Overlap between Sea Level Rise Projections and Whooping Crane Habitat

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ABSTRACT

Sea level rise disproportionately impacts coastal habitats, which threatens the conservation of endangered coastal wildlife. The Whooping Crane (*Grus americana*) is an endangered avian species that inhabits the coastal wetlands of Aransas National Wildlife Refuge (ANWR), Texas. Currently, there is limited research on the potential effects of sea level rise on the Whooping Crane population in ANWR. I assessed the relationship between sea level rise projections and Whooping Crane occurrence sightings. In order to assess impacts of sea level rise, I determined the overlap between Whooping Crane occurrence sightings and both inundation and coastal erosion projections. Sea level rise projections and Whooping Crane occurrence sightings exhibited a statistically significant relationship with overall p values < 0.05, except at 6 ft in which $p < 0.1$. This suggests a potential effect of sea level rise on Whooping Crane species abundance that should be further investigated. Whooping Crane occurrence sightings overlapped with each projected level of inundation, ranging from 12.85% to 59.64%. Additionally, 96.4% of occurrences were most vulnerable to moderate coastal erosion, but other coastal erosion projections also had overlapping occurrences to a smaller degree. My results indicate that both inundation and coastal erosion will likely affect habitat availability and composition for the Whooping Crane. As a coastal wetland bird, the Whooping Crane is highly susceptible to sea level rise and its associated threats. In order to preserve the future of the Whooping Crane, it is crucial to implement conservation strategies through intensive research and management efforts.

KEYWORDS

inundation, coastal erosion, *Grus americana*, endangered species conservation, coastal wetlands

INTRODUCTION

Climate change is a global phenomenon that carries grave consequences, especially for ecosystems that depend on certain climatic conditions (Schofield 2011) (IPCC 2021). A particularly concerning effect of climate change is sea level rise. Global sea level rise occurs due to thermal expansion of seawater and the melting of glaciers and ice sheets (Nicholls and Cazenave 2010). Current IPCC projections predict that the average global sea level will rise by 0.59 to 1.93 feet by 2099 (Montagna et al. 2007). However, regional sea level rise varies due to local subsidence effects (March and Smith 2012), creating a disparity between the vulnerability of coastal ecosystems in different areas. Sea level rise poses one of the greatest risks to coastal ecosystems, but its potential impact on coastal species is still not fully understood.

Coastal ecosystems are diverse habitats that maintain a delicate balance between aquatic and terrestrial life. Low-lying coastal ecosystems are particularly vulnerable to sea level rise due to their elevation and dependence on inundation and salinity regimes (Morris et al. 2002). Threats associated with sea level rise include coastal erosion and inundation (Garner et al. 2015) which can impact biotic functions and underlying processes, such as nutrient cycling, of coastal ecosystems (Michener et al. 1997). Sea level rise will also likely affect habitat distribution and storm and drought frequency (Montagna et al. 2007). Consequently, sea level rise may endanger vulnerable coastal species through the alteration of their coastal wetland habitats.

One of the most charismatic and imperiled coastal species in the United States is the Whooping Crane (*Grus americana*). The Whooping Crane is a wading bird that is currently listed as endangered by the IUCN and inhabits coastal wetland regions with shallow water. The only current self-sustaining wild population of the Whooping Crane migrates between Aransas National Wildlife Refuge in Texas, USA and the Wood Buffalo National Park in Canada (Chavez-Ramirez et al. 2012). The Whooping Cranes' wintering grounds are located in the Gulf Coast of Texas (Wright et al. 2014), and these coastal ecosystems are at higher risk of negative impacts of climate change and sea level rise (Thorne et al. 2012). Aransas National Wildlife Refuge, the primary wintering grounds of the Whooping Crane, is especially vulnerable to sea level rise due to land subsidence (Stehn 2011). Thus, it is critical to assess how sea level rise will influence coastal ecosystems that act as critical overwintering grounds for the Whooping Cranes.

