

WINTERING WHOOPING CRANE BEHAVIOR AND HABITAT QUALITY AT THE
ARANSAS NATIONAL WILDLIFE REFUGE ON THE TEXAS GULF COAST

A Thesis

Presented to

The Faculty of the Department of Biological Sciences

Sam Houston State University

In Partial Fulfillment

of the Requirements for the Degree of

Master of Science

by

Lindsey A. Tiegs

December, 2017

WINTERING WHOOPING CRANE BEHAVIOR AND HABITAT QUALITY AT THE
ARANSAS NATIONAL WILDLIFE REFUGE ON THE TEXAS GULF COAST

by

Lindsey A. Tiegs

APPROVED:

Jeffrey R. Wozniak, PhD
Thesis Director

Diane L. Neudorf, PhD
Committee Member

William I. Lutterschmidt, PhD
Committee Member

John B. Pascarella, PhD
Dean, College of Science and Engineering
Technology

DEDICATION

I dedicate this thesis to all of our 2016/2017 Earthwatch volunteers: Elise Begin, Linda Benson, Dianna Bell, Diane Berry, Joanne Black, Mike Brady, Rick Bryant, Kathleen Carusone, Richard and Eleanor Dawson, Kenneth and Barbara Dowell, Emily Endert, Sue Fine, Robert and Avelina Friedman, Kim Green, Mary Harris (Errspamer), Larry and Tonna Harris-Haller, CJ Hauser, Marcia Henderson, Marcie Herry, Deb Hirt, Amy Horton, Janet Hutley, Osauma Iida, Leesa Key, Ingrid Kircher Nietfield, Gloria Leonard, Gene Masters, Madeline Maxwell, Mary Lou Miller, Cathy Newman, Shirley Nishino, Mareka Ohlson, Susan Ordway, Michelle Paladino, Dave Rein, Janet Riggle, Suzanne Ross, Mary Rowe, Barb Rumber, Jean Schaffert, Allyn Schneider, Carolyn Steglich, Warren Stortroen, Robert Surpernant, Terri Tipping, Susan Walker, Priscilla Williams, and Kenia Wittgow. The extensive amount of data collected for this study would not have been possible without their tremendous manpower, passion for conservation, and financial support.

I also dedicate this thesis to my parents, Don and Judy, and my partner, Kevin, who have always encouraged me to follow my dreams, regardless of where they take me.

ABSTRACT

Tiegs, Lindsey A., *Wintering whooping crane behavior and habitat quality at the Aransas National Wildlife Refuge on the Texas Gulf Coast*. Master of Science (Biology), December, 2017, Sam Houston State University, Huntsville, Texas.

The Aransas-Wood Buffalo population of Whooping Cranes (*Grus americana*) exclusively overwinters in coastal saltmarshes of Texas. This study examined how Whooping Crane behavior and habitat quality shift over the course of a winter season, and attempted to discover linkages between their behavior and habitat quality, with the ultimate goal of finding a non-invasive method to infer habitat quality through behavioral observations. Whooping Crane behavioral observations and habitat assessments were conducted at the Aransas National Wildlife Refuge (NWR) and at adjacent urban upland sites January-March of 2016 and 2017. Cranes visiting urban upland sites with game feeders spent significantly less time foraging, and more time resting and in comfort/maintenance activities than cranes observed in their natural saltmarsh territories. On average, birds observed in their saltmarsh territories sequentially spent more time foraging each month during both winters, which correlated to a decrease in the time spent resting each month in 2017. Adult cranes spent significantly more time on alert than juveniles both years. Intra-site variability significantly exceeded inter-site variability in marsh pond salinity, but not in Blue Crab (*Callinectes sapidus*) or Carolina Wolfberry (*Lycium carolinianum*) fruit density. Saltmarsh salinity and Blue Crab density dramatically changed throughout the two winters, which were both negatively correlated to mean sea level. Marsh water quality was variable across sites, with some mainland regions and islands possessing similar water quality traits. Whooping Crane time activity budgets were not similar across sites comparable in resource availability, nor did their

behavior reflect shifts in pond salinity or Blue Crab density. Whooping Crane behavior also did not consistently correlate to time of day, observation distance, wind speed, air temperature, or mean sea level. To investigate which structural components make one saltmarsh territory more plentiful in Whooping Crane resources than another, future geospatial modeling of the microtopographic variations along the Aransas NWR could be paired with the food density and marsh pond salinity data from this study, to ultimately be applied in future land purchase, protection of existing lands, environmental easement, and restoration decisions.

KEY WORDS: Aransas National Wildlife Refuge, Behavioral ecology, Blackjack Peninsula, Blue Crab, Saltmarsh hydrology, Time activity budgets, Wading bird ecology, Whooping Crane.

ACKNOWLEDGEMENTS

First I would like to acknowledge my graduate advisor, Jeff Wozniak, for allowing me the tremendous opportunity to study one of the rarest bird species in North America by securing funding for this study and agreeing to take me on as his graduate student. I came to Sam Houston State University an endangered bird enthusiast and left as a wetland ecologist; I will forever credit Dr. Wozniak for training my eyes to zoom out and examine the bigger picture. His influence will undoubtedly continue to resonate throughout my entire scientific career. I have immensely enjoyed picking his brain in both the field and the classroom, and I very much look forward to future collaborations.

I am also extremely grateful for Liz Smith, who has consistently contributed to the development of this research project, as well as to my own personal understanding of how our uniquely complex study system functions. Thank you for your continued interest and enthusiasm in my progression as a scientist.

The completion of this thesis was also facilitated through intellectual guidance from my two committee members, Diane Neudorf and William Lutterschmidt, as well as Chris Schalk. All three have taken time out of their busy lives to talk stats with me, which has been crucial to the advancement of my thesis. Also, previous studies by Felipe Chavez-Ramirez helped shape much of the conceptual groundwork of this project.

I thank the Earthwatch Institute for funding my master's thesis research through a series of grants awarded to Jeff Wozniak, as well as the 54 Earthwatch volunteers who participated in our field expeditions during the winters of 2016 and 2017. This research was also made possible by the US Fish and Wildlife Department at the Aransas National Wildlife Refuge through the approval of annual permits.

TABLE OF CONTENTS

	Page
DEDICATION	iii
ABSTRACT.....	iv
ACKNOWLEDGEMENTS	vi
TABLE OF CONTENTS.....	vii
LIST OF TABLES	x
LIST OF FIGURES	xii
CHAPTER	
I INTRODUCTION	1
Wading Bird Foraging Ecology	1
Whooping Crane Conservation and Natural History	6
Estuarine Ecology	12
Study Site	15
Hypotheses and Objectives	17
II ANALYSIS OF WINTERING WHOOPING CRANE TIME ACTIVITY	
BUDGETS	22
Abstract	23
Introduction.....	24
Methods.....	31
Results.....	37
Discussion	46
Acknowledgments.....	52

Literature Cited	53
III ENVIRONMENTAL ASSESSMENT OF COASTAL SALTMARSH	
HABITAT QUALITY	56
Abstract	57
Introduction.....	58
Methods.....	64
Results.....	69
Discussion	87
Acknowledgments.....	90
Literature Cited	91
IV DOES WINTERING WHOOPING CRANE BEHAVIOR REFLECT	
SHIFTS IN HABITAT QUALITY?	94
Abstract	95
Introduction.....	96
Methods.....	100
Results.....	109
Discussion	118
Acknowledgments.....	122
Literature Cited	123
V SUMMARY	126
Wintering Whooping Crane behavior	126
Coastal saltmarsh habitat quality	134
Relationships between Whooping Crane behavior and habitat quality	138

Importance of continued waterbird conservation efforts.	141
REFERENCES	146
APPENDIX A.....	155
APPENDIX B	157
APPENDIX C	158
APPENDIX D.....	161
APPENDIX E	162
APPENDIX F.....	163
APPENDIX G.....	164
VITA.....	167

LIST OF TABLES

Table	Page
1 The number of individual Whooping Cranes surveyed in natural saltmarsh territories (“Natural”) and at game feeders in urban upland sites (“Urban”) per sampling month in 2016 and 2017.....	38
2 Comparison of observed Whooping Crane behavior in natural saltmarsh and urban upland habitats by individual behavior category through Kruskall-Wallace.	40
3 Kruskall-Wallace results comparing the fraction of time spent in each behavior category each month (Jan, Feb, and March) for 2016 and 2017.....	42
4 Kruskall-Wallace comparing fraction of time spent in each behavior category by adult and juvenile Whooping Cranes in 2016 and 2017.	43
5 Number of observational surveys conducted on juvenile Whooping Cranes per sampling month.....	45
6 Kruskall-Wallace significance results of the variance in time spent by juvenile Whooping Cranes in each behavior category each month (Jan, Feb, and March). Data was arcsine transformed.....	45
7 Kruskall-Wallace results comparing inter versus intra site variability in Blue Crab density (crabs/100m), red Carolina Wolfberry fruit density (red berries/square meter), and marsh pond salinity (ppt).....	77
8 Kruskall-Wallace significance values for differences in Blue Crab density (crabs/100m), marsh pond salinity (ppt) and red Carolina Wolfberry fruit	

	density (berries/meter ²) for three sites that were assessed each sampling month (January, February, March) in 2016.	80
9	Kruskall-Wallace significance values for differences in Blue Crab density (crabs/100m), marsh pond salinity (ppt) and red Carolina Wolfberry fruit density (berries/meter ²) for three sites that were assessed each sampling month (January, February, March) in 2017.	82

LIST OF FIGURES

Figure	Page
1 (Left) A map of where crane observations occurred, with the location of the natural saltmarsh sites circled in black and the location of the urban upland sites circled in yellow. (Right) Cranes in natural saltmarsh habitat (top/black) and cranes in an urban upland habitat (bottom/yellow).....	33
2 Images of Whooping Cranes displaying each behavioral category used during observational surveys: Foraging (A), Alert (B), Rest (C), Comfort/Maintenance (D), Locomotion (E), and Interaction (F).	36
3 Comparison of average time activity budgets of observed Whooping Cranes by habitat type (natural and urban upland) and year (2016 and 2017).	39
4 Bar charts with 95% CI of behavior categories in which Whooping Cranes spent significantly different amounts of time in saltmarsh territories (“Natural) versus game feeders in urban upland habitats (“Urban”).....	41
5 Bar charts with 95% CI of the fraction of time spent on alert by adult and juvenile Whooping Cranes observed at the Aransas National Wildlife Refuge in 2016 and 2017.....	44
6 Conceptual diagram of Carolina Wolfberry fruit survey protocol, with the four people involved labeled as “A”, “B”, “C”, and “Recorder”.	66
7 Blue Crab size difference between each size class as measured by carapace width (left to right): large (>10 cm), medium (6-10 cm) and small (<6 cm).....	67

