Predicting the effects of sea level rise on marsh birds of conservation concern in coastal North Carolina

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Abstract

Sea level rise (SLR) and habitat loss across the array of expansive marsh habitat that encompass the NC Sentinel Site Cooperative (NCSSC) is potentially imperiling many marsh specialist species. Tidal marshes are essential for many species' survival, but tidal marshes are being degraded for a multitude of reasons, including anthropogenic activities. Saltmarsh and seaside sparrows are endemic to tidal marshes, which potentially makes them susceptible to population limitation from SLR. Population limitations will likely have a particular impact on saltmarsh sparrows whose populations have already decreased ~75% since the late 1990's. There is a large gap in knowledge regarding the impacts of SLR on winter populations of marsh sparrow limiting our ability to effectively develop conservation strategies. In order to fill these gaps in knowledge we are investigating the impacts of SLR, using Sea Level Affecting Marshes Model (SLAMM), on known densities of saltmarsh and seaside sparrows at two locations in North Carolina; Masonboro Island (MB) and Bald Head State Natural Area (BHI). Our objectives are to determine habitat changes on our study sites through 2060 at low, moderate, and high SLR projections and to determine if SLR will affect the extent of tidal marsh habitat used by saltmarsh and seaside sparrows for locations where we have known density estimates. Regularly flooded marsh habitat decreased from 37.6% to 7% and 59.2% to 9% on MB and BHI respectively from 2020 through 2060. Habitats on Masonboro Island and Bald Head State Natural Area transitioned drastically from 2020 to 2040 and then proceeded without much change from 2040 to 2060 for at all SLR scenarios. Predicted abundances of saltmarsh and seaside sparrows decreased sharply at both sites by 2060 (MB: SALS 11(2020)–2.12(2060), MB: SESP 229(2020)–8.5(2060), BHI: SALS 76(2020) –16.3(2060), BHI: SESP 114(2020) –31.1(2060)). Based on our models, winter habitat for both species will be reduced dramatically by 2040, leading to population limitations. It is possible that the small amount of habitat remaining in 2040 and 2060 would be too small to support any individuals of our study species. Without adaptive management, SLR will lead to loss of essential habitat for an array of marsh specialist. More research is needed to address impacts of SLR on vulnerable marsh species.

Introduction

North Carolina is a coastal state that is beginning to see exceptional environmental, social and economic challenges posed by sea level rise (SLR) across the landscape's array of natural habitats that range from beaches to expansive tidal marshes (Bin et al. 2007). North Carolina is one of the five NOAA Sentinel Sites, which aim to study the effects of sea level rise while engaging in collaboration and addressing the impacts of rising seas on coastal communities. The NC Sentinel Site Cooperative (NCSSC) is home to expansive marsh complexes that support many species of birds that are potentially imperiled by SLR and habitat loss throughout the year. Due to human induced climate change, habitat degradation and a multitude of other factors we are currently in the 6th mass extinction event, where we are beginning to see extinction events due to climate change, for example the recent extinction of the Bramble Cay melomy, a small rodent that was endemic to Bramble Cay, an Australia island (Waller et al. 2017, Roman-Palacios and Wiens 2020).

Although only encompassing ~5.5Mha worldwide, saltmarshes are home to many specialist species that form the essential marsh ecosystem we rely on for both protection and resources (McOwen et al. 2017). Tidal marshes are extremely productive and are home to a multitude of species, both terrestrial and aquatic including ~25 marsh endemic terrestrial vertebrates (Greenberg et al. 2006). Tidal marshes are essential for many species' survival, but tidal marshes have been degrading due to anthropogenic activities. Humans have been exploiting tidal marshes for centuries, leading to the current threats to tidal marsh ecosystems. Development in and around tidal marshes is a driver to marsh loss, and with an influx of people living and moving into coastal communities, there is a further loss and degradation on the saltmarsh ecosystems (Greenberg et al. 2006). Globally, the coast makes up only 4% of land mass, but more than 40% of the human population resides in these coastal areas, and the abundance of people is growing (Bertness and Silliman 2008). With development of roads and structures along marshes, marshes are limited to where movement can occur leading to marsh loss instead of marsh migration (Wiest et al. 2016). Marsh habitat has been used for agriculture and grazing animals since the Neolithic period, marsh grass was also harvested for salt hay, and marshes have been diked and dried to form agricultural fields (Greenberg et al. 2006, Gedan et al. 2009). Changes to hydrology have harmed tidal marshes by humans building channels, and ditching. Channels have been created for shipping lanes, and ditching has affected over 90% of all salt marshes (Silliman et al. 2009). Invasive species have been a driver of marsh loss and changes, including invasion of Phragmites, and animals such as the nutria (Silliman et al. 2009). Lastly, climate change and sea-level rise are impacting erosion and accretion on salt marshes via water inundation, changes in salinity, increased storm severity, and water levels and tides becoming more extreme (Greenberg et al. 2006, Gedan et al. 2009, Bayard and Elphick 2011, Wiest et al. 2016). In addition to loss of marshes on the periphery, interior sections of marshes are also being inundated and preventing marsh plants to thrive and survive (Greenberg et al. 2006). In order to better understand how SLR will affect critical wildlife habitats, we need to fill our gaps in knowledge of species use of these habitats and predict habitat extent in the future.

For many vertebrates, including birds, their non-breeding and breeding periods are inextricably linked, and what occurs during one period can carry-over to affect the next period of life (Marra et al. 2015). In addition, research on population limitation has historically focused on the breeding season (spring/summer), creating large gaps in knowledge regarding the potential for limitation in the non-breeding season (fall/winter) for many species (Marra et al. 2015). This dearth of data may limit our ability to develop effective conservation plans for many species of conservation concern, including two species of marsh sparrows that winter in NC: the saltmarsh (*Ammospiza caudacutus)* and seaside sparrows (*Ammospiza maritima*) (Greenlaw et al. 2020, Post and Greenlaw 2020).

Saltmarsh and seaside sparrows are endemic to tidal marshes, which potentially makes them susceptible to population limitation from SLR (Roberts et al. 2019). Saltmarsh sparrow breeding populations have declined by 9% a year since 1998 and are expected to go extinct between 2035 and 2060 (Correll et al. 2017, Field et al. 2017, Greenlaw et al. 2020). Seaside sparrow populations are vulnerable depending on location, but one subspecies—the dusky seaside sparrow—has gone extinct, with another subspecies—cape sable seaside sparrow—listed as Endangered (Post and Greenlaw 2020). The US Fish and Wildlife Service are scheduled to determine if the saltmarsh sparrow should be listed as Threatened or Endangered in 2023 and will therefore soon request information on the biology of this species to help make the most informed listing decision. SLR is predicted to reduce the extent of suitable breeding habitat for both saltmarsh and seaside sparrows (Roberts et al. 2019), however given the recognized importance of full annual cycle biology, lack of predicted effects of SLR on wintering habitats may render current estimates of population persistence to be anticonservative.

Objectives

This project used density estimates for saltmarsh and seaside sparrows at two study sites in southeastern North Carolina, and sea level rise models for the larger area around the study sites to address the following Sentinel Site Cooperative focal areas: 1) SLR impacts on coastal habitats and their associated ecosystem services; 2) Marsh and wetland sediment supply and distribution; 3) Economic assessments of SLR on coastal ecosystems; 4) Development of K-12 pedagogical approaches to climate and SLR education. This study addresses the following objectives and hypotheses.

1) Determine habitat changes on Masonboro Island and Bald Head Island State Natural Area through 2060 at low, moderate, and high SLR projections

2) Determine if SLR will affect the extent of tidal marsh habitats used by saltmarsh and seaside sparrows in NC by modeling for sea level rise in locations where we have known density estimates for both species.
    - **Hypothesis 1: SLR will be a main driver of habitat loss on the wintering grounds of saltmarsh and seaside sparrows.** I predict that net habitat change will be negative for saltmarsh and seaside sparrows and that marsh migration will be insufficient to make up for habitat loss.
    - **Hypothesis 2: Habitat loss from SLR will be severe enough to reduce population sizes of saltmarsh and seaside sparrows in winter.** I predict that habitat predictions from H1 combined with my population estimates of marsh birds will show that SLR will reduce population sizes by decreasing usable habitat.
    - **Hypothesis 3: The open nature of the tidal flats will not offer enough cover for protection from predators and/or have preferred prey items for saltmarsh and seaside sparrow**. I predict that once habitat types mostly shift to tidal flats habitat will be insufficient to sustain current populations.

Methods

Study Sites

Masonboro Island is managed by the North Carolina National Estuarine Research Reserve System (NC NERRS) and is located in New Hanover County, North Carolina (Fig. 1). NERRS focuses on research and education at their reserves, including Masonboro Island Reserve. At 13-km long, Masonboro Island is an undisturbed barrier island that consists of many habitat types, including tidal marshes, dunes, and beach habitats. Masonboro Island is made up of a large stretch of beach with marsh habitat extending out to the dredge spoil islands that were built on the Intracoastal Waterway (ICW). The largest of its kind in Southeastern North Carolina, Masonboro Island is host to a multitude of species including the bird species of interest for this study (Halls et al. 2018). Masonboro is a barrier island, and lies between two bodies of water, the Atlantic Intracoastal Waterway on the west side, and the Atlantic Ocean on the east, and has expansive tidal marsh habitat that encompasses eighty-seven percent of the island. The site for density estimates on Masonboro Island was centered around the following coordinates (Zone 18S E:237306.38, N:3780829.50) and is located near the middle of the island at a remnant inlet; I will refer to this site as Old Cabbage Inlet (OCI) (Fig. 1 & 2A).

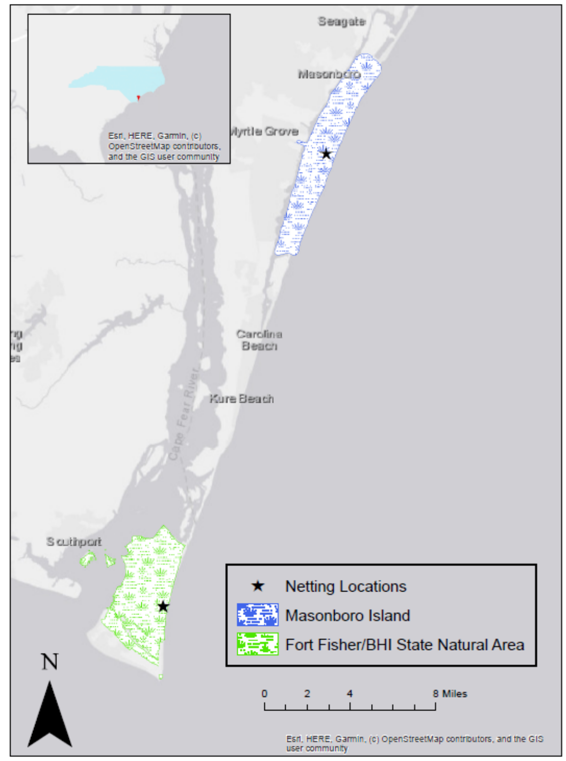


Figure 1. Map of study sites.

Bald Head Island State Natural Area is managed by North Carolina State Parks system and is located Brunswick County, NC across the Cape Fear River from Southport, NC (Fig. 1). Bald Head State Natural Area is part of the Bald Head Smith Island complex that spans from Fort Fisher State Park to Bald Head Island and encompasses a large variety of habitats from upland forest to large areas of marsh. The complex used to be separated by inlets but has recently reformed into a single strip of beach (Sherrill et al. 2010). Bald Head Island State Natural area is between the mouth of the Cape Fear River and the Atlantic Ocean. The site for density estimates at Bald Head Island was centered around the following coordinates (Zone 18S E:226354.33, N:3753082.71) and SLR was modeled for Bald Head State Natural Area (Fig. 1 & 2B). This site will be referred to as BHI for the remainder of the report.

Figure 2. Pictures from supratidal high tide habitat. A) Masonboro Island (OCI) B) Bald Head Island State Natural Area (BHI

Study Species

The saltmarsh sparrow (*Ammospiza caudacuta*; SALS, Fig. 3A) is a new world sparrow that lives on the East Coast of North America. Saltmarsh sparrows are specialist that live exclusively in saltmarshes. Saltmarsh sparrows are a species of concern globally, nationally, and regionally, and requires conservation efforts immediately (Bayard and Elphick 2011). Saltmarsh sparrow breeding populations have declined by 9% a year since 1998 and are expected to go extinct between 2035 and 2060 (Correll et al. 2017, Field et al. 2017). Their population estimates for individual birds are currently between 30,000–50,000 but has likely decreased since population estimates were established in 2016 (Wiest et al. 2016). The determination whether SALS should federally listed as Threatened or Endangered by the US Fish and Wildlife Service is planned for 2023 and the Atlantic Coast Joint Venture long-term population plan calls for sustaining 25,000 breeding birds to stabilize the population(2019).

