many studies in salt marshes focus on temperature, salinity, and dissolved oxygen as the main variables that influence species diversity (Jennings & Weyers, 2002; Edwards et al., 2004; Robinson & Jennings, 2014; Carswell et al., 2015). Edwards et al. (2004) concluded that temperature is dominated by daily temporal and seasonal patterns on Sapelo Island, GA (USA).

I did not detect significantly different water temperature between altered and unaltered marshes during 2019 but did find differences between the conditions in summer and fall samples in 2018. In the July 2018 campaign, water temperature was slightly warmer (by ~3 ºC) in altered marshes and slightly warmer (by ~2 ºC) in unaltered marshes during the October 2018 campaign. Standard error bars did not overlap but were close during both campaigns. While these significant differences are worthy of noting, these minute differences are not likely to reduce the quality of both conditions regarding fish habitat. My results coincide with Carswell et al. (2015), who found a nominal difference in mean temperatures between waterfowl and fish managed impoundments. Temperature ranges from this study were not far from the ranges measured in the South Carolina impoundments in Carswell's study. I did find a smaller range of water temperature in reference marshes, which could suggest a more stable habitat for ecologically sensitive fishes. Generalist species in Georgia marsh creeks can thrive in habitats with wide temperature ranges (generally within 10-40 ºC), whereas sensitive fishes that require a smaller range of temperature around 10-30 ºC would seek habitat with more stable conditions (Subramanyam & Drake, 1975).

Salinity was also an important variable in the study, as it provides data regarding connectivity to a larger water source and tidal inundation by interpreting saline concentrations (Edwards et al., 2004). Mean salinity for littoral oceanic habitat is 32 ppt, and I found consistently higher values in 2019, but lower values in 2018. Standard errors overlapped during each campaign suggested no difference between saline concentrations among altered and unaltered marshes. Diadromous fishes seeking shelter would not be impacted by parallel grid ditches if salinity is the driving factor of their migration. Altered marshes often contain isolated and fragmented habitats that remain relatively stagnant, allowing for evaporation of freshwater and increased salt concentrations. I did not see this in the data and analyses and conclude that altered marshes were receiving sufficient tidal inundation to maintain consistent and comparable conditions to reference marshes. This is consistent with results from Carswell et al. (2015) who found nominally higher salinity concentrations in waterfowl managed wetlands, likely a result of evaporation occurring from tidal impediment. The salinity concentrations from my study were much higher than those measured in the South Carolina impoundments in Carswell's study, likely attributed to the proximity to oceanic habitats on LSSI. I also found that salinity ranges were narrower in reference marshes on LSSI than parallel grid ditch creeks. Euryhaline species such as striped mullet, mummichog, and sailfin molly can thrive in habitats ranging from 10-40 ppt, whereas sensitive species require habitats with a narrower salinity concentration (Tagatz & Dudley, 1961). Highly migratory fishes such as bay anchovy are sensitive to wide ranging salinity concentrations and would likely occur in habitats with salinity ranging from 25-34 ppt.

Invertebrate Diversity

The diversity of invertebrates I sampled did not differ among altered and unaltered marshes (Figures 4 & 5). Linear models did not show a strong relationship with water quality variables and ENS in both conditions.

Invertebrate diversity in the lens of ENS was very consistent and comparable between marsh conditions throughout the year and did not support the use of active management for marsh restoration. While parallel grid ditches may lack the sinuous structures found in reference marshes, both parallel grid ditches and reference marshes provide adequate habitat and water quality to sustain healthy assemblages of invertebrates on LSSI.

Fish Diversity

Fish ENS was not different between altered and unaltered marshes indicting that marsh channelization did not have a significant effect on fish species diversity on LSSI. The fish ENS linear models had a higher adjusted R-squared value than the invertebrate ENS models. Since models do not explain much of the variation in fish abundance, additional parameters including substrate, dissolved oxygen, available cover, and water depth should be included in ongoing studies to determine a stronger model predicting fish ENS. Hoese (2007) tested diversities of resident and non-resident fishes between reference marshes and various managed marshes in Louisiana, and also did not find noticeable differences in fish diversity.

My results indicate that as water temperature increases, ENS increases in both altered and unaltered marshes. This positive relationship was seen in another study in Southeastern salt marsh habitats. Carswell et al. (2015) found ENS for fishes in an altered waterfowl pond was 1.27±0.14 in the summer and 1.06±0.09 in the winter, whereas mean ENS in an unaltered fish impoundment was 2.52±0.20 in summer samples and 2.02±0.66 in winter samples. Many larval and juvenile fishes spawned in the spring are large enough by fall to begin emigrating their nursery habitat, which may explain the lower ENS in the fall.

The ENS values from LSSI were likely higher than previous studies because of a lack of anthropogenic disturbance. The altered and unaltered sites are rarely used to harvest fish, outside the scope of this project. With a lack of consistent fish removal and boat usage, it is likely that both marsh conditions provide undisturbed shelter for a wider variety of fishes.

Another source of higher diversity could include proximity to the Altamaha River; a 137-mile free flowing river that drains approximately 25% of water in Georgia (Georgia River Network, 2018). The Altamaha flows into the ocean at the north end of LSSI and is the main source of tidal exchange for several of the marsh sites samples in this project. Fresh and brackish water from upstream provides nourishment for fishes and invertebrates and could explain the higher fish species diversity on LSSI reported in my study (Sheldon & Burd, 2014).

Aside from ENS range differences with other studies, my results clearly show comparable species diversities between parallel grid ditches and reference marshes through the yearly temperature and salinity regimes on LSSI.

Similarity Indices

The heatmap displaying Morisita's index of similarity between altered and unaltered marshes during each campaign showed a consistent trend of low or moderately similar assemblages during summer months, and high assemblage similarity during fall months (Figure 8). This suggests fairly dissimilar fish assemblages between altered and unaltered marshes when fish diversity was measured to be the highest. Although fish diversity was not measured to be different between altered and unaltered marshes during these months, the similarity index suggests that assemblages are quite dissimilar. Morisita's index of similarity was used in another study done in South Carolina and found a consistent difference of fish assemblages between waterfowl managed impoundments and other tidal creeks in North and South Carolina (Robinson, 2011). Robinson and Jennings (2014) found a strong effect of tidal differentiation on assemblages of fishes, which could further elucidate my findings as well. If parallel grid ditches do in fact affect tidal flow, this phenomenon may be the source of differentiation for assemblage differences found among parallel grid ditches and reference streams during summer months.

Assemblages of fishes in fall months were nearly identical between altered and unaltered marshes, suggesting equal usage of both reference streams and parallel grid ditches. I captured the largest numbers of fish and invertebrates during fall samples, and the index values suggest that assemblages are not preferential towards one condition. Therefore, parallel grid ditches do not affect fish on an assemblage level during fall months.

Fish Occurrence

Summary of GLM

Generalist species such as mummichog, sailfin molly, and white mullet had a higher predicted occurrence in altered marshes throughout the year. Spot, a more specialist species, was equally likely to occur in both reference marshes and parallel grid ditches across mean annual temperature ranges. These fish species are also residential inhabitants of LSSI, that reside in salt marsh habitats during most of their life span (Subramanyam & Drake, 1975).

Highly migratory species such as bay anchovy and Atlantic silversides were predicted to occur in reference marshes throughout the year. My results suggest a higher occurrence for these two migratory species, and additional studies from my data set may show trends supporting or negating these findings for other highly migratory fishes utilizing marshes on LSSI.

The ecological significance of these findings, as well as the findings from the water quality data imply that reference marshes provide a narrower range of temperature and salinities than parallel grid ditches. Euryhaline and eurythermal fish species such as mummichog, sailfin molly, and white mullet were predicted to occur in altered marshes at a higher abundance, whereas sensitive species such as bay anchovy were more likely to occur in unaltered marshes. While there were sensitive and generalist species that were predicted to occur in high abundance in altered and unaltered marshes, the general summary is that unaltered reference marshes have a narrower range of water temperature and salinity and provide more suitable habitats for habitat specialists.

Atlantic Silversides

My results demonstrate that temperature and condition affected the occurrence of Atlantic silverside, whereas salinity did not. According to the best fit model, temperature and condition interacting has a strong effect on the assemblages of Atlantic silversides, with a higher chance that they will occupy unaltered marshes when water conditions are between 15-26 ºC (Figure 9). Tagatz and Dudley (1961) used seine haul analyses to sample for marine fishes in four salt creeks in Beaufort, NC with temperatures between 1.5-32.0 ºC and found similar results for Atlantic silversides (n= 34,223). Conversely, mean salinity values were not different between the conditions during each sampling campaign, and Atlantic silversides were found in both habitats. Therefore, salinity does not seem to be a driving factor that influences the occurrences of this species on LSSI. Similar results were reported for marshes with similar salinities (Tagatz & Dudley, 1961).

My results suggest that unaltered marshes provided preferable habitat to diadromous Atlantic silverside when they are most likely to reside on LSSI. This increased use may be linked to oyster reef habitat that is plentiful in the site nested in Sancho Panza Creek (UNALT01). Atlantic silversides seek habitats with high oxygen and low water temperatures, and unaltered sites may provide better water quality conditions. As water temperatures reached approximately 24 ºC, the likelihood of Atlantic silversides utilizing parallel grid ditches increased to 80% (Figure 9). These findings suggest that while Atlantic silversides are more likely to utilize unaltered marshes when water temperature is below 25 ºC, they are also likely to utilize parallel grid ditches.

Salinity ranges were much wider in altered marshes, and my results showed that parallel grid ditches may have salinities as low as 15 ppt, while unaltered marshes contained minimum salinity concentrations of 23 ppt (Figures 5 & 7). Knowing that Atlantic silversides are a highly euryhaline species, they are likely to reside in both conditions of salt marsh, temperature permitting, and may migrate between conditions in search for food and shelter.

Bay anchovy

My results displayed that temperature, salinity, and condition all affected the occurrence of bay anchovy (Figure 10). The data and models suggest that during fall months when bay anchovy presence is the highest in salt marshes on LSSI, assemblages of bay anchovies are more likely to inhabit unaltered salt marsh habitat over parallel grid ditch habitats.

Bay anchovy are a highly migratory species that inhabit pelagic, littoral, estuarine, and salt marsh habitats for foraging and spawning (Moyle & Cech, 2004). They are an environmentally sensitive order of fishes that are not able to withstand large ranges of water temperature and salinity in an acute time period. My models predict that the parallel grid ditches on LSSI provide diminished water quality variables needed for bay anchovies, likely due to incomplete tide cycles that prevent complete inundation from occurring. It should be noted that while unaltered marshes provide more suitable habitat for bay anchovies, assemblages of bay anchovies still have a high chance of occupying altered parallel grid ditches during the yearly temperature and salinity ranges.

Mummichog and Sailfin Molly

Mummichog and sailfin molly, represented by the order Cyprinodontiformes, are extreme generalists with high tolerance in saline and temperature conditions. Parallel grid ditches were installed to attract killifishes, thus I anticipated finding a higher representation in altered sites. The results demonstrated that condition influenced the occurrence of both mummichog and sailfin molly, whereas temperature and salinity did not (Figure 11-12).

These fishes are “true residents” of salt marshes in North America because of their complete lifecycle that takes place entirely in marshes and creeks (Moyle & Cech, 2004). Their extreme agility in temperature and salinity resilience makes them especially suited for unpredictable tidal variance. Mummichogs and sailfin molly can inhabit temperatures with a range from 0.5ºC-40 ºC and can thrive in freshwater (0 ppt) to systems with nearly double the salinity of the ocean (60 ppt).

The data from this study coincides with most salt marsh studies in that I captured a large population of fishes in the order Cyprinodontiforms in both conditions of marsh, and in a high range of temperature and salinity readings. Subrahmanyam and Drake (1975) found adult and juveniles representative of seven Cyprinodontiform species in two unaltered Northern Florida salt marsh between the months of May-December. They also found that killifish abundances were positively correlated with warmer temperatures.

Striped and white mullet

Mullets are catadromous spawners and do not utilize the marshes of LSSI for nursery habitat (Hoese, 1985). Mullet are not piscivorous; they feed on detritus and algal cells on benthic substrates (Moyle & Cech, 2004). Their presence or absence in a salt marsh would only effect higher trophic levels and while they are an important food fish for piscivorous birds, mammals, fish, and reptiles, their populations on the island are extremely abundant.

My results demonstrated that striped mullet are more likely to occur in unaltered marshes when water temperature is below 26 ºC but are more likely to occupy altered marshes when water temperature is above 30 ºC (Figure 13). The models show clearly that reference marshes provided suitable conditions during fall months, and parallel grid ditches provide suitable condition during summer months. White mullet exhibited an opposite trend; assemblages of white mullets occurred in altered marshes at nearly all temperature ranges, except for ranges of 27-30 ºC, when altered and unaltered marshes had overlapping standard errors (Figure 14).

I also found that striped mullet are likely to inhabit altered marshes across most salinity concentrations throughout the year, with the exception when concentrations are between 23-25 ppt. Both striped and white mullet are extremely euryhaline and can withstand large salinity ranges. I did not find a significant effect of salinity interacting with condition for white mullet.

I conclude that unaltered marshes provide more suitable habitat across the annual range of water temperature for striped mullet, and altered marshes provide more suitable habitat across the full spectrum of salinity concentrations. For white mullet, altered marshes provide more suitable habitat across the annual range of water temperature.

Spot

My results demonstrated that condition and water temperature will have significant effects on the occurrences of spot (Figure 15). This means that spot are more likely to occur in parallel grid ditches over reference marshes throughout the year. The best model displayed overlapping confidence intervals among altered and unaltered marshes when temperature ranges were between 15-25 ºC, suggesting that spot are occurring in both altered and unaltered marshes equally during fall months.

I did not find an effect from salinity on the occurrences of spot, but other studies have found that higher salinities and lower water temperatures are driving factors that influences spot abundance (Subrahmanyam & Drake, 1975).

While they are using both conditions in the fall months, my results suggest reliance on parallel grid ditches during summer months, with knowledge that they are utilized by larval, juvenile, and adult species of spot.

Potential Error

The variation in tidal cycles between altered and unaltered marshes needs further elucidation to characterize all potential effects hydrology and water quality can have on fish assemblage structure. Predicting the tidal cycles in interior island sites given the nature of delayed tidal fluctuations in smaller creeks is difficult. Although projects to analyze and interpret tide cycles at some of the sites on LSSI are underway, there has yet to be a long-term comparative study detailing hydrological and water quality patterns. Data from this project should supplement ongoing research evaluating any detrimental effects of salt marsh channelization on fish and invertebrate community structure.

Wind, ambient temperature, water quality, and other precipitation varied between sampling periods, and hurricane forces and tropical storms did not affect the data collection process. My sample dates were chosen based on the NOAA tidal amplitude chart but were drastically affected by heavy winds throughout the data collection processes, and some sites did not display a complete ebb tide cycle. To combat the stochastic effects of climatic variability, I ensured that all nets would soak for 4 hours. However, there were a few cases that complete tidal drainage did not occur, so I pulled those nets before the allotted soak time to avoid losing the catch from a switched tide cycle. I lost one of my nets during the 5th sampling period due to strong tidal flow and complications with anchoring the net in oyster reef habitat. This net was replaced with a net of the same mesh size, but slightly narrower in width and was white, as opposed to green for all other net sets. While this temporary change in sampling regime may have affected the catch rate or total abundance of fishes caught, the fish assemblage composition catch among nets were similar. Accordingly, this indicated that the alternate seining method did not affect the overall conclusions regarding fish assemblages.