8	Mean sea level (m) of the San Antonio Bay as recorded at the NOAA water data collection station in Rockport, Texas (station ID#8774770) from January 1 st -March 31 st , 2016.	70
9	Mean sea level (m) of the San Antonio Bay as recorded at the NOAA water data collection station in Rockport, Texas (station ID#8774770) from January 1 st -March 31 st , 2017.	71
10	Daily average discharge rate of the Guadalupe River (ft ³ /sec) from January 2016 to April 2017 as recorded by the USGS water data collection station in Spring Branch, Texas (Station ID#8167500).....	72
11	Total monthly (Jan-March) precipitation in Port Lavaca, Texas in 2016 and 2017 as reported by Weather Underground.	73
12	Monthly (Jan-March) average of daily minimum (blue), mean (green) and maximum (red) temperatures in 2016 and 2017 as recorded in Port Lavaca, Texas by Weather Underground.	73
13	Location of sites where environmental assessments were conducted each month in 2016 and 2017.	75
14	Name and location of the three sites in 2016 (left) and 2017 (right) that were repeatedly sampled each month (January, February and March) of that given year.....	76
15	Bar charts with 95% CI of habitat quality through time (January, February, March) in 2016 at Boat Ramp, Rattlesnake Island, and Dunham Marsh sites.	79
16	Bar charts with 95% CI of habitat quality through time (January, February, March) in 2017 at Boat Ramp, Ayer’s Island and South Sundown Bay Sites.....	81

17	PCA of water quality (salinity, temperature, and conductivity) derived from averaged PCA1 (x-axis) and PCA2 (y-axis) values per site sampled each month in 2016, with sites having <1 unit distance between them circled and given an alphabetical cluster label (left), paired with the location of each site in a given cluster (sites not part of a cluster labeled as “X”; right).	83
18	PCA of water quality (salinity, temperature, and conductivity) derived from averaged PCA1 (x-axis) and PCA2 (y-axis) values per site sampled each month in 2017, with sites having <1 unit distance between them circled and given an alphabetical cluster label (left), paired with the location of each site in a given cluster (sites not part of a cluster labeled as “X”; right).	84
19	The locations of sites/regions where five notable trends of similar or dissimilar water quality parameters occurred during more than one of the six sampling months.	86
20	Images of Whooping Cranes displaying each behavioral category used during observational surveys: Foraging (A), Alert (B), Rest (C), Comfort/Maintenance (D), Locomotion (E), and Interaction (F).	103
21	Conceptual diagram of Carolina Wolfberry fruit survey protocol, with the four people involved labeled as “A”, “B”, “C”, and “Recorder”.	106
22	Blue Crab size difference between each size class as measured by carapace width (left to right): large (>10 cm), medium (6-10 cm) and small (<6 cm).....	107
23	Monthly XY plots with SE of Blue Crabs/100m (x) and marsh pond salinity (y) at sites sampled in 2016.	110

24	Monthly XY plots with SE of Blue Crabs/100m (x) and marsh pond salinity (y) at sites sampled in 2017.	111
25	PCA of average Whooping Crane time activity budget per site each month of 2016, with sites deemed similar in resource availability designated by either shared color (red, green, purple) or symbol (dot, square, filled square, X).....	113
26	PCA of average Whooping Crane time activity budget per site each month of 2017, with sites deemed similar in resource availability designated by either shared color (red, green, purple) or symbol (dot, square, filled square, X).....	114
27	(Left) Bray-Curtis NMDS plots of the influence of marsh pond salinity and Blue Crab density on monthly Whooping Crane time activity budgets at sites repeatedly sampled (Boat Ramp=black, Rattlesnake Island=red, Dunham Marsh=blue) in January (dots), February (squares) and March (X's) of 2016. (Right) Monthly shifts in Blue Crab density and marsh pond salinity at the three sites.	116
28	(Left) Bray-Curtis NMDS plots of the influence of marsh pond salinity and Blue Crab density on monthly Whooping Crane time activity budgets at sites repeatedly sampled (Boat Ramp=black, Ayer's Island=blue, South Sundown Bay=bred) in January (dots), February (squares) and March (X's) of 2017. (Right) Monthly shifts in Blue Crab density and marsh pond salinity at the three sites.	117

CHAPTER I

Introduction

Wading Bird Foraging Ecology

The National Audubon Society defines the term “wading birds” as the group of birds that forage for food by wading in shallow water, which includes birds such as egrets, cranes, herons, ibises, storks and spoonbills. Water levels at which a particular wading bird species can forage in is largely a function of their leg length (Custer and Osborn 1978), and increasing water levels can result in loss of foraging habitat for shorter-legged species, and potentially decrease prey capture rates by increasing water turbidity (Kushlan 1981). An increase in aquatic prey density due to seasonal decreases in water levels often provides crucial heightened food availability for many different wading birds (Kushlan 1986). The sensitivity of wading birds to their aquatic environment has even led to them being labeled as useful indicators of ecological change (Kushlan 1993).

One of the earliest studies describing a strong link between hydroperiod, water depth and wading bird nesting and foraging ecology was through the observation of Wood Storks (*Mycteria americana*) in the Everglades by Kahl (1964). While Kahl was not the first to notice that Wood Storks use their bills to grope through the water column to find prey items, he did conclude with captive behavior experiments that storks strictly rely upon touch, not sight, for prey detection (Kahl 1964). Through this discovery, Kahl realized that Wood Stork prey capture success was extremely dependent upon prey density, which is in turn largely dictated by water level (Kahl 1964). Kahl (1964) concluded that seasonal dry downs during the breeding season are necessary to increase prey density for the Wood Stork, and that optimal food density occurs after a long wet

season, as the antecedent wet season facilitated fish recruitment and growth into the system prior to the dry down.

The most frequently published scientist of early wading bird studies in relation to fluctuating water levels was James A. Kushlan, whose studies of wading birds in the Florida Everglades complimented Kahl's previous work. Kushlan (1986) concluded that Wood Storks forage optimally in ponds with lower water levels due to the increase in fish density, and that White Ibis (*Eudocimus albus*) do not forage in water deeper than 30cm. Peter G. David's 1994 study of wading bird use of Lake Okeechobee, Florida in response to fluctuating water levels mirrors Kahl and Kushlan's earlier studies by also concluding that water level influenced wading bird foraging ecology. The study also showed that a lower abundance of wading birds utilized Lake Okeechobee for foraging habitat when the lake stage was too high (David 1994). David (1994) attributed the decrease in foraging on Lake Okeechobee to the effect of water level on the vegetative community structure. A study of an irrigation reservoir in Greece by Dimalexis and Pyrovetsi (1997) investigated the impacts of extreme water level fluctuations (>5m annually) on usage of the lake by Great Egrets (*Ardea alba*), Little Egrets (*Egretta garzetta*), and Grey Herons (*Ardea cinerea*). The extreme water level fluctuations were a result of seasonal demand for water in the reservoir by local agriculture (Dimalexis and Pyrovetsi 1997). Lake stage greatly dictated habitat use by all of the focal wading bird species, and during high water stages, the surrounding littoral and marsh habitats were largely inundated, decreasing the amount of available foraging habitat (Dimalexis and Pyrovetsi 1997). The Grey Heron and Great Egret, both predominately fish-eating species, maximized their prey capture rates from

September to February during the dry down of the adjacent wetlands (Dimalexis and Pyrovetsi 1997).

A field experiment study by Gawlik (2002) in the Florida Everglades provided insight into how various wading birds numerically respond to shifts in prey availability. This research agreed with previous studies (Kahl 1964; Kushlan *et al.* 1975) in that tactile feeders (storks and ibis) are more sensitive to decreasing prey densities than “searcher” species (Wood Storks, White Ibis and Snowy Egrets [*Egretta thula*]) which simply abandoned experimental ponds after prey density decreased (Gawlik 2002). Conversely, his “exploiter” species (Great Blue Heron [*Ardea herodias*], Great Egret, Glossy Ibis [*Plegadis falcinellus*], Little Blue Heron [*Egretta caerulea*] and Tricolored Heron [*Egretta tricolor*]) did not abandon a pond after prey density decreased, but instead either showed a large degree of behavioral plasticity, exploited a larger range of water depths due to longer legs, or exploited a larger range of prey by having a relatively thick bill size (Gawlik 2002). Therefore, Gawlik (2002) suggests that in an increasingly variable environment, the combination of morphology and behavioral plasticity will ultimately dictate a species’ ability to adapt and persist.

Russell *et al.* (2002) modeled the effectiveness of different water management strategies on wading bird breeding success. Specifically, the goal of the study was to examine how varying levels of water depth, drying rate, and disruption impacted different wading bird species. The study concluded that: 1) optimal foraging depth varied by species as a result of morphology, prey type, and foraging strategy; 2) a rapid drying regime provides optimal foraging habitat for all species; 3) prey dispersal increases with water depth; and 4) intermediate water levels throughout the Everglades with quick dry

down and an absence of dry down disruption benefits all wading bird species (Russell *et al.* 2002). Russell *et al.* (2002) stress the need for a decrease in human involvement of water regulation within the Everglades so that the system can return to the more natural conditions that provide optimal habitat for wading birds. They also mention that variation due to unusual precipitation patterns and extreme weather events (such as those associated with global climate change) can yield even more dramatic changes to the natural hydrological regime of the Everglades than human water management activities (Russell *et al.* 2002).

Matsinos *et al.* (2012) utilized our knowledge of wading bird sensitivity to water level fluctuations to build individual-based models for Wood Storks and Great Blue Herons, with the goal of investigating how different foraging strategies were more or less negatively impacted by an increase in precipitation. Their models suggested that Wood Storks, being tactile feeders, were significantly more inconvenienced by increased mean water levels than visually foraging Great Blue Herons because Wood Stork prey capture success is much more reliant upon prey density (Matsinos *et al.* 2012). During times of lower prey density, visually foraging Great Blue Herons were able to strictly focus on the capture of larger prey (Matsinos *et al.* 2012). This models also suggested that foraging flocks were more sensitive to increasing water levels than solitary foragers were, as solitary foragers were able to better mitigate decreased prey density by having lower predator density in a given area (Matsinos *et al.* 2012).

One of the most constructive and comprehensive studies on how to regulate hydrology for the future needs of different types of wading birds is a study linking prey selection to number of nests in the Florida Everglades by Klassen *et al.* (2016). While it

is widely understood that food availability is going to influence a population's growth, they recognized that this specific relationship cannot be fully understood until species-specific prey selection patterns are well understood; therefore, ecosystem management projects cannot be maximized until species-specific prey selection is known (Klassen *et al.* 2016). The study examined prey selection of the Tricolored Heron, Snowy Egret, and Little Blue Heron through the analysis of nestling boluses across three breeding seasons (2012-2014) and observed that all three of these small heron species were consistent in their prey selection across years (Klassen *et al.* 2016). All three species consistently preyed upon the same general marsh fishes each year, and prey selection was not proportionally consistent with prey availability within the landscape, implying that these small heron species are less flexible, specialist predators (Klassen *et al.* 2016).