My central research question is how sea level rise affects the wild Whooping Crane population in Texas. In order to answer this question, I assessed the following: (I) relationship between sea level rise and species occurrence sightings; (II) percentage overlap of occurrence sightings with inundation projections; (III) and percentage overlap of occurrence sightings with coastal erosion projections. The Whooping Crane largely inhabits marine coastal and supratidal habitats, so sea level rise will likely affect their ecosystem and food sources. The birds' locale may contribute to a high percentage overlap with occurrence sightings and current SLR threat projections. If the percentage overlap is considerably high, this will be a cause of concern for their status as a species.

METHODS

Study site

My study site is the Aransas National Wildlife Refuge (ANWR) located near Austwell, Texas, USA (Figure 1). The refuge is the primary wintering grounds site for the Whooping Crane, covering a total area of 115,324 acres (466.70 km^2). ANWR is situated along San Antonio Bay and the Gulf Coast of Texas, and includes Matagorda Island. The Gulf Coast of Texas consists of barrier islands, bays, bayous, and estuaries that contribute to a general brackish habitat (Bernacchi et al. 2015). Whooping Cranes are a wetland dependent species who inhabit coastal brackish wetlands (Chavez-Ramirez et al. 2012). However, Whooping Cranes move upland or toward bays to forage as well (Stehn 2011).

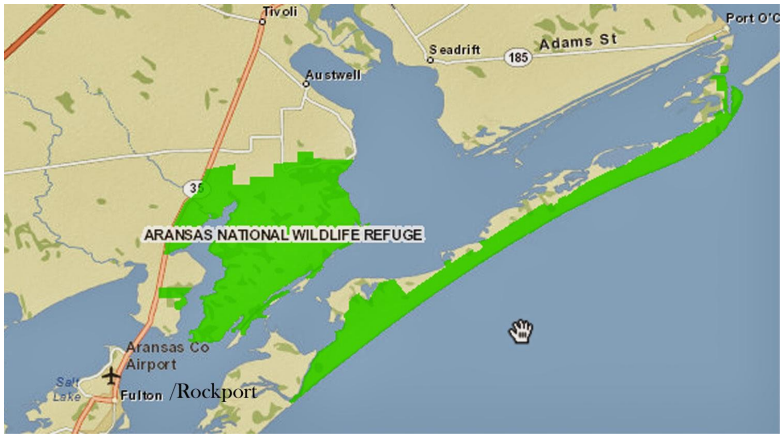

Figure 1. Aransas National Wildlife Refuge (ANWR). Study site depicted in green. (Cummings 2014)

Whooping Crane ecology

The Whooping Crane migrates twice a year during the winter and spring (Chavez-Ramirez et al. 2012). Whooping Cranes breed in the springtime with their primary nesting grounds in Wood Buffalo National Park in Canada (Chavez-Ramirez et al. 2012). They migrate from their breeding grounds near Canada, beginning in early September to early October (Chavez-Ramirez et al. 2012). Whooping Cranes spend 6-7 months in Aransas National Wildlife Refuge from October to April (Chavez-Ramirez et al. 2012). They migrate from their wintering grounds in Aransas National Wildlife Refuge, beginning in late March to early May (Chavez-Ramirez et al. 2012).

Data collection

Sea level rise and occurrence sightings

To assess the impact of SLR on the Whooping Crane, I extracted Whooping Crane occurrence data from eBird, a publicly available dataset in which users record bird sightings (eBird). I established the time frame for species occurrence sightings from 2010 to 2020, between October to April in each year when the Whooping Cranes reside in ANWR

(Chavez-Ramirez et al. 2012). Additionally, I used NOAA sea level rise projections that depict potential inundation of the refuge (NOAA).

Occurrences vs. SLR threats

I assessed both inundation and coastal erosion, which are threats associated with sea level rise, and their impact on the Whooping Crane. I used NOAA data for coastal inundation projections, which visualizes potential inundation in feet based on current Mean Higher High Water (MHHW) conditions (NOAA). I used USGS data for coastal erosion projections, which includes short-term and long-term shoreline change rates in m/yr along ANWR (USGS).

