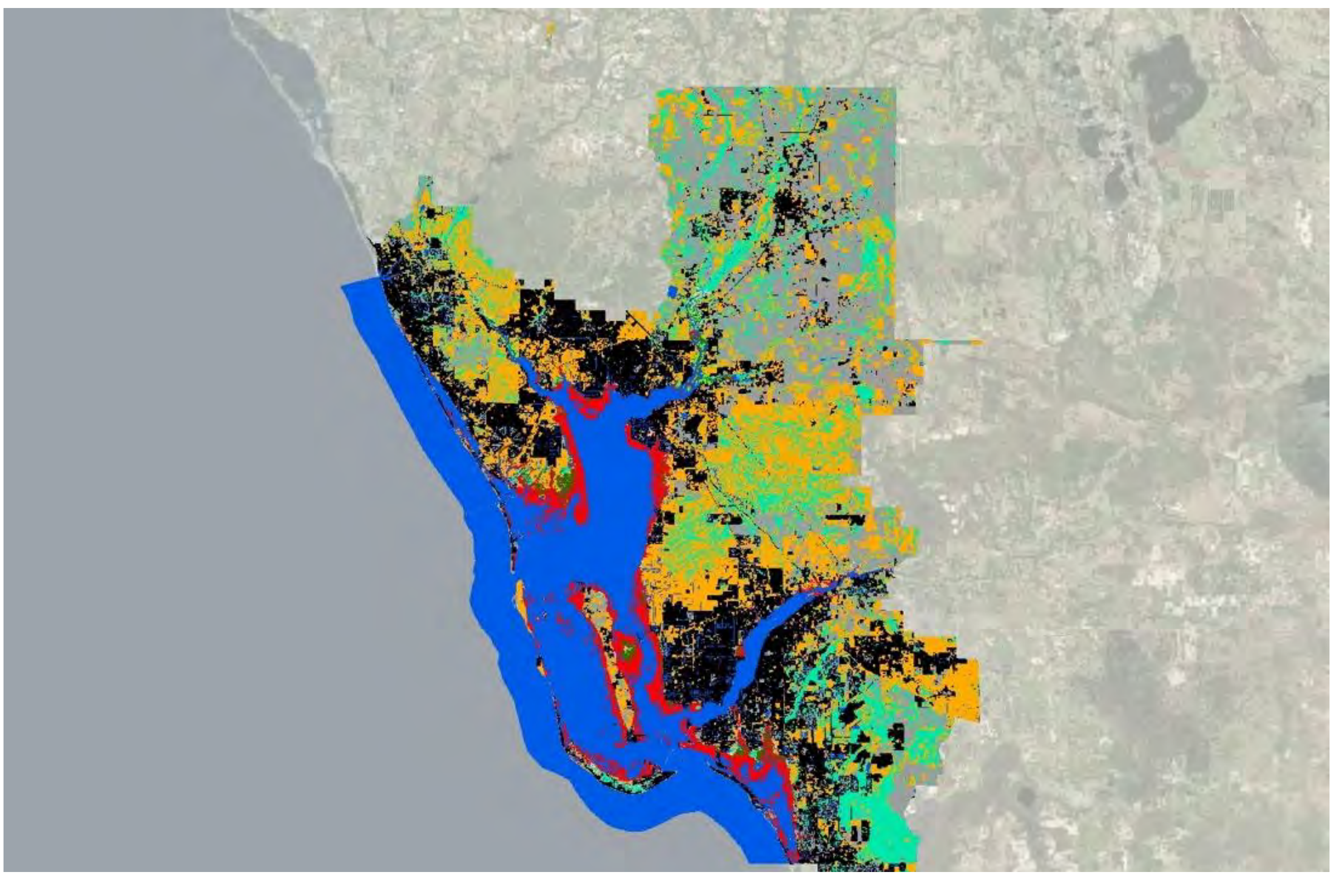
CHARLOTTE HARBOR NATIONAL ESTUARY PROGRAM (CHNEP) HABITAT RESILIENCY TO CLIMATE CHANGE

Habitat Evolution Modeling Report

Prepared for

CHNEP

Revised February 2019



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Charlotte Harbor National Estuary Program (CHNEP) Habitat Projection Modeling

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1. MODEL DEVELOPMENT

A GIS-based marsh habitat evolution model was developed for the CHNEP study area to estimate the change in acreages of salt marsh, *Juncus* marsh, freshwater marsh, mangrove, and salt barren habitats over time for future conditions. Inputs to the model include topography, vegetation and habitat data, tides, projected future sea-level rise, areas of freshwater influence, and habitat-specific accretion rates. The model produces maps of habitat types and habitat acreages on decade intervals (i.e., through 2120 for this analysis).

This draft report includes model runs for baseline conditions (current bay habitats and topography, projected sea-level rise, and sedimentation), as well as a sensitivity analysis of model parameters to assess the range of likely future habitat acreages under baseline conditions. In the future, proposed restoration actions could be incorporated into the model and compared to baseline conditions, to inform development of sustainable restoration alternatives and to quantify restoration benefits.

ESA has developed and applied a GIS habitat evolution model (HEM) that recreates some features of Sea-levels Affecting Marshes Model (SLAMM), an Environmental Protection Agency (EPA) habitat evolution model to the CHNEP study area. Based on previous habitat evolution modeling work conducted for Tampa Bay (Sheehan et. al. 2016), the HEM enhances SLAMM by increasing representation of habitat conversion processes for tropical locations. SLAMM maps habitat distribution over time in response to sea-level rise, accretion and erosion, and freshwater influence. However, for tropical locations such as the Florida Gulf coastline, almost all of the habitat categories convert to mangroves as sea-level rise drowns the existing habitat in SLAMM. This leads to an overestimate of the area of mangroves predicted for the future. Similarly, none of the habitats convert to irregularly flooded marsh/brackish marsh, a category that would include salt barrens, so the prediction shows an underestimate of the area of brackish marsh or salt barren habitat. To address these differences, ESA developed a GIS habitat evolution model (HEM) that recreated some of the features of SLAMM and added in other processes that were important to the system in the CHNEP study area. The HEM increases precision and accuracy compared to SLAMM by:

- Creating flexibility to edit the habitat categories to facilitate cross-walks from site-specific vegetation mapping.
- Updating the decision tree to change from one habitat category to another based on biological processes.
- Creating a structure that allows for different "modules" to be added to or updated in the model. For example, the module that determines areas of freshwater influence can be refined so that changes in freshwater flows can be simulated in conjunction with hydrodynamic modeling as a next step.
- The HEM has been run at other sites to recreate and match the outputs of SLAMM (ESA 2015). Once the replication of SLAMM was successfully completed, the model was expanded and improved as described above.

To add flexibility to the habitat categories, the HEM allows the user to input habitat types that are specific to the marsh system. For example, habitats within the CHNEP study area typically have high salt marsh between salt barrens and mangrove habitats. In SLAMM, salt barren habitats evolve straight to mangroves, without any representation of a high salt marsh zone. The HEM evolves salt barren habitats to high salt marsh and then to mangroves, and has the flexibility to add additional habitats as needed.

Additionally, the habitat decision tree was revised to allow habitats to evolve in the "reverse direction." For example, mangroves can now evolve to high salt marsh (due to sedimentation). In SLAMM, habitats can only evolve to lower elevation habitats and eventually drown out due to sea-level rise.

The HEM has been set up in a way to easily allow the addition of modules as they become available. For example, a new module can be developed to represent changes to the area of freshwater influence in response to changes in flow. Currently, the HEM replicates the SLAMM method for determining freshwater and brackish marsh habitats based on a polygon input defining the area of freshwater influence. In the current HEM for the CHNEP study area, the area of freshwater influence is initially defined by the boundary between the existing salt and brackish/freshwater habitats. For each time step, the freshwater boundary is modified to represent the saltwater intrusion with sea-level rise. As a next step to further develop the model, the freshwater influence module could be refined to simulate hydrodynamic changes in the area of freshwater influence in response to changes in freshwater flows (e.g., to evaluate bay habitat response to reduced or increased freshwater baseflows). This module could be developed in conjunction with hydrodynamic modeling of the Harbor salinity. The development of a hydrodynamic model at a later stage could therefore facilitate revising the existing freshwater module.

Note that the HEM is focused on long-term habitat changes and processes occurring over a multi-decade time frame. Certain shorter-term processes affect habitat evolution, but are accounted for by modeling long-term cumulative processes and habitat change rather than directly representing these shorter term processes. For example, episodic sediment delivery from large storms events, such as hurricanes, which occur and vary on seasonal and interannual timescales, are not considered directly in the model. Rather, the model uses average decadal sediment loads to account for the overall cumulative amount of sediment that enters marshes within the CHNEP study area in the long-term.

2. CONCEPTUAL MODEL OF CHARLOTTE HARBOR HABITATS

2.1 Tides

Salt marsh and intertidal habitats establish within zones corresponding to tidal inundation. Tides and tidal inundation within Charlotte Harbor are therefore important processes affecting habitats within the CHNEP study area. The Charlotte Harbor tides are driven by ocean tides that propagate through the Harbor mouth and which affect tidal heights in the Harbor relative to tidal heights in the ocean (e.g, through tidal muting or damping)

The Florida Gulf coast experiences mixed semidiurnal tides, with two high and two low tides of unequal heights each day. In addition, the tides exhibit strong spring-neap tide variability; spring tides exhibit the greatest difference between high and low tides while neap tides show a smaller than average range. Tidal datums for the different gages in Charlotte Harbor are summarized in Table 1 (NOAA Tides and Currents). Since no Highest Astronomical Tide (HAT) value was reported for the Punta Gorda gage, the HAT value was extrapolated by analyzing latitudinal trends in reported HAT values from neighboring tide gages on the Florida Gulf coast. Mean higher low water (MHLW) was calculated as the difference between MLW and MLLW above MLW (e.g MHLW = MLW + (MLW-MLLW)). Figure 1 shows the gage locations in Charlotte Harbor.