Conversely, the Wood Stork, although more of a generalist feeder which is therefore less susceptible to declines in specific prey items, has a longer nesting cycle of approximately 100 days (Kahl 1964), and is therefore much less flexible in its ability to delay nesting until food availability is ideal (Klassen *et al.* 2016). While dry down and recession rates are important drivers of food availability to these birds, seasonal high water levels are necessary for the migration and growth of prey populations into the Everglades marsh complex (Klassen *et al.* 2016). In order to provide food sources for all the wading bird species, Klassen *et al.* (2016) recommend that Everglades water management strategies “balance maintaining and drying long hydroperiod areas to increase the abundance and availability of larger bodied fishes.” Here, the idea is that if Wood Storks are afforded their necessary 100 days of high food availability during nesting time, then the shorter nesting small herons' food availability needs will also be met as well.

Whooping Crane Conservation and Natural History

History of species decline and conservation efforts. The Whooping Crane (*Grus americana*), a large endemic wading bird of North America, could once be found along the Atlantic and Gulf Coasts, Northwest Rocky Mountain states, New Mexico, Central Mexico, and widely throughout the Prairie Pothole Region (CWS and USFWS 2007). Allen (1952) estimated that there were about 1,300-1,400 Whooping Cranes in North America around 1860, and Banks (1978) estimated 500-700 individuals alive as of 1870.

Whooping Cranes were extirpated from their expansive breeding grounds throughout the Prairie Potholes of the north-central United States by the 1890's and only two populations, totaling 21 birds, remained as of 1944: the migratory Aransas-Wood Buffalo population (AWBP) and a non-migratory population in coastal Louisiana (CWS and USFWS 2007). The non-migratory population in Louisiana was officially extinguished in 1950 (CWS and USFWS 2007), making the AWBP the sole remaining natural flock of the species left in the world. This major historic decline and near extinction of the entire species is credited to the mass destruction of suitable nesting grounds, habitat displacement from conversion to agricultural lands, and excessive hunting (CWS and USFWS 2007).

As the AWBP breeds in Canada and winters in the United States, both countries share responsibility in the recovery of the Whooping Crane. The US Fish and Wildlife Service (USFWS) listed the Whooping Crane as "threatened with extinction" in 1967 and "endangered" in 1970, ultimately facilitating their "endangered" status under The Endangered Species Act of 1973 (CWS and USFWS 2007). In 1978, the species was

listed as “endangered” by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC). Prior to their official “endangered” status in either country, both the wintering and breeding grounds of the AWBP were already under federal protection for the benefit of other local wildlife species. Franklin Delano Roosevelt established the Aransas National Wildlife Refuge (NWR) in Texas in 1937 to protect the breeding grounds of migratory waterfowl; Wood Buffalo National Park of north-central Canada was established in 1922 for the protection of the Wood Bison.

Following the formation of the Endangered Species act in 1973, the initial Whooping Crane Recovery Plan (WCRP) was prepared (CWS and USFWS 2007). Current implementation of the most recent version of the Whooping Crane Recovery Plan involves a large number of federal, state/provincial, non-profit, and zoological organizations in both the United States and Canada. The ultimate recovery goal of the WCRP is the removal of the species from the Threatened and Endangered lists of the Endangered Species Act; this goal is anticipated to be reached by 2035, with an annual cost of \$6.1 million USD (CWS and USFWS 2007). The main strategies to achieve the ultimate goal of downlisting are described in the WCRP as, “[the] protection and enhancement of the breeding, migrating, and wintering habitat for the AWBP to allow the wild flock to grow and reach ecological and genetic stability; reintroduction and establishment of self-sustaining wild flocks within the species’ historic range and that are geographically separate from the AWBP to ensure resilience to catastrophic events; and maintenance of a captive breeding stock to protect against extinction” (CWS and USFWS 2007).

Since the initial establishment of the WCRP, a large amount of time and resources have been allocated towards attempts to re-introduce populations into regions within their historical range. Stocks for captive breeding and subsequent reintroduction programs were mainly obtained through the removal of an egg from nests of the AWBP, which occurred 1975-1988 (CWS and USFWS 2007). As one chick per wild nest (if any) typically survives the nestling stage, this life history characteristic allowed biologists to take one egg per nest to build a captive population, all while imposing a minimal impact on the size of the AWBP. An early reintroduction attempt in the late 1970's involved the release of captive-reared Whooping Cranes cross-fostered by Sandhill Cranes (*Grus canadensis*) into the wild, which is referred to as the Rocky Mountain Population (RMP); due to complications related to imprinting, these birds did not successfully reproduce (CWS and USFWS 2007). The majority of the known causes of mortality to birds of the RMP involved collision with man-made structures, such as power lines and fences (Brown *et al.* 1987), and the last individual died in 2002 (CWS and USFWS 2007). 289 captive-raised Whooping Cranes were released in Central Florida from 1993-2004, but due to complications in reproduction and survival linked to drought, only 31 surviving birds remained as of 2008 (Florida Fish and Wildlife Conservation Commission 2008).

The Whooping Crane Eastern Partnership (WCEP), a collaboration between nine governmental and private agencies, was formed in 1999. Shortly after, the release of individuals into the Eastern Migratory Population (EMP), an attempt to establish a migratory population that breeds in Wisconsin and winters in Florida, began in 2001. As the struggle of the EMP to sustain itself became increasingly evident, the use of puppet-rearing and ultra-light flights were discontinued as of 2016.

The introduction of a non-migratory population at the White Lake Wetlands Conservation Area (WLWCA) in coastal Louisiana began in 2011. In April 2016, a mated pair in this population reached sexual maturity and successfully hatched two chicks, marking the first time a Whooping Crane egg has hatched in the state of Louisiana since 1939 (State of Louisiana Department of Wildlife and Fisheries 2016). Unfortunately, the biggest threat to this population's success has been reoccurring bouts of vandalistic shootings, not predation or failure to reproduce.

Of all the current populations of Whooping Cranes, only the sole natural population (AWBP), is self-sustaining and consistently exhibiting a natural increase in population size. If the continued increase of the AWBP is the Whooping Crane's primary chance at achieving future downlisting, the AWBP needs to eventually contain 1,000 individuals or 250 breeding pairs (CWS and USFWS 2007). The winter 2016-2017 Whooping Crane survey conducted by the USFWS at Aransas NWR estimated 431 individuals (95% CI=371-493) in the population (USFWS 2017). To achieve the goal of 1,000 individuals or 250 breeding pairs in the AWBP, a considerable increase in high quality coastal habitat must be acquired to provide the required territory and food resources to support this increase in population size (CWS and USFWS 2005). Identifying and securing these coastal habitats is a grand challenge, especially amidst the various anthropogenic impacts to the coastal ecosystem. To achieve this goal, the Aransas NWR has initiated projects to expand the refuge's land holdings, created more coastal habitat within the refuge through the use of dredging material to create new coastal habitats (Darnell and Smith 2004), and restored previously impacted sites.

Whooping Crane natural history and ecology. Whooping Cranes utilize coastal marshes, estuaries, lakes, ponds, freshwater marshes, wet meadows, rivers and agricultural fields to provide necessary resources during breeding, wintering and migration (CWS and USFWS 2007). Wild nesting Whooping Cranes typically lay two eggs per clutch, but it is extremely rare that both offspring of a given clutch survive (Kuyt 1981). In a fierce competition for resources, the chick that hatches first often pushes the younger, weaker chick out of the nest, ultimately resulting in sibling infanticide; only exceptionally high food availability at the breeding grounds can alleviate this competition and enable both siblings to live long enough to make the fall migration. A hatchling Whooping Crane's plumage is cinnamon-brown, and a slow transition to all-white plumage occurs throughout the first year. A juvenile Whooping Crane in a migratory population will migrate in the fall alongside its parents down to their wintering grounds. Whooping Cranes establish large territories in their wintering grounds, historically averaging 196-314 hectares in area, and a given adult pair will typically return to and defend the same territory year after year (Stehn and Prieto 2010; Pugsek *et al.* 2013). Juveniles that survive fall migration typically spend the majority of the winter season with their parents in their territory (Stehn 1992). During or following spring migration the now nearly all-white juveniles separate from their parents, and join other young adults to form what is called a "sub-adult" group. Young adult Whooping Cranes typically stay in this sub-adult group until they reach sexual maturity at 3-6 years of age (Binkley and Miller 1988; Gil de Weir 2006; Tischendorf 2004) and pair off with a mate. The majority of newly breeding pairs establish their own breeding territory within 20km of their own natal territory (Johns *et al.* 2005). Crane species, including Whooping

Cranes, are generally classified as perennially monogamous, and they regularly maintain these pair bonds through courtship rituals and calling in unison (Ellis *et al.* 1998). They are a relatively long-lived species with an estimated lifespan of 24-27 years in the wild (Binkley and Miller 1980, 1988; Gil de Weir 2006).

Whooping Cranes in the AWBP spend the summer breeding season at Wood Buffalo National Park (NP) in Alberta, Canada. During the breeding season, the cranes partake in a wide array of associated breeding behaviors- elegant courtship dances, copulation, nesting, rearing of chicks (Ellis *et al.* 1998), and eventually the preparation of their juvenile offspring for spring migration down to the Aransas NWR. During the breeding season they utilize freshwater wetlands within Wood Buffalo NP, where they opportunistically feed upon a large variety of prey items. They build their nests and sleep in the middle of a shallow pond; this strategy is presumably useful for predator detection by enhancing their ability to hear any incoming threats (Folk *et al.* 2014).

Mated pairs, family groups, and sub-adult groups typically leave August-September and migrate the approximately 4,000km together to their wintering grounds. Roughly 9 weeks each year is spent in migration between their breeding and wintering grounds (Chavez-Ramirez and Wehtje 2012; CWS and USFWS 2007), and they stop in the evenings to roost in shallow open water. As the majority of Whooping Crane mortalities occur during migration (CWS and USFWS 2007), they are extremely dependent upon the availability of suitable stop-over habitat throughout their 300 mile wide migration corridor; a recent increase in the number of wind turbine farms along their migration route has notably resulted in loss of Whooping Crane stop-over habitat (CWS and USFWS 2007).

During the winter season at the Aransas NWR, Whooping Cranes in the AWBP prefer to occupy coastal saltmarsh territories. After arrival at the Aransas NWR, most of their time is spent foraging, looking out for possible threats (alert behaviors), preening, and resting (Lafever 2006) until they migrate back to Wood Buffalo NP in the spring. While considered to be opportunistic feeders while wintering at Aransas NWR, they primarily feed upon Blue Crabs (*Callinectes sapidus*) and Carolina Wolfberry fruit (*Lycium carolinianum*) (Chavez-Ramirez 1996; Butzler 2006).