Management Implications

LSSI provided an ideal location for a comparative study of fishes and invertebrates in altered and unaltered marshes. I found that parallel grid ditches did not have a significant effect on species diversity (as measured by ENS) or fall fish assemblages. Summer fish assemblages, however, were dissimilar between the altered and unaltered marshes. While parallel grid ditches may alter assemblage composition relative to reference sites, my results indicate that they still support important estuarine fishes. As such, a management plan to restore the parallel grid ditches back to a historic state may not be necessary at this time. There may be other considerations, however, beyond the scope of fish, invertebrates, and water quality variables that would justify either a hands-off or hands-on management approach to managing the salt marshes on LSSI.

A hands-off approach would allow the altered habitats to remain as they are, as environmental and climatic conditions could partially restore the sinuous nature of the parallel grid ditches and improve hydrological function and connectivity. This no-action management decision is low risk and economically advantageous because these data demonstrate that there are healthy populations of fishes and invertebrates in both altered and unaltered marshes. The heterogenous marsh creek system provides diverse habitat and food for diadromous and resident fishes with varying life history strategies. The drawback of course is that the natural restoration of unaltered tidal flow may take decades to induce noticeable and measurable change.

A hands-on management plan that involves artificial structure or design could yield faster results and improved habitat where there are currently parallel grid ditches, but such perturbation could also cause a new disturbance that would revert a mature (though previously altered) habitat to a pioneer community. A brand-new landscape for colonizers would introduce obstacles to habitat specialists that would likely not integrate well in the “new” environment. All marsh restoration projects must undergo a cost and benefit analysis to determine whether this re-engineering is both fiscally sound and environmentally effective. While altered marshes support lower diversity and dissimilar species than the unaltered marshes in the summer, these data do not justify management restoration. However, since LSSI may value improved hydrological function that could improve vegetation communities within impaired marsh watersheds, then a hands-on approach may be warranted. OMWM has been used in many salt marsh systems in New England and Louisiana, with the main goal of mosquito control (Wolfe, 1996; Vincent et al., 2014). Vincent et al. (2014) concluded that OMWM had “no detrimental long-term impacts on water quality”, and “viable fish populations are maintained in OMWM systems”. The draw backs of OMWM were mainly economic concerns on a large-scale restoration project (Wolfe, 1996; Lesser, 2007; Vincent et al., 2014; C. Talbot et al., 2018). Structured Decision Making could be a vital tool to optimize future island habitat management actions by including all stakeholders in prioritization and implementation based on common goals (Martin et al., 2011).

Ecological integrity assessments of existing marshes and potential restoration alternatives should include all island ecosystems and be viewed through the lens of climate change flooding. Existing knowledge on predicted sea level rise in the Southeastern United States and known negative effects of this phenomenon are primary drivers changing geological structure of barrier islands and tidal dynamics within decades. The National Oceanic and Atmospheric Administration (NOAA) developed models predicting a 2-foot sea level rise by 2045 (Spanger-Siegfried et al., 2017). This drastic increase in mean high tides could lead to inundation into upland marshes and maritime forests in barrier islands along the Atlantic bight. While these are predictions, LSSI would be transformed by sea level rise of this magnitude. Considering tidal inundation predicted to occur within decades and focus management on removing any manmade hindrances altering natural water flow would be prudent. Climate change may induce rapid vegetation regeneration as larger storms carve out old creek channels with an accelerated return to natural tidal flow. Salt marshes are naturally resilient to storm surges if hydrological function is restored. Ecosystem services of functioning coastal marshes include an economic benefit for all people by reducing storm surge flooding, filtering out nutrients/contaminants, and still providing healthy, sustainable food.

Future Directions and Recommended Research

With this research as a baseline analysis providing a water quality and fish biological assessment of the salt marsh creeks, a large-scale comprehensive review should be compiled to integrate these data with results from ongoing marsh bird surveys and tide cycle studies. Using vegetative ground cover data collected (but not included in this study), future researchers could evaluate interactions between surveys of secretive marsh birds and the assemblages of terrestrial invertebrates found in *Spartina* vegetation plots. The presence of invertebrates such as periwinkle snails (*Littorina littorea*) and fiddler crabs (*Uca* sp.) support the higher quality habitat for wading birds and seclusive birds such as clapper rails (Luk & Zajac, 2013).

During the data collection process (and many hours spent conducting fish collections by hook and line), I quickly learned that sites with oyster reef habitat had a positive relationship with large schools of fish. Further research should be conducted regarding the value of oyster reef, artificial reefs via living shoreline implementation, and whether the addition of an artificial reef in some of the parallel grid ditch sites would be a feasible option. My observation is that marine fishes tend to use oyster reef habitat for food and protection, in altered and unaltered sites alike.

While I collected soil surveys from each location during each season, we did not perform tests to measure soil chemistry. Recent improvement in satellite and drone imagery allow us to view regions of the altered LSSI marsh have visible iron mobilization (orange-brown surficial sediments) (DSEWPC, 2012). These acid sulfate soils have been documented in various altered wetland systems worldwide. This could provide some useful insight into direct effects of altered tidal flow on soil chemistry and subsequent alterations in marsh vegetation communities.

Lastly, if a restoration plan were conducted and implemented, I would also highly recommend fish seining in the same six locations to collect post-treatment data. Comparing post treatment fish communities with this project could provide valuable insight regarding the effect of the restoration plans on resident and migratory fishes on LSSI. It would also further test my conclusion that some important migratory fish species have a higher probability of occupying unaltered marshes and support island management to restore natural tidal flow in parallel grid ditches closer to the historic state of pristine salt marshes of the south east Atlantic coast.

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TABLES AND FIGURES

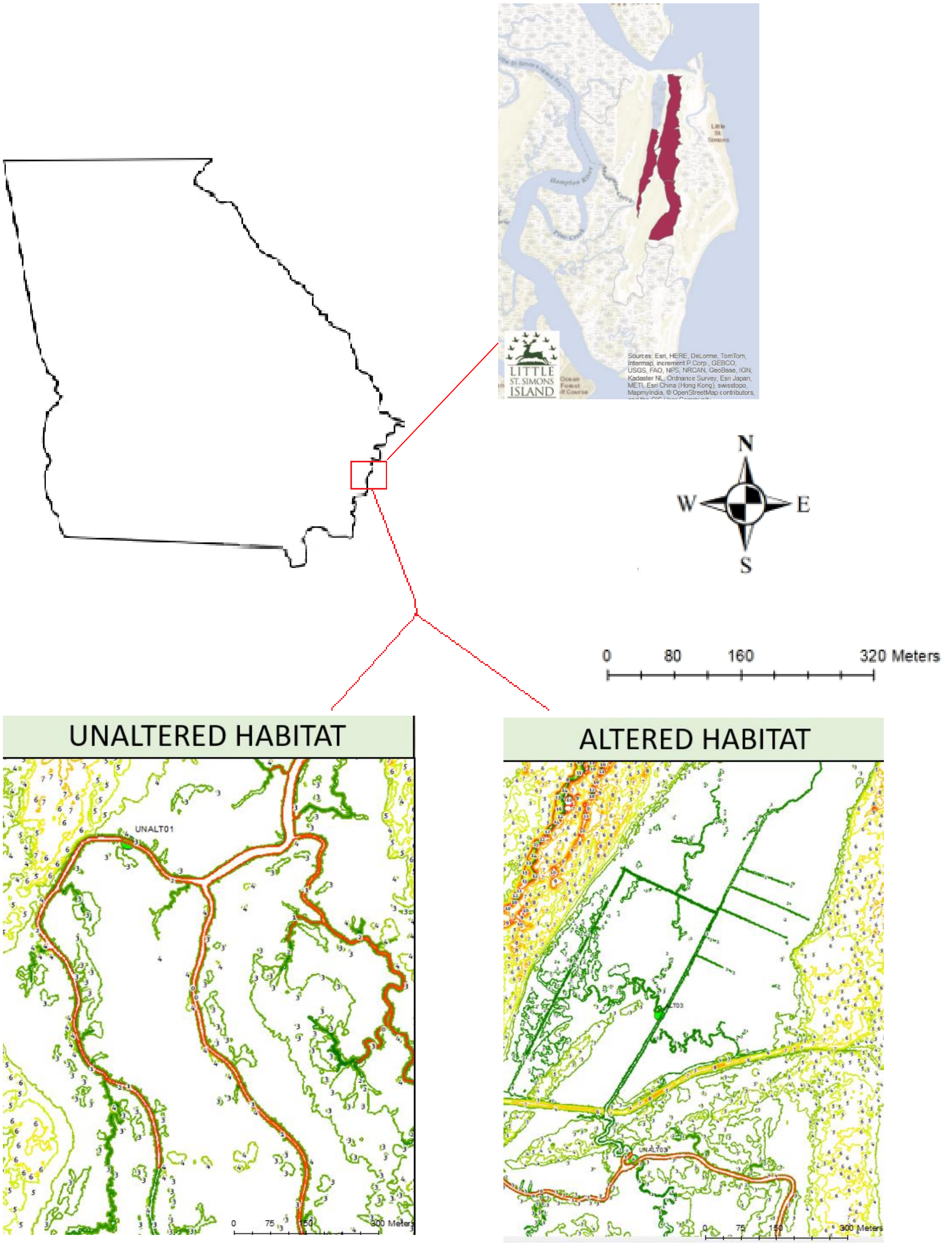


Figure 1. Contour maps displaying 1-foot contour lines at an unaltered and an altered parallel grid ditching site on Little Saint Simons Island (Georgia, USA) to highlight change in sinuosity.

Map made by Eric Cohen-Kivett, June 15, 2018

Figure 2. Map of Little Saint Simons Island (Georgia, USA) displaying the three altered and three unaltered sites. The area denoted as “Degraded_Saltmarsh” is the estimated polygon of salt marshes and upland habitats impacted by parallel grid ditching.

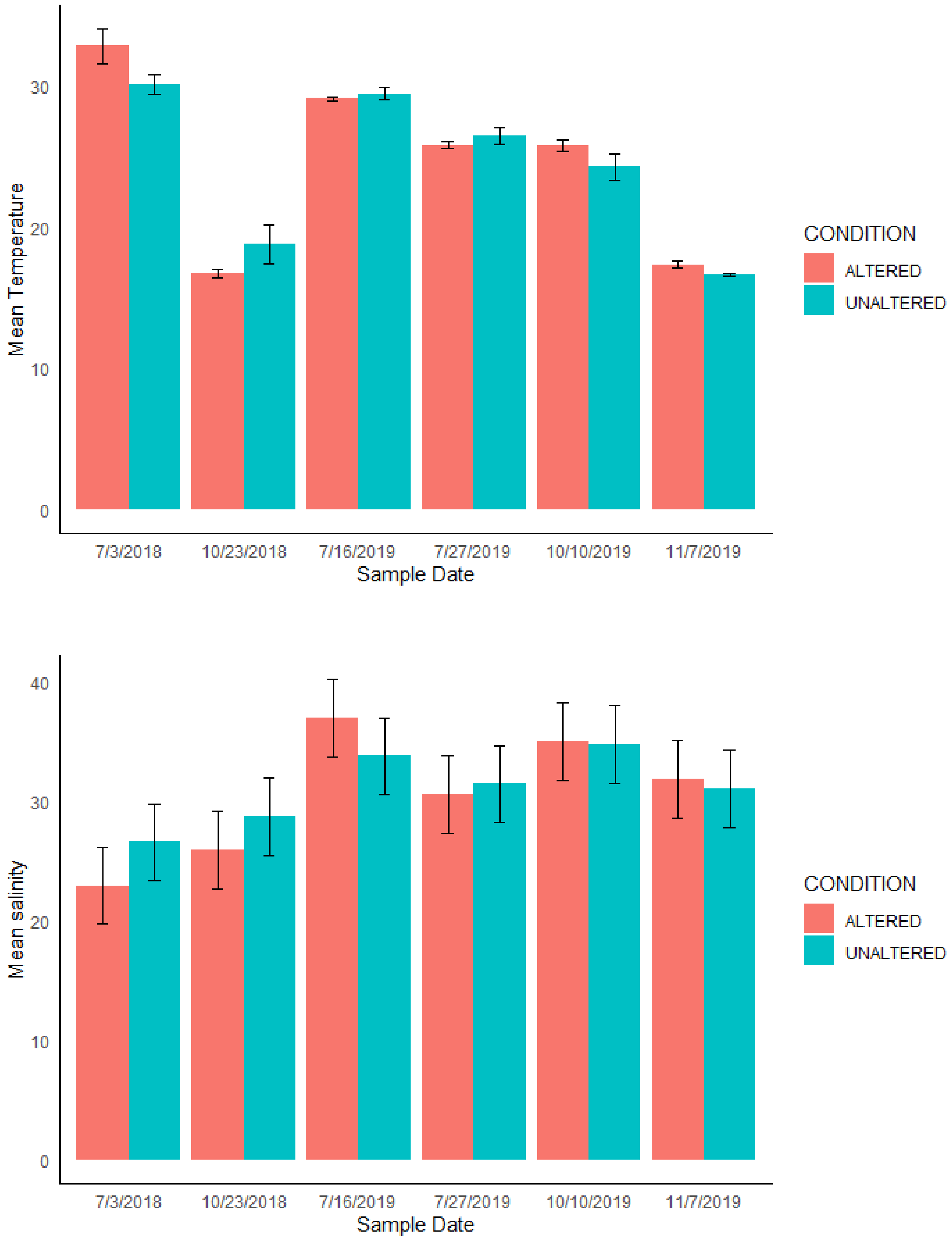


Figure 3. Mean water temperature and salinity measured with 95% standard error bars from altered parallel grid ditches and unaltered reference marshes on Little Saint Simons Island (Georgia, USA) during the 6 campaigns.