Table 1
NOAA Tidal Datums for Charlotte Harbor

	Fort Myers		Punta Gorda	
Tidal Datum	**ft MLLW**	**ft NAVD**	**ft MLLW**	**ft NAVD[1]**
Highest Astronomical Tide (HAT)	2.08	1.04	2.80	1.15
Mean Higher High Water (MHHW)	1.32	0.27	1.96	0.31
Mean High Water (MHW)	1.10	0.06	1.70	0.06
North American Vertical Datum of 1988 (NAVD)	1.04	0.00	1.65	0.00
Mean Tide Level (MTL)	0.63	-0.42	1.08	-0.57
Mean Sea-level (MSL)	0.63	-0.41	1.07	-0.58
Mean Low Water (MLW)	0.15	-0.89	0.45	-1.20
Mean Lower Low Water (MLLW)	0.00	-1.04	0.00	-1.65

SOURCE: ESRI (Aerial), NOAA Tide and Currents

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Figure 1
Tide Gage Locations

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2.2 Topography and Accretion

The elevation of an area determines the frequency of tidal inundation and salinity, which then influences the type of vegetation that will establish. If the topography changes due to accretion (or restoration/grading), the habitat types can change in response.

The Harbor receives sediment from its watershed and tributary creeks. Sediment carried by creek flows during storm events is deposited in the Harbor. Salt marsh or tidal accretion results from suspended sediment deposition due to storm events and tidal inundation, as well as from the accumulation of plant biomass over time. Note that some portion of the watershed sediment load is also exported through these systems to the ocean by storm flows.

Accretion rates in Charlotte Harbor are likely to vary depending on location and habitat type. Sheehan and Crooks (2016) evaluated accretion rates for Tampa Bay, which are expected to be similar to accretion rates found in Charlotte Harbor. For salt marsh, the study found accretion rates in the literature varied from 1.6 – 3.0 mm/yr while brackish marsh habitat likely experiences accretion rates of 2.25 – 3.75 mm/yr, and freshwater marsh is as high as 3.75 - 4 mm/yr. The study found accretion in mangroves varies even more in the literature depending on the type of mangrove habitat, and that mangroves are expected to accrete between 1.6 and 5 mm/yr.

2.3 Freshwater Inflow

Freshwater and brackish marsh habitats form in areas influenced by freshwater inflows. These areas of freshwater influence are either inundated solely by freshwater or are characterized by tidal mixing of ocean water and freshwater inflows, creating brackish salinities. The influence of freshwater determines what type of vegetation can establish in that area. If the extent of freshwater influence increases, the extent of freshwater and brackish marsh habitats will increase. Conversely, if the area of freshwater influence is reduced, the extent of freshwater habitats will be reduced. The area or extent of freshwater influence can be inferred from the extent of existing freshwater habitats, correlated to freshwater inflows, and/or quantified through monitoring and modeling of freshwater inflows and salinity gradients.

Charlotte Harbor receives freshwater input from three major rivers, the Myakka, Peace and Caloosahatchee. Flows are highest in the summer rainy season (e.g. August and September). These waters mix with salt water arriving from the Boca Grande Pass from the Gulf of Mexico to create a range of environments, from fresh to brackish to salty.

2.4 Habitat Zones

Habitat zones within the CHNEP study region can be defined for different areas based on the elevation of the area relative to tidal datums (i.e., as a surrogate for the frequency of tidal inundation) and whether the area is within the zone of freshwater influence. When there is no freshwater in the area, the upland species establish at the highest elevations, followed by salt barren, high salt marsh, mangroves, and lastly, subtidal habitat. When a freshwater influence is present, freshwater marsh establishes at the highest elevations, followed by salt barren, high salt marsh, low (*Juncus*) salt marsh, mudflat, and subtidal habitat.

The area of freshwater influence can be inferred from existing habitats and topography within the CHNEP study area, and the conceptual habitat zone scheme can be compared and validated against existing habitats. Section 5.1 includes a quantitative comparison of the modeled habitat zones and existing habitats for the CHNEP study area.

2.5 Sea-Level Rise

Sea-level rise is expected be a major driver of habitat evolution in Charlotte Harbor. Since most vegetation establishes in areas based on the local tidal inundation and salinity, habitats will evolve when the tides rise.

No specific study examining sea-level rise in Charlotte Harbor has been produced. However, the National Oceanic and Atmospheric Administration (NOAA) prepared a report in 2017 to address sea-level rise rates for the United States. Therefore, the sea-level change scenarios predicted by NOAA (2017) were used for Charlotte Harbor. The report offers decadal estimates of sea-level rise through 2200. Table 2 provides values at select decades for the low, intermediate low, and intermediate high scenarios.

Table 2
Sea-Level Rise
(Values in Inches)

Year	Low Scenario	Intermediate Low Scenario	Intermediate High Scenario
2020	2.4	3.2	3.9
2040	5.1	7.1	11.8
2070	8.7	13.8	31.1
2120	13.4	23.6	78.7

With climate change, extreme high water levels may change more than mean sea-levels due to alterations in the occurrence of strong winds and low pressures. However, this has not been extensively studied for the project area, so it is not included in this conceptual model.

3. MODEL INPUTS

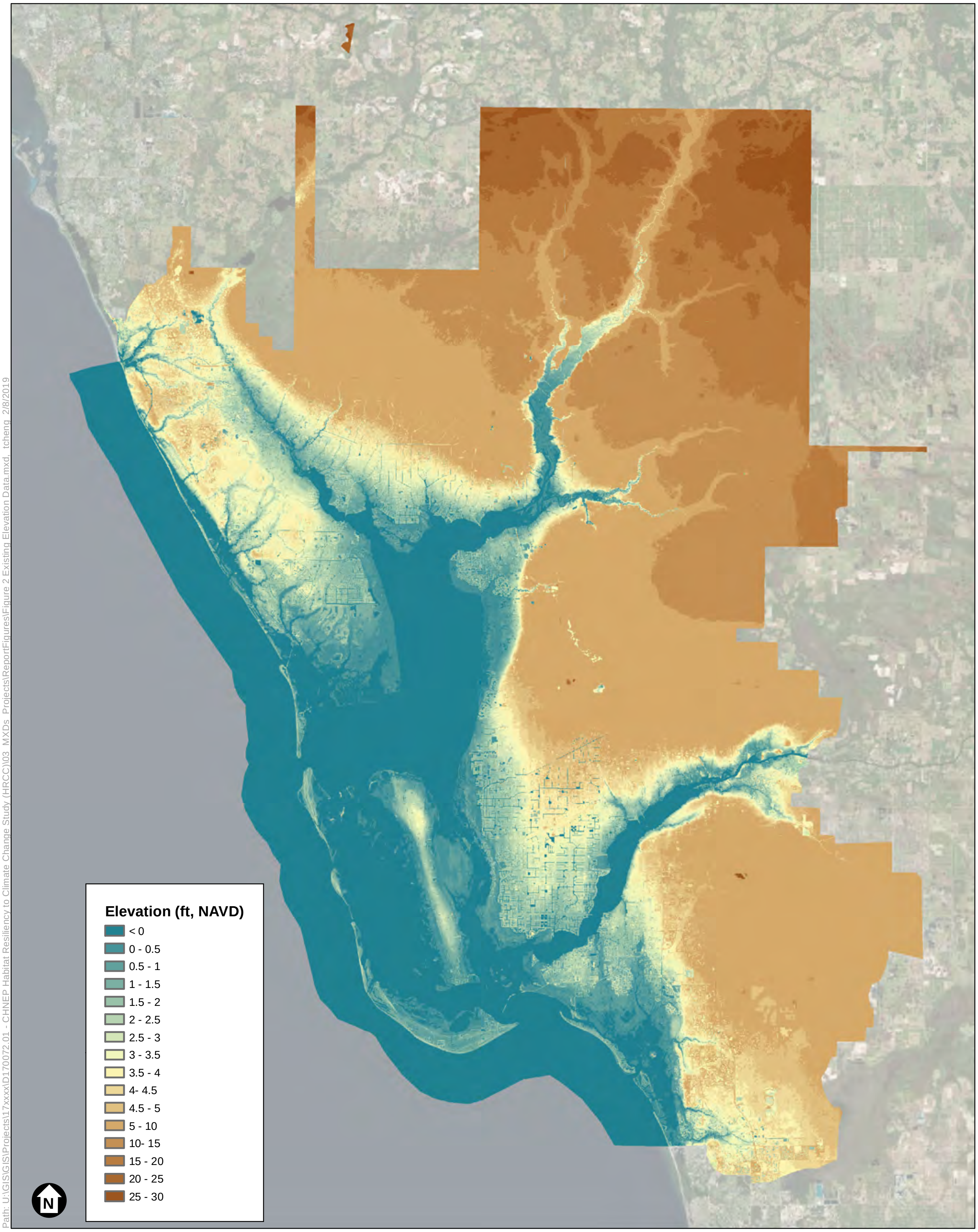
The HEM was run with the following inputs to look at habitat evolution in the CHNEP study area under baseline conditions and to test the sensitivity of the model to different model parameters. Subsequent model runs could be conducted to evaluate potential restoration projects, which can be compared to habitats projected under baseline conditions to quantify enhancement benefits over time.

3.1 Topography and Bathymetry

Topography is used in the model as input to the habitat evolution decision tree (see Section 3.2). Figure 2 presents the existing topography of the CHENP study area, which is from the 2016 NOAA Office for Coastal Management Coastal Inundation Digital Elevation Model (DEM). The resulting topography was converted to 10 m cells to provide a spatial resolution that is consistent with the vegetation mapping and maintains reasonable model run times.