Data analysis

Sea level rise and occurrence sightings

To evaluate the relationship between sea level rise and the number of Whooping Crane occurrence sightings, I used logistic regression. The use of logistic regression revealed if there is a statistically significant relationship between sea level rise and occurrence sightings. I treated the occurrence data as presence-absence data. I established the time frame for the logistic regression model from 2010 to 2020.

Occurrences vs. SLR threats

In order to evaluate the impact of SLR threats on the Whooping Crane population, I determined the area of overlap between both inundation and coastal erosion projections and Whooping Crane occurrence sightings.

I identified all the areas where Whooping Cranes have been observed and treated these areas as their designated habitat. Next, I combined the two threatened zones, provided by inundation and coastal erosion projections, with the total geographic area of occupancy of the Whooping Crane.

To determine the area of overlap, I visually compared the geographic area of the two threatened zones and the occupied regions of the Whooping Crane through spatial data-plotting. I utilized this overlapping area to find the percentage of each occurrence within a certain threat projection (Garner et al. 2015). In doing so, I predicted the level at which Whooping Cranes are vulnerable to inundation and coastal erosion. I conducted all statistical analyses in R (R 2014).

RESULTS

Data collection

While the Whooping Cranes were found throughout Aransas, they exhibited a clumped distribution near coastal wetlands compared to other areas (Figure 2). Coastal areas were at higher risk compared to inland areas of the refuge, and were more likely to experience higher inundation levels. However, there were inland areas that may experience up to 2 ft of inundation (Figure 3a). Depending on the severity, coastal erosion may result in shoreline recession and impact the availability of wetland habitat for the Whooping Crane (Figure 3b).

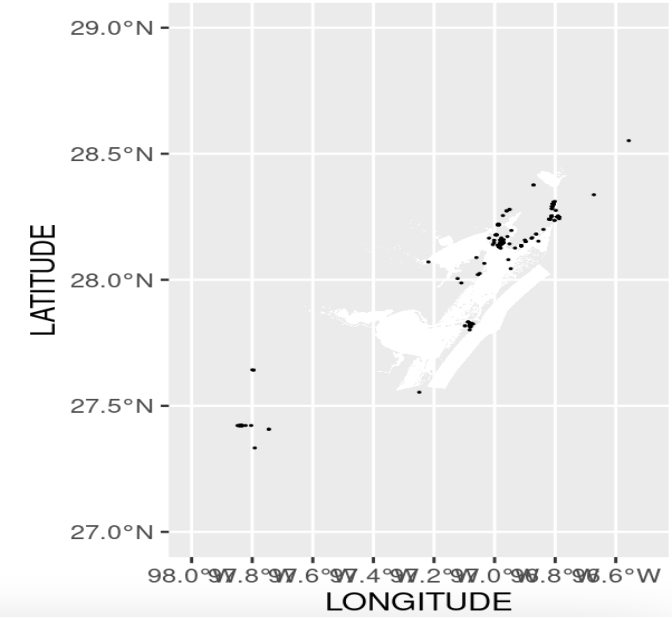

Figure 2. Spatial visualization of occurrence data. The black points represent Whooping Crane occurrences within Aransas National Wildlife Refuge (ANWR).