The seaside sparrow (*Ammospiza maritima*; SESP, Fig. 3B) is a new world sparrow that lives in tidal marshes on the Atlantic Coast of North America and the Gulf of Mexico. Some seaside sparrows are migratory, while some are year-round residents, making them facultative migrants (Post and Greenlaw 1994, Post and Greenlaw 2020). Seaside sparrows can be used as an indicator species because they are tidal marsh specialists, which makes them reliable indicators of coastal marsh health and degradation (Post and Greenlaw 2020).

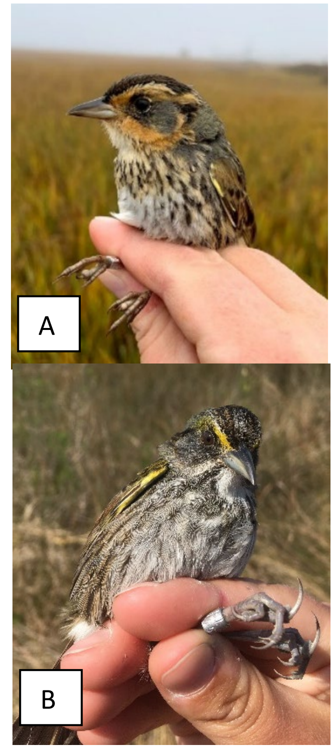


Figure 3. Study species.
A) Saltmarsh sparrow
B) Seaside sparrow

Density Estimates

Estimates of bird density within habitats are important for assessing conservation value of habitats and are necessary to estimate population sizes at any scale (Veloz et al. 2015). We do not have density estimates for SALS nor SESP in winter. This gap in knowledge results from the species' daily movements, which poses challenges for estimating density. Specifically, SALS and SESP sparrows spread out into the marsh at low tide and congregate in small patches of exposed vegetation at high tide (Winder and Emslie 2012). We hypothesize that densities (and therefore population sizes) of these sparrows are limited by low-tide habitat availability. This expectation is based on the fact that both species primarily forage for insects and seeds in mud that is exposed below the high tide line, and that food availability limits population densities of a related species (swamp sparrow, *Melospiza georgiana*: (Danner et al. 2013)). This suggests that population sizes should be estimated from the extent of low tide habitat. However, it has been difficult to estimate densities of these marsh sparrows at low tide in winter because they occur in low density when spread across the marsh, which results in small sample sizes. In order to estimate abundance at low tide habitats, we used both mark recapture and radio telemetry to understand the extent of low tide habitat used by each species. This method allows us to get at the question of how far from high tide SALS and SESP are moving out to forage at low tide and to understand what habitat types they rely on at both high and low tides. Briefly, for mark recapture, we placed nets in the supratidal habitat ("high tide location") and during high tides would actively flush birds into mist nets. Mark-recapture allowed us to band birds and place radio tags on a subset of individuals. After all mark-recapture sessions were completed for the season, we estimated abundance by first estimating within-season recapture probability (p) using Cormack-Jolly-Seber (CJS) models, and then following methods of Gimenez (2016); as planned, abundance estimation was led by graduate student Evangelyn Buckland (Lebreton et al. 1992, Gimenez 2016, Laake 2018). With the subset of birds with radio tags, we were able to track the birds at all tidal levels using null-peak radio telemetry. Null-peak telemetry allowed for more accurate and precisely triangulated locations of the birds. The life of the tag was ~27 days and we tracked each bird for the lifespan of the tag. To triangulate the bird's location in the marsh, we used LOAS 4.0 (Ecological Software Solutions, LLC) to determine locations of the birds throughout the tidal cycle (White and Garrott 1990). I then imported bird locations into R and calculated minimum convex polygons (MCP). The MCP allowed us to make a polygon around the furthest extent of habitat used by SALS and SESP throughout their winter stationary period. To estimate density, we divided abundance by area used by each species.

Sea Level Rise Modeling

We are using Sea Level Affecting Marshes Models (SLAMM version 6.7) to model how SLR will affect marsh habitats in coastal NC (Clough et al. 2016). We are modeling SLR for two locations in southeastern NC: Masonboro Island (managed by NC NERR) and Bald Head Island State Natural Area (managed by NC State Parks) (Fig 1). Both areas being modeled are undeveloped natural areas and are relatively undisturbed. We are developing density estimates for our study species, saltmarsh and seaside sparrows.

We used data from a variety of sources to parameterize our SLAMM models. The inputs necessary for SLAMM models are digital elevation models (DEM), slope file, and National Wetland Inventory (NWI) classifications. All files were prepared for input in ArcMap10.7.1. We ran models with open-source data. We used Lidar data from NOAA's Digital Coast Data Access Viewer from 2014 NOAA NGS Topobathy Lidar with a vertical accuracy of 6.2(cm) that was tested vertical root mean square error (RMSEz) (NOAA 2015). We derived a slope file from the DEM in ArcMap. NWI data was gathered from the USFWS National Wetlands Inventory Wetland Mapper. NWI data was collected in 2010 with True Color at a 1-meter scale (Service 2019). To prepare NWI for SLAMM, we used the SLAMM category cross-walk and added a field in the NWI attribute table in ArcMap. Parameters for the models were also included to increase model accuracy. DEM date and NWI date were parameterized since that data was not collected in the initial model year.

For SLR, we used local historic SLR trends (2.47 mm/yr for Wilmington, NC; NOAA Tides and Currents) because we were modeling for global/eustatic SLR at 1, 1.5 and 2m (NOAA 2020). For erosion rates, accretion rates, and beach sediment rates, we used default values from SLAMM Version 5.0 (Table 1). Once we started running the SLAMM models, we decided to adjust some of our parameters. We did not parametrize for overwash events and we unable to account for king tides, but we did parameterize for the great diurnal tide range. We intended to ground truth the Lidar DEM data in late spring 2020, but this was prevented by field restrictions resulting from Covid-19; we will ground truth Lidar data for future models. We modeled for SLR for years 2020, 2040 and 2060 for 1m, 1.5m, and 2m of SLR which are projected from 1990-2100

For objective 1, we assessed habitat change from SLR at years 2020, 2040 and 2060 at 1m, 1.5m, and 2m SLR projections. We calculated the percent change of different habitat types at each time for both sites. We conducted this analysis in ArcGIS.

For objective 2, we combined percent change in habitat area (from objective 1) and densities for both species to predict future abundances of SALS and SESP at OCI and BHI. We used ArcGIS to clip the polygons of areas used by each species at each site to the SLAMM model outputs for all years and SLR projections. We calculated changes in abundance by determining percent change in suitable bird habitat, classified as irregularly flooded marsh and regularly flooded marsh. After calculating suitable habitat for 2040 and 2060 in hectares, we determined future abundances. For this study, we assumed that density remained constant through time, so we calculated changes in abundances from 2020 to 2040 and 2060 at all SLR projections.

Table 1. Parameters used for SLAMM

Parameters	MB	BHI
NWI Photo Date (YYYY)	2010	2010
DEM Date (YYYY)	2014	2014
Direction Offshore	S	S
Historic Trend (mm/yr)	2.47	2.47
MTL-NAVD88 (m)	-0.172	-0.093
GT Great Diurnal Tide Range (m)	4.48	4.68
Marsh Erosion (horz. m /yr)	2	2
Swamp Erosion (horz. m/yr)	1	1
Tidal Flat Erosion	6	6
Reg Flood Mrsh Accr (mm/yr)	1.9	1.9
Irreg Fooded Marsh Accr	1.9	1.9
Tidal Fresh Marsh Accr	4.8	4.8
Inland Fresh Marsh Accr	4.8	4.8
Beach Sed. Rate (mm/yr)	0.5	0.5

Results

Density Estimates

Density estimates varied by site and by species (Table 2, Fig. 4). The largest area used was by SESP at OCI (Fig. 4). Saltmarsh sparrows at OCI had the lowest density at 0.85 SALS/ha whereas they had the highest density at BHI (Table 2). At OCI there was a small abundance of saltmarsh sparrows compared to seaside sparrows, whereas and the abundances of sparrows at BHI were fairly similar showing inter-site differences.

Table 2. Density estimates for SALS and SESP at OCI and BHI.

Site	Species	Abundance (+/-95 CI)	Area (ha)	Density (birds/ha; +/-95 CI)
OCI	SALS	11 (2–23)	13	0.85 (0.15–1.77)
OCI	SESP	229 (97–333)	106	2.16 (0.92–3.14)
BHI	SALS	76 (30–137)	22	3.46 (1.36–6.23)
BHI	SESP	114 (49–197)	49	2.33 (1.00–4.02)

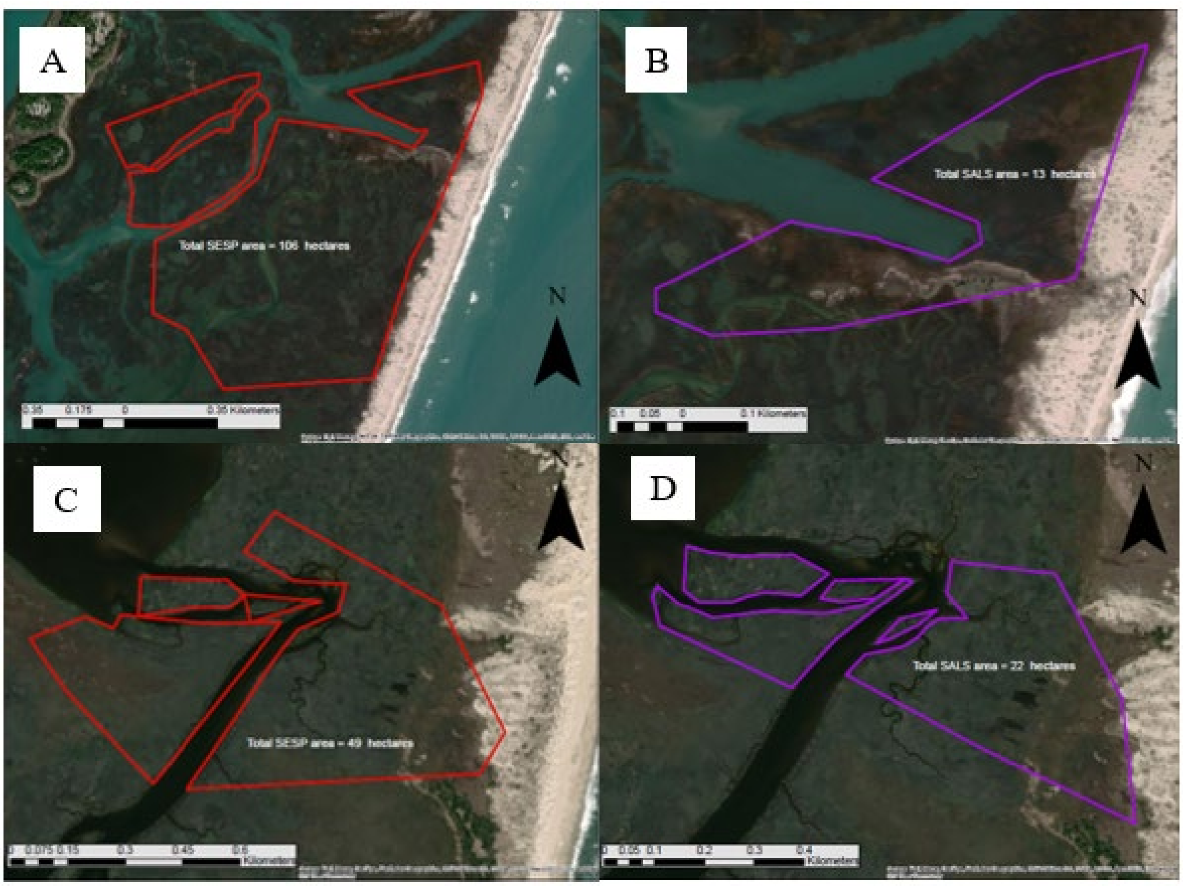


Figure 4. Total area calculated by taking the furthest extent of habitat used by radio tagged sparrows. A) Total area used by SESP at OCI. B) Total area used by SALS at OCI. C) Total area used by SESP at BHI. D) Total area used by SALS at BHI.

Sea Level Rise Models

The outputs from SLAMM provided shapefiles of habitat extent and distribution for future years compared to the current state. For both Masonboro Island (MB) and Bald Head Island State Natural Area (BHI) there was a large shift in habitat from 2020 to 2040 with a less drastic change from 2040 to 2060 with minimal differences in the low (1m), moderate (1.5m) and high (2m) SLR scenarios (Figs. 5 and 6).

At Masonboro Island, regularly flooded marsh habitat is currently 37.6% of the area, but by 2040 all rates of SLR decrease this habitat to 7% and remain at 7% through 2060. Regularly flooded marsh generally transitions to tidal flat with SLR, which explains why tidal flat currently encompasses 24.2% of Masonboro and doubles to 48% for all SLR scenarios and years. Tidal flats generally transition to estuarine open water. In 2020 estuarine open water is 27.6% of Masonboro Island and increases to 38% by 2060 in all scenarios (Figs. 7, 8 and 9).