3.2 Vegetation Mapping

To evaluate how habitats will evolve over time, existing conditions vegetation mapping is needed. As shown in Figure 3, Florida Land Use mapping from 2009-2011, conducted by the Southwest Florida Water Management District (SWFMD), was updated with available data from Beever (2016). The land use map was cross-walked into HEM habitat categories, which is presented in Appendix A. The cross-walk was developed based on inundation frequency, salinity preferences, and expected evolution under sea-level rise for each vegetation type. The habitat evolution decision tree is presented in Figure 4.



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SOURCE: ESRI (Aerial), NOAA Office for Coastal Management Coastal Inundation DEM (2016)

Figure 2
Existing Elevation Data
CHNEP Study Area

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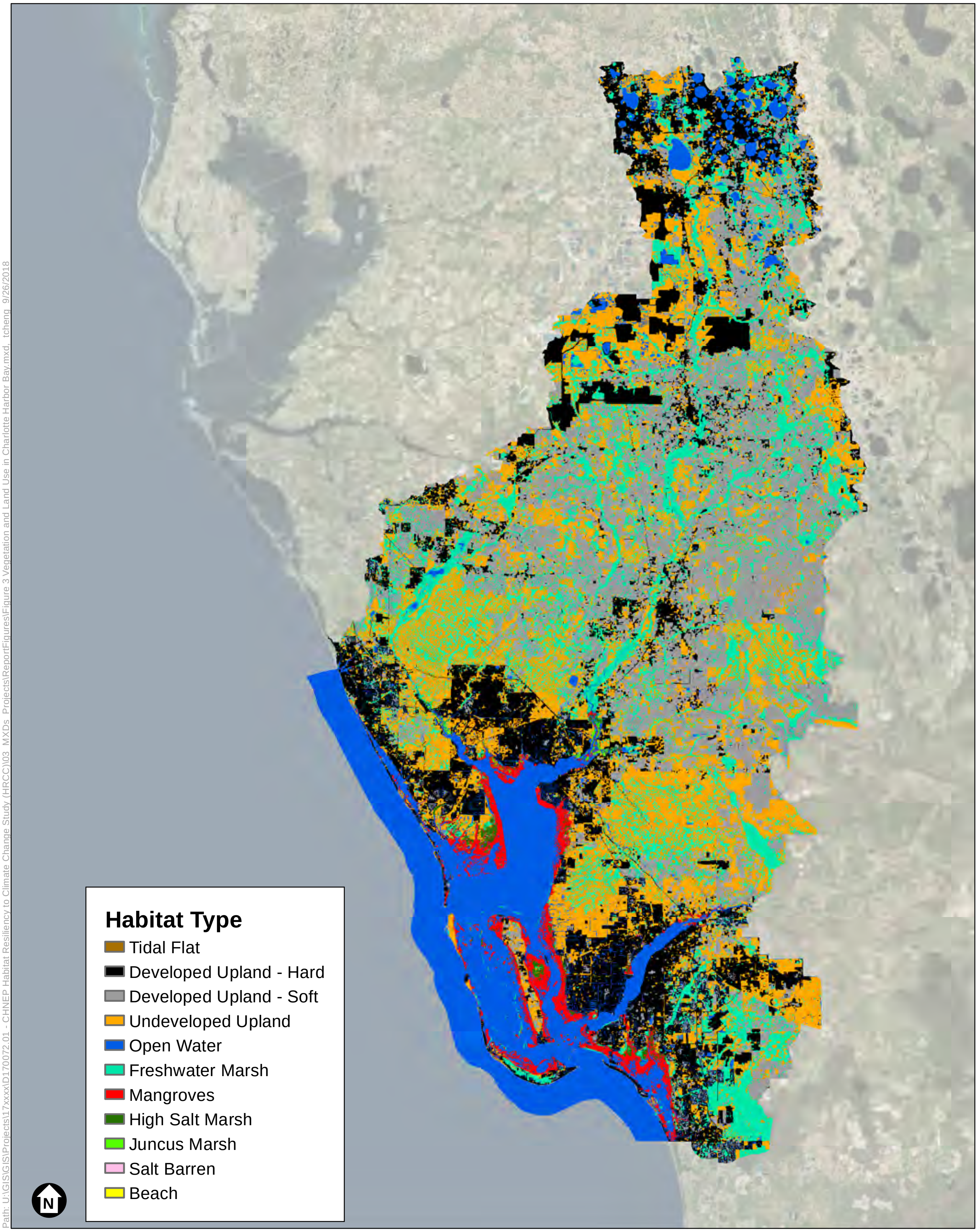

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SOURCE: ESRI (Aerial), 2009-2011 District FLUCCS, Beever (2016)

Figure 3
Vegetation/Land Use in CHNEP Study Area

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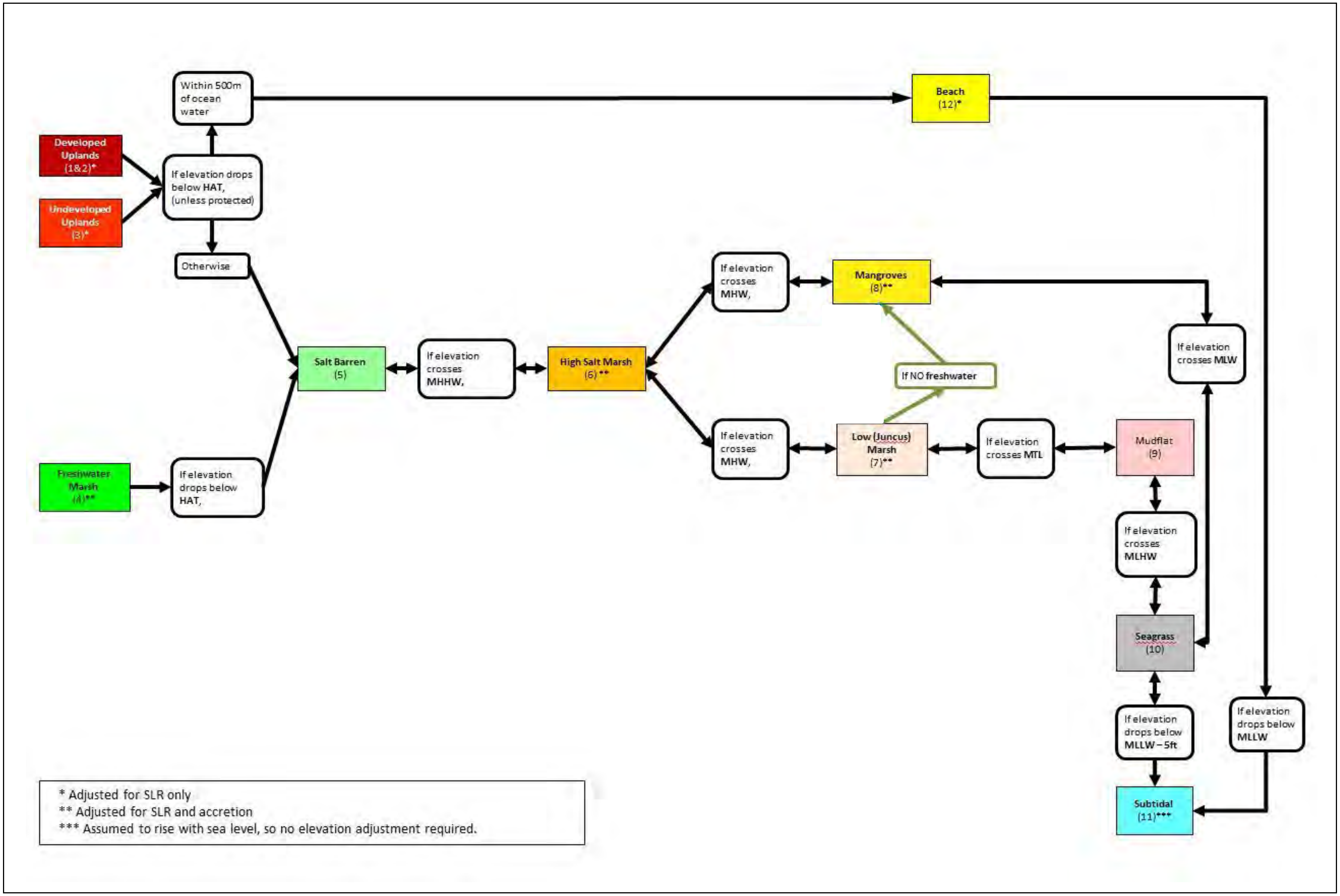


Figure 4
Habitat Evolution Decision Tree

3.3 Tidal Water Levels

3.3.1 Tidal Datums

Tidal datums are used within the model as an input to the habitat evolution decision tree (see Section 2.1). For example, MLLW is the boundary between open water and mudflat or beach, because it indicates the elevation at which land is always inundated (during an average day). If land is below MLLW, it is assumed to be open water; if land is just above, it is either mudflat or beach.

The model is divided up into eight basins (Myakka River, Peace River, Pine Island and Matlacha Pass, Charlotte Harbor, Caloosahatchee River, Estero Bay, Lemon Bay, Dona-Roberts Bay) to capture the variation in the tidal datums and to reduce run times. Figure 5 shows the basin boundaries. The Fort Myers and Punta Gorda gages were assumed to be representative of coastal and bay tide datums, respectively. Therefore, the Fort Myers datum values were used for Pine Island Sound, Matlacha Pass, Caloosahatchee River, Estero Bay, Lemon Bay and Dona-Roberts Bay basins. The Punta Gorda datum values were used for Myakka River, Peace River and Charlotte Harbor basins. Table 1 presents the tidal datums used in the model.

3.3.2 Sea-Level Rise

In the model, sea-level rise is added to each datum by decade. Sea-level rise values evaluated by NOAA (2017) were used for the CHNEP study area, since no specific projections have been made for the region. To test the sensitivity of the model to sea-level rise predictions, the model was run with the NOAA Low, Intermediate Low, and Intermediate High rates.