Estuarine Ecology

Estuaries form a transition zone between riverine and marine environments, where freshwater runoff from the land mixes with the saltwater in the ocean and bays (Morrison and Greening 2011). Along the coastal margin, river outputs supply freshwater, sediment, nutrients, and organic matter to nearshore environments while the shallow waters create ideal conditions for a wide range of primary producers (Day *et al.* 2007). For this reason, estuaries are one of the most biologically productive ecosystems in the world, and are therefore relied upon heavily by both humans and a wide variety of other organisms (Day *et al.* 2013). For example, many aquatic species, including multiple fish and crab species, rely upon the relatively shallow, productive, sheltered waters of the estuary in order to complete their life cycle, while a diverse array of avian species call estuaries their home either seasonally, in passing during migration, or year-round. Estuaries possess a high diversity of habitat types and a rich community of specialized niches, which support a broad distribution of many different types of birds. Environmental factors such as water depth and vegetation cover directly influence habitat

type and result in birds selecting specific habitats based on their preferred food resources and foraging method along the tidal gradient (Takekawa *et al.* 2011).

Humans have colonized deltas and floodplains for thousands of years, exploiting their nutrient rich soils and easy access to freshwater for agriculture (Kennett and Kennett 2006). In 2011, it was calculated that 39% of the United States' population, approximately 123 million people, dwelled within coastal counties, which comprise less than 10% of the area of the contiguous United States (United States Census Bureau 2011; NOAA 2012). To provide freshwater to these large coastal communities and growing populations further inland in the watershed, increased volumes of freshwater are being extracted for municipal and agricultural purposes year in and year out, with the global human population using an estimated 50% of the readily available freshwater runoff (Montagna *et al.* 2002). In addition to the previously mentioned linkages to estuarine health, freshwater inflows have a direct impact on estuarine salinity regimes, nutrient concentrations, and sediment transport into the system (Longley 1994). When freshwater inflows are diminished, hypersaline conditions can have detrimental effects on the aquatic organisms within the estuarine system, directly inhibiting primary production and subsequently impact food web dynamics at higher trophic levels throughout the estuary (Longley 1994). Coastal ecosystems are among both the most highly biologically productive and biodiverse areas in the world. The anthropogenic impacts and pressures imposed by urbanization (e.g., freshwater extraction, water column pollution, and coastal habitat loss) on estuaries threaten an astounding abundance and diversity of species globally.

Along the Gulf Coast of Texas there are 7 major bay and estuarine systems (National Wildlife Federation 2004), all varying in the volume of freshwater inflow, watershed size and the degree of anthropogenic influence. Previous studies have shown that levels of freshwater inflows are the defining factor in dictating biological productivity within these Texas estuaries (Copeland 1966; Armstrong 1987). Generally, there is a predominantly diminishing precipitation gradient as you move from east to west within the state of Texas (Daly *et al.* 2008). Therefore, in Texas estuaries south of Galveston Bay, evaporation rates often exceed precipitation rates, resulting in exaggerated hypersaline conditions (Bianchi *et al.* 1999). In addition, the influence of urban growth in Texas has had a pronounced influence on coastal systems. The appropriation of freshwater permits within watersheds by the state of Texas can result in diminished freshwater flows reaching the coastline (National Wildlife Federation 2004), which has evoked great debate within the state on the necessity and ecological requirements for adequate freshwater inflows on the coast. This had lead the Texas Commission on Environmental Quality (TCEQ) to form the Basin and Bay Area Stakeholder Committee (BBASC) and the Basin and Bay Area Expert Science Team (BBEST), which are tasked with the creation of Environmental Flows Recommendation Reports for several Texas estuaries.

Estuaries are dynamic, highly productive ecosystems that provide critical habitat for a wide range of aquatic, terrestrial and avian species. Growing global population, coastal urbanization and the associated environmental impacts (e.g., salinization, global climate change and sea level rise) have negative impacts on coastal habitats. These trials

can propose major challenges to threatened and endangered coastal species, such as the Whooping Crane, who already struggle for survival along the coastal margin.

Study Site

Established as a National Wildlife Refuge by the US Fish and Wildlife Service in 1937, the coastal marshes of the Aransas National Wildlife Refuge (NWR) are part of an estuarine system receiving freshwater inflows from the Guadalupe and San Antonio River watersheds into the San Antonio Bay. The highly heterogeneous coastal landscape of the refuge is comprised of saltwater ponds, open bays, tidal creeks and high elevation marsh habitats, all experiencing unique fluctuations in hydrological connectivity to the estuary (Wozniak *et al.* 2012). The water level of the San Antonio Bay dictates the magnitude of adjacent saltmarsh inundation or isolation from the bay, and the salinity of the San Antonio Bay is largely influenced by freshwater inflows. The hydrologically dynamic coastal marshes of the Aransas NWR and surrounding areas along Texas Gulf Coast make up the sole wintering grounds of the Aransas-Wood Buffalo population of Whooping Cranes. Studies have shown that early in the wintering season Whooping Cranes primarily feed upon Carolina Wolfberry fruit as they are widely abundant at that time in the season (Chavez-Ramirez 1996; Lafever 2006; Wozniak *et al.* 2012). Even though Carolina Wolfberry plants are evenly distributed in Aransas NWR coastal salt marshes, different sites along the peninsula have been known to vary significantly in berry production (Butzler 2006). Wolfberry plants produce more fruit during the winter of years when summer mean salinities of the San Antonio Bay are relatively low, which emphasizes the need to maintain substantial freshwater inflows into the San Antonio Bay year-round (Wozniak *et al.* 2012). Whooping Cranes are also reliant upon sufficient

freshwater inflows to provide relatively fresh drinking water in their coastal territories, especially during periods of drought; reductions in the volume of freshwater inflows into the San Antonio Bay correlate to elevations in marsh salinity (Wozniak *et al.* 2012), which further emphasizes their reliance on sufficient freshwater inflows into the estuary.

Blue Crabs are an important source of protein and biomass for the cranes towards the end of the wintering season before they migrate back to Wood Buffalo NP (Chavez-Ramirez 1996; Greer 2010); a significant non-linear relationship between low Blue Crab abundance towards the end of the winter season (March) and heightened mortality of Whooping Cranes has been observed (Pugesek *et al.* 2013). Blue Crab larvae depend upon low salinities in the estuary for larvae development and survival (Sandoz and Rogers 1944). While the cranes primarily utilize salt marsh habitat for foraging, it has also been widely observed that they will forage for clams in open bays, eat roasted acorns after a prescribed burn in upland habitats, foraging in adjacent agricultural fields, and visit game feeders in nearby urban sites (Chavez-Ramirez 1996; Lafever 2006; Stehn 1992).

The Whooping Crane is not the only large wading bird foraging throughout the saltmarshes of the Aransas NWR. A rich diversity of heron and egret species also call these habitats throughout the region home. The largest of which are also heavily reliant upon saltmarsh ponds and the bay to provide the open water habitats crucial for foraging (Chavez-Ramirez and Slack 1995). Of the open water habitats, these focal heron and egret species most frequently utilized pools ($<4\text{m}^2$) and lakes ($>100\text{m}^2$; Chavez-Ramirez and Slack 1995).

Hypotheses and Objectives

My master's thesis work is organized into two broad field research efforts: 1) Whooping Crane behavioral observations and 2) environmental assessment of coastal salt marsh territories. Observations were conducted using a 20 minute "snapshot" survey method and environmental assessments included *in situ* water quality, Blue Crab and Carolina Wolfberry fruit surveys. The purpose of these two types of data collection efforts was to inquire how coastal saltmarsh habitat quality (in reference to Whooping Crane needs) shifts through time and space, differences in wintering Whooping Crane behavior through time and space, and whether Whooping Crane behavior reflects habitat quality.

Objective 1: Investigation of Whooping Crane behavior

Question: how does Whooping Crane behavior vary spatially between different coastal territories and temporally throughout the winter season in the coastal marshes at the Aransas NWR?

Hypotheses:

- 1) Cranes will exhibit dramatically different behaviors when in their coastal territories versus when they are visiting game feeders in urban upland sites.
- 2) Crane behavior will change through time (as spring migration nears)
- 3) Juvenile Whooping Crane behavior will differ from adult Whooping Crane behavior, and dramatically change as the season progresses.

The first goal of this objective was to investigate how behaviors exhibited by wintering Whooping Cranes while occupying their natural saltmarsh territories vary from those observed in urban upland habitats. While most of the cranes spend the winter season within the natural coastal territories of the Aransas NWR, some choose to spend time at nearby urban areas, often in association with game feeders. As the future implantation of supplemental feeders could possibly support a struggling population during years of extreme drought, there are many questions regarding the behavioral and energetic impacts on the cranes visiting feeders. While supplemental feeders have not previously been deployed to supplement wintering AWB Whooping Cranes by officials of the Whooping Crane Recovery Program, their behavior at game feeders can be observed at known locations in nearby upland areas where local residents maintain feeders on their private property. A comparison of their behavior in typical saltmarsh territories to that in urban upland sites when visiting game feeders could provide valuable insight to the discussion of whether to provide the population with supplemental food during extreme drought.

The second goal of this objective was to investigate how wintering Whooping Crane behavior changes temporally across the wintering season within the coastal marshes at the Aransas NWR. Their initial arrival to the Texas Gulf Coast in the fall occurs after an approximately 4,000 km migration from their Canadian breeding grounds, which likely influences their behavior through a relative lack of energy early in the season. As winter transitions to spring, their upcoming, energetically daunting migration back to the breeding grounds may also likely influence how they spend their remaining time in their Texas territories.

Lastly, the third goal of this objective was to examine how the behavior of juvenile birds compare to the behavior of their parents. Wintering juvenile Whooping Cranes at the Aransas NWR, identified by an ongoing transition of plumage color from rusty brown to the stark-white feathers of their parents, are experiencing coastal saltmarsh habitat for the first time in their young lives. Conversely, these saltmarshes are no longer novel to the white plumaged adult birds (sub-adults and adults) who have previously spent at least one winter season along the Texas Gulf Coast.

Objective 2: Coastal Habitat Quality

Question: how does salinity and the abundance of Blue Crab and wolfberry fruit (critical Whooping Crane food resources) vary throughout the winter season in coastal marshes at the Aransas NWR?

Hypotheses:

- 1) Inter-site variability in habitat quality will be greater than intra-site variability at a given point in time.
- 2) Habitat quality at a given site will change through time.
- 3) Saltmarsh water quality is patchy and will therefore vary spatially along the Blackjack Peninsula.

The primary goal of this objective is to expand our knowledge on which combination of factors create high quality wintering Whooping Crane habitat. As a result of the heterogeneous nature of saltmarshes largely driven by microtopographic shifts in elevation, large-scale hydrological events throughout the greater estuary can yield highly

variable effects across the saltmarsh landscape. As the population of this territorial species continues to expand spatially across the region, more land must be acquired and protected to ensure their continued spatial expansion, population growth and eventual downlisting. The identification of which saltmarsh territories consistently provide abundant food resources and fresh drinking water to Whooping Cranes throughout the winter season could contribute to the future prioritization of which areas should be acquired, maximizing the Whooping Crane conservation benefits gained per investment.