Bald Head Island State Natural Area regularly flooded marsh habitat is 59.2% in 2020 and decreases to 9% in all SLR scenarios and 2040 and 2060. Tidal flats are 8.2% in 2020 and will increase to approximately 50% in 2040 and then 40% in 2060. Tidal flats transitioning to estuarine open water lead to an increase from 27.6% in 2020 to ~38% in 2040 to ~48% in 2060 (Figs. 10, 11 and 12).

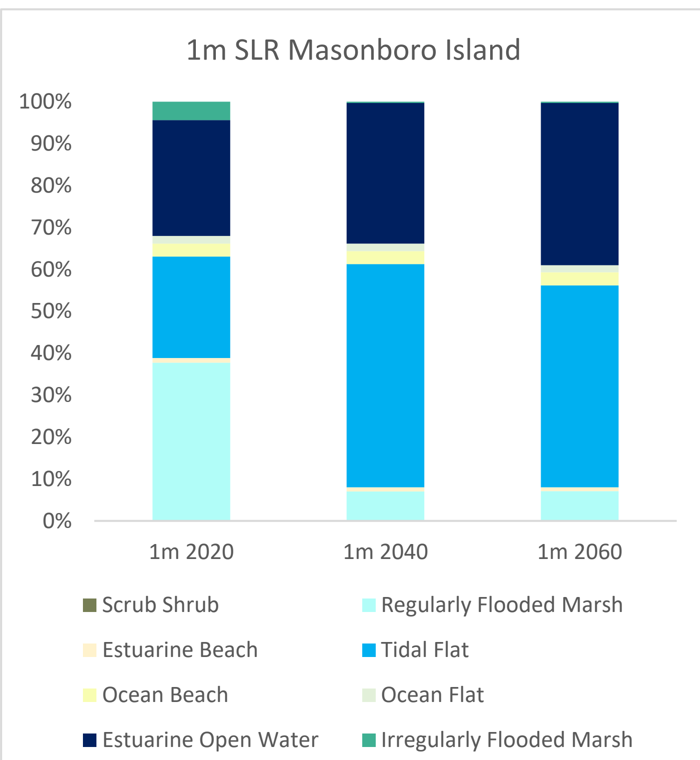


Figure 5. Bar graph representing habitat types from SLAMM at 1m SLR on Masonboro Island

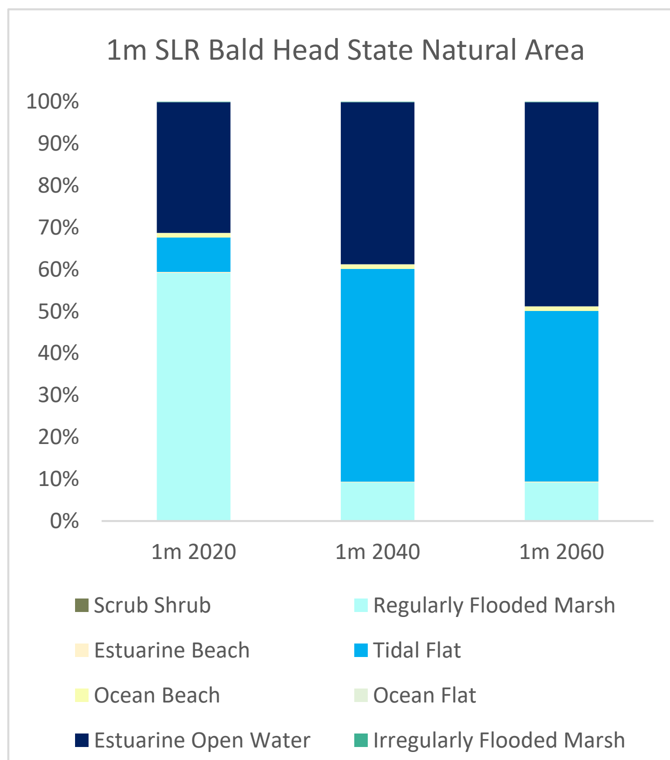
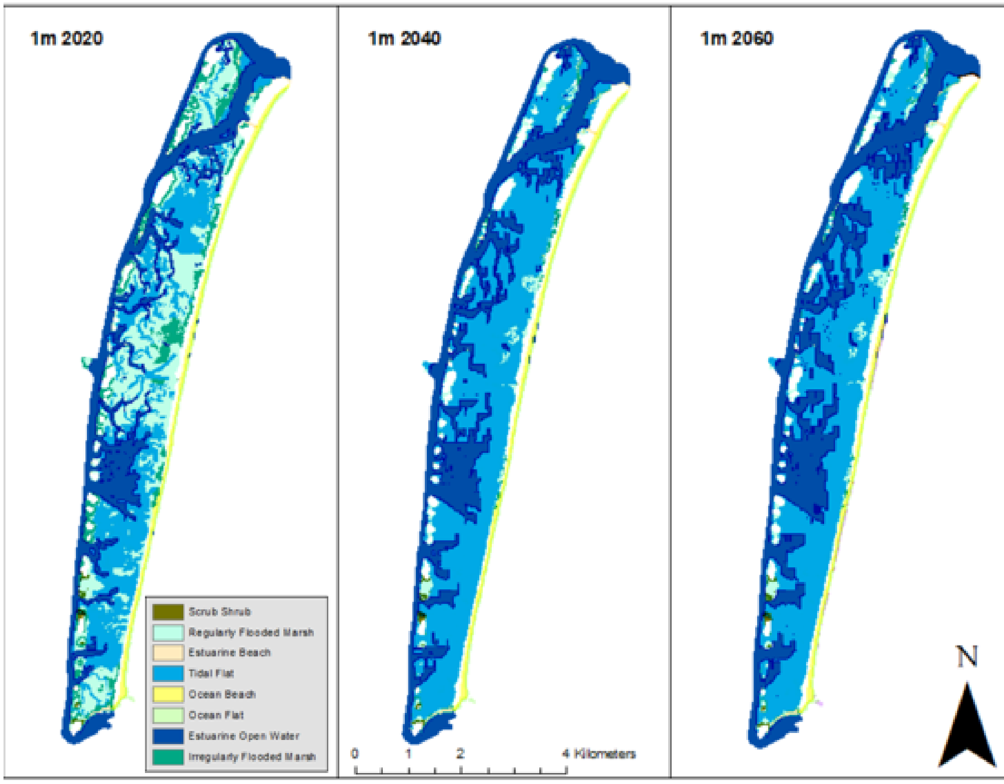


Figure 6. Bar graph representing habitat types from SLAMM at 1m SLR on Bald Head State Natural Area

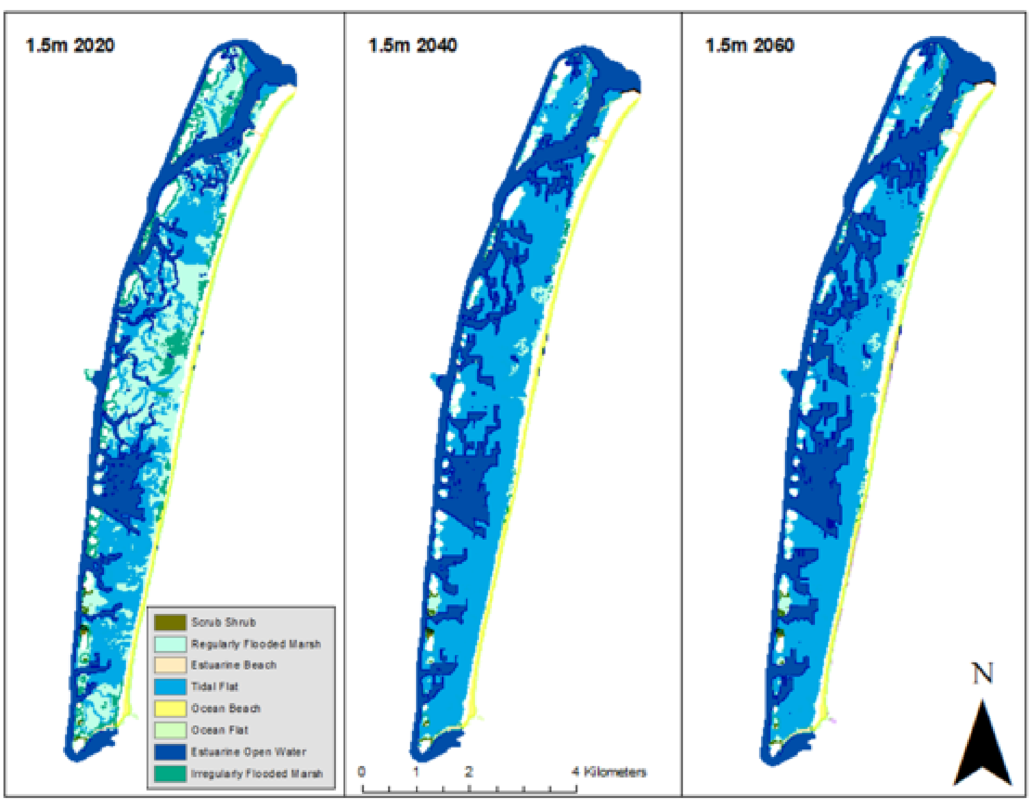


Habitat Type 2020	% Habitat
Scrub Shrub	0.1%
Regularly Flooded Marsh	37.6%
Estuarine Beach	1.1%
Tidal Flat	24.2%
Ocean Beach	3.1%
Ocean Flat	1.8%
Estuarine Open Water	27.6%
Irregularly Flooded Marsh	4.4%

Habitat Type 2040	% Habitat
Scrub Shrub	.1%
Regularly Flooded Marsh	6.9%
Estuarine Beach	1.0%
Tidal Flat	53.2%
Ocean Beach	3.1%
Ocean Flat	1.8%
Estuarine Open Water	33.5%
Irregularly Flooded Marsh	0.3%

Habitat Type 2060	% Habitat
Scrub Shrub	.1%
Regularly Flooded Marsh	7.0%
Estuarine Beach	.9%
Tidal Flat	48.2%
Ocean Beach	3.1%
Ocean Flat	1.7%
Estuarine Open Water	38.7%
Irregularly Flooded Marsh	0.3%

Figure 7. SLAMM habitat type maps for Masonboro Island at 1m of SLR.

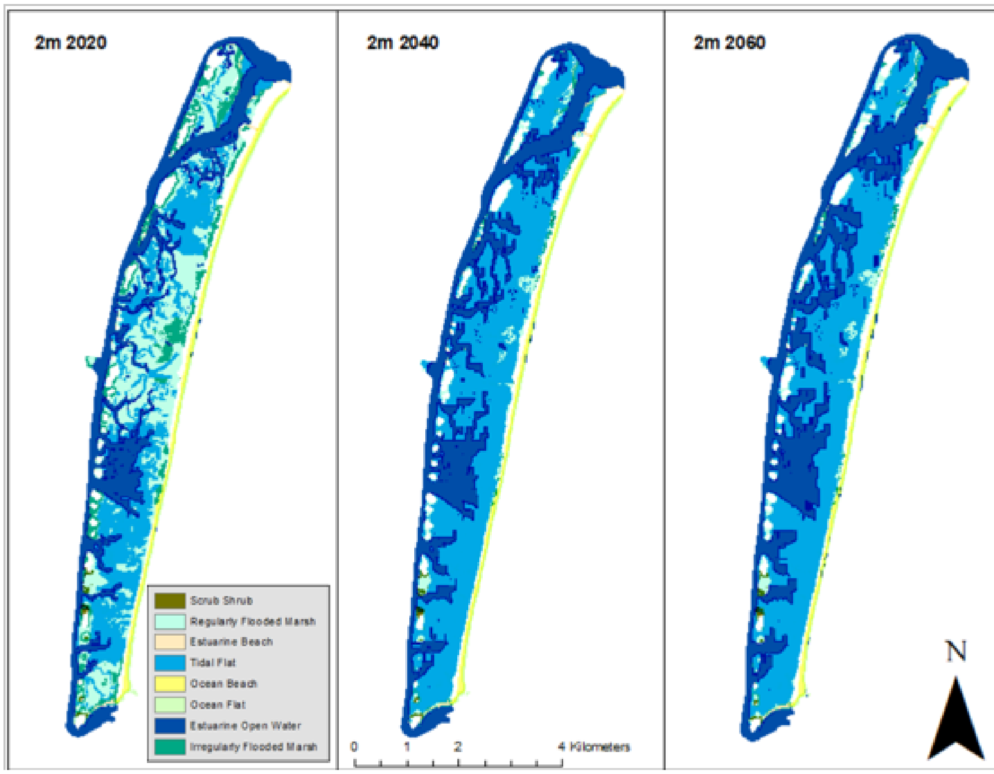


Habitat Type 2020	% Habitat
Scrub Shrub	0.1%
Regularly Flooded Marsh	37.6%
Estuarine Beach	1.1%
Tidal Flat	24.2%
Ocean Beach	3.1%
Ocean Flat	1.8%
Estuarine Open Water	27.6%
Irregularly Flooded Marsh	4.4%

Habitat Type 2020	% Habitat
Scrub Shrub	0.1%
Regularly Flooded Marsh	7.0%
Estuarine Beach	1.0%
Tidal Flat	53.3%
Ocean Beach	3.1%
Ocean Flat	1.8%
Estuarine Open Water	33.4%
Irregularly Flooded Marsh	0.3%

Habitat Type 2020	% Habitat
Scrub Shrub	0.1%
Regularly Flooded Marsh	7.0%
Estuarine Beach	0.9%
Tidal Flat	48.2%
Ocean Beach	3.1%
Ocean Flat	1.7%
Estuarine Open Water	38.8%
Irregularly Flooded Marsh	0.3%

Figure 8. SLAMM habitat type maps for Masonboro Island at 1.5m.