3.4 Sedimentation

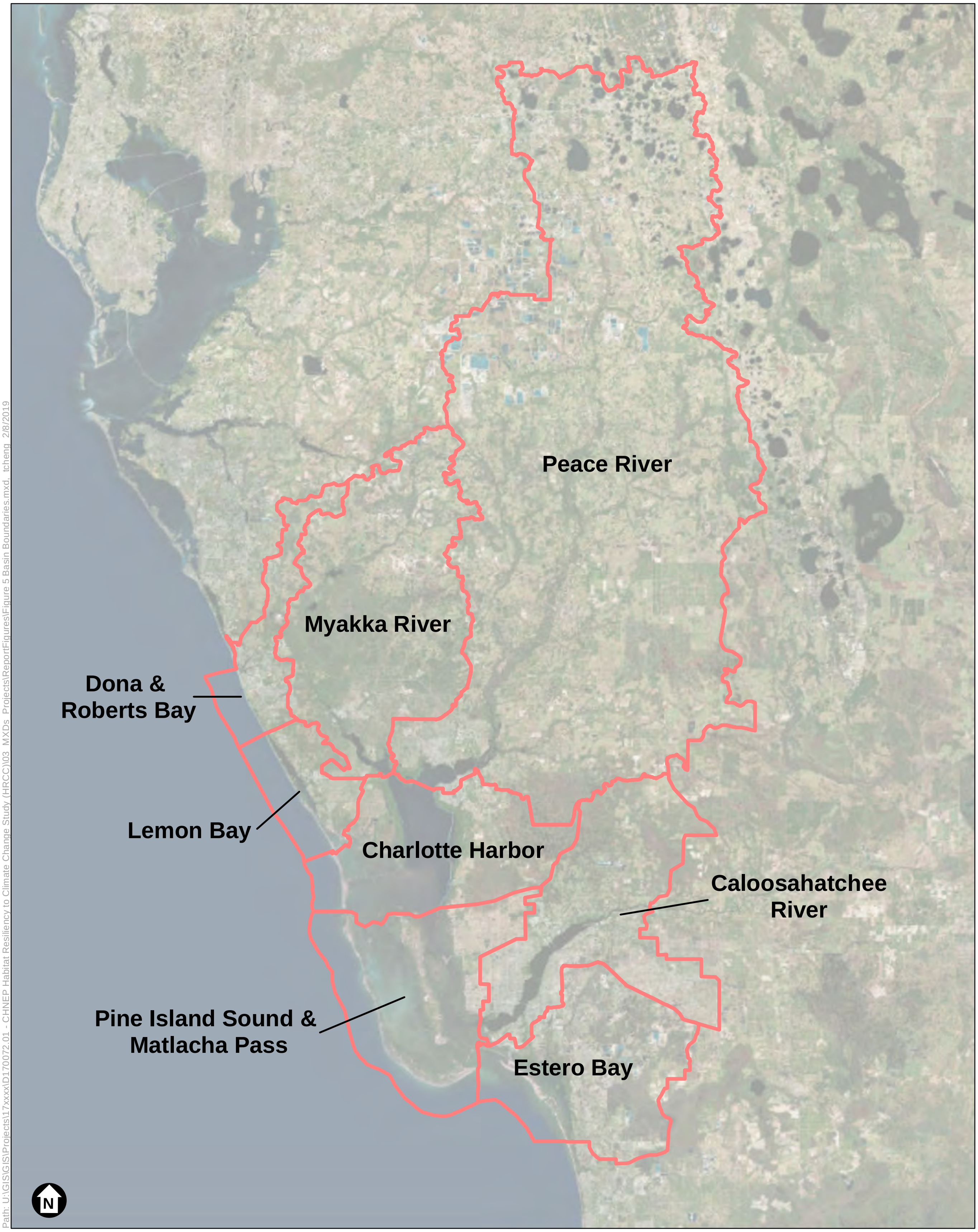
To evaluate the sensitivity of the model to different accretion rates, two accretion scenarios were run in the model. Table 3 presents the accretion rates by habitat for the high and low accretion scenarios. These values were based on the high and low accretion rates for each habitat type found in Sheehan and Crooks (2016).

Table 3
Modeled Accretion Rates

Habitat	Low Accretion Scenario (mm/yr)	High Accretion Scenario (mm/yr)
Salt Marsh	1.6	3.0
Juncus Marsh (Freshwater Marsh)	3.75	4.0
Mangrove	1.6	5.0

3.5 Freshwater Inflow

The model defines the area of year-round freshwater influences based on a freshwater influence polygon. For existing conditions, this polygon was defined based on the Bay-ward limits of low (*Juncus*) marsh (Figure 6). Because the Bay-ward limit is expected to shift inland throughout the century, freshwater extents for future decades were defined as model inputs for different sea-level rise scenarios. A future version of this model could incorporate hydrodynamic modeling of Charlotte Harbor salinities for existing conditions and future conditions with reduced or increased freshwater flow to quantify changes to the habitat.



Path: U:\GIS\GIS\Projects\17xxxx\D170072.01 - CHNEP Habitat Resiliency to Climate Change Study (HRCC)\03_MXDs_Projects\ReportFigures\Figure 5 Basin Boundaries.mxd, tcheng 2/8/2019

SOURCE: ESRI (Aerial), NOAA Tide and Currents

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Figure 3
Basin Boundaries
CHNEP Study Area

ESA

SOURCE: ESRI (Aerial)

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Figure 6
Freshwater Influence

4. MODEL RUNS

Table 4 presents the scenarios that were run in the HEM to test the model sensitivity. Low, Intermediate Low, and Intermediate High rates of sea-level rise were evaluated with low and high accretion rates. The depiction of existing development land use was retained for all model runs.

Table 4
Run Catalog

Run	Sea-level Rise	Accretion
Run 1	NOAA Low	Low (see Table 3)
Run 2	NOAA Int. Low	Low
Run 3	NOAA Int. High	Low
Run 4	NOAA Int. High	High (see Table 3)

5 RESULTS

The runs in Table 4 allowed for comparisons between different sea-level rise scenarios and accretion rates. Below, Section 5.1 presents the model "validation" of existing habitat types. Sections 5.2 – 5.3 present the results for sea-level rise and accretion rate options, respectively. Appendix B includes the habitat maps for the CHNEP study area for each year from Runs 1-4.

5.1 Model Validation

The model was compared to existing vegetation to check the model assumptions for the habitat evolution decision tree. Current topography and existing tidal datums were input to the model with no sea-level rise to model the existing conditions (2016) and to validate the model. Table 5 presents habitat acreages from the 2016 mapped vegetation and from the 2016 modeled habitats. Figure 7 shows the mapped vegetation compared to the modeled habitats.

Table 5
Habitat Acreages for Mapped vs. Modeled

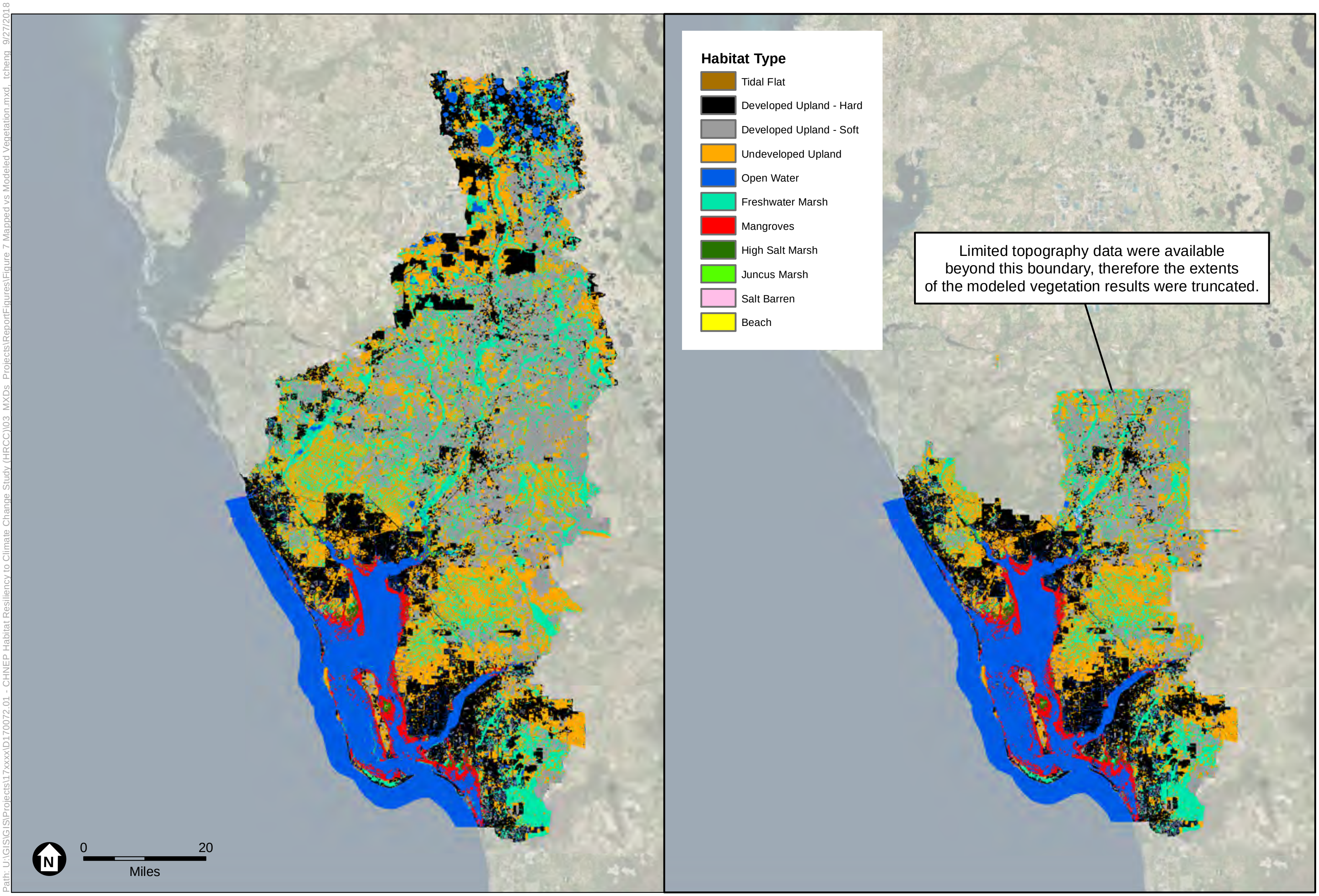
Run	2016 Mapped Vegetation	2016 Modeled Vegetation	Difference	% Difference	Notes
Developed Upland - Hard	298,200	298,200	0	0%	
Developed Upland - Soft	279,600	279,600	0	0%	
Undeveloped Upland	375,100	374,200	-1000	-0.3%	The model converts uplands at lower elevation to salt barrens, high salt marsh, *Juncus* marsh, and mangrove habitats.
Freshwater Marsh	206,100	201,300	-4,700	-2%	The model converts freshwater marsh at lower elevation to salt barrens, high salt marsh, *Juncus* marsh, and mangrove habitats.
Salt Barrens	410	2,900	2,500	604%	The model converts freshwater marsh and uplands at lower elevation to salt barrens.
High Salt Marsh	10,600	10,300	-300	-3%	The model converts freshwater marsh and uplands at lower elevation to high salt marsh, but also converts high salt marsh to mangroves.
Juncus Marsh	2,700	2,000	-700	-25%	The model converts freshwater marsh and uplands at lower elevation to *Juncus* marsh. The model also converts *Juncus* marsh to mangroves based on the freshwater influence.
Mangroves	64,700	68,800	4,100	6%	The model converts freshwater marsh and uplands at lower elevation to mangroves. The model also converts *Juncus* marsh to mangroves based on the freshwater influence.
Tidal Flat	220	280	60	26%	
Open Water	420,000	420,000	10	0%	
Beach	19	19	0	0%	