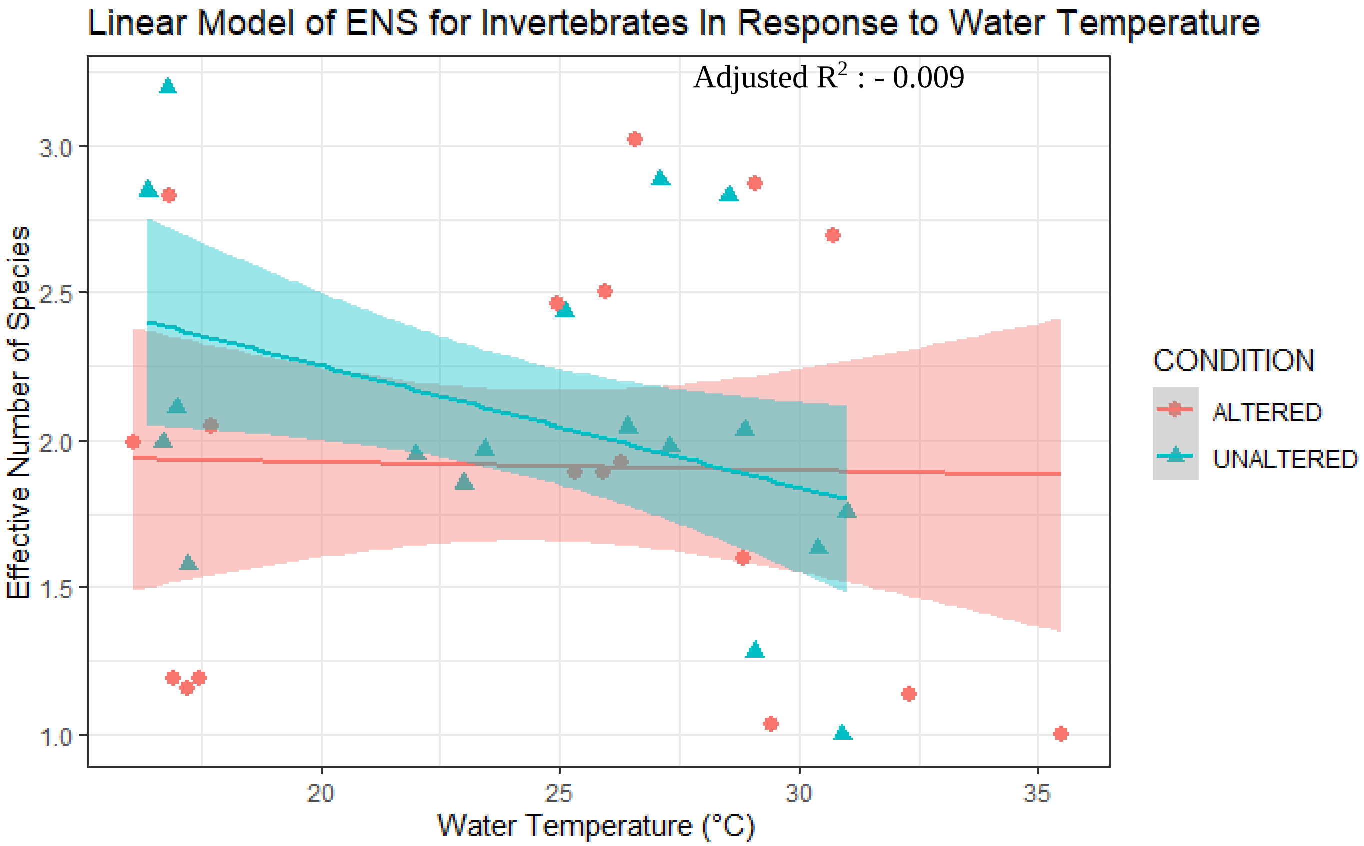


Figure 4. Linear model with 85% CI displaying the effect of water temperature on Effective Number of Species (ENS) of invertebrates captured from altered parallel grid ditches and unaltered reference marshes on Little Saint Simons Island (Georgia, USA) from 2018-2019.

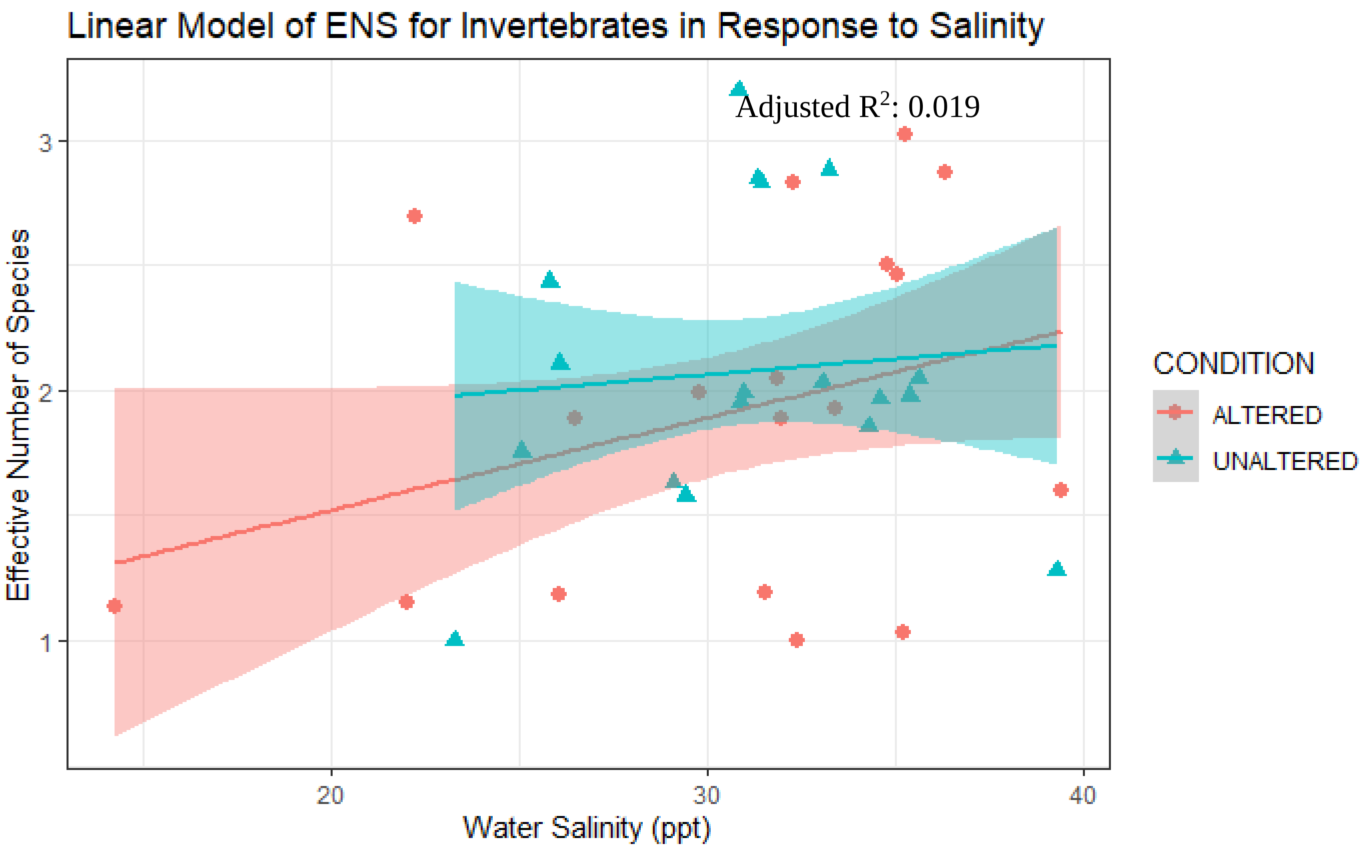


Figure 5. Linear model with 85% CI displaying the effect of salinity on Effective Number of Species (ENS) of invertebrates captured from altered parallel grid ditches and unaltered reference marshes on Little Saint Simons Island (Georgia, USA) from 2018-2019.

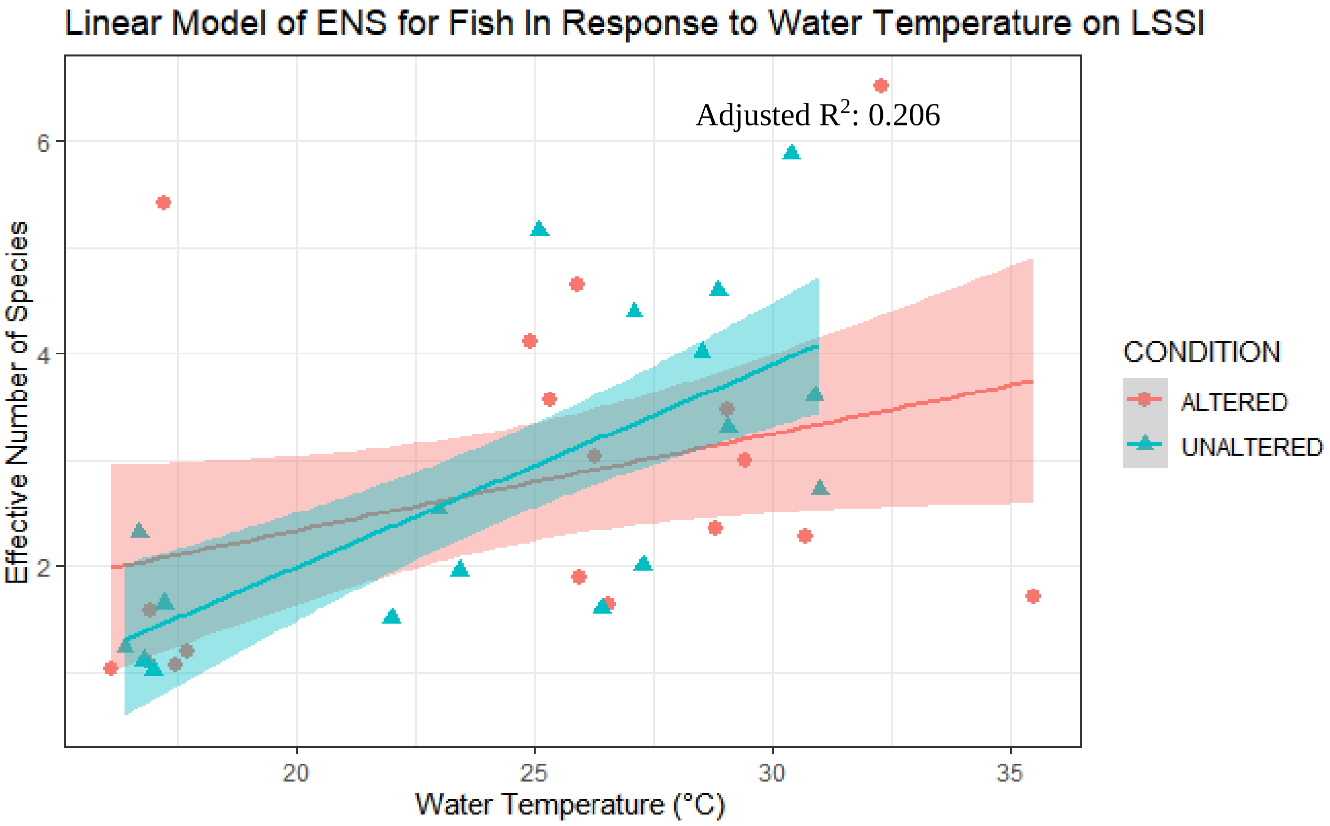


Figure 6. Linear model with 85% CI displaying the effect of water temperature on Effective Number of Species (ENS) of fishes captured from altered parallel grid ditches and unaltered reference marshes on Little Saint Simons Island (Georgia, USA) from 2018-2019.

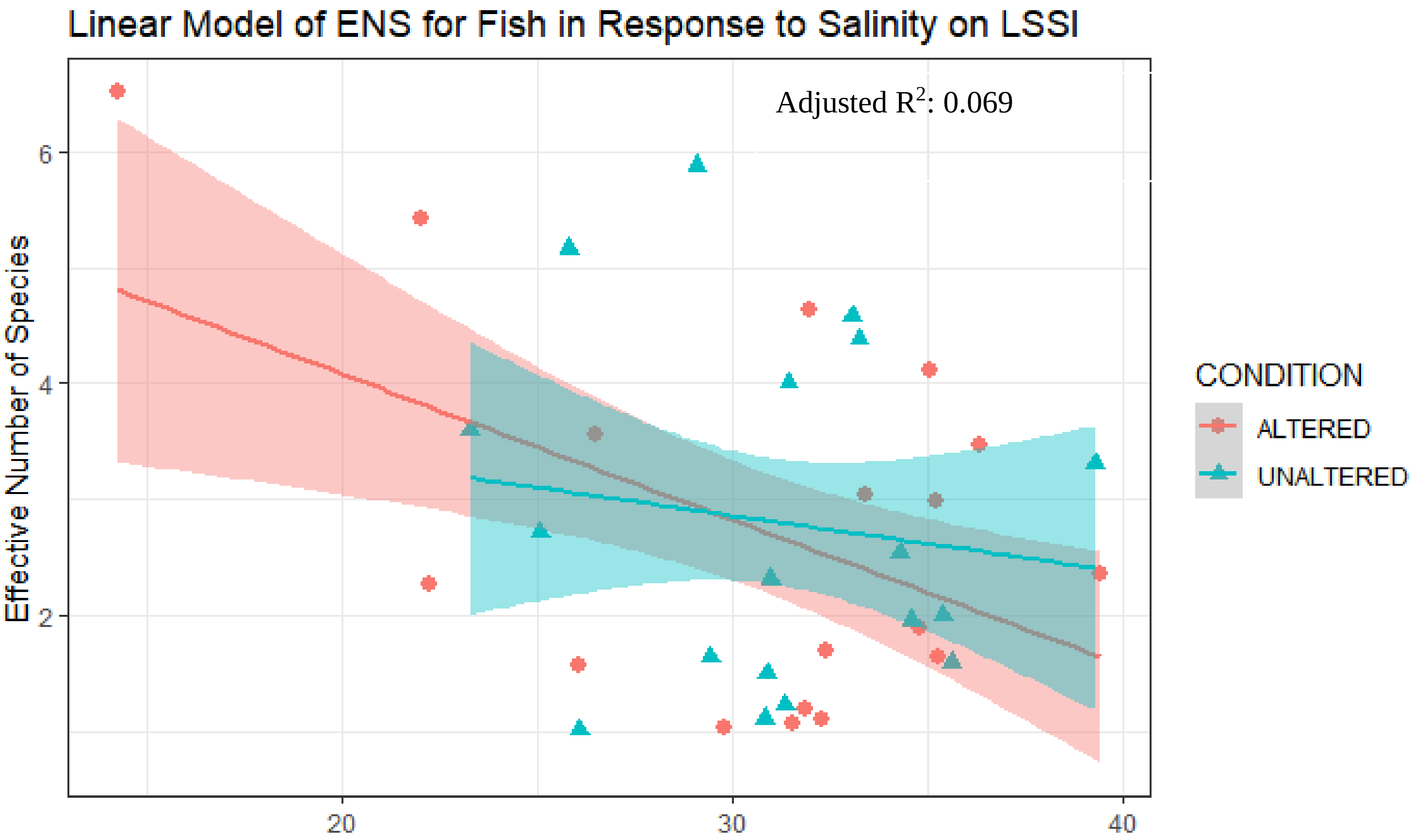
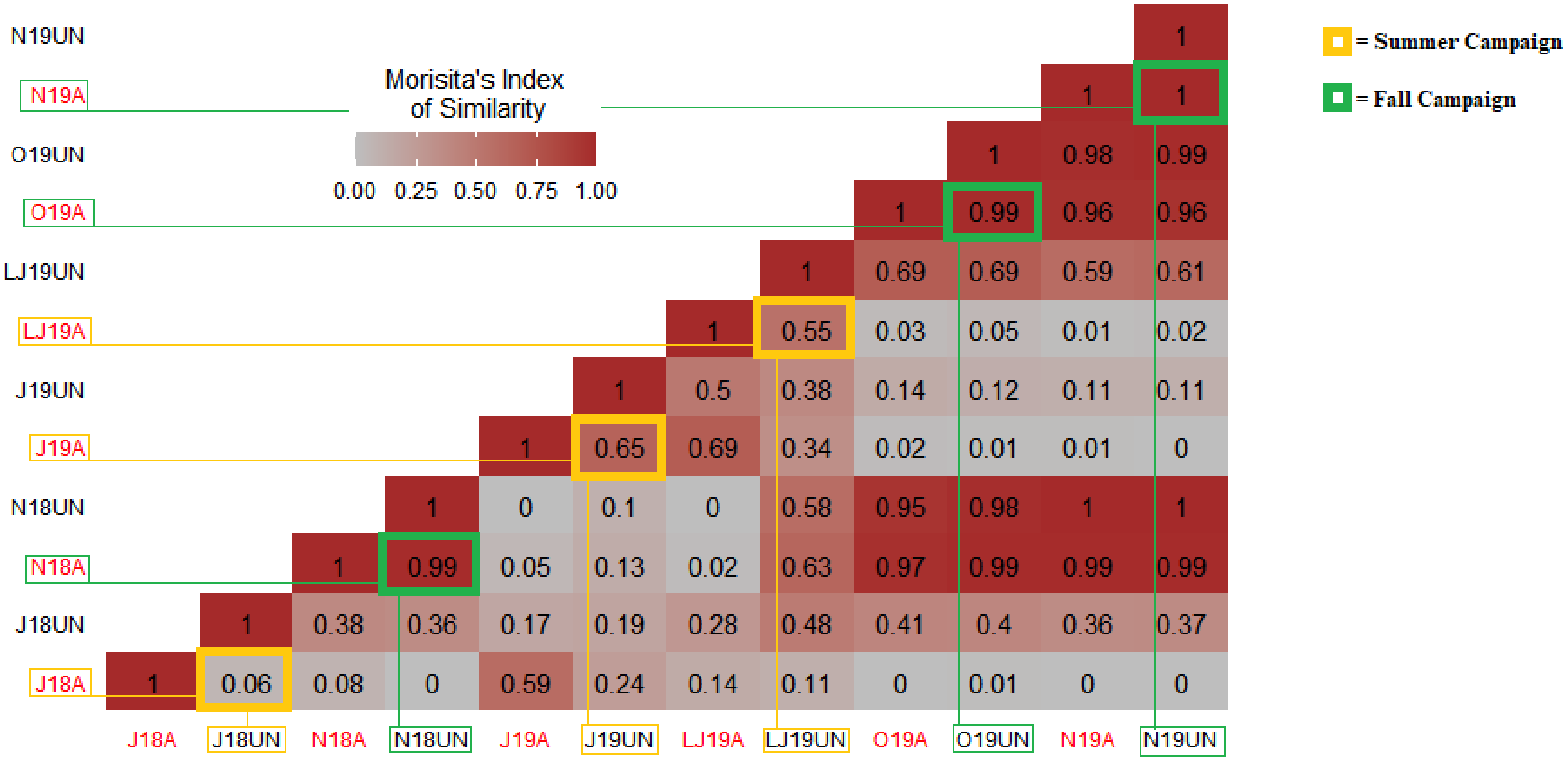