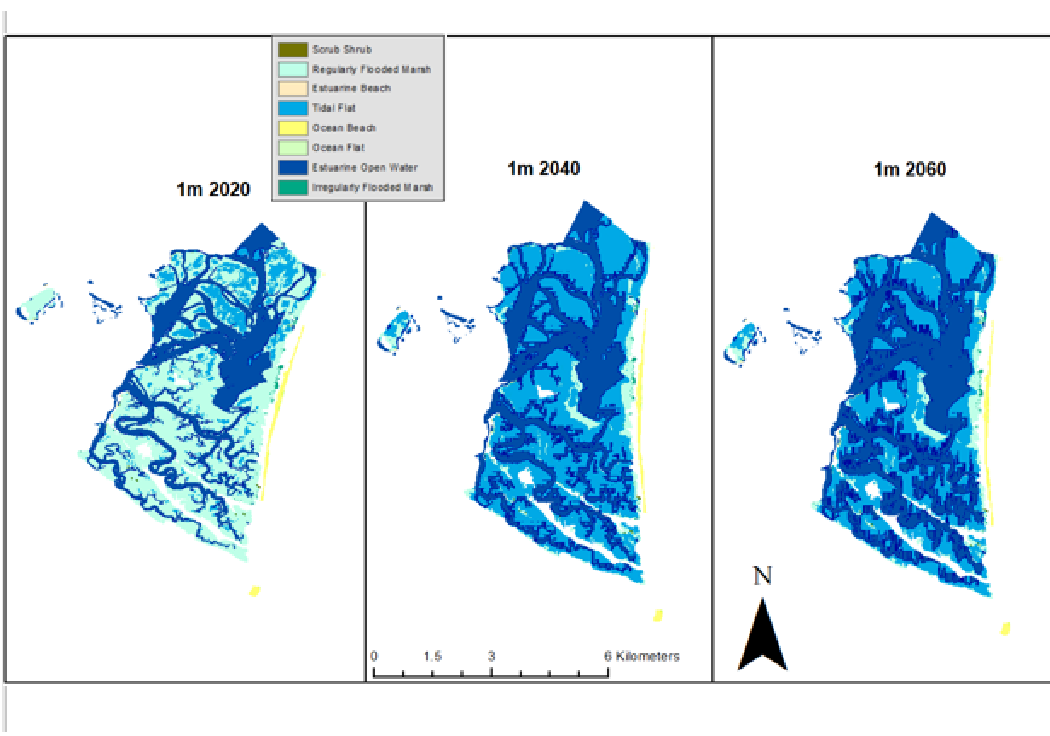


Habitat Type 2020	% Habitat
Scrub Shrub	0.1%
Regularly Flooded Marsh	37.6%
Estuarine Beach	1.1%
Tidal Flat	24.2%
Ocean Beach	3.1%
Ocean Flat	1.8%
Estuarine Open Water	27.6%
Irregularly Flooded Marsh	4.4%

Habitat Type 2020	% Habitat
Scrub Shrub	0.1%
Regularly Flooded Marsh	7.0%
Estuarine Beach	1.0%
Tidal Flat	53.2%
Ocean Beach	3.1%
Ocean Flat	1.7%
Estuarine Open Water	33.6%
Irregularly Flooded Marsh	0.3%

Habitat Type 2020	% Habitat
Scrub Shrub	0.1%
Regularly Flooded Marsh	7.0%
Estuarine Beach	0.9%
Tidal Flat	48.1%
Ocean Beach	3.1%
Ocean Flat	1.6%
Estuarine Open Water	38.8%
Irregularly Flooded Marsh	0.3%

Figure 9. SLAMM habitat type maps for Masonboro Island at 2m of SLR.

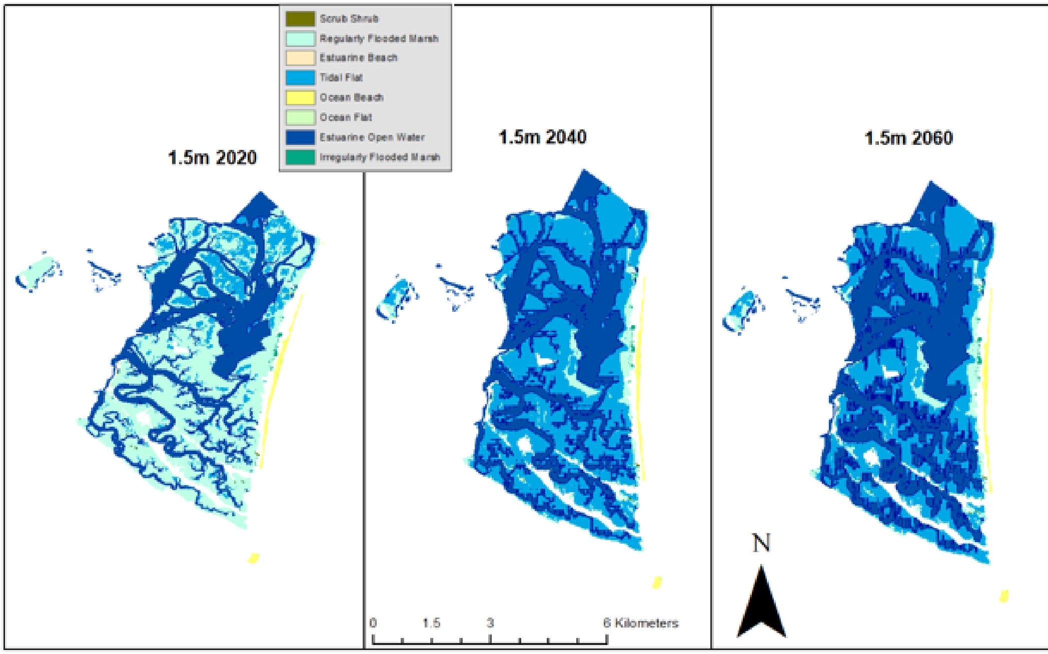


Habitat Type 2020	% Habitat
Scrub Shrub	0.01%
Regularly Flooded Marsh	59.2%
Estuarine Beach	0.2%
Tidal Flat	8.2%
Ocean Beach	1.1%
Ocean Flat	0.02%
Estuarine Open Water	31.2%
Irregularly Flooded Marsh	0.1%

Habitat Type 2020	% Habitat
Scrub Shrub	0.01%
Regularly Flooded Marsh	9.2%
Estuarine Beach	0.2%
Tidal Flat	50.8%
Ocean Beach	1.1%
Ocean Flat	0.02%
Estuarine Open Water	38.7%
Irregularly Flooded Marsh	0.1%

Habitat Type 2020	% Habitat
Scrub Shrub	0.01%
Regularly Flooded Marsh	9.2%
Estuarine Beach	0.2%
Tidal Flat	40.7%
Ocean Beach	1.1%
Ocean Flat	0.02%
Estuarine Open Water	48.7%
Irregularly Flooded Marsh	0.1%

Figure 10. SLAMM habitat type maps for Bald Head Island State Natural Area at 1m of SLR.

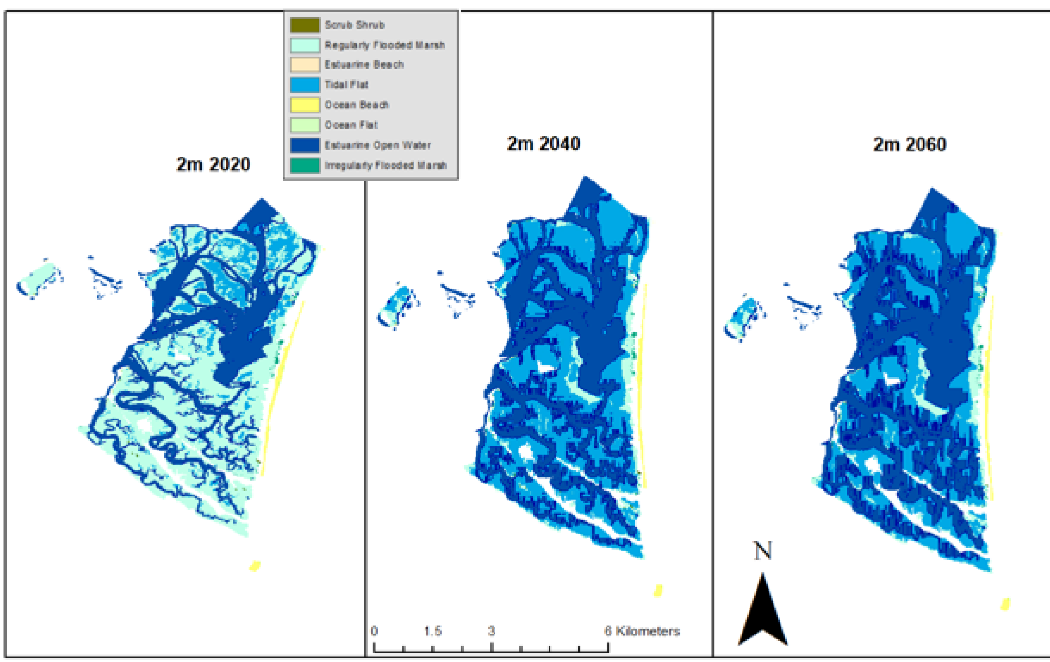


Habitat Type 2020	% Habitat
Scrub Shrub	0.01%
Regularly Flooded Marsh	59.2%
Estuarine Beach	0.2%
Tidal Flat	8.2%
Ocean Beach	1.1%
Ocean Flat	0.02%
Estuarine Open Water	31.2%
Irregularly Flooded Marsh	0.1%

Habitat Type 2020	% Habitat
Scrub Shrub	0.01%
Regularly Flooded Marsh	9.2%
Estuarine Beach	0.2%
Tidal Flat	50.8%
Ocean Beach	1.1%
Ocean Flat	0.02%
Estuarine Open Water	38.6%
Irregularly Flooded Marsh	0.1%

Habitat Type 2020	% Habitat
Scrub Shrub	0.01%
Regularly Flooded Marsh	9.2%
Estuarine Beach	0.2%
Tidal Flat	40.7%
Ocean Beach	1.1%
Ocean Flat	0.02%
Estuarine Open Water	48.8%

Figure 11. SLAMM habitat type maps for Bald Head Island State Natural Area at 1.5 m of SLR.



Habitat Type 2020	% Habitat
Scrub Shrub	0.01%
Regularly Flooded Marsh	59.2%
Estuarine Beach	0.2%
Tidal Flat	8.2%
Ocean Beach	1.1%
Ocean Flat	0.02%
Estuarine Open Water	31.2%
Irregularly Flooded Marsh	0.1%

Habitat Type 2020	% Habitat
Scrub Shrub	0.01%
Regularly Flooded Marsh	9.2%
Estuarine Beach	0.2%
Tidal Flat	45.4%
Ocean Beach	1.1%
Ocean Flat	0.02%
Estuarine Open Water	44.1%
Irregularly Flooded Marsh	0.1%

Habitat Type 2020	% Habitat
Scrub Shrub	0.001%
Regularly Flooded Marsh	9.2%
Estuarine Beach	0.2%
Tidal Flat	37.6%
Ocean Beach	1.1%
Ocean Flat	0.02%
Estuarine Open Water	51.9%
Irregularly Flooded Marsh	0.1%

Figure 12. SLAMM habitat type maps for Bald Head Island State Natural Area at 2m of SLR.

Sea Level Rise Impacts on SALS and SESP

Based on radio telemetry data, we found that SALS and SESP use regularly flooded marsh and irregularly flooded marsh, but not tidal flats and estuarine open water. We hypothesize that the open nature of the tidal flats does not offer enough cover for protection from predators or that their preferred prey items are not available. These species do not swim, so they cannot forage in estuarine open water.

Our analyses show large reductions in suitable habitat for both species from 2020 to 2040 (Figs. 13 and 14). In year 2020, >90% of habitat is suitable for sparrows, with a portion of the habitat being uninhabitable due to the way habitat polygons were drawn and small ponds or creeks that were not excluded. By observation, we know that SALS and SESP use edges of creeks and fly over small creeks to get to other patches of usable habitat so our polygons for 2020 do not represent 100% of usable habitat.

