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Effects of Sea Level Rise on Foraging Habitat of the Piping Plover (*Charadrius melodus*): A Geographic Information Systems Approach

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ABSTRACT: The shorebird species, Piping Plover (*Charadrius melodus* Ord), an at-risk species with populations along the United States Atlantic shoreline, is predicted to experience negative impacts from rising sea levels over the next century. The breeding and foraging habitat of *C. melodus* is currently under threat from human disturbances and, over the next century, rising sea levels will further threaten its foraging habitat. Many coastal ecosystems are at risk from the global average sea level rise; the risk along the Mid-Atlantic shoreline of the United States is greater than many coastal ecosystems due to localized sinking/subsidence of the land surface. Due to these sea level changes, Mid-Atlantic coastal wetlands, which are an important foraging habitat for *C. melodus* chicks, are predicted to be at risk. To investigate the probability of effects on *C. melodus* foraging habitat, we modeled the influence of predicted magnitude of sea level rise at wetlands within the predicted suitable habitat of *C. melodus* at time intervals of 30, 60, and 120 years using Geographic Information Systems (GIS). Results demonstrate that sea level rise effects will vary markedly depending on the location of the wetlands habitat of *C. melodus*. Both barrier islands, Assateague Island National Seashore (Maryland) and Chincoteague National Wildlife Refuge (Virginia), are projected to have substantial net losses in 120 years ranging from 73-94% and 48-90 % for Assateague and Chincoteague, respectively. Conversely, habitats at Cape May Point State Park (New Jersey) show little-to-no negative impact from sea-level rise. The results from this assessment suggests that: 1) the effect of sea level rise over the next 120 years on wetlands foraging habitat for *C. melodus* is strongly site specific; 2) some locations are likely to see significant losses of wetlands foraging habitat for this species; and 3) the sites at greatest risk are barrier islands. Since the magnitude of projected habitat loss in the two barrier islands in 120 years approaches or exceeds 50% and may be as high as 94%, and given that *C. melodus* is already threatened, this anticipated loss of foraging habitat would place an additional stress on this and other similar species' conservation status.

Keywords: *Charadrius melodus*, foraging habitat, Geographic Information Systems, GIS, Piping Plover, predicted suitable habitat, sea level rise, wetlands

INTRODUCTION

Global climate change is expected to increase the rate of habitat loss for many wildlife species, resulting in the possible extinction and/or extirpation of vulnerable species (Thomas et al. 2004). Mid-Atlantic sea level rise in North America is likely to be at a significantly greater risk than the observed global sea level rise due to localized sinking of the land surface (Cahoon et al. 2006). Global sea level has risen approximately 120 m (394 ft) due to natural processes over the last ~23,000 years. Currently, global sea level rise rate has increased beyond the naturally occurring rate due to climatic changes (Cahoon et al. 2006).

Shorebirds are particularly at risk from sea level rise (Jetz et al. 2007, Convertino et al. 2011). Recent projections of future habitat loss for shoreline-dependent species at coastal sites in the United States range from 20-70% (Galbraith et al. 2002). One shorebird species of interest is the Piping Plover (*Charadrius melodus* Ord), federally listed as threatened in the United States Atlantic Coast (*C. m. melodus*) and Northern Great Plains (*C. m. circumcinctus*), and as endangered in the Great Lakes of the United States and Canada (*C. m. circumcinctus*) in 1986 due to habitat loss from human development (USFWS 2009). Over the past 20 years, conservation management has led to an overall increase of 25% in *C. melodus* populations; however, recovery goals have not been fully met (USFWS 2009).

The Atlantic population of *C. melodus* is uniquely vulnerable to global climate change because of the threat of sea level rise on their coastal habitat used for both breeding (Figure 1) and foraging (Figure 2; Convertino et al. 2011, USGS GAP 2011). Since the Atlantic population breeds only on the coast (Loegering and Fraser 1995) and is at risk from sea level rise, this study focuses on three Mid-Atlantic locations -- Assateague Island National Seashore (Maryland), Chincoteague National Wildlife Refuge (Virginia), and Cape May Point State Park (New Jersey). The barrier islands, which include both Assateague and Chincoteague, have more than 57 km^2 (22 mi^2) of beach, dunes, marsh, and maritime forest, which provide habitat for shorebirds. Because of Cape May's geographical location and orientation between Delaware Bay and the Atlantic Ocean, migratory birds congregate on the Cape May Peninsula (Burger et al. 1997). Records show that *C. melodus* has nested on the three chosen Mid-Atlantic locations (USFWS 2009).