Figure 7. Linear model with 85% CI displaying the effect of salinity on Effective Number of Species (ENS) of invertebrates captured from altered parallel grid ditches and unaltered reference marshes on Little Saint Simons Island (Georgia, USA) from 2018-2019.



	J18A	J18UN	N18A	N18UN	J19A	J19UN	LJ19A	LJ19UN	O19A	O19UN	N19A	N19UN
N19UN												1
N19A											1	1
O19UN										1	0.98	0.99
O19A									1	0.99	0.96	0.96
LJ19UN								1	0.69	0.69	0.59	0.61
LJ19A							1	0.55	0.03	0.05	0.01	0.02
J19UN						1	0.5	0.38	0.14	0.12	0.11	0.11
J19A					1	0.65	0.69	0.34	0.02	0.01	0.01	0
N18UN				1	0	0.1	0	0.58	0.95	0.98	1	1
N18A			1	0.99	0.05	0.13	0.02	0.63	0.97	0.99	0.99	0.99
J18UN		1	0.38	0.36	0.17	0.19	0.28	0.48	0.41	0.4	0.36	0.37
J18A	1	0.06	0.08	0	0.59	0.24	0.14	0.11	0	0.01	0	0

Figure 8. Heatmap of Morisita's index of similarity values comparing communities of fishes captured from altered parallel grid ditches (coded in red text) and unaltered reference marshes on Little Saint Simons Island (Georgia, USA) over 6 campaigns.

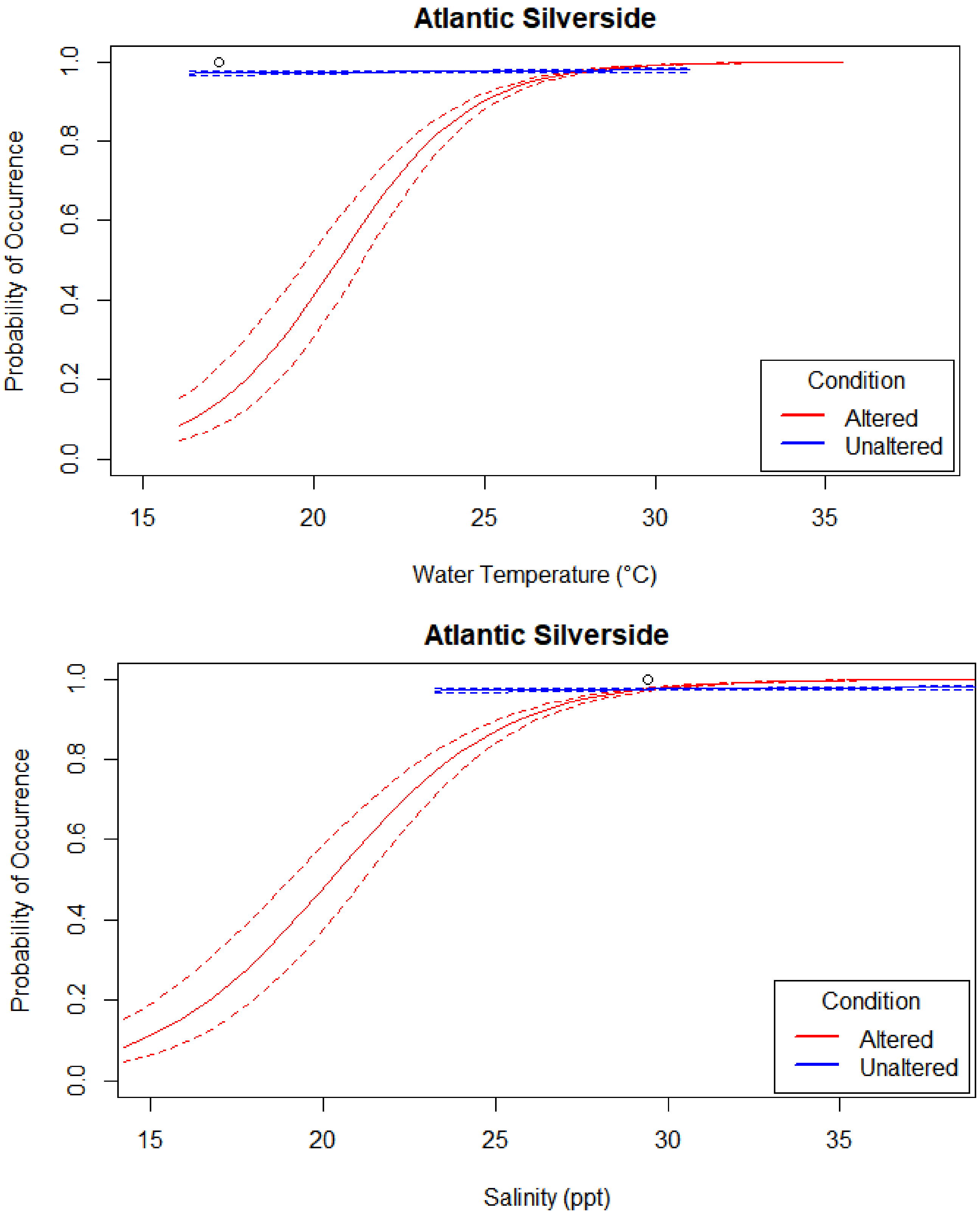


Figure 9. Visual representation of the best GLM models with 85% CI to compare assemblages of Atlantic silverside (*Menidia menidia*) captured in altered and unaltered marshes on Little Saint Simons Island with predictor variables temperature (°C) and salinity (ppt) (GA, USA) in 2018-2019.

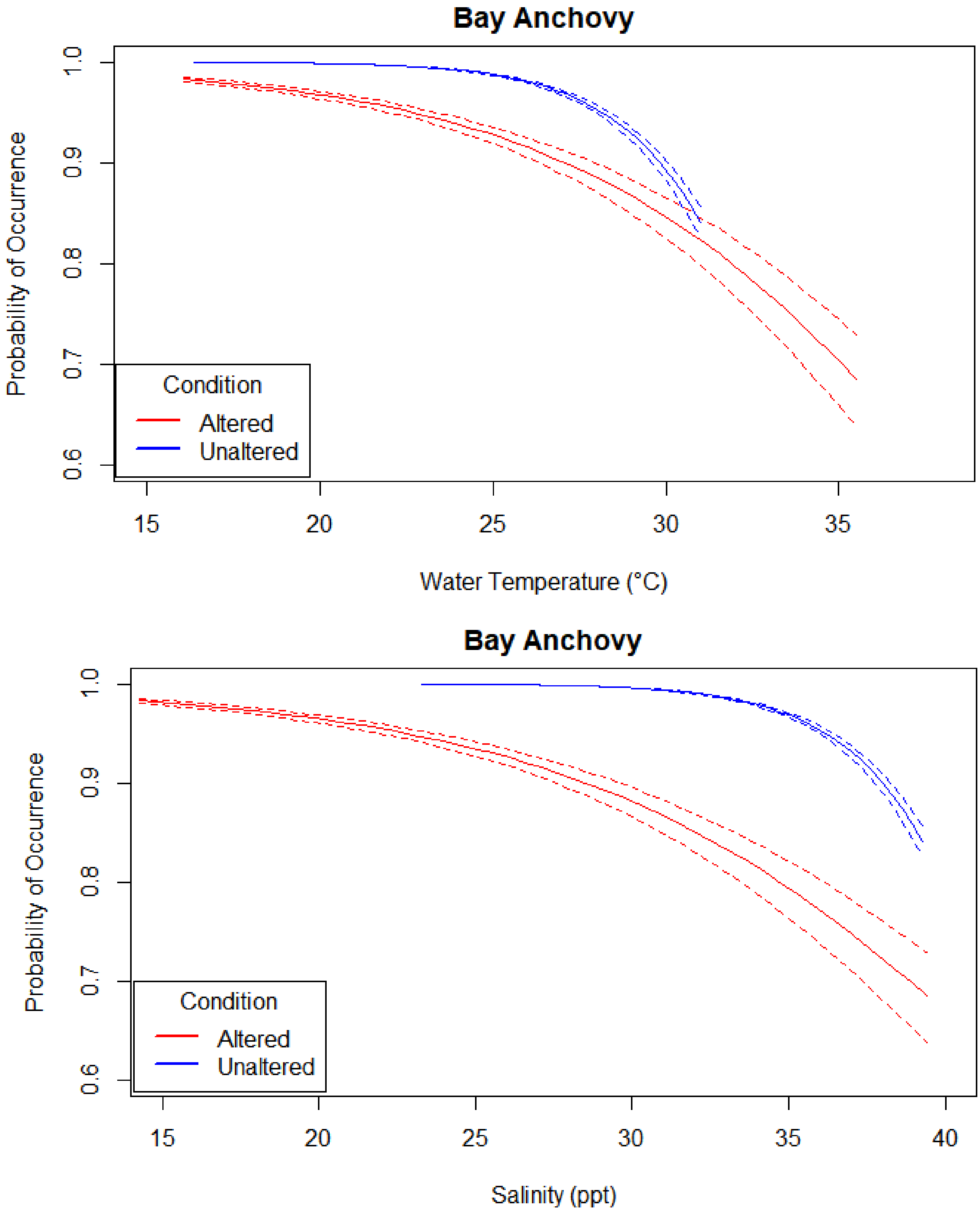
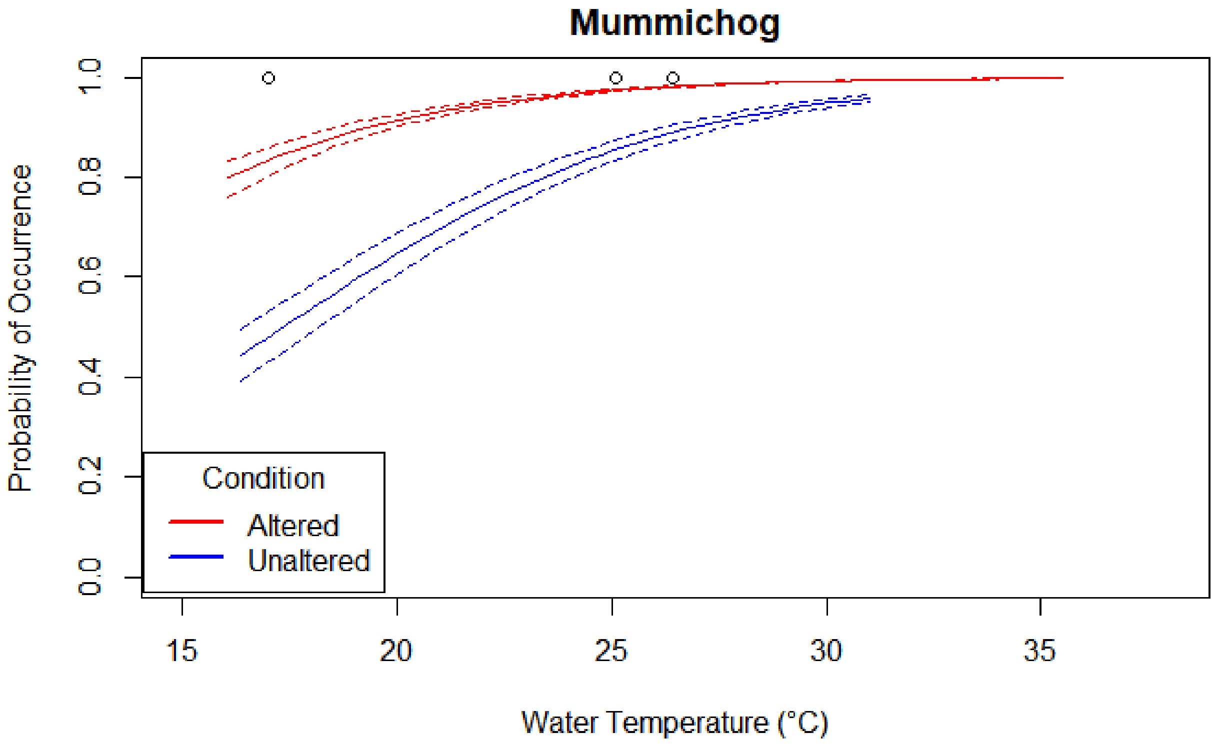


Figure 10. Visual representation of the best GLM models with 85% CI to compare assemblages of bay anchovy (*Anchoa mitchelli*) captured in altered and unaltered marshes on Little Saint Simons Island with predictor variables temperature (°C) and salinity (ppt) (GA, USA) in 2018-2019.