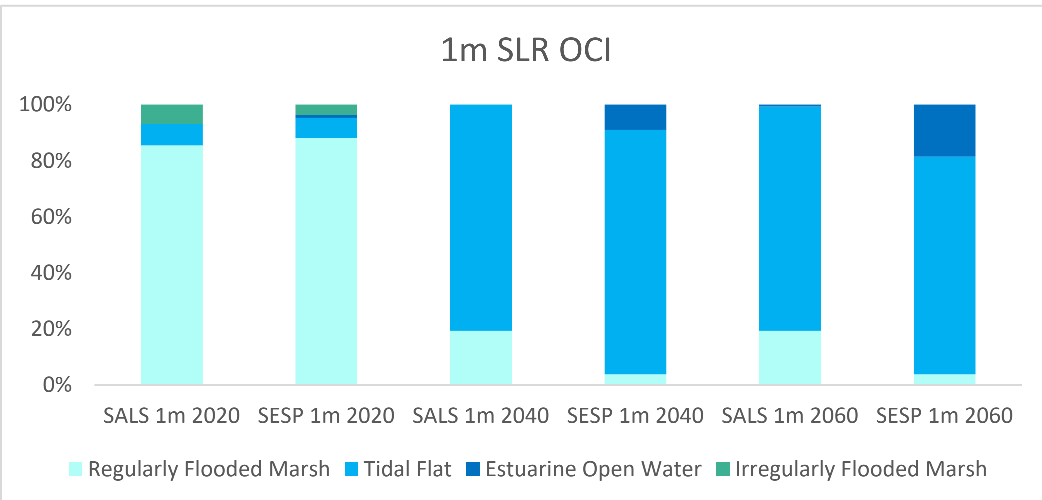


Figure 13. Bar graph representing habitat change at 1m of SLR at OCI on SALS and SESP habitat

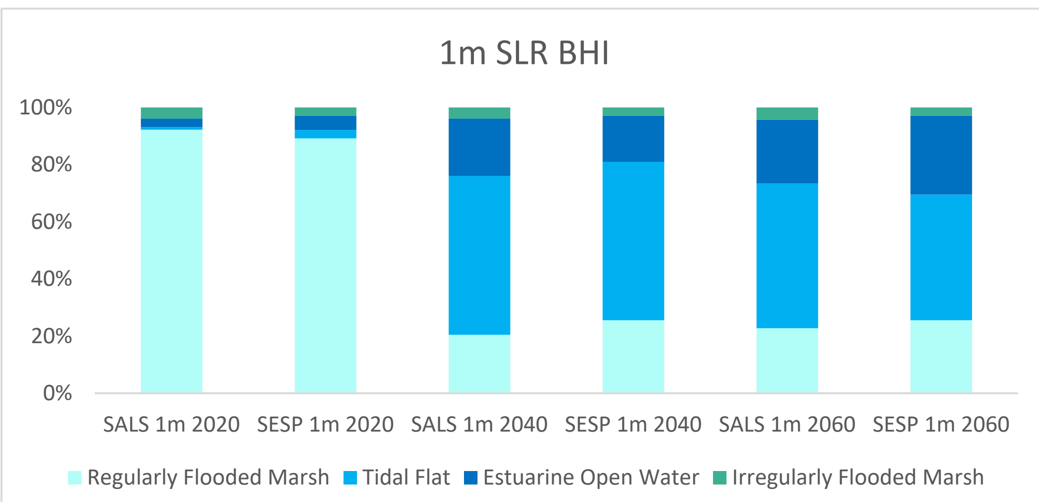
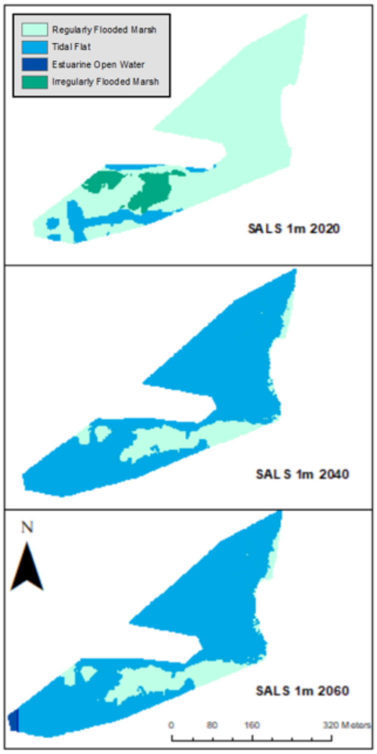


Figure 14. Bar graph representing habitat change at 1m of SLR at BHI on SALS and SESP habitat

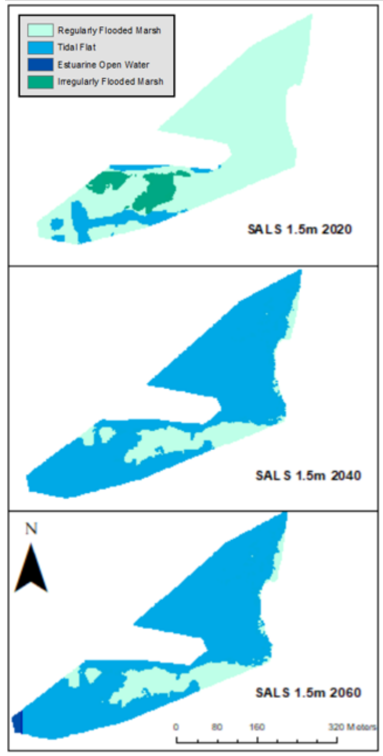


Habitat Type	% Habitat
Regularly Flooded Marsh	85.5%
Tidal Flat	7.7%
Estuarine Open Water	0%
Irregularly Flooded Marsh	6.9%

Habitat Type	% Habitat
Regularly Flooded Marsh	19.3%
Tidal Flat	80.7%
Estuarine Open Water	0%
Irregularly Flooded Marsh	0%

Habitat Type	% Habitat
Regularly Flooded Marsh	19.3%
Tidal Flat	80.0%
Estuarine Open Water	0.7%
Irregularly Flooded Marsh	0%

Figure 15. SALS habitat at 1m of SLR at OCI.

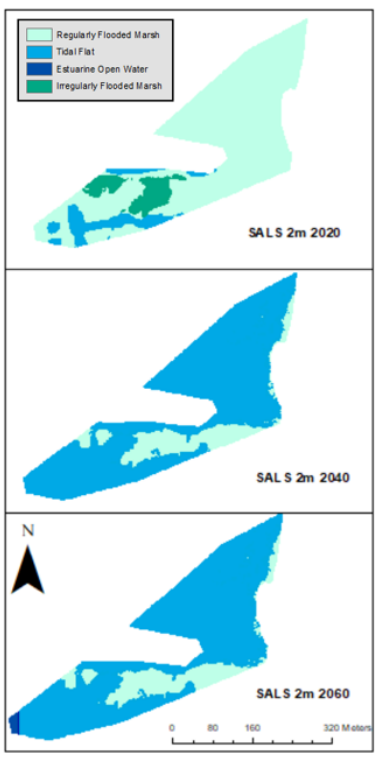


Habitat Type	% Habitat
Regularly Flooded Marsh	85.5%
Tidal Flat	7.7%
Estuarine Open Water	0%
Irregularly Flooded Marsh	6.9%

Habitat Type	% Habitat
Regularly Flooded Marsh	19.3%
Tidal Flat	80.7%
Estuarine Open Water	0%
Irregularly Flooded Marsh	0%

Habitat Type	% Habitat
Regularly Flooded Marsh	19.3%
Tidal Flat	80.0%
Estuarine Open Water	0.7%
Irregularly Flooded Marsh	0%

Figure 16. SALS habitat at 1.5m of SLR at OCI.



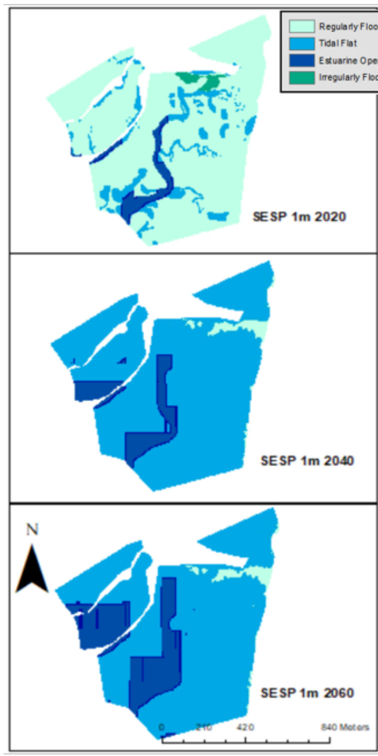
Habitat Type	% Habitat
Regularly Flooded Marsh	85.5%
Tidal Flat	7.7%
Estuarine Open Water	0%
Irregularly Flooded Marsh	6.9%

Habitat Type	% Habitat
Regularly Flooded Marsh	19.3%
Tidal Flat	80.7%
Estuarine Open Water	0%
Irregularly Flooded Marsh	0%

Habitat Type	% Habitat
Regularly Flooded Marsh	19.3%
Tidal Flat	80.0%
Estuarine Open Water	0.7%
Irregularly Flooded Marsh	0%

Figure 17. SALS habitat at 2m of SLR at OCI.

Saltmarsh sparrow habitat at OCI was reduced to less than a quarter of current extent between 2020 to 2040 in all SLR scenarios. From 2040 to 2060, there were smaller changes with all SLR scenarios having similar habitat changes. In 2020, 92.4% of the habitat within the use-polygon was suitable and that shifted to 19.3% in 2040 and remaining 19.3% through 2060 (Figs. 15, 16 and 17). For both 2040 and 2060 at 1m 1.5m and 2m of SLR habitable areas are decreased to 2.51ha and since OCI has a density of 0.85birds/ha this habitat can only support approximately 2.13 SALS compared to 11 birds in 2020. By 2040 the main habitat type had transitioned into tidal flat due to water inundation.

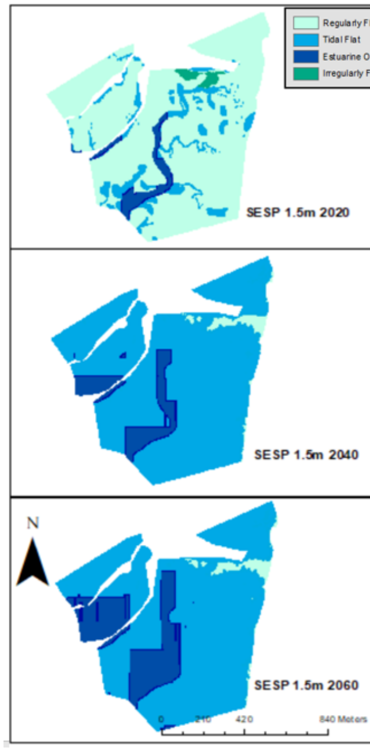


Habitat Type	% Habitat
Regularly Flooded Marsh	88%
Tidal Flat	7.3%
Estuarine Open Water	1.0%
Irregularly Flooded Marsh	3.7%

Habitat Type	% Habitat
Regularly Flooded Marsh	3.7%
Tidal Flat	87.3%
Estuarine Open Water	9.0%
Irregularly Flooded Marsh	0%

Habitat Type	% Habitat
Regularly Flooded Marsh	3.7%
Tidal Flat	77,7%
Estuarine Open Water	18.6%
Irregularly Flooded Marsh	0%

Figure 18. SESP habitat at 1m of SLR at OCI.

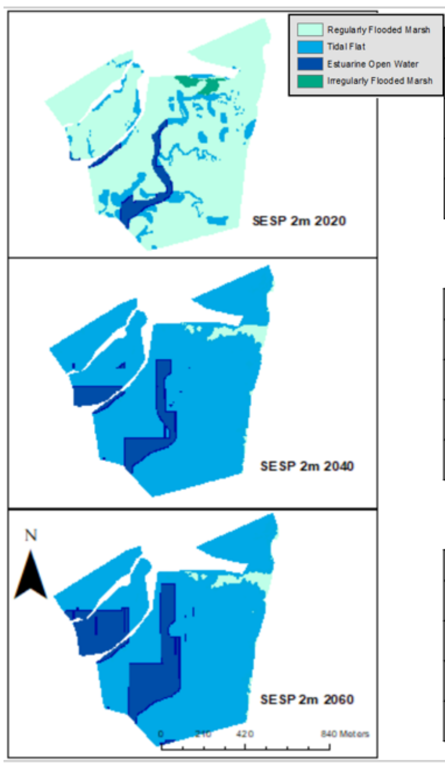


Habitat Type	% Habitat
Regularly Flooded Marsh	88%
Tidal Flat	7.3%
Estuarine Open Water	1.0%
Irregularly Flooded Marsh	3.7%

Habitat Type	% Habitat
Regularly Flooded Marsh	3.7%
Tidal Flat	87.3%
Estuarine Open Water	9.0%
Irregularly Flooded Marsh	0%

Habitat Type	% Habitat
Regularly Flooded Marsh	3.7%
Tidal Flat	77.6%
Estuarine Open Water	18.5%
Irregularly Flooded Marsh	0%

Figure 19. SESP habitat at 1.5m of SLR at OCI.