Coastal wetlands habitats are expected to experience acute negative impacts from sea level rise, as compared to all continental coast habitats, because their

Figure 1: Day-old Piping Plover (*Charadrius melodus*) chicks with a hatching egg between them. Assateague Island National Seashore, Maryland, 31 May 2012 (Photographed by PLL).

Figure 2: Adult Piping Plover foraging in wetland area. Cape May Point State Park, New Jersey, 10 May 2013 (Photographed by PLL).

low elevations and process of vertical land building (wetland accretion and subsidence) are not expected to keep pace with future relative sea level rise (Titus 1988, Titus et al. 2009). If sea level rises faster than localized wetland accretion, coastal wetlands will become submerged and disappear.

The Atlantic population of *C. melodus* during breeding season comprises almost half of the United States population (Elliott-Smith et al. 2009). Therefore, it is critical for their population's recovery to study the impacts of sea level rise on *C. melodus* habitat along wetlands on the United States Atlantic coast during breeding season. According to the 2006 Piping Plover census (Elliott-Smith et al. 2009), the United States Atlantic coast population represents approximately 48% of the total *C. melodus* United States population. In 2001, the United States Atlantic coast population of *C. melodus* represented 54% of the United States breeding population. This indicates a six percentage point drop in the United States Atlantic population from 2001 to 2006 (Haig et al. 2005, Elliott-Smith et al. 2009). Although both the United States Atlantic and Great Plains *C. melodus* populations increased from 2001 to 2006, the 15% increase in the Atlantic population was less than the Great Plains 33% increase in population (Haig et al. 2005, Elliott-Smith et al. 2009). Thus, the *C. melodus* populations in the Great Plains are improving faster than their Atlantic counterparts.

Although *C. melodus* nest on bare sand or pebble beaches (Burger 1987), chicks (and adults) take advantage of wetlands habitats, including bay tidal flats, salt and freshwater marshes, and herbaceous wetlands, for foraging. This gives them access to greater food sources than chicks foraging exclusively in ocean beach habitats. This advantage increases the chances of survival in *C. melodus* chicks (Loegering and Fraser 1995). The majority of chick mortality occurs in the first ten days after hatching, starvation being the main cause of death (Loegering and Fraser 1995). Chicks that forage exclusively on ocean beaches weigh less, eat at a lower rate, and have a higher mortality than chicks with access to interior wetlands for foraging (Loegering and Fraser 1995). Chicks with access to interior wetlands habitats have a 38% increased chance of survival in their first 25 days of life, than chicks without access to interior wetlands (Loegering and Fraser 1995). Chicks from 3-20 days old with access to interior wetland habitats choose to forage in those areas over ocean beaches (Loegering and Fraser 1995). Accordingly, this study focused on the foraging habitat of wetlands, since having access to wetlands is advantageous and critical to *C. melodus* and other shorebirds that use these transitional habitats.

OBJECTIVES

The major goal of this analysis was to investigate and predict the effect of sea level rise on the habitat for *C. melodus*; specifically:

1. To organize all Geographic Information Systems (GIS) datasets needed to perform the analysis; and
2. To investigate prospective effects of sea level rise on wetlands within the predicted suitable habitat of *C. melodus* at time intervals of 30, 60, and 120 years using GIS.

METHODS

We started with *C. melodus* predicted suitable habitat data (USGS GAP 2011), which is GIS data showing all potential suitable habitats for the species within an observed range. This includes all habitat types that *C. melodus* have been observed using, whether or not they may be optimal for their survival. Using 30-m (98-ft) land cover data, wetlands habitat (i.e., salt marshes, herbaceous wetlands, and tidal flats) within the predicted suitable habitat (USGS GAP 2011) was separated from other habitat types by cutting and reclassifying layers within GIS (ArcGIS 10x). The effects of sea level rise were then investigated only in wetlands within the predicted suitable habitat at each of the three locations (Figure 3; USGS GAP 2011).

In Figure 3, wetlands within *C. melodus* predicted suitable habitat are shaded dark orange. The light orange shaded areas represent all other habitat types that are not wetlands within the predicted suitable habitat, for example, oceanside beaches. Finally, the entire shaded area, consisting of both the dark and light orange colors, represents the entire predicted suitable habitat for *C. melodus*.

A 30-m (98-ft) North American digital elevation model (DEM) was used to display and analyze the height of the predicted sea level rise on the *C. melodus* suitable habitat. The DEM was cut to only the area of the wetlands within the predicted suitable habitat of *C. melodus* (dark orange shaded areas) generated from Figure 3. Elevational landscapes within *C. melodus* predicted suitable habitat but outside of the wetlands (light orange shaded areas) were considered not necessary for this analysis.