Objective 3: Linking Behavior to Habitat Quality

Question: is it possible to link environmental conditions (water quality and food availability) to Whooping Crane behavior?

Hypotheses:

- 1) Observed Whooping Crane time activity budgets will be similar in coastal marsh territories similar in habitat quality.
- 2) Shifts in habitat quality will correlate to shifts in Whooping Crane behavior.

The objective of this portion of the study is to find links between environmental conditions (regional and local/territory scale) to Whooping Crane behavior, for the ultimate purpose of deducing the habitat quality at a given site (in reference to Whooping Crane needs) through behavioral observation surveys. If successful, this provides a relatively non-invasive method of surveying Whooping Crane habitat quality at a given

site, which could in turn ultimately inform our currently limited knowledge of which environmental elements make one saltmarsh territory more profitable than another, and be useful in future land acquisition decisions.

CHAPTER II

Analysis of Wintering Whooping Crane Time Activity Budgets

This thesis follows the style and format of *Waterbirds*.

Abstract

The Aransas-Wood Buffalo population of Whooping Cranes (*Grus americana*) exclusively overwinters in coastal Texas saltmarshes. This study examined how wintering Whooping Crane behavior varies through time, by habitat type, and between age groups. Behavioral observations of cranes wintering in natural saltmarsh territories within the Aransas National Wildlife Refuge and at game feeders in adjacent urban upland sites were conducted in 2016 and 2017. Cranes in saltmarsh territories significantly increased their time spent foraging through the season in 2017, but not in 2016. The temporal increase in forage time in 2017 coincided with a decrease in time spent resting each month that year. Conversely, behavior through time in 2016 highly correlated to shifts in bay water level. Adults spent more time on alert than juveniles both years. Cranes in saltmarsh territories spent significantly more time foraging and less time resting and comfort/maintenance activities than birds in urban upland sites. A lack of banding on cranes visiting the feeders limits our ability to investigate the drivers of their unconventional foraging habitat selection. The presence of game feeders in urban settings may have a more significant influence on crane behavior than time of season, age group, and territory quality.

KEY WORDS: Aransas National Wildlife Refuge, endangered species, *Grus americana*, supplemental feeding, Whooping Crane, wintering crane behavior.

Analysis of Wintering Whooping Crane Time Activity Budgets

Introduction

Wintering crane behavior. There are fifteen species of cranes globally. Seven of those species are currently classified as vulnerable, three are listed as endangered, and one as critically endangered by the International Union for the Conservation of Nature (IUCN), making the future persistence of eleven of the fifteen total crane species around the world uncertain. For migratory populations, the protection of both their critical breeding and wintering grounds is crucial to their continued existence. Therefore, behavioral studies of crane populations during both seasons at their respective grounds are crucial to their continued subsistence. As behavior is driven by largely dissimilar factors during the breeding and wintering seasons and this study solely focused on wintering cranes, studies of crane behaviors during the breeding season cannot necessarily be directly applied to this study.

Previous analyses of time activity budgets have been conducted on many populations of wintering cranes. Alonso and Alonso (1992) investigated how the time activity budget of wintering Common Cranes (*Grus grus*) in northeast Spain varied throughout the course of a given day, and found that the percent of time spent foraging peaked in the early morning and late afternoon, while conversely the time spent in vigilance (alert) and preening (comfort/maintenance) behaviors peaked during midday. The wintering Common Cranes also spent more time in locomotion and occupied habitats of higher food availability in the early morning relative to those during midday (Alonso and Alonso 1992). Another study of wintering Common Cranes by Avilés (2003) in

southwestern Spain compared the time activity budgets of adults and juveniles, and examined how the presence or absence of a juvenile influenced adult crane behavior. Adult cranes were more vigilant (spent more time on alert) than juveniles, while juveniles spent more time foraging (Avilés 2003). When in large flocks, adults with a juvenile present experienced a higher frequency of aggressive encounters with other cranes than adults without juveniles; an opposite effect was observed when flock size was relatively smaller (Avilés 2003). A study of Hooded Cranes (*Grus monacha*) in Shengjin, China observed that across the wintering season the population spent an average of 60.4% of their time activity budget foraging and 15.5% on alert (Zhou *et al.* 2010). However, the average time spent foraging increased as the season progressed while time spent on alert decreased throughout the season (Zhou *et al.* 2010). Comparable to behaviors observed in wintering Common Cranes (Alonso and Alonso 1992), adult Hooded Cranes on average spent more time on alert, in comfort activities, locomotion and in social behaviors than juveniles, while the juveniles spent more time foraging than adults (Zhou *et al.* 2010). Adult and juvenile Hooded Crane time activity budgets were significantly different early and mid-wintering season, but not during the end of the season (Zhou *et al.* 2010).

Winter foraging ecology studies have been conducted on common and Siberian (*Grus leucogeranus*) cranes (Alonso *et al.* 1995; Bautista *et al.* 1998; Burnham *et al.* 2017; Jia *et al.* 2013). Alonso *et al.* (1995) tested the marginal value theorem in Common Cranes in northeastern Spain to see if the time spent in a foraging patch would increase with patch quality. However, the Common Cranes only supported the marginal value theorem when a given patch could not provide the sufficient intake rates to fulfill an individual's daily energy requirements, and also left higher quality patches earlier than

expected (Alonso *et al.* 1995). A study of kleptoparasitism within the same population by Bautista *et al.* (1998) found that wintering Common Cranes would steal food items from conspecifics when their food intake rate was lower than that required for survival, and that cranes with above average intake rates were targeted. A complete shift in the selection of foraging habitat following a severe flood event has been documented in Siberian Cranes wintering at Poyang Lake, China (Burnham *et al.* 2017; Jia *et al.* 2013). When the availability of *Vallisneria* tubers drastically declined throughout their preferred mudflat and shallow water habitats as a result of the flood, the Siberian Cranes adopted a novel foraging strategy and fed on *Potentilla limprichtii* in adjacent wet meadows (Burnham *et al.* 2017; Jia *et al.* 2013). While the alternative food source obtained in the wet meadows during the high-water conditions secured the population's survival that winter, there was an observed decrease in reproductive success during the following breeding season, which emphasizes the importance of sustaining high *Vallisneria* availability at Poyang Lake (Burnham *et al.* 2017).

The influence of human disturbance on wintering behavior has been studied in populations of Red-crowned (*Grus japonensis*), White-naped (*Grus vipio*), Hooded, and Common Cranes (Avilés, 2003; Díaz *et al.* 1996; Lee *et al.* 2007; Li *et al.* 2015; Wang *et al.* 2011). The wintering grounds of Common Cranes in central Spain experience a gradient of agricultural management, consisting of heavily grazed grasslands, scrublands with occasional livestock grazing, and croplands without grazing (Díaz *et al.* 1996). Cranes in this area are heavily reliant upon acorns, and typically prefer to forage in the croplands due to the absence of food competition with livestock (Díaz *et al.* 1996). While the presence of livestock can stimulate the abundance of earthworms, an alternative food

source for the cranes, the increase in earthworms is not sufficient to compensate for the loss of acorns; therefore, it is predicted that increased grazing pressure in this region would have a strong negative impact on this population (Díaz *et al.* 1996). Conversely, adult Common Cranes in the presence of juveniles preferred grazed grasslands, likely due to the decreased flock sizes in these areas which subsequently result in lower frequency of agonistic encounters with other cranes (Avilés 2003). A population of Red-crowned Cranes wintering in China exhibited an increase in vigilance (alert) when occupying areas of high human activity when part of smaller flocks, which suggests that these cranes are afforded less time to forage in these habitats due to increased disturbance (Wang *et al.* 2011). This effect has also been observed in wintering Hooded Cranes (Li *et al.* 2015). A shift from farmers historically plowing their fields in the spring to now plowing in the fall near the Demilitarized Zone of Korea is having negative impacts on wintering Red-Crowned and White-naped Cranes (Lee *et al.* 2007). As these two imperiled species have previously relied upon the unplowed fields to provide a high amount of food resources over the winter season, this shift in the timing of field plowing could be detrimental to both species (Lee *et al.* 2007).

Previous behavioral studies of the Aransas-Wood Buffalo (AWB) population of Whooping Cranes. The sole remaining natural flock of endangered Whooping Cranes (*Grus americana*) exclusively winter along the Texas Gulf Coast in the saltmarshes of Matagorda Island, the Aransas National Wildlife Refuge (NWR), San Jose Island, Welder Flats and Lamar Peninsula (Stehn and Prieto 2010). As a result of excessive hunting and habitat loss, the Whooping Crane narrowly avoided extinction when there was an estimated low of about 16 individual birds in 1941. As the current size of this Aransas-

Wood Buffalo population is still less than half of that required for downlisting, extensive conservation efforts in their breeding and wintering grounds by a wide range of governmental, academic, and non-profit agencies are on-going (CWS and USFWS 2005). Multiple detailed studies of the wintering behaviors of the Aransas-Wood Buffalo population of Whooping Cranes have been published since the 1990's.

Chavez-Ramirez (1996) provided extensive information regarding wintering Whooping Crane habitat use, foraging behaviors, time activity budgets, and energy requirements at the Aransas NWR. It was observed that on average the population spent 87% of their time in saltmarsh habitats, with an increased use of saltmarsh vegetation early in the season when Carolina Wolfberry (*Lycium carolinianum*) fruit are abundant, and a shift to open water habitats later in the season as Carolina Wolfberry fruit are diminished (Chavez-Ramirez 1996). The cranes were observed to venture out of their typical saltmarsh habitat when Blue Crab (*Callinectes sapidus*) densities were low and when clam (*Tagellus plebius*) abundance was high in the San Antonio Bay (Chavez-Ramirez 1996). Mated pairs of Whooping Cranes typically establish and defend saltmarsh territories in their wintering grounds, and groups of non-familial birds were most often observed in upland habitats during both years of the study (Chavez-Ramirez 1996). Cranes exhibited different time activity budgets across different habitat types (saltmarsh vegetation, saltmarsh open water, bay, upland) during the first year but not the second year of the study (Chavez-Ramirez 1996). Cranes in upland habitats spent very little time foraging and an abnormally high amount of time resting compared to when in other habitats (Chavez-Ramirez 1996). Through the construction of a wintering Whooping Crane energy budget, Chavez-Ramirez (1996) concluded that 88% of an

individual's total energy is derived from the consumption of Blue Crabs, and that at least 5.26 crabs must be consumed per day to meet their daily energy requirements.

Lafever (2006) found that Whooping Cranes spent an average of 63% and 66% of their time activity budget foraging, and 15% of their time on alert. Adults spent more time on alert than juveniles in January and February, and instances of flight were highest in November and December, likely due to the delineation of territory boundaries after arrival (Lafever, 2006). As mentioned earlier, an increase in disturbance can result in more time spent on alert, effectively decreasing the amount of time cranes can spend foraging. As the Gulf Intracoastal Waterway (GIWW) runs the length of the Aransas NWR, there was interest in the impact of the high level of human activity (e.g., recreational fishing, barge traffic) on wintering Whooping Crane behavior. However, Lefever (2006) concluded that the current levels of activity within the GIWW were not detrimental to the cranes with bordering territories.