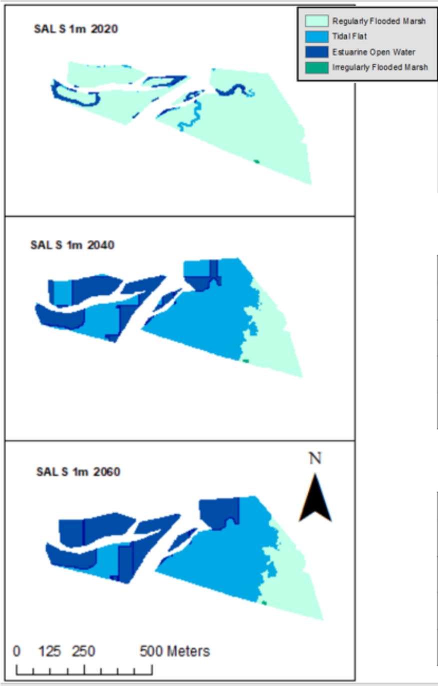
Habitat Type	% Habitat
Regularly Flooded Marsh	88%
Tidal Flat	7.3%
Estuarine Open Water	1.0%
Irregularly Flooded Marsh	3.7%

Habitat Type	% Habitat
Regularly Flooded Marsh	3.7%
Tidal Flat	87.3%
Estuarine Open Water	9.0%
Irregularly Flooded Marsh	0%

Habitat Type	% Habitat
Regularly Flooded Marsh	3.7%
Tidal Flat	77.7%
Estuarine Open Water	18.6%
Irregularly Flooded Marsh	0%

Figure 20. SESP habitat at 2m of SLR at OCI.

Seaside sparrow habitat at OCI reduced to less than tenth of current extent between 2020 to 2040 in all SLR scenarios and then only shifted slightly from 2040 to 2060 with all SLR scenarios having the same habitat changes. In 2020 91.7% of the habitat within the use-polygon was suitable and that shifted to 3.7% in 2040 and remaining 3.7% through 2060 (Figs. 18, 19 and 20). For both 2040 and 2060 at 1m, 1.5m, and 2m of SLR habitable areas are decreased to 3.9ha and since OCI has a density of 2.16birds/ha this habitat can only support approximately 8.5 SESP compared to an abundance of 229 SESP in 2020. By 2040 the main habitat type had transitioned into tidal flat due to water inundation.

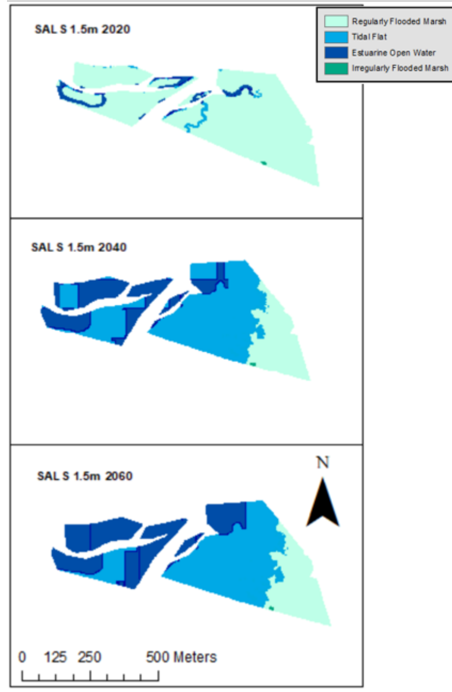


Habitat Type	% Habitat
Regularly Flooded Marsh	95.9%
Tidal Flat	1.0%
Estuarine Open Water	3.1%
Irregularly Flooded Marsh	0.04%

Habitat Type	% Habitat
Regularly Flooded Marsh	21.3%
Tidal Flat	57.7%
Estuarine Open Water	20.9%
Irregularly Flooded Marsh	0.04%

Habitat Type	% Habitat
Regularly Flooded Marsh	21.3%
Tidal Flat	47.3%
Estuarine Open Water	31.3%
Irregularly Flooded Marsh	0.04%

Figure 21. SALS habitat at 1m of SLR at BHI.

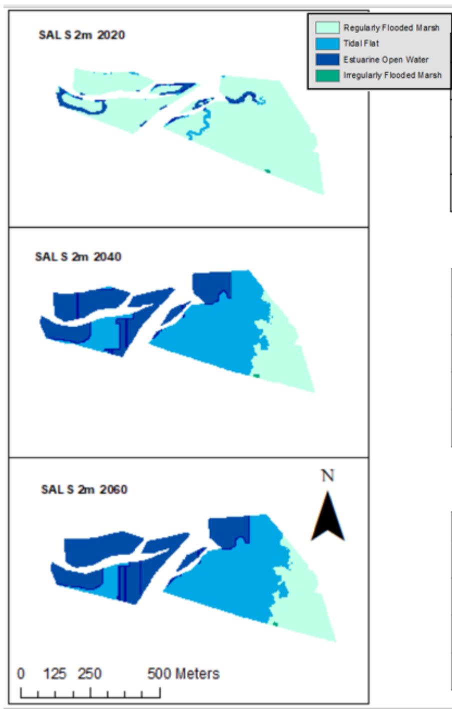


Habitat Type	% Habitat
Regularly Flooded Marsh	95.9%
Tidal Flat	1%
Estuarine Open Water	3.1%
Irregularly Flooded Marsh	0.04%

Habitat Type	% Habitat
Regularly Flooded Marsh	21.3%
Tidal Flat	57.7%
Estuarine Open Water	20.9%
Irregularly Flooded Marsh	0.04%

Habitat Type	% Habitat
Regularly Flooded Marsh	21.3%
Tidal Flat	47.3%
Estuarine Open Water	31.4%
Irregularly Flooded Marsh	0.04%

Figure 22. SALS habitat at 1.5m of SLR at BHI.



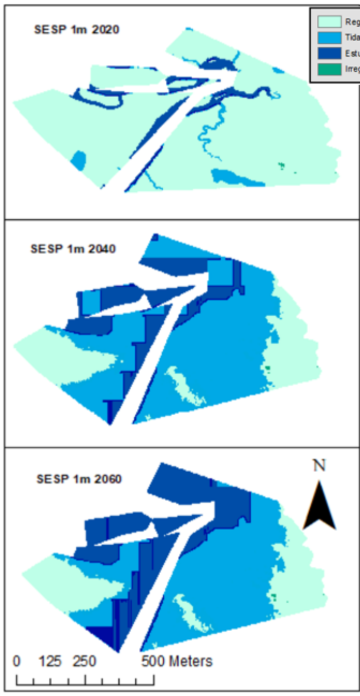
Habitat Type	% Habitat
Regularly Flooded Marsh	95.9%
Tidal Flat	1%
Estuarine Open Water	3.1%
Irregularly Flooded Marsh	0.04%

Habitat Type	% Habitat
Regularly Flooded Marsh	21.3%
Tidal Flat	49.1%
Estuarine Open Water	29.6%
Irregularly Flooded Marsh	0.04%

Habitat Type	% Habitat
Regularly Flooded Marsh	21.3%
Tidal Flat	46.2%
Estuarine Open Water	32.5%
Irregularly Flooded Marsh	0.04%

Figure 23. SALS habitat at 2m of SLR at BHI.

Saltmarsh sparrow habitat at BHI reduced to less than a quarter 2020 to 2040 in all SLR scenarios and then only shifted slightly from 2040 to 2060. In 2040 and 2060 at all three SLR scenarios there is negligible change in habitat. In 2020 95.94% of the habitat within the use-polygon was suitable and that shifted to 21.34% in 2040 and remaining 21.34% through 2060 (Figs. 21, 22 and 23). For both 2040 and 2060 at 1m, 1.5m, and 2m of SLR habitable areas are decreased to 4.7ha and since BHI has a density of 3.46 birds/ha this habitat can only support approximately 16.3 SALS compared to 76 birds in 2020. By 2040 and 2060 main habitat types had transitioned into tidal flat and estuarine open water due to water inundation.

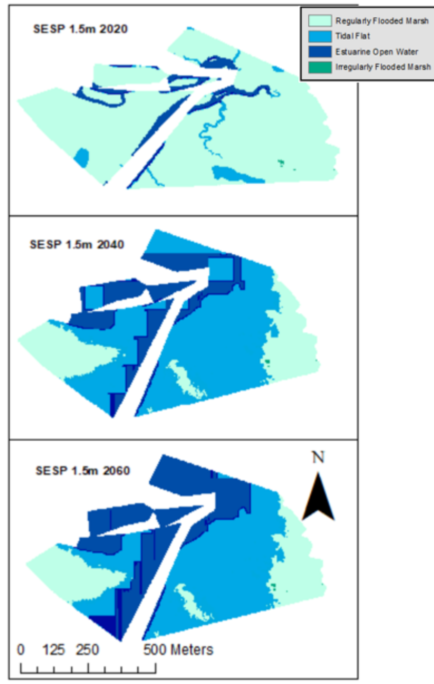


Habitat Type	% Habitat
Regularly Flooded Marsh	91.8%
Tidal Flat	3.0%
Estuarine Open Water	5.1%
Irregularly Flooded Marsh	0.03%

Habitat Type	% Habitat
Regularly Flooded Marsh	26.3%
Tidal Flat	57.1%
Estuarine Open Water	16.6%
Irregularly Flooded Marsh	0.03%

Habitat Type	% Habitat
Regularly Flooded Marsh	26.3%
Tidal Flat	45.3%
Estuarine Open Water	28.4%
Irregularly Flooded Marsh	0.03%

Figure 24. SESP habitat at 1m of SLR at BHI.

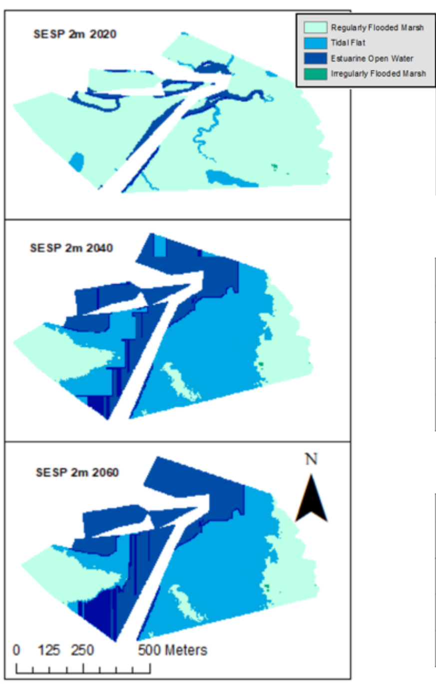


Habitat Type	% Habitat
Regularly Flooded Marsh	91.8%
Tidal Flat	3.0%
Estuarine Open Water	5.1%
Irregularly Flooded Marsh	0.03%

Habitat Type	% Habitat
Regularly Flooded Marsh	26.3%
Tidal Flat	56.9%
Estuarine Open Water	16.8%
Irregularly Flooded Marsh	0.03%

Habitat Type	% Habitat
Regularly Flooded Marsh	26.3%
Tidal Flat	45.2%
Estuarine Open Water	28.5%
Irregularly Flooded Marsh	0.03%

Figure 25. SESP habitat at 1.5m of SLR at BHI.



Habitat Type	% Habitat
Regularly Flooded Marsh	91.8%
Tidal Flat	3.0%
Estuarine Open Water	5.1%
Irregularly Flooded Marsh	0.03%

Habitat Type	% Habitat
Regularly Flooded Marsh	26.3%
Tidal Flat	48.5%
Estuarine Open Water	25.2%
Irregularly Flooded Marsh	0.03%

Habitat Type	% Habitat
Regularly Flooded Marsh	26.3%
Tidal Flat	43.5%
Estuarine Open Water	30.3%
Irregularly Flooded Marsh	0.03%

Figure 26. SESP habitat at 2m of SLR at BHI.

Seaside sparrow habitat at BHI reduced over half from 2020 to 2040 in all SLR scenarios and then only shifted slightly from 2040 to 2060. In 2040 and 2060 at all three SLR scenarios there is negligible change in habitat. In 2020 91.83% of the habitat within the use-polygon was suitable and that shifted to 26.33 % in 2040 and remaining 26.33 % through 2060 (Figs. 24, 25 and 16). For both 2040 and 2060 at 1m, 1.5m, and 2m of SLR habitable areas are decreased to 12.9ha and since BHI has a density of 2.33 birds/ha this habitat can only support approximately 31.1 SESP compared to 114 birds in 2020. By 2040 and 2060 tidal flat and estuarine open water are the dominate habitat types.

Discussion

Density Estimates

Densities of saltmarsh and seaside sparrows varied between site and species. SALS had the largest difference in densities between sites with 0.85 SALS/ha at OCI and 3.46 SALS/ha at BHI. We hypothesize that the differences result from differences in habitat availability or arrangement, or competition between species. Saltmarsh sparrows seem to have more specific habitat requirements with a preference for short form *Spartina alterniflora*, which is more abundant at BHI (Lindquist & Buckland personal observations). Seaside sparrows utilize larger home ranges (Lindquist unpublished data) and seem to utilize a wider range of habitats, and we hypothesize that this caused the similar densities between sites. It is possible that we did not detect all individuals that use the areas in the study sites, which would make our density estimates conservative. Conservative estimates should not affect our estimates of proportional declines in bird abundance under future scenarios of habitat change.