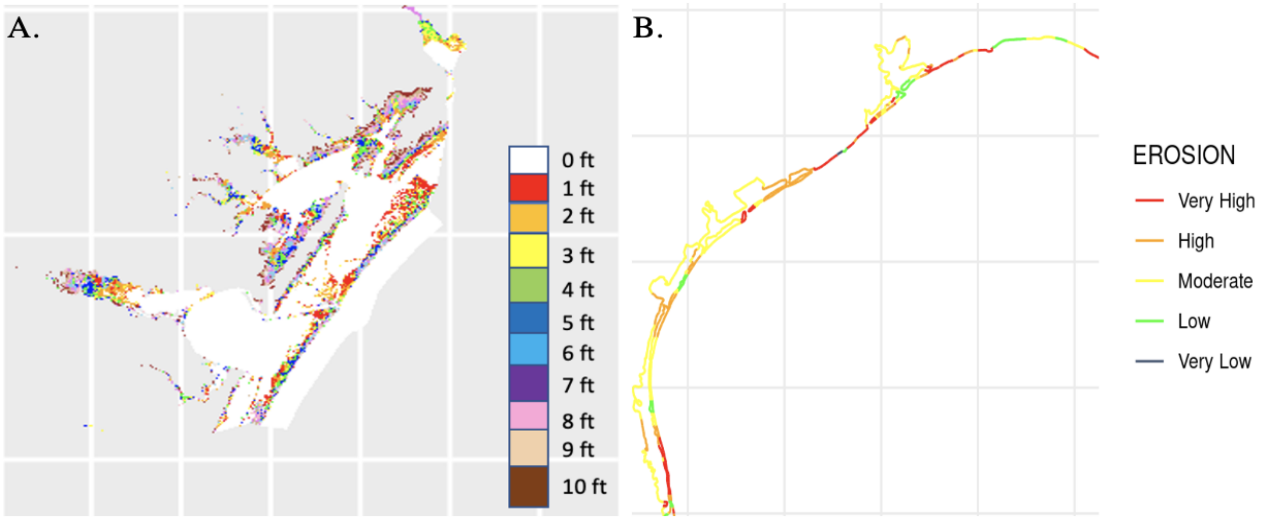

Figure 3. Spatial visualization of climate change projections. (a) The colored regions correspond to different projected levels of inundation in Aransas National Wildlife Refuge, ranging from 0 to 10 ft. (b) The colored line represents different coastal erosion projections along the Gulf Coast, ranging in severity.

Data analysis results

Relationship between sea level rise and occurrences

I found evidence to reject the null hypothesis that the presence of Whooping Cranes in Aransas National Wildlife Refuge is unaffected by inundation level with significance values of $p < 0.05$ (Table 1). However, one exception is at 6 ft, in which $p < 0.1$.

Table 1. Logistic regression of relationship between inundation level and Whooping Crane presence in occurrence sightings. The estimate reveals the effect of inundation level on the likelihood of Whooping Crane occurrence. At all levels except 6 ft ($p < 0.1$), the results are statistically significant with $p < 0.05$.

Inundation Level	Estimate	Standard Error	P Value
Intercept	-4.9547	0.1292	<2e-16
0 ft	2.3920	0.2840	<2e-16
1 ft	-0.8049	0.3626	0.026434
2 ft	-1.1602	0.2512	3.86e-06
3 ft	-4.3636	0.5518	2.61e-15

4 ft	0.4174	0.1168	0.000354
5 ft	2.2394	0.2109	< 2e-16
6 ft	0.3293	0.1780	0.064313
7 ft	-1.6106	0.1391	< 2e-16
8 ft	-0.7442	0.2127	0.000466
9 ft	1.6265	0.1993	3.38e-16
10 ft	2.5926	0.2466	< 2e-16

Occurrences vs. inundation

I found that Whooping Crane occurrence sightings overlapped with each projected level of inundation (Figure 4). With each subsequent increase by foot for inundation projections, the percentage of overlapping occurrences gradually increased (Table 2). Exceptions include 3 ft and 10 ft, which had the same percentage of overlapping occurrences as the levels below (2 ft and 9 ft respectively).