The net loss or gain of wetlands from sea level rise are predicted from the following equation, used to calculate the difference of wetland accretion from sea level rise (Stevenson 1986, Reed 1995, Cahoon 1997).

$$SL - WA = \text{elevation change}$$

SL = Average yearly relative sea level rise (Zervas 2009)
WA = Predicted average yearly wetland accretion (Reed et al. 2008)

The accretion rate is the rate at which wetlands vertically rise in elevation due to coastal geomorphological processes. This upward movement offsets the effect of

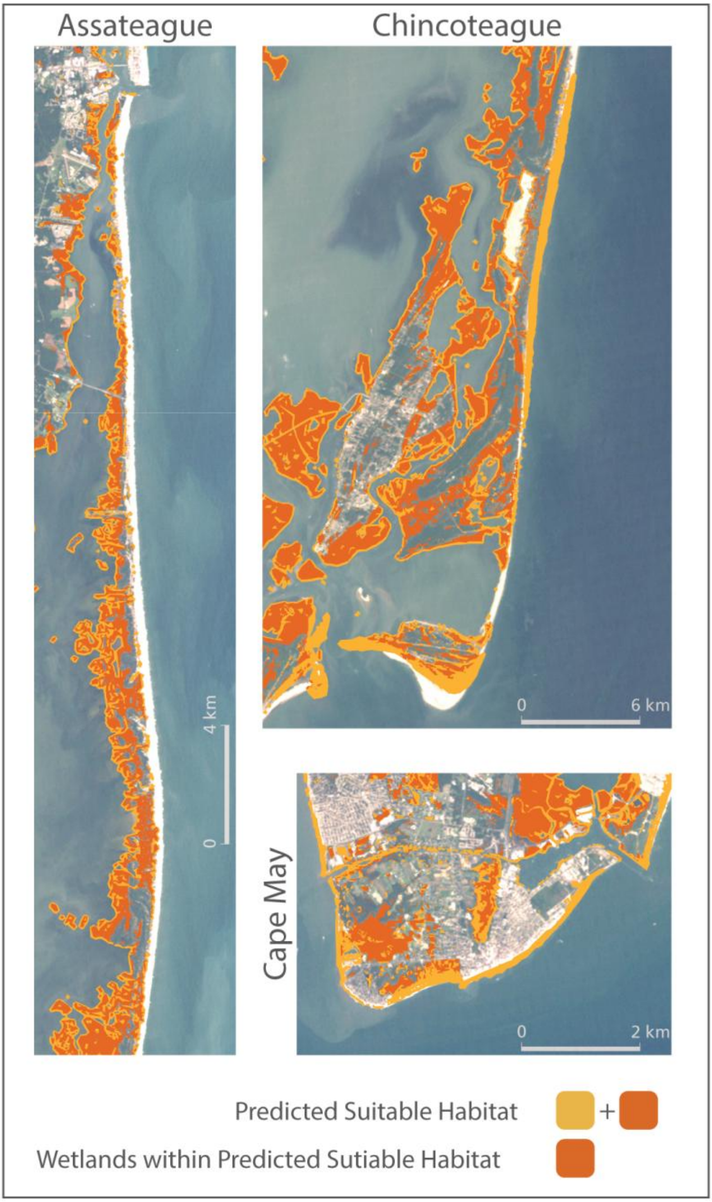

Figure 3. "Predicted potential suitable habitat" and "wetlands within the predicted suitable habitat" for *C. melodus* at Assateague Island National Seashore, Chincoteague National Wildlife Refuge, and Cape May Point State Park.

sea level rise. The equation is applied to three time intervals: 30, 60, and 120 years in the future (2006 baseline), with "SL" equaling the "low", "mean", or "high" yearly rates of sea level rise for each location. Thus, nine scenarios were investigated at each of the three locations.

The height differences, found with the elevation change equation, were then mapped. The results of the equation, for the nine scenarios at each of the three locations, were displayed using the 30-m (98-ft) DEM. All wetlands habitat within the *C. melodus* predicted suitable habitat could show a net loss, gain, or unchanged rate of elevational change.

If sea level rise was greater than the vertical accretion of wetlands, an elevation deficit was present. The wetland habitat within the predicted suitable habitat of *C. melodus* was mapped as submerged if its elevation was less than the elevation deficit. If the difference between the accretion of wetlands and relative sea level was equivalent, the wetland maintained its current state. If relative sea level rise was predicted to be less than the vertical accretion of wetlands, elevation deficit was not present. In this case, additional wetlands may be added to the existing wetland habitat within the predicted suitable habitat of *C. melodus*. If a gain of wetlands was predicted, it was discussed but not mapped. Thus, only negative effects (elevation deficit) to *C. melodus* were mapped.