SLAMM Outputs

Habitats on Masonboro Island and Bald Head State Natural Area transitioned drastically from 2020 to 2040 and then proceeded without much change from 2040 to 2060 for at all SLR scenarios. This pattern is due in large part to shift from regularly flooded marsh to tidal flat by 2040. In particular, a relatively small amount of SLR causes the transition of marsh to of tidal flats, but substantially more SLR is required to reach the next habitat category: estuarine open water. SLAMM assesses elevation using the site-specific parameters which determine how habitat will change over time and regularly flooded marsh transitions to tidal flat which transitions to estuarine open water, which means that area is always inundated with water (Clough et al. 2016). We assume if we ran the models out through 2100 that the habitat would transition mostly to estuarine open water.

Our models track well with other models such as NOAA's SLR Viewer and SAMBI Designing Sustainable Landscapes Project, so although there are possible sources of error, the models are not substantially different from other for the same region and timeline (Rubino 2012, Sweet et al. 2017). Possible sources of error in SLAMM outputs include not having the most up to date erosion and accretion data, not being unable to ground truth the Lidar due to the COVID-19 pandemic and having lack of DEM and NWI data from the past few years. We have plans to remedy most of these potential limitations for the next iterations of the models. First, we plan to get site-specific erosion and accretion rates that were not yet available from the surface elevation tables (SETs) for Masonboro and Zeke's Island. Second, ideally for DEM, we will use more site-specific drone Lidar that will allow for increased vertical accuracy. Third, for habitat data, we plan to use WorldView3 imagery, drone imagery, and ground truthing to obtain high-resolution habitat data for each species.

Sea Level Rise Impacts on Marsh Species

At both field sites, SLR led to drastic reductions in suitable habitat for both species. Based on our models, populations of both species will be reduced dramatically by 2040. Although we only sampled density at one location on each island, the SLR models show that this pattern of habitat loss is representative for entire islands at both study areas. In addition, our focal study areas appear to support many more individuals than most other marsh across the study islands. This information comes from the fact that OCI has long been known as a congregating spot for the species at high tide. Similarly, we picked the site at BHI because we observed many individuals there. Also, we observed few individuals throughout the islands while on scouting trips. These observations suggest that loss of habitat in our study locations would not be mitigated by population increases or stability in other locations.

It is possible that the small amount of habitat remaining in 2040 and 2060 would be too small to support any individuals of our study species, and even if they can support small populations this could be at risk due to stochastic extinction (Post and Greenlaw 2020). The reason is that we have preliminarily observed that our study species seem not to use small patches of habitat. We also have seen through scouting and beginning to understand winter abundances and habitat use for both species that they are not spread evenly across the landscape and have high site fidelity within and between seasons. It is difficult to imagine without adaptive management strategies that the habitat remining in the year 2040 can sustain a population. From personal observation it seems that small patches of "livable" habitat during the winter stationary period may support only a handful of marsh sparrows, but this need to be research further. This highlights the need for studies of patch size occupancy for both species (Bowers and Matter 1997).

It is unclear if the predicted habitat loss would limit carry-over effects or additive mortality in the winter. We know based on previous research that the habitat on breeding grounds for both species is going to be impacted by SLR and so it is important to understand that habitat loss is also occurring in the wintering grounds and is bound to impact marsh sparrow populations (Field et al. 2017, Roberts et al. 2019). We also have breeding populations of SESP in our study areas and based off our models it is safe to assume that breeding habitat will decrease as well, but further research of breeding populations in our study area is needed. It is important to understand the full annual cycle of the sparrows and if fitness is decreased due to SLR in the wintering ground that could have carry-over effects through migration and breeding (Marra et al. 2015). There is a need for an integrated population model (IPM) to help understand the role of winter biology in the full annual cycle of these species (Schaub and Abadi 2011). We may also see winter survival decrease due to SLR. Based on the large changes in habitat in both models by 2040 it is likely that this will also decrease food availability for both species. Future research it would be important to use visual observations to gather abundance data for large areas to try to understand how at an island wide or larger scale populations will be impacted by sea level rise over time. Even if with conservation efforts saltmarsh sparrow populations stabilize, habitat loss will likely still be an issue due to SLR.

Our results about the effects of SLR on two marsh sparrows may help assess impacts of other marsh species. For example, we predict declines in abundance of birds at two study sites, but the larger island-wide SLR scenarios suggest habitat loss is ubiquitous across the landscape. It is difficult to imagine that the large shift in habitat from regularly flooded marsh to tidal flat and estuarine open water will not have large impacts on a large swath of species that live in these marsh ecosystems. Populations of these species may be more of a risk as well because they are living in an environment that cannot easily shift. Masonboro Island has the Atlantic Ocean to the east and the ICW on the west and inlets north and south leading to that island having nowhere to move, it had no where to migrant landward due to those restrictions. It will be important to study populations of marsh birds in locations where marshes may be able to migrate with rising seas, since most marshes do not have the ability to move.

Adaptive Management Strategies

There may be ways to assist in the conservation of these species by adaptively managing the marsh. Without mitigation the models predict very small populations may not persist. Implementation of thin layer deposition may elevate the marsh enough to prevent the transition from regularly flooded marsh to tidal flat since the driver of that transition in marsh elevation. One possible use of SLAMM models for future research could be modeling different rates of accretion or thin layer deposition to model how habitat will change over time with the increased marsh elevation (Berkowitz et al. 2019). Also, living shorelines could be an option to help prevent edge erosion (Currin et al. 2010). Pairing thin layer deposition with living shorelines could prevent the erosion from the edge and the thin layer deposition could help the marsh vegetation remain at a sustainable elevation that may be able to keep up with eustatic SLR. Without adaptive management, SLR will lead to loss of essential habitat for an array of marsh specialist.

Outreach and Research Dissemination Plan

Undergraduate Student Engagement

This grant helped support two undergraduate research assistants. We were fortunate to be able to provide a small stipend for our undergraduate students for their work on projects, each assistant worked 7 hours a week at $10 an hour for the spring semester of 2020 and were mentored throughout their position. Cassidy Mason was a senior at UNCW getting a degree from the Department of Environmental Science. Her position focused on assisting with preparing data files for the models, running initial SLAMM models, and creating a protocol for running subsequent models. She gained valuable experience learning how to work with computer models and learning how to work independently when a task was provided. Cassidy started in a graduate program at NC State Fall 2020. Sofia Campuzano was a senior at UNCW getting a degree from the Department of Biology and Marine Biology. Sofia's position focused on assisting in the data collection for the density estimates in the field. She assisted with mark-recapture and radio telemetry and gained valuable experience learning these field techniques, how to work in the field with a group, but also to work independently when needed. The skills Sofia learned will hopefully help her achieve her goal of going to graduate school for biology.

Presentations

I presented this research plan at the 2019 Meeting of the NC Sentinel Site Cooperative for the Core Management Team. I had intended to present this research at the Benthic Ecology Meeting in April 2020, but the conference was canceled due to Covid-19. I gave an invited seminar on this research for the NC Coastal Land Trust on September 18th. I am also currently working on blog post for NC Audubon and NC Sea Grant.

Outreach Curriculum

We created an outreach curriculum about the impacts of sea level rise on coastal marsh species in North Carolina. This program was created to be completed in an all virtual format if needed and we performed this outreach to Virtual MarineQuest, we reached a total of 32 students with 6 volunteers with this curriculum and unfortunately due to Covid up to this point we have not been able to do this outreach with other schools or camps. We are currently working with MarineQuest to create video content to go along with the curriculum, and MQ plans to continue using our curriculum their school field trips this year and into the future. We also intend to provide this as free curriculum on the Danner Lab website as well as my personal website (maraelindquist.com) for any teacher/educator to use. The curriculum comes with a presentation, created on ArcGIS online and viewable by anyone, an educator guide, analysis worksheets, and videos that are being created for easy use during virtual education. We are also translating the whole curriculum into Spanish so it will be more inclusive. As a metric for success the last portion of the program requires students to work in groups, either in person or virtually to create a poster (poster template provided) that they then have to present to the group (Fig. 27). The poster shows an understanding of the subject of SLR and the impacts on coastal species. The objective of the outreach is to provide students with a simple introduction to the scientific method by having them do a mini experiment after learning about SLR and the impacts on coastal species and then creating a poster to present to their cohort. We plan to continue improving this curriculum by working with NC NERR. We used ArcGIS online to create content so it can easily be shared and used by others. URLs for ArcGIS StoryMap and ArcGIS Dashboard Maps are listed below (Figs. 28, 29. 30, 31. 32, 33 and 34).

StoryMap:

https://storymaps.arcgis.com/stories/8fd37ac8813444c08462e9f08968bc04

Dashboard Maps:

https://uncw.maps.arcgis.com/apps/opsdashboard/index.html#/016cc1b62c9f4661b3cafcc5765e52ed

https://uncw.maps.arcgis.com/apps/opsdashboard/index.html#/8e1165c79d0743faa17acf75fe1e54fc

https://uncw.maps.arcgis.com/apps/opsdashboard/index.html#/cd73e3ac728048dfa0e36cc4a9524968

https://uncw.maps.arcgis.com/apps/opsdashboard/index.html#/749d8520cb334be6aeae2460e4cd7aef

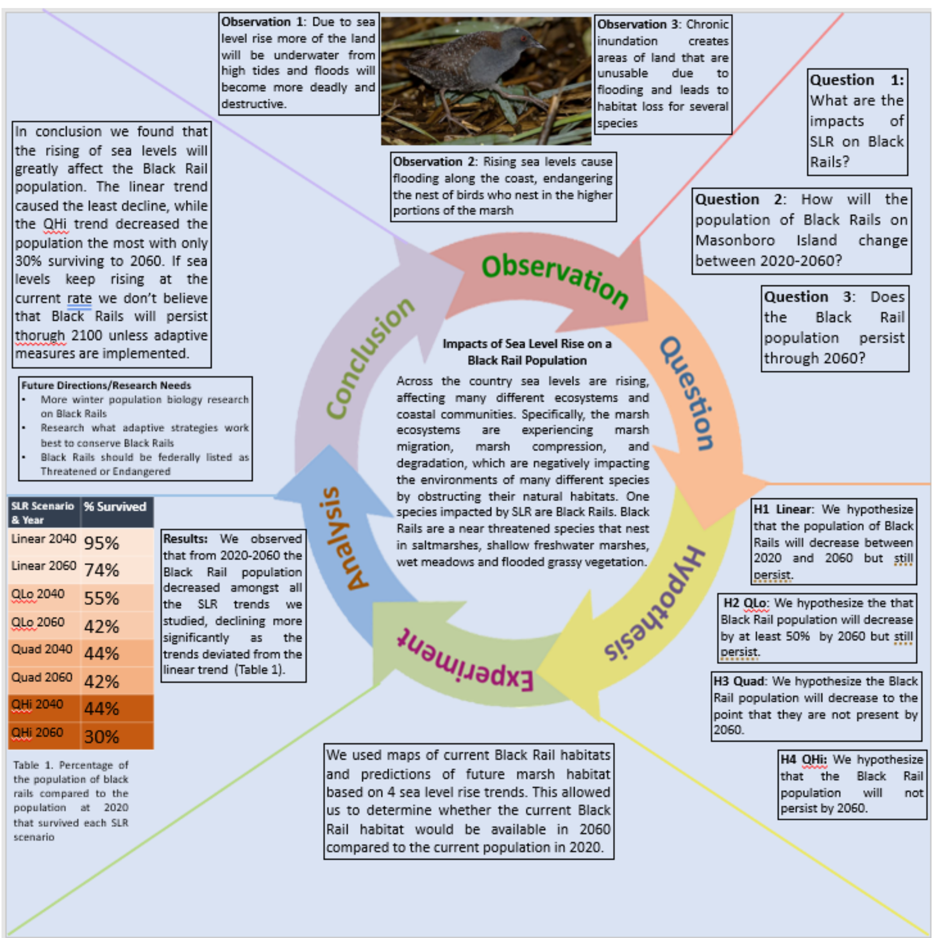


Figure 27. Example poster from outreach curriculum that are the end product of learning about impacts of SLR on vulnerable marsh species