Note: values are rounded, so in some cases the difference may not be the same as subtracted the mapped and modeled results.

When the mapped vegetation is input to the model, some habitats change, since actual vegetation does not always follow the rules of the model. Discussion of some of these habitat shifts is presented below.

- **Undeveloped Upland.** Some mapped upland areas are at elevations that would be suitable for salt barren, salt marsh, mangrove, and *Juncus* marsh habitat, so the model classifies these areas accordingly.
- **Salt Barrens and Salt Marsh.** As mentioned above, the model classifies upland as salt barren and high salt marsh habitat based on the lower elevations where upland occurs. However, some salt marsh is also converted to mangroves based on the lower elevations where it occurs.
- **Mangroves and *Juncus* Marsh.** In the model in areas where freshwater is not defined, *Juncus* marsh converts to mangrove habitat. Additionally, the lower elevation uplands are converted to mangrove, showing an overestimate of mangrove.
- **Tidal Flat.** Some areas that are not currently mapped as tidal flat are classified as this habitat in the model due to low elevations of other habitat types.

The overall difference between mapped and modeled habitats is less than 1%, which means the model is capturing the existing habitats fairly well. The model likely overestimates salt barren and mangroves, while underestimating salt marsh and *Juncus* marsh. Salt barren habitat requires minor changes in topography that will allow salt water to pond and then evaporate, and this specificity is not captured in the model. Additionally, *Juncus* marsh is able to compete with mangroves in areas on the outside border of the freshwater influence, but this interplay is not captured in the model.



SOURCE:

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Figure 7
Mapped vs. Modeled Vegetation

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5.2 Sea-level Rise Curves

Table 6 presents the habitat acreages for the low (Run 1, low), intermediate low (Run 2, int. low) and intermediate high (Run 3, int. high) rates of sea-level rise at 2120, as well as the difference between these habitat acreages and the 2016 modeled habitats. Figure 8 shows the 2120 habitat maps for int. low and int. high sea-level rise. (See Appendix A for habitat maps for 2040 and 2070 for Runs 1-4) With higher rates of sea-level rise, higher elevation habitats convert to lower habitat types. For example, under the int. high scenario, there is less upland, freshwater marsh, high salt marsh, *Juncus* marsh, and mangroves than under the int. low scenario and open water increases dramatically.

Salt barren also shows an increase with more sea-level rise, but this is likely overestimated. As discussed in Section 5.1, salt barren habitat depends on complex topographic variations that are not captured in the model, so while the model is predicting an increase in the areas where salt barren could develop, the area of salt barren that will develop is likely much smaller.

It is also interesting that the most mangrove habitat is achieved under the middle sea-level rise prediction (the intermediate low scenario). As other habitats drown out, more mangrove will be able to establish, so under the low sea-level rise scenario, mangrove has less opportunity to expand upland, resulting in a smaller acreage of mangrove than under the intermediate low scenario. On the other hand, under the intermediate high scenario, more mangrove habitat drowns out. As shown in the last three columns of Table 8, the intermediate low scenario actually shows an increase in mangrove habitat by 2120 compared to 2016, while the other scenarios show decreases.

Figures 9, 10, and 11 show the evolution of habitats over time for the low (Run 1), int. low (Run 2) and int. high (Run 3) rates of sea-level rise. Under low sea-level rise, salt marsh and *Juncus* marsh are actually able to expand into more upland habitats and increase in area over time. Under int. low sea-level rise, mangrove habitat increases, with some loss in freshwater marsh and *Juncus* marsh. In the int. high sea-level rise scenario, freshwater marsh, *Juncus* marsh and mangrove habitat dramatically decrease and are converted to open water.

Table 6
Habitat Acreages for Sea-Level Rise

Run	Modeled Acreage in 2016	Acreage in 2120			Acreage difference 2120-2016		
		(Run 1) Low	(Run 2) Int. Low	(Run 3) Int. High	(Run 1) Low	(Run 2) Int. Low	(Run 3) Int. High
Developed Upland- Hard	298,200	298,200	298,200	298,200	0	0	0
Developed Upland- Soft	279,600	279,600	279,600	279,600	0	0	0
Undeveloped Upland	374,200	371,400	366,500	323,200	-2800	-7700	-51000
Freshwater Marsh	201,300	196,900	193,000	181,700	-4400	-8300	-19600
Salt Barrens	2,861	5,800	8,200	9,400	2939	5339	6539
High Salt Marsh	10,280	11,500	9,700	2,900	1220	-580	-7380
Juncus Marsh	2,000	2,900	470	450	900	-1530	-1550
Mangroves	68,800	67,200	73,000	14,100	-1600	4200	-54700
Tidal Flat	280	460	280	260	180	0	-20
Beach	19	17	17	15	-2	-2	-4
Open Water	420,000	423,600	428,600	547,900	3,600	8,600	127,900

5.3 Accretion Rates

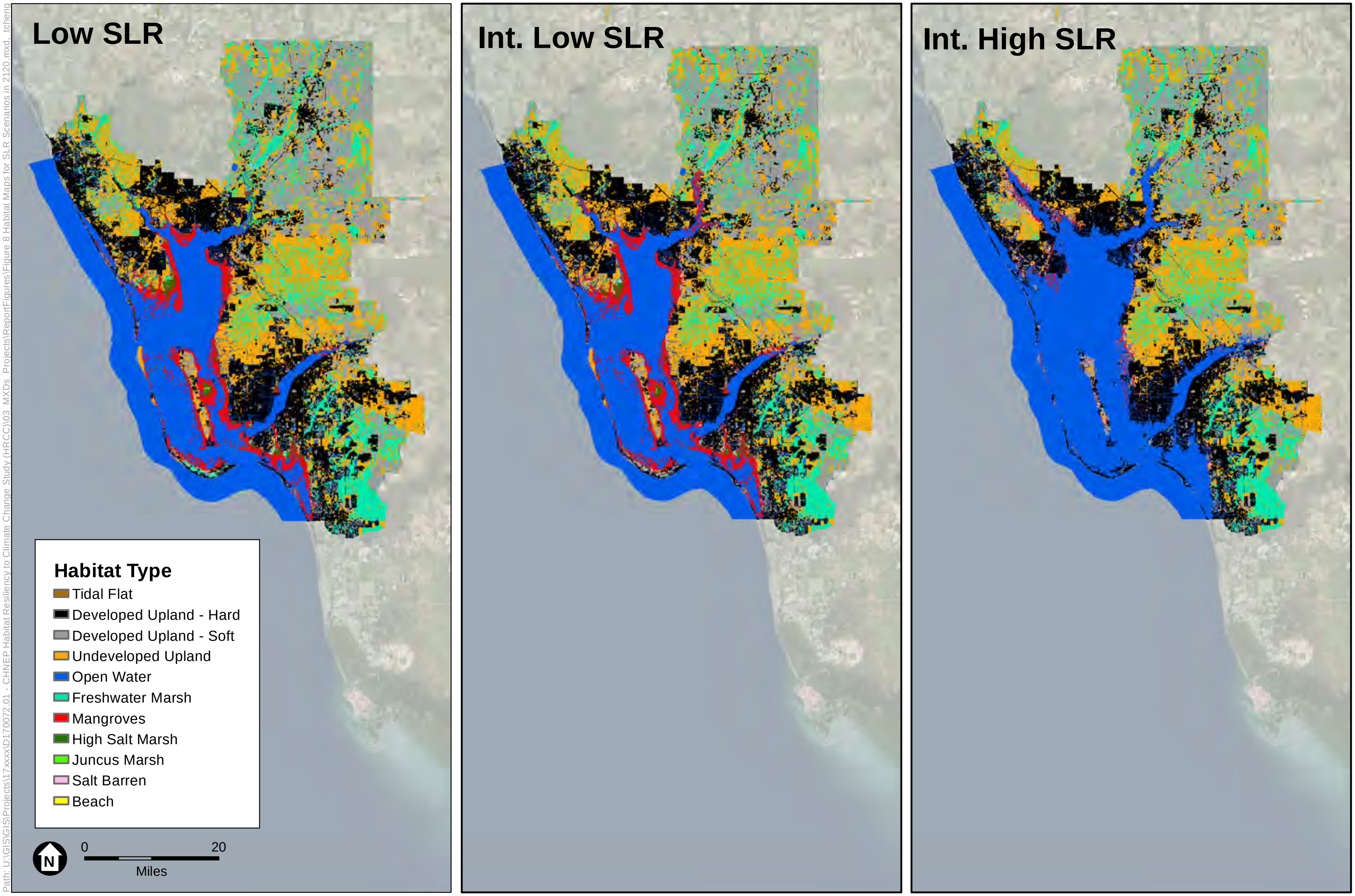
Table 7 compares the habitat acreage at 2120 for the modeled low and high accretion rates (Runs 3 and 4) under the intermediate high sea-level rise scenario. Figure 12 shows the 2120 habitat maps under the two accretion scenarios and int. high sea-level rise compared to the 2016 modeled habitats. Figures 13 and 14 show the habitat evolution over time for low and high accretion rates, assuming an int. low and int. high sea-level rise rate.