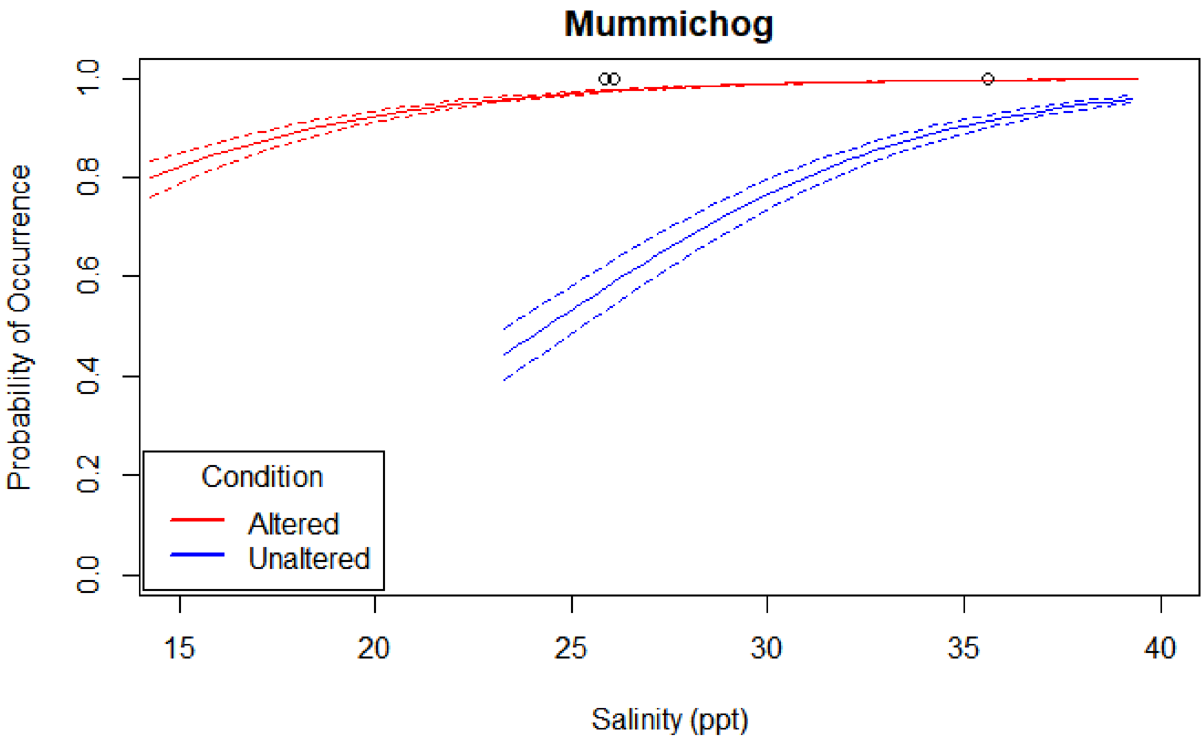


Figure 11. Visual representation of the best GLM models with 85% CI to compare assemblages of mummichog (*Fundulus heteroclitus*) captured in altered and unaltered marshes on Little Saint Simons Island with predictor variables temperature (°C) and salinity (ppt) (GA, USA) in 2018-2019.

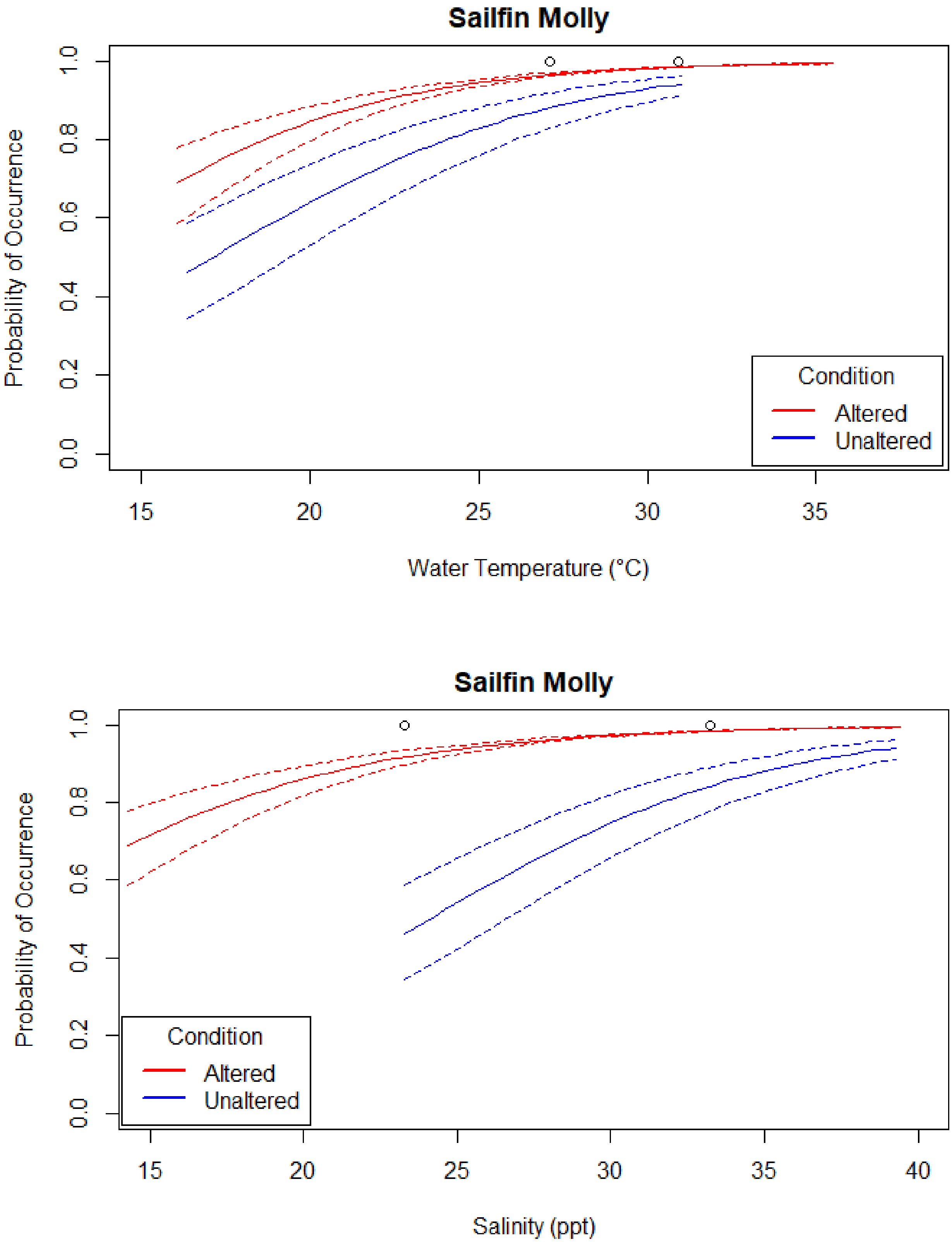


Figure 12. Visual representation of the best GLM models with 85% CI to compare assemblages of sailfin molly (*Poecilia latipinna*) captured in altered and unaltered marshes on Little Saint Simons Island with predictor variables temperature (°C) and salinity (ppt) (GA, USA) in 2018-2019.

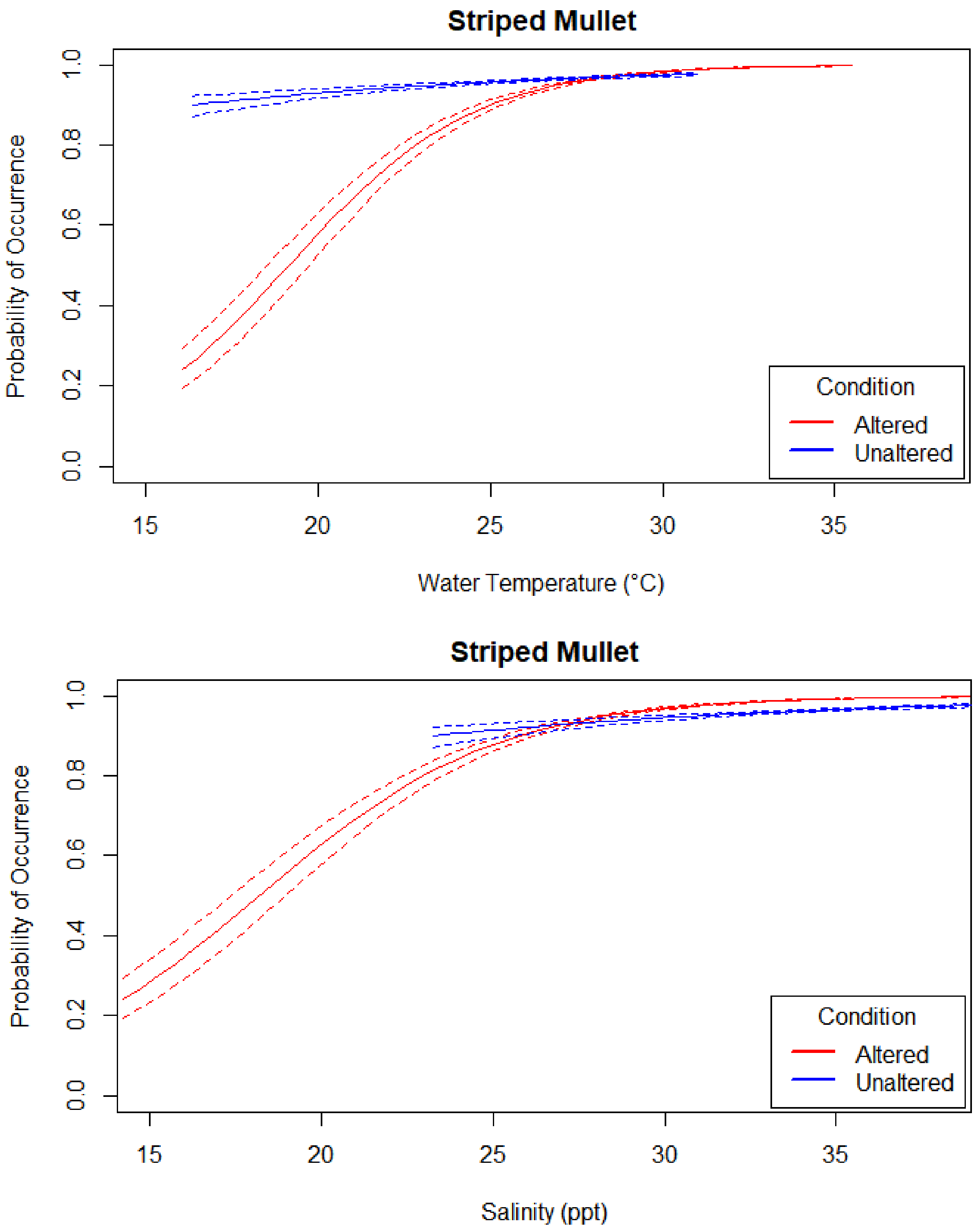


Figure 13. Visual representation of the best GLM models with 85% CI to compare assemblages of striped mullet (*Mugil cephalus*) captured in altered and unaltered marshes on Little Saint Simons Island with predictor variables temperature (°C) and salinity (ppt) (GA, USA) in 2018-2019.

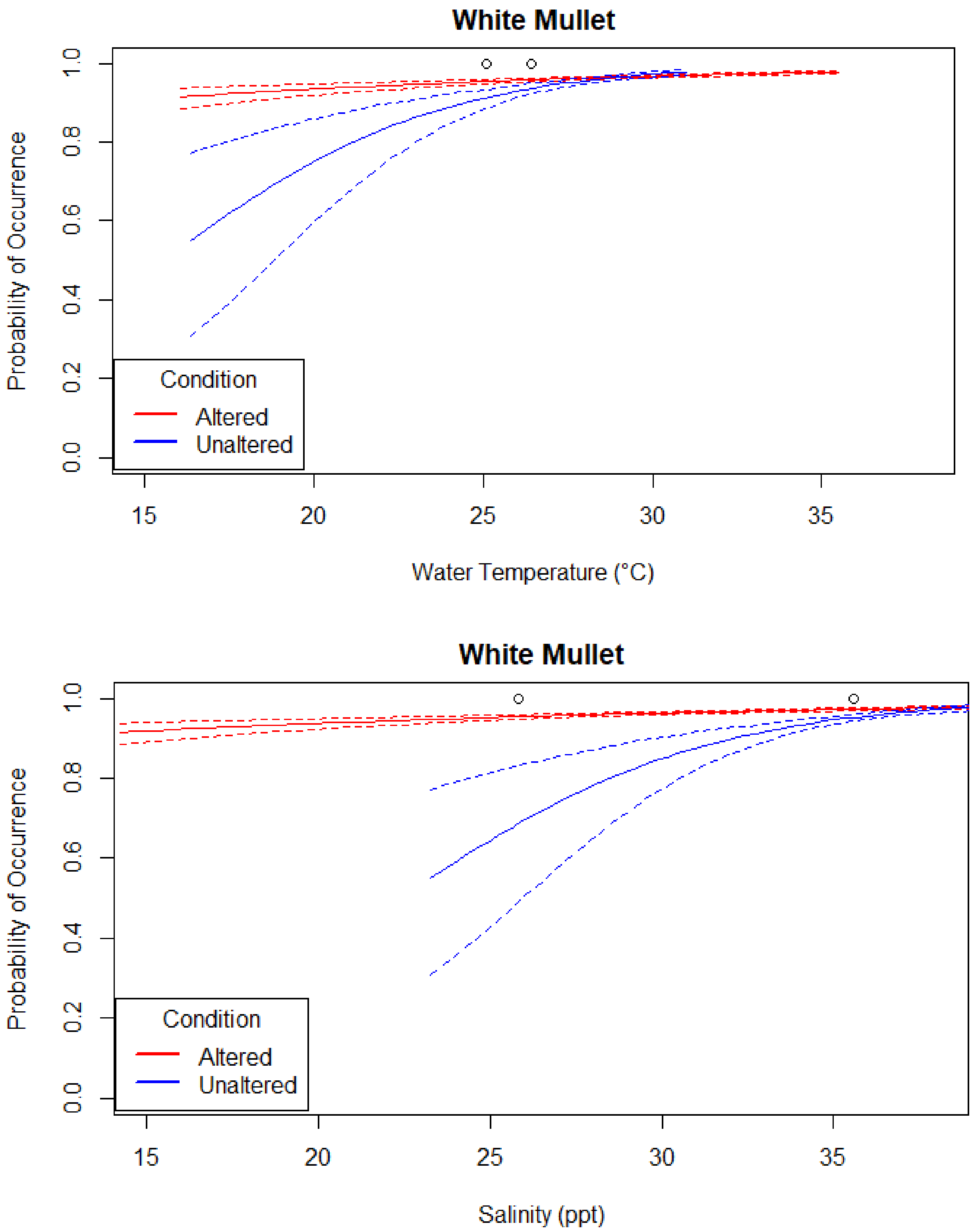


Figure 14. Visual representation of the best GLM models with 85% CI to compare assemblages of white mullet (*Mugil curema*) captured in altered and unaltered marshes on Little Saint Simons Island with predictor variables temperature (°C) and salinity (ppt) (GA, USA) in 2018-2019.