Figure 28. Beginning of StoryMap for SLR curriculum

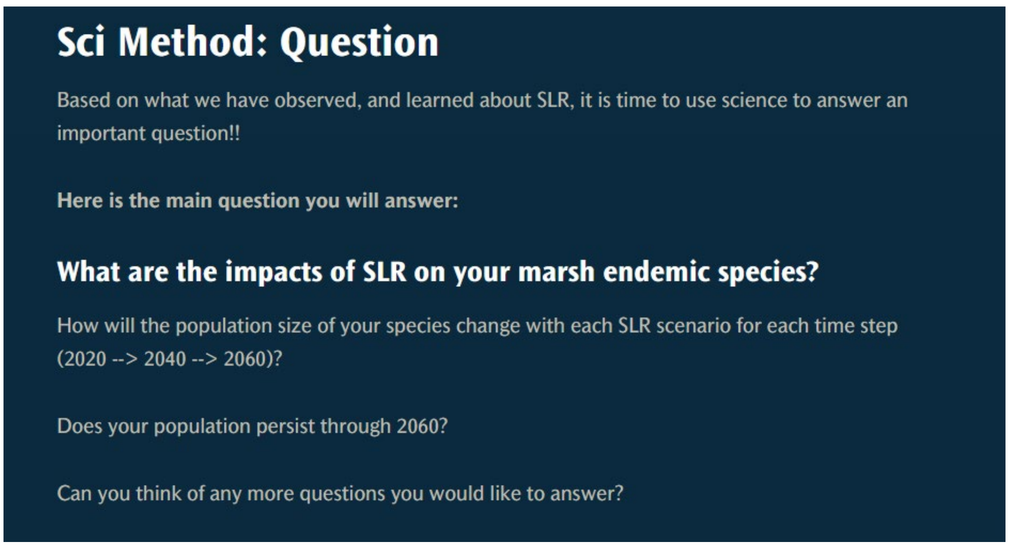


Figure 29. Question section of SLR curriculum

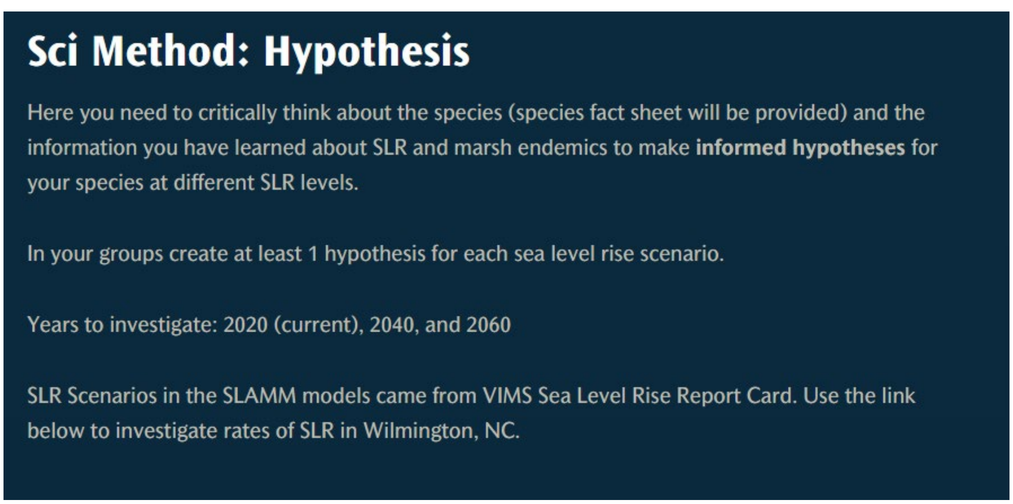


Figure 30. Hypothesis section of SLR curriculum

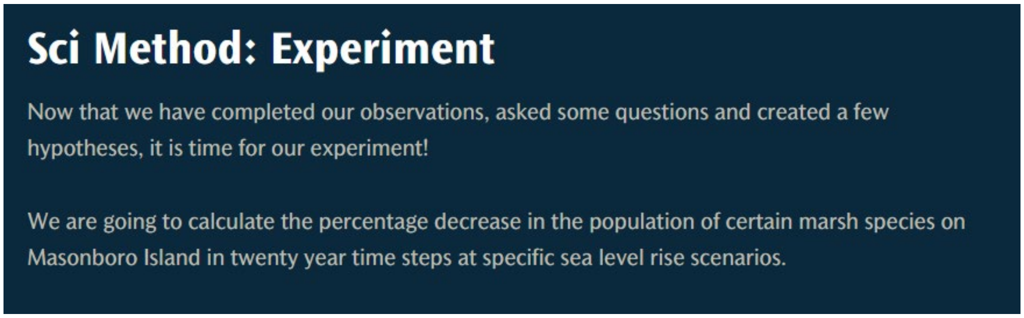


Figure 31. Experiment section of SLR curriculum

Figure 32. Analysis section of SLR curriculum

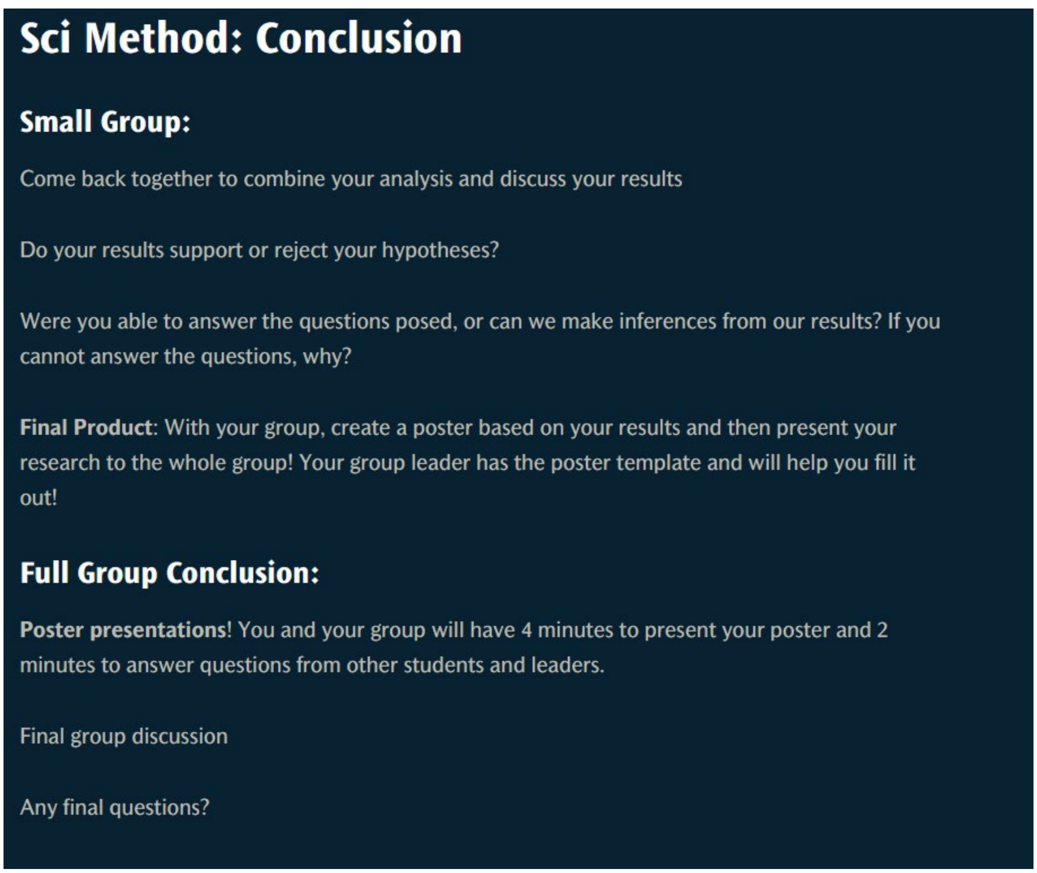


Figure 33. Conclusion section of SLR curriculum

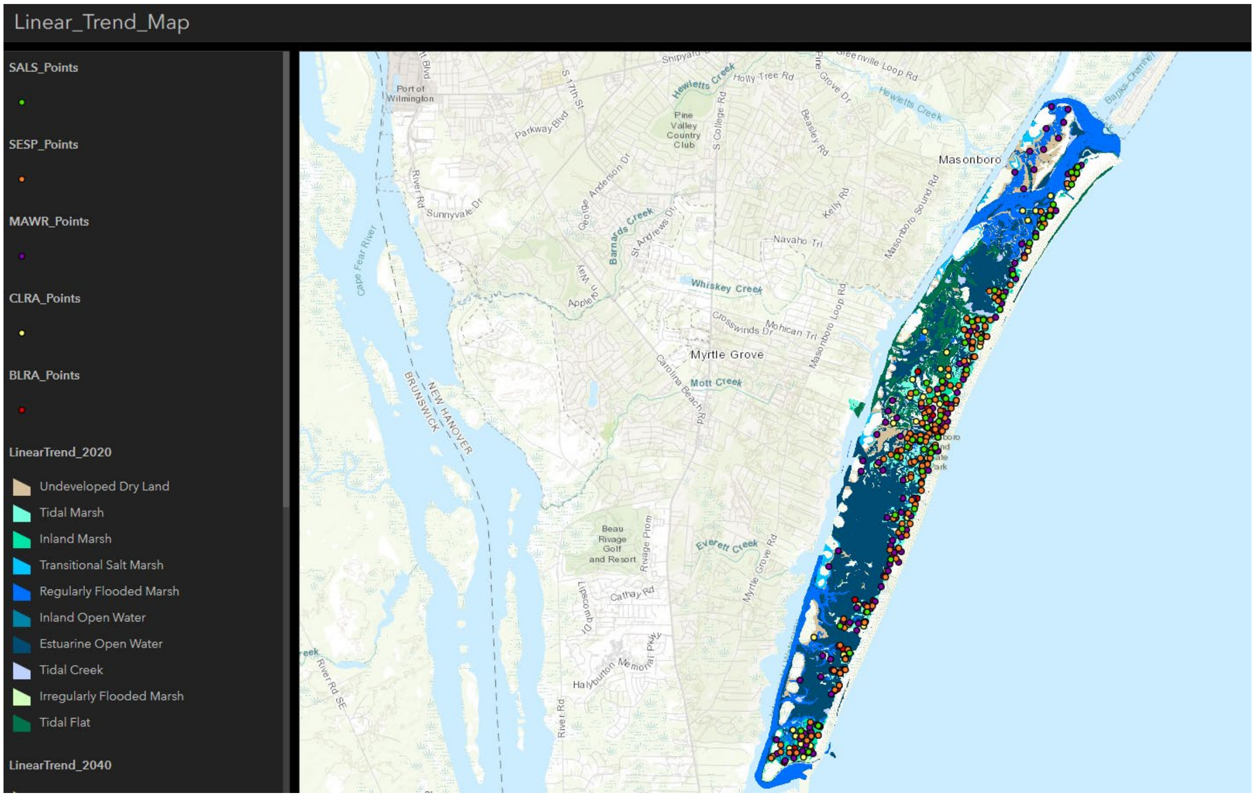


Figure 34. Screen shot of map used for SLR curriculum

Collaborators

We collaborated with NC NERRS for data collection on their properties. NC State Parks manages Bald Head State Natural Area so we worked closely with parks staff. This project also had collaboration with the NC Wildlife Resources Commission for the density portion on the project. We collaborated with UNCW Earth and Ocean Sciences department by working with Dr. Eman Ghoneim who assisted with the initial SLAMM models and she is also part of my dissertation committee. We provided important information regarding winter population biology of saltmarsh and seaside sparrows to the US Fish and Wildlife Service and the Atlantic Coast Joint Venture. Dr. Ghoneim will be providing me with access to WorldView3 and the methodology for increasing accuracy of habitat classifications for future models.

Data Management Plan

The Sea Level Rise Modeling on Marsh Sparrow Population Project, implemented by Marae Lindquist, will generate environmental data and information, including sea level rise estimates for coastal North Carolina, and marsh sparrow population estimates using SLAMM version 6.7 model. Data for the models will be collected from NOAA tides and currents, and the National Wetlands Inventory. Datasets will provide water level data from sites that collect water levels every 6 minutes or less as in accordance with NOAA standards. Data will be pooled and collected by Marae Lindquist according to the SLAMM model created by Jim Morris and Warren Pinnacle Consulting, Inc, and stored at the University of North Carolina Wilmington. The data and models will be available to Sea Grant upon request starting at the conclusion of the grant (July 31st) and in the concluding report. At this time, it is unknown the total volume of data that will be collected. Contact Marae Lindquist at mcl6280@uncw.edu or Dr. Raymond Danner at dannerr@uncw.edu for more information or to make a data request. In the past Dr. Danner has shared similar data through a former Sea Grant report, online data repositories including Dryad, Dr. Danner's academic webpage, supplemental data files in scientific papers, data files shared on the Smithsonian Migratory Bird Center's page, through GitHub, and Comprehensive R Archive Network (CRAN). All future sub-awardees not identified in this plan will as a condition of their contract acceptance of this data sharing plan. Any additional data sharing stipulations for future sub-awardees may be outlined at that time and descried in their contract.

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Dr. Eman Ghoneim and her graduate student Joshua Slocumb for teaching me how to use the SLAMM software.

Cassidy Mason for being a great technician and doing amazing work learning how to process data for SLAMM and working closely with me to get this project completed.

Sofia Campuzano for being the most enthusiastic and helpful field technician whose unwavering excitement help everyone stay positive even on the longest days.

John Carpenter and NCWRC for funding our study on the winter population biology of marsh sparrows that gave me the inspiration for this research and helping design the field data methods that formed the basis for this project and field data collection. Also thank you to John Carpenters technicians, Alex Work and Ben Nickley for helping collect data.

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