The coastal wetlands within the predicted suitable habitat that were less than the height of the elevation deficit became isolated from the remaining coastal wetlands elevated higher than the elevation deficit. These were represented as submerged wetlands due to sea level rise and are no longer suitable for *C. melodus*. Maps were generated for three time intervals at each of the three locations. Thus, a total of nine maps were created. A raster calculation was performed for each scenario at each location within the GIS to obtain the exact net loss of wetlands.

The results for the yearly "mean" sea level rise and accretion rates for each location (Table 1) were averaged from data collected from previous years. The yearly "low" and "high" sea level rise rates were estimated by adding or subtracting the 95% confidence interval from the "mean" sea level rise. Subtracting the confidence interval from the "mean" sea level rise represents the range of potential variation in predicting the "low" sea level rise rate; adding the confidence interval to the "mean" sea level rise represents a range of potential variation of the "high" yearly sea level rise rate;. The 95% confidence interval was provided by the National Oceanic and Atmospheric Administration (Zervas 2009). Because both locations share the same barrier island and Chincoteague Bay, the associated rates of sea level rise and accretion for Assateague and Chincoteague were comparable (Zervas 2009). However, the same sea level rise and accretion rates have different impacts on the two locations because the site-specific elevations differ.

Table 1. Average annual sea level rise and accretion rates for each location (Reed et al. 2008, Zervas 2009).

	Sea Level Rise/Year (mm)			
	Low	Mean	High	Accretion/Year (mm)
Assateague Island NS	4	5	7	2
Chincoteague NWR	4	5	7	2
Cape May Point SP	3	4	5	2

The three rates of sea level rise ("low," "mean," and "high") and accretion were multiplied by the three time intervals (30, 60, and 120 years from 2006) for each location (Table 2).

The elevation change equation was applied to the site-specific data (Table 3). A negative elevation change is one that is submerged due to sea level rise, and a positive elevation change is one that gained due to sea level rise.

The predicted net loss of area (Table 4) was derived from the raster calculation equation for each scenario from Figures 4, 5, and 6. To obtain percentages, the total count of pixels from each of the net loss scenarios was multiplied by 30^2 (each pixel is 30 m^2 [323 ft^2]) and divided by the total area of wetlands within *C. melodus* predicted suitable habitat. The higher the percentage, the more submerged the wetlands for *C. melodus* became. The scenarios shown as 0% represent either a net gain or balanced result, since this effort focused on the loss of wetlands habitat for *C. melodus*.

RESULTS

The three rates of sea level rise ("low", "mean", "high") and accretion were multiplied by the three time intervals (30, 60, and 120 years from 2006) for each location (Table 2). The further into the future, the greater is the sea level rise and the greater is the accretion.

<u>Assateague Island National Seashore</u>
The model predicts a sufficient net loss of wetlands habitat for *C. melodus* at Assateague after the first 30 years, even with the "low" rate of sea level rise (Figure 4). At Assateague, there is a predicted net loss of wetlands habitat for *C. melodus* of 26-44% in 30 years, 37-84% in 60 years, and 73-94% in 120 years (Table 4, Figure 7). A large portion of wetlands will be lost from the least

possible negative scenario, 30 years with the "low" sea level rise rate. However, Assateague loses most of its wetlands habitat within the predicted suitable habitat of *C. melodus* in 120 years even at the lowest projected sea level rise estimates. If any of the sea level rise rates are realized, even at the lowest, Assateague will lose the greatest wetlands habitat for *C. melodus* of the three locations in 120 years (Figures 4 and 7).

Table 2. Predicted future sea level rise and accretion for 30, 60, and 120 years at each location.

	Sea Level Rise (mm)			
Time Interval	**Low**	**Mean**	**High**	**Accretion (mm)**
30 years				
Assateague Island NS	114	164	215	45
Chincoteague NWR	114	164	215	45
Cape May Point SP	100	122	144	120
60 years				
Assateague Island NS	229	329	429	90
Chincoteague NWR	229	329	429	90
Cape May Point SP	199	244	288	240
120 years				
Assateague Island NS	457	658	858	180
Chincoteague NWR	457	658	858	180
Cape May Point SP	398	487	576	480