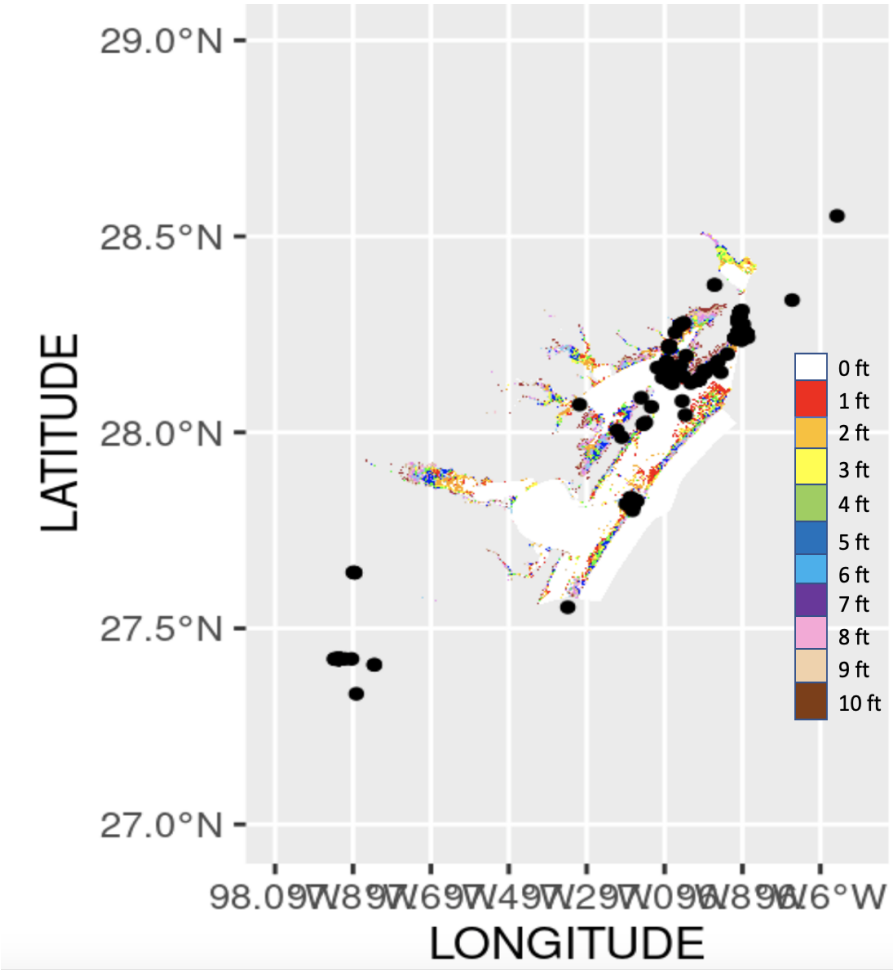

Figure 4. Occurrence sightings vs. inundation projections. The black points represent occurrences while the area on the map is denoted by color, depending on the projected inundation level.

Table 2. Overlap between inundation projections vs. occurrence sightings. Inundation levels range from 0 to 10 ft with corresponding % of overlapping occurrences.

Inundation (ft)	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Overlapping Occurrences (%)	12.85	13.68	14.85	14.85	38.97	55.8	56.32	56.59	56.73	59.64	59.64

Occurrences vs. coastal erosion

Whooping Crane occurrence sightings were mainly aggregated near coastal shorelines subject to moderate erosion (Figure 5). While there were occurrences overlapping or neighboring each category of coastal erosion, almost all (96.4%) were most vulnerable to moderate coastal erosion in their current habitat (Table 3).

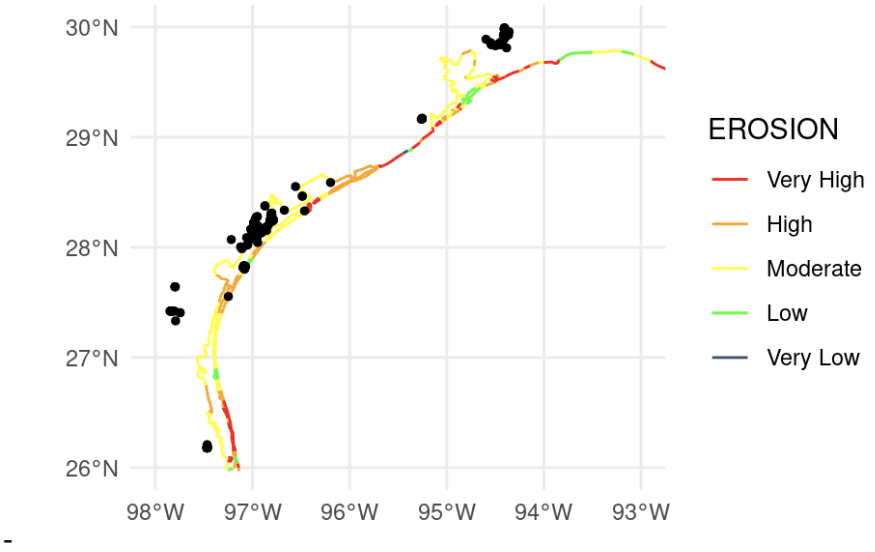

Figure 5. Occurrences vs. coastal erosion projections. The black points represent Whooping Crane occurrences while the different colors signify the severity of coastal erosion along the Gulf Coast.