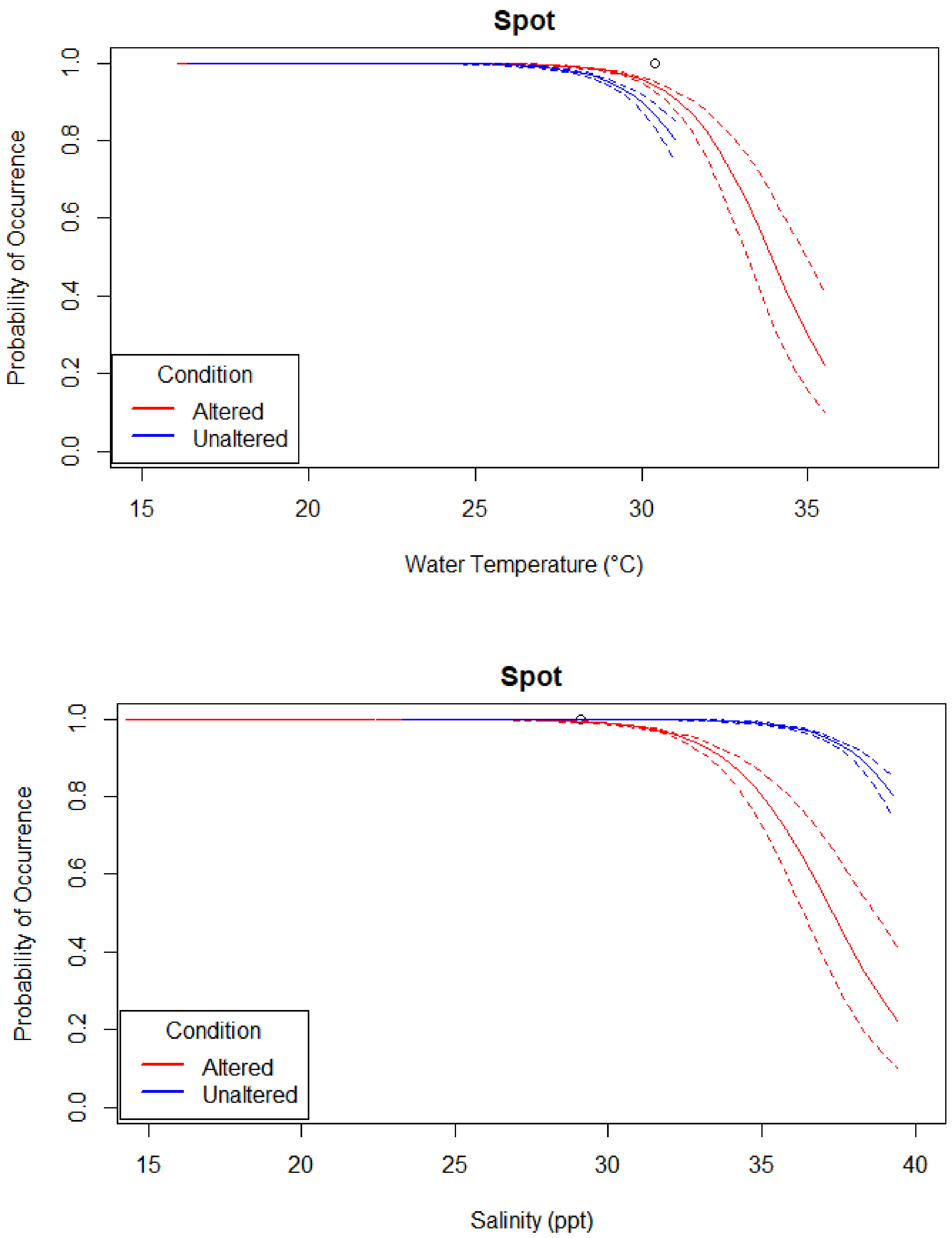


Figure 15. Visual representation of the best GLM models with 85% CI to compare assemblages of spot (*Leiostomus* xanthurus) captured in altered and unaltered marshes on Little Saint Simons Island with predictor variables temperature (°C) and salinity (ppt) (GA, USA) in 2018-2019.

Table 1. Mean water temperature (ºC) and salinity (ppt) readings collected from six sites over six samples on Little Saint Simons Island (Georgia, USA) from 2018-2019. Each mean value was taken from three readings collected at high tide directly after seine net were set for

SITE	**6/3/2018**	**10/26/2018**	**7/16/2019**	**7/27/2019**	**10/10/2019**	**11/7/2019**
			Temperature (°C)			
ALT01	32.30	16.93	29.43	25.90	25.93	14.47
ALT02	30.70	17.23	29.07	25.33	26.57	17.70
ALT03	35.50	16.40	28.83	26.27	24.93	16.83
UNALT01	30.90	17.00	30.40	27.10	23.00	16.40
UNALT02	31.00	22.00	28.87	25.10	26.43	16.80
UNALT03	28.53	17.23	29.07	27.30	23.43	16.70
			Salinity (ppt)			
ALT01	14.26	26.07	35.20	31.98	34.77	31.51
ALT02	22.24	22.01	36.32	26.51	35.26	31.83
ALT03	32.38	29.76	39.39	33.40	35.05	32.27
UNALT01	23.28	26.07	29.09	33.23	34.28	31.34
UNALT02	25.07	30.88	33.06	25.82	35.60	30.82
UNALT03	31.43	29.42	39.26	35.37	34.57	31.00

Table 2. Total number of invertebrates captured in three different altered locations via bag seine on Little Saint Simons Island (Georgia, USA) in 2018-2019.

Order	**Family**	**Scientific Name**	**Common Name**	**ALT01**	**ALT02**	**ALT03**
Decapoda	Alpheidae	*Alpheus heterochaelis*	Big-clawed snapping shrimp	0	14	0
Decapoda	Paleomonidae	*Palaemonetes vulgaris*	Grass Shrimp	2077	234	549
Decapoda	Penaeidae	*Penaeus sp.*	White/Brown Shrimp	7	68	450
Decapoda	Portunidae	*Callinectes sapidus*	Blue crab	50	17	11
Myopsida	Loliginidae	*Lolliguncula brevis*	Atlantic brief squid	10	1	2
Mytilida	Mytilidae	*Geukensia demissa*	Ribbed mussel	1	0	0

Table 3. Total number of invertebrates captured in three different altered locations via bag seine on Little Saint Simons Island (Georgia, USA) in 2018-2019.

Order	**Family**	**Scientific Name (Family)**	**Common Name**	**UNALT01**	**UNALT02**	**UNALT03**
Decapoda	Alpheidae	*Alpheus heterochaelis*	Big-clawed snapping shrimp	0	1	0
Decapoda	Portunidae	*Callinectes sapidus*	Blue crab	8	21	3
Decapoda	Paleomonidae	*Palaemonetes vulgaris*	Grass Shrimp	224	77	4963
Decapoda	Penaeidae	*Penaeus sp.*	White/Brown Shrimp	165	195	501
Myopsida	Loliginidae	*Lolliguncula brevis*	Atlantic brief squid	45	50	2

Table 4. Total number of sub-adult fishes captured in three different altered locations via bag seine on Little Saint Simons Island (Georgia, USA) in

Order	Family	Scientific Name	Common Name	ALT01	ALT02	ALT03
Atheriniformes	Atherinopsidae	*Menidia menidia*	Atlantic Silverside	5	7	213
Bleniiformes	Blennidae	*Chasmodes bosquianus*	Striped Blenny	2	5	2
Carangiformes	Carangidae	*Chloroscombrus chrysurus*	Atlantic Bumper	0	0	1
Carangiformes	Carangidae	*Selene vomer*	Atlantic Lookdown	2	0	1
Carangiformes	Carangidae	*Caranx hippos*	Crevalle Jack	0	0	3
Carangiformes	Carangidae	*Oligoplites saurus*	Leatherjacket	2	4	1
Carangiformes	Carangidae	*Trachinotus falcatus*	Permit (Juvenile)	0	1	0
Clupeiformes	Clupeidae	*Alosa sp.*	Shad sp.	0	0	2
Clupeiformes	Clupeidae	*Dorosoma petenense*	Threadfin Shad	0	0	1
Clupeiformes	Engraulidae	*Anchoa mitchelli*	Bay Anchovy	2,895	1,240	1,925
Clupeiformes	Engraulidae	*Anchoa hepsetus*	Striped Anchovy	1	0	1
Cyprinodontiformes	Cyprinodontidae	*Cyprinodon variegatus*	Sheepshead Minnow	199	5	4
Cyprinodontiformes	Fundulidae	*Fundulus heteroclitus*	Mummichog	322	25	839
Cyprinodontiformes	Fundulidae	*Fundulus majalis*	Striped Killifish	14	0	31
Cyprinodontiformes	Poeciliidae	*Gambusia affinis*	Mosquitofish	0	1	0
Cyprinodontiformes	Poeciliidae	*Poecilia latipinna*	Sailfin Molly	295	6	18
Elopiformes	Elopidae	*Elops saurus*	Ladyfish	1	0	2
Elopiformes	Elopidae	Unidentified	Leptocephalus larvae	0	0	5
Gobiiformes	Gobiidae	*Ctenogobius smaragdus*	Emerald Goby	1	0	0
Mugiliformes	Mugilidae	*Mugil cephalus*	Striped Mullet	170	238	1,020
Mugiliformes	Mugilidae	*Mugil curema*	White Mullet	68	18	168
Perciformes	Gerreidae	*Eucinostomus argenteus*	Spotfin mojarra	0	5	0
Perciformes	Monacanthidae	*Stephanolepid hispidus*	Planehead Filefish	2	0	1
Perciformes	Sciaenidae	*Micropogonias undulates*	Atlantic Croaker	1	68	2
Perciformes	Sciaenidae	*Bairdiella chrysoura*	Silver Perch	9	8	0
Perciformes	Sciaenidae	*Leiostomus xanthhuras*	Spot	1	105	11
Perciformes	Sciaenidae	*Cynoscion nebulosus*	Spotted Seatrout	1	0	0
Perciformes	Sparidae	*Lagodon rhomboides*	Pinfish	0	2	1
Perciformes	Stromatidae	*Peprilus triacanthus*	Atlantic Butterfish	1	0	1
Perciformes	Trichiuridae	*Triuchiurus lepturus*	Atlantic Cutlassfish	0	1	5
Pleuronectiformes	Cyanoglossidae	*Symphurus plagiusa*	Blackcheek Tonguefish	0	1	0

Table 5. Total number of sub-adult fishes captured in three different unaltered locations via bag seine on Little Saint Simons Island (Georgia, USA) in

Order	**Family**	**Scientific Name**	**Common Name**	**UNALT01**	**UNALT02**	**UNALT03**
Atheriniformes	Atherinopsidae	*Menidia menidia*	Atlantic Silverside	351	20	1
Beloniformes	Hemiramphidae	*Hemiramphus brasiliensis*	Ballyhoo	2	1	0
Bleniiformes	Blennidae	*Chasmodes bosquianus*	Striped Blenny	0	1	1
Carangiformes	Carangidae	*Caranx hippos*	Crevalle Jack	0	1	0
Carangiformes	Carangidae	*Oligoplites saurus*	Leatherjacket	40	8	1
Carangiformes	Carangidae	*Trachinotus falcatus*	Permit	0	1	0
Clupeiformes	Clupeidae	*Brevoortia tyrannus*	Atlantic Menhaden	1	33	0
Clupeiformes	Clupeidae	*Alosa sp.*	Shad sp.	1	0	0
Clupeiformes	Clupeidae	*Brevoortia patronus*	Yellowfin Menhaden	197	0	0
Clupeiformes	Engraulidae	*Anchoa mitchelli*	Bay Anchovy	7,397	1,926	33
Clupeiformes	Engraulidae	*Anchoa hepsetus*	Striped Anchovy	0	5	0
Cyprinodontiformes	Cyprinodontidae	*Cyprinodon variegatus*	Sheepshead Minnow	0	23	0
Cyprinodontiformes	Fundulidae	*Fundulus heteroclitus*	Mummichog	43	16	26
Cyprinodontiformes	Poeciliidae	*Poecilia latipinna*	Sailfin Molly	2	0	10
Gobiiformes	Gobiidae	*Ctenogobius smaragdus*	Emerald Goby	1	1	0
Gobiiformes	Gobiidae	*Dormitator maculatus*	Fat Sleeper	0	1	0
Lobotiformes	Lobotidae	*Lobotes surinamensis*	Atlantic Tripletail	0	1	0
Mugiliformes	Mugilidae	*Mugil cephalus*	Striped Mullet	76	112	107
Mugiliformes	Mugilidae	*Mugil curema*	White Mullet	54	6	25
Perciformes	Ephippidae	*Chaetodipterus faber*	Atlantic Spadefish	0	1	0
Perciformes	Gerreidae	*Eucinostomus argenteus*	Spotfin mojarra	2	3	6
Perciformes	Haemulidae	*Haemulon sp.*	Grunt (Unidentified)	2	1	0
Perciformes	Monacanthidae	*Stephanolepid hispidus*	Planehead Filefish	1	1	0
Perciformes	Sciaenidae	*Micropogonias undulates*	Atlantic Croaker	0	83	3
Perciformes	Sciaenidae	*Pogonias cromis*	Black Drum	0	5	0
Perciformes	Sciaenidae	*Bairdiella chrysoura*	Silver Perch	8	83	11
Perciformes	Sciaenidae	*Leiostomus xanthhuras*	Spot	1	65	10
Perciformes	Sciaenidae	*Cynoscion nebulosus*	Spotted Seatrout	0	1	1
Perciformes	Sciaenidae	*Stellifer lanceolatus*	Star Drum	1	5	0
Perciformes	Sparidae	*Lagodon rhomboides*	Pinfish	0	2	4
Perciformes	Stromatidae	*Peprilus paru*	Atlantic Harvestfish	1	1	0
Perciformes	Trichiuridae	*Trichiurus lepturus*	Atlantic Cutlassfish	1	16	0
Pleuronectiformes	Cyanoglossidae	*Symphurus plagiusa*	Blackcheek Tonguefish	0	2	0
Pleuronectiformes	Paralichthyidae	*Paralichthys lethostigma*	Southern Flounder	0	0	1
Tetraodontiformes	Diodontidae	*Chilomycterys schoepfi*	Striped Burrfish	2	0	0

Table 6. Predictor variables for assemblages of prevalent fishes captured on LSSI, number of parameters (K), AIC*c*, difference of previous candidate model AIC*c* (Δ*i*), and Akaike weight *(ωi)* for candidate models to predict the effects of condition (altered or unaltered), water temperature, salinity, and interaction terms. Data for these models were collected on Little Saint Simons Island, GA during 2018-2019.