<u>Chincoteague National Wildlife Refuge</u>

The "low" and "mean" net losses of wetlands habitat are negligible at Chincoteague in 30 years, but accelerate to a large net loss (29%) under a "high" rate of sea level rise in 30 years (Table 4). A large portion of the wetlands habitat of *C. melodus* at Chincoteague will be submerged between 119 and 170 mm (4.7 and 6.7 in) in the 30-year "mean" and "high" scenarios respectively (Table 3); therefore, the predicted net loss of wetlands habitat for *C. melodus* is small for 30 years and then drastically increases in 60 years (Table 4, Figure 5). At Chincoteague there is a predicted net loss of wetlands habitat for *C. melodus* of 4-29% in 30 years, 26-61% in 60 years, and 48-90% in 120 years (Table 4, Figure 7). Chincoteague experiences the majority of wetlands habitat loss for *C. melodus* at 60 and 120 years into the future. If the "mean" or "high" rate of sea level rise occurs, Chincoteague will lose the majority of its wetlands habitat for *C. melodus* in 120 years (Figures 5 and 7).

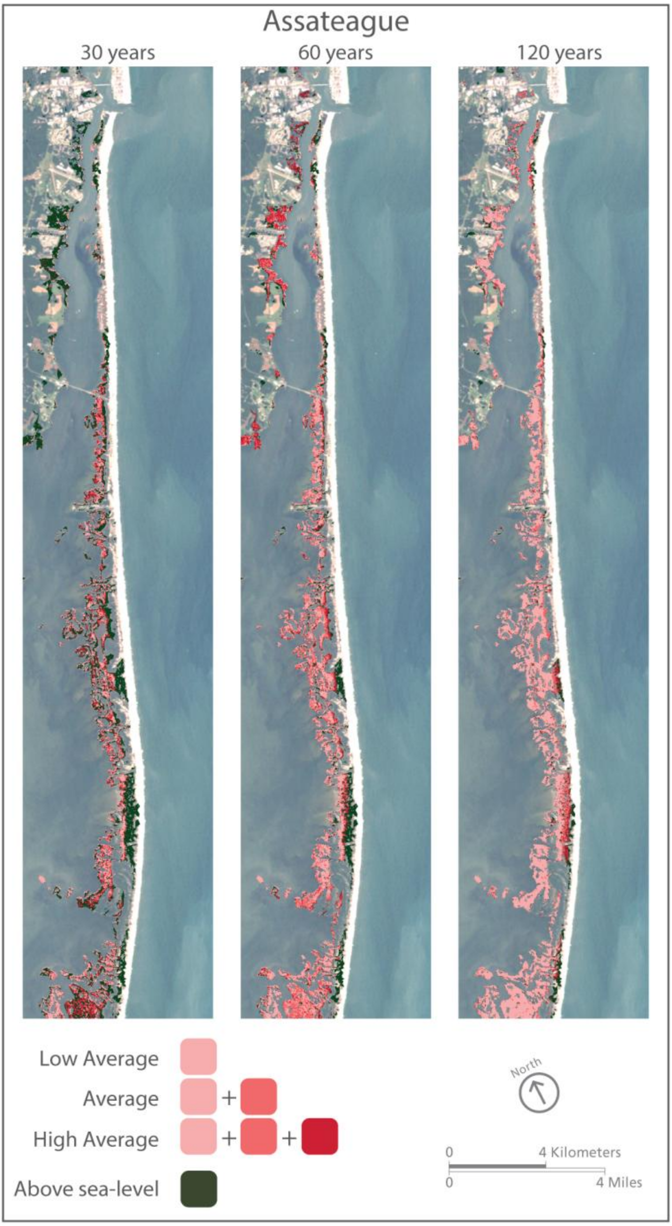

Figure 4. Predicted net loss of wetlands within *C. melodus* predicted suitable habitat due to sea level rise for Assateague Island National Seashore.

Table 3. Predicted elevation change for 30, 60, and 120 years at each location after applying the elevation change equation.

	Predicted Elevation Change (mm)		
Time Interval	**Low**	**Mean**	**High**
30 years			
Assateague Island NS	-69	-119	-170
Chincoteague NWR	-69	-119	-170
Cape May Point SP	20	-2	-24
60 years			
Assateague Island NS	-139	-239	-339
Chincoteague NWR	-139	-239	-339
Cape May Point SP	41	-4	-48
120 years			
Assateague Island NS	-277	-478	-678
Chincoteague NWR	-277	-478	-678
Cape May Point SP	82	-7	-96

Table 4. Predicted net loss of wetlands within *C. melodus* predicted suitable habitat due to submergence for 30, 60, and 120 years at each location. Percentages created after applying data from Table 3 to a digital elevation model in the Geographic Information Systems.