Historical territory and range data from 1950-2006 was compiled and used by Stehn and Prieto (2010) to deduce average territory size and project the future area of protected habitat required to support a population large enough to warrant the downlisting of the species (1000 individuals or 250 breeding pairs; CWS and USFWS 2005). Their analysis revealed that newly-paired male cranes typically establish their territory near the territory of his parents (Stehn and Prieto 2010). They calculated the minimum territory size at the Aransas NWR to be 101 ha and the overall average minimum territory size across all wintering locations to be 172 ha (Stehn and Prieto 2010). The study ultimately projected that there was currently not enough protected suitable habitat for the population

to reach the recovery goal as a result of continued development of coastal lands and sea level rise (Stehn and Prieto 2010).

Objectives and hypotheses. The first goal of this study was to investigate how behaviors exhibited by wintering Whooping Cranes while occupying their natural saltmarsh territories varies from those observed in urban upland habitats. While most of the cranes spend the winter season within the natural coastal territories of the Aransas NWR, some choose to spend time at nearby urban areas, often in association with game feeders. As the future implantation of supplemental feeders could support a struggling population during years of extreme drought, there are many questions regarding the behavioral and energetic impacts on the cranes visiting feeders. While supplemental feeders have not previously been deployed to supplement wintering AWB Whooping Cranes by officials of the Whooping Crane Recovery Program, their behavior at game feeders can be observed at known locations in nearby upland areas where local residents maintain feeders on their private property. A comparison of their behavior in typical saltmarsh territories to that in urban upland sites when visiting game feeders could provide valuable insight to the discussion of whether to provide the population with supplemental food during extreme drought.

The second goal of this study was to investigate how wintering Whooping Crane behavior changes temporally across the wintering season within the coastal marshes at the Aransas NWR. Their initial arrival to the Texas Gulf Coast in the fall occurs after an approximately 4,000 km migration from their Canadian breeding grounds, which likely influences their behavior through a relative lack of energy early in the season. As winter transitions to spring, their upcoming, energetically daunting migration back to the

breeding grounds may also likely influence how they spend their remaining time in their Texas territories.

Lastly, the third goal of this study was to examine how the behavior of juvenile birds compare to the behavior of their parents. Wintering juvenile Whooping Cranes at the Aransas NWR, identified by an ongoing transition of plumage color from rusty brown to the stark-white feathers of their parents, are experiencing coastal saltmarsh habitat for the first time in their young lives. Conversely, these saltmarshes are no longer novel to the white plumaged adult birds (sub-adults and adults) who have previously spent at least one winter season along the Texas Gulf Coast.

Hypotheses:

1. Cranes will exhibit dramatically different behaviors when in their coastal territories versus when they are visiting urban game feeders.
2. Crane behavior will change through time (as spring migration nears).
3. Juvenile Whooping Crane behavior will differ from adult Whooping Crane behavior, and dramatically change as the season progresses.

Methods

Study area. Established as a National Wildlife Refuge by the US Fish and Wildlife Service in 1937, the coastal marshes of the Aransas National Wildlife Refuge (NWR) are part of an estuarine system receiving freshwater inflows from the Guadalupe and San Antonio River watersheds into the San Antonio Bay. The highly heterogeneous coastal landscape of the refuge is comprised of saltwater ponds, open bays, tidal creeks and high elevation marsh habitats, all experiencing unique fluctuations in hydrological connectivity to the estuary (Wozniak *et al.* 2012). Behavioral surveys of birds in natural

saltmarsh territories were conducted at the Aransas NWR along ~12 miles of coastal saltmarshes of the Blackjack Peninsula and the barrier islands of the Gulf Intracoastal Waterway (GIWW). The GIWW, a shipping channel along the coast of the Blackjack Peninsula, is heavily utilized by an estimated 50,000 shipping vessels annually (USACE 2004), commercial fisheries, and recreational boaters. Behavioral surveys of Whooping Cranes in their saltmarsh territories were conducted by boat from the GIWW.

Behavioral surveys of Whooping Cranes visiting game feeders in urban upland sites were exclusively conducted at the southern-most end of the Lamar Peninsula, directly across Saint Charles Bay from the Blackjack Peninsula (Fig. 1). The Lamar Peninsula is home to Goose Island State Park and several private residences, some of which maintain game feeder(s) in their yards. These tripod game feeders automatically dispense corn feed onto the ground in unknown time intervals. To respect the private properties of the home owners, observations of birds on the Lamar Peninsula occurred along the sides of the roads bordering their properties. As this area is well known to provide one of the closest views of Whooping Cranes in the region, many birding onlookers frequent these sites on a daily basis.



Figure 1. (Left) A map of where crane observations occurred, with the location of the natural saltmarsh sites circled in black and the location of the urban upland sites circled in yellow. (Right) Cranes in natural saltmarsh habitat (top/black) and cranes in an urban upland habitat (bottom/yellow).

Sampling methods. Whooping Crane behavior was sampled monthly from January-March of 2016 and 2017. This research was funded by Earthwatch Institute, and data was collected with the assistance of a total of 54 Earthwatch citizen scientists. To sample Whooping Crane behavior we employed a modified version of a previously established time-activity budget sampling protocol (Chavez-Ramirez 1996). Each behavioral survey occurred over a twenty minute period, with Whooping Crane behavior category recorded every 15 second interval. The first step was to locate a group of Whooping Cranes (either an individual, a pair, a family group, or sub-adult group) in either a natural coastal saltmarsh or urban upland site where they are close enough to be accurately observed yet far away enough to not be disturbed by our presence (optimal range ~200-400m). Once observable cranes were located, metadata (e.g., air temperature, wind speed, wind direction, GPS location, observation range and compass heading to birds) was collected prior to initiation of the behavior survey (see Appendix A). During each 20 minute observational “snapshot” interval, the main categories that were recorded include the following: foraging, resting, alert, comfort/maintenance, locomotion, and interaction (Fig. 2). The *foraging* category refers to any action related to searching for, obtaining, processing or consuming a food item. The *comfort/maintenance* category involves behaviors such as scratching, stretching, preening and ruffling of feathers. *Locomotion* refers to walking, running, or flying. Locomotion can be distinguished from active foraging by the position of the head- during foraging, the crane is slowly walking with its head down while it is actively searching for food, compared to walking/running where the neck is erect and the head is in the upright position, facing in the direction of transit. *Interaction* refers any action in response to other cranes or organisms, and

antagonistic behaviors towards other Whooping Cranes for the purpose of territory defense was specifically noted. The *alert* behavior category is characterized by a stiff neck as the crane investigates for any possible threats. The *resting* category is most easily identified by a relaxed, more “S” shaped neck, and is characterized by a complete lack of noticeable movement. If a crane becomes nonvisible during the behavior survey, “ND” for No Data was documented for each interval until the bird became visible again. Any unusual occurrences during a behavior survey, such as a disturbance or interaction was documented in detail in the comments section of that given survey. As the majority of the Whooping Cranes along the Blackjack Peninsula are not banded, we differentiated pairs and family groups by general territory location. An IACUC exemption was approved by Sam Houston State University, as no vertebrates were handled or collected during this study (ID#16-03-16-1020-10-01).

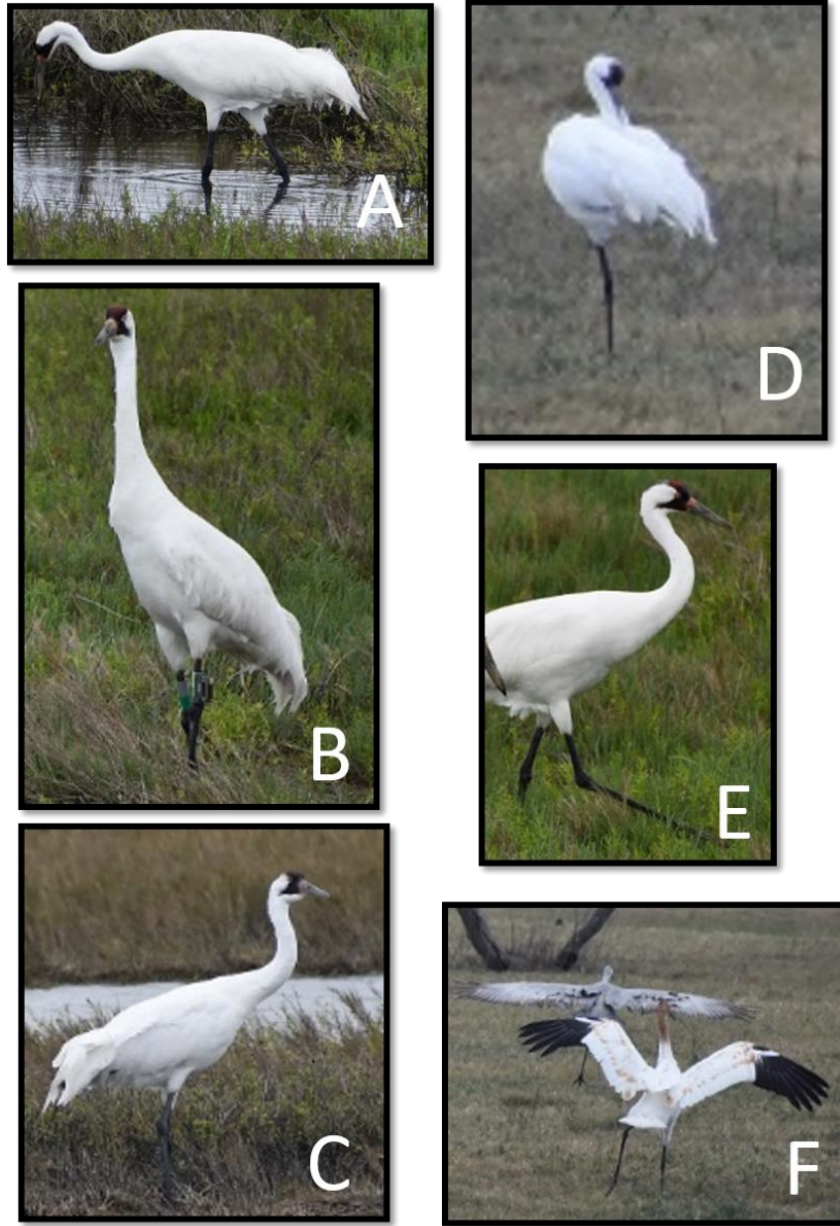


Figure 2. Images of Whooping Cranes displaying each behavioral category used during observational surveys: Foraging (A), Alert (B), Rest (C), Comfort/Maintenance (D), Locomotion (E), and Interaction (F).