Under a high accretion rate, more mangrove habitat and a small amount of salt marsh is maintained. However, under both scenarios, mangrove habitat still decreases in acreage by 2120. Accretion rates may play a bigger role in habitat sustainability under lower rates of sea-level rise, where the additional sediment might make the difference of a habitat drowning out or being able to keep up with rising waters.

Table 7
Habitat Acreages for Accretion Rates

Run	Modeled Acreage in 2016	Acreage in 2120 (Run 3) Low	Acreage in 2120 (Run 4) High	Acreage difference Difference (Run 4 – Run 3)
Developed Upland- Hard	298,200	298,200	298,200	0
Developed Upland- Soft	279,600	279,600	279,600	0
Undeveloped Upland	374,200	323,200	323,200	0
Freshwater Marsh	201,300	181,700	181,700	0
Salt Barrens	2,861	9,400	9,400	0
High Salt Marsh	10,280	2.920	2,940	14
Juncus Marsh	2,000	450	450	0
Mangroves	68,800	14,100	17,900	3,800
Tidal Flat	280	260	260	0
Beach	19	15	15	0
Open Water	420,000	547,900	544,100	-3,800

Note: values are rounded, so in some cases the difference may not be the same as subtracted the mapped and modeled results.



SOURCE: ESA

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Figure 8
Habitat Maps for SLR Scenarios in 2120

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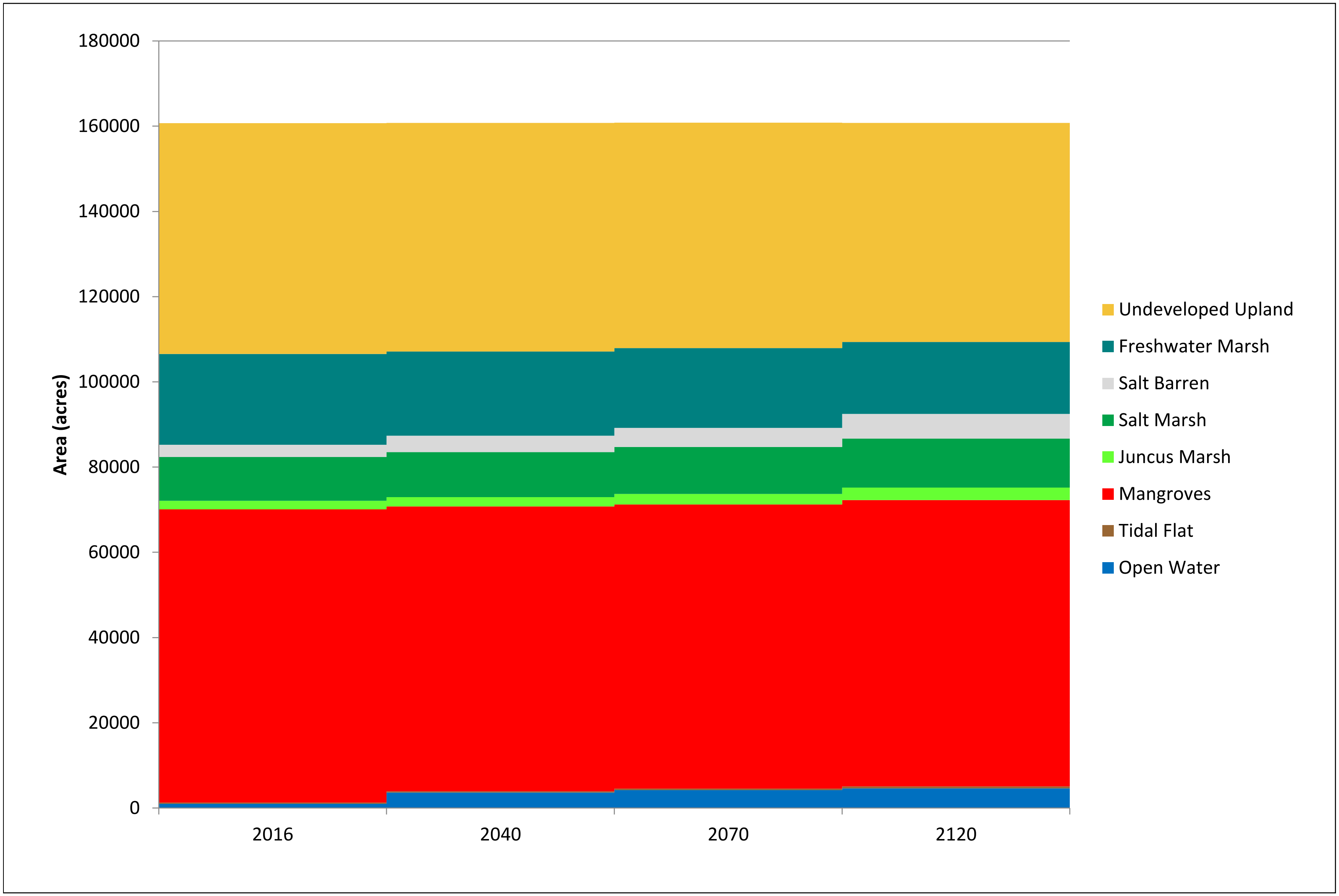
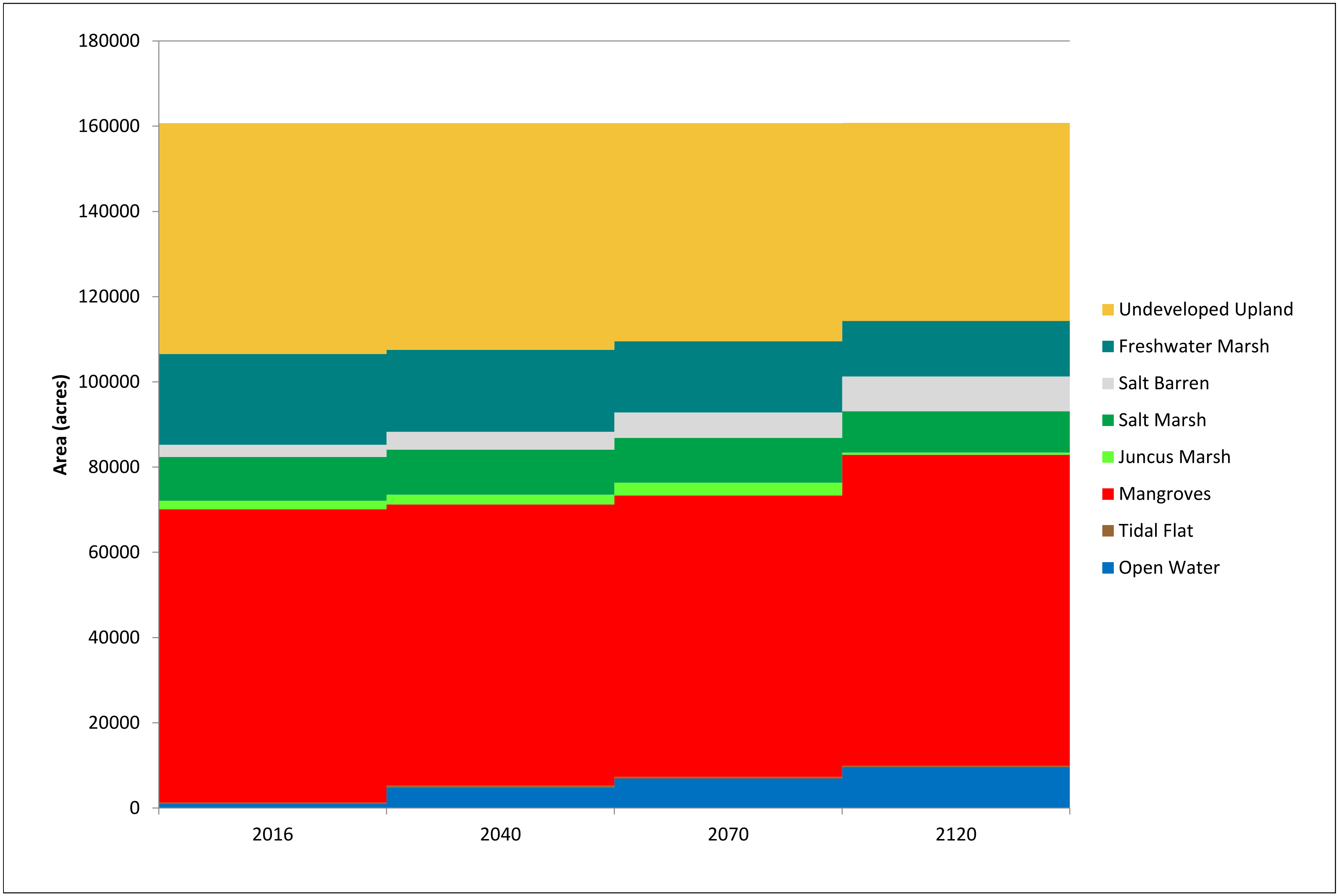