Table 3. Overlap between coastal erosion projections and % occurrence sightings. The table shows a range of coastal erosion levels with corresponding percentage of overlapping and/or closest occurrence sightings.

Coastal Erosion	Low	Moderate	High	Very High
Occurrences	3.11%	96.4%	0.28%	0.21%

DISCUSSION

Sea level rise presents an alarming concern for the conservation of the endangered Whooping Crane population (Chavez-Ramirez et al. 2012). While it is generally understood that coastal species like the Whooping Crane are vulnerable to sea level rise, there is limited research on the potential effects of sea level rise on the Whooping Crane population in ANWR. My

results revealed a statistically significant relationship between sea level rise and Whooping Crane occurrences, which suggests that sea level rise will impact the current Whooping Crane population. Furthermore, Whooping Crane occurrences overlapped with each inundation projection with 12.85% to 59.64% of occurrences affected. Whooping Crane occurrences overlapped with each coastal erosion projection, but 96.4% coincided with areas impacted by moderate erosion. Therefore, a majority of the Whooping Crane population in ANWR is susceptible to the effects of sea level rise.

Relationship between sea level rise and Whooping Crane occurrence sightings

Sea level rise projections and Whooping Crane occurrence sightings exhibited a statistically significant relationship. In alignment with my hypothesis, my results prompt further investigation into the impacts of sea level rise on the Whooping Crane population. The Whooping Crane largely inhabits marine coastal and supratidal habitats, so sea level rise may affect their ecosystem and food sources. Other studies have shown similar findings in which sea level rise may lead to severe losses of coastal wetlands (Hoozemans et al., 1993; Bijlsma et al., 1996). Additionally, previous studies have found that the coastal wetlands along the Gulf Coast of Texas are especially vulnerable to sea level rise (Nicholls et al. 1999, Chavez-Ramirez et al. 2012). These findings suggest that sea level rise will impact both Whooping Crane habitat and population abundance. However, another possibility is that confounding variables create a false correlation between sea level rise and Whooping Crane occurrences, suggesting that further study may be warranted. Ultimately, the connection between sea level rise and Whooping Crane occurrences presents a potential concern to the endangered Whooping Crane species.

Occurrences vs. inundation projections

Whooping Crane occurrences overlapped with every inundation projection, ranging from 12.85% at 0 feet and 59.64% at 9 and 10 feet. My findings support my hypothesis that inundation will most likely affect future habitat availability and composition in ANWR. Current Whooping Crane habitats may become inundated, resulting in the need for the population to migrate to less impacted areas. This will affect the overall habitat composition of the Whooping Crane in

ANWR, which is supported by other studies on the effects of sea level rise on coastal marsh habitats (Clough et al. 2010, Torio et al. 2015, Nicholls et al. 1999). However, other studies have found that sea level rise may expand the habitat availability of salt marshes to the benefit of coastal avian species like the Whooping Crane (Geselbracht et al. 2011). Because the composition of each coastal marsh habitat is highly variable, it is difficult to predict whether or not sea level rise will act to the benefit or detriment of wetland dependent species. In addition to inundation, sea level rise poses another alarming threat that may impact the Whooping Crane habitat in ANWR.