Atlantic Silverside Candidate Model	**K**	**AIC*c***	**Δ*i***	**ω*i***	**% of max ωi**
Condition, Temperature, Salinity, Condition*Temperature, Condition *Salinity	7	1122.13	0.00	1.00	100%
Condition, Temperature, Salinity, Condition*Temperature	5	1150.91	28.78	0.00	0%
Condition, Salinity, Condition *Salinity	4	1243.44	121.31	0.00	0%
Condition, Temperature, Salinity, Condition*Salinity	5	1247.49	125.36	0.00	0%
Condition, Temperature, Salinity	4	1308.56	186.43	0.00	0%
Salinity	2	1310.43	188.30	0.00	0%
Condition, Temperature, Condition*Temperature	4	1357.53	235.40	0.00	0%
Condition	2	1509.57	387.44	0.00	0%
Condition, Temperature	3	1510.69	388.56	0.00	0%
Temperature	2	1527.00	404.87	0.00	0%

Bay Anchovy Candidate Model	**K**	**AIC*c***	**Δ*i***	**ω*i***	**% of max ωi**
Condition, Temperature, Salinity, Condition*Temperature, Condition *Salinity	7	11955.67	0.00	1.00	100%
Condition, Temperature, Salinity, Condition*Salinity	5	11987.45	31.78	0.00	0%
Condition, Temperature, Salinity, Condition*Temperature	5	13621.18	1665.51	0.00	0%
Condition, Temperature, Salinity	4	13640.22	1684.56	0.00	0%
Condition, Temperature, Condition*Temperature	4	14009.10	2053.43	0.00	0%
Condition, Temperature	3	14052.16	2096.50	0.00	0%
Temperature	2	15654.90	3699.28	0.00	0%
Condition, Salinity, Condition *Salinity	4	30195.67	18240.0	0.00	0%
Salinity	2	30530.46	18574.8	0.00	0%
Condition	2	30677.83	18722.1	0.00	0%

(Table 6. continued)

Mummichog Candidate Model	**K**	**AIC*c***	**Δ*i***	**ω*i***	**% of max ωi**
Condition, Temperature, Salinity	4	1478.00	0.00	0.61	100%
Condition, Temperature, Salinity, Condition*Salinity	5	1479.66	1.66	0.26	43%
Condition, Temperature, Salinity, Condition*Temperature	5	1481.21	3.22	0.12	20%
Condition, Temperature, Salinity, Condition*Temperature, Condition *Salinity	7	1487.59	9.32	0.01	2%
Condition, Salinity, Condition *Salinity	4	1731.59	253.59	0.00	0%
Condition, Temperature	3	1944.99	466.99	0.00	0%
Condition, Temperature, Condition*Temperature	4	1947.78	469.79	0.00	0%
Condition	2	2378.62	900.62	0.00	0%
Salinity	2	2986.40	1508.40	0.00	0%
Temperature	2	3163.98	1685.98	0.00	0%

Sailfin Molly Candidate Model	**K**	**AIC*c***	**Δ*i***	**ω*i***	**% of maximum ωi**
Condition, Temperature, Salinity, Condition*Salinity	4	624.63	0.00	0.94	100%
Condition, Salinity, Condition *Salinity	4	631.91	7.28	0.02	2%
Condition, Temperature, Salinity, Condition*Temperature	5	632.23	7.60	0.02	2%
Condition, Temperature, Salinity, Condition*Salinity	5	633.53	8.90	0.01	1%
Condition, Temperature, Salinity, Condition*Temperature, Condition *Salinity	7	667.88	43.25	0.00	0%
Salinity	2	747.96	123.32	0.00	0%
Condition, Temperature	3	784.97	160.33	0.00	0%
Condition, Temperature, Condition*Temperature	4	790.14	165.51	0.00	0%
Condition	2	820.10	195.47	0.00	0%
Temperature	2	935.31	310.68	0.00	0%

(Table 6. continued)

Striped Mullet Candidate Model	**K**	**AIC*c***	**Δ*i***	**ω*i***	**% of max ωi**
Condition, Temperature, Salinity, Condition*Temperature, Condition *Salinity	7	1900.17	0.00	1.00	100%
Condition, Temperature, Salinity, Condition*Salinity	5	1913.05	12.88	0.00	0%
Condition, Salinity, Condition *Salinity	4	1913.43	13.26	0.00	0%
Condition, Temperature, Salinity, Condition*Salinity	4	2129.93	229.76	0.00	0%
Condition, Temperature, Salinity, Condition*Temperature	5	2131.37	231.20	0.00	0%
Salinity	2	2714.36	814.19	0.00	0%
Condition, Temperature	3	3444.46	1544.29	0.00	0%
Condition, Temperature, Condition*Temperature	4	3446.66	1546.49	0.00	0%
Condition	2	3527.52	1627.35	0.00	0%
Temperature	2	4134.10	2233.96	0.00	0%

White Mullet Candidate Model	**K**	**AIC*c***	**Δ*i***	**ω*i***	**% of max ωi**
Condition, Temperature, Salinity, Condition*Temperature	5	541.57	0.00	0.91	100%
Condition, Temperature, Salinity, Condition*Salinity	4	547.64	6.08	0.04	4%
Condition, Salinity, Condition *Salinity	4	547.89	6.32	0.04	4%
Condition, Temperature, Salinity, Condition*Temperature, Condition *Salinity	7	551.31	9.74	0.01	1%
Condition, Temperature, Salinity, Condition*Salinity	5	551.88	10.31	0.01	1%
Salinity	2	569.49	27.93	0.00	0%
Condition	2	590.49	48.93	0.00	0%
Condition, Temperature	3	592.24	50.67	0.00	0%
Condition, Temperature, Condition*Temperature	4	593.52	51.95	0.00	0%
Temperature	2	620.74	79.17	0.00	0%

(Table 6. continued)

Spot Candidate Model	**K**	**AIC*c***	**Δ*i***	**ω*i***	**% of max ωi**
Condition, Temperature	3	303.23	0.00	0.91	100%
Condition, Temperature, Salinity, Condition*Salinity	4	308.72	5.49	0.06	7%
Condition	4	310.27	7.04	0.03	3%
Condition, Temperature, Salinity, Condition*Temperature	5	319.32	16.09	0.00	0%
Condition, Temperature, Salinity, Condition*Salinity	5	319.77	16.54	0.00	0%
Temperature	2	333.90	30.69	0.00	0%
Condition, Salinity, Condition *Salinity	4	357.58	54.35	0.00	0%
Salinity	2	362.06	58.83	0.00	0%
Condition, Temperature, Salinity, Condition*Temperature, Condition *Salinity	7	413.38	110.15	0.00	0%
Condition	2	437.30	134.06	0.00	0%

Table 7. Parameter estimates for prevalent fishes captured in unaltered marshes, standard errors, and 85% confidence intervals used in generalized linear models (GLM) to predict the effects of condition (altered or unaltered), water temperature, salinity, and interaction terms on the assemblages of fishes within the orders. Data for these models were collected on Little Saint Simons Island, GA during 2018-2019. The tables below represent the parameter estimates, standard errors, and lower and upper 85% confidence intervals from the best fit models for each GLM.

	SOURCE	Estimate	SE	Lower	Upper
Atlantic Silverside	(INTERCEPT)	-9.149	0.944	-10.50	-7.790
	CONDITION	11.858	1.104	10.268	13.448
	TEMPERATURE	0.217	0.025	0.180	0.253
	SALINITY	0.230	0.019	0.203	0.257
	CONDITION * TEMPERATURE	-0.274	0.027	-0.314	-0.235
	CONDITION * SALINITY	-0.155	0.025	-0.192	-0.119

	SOURCE	Estimate	SE	Lower	Upper
Bay Anchovy	(INTERCEPT)	8.135	0.186	7.867	8.404
	CONDITION	7.908	0.239	7.564	8.253
	TEMPERATURE	-0.435	0.009	-0.447	-0.422
	SALINITY	0.205	0.006	0.197	0.214
	CONDITION * TEMPERATURE	0.063	0.010	0.049	0.078
	CONDITION * SALINITY	-0.278	0.007	-0.288	-0.267

	SOURCE	Estimate	SE	Lower	Upper
Mummichog	(INTERCEPT)	-1.951	0.285	-2.360	-1.541
	CONDITION	-2.656	0.113	-2.818	-2.493
	TEMPERATURE	0.107	0.007	0.097	0.117
	SALINITY	0.113	0.006	0.104	0.122

	SOURCE	Estimate	SE	Lower	Upper
Sailfin molly	(INTERCEPT)	-1.940	0.597	-2.799	-1.080
	CONDITION	-2.266	0.296	-2.693	-1.840
	TEMPERATURE	0.042	0.015	0.021	0.064
	SALINITY	0.144	0.015	0.123	0.166

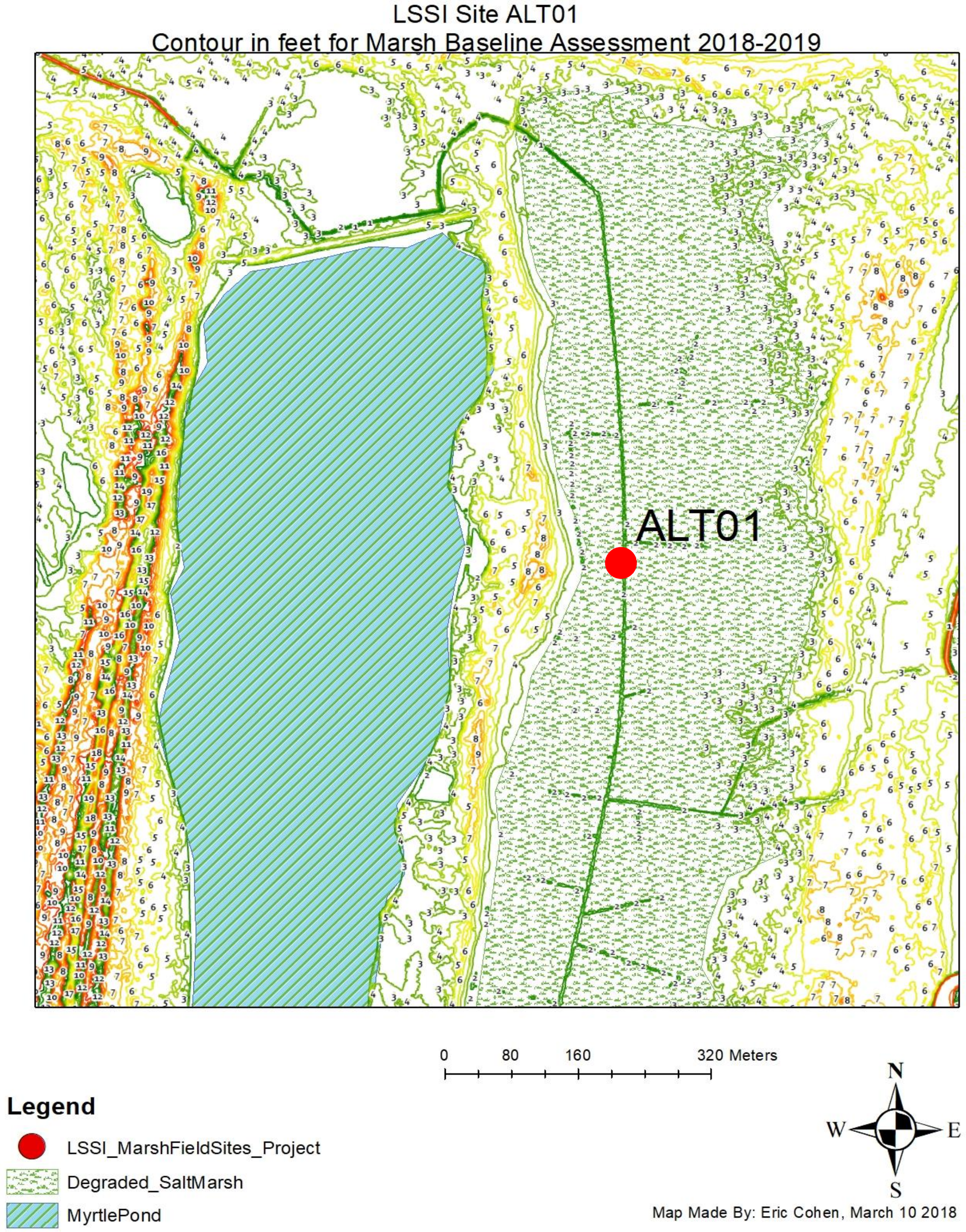
	SOURCE	Estimate	SE	Lower	Upper
Striped mullet	(INTERCEPT)	-5.244	0.321	-5.706	-4.782
	CONDITION	5.448	0.653	4.509	6.388
	TEMPERATURE	-0.008	0.008	-0.020	0.004
	SALINITY	0.296	0.010	0.282	0.311
	CONDITION * TEMPERATURE	0.067	0.016	0.044	0.089
	CONDITION * SALINITY	-0.252	0.016	-0.276	-0.229

(Table 7. continued)

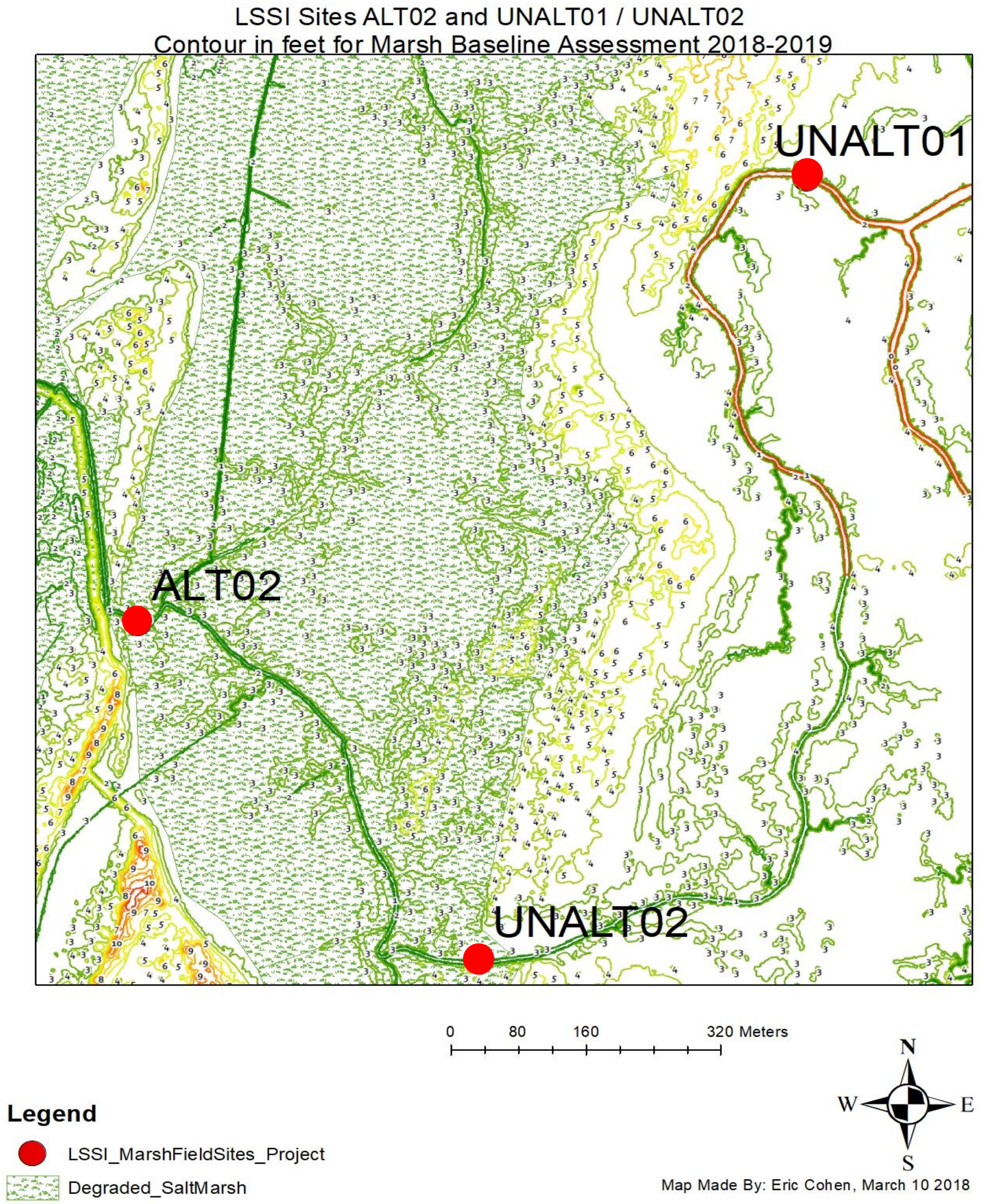
	SOURCE	Estimate	SE	Lower	Upper
White mullet	(INTERCEPT)	1.688	0.469	1.012	2.363
	CONDITION	-5.934	1.646	-8.305	-3.563
	TEMPERATURE	-0.022	0.014	-0.041	-0.002
	SALINITY	0.073	0.010	0.058	0.088
	CONDITION * TEMPERATURE	0.189	0.058	0.106	0.273