	Predicted Net Loss of Wetlands (%)		
Time Interval	**Low**	**Mean**	**High**
30 years			
Assateague Island NS	26	33	44
Chincoteague NWR	4	7	29
Cape May Point SP	0	4	5
60 years			
Assateague Island NS	37	63	84
Chincoteague NWR	26	40	61
Cape May Point SP	0	4	5
120 years			
Assateague Island NS	73	90	94
Chincoteague NWR	48	83	90
Cape May Point SP	0	4	5

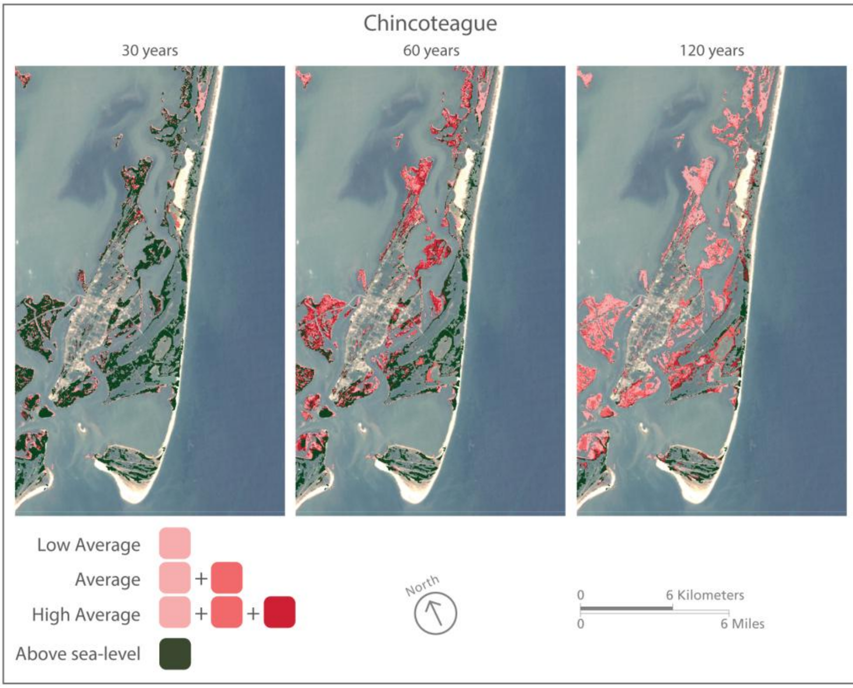

Figure 5. Predicted net loss of wetlands within *C. melodus* predicted suitable habitat due to sea level rise for Chincoteague National Wildlife Refuge.

Cape May Point State Park

With the "low" sea level rise rate, there is no predicted net loss at Cape May for all time intervals (Figures 6 and 7, Tables 3 and 4). In actual fact, Cape May gains wetlands habitat for *C. melodus* with the predicted "low" rate of sea level rise (Table 3); since this analysis focused exclusively on the negative impact of sea level rise on *C. melodus*, the wetlands habitat gained is not calculated. Under the most negative possible scenario, in 120 years and with the highest sea level rise rate, Cape May is predicted to experience a 5% net loss of wetlands habitat within the predicted suitable habitat of *C. melodus* (Table 4, Figure 7).

The predicted net loss of wetlands habitat due to sea level rise at both Assateague and Chincoteague will be at least twice the predicted net loss at Cape May for almost all sea level rise scenarios at each time interval, the exception being the 30-year "mean" compared to Chincoteague. Assateague and Chincoteague are at the greatest risk, Assateague being most at risk, while