Occurrences vs. coastal erosion projections

As I hypothesized, my study found that 96.4% of Whooping Crane occurrences overlapped with the moderate coastal erosion projection, though there were a few occurrences within every other projection level. Because the Whooping Cranes inhabit the Gulf Coast of Texas, coastal erosion will likely impact their coastal wetland habitat. This may affect the habitat distribution and availability for the Whooping Crane by permanently altering their shallow water environment (Montagna et al. 2007, Cui et al. 2015). However, a previous study found that Galveston Bay, close to ANWR, will not be affected by shoreline changes from coastal erosion due to preexisting manmade structures (Leatherman 1984). Whooping Cranes tend to move upland or toward bays to forage when there are less resources available in the refuge (Stehn 2011). Galveston Bay is within close proximity to the refuge, which may offer protection from the negative impacts of coastal erosion. While the Whooping Crane's response to coastal erosion is undetermined, their coastal wetland habitat is at high risk. Thus, the Whooping Crane population in ANWR may be highly vulnerable to both inundation and coastal erosion given current projections.

Based on my findings, sea level rise will likely have an adverse effect on the habitat available to the Whooping Crane, which is supported by other researchers in this field (Chavez-Ramirez et al. 2012, Montagna et al. 2007, Smith et al. 2014, Nicholls et al. 1999). With habitat changes inevitable under sea level rise, it is difficult to predict the future of the Whooping Crane conservation status. Inundation will likely alter the Whooping Crane's coastal wetland habitat and the availability of their food sources (Chavez-Ramirez et al. 2012). ANWR has a low

elevation, making the refuge more vulnerable to land subsidence and coastal erosion (Montagna et al. 2007). My research corroborates the Whooping Cranes' highly vulnerable status under current sea level rise projections, emphasizing the urgent need to take countermeasures and ensure their conservation.

Limitations

While my findings emphasize the need to implement conservation efforts for the ANWR Whooping Crane population against sea level rise, there are limitations with the datas and methods I used. I treated occurrence data as presence-absence data in my analysis. However, citizen science databases are not fully accurate because any member of the public can contribute data. Observational data contains bias due to the data source, location, and time of observation (Boakes et al. 2010). There is also bias based on conservation status. Although threatened species are often less detectable and occupy a smaller geographic area, they comprise a large proportion of citizen science databases (Boakes et al. 2010). This shows a discrepancy in the occurrence data since their species abundance should be lower compared to non-threatened species. Another significant limitation is that my study design was not properly controlled. I did not take confounding variables into account when studying the correlation between sea level rise and Whooping Crane occurrences. Despite these limitations, my findings suggest further research to better understand the impacts of sea level rise on the Whooping Crane population.

Future directions

My results indicate new pathways of research in order to elucidate the relationship between sea level rise and the Whooping Crane population. Because sea level rise will likely impact their coastal wetland habitat, the Whooping Cranes will likely migrate to new habitats less affected by sea level rise. Monitoring their fluctuating spatial distribution under sea level rise is crucial in order to ensure successful conservation of the Whooping Crane. Other areas of research include studying the Whooping Crane population in Canada during their breeding season to further understand the wild Whooping Crane population overall. Other threats associated with sea level rise besides inundation and coastal erosion may be analyzed in order to

ascertain which threats pose the greatest risk to the Whooping Crane and correspondingly receive more attention and funding. Another important area of research that needs further investigation is the effect of sea level rise on Whooping Crane habitat composition and availability of food sources. Furthermore, direct monitoring of the Whooping Crane population could provide vital information on their response to sea level rise and improve current conservation efforts.

Broader implications

As a coastal wetland bird, the Whooping Crane is highly susceptible to sea level rise and its associated threats. Sea level rise will likely decrease the habitat range of the Whooping Crane, emphasizing the need for policymakers to take countermeasures. There is a pressing need to better understand the relationship between sea level rise and the Whooping Crane population because of their endangered status. Direct monitoring of the Whooping Crane population in ANWR is critical in order to better understand the impacts of sea level rise on their conservation status. The Texas government should allocate more funding to mitigate inundation and coastal erosion in order to ensure the future of the Whooping Crane. There are methods to extend and protect wetland areas through construction and manage sedimentation (Cui et al. 2015). Given current technological and scientific advances, the Whooping Crane population can be conserved in the midst of climate change with dedicated research and management efforts. While the effects of sea level rise will likely impact the Whooping Crane population, there is still time to mitigate the detrimental impacts of sea level rise and ensure the conservation of the species.

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