Note: Upland, Freshwater Marsh, and Open Water habitat adjusted/reduced to better show change

Figure 9

Run 1 Habitats Over Time
(Low Sea Level Rise and Low Accretion)

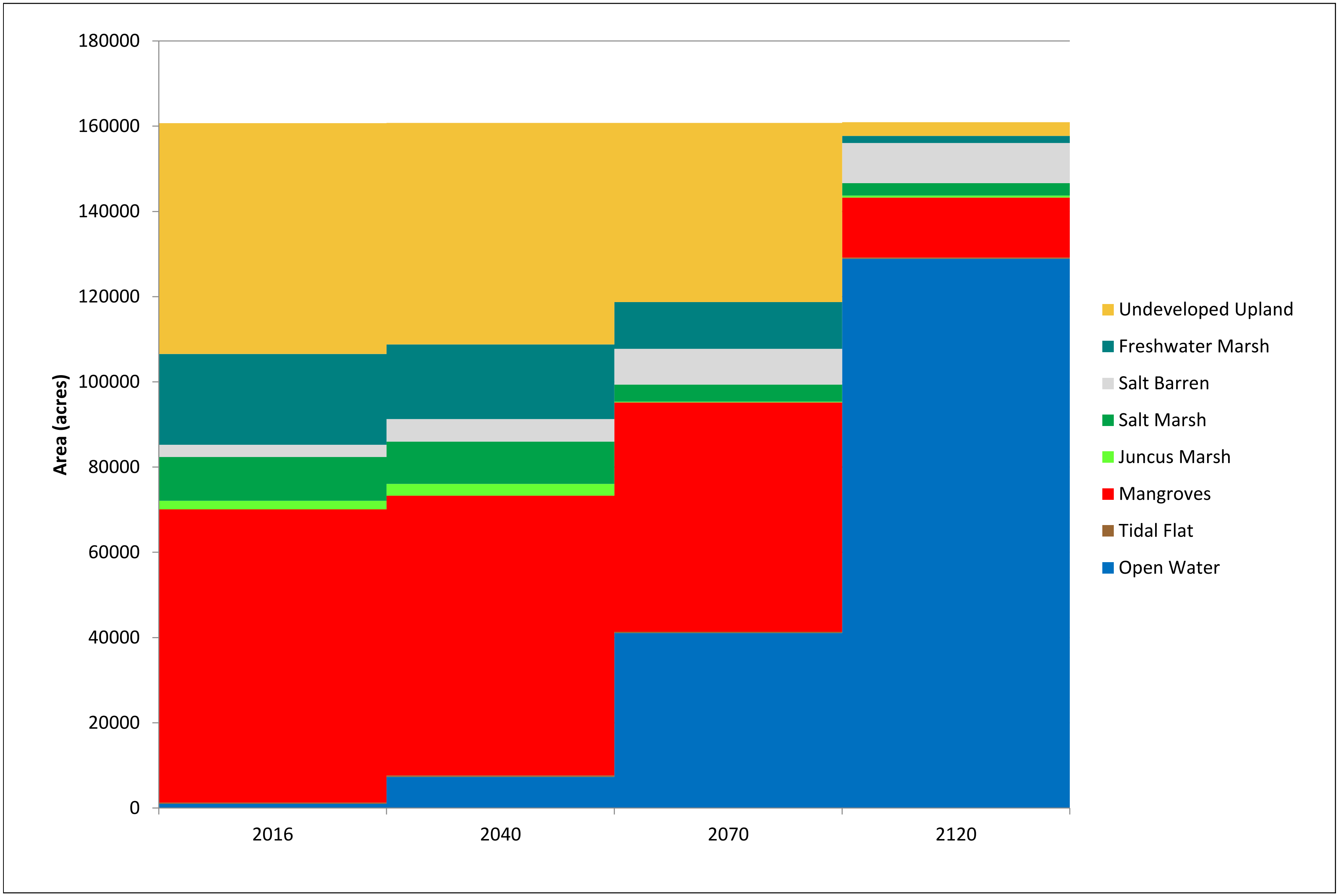


Note: Upland, Freshwater Marsh, and Open Water habitat adjusted/reduced to better show change

Figure 10

Run 2 Habitats Over Time

(Int. Low Sea Level Rise and Low Accretion)



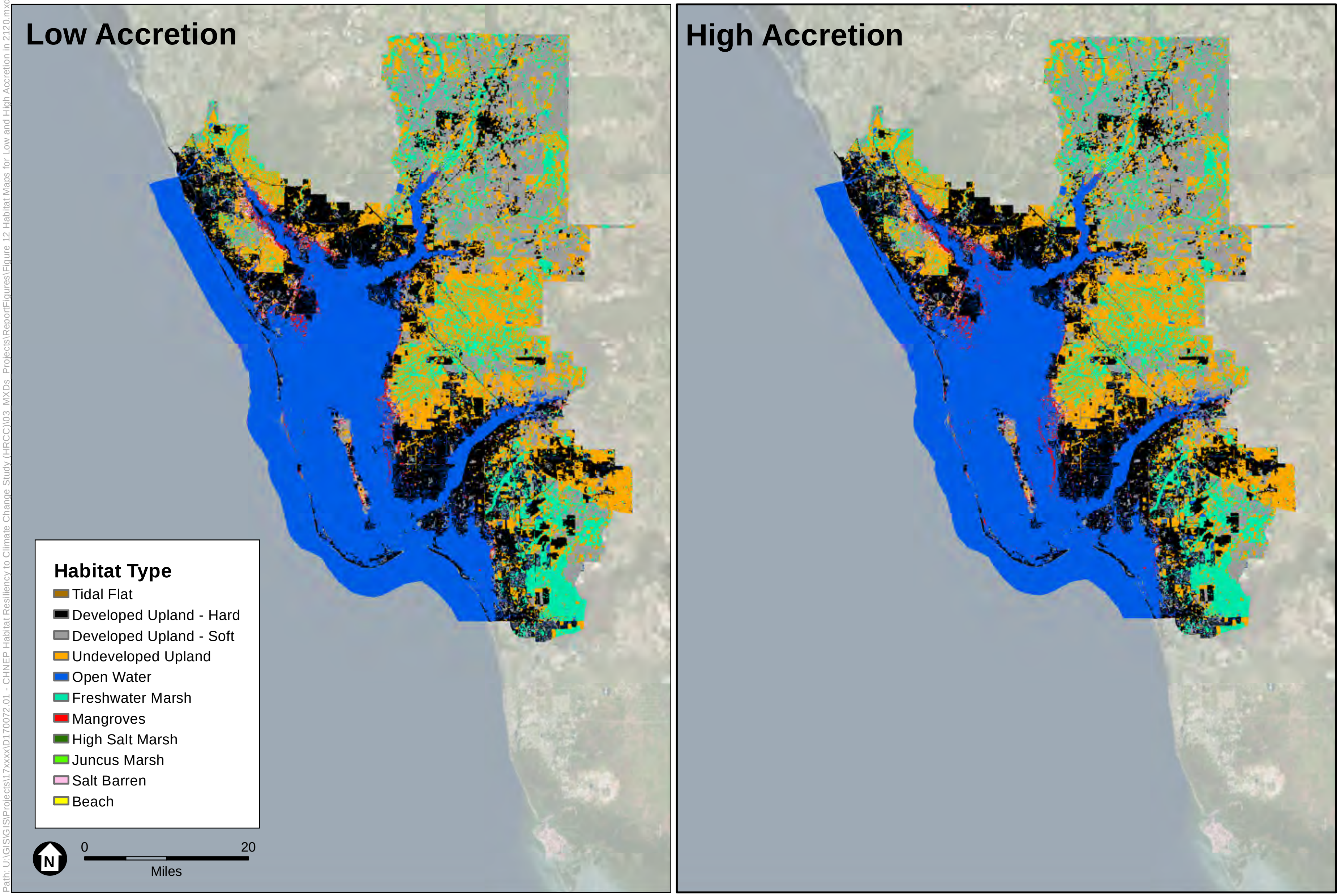
Note: Upland, Freshwater Marsh, and Open Water habitat adjusted/reduced to better show change

CHNEP Habitat Resiliency to Climate Change . D170072.01

Figure 11

Run 3 Habitats Over Time

(Int. High Sea Level Rise and Low Accretion)