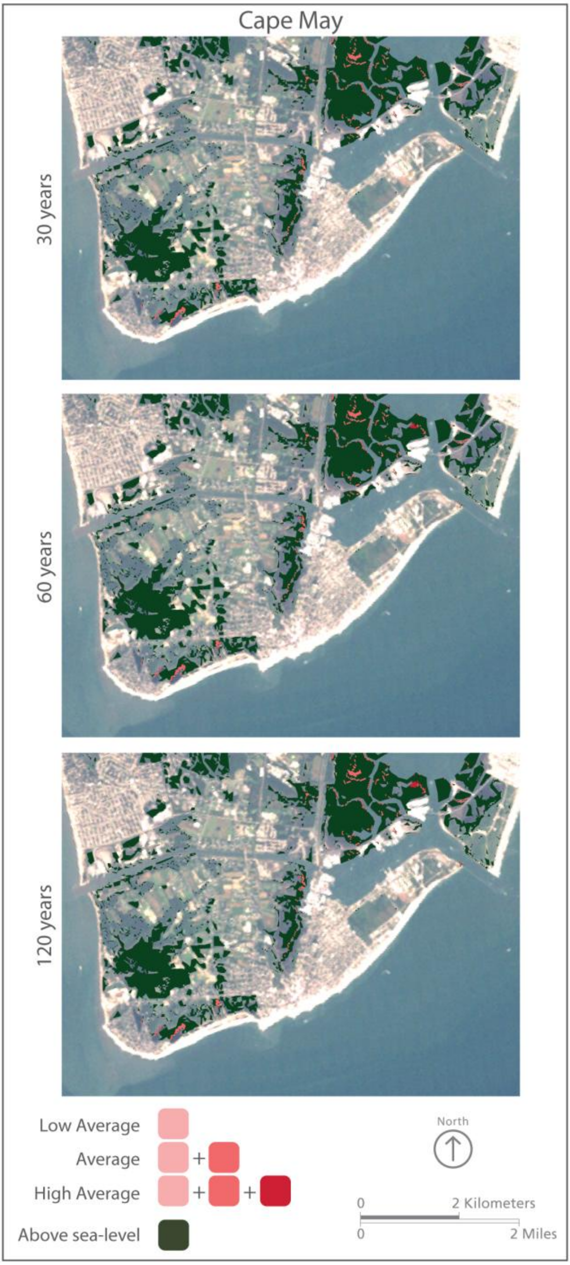

Figure 6. Predicted net loss of wetlands within *C. melodus* predicted suitable habitat due to sea level rise for Cape May Point State Park.

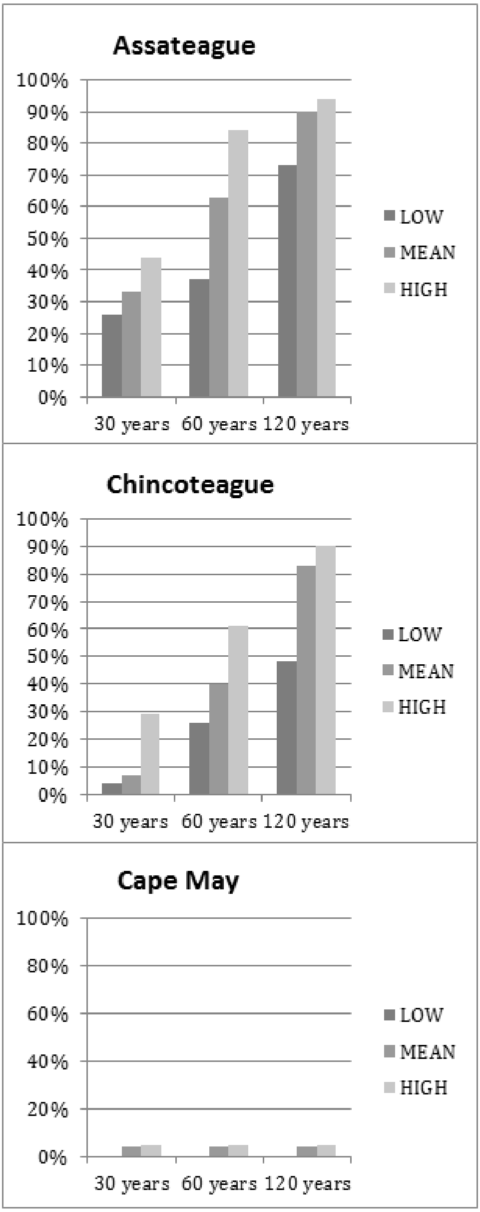

Figure 7. The predicted net loss of wetlands (%) within *C. melodus* predicted suitable habitat submerged at Assateague Island National Seashore, Chincoteague National Wildlife Refuge, and Cape May Point State Park for every time interval and with all sea level rise rates.

predictions for Cape May are the least. For Cape May, the yearly accretion rates generally keep pace with the yearly sea level rise.

DISCUSSION

It is no coincidence that Assateague and Chincoteague have a higher yearly sea level rise and lower yearly accretion than Cape May (Table 2). Assateague and Chincoteague are part of the same barrier island and, as their wetlands face the Chincoteague Bay, their wetlands interiors are directly connected to the ocean. Cape May is not a barrier island and, therefore, its interior wetlands are not as directly affected by sea level rise as are the bayside wetlands of barrier islands. Cape May's accretion rates are projected to keep pace with the sea level rise rate. With the "low" rate of sea level rise, the accretion rate is higher than the sea level rise rate at Cape May. Thus, there will be more sediment vertically accreted by the wetlands than the sea level rise, resulting in a gain of wetlands in this scenario (Table 3).