Data analysis. To translate the time activity budget of each bird observed from a series of percentages to continuous data, the fraction of time spent in each behavior category was transformed using arcsine square-root. The transformed data was not

always normally distributed and the independence of behavior observed between individuals within the same social group is questionable, therefore Kruskal-Wallis tests were used to compare behavior across habitat types, months, and age groups.

Results

Behavioral observation survey data was collected January 12-14, February 16-19, and March 8-11 of 2016, and January 10-14, February 14-17, and March 14-16 of winter 2017. During winter 2016, behavioral observation surveys were completed on a total of 77 individuals belonging to groups occupying unique areas of natural saltmarsh along the Blackjack Peninsula, and 10 individuals were observed at an urban game feeder site on the Lamar Peninsula. In 2017 a total of 88 individuals were surveyed in natural saltmarsh habitat and 16 individuals were observed at urban game feeder sites on the Lamar Peninsula (Table 1).

Table 1

The number of individual Whooping Cranes surveyed in natural saltmarsh territories (“Natural”) and at game feeders in urban upland sites (“Urban”) per sampling month in 2016 and 2017.

Year	Month	Natural	Urban
2016	January	25	1
	February	29	5
	March	23	4
	Total	77	10
2017	January	33	6
	February	24	4
	March	31	6
	Total	88	16

Note. “Natural” observations were conducted by boat on birds in saltmarsh territories at the Aransas National Wildlife Refuge. “Urban” observation surveys were conducted on birds visiting game feeders on residential properties on the Lamar Peninsula.

Natural saltmarsh territories versus urban sites. On average, the Whooping Cranes observed in natural saltmarsh territories in 2016 and 2017 spent 66.2% and 60.1% of their time foraging, 9.6% and 10.1% on alert, 6.4% and 9.8% resting, 2.8% and 3.8% in comfort/maintenance, and 12.2% and 13.6% in locomotion, respectively. The average time activity budget of cranes observed near urban game feeders at urban upland sites in 2016 and 2017 dedicated 8.1% and 25.4% to foraging, 12% and 5.9% on alert, 33.5% and 36.3% resting, 35.3% and 23.2% in comfort/maintenance, and 7.5% and 5.1% in locomotion (Fig. 3). The average percent of time spent in interaction was <1% in both habitat types either year.

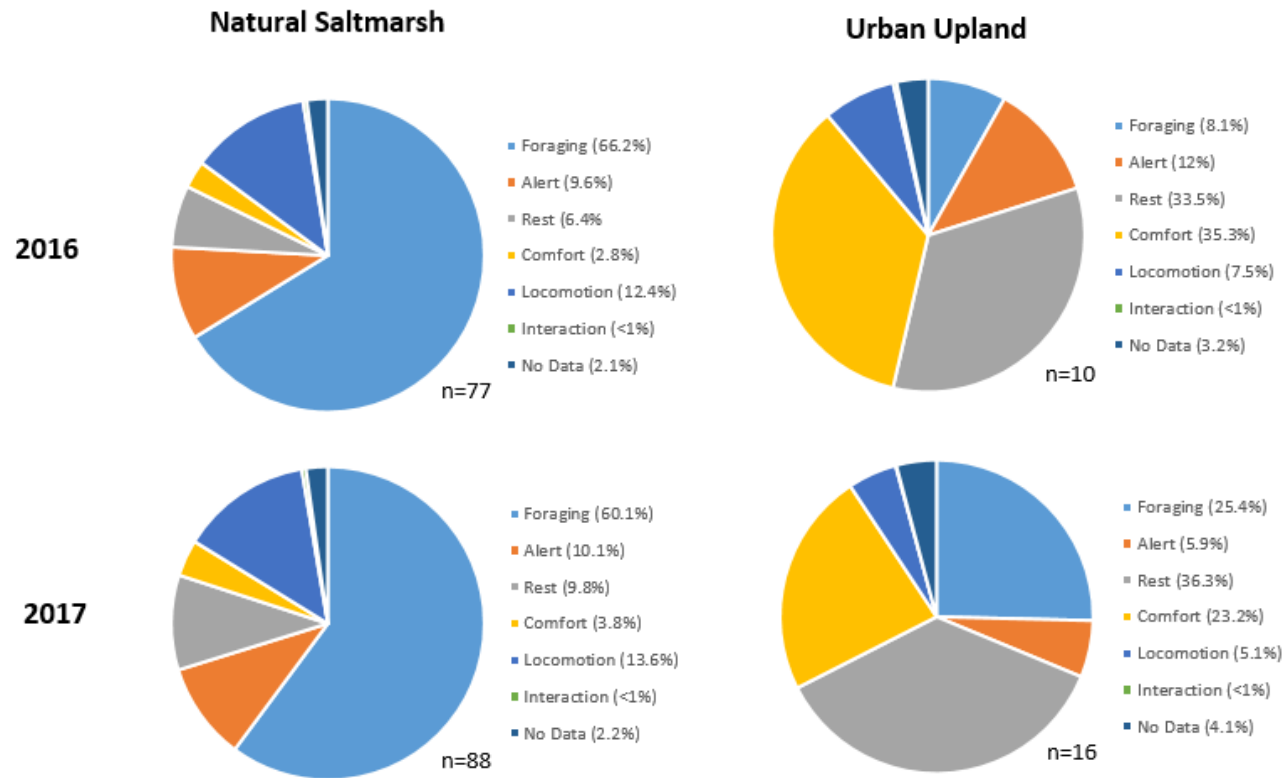


Figure 3. Comparison of average time activity budgets of observed Whooping Cranes by habitat type (natural and urban upland) and year (2016 and 2017). “Natural” observations occurred on cranes occupying saltmarsh territories at the Aransas National Wildlife Refuge and “Urban Upland” observations were conducted on cranes visiting game feeders on upland residential properties on the Lamar Peninsula.

During the two year study, the overall time activity budgets of Whooping Cranes observed in the two habitat types differed significantly ($F_{12,156}=2.186E67$, $P<0.001^{***}$; MANOVA). The significant difference in overall time activity budgets in natural and urban habitats is a result of very highly significant dissimilarity in the amount of time spent foraging, resting, in comfort/maintenance and locomotion ($P<0.001$, Kruskal-Wallis; Table 2). Cranes in natural saltmarsh habitat dedicated more time to foraging and locomotion, while cranes at urban game feeder sites spent more time resting and in comfort/maintenance activities (Fig. 4).

Table 2

Comparison of observed Whooping Crane behavior in natural saltmarsh and urban upland habitats by individual behavior category through Kruskal-Wallis.

Behavior Category	P value
Foraging	$P<0.001^{***}$
Alert	$P=0.069$
Rest	$P<0.001^{***}$
Comfort/Maintenance	$P<0.001^{***}$
Locomotion	$P<0.001^{***}$
Interaction	$P=0.6464$

*Note. $*P<0.05$, $**P<0.01$, $***P<0.001$. Fraction of time activity budget spent in each behavior was arcsine transformed.*

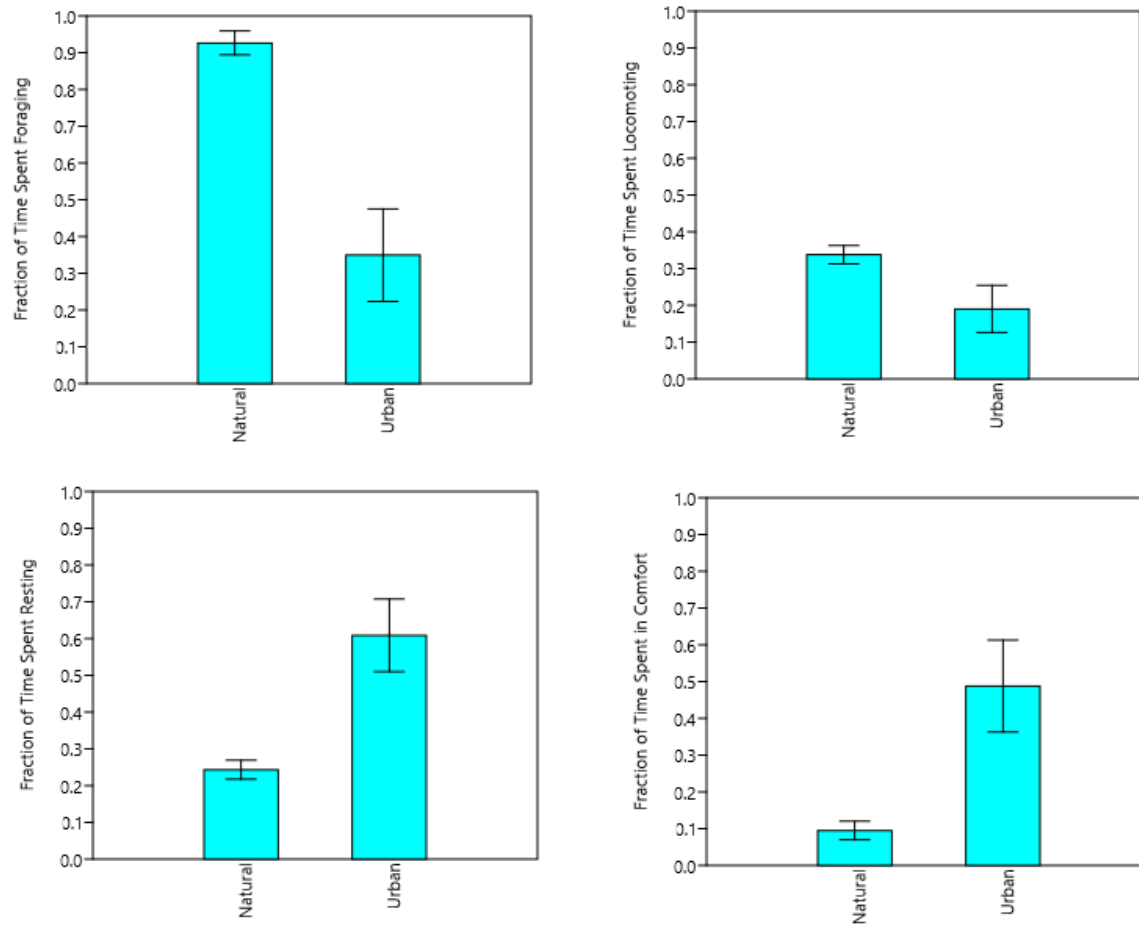


Figure 4. Bar charts with 95% CI of behavior categories in which Whooping Cranes spent significantly different amounts of time in saltmarsh territories (“Natural”) versus game feeders in urban upland habitats (“Urban”) Data represents the combined results of both sampling years (2016 and 2017), which was arcsine transformed.

Behavior as the winter season progresses. On average, the amount of time spent foraging consistently increased each sampling month both years (63.2% in January, 66% in February, and 69.8% in March of 2016; 49.9% in January, 62.6% in February, and 69.2% in March of 2017). Sampling month did not show a consistent effect on the fraction of time spent in any other the other behaviors besides foraging, and the increased time spent foraging each month was not significant in 2016 (Table 3). While behavior trends through time were not consistent across the two sampling years, there were, however, significant differences in the amount of time spent in certain behavior categories within a given year (Table 3).