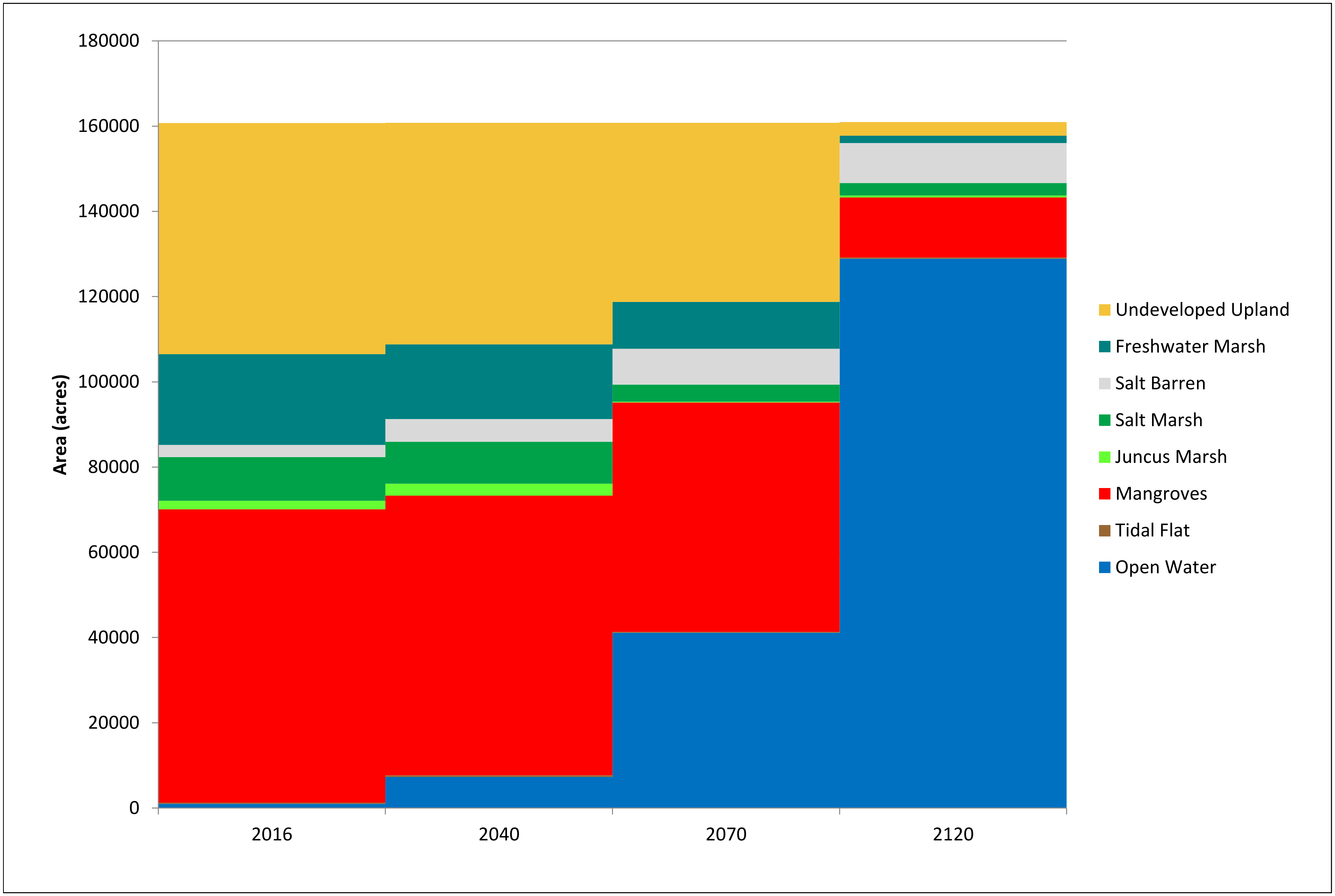


SOURCE: ESA

CHNEP Habitat Resiliency to Climate Change . D170072.01

Figure 12
Habitat Maps for Low and High Accretion Scenarios
2120

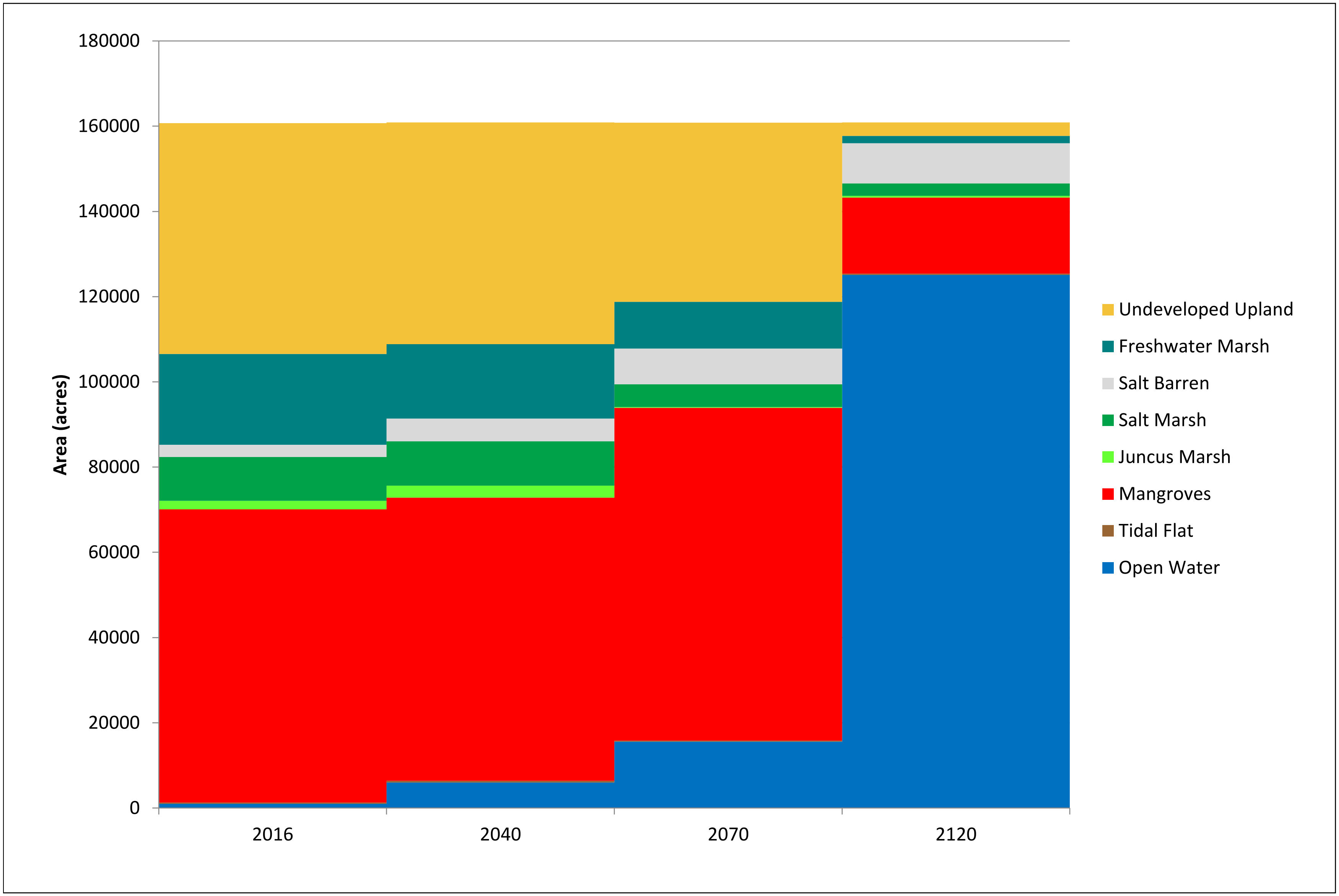
ESA



Note: Upland, Freshwater Marsh, and Open Water habitat adjusted/reduced to better show change

Figure 13

Run 3 Habitats Over Time
(Int. High Sea Level Rise and Low Accretion)



Note: Upland, Freshwater Marsh, and Open Water habitat adjusted/reduced to better show change

Figure 14

Run 4 Habitats Over Time

(Int. High Sea Level Rise and High Accretion)

6. DISCUSSION

6.1 Model Calibration

The HEM provides a look into the future at the different habitat types that may occupy the CHNEP study area. The results presented here look at the base conditions and project future conditions under distinct sea-level rise and accretion rates, retaining the depiction of existing development land use.

The current model setup captures many of the habitat categories adequately with a few exceptions:

- **The model assumes there is a line between freshwater and salt water habitats.** In reality, habitats such as mangrove and *Juncus* marsh can grow in the same area. The model assumes that any area that is not influenced by freshwater will not have *Juncus* marsh habitat (and only mangroves), so the complexity of these areas is not captured by the model.
- **While vegetation occurs mostly within well-defined elevations, there is always some vegetation that will establish above or below these elevations, and the model does not capture this.** Although the habitat elevation ranges in the model capture most of the existing habitats in the CHNEP study area, the ranges are not representative of all existing vegetation. For example, the model likely overestimates salt barrens based on the elevation ranges, because, in reality, the formation of a salt barren is a more complex process, which depends on slight variations in the topography.

6.2 Sea-level Rise

Variations in sea-level rise rates produced a range of results for the habitat types. Under a low sea-level rise scenario, *Juncus* marsh, salt barren and high salt marsh habitats steadily increased in acreage through 2120, concurrent with impacts of saltwater on freshwater habitats. Mangrove habitat stays approximately the same. However, in the int. low sea-level rise case, mangrove habitat increases more dramatically through 2120, while the acreage of *Juncus* marsh and high salt marsh decrease sharply. The int. high sea-level rise scenario predicts an accelerated loss of freshwater, mangrove, and high salt marsh habitats, and an expected increase in open water habitat.

6.3 Accretion Rates

The model results indicate that under a int. high sea-level rise scenario, higher levels of accretion could result in increased longevity of mangrove habitat through 2070, although it does not prevent conversion into open water by 2120. No significant changes in other habitat types, such as *Juncus* marsh, and high salt marsh were predicted from the model results. The impacts of variable accretion rate on habitats within the CHNEP study area may be more significant under a lower sea-level rise scenario.

6.4 Conclusions

The HEM forecasts that for the lower rates of sea-level rise (low and int. low), the total extent of intertidal habitat changes little through time, and actually increases in 2120 for the int. low scenario. However, under the int. high scenario, intertidal habitat is expected to decrease dramatically (63% loss) even with high accretion rates. While mangroves will transgress into salt and freshwater wetland areas, there is a projected decline of mangrove area once rates of sea-level rise increase in the end of this century and the beginning of the next.

Coastal managers can use the HEM results to identify areas that should be prioritized for restoration. Even greater benefits could be gained by identifying harder development that may not be sustainable in the long-term for restoration as well. Finally, lower sea-level rise allows habitats to persist, so strategies to reduce emissions elsewhere and to limit climate change will have a positive effect on habitat extents in the future.

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