The net loss at Assateague and Chincoteague is greater than the net loss at Cape May by at least a factor of two for each of the 60 and 120 year sea level rise scenarios. Assateague and Chincoteague are at the greatest risk, with Assateague being the most at risk, while Cape May has no risk of wetlands habitat loss for *C. melodus* from sea level rise, since Cape May's yearly accretion rates keep pace with yearly sea level rise rates.

Although serious negative impacts to wetlands habitat for *C. melodus* are predicted at both Assateague and Chincoteague, it is uncertain how *C. melodus* will respond. However, it is clear that the loss of dependable foraging habitat for chicks will not have a positive effect on *C. melodus*. Left unresolved is the uncertainty whether the species will be able to survive the predicted environmental changes that will reduce their foraging habitat. Assateague and Chincoteague will need the most conservation management to help preserve its wetlands. Cape May, on the other hand, should be encouraged to continue its wetlands conservation efforts, as *C. melodus* may need to use Cape May as a future stronghold since the species' breeding habitat is less at risk.

This sea level rise research illustrates the importance of site-specific management to help conserve habitat and survivorship for *C. melodus*. Site-specific risk identifiers need to be conducted with all possible threat factors for *C. melodus*. Conservation efforts should not be directly based on the linear data calculated showing the predicted loss of wetlands habitat with the predicted suitable habitat of *C. melodus*. Conversely, the purpose of this study is to prompt an increase in research, as the data reveals additional risk within its distribution. It is also important to point out that other shorebird species that have overlapping breeding ranges with *C. melodus* may not be as severely affected from sea level rise, because many of these species do not have as specific nesting and foraging habitat restrictions as do *C. melodus*, as well as its overall very narrow total breeding range.

By concentrating the research on coastal wetlands foraging habitat, rather than the oceanside ones of *C. melodus*, this study exposes a lapse in current research and conservation efforts. Research shows that when *C. melodus* have access to foraging in wetlands habitat, adults and especially chicks choose to forage in those habitats over oceanside habitats (Patterson et al. 1991, Loegering and Fraser 1995, Elias et al. 2000). The majority of conservation efforts are still being focused on *C. melodus* nesting locations and not the availability of foraging habitats within their distribution. The study emphasizes the future effects of climate change on this vital foraging habitat of *C. melodus*. Current conservation efforts for *C. melodus* include the following: identification of nesting sites; public education; prevention of pedestrians, free-ranging pets, and off-road vehicles near nesting sites; and removal of foxes, raccoons, skunks, and other predators which live near the nesting locations (USFWS 2009). With these conservation enforcements, there has been an increase in populations of *C. melodus*. While these conservation strategies are important for the species recovery, there are few conservation efforts focusing on the foraging habitat of *C. melodus*. Furthermore, the state of *C. melodus* recovery is still fragile, as progress toward recovery could become slowed, halted, or reversed by even small decreases in survivability (USFWS 2009). This study examines how future changes from sea level rise will affect the wetlands foraging habitat of *C. melodus* and, therefore, the species' survivability. In order to establish conservation efforts for the wetlands foraging habitat of *C. melodus*, it is important to first implement site-specific studies on the effects of sea level rise, as different locations will have different risk factors.

CONCLUSION

The goal of this analysis was to quantify potential effects of sea level rise on the foraging habitat of *C. melodus* along coastal wetlands. The habitat suitability model for *C. melodus* was used to assess the vulnerability of coastal areas to sea level rise predictions. The in situ validation of the model's observation of the foraging behavior of *C. melodus* confirmed that adult and chicks preferentially utilize the bayside wetlands habitats. Using GIS, Assateague Island National Seashore, Maryland, experienced the highest net loss of wetland habitat for every scenario within *C. melodus* predicted suitable habitat; Chincoteague National Wildlife Refuge, Virginia, experienced the second highest net loss (though a similar risk factor to Assateague); and Cape May Point State Park, New Jersey, experienced the lowest net loss. The loss of foraging wetlands at Assateague and Chincoteague approaches 50% for many of the scenarios and may be as high as 94%. An important outcome of this study is that different locations within *C. melodus* predicted suitable habitat respond differently to the threat of sea level rise. Many areas within the predicted suitable habitat of *C. melodus* (e.g., barrier islands) are at greater risk than other locations based on their geomorphology and localized subsidence. It is important to recognize site-specific landscape features for any further implications regarding climatic impacts, including changes in weather patterns, food abundance, changes in community structure, and other indirect effects of climate change on *C. melodus* and perhaps other coastal species.

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