	SOURCE	Estimate	SE	Lower	Upper
Spot	(INTERCEPT)	26.754	2.910	22.564	30.943
	CONDITION	-0.887	0.151	-1.104	-0.670
	TEMPERATURE	-0.789	0.099	-0.932	-0.646

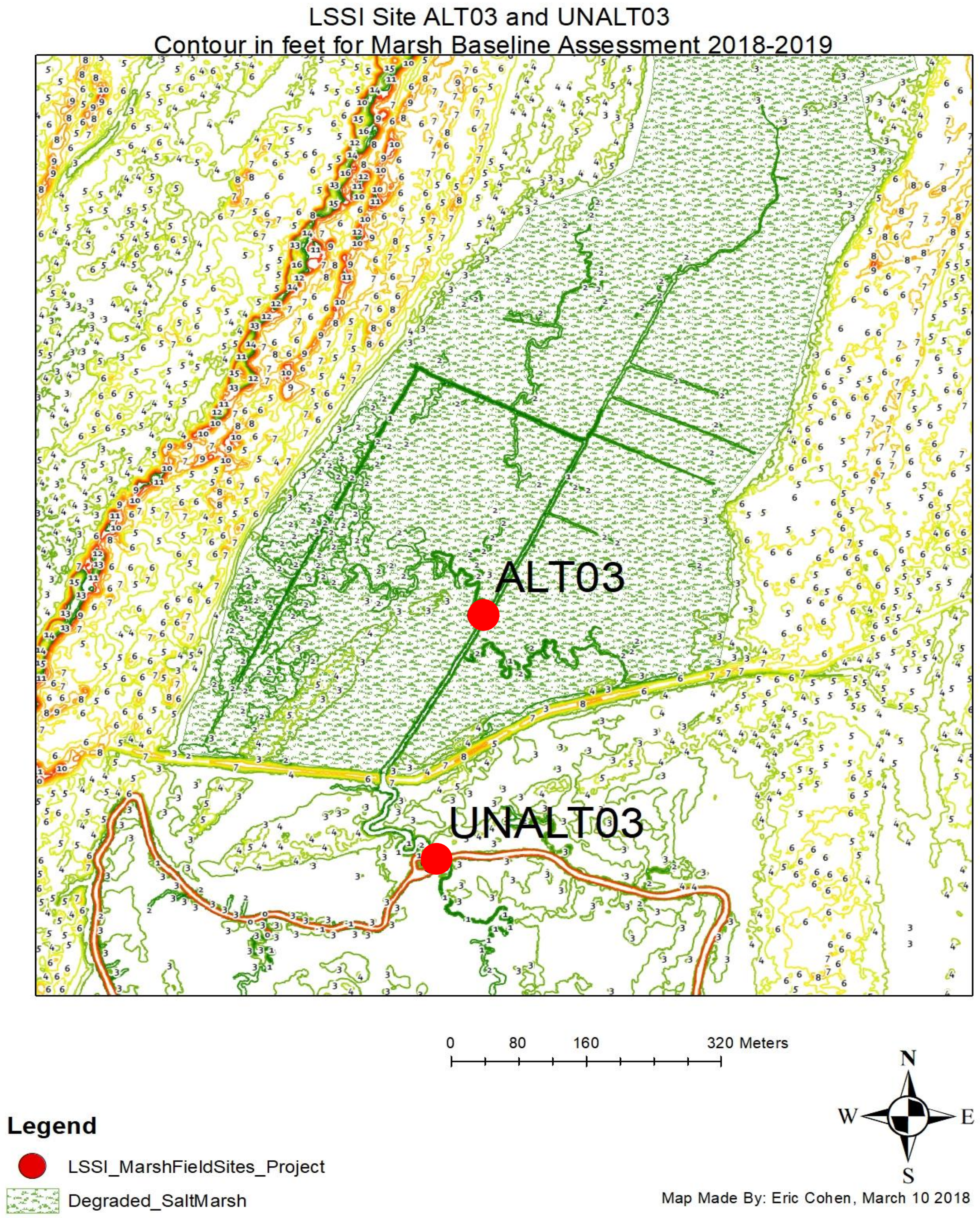
APPENDICES



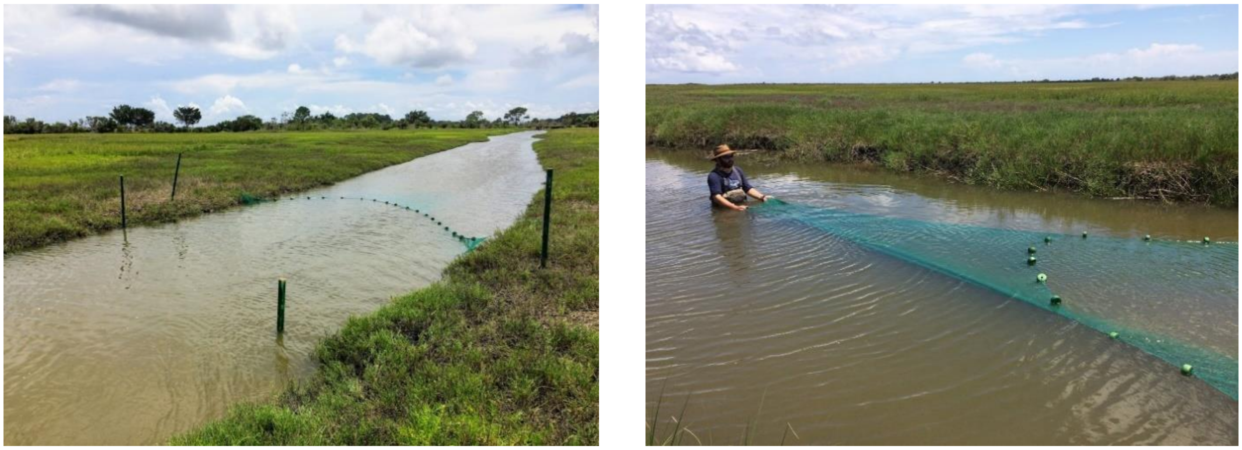
Appendix A. Site ALT01 located east of Myrtle Pond on Little Saint Simons Island (Georgia, USA). The map displays elevation via 1-foot contour lines.



Appendix B. Site UNALT01 located at Hole 3 of Sancho Panza Creek, and sites ALT02 and UNALT02 located east of Marsh Road on Little Saint Simons Island (Georgia, USA). The map displays elevation via 1-foot contour lines.

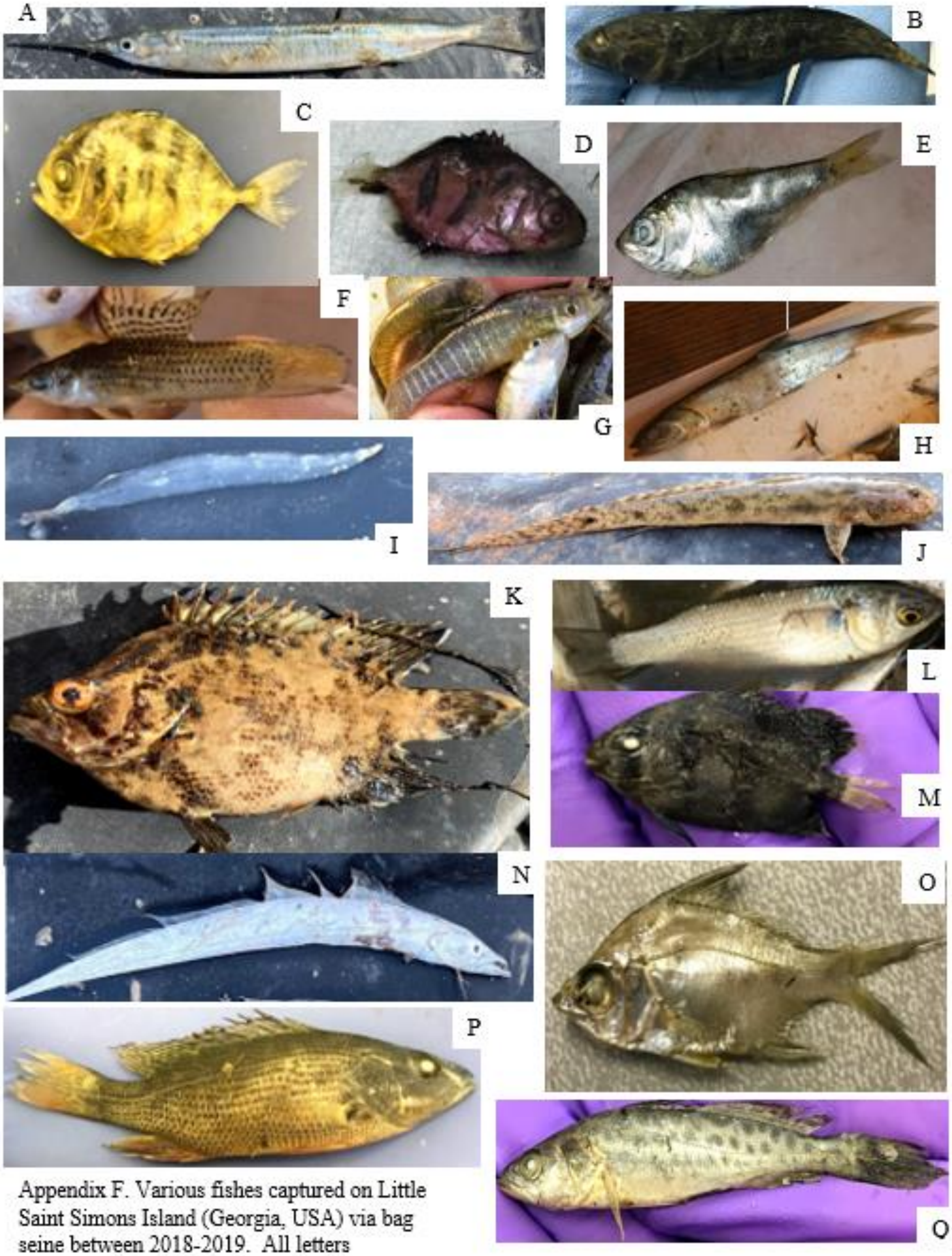


Appendix C. Sites ALT03 and UNALT03 located near Beach Road Bridge on Little Saint Simons Island (Georgia, USA). The map displays elevation via 1-foot contour lines.



Appendix D. Depiction of a bag seine being set at slack high tide at site ALT03. The two PVC pipes in the water are attached to the led line, and the two PVC pipes in the riparian zone of the creek is attached to the float line by a free moving loop that moves with the tide. In order to begin the sample at the exact moment of the ebb tide, we held the net until the current changed the proper direction. This method was repeated at all sites throughout the project.

Appendix E. Depiction of a bag seine after a 4-hour soak. The bag has enclosed over the 4-hour soak period allowing us to capture the fishes utilizing the salt marsh habitats at high tide. The net is then pulled ashore and all fish were placed into a jar containing 95% Ethanol, for further processing in a laboratory at The University of Georgia.



Appendix F. Various fishes captured on Little Saint Simons Island (Georgia, USA) via bag seine between 2018-2019. All letters correspond to a label in Appendix G.

Appendix G. Legend of fishes corresponding to Figure 2.11.
“O” represents Order and “F” represents Family.

A) Beloniformes (O); Hemiramphidae (F); *Hemiramphus brasiliensis*
B) Bleniiformes (O); Bleniidae (F); *Chasmodes bosquianus*
C) Carangiformes (O); Carangidae (F); *Caranx hippos*
D) Carangiformes (O); Carangidae (F); *Trachionotus falcatus*
E) Clupeiformes (O); Clupeidae (F); *Brevootia patronus*
F) Cyprinodontiformes (O); Poecillidae (F); *Poecilia latipinna*
G) Cyprinodontiformes (O); Fundulidae (F); *Fundulus heteroclitus*
H) Elopiformes (O); Elopidae (F); *Elops saurus*
I) Elopiformes (O); Elopidae (F); Leptocephalus larvae
J) Gobiiformes (O); Gobiidae (F); *Ctenogobius smaragdus*
K) Lobotiiformes (O); Lobotiidae (F); *Lobotes surinamensis*
L) Mugiliformes (O); Mugilidae (F); *Mugil cephalus*
M) Perciformes (O); Ephippidae (F); *Chaetodipterus faber*
N) Perciformes (O); Trichiuruidae (F); *Trichiurus lepturus*
O) Perciformes (O); Gerreidae (F); *Eucinostomus argenteus*
P) Perciformes (O); Haemulidae (F); *Haemulon sp.*
Q) Perciformes (O); Trichiuridae (F); *Cynoscion nebulosus*

Appendix H. Sampling seasons for the baseline analysis project on Little Saint Simons Island (Georgia, USA). EC1, EC3, and EC4 occurred during the summer, and EC2, EC5, and EC6 occurred during the fall. During each visit, each of the 6 sites was sampled using the bag seine method, and water quality and soil data was collected.

SAMPLE SET	DATE
EC1	7/3/2018 - 7/10/2018
EC2	10/26/2018; 11/18/2019 - 11/20/2019
EC3	7/16/2019 - 7/19/2019
EC4	7/27/2019 - 7/30/2019
EC5	10/10/2019 - 10/13/2019
EC6	11/07/2019 – 11/11/2019

Appendix I. Detailed metadata of the 3 altered and 3 unaltered sites on Little Saint Simons Island (Georgia, USA). GPS data was collected using a Garmin GPS Unit. All other data was obtained from several public layers on ArcMap found through literature research or public domain.

SITE	**GPS**	**STREAM LOCATION**	**STREAM WIDTH**	**DISTANCE TO ROAD**	**VEGETATION TYPE**	**ELEV**	**EBB CURRANT DIRECTION**	**EBB CURRANT DESTINATION**
ALT01	31.284074 - 81.289535	Myrtle Pond Channel	2.5 m	71 m	Southern Atlantic Coastal Plain Salt and Brackish Tidal Marsh	2 ft	North	Altamaha River
ALT02	31.267703 - 81.293471	Marsh Road Channel	3 m	31.6 m	Southern Atlantic Coastal Plain Salt and Brackish Tidal Marsh	3 ft	East	Sancho Panza Creek
ALT03	31.251511 - 81.292284	Beach Road Channel	4.3 m	216 m	Southern Atlantic Coastal Plain Salt and Brackish Tidal Marsh	1 ft	South	Mosquito Creek
UNALT01	31.272845 - 81.285158	Sancho Panza Creek Hole 3	4.4 m	88 m	Southern Atlantic Coastal Plain Salt and Brackish Tidal Marsh	4 ft	North	Altamaha River
UNALT02	31.263838 - 81.289214	Southeastern Sancho Panza Creek	3.3 m	123.4 m	Southern Atlantic Coastal Plain Salt and Brackish Tidal Marsh	2 ft	West	Sancho Panza Creek
UNALT03	31.248713 - 81.292861	Mosquito Creek	5.3 m	110 m	Southern Atlantic Coastal Plain Salt and Brackish Tidal Marsh	4 ft	West	Atlantic Ocean