Table 3

Kruskall-Wallis results comparing the fraction of time spent in each behavior category each month (Jan, Feb, and March) for 2016 and 2017.

Behavior	P value (2016)	Trend (2016)	P value (2017)	Trend (2017)
Foraging	0.6764	NA	<0.001***	Increase through time
Alert	<0.01**	Higher in Feb.	0.5548	NA
Rest	<0.01**	Lower in Feb.	0.01**	Decrease through time
Comfort/maintenance	0.6927	NA	<0.001***	Higher in Jan.
Locomotion	0.0749	NA	0.0307*	Higher in Feb.
Interaction	0.1786	NA	0.01**	No Interaction in March

*Note. No variance in time spent in interaction in 2016 or 2017. * $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$. Fraction of time spent in each behavior category was arcsine transformed.*

Juvenile versus adult behavior. In 2016, behavioral surveys were conducted on 64 adult and 13 juvenile individuals in natural saltmarsh habitat, and 66 adults and 22 juveniles were observed in 2017. As the “juvenile” age group only refers to cranes born earlier that year, the large disparity in sample sizes between the two age groups was unavoidable. Analyses of the comparison between overall adult and juvenile Whooping Crane behavior through 2x7 MANOVA’s showed that behavior was statistically different between the two age groups in both 2016 and 2017 ($F_{7,69}=2.513$, $P=0.02317$ and $F_{7,80}=2.858$, $P=0.0103$, respectively). However, Kruskal-Wallis tests of each individual behavior category between the two age groups revealed that the only specific behavior in which they significantly varied was in the amount of time spent on alert (Table 4); adults spent significantly more time on alert than juveniles both years (Fig. 5).

Table 4

Kruskal-Wallis comparing fraction of time spent in each behavior category by adult and juvenile Whooping Cranes in 2016 and 2017.

Behavior	P value (2016)	P value (2017)
Foraging	0.4038	0.0906
Alert	0.01**	<0.01*
Rest	0.1758	0.5205
Comfort/maintenance	0.5280	0.0352*
Locomotion	0.4168	0.2204
Interaction	0.7495	0.2094

*Note. Fraction of time spent in each behavior category arcsine transformed. * $P<0.05$, ** $P<0.01$, *** $P<0.001$.*

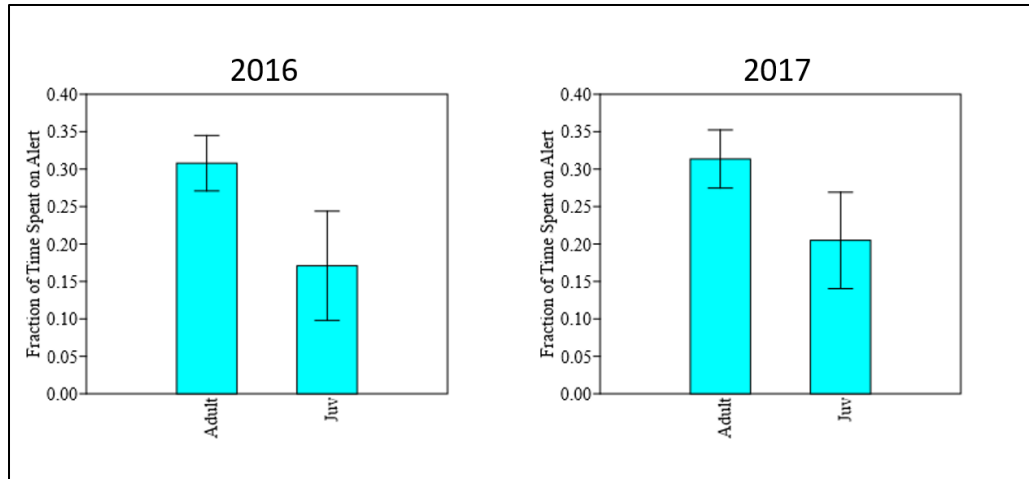


Figure 5. Bar charts with 95% CI of the fraction of time spent on alert by adult and juvenile Whooping Cranes observed at the Aransas National Wildlife Refuge in 2016 and 2017. Fraction of time spent on alert was arcsine transformed.

Juvenile behavior through time. Due to the aforementioned relatively lower abundance of juvenile cranes compared to adult cranes present in the sample region, less than ten juveniles were observed each of the six sampling months (Table 5). On average, the time juvenile cranes spent resting decreased as the year progressed in 2016, but not significantly; this was the only temporal trend in the average amount of time spent in any behavior category by juveniles either year. The amount of time spent in locomotion significantly varied per month in 2016 ($P=0.0328$, Kruskal-Wallace) and time spent on alert each month significantly varied in 2017 ($P=0.0278$, Kruskal-Wallace; Table 6); less time was devoted to locomotion in February than in January and March of 2016, and more time was spent on alert in March than in January of 2017.

Table 5

Number of observational surveys conducted on juvenile Whooping Cranes per sampling month.

Year	Month	N
2016	January	3
	February	6
	March	4
	Total	13
2017	January	9
	February	6
	March	7
	Total	22

Note. Observations conducted on cranes in saltmarsh territories at the Aransas National Wildlife Refuge by boat via the Gulf Intra-Coastal Waterway.

Table 6

Kruskall-Wallis significance results of the variance in time spent by juvenile Whooping Cranes in each behavior category each month (Jan, Feb, and March). Data was arcsine transformed.

Behavior	P value (2016)	P value (2017)
Foraging	0.2024	0.1287
Alert	0.6409	0.0278*
Rest	0.6986	0.1081
Comfort/maintenance	0.7781	0.3113
Locomotion	0.0328*	0.2432
Interaction	0.5580	0.0612

*Note. *P<0.05, **P<0.01, ***P<0.001.*

Discussion

Wintering Red-crowned Cranes have been observed to spend more time on alert when utilizing highly populated urban areas (Wang *et al.* 2011). The Whooping Cranes spending time in urban upland sites in this study, however, did not spend more time on alert than the cranes observed in their natural saltmarsh territories. Cranes in urban upland sites are in close proximity to people, cars, dogs and cattle, but the vegetation of the generally flat residential properties is relatively short and often maintained by mowing, allowing them a clear view of their surroundings. Cranes in their natural saltmarsh territories are also subjected to sporadic vehicular traffic, but in the form of boats and barges along the Gulf Intracoastal Waterway. While cranes in their natural territories are not in such close proximity to humans nor encounter domestic dogs and cattle, they are always susceptible to predation by their natural predators (e.g., coyotes, bobcats), and are in habitats with relatively higher vegetation and variable elevation. Unlike the cranes at urban upland sites, those in their natural territories have the ability to utilize auditory cues of incoming predators relayed by standing water in the marsh. The similar amount of time spent on alert by cranes in urban upland sites and natural territories may indicate that while the types of disturbances, predators, and predator detection mechanisms vary between the two habitat types, they are overall matched in the level of security as perceived by the cranes.

The time activity budgets of wintering Whooping Cranes observed in their saltmarsh territories in this study were comparable to earlier studies conducted in a similar fashion at the Aransas NWR (Chavez-Ramirez 1996; Lavever 2006). Cranes observed in their natural saltmarsh territories spent more time foraging and in

locomotion, two energy consumptive behaviors, than those visiting game feeders in urban upland sites. Whooping cranes occupying their natural territories must actively forage for food items throughout the dynamic saltmarsh landscape. In contrast, cranes visiting game feeders at urban upland sites are provided corn every time the feeder dispenses, which is quickly and easily consumed. With much less of their time being dedicated to foraging, the cranes in urban upland sites spent significantly more time resting and in comfort/maintenance activities, two relatively energy conservative behaviors, than those in their natural territories. As the feeders are situated in the homogenous lawns of residential properties, it is likely that there are not many other food items for the cranes to find and eat as they wait for the corn to be dispensed again. Therefore, foraging for non-corn resources between dispenses is likely to consume more energy than would be gained. Wintering Common Cranes exploiting cereal farmlands in Spain were observed to leave a foraging patch when their energy intake rate decreased below that required to meet their daily energy requirements (Alonso 1995). This observation in Common Cranes, in addition to the consistent use of and long duration of time spent sitting by game feeders in urban upland sites, could indicate that the cranes visiting these sites are meeting their daily energy requirements, even when the flight to and from the game feeder is energetically costly. However, energetically speaking, spending the day at a game feeder may not be worth the trip for cranes with territories that are not in close proximity to the urban upland sites. Also, it is important that wintering AWB Whooping Cranes exceed their daily energy requirements, not simply meet them.

A crane's net daily energy budget dictates how much energy is stored as fat, and these energy reserves are necessary for successful spring migration, and can influence

that year's subsequent reproductive effort (Gil de Weir 2006; Gil de Weir *et al.* 2012). By foraging less and devoting more time to energy conservative activities, cranes in urban upland sites expended less energy than those in natural sites. Even though they are reducing their daily energy expenditure by sitting at game feeders in urban upland sites, the cranes in their natural saltmarsh territories are consuming a larger variety of food items, which are likely to be of higher nutritional value than the corn dispensed from the feeders. As the majority of the birds observed at the urban sites are not banded, it is impossible to monitor which individuals are visiting the game feeders and at what frequency, and whether these individuals experience any negative consequences after they leave their wintering grounds.

Siberian Cranes have been documented to forage in novel habitats when their preferred food item is not available (Burnham *et al.* 2017; Jia *et al.* 2013); are Whooping Cranes visiting the urban game feeders due to low food availability within their own territory, or simply because their territories are close by? Like the Whooping Cranes at game feeders in this study, Siberian Cranes also exhibited a decrease in the amount of time spent foraging while visiting unconventional habitats compared to when they are in their historically preferred foraging habitats (Jia *et al.* 2013), and there was an observed decrease in the number of juveniles that arrived at their wintering grounds the following year (Burnham *et al.* 2017). Therefore, there is increased merit in future efforts to band the individuals visiting the game feeders to investigate their subsequent reproductive success. If individuals spending their winter days at a game feeder experience a significant decrease in fecundity, this information could be considered in future

population management decisions. Without these birds being banded, there is currently no way to track which territory they return to at the end of the day.

Similar to the wintering Whooping Cranes observed in this study, an increase in the amount of time spent foraging as the winter season progresses and spring migration nears has also been observed in Hooded Cranes (Zhou *et al.* 2010). This phenomenon could be driven not only by the looming energetically expensive migration, but could also be a result of a decrease in food item density as the amount of time the cranes have foraged in their territory increases. The increased amount of time spent foraging each month by the wintering Hooded Cranes coincided with a sequential decrease in the amount of time spent on alert each month (Zhou *et al.* 2010). The significant increase in foraging through time by the Whooping Cranes observed in this study in 2017 coincided with a significant decrease in time spent resting each that year. As the cranes increased the amount of time spent foraging each month, it is logical that they had increasingly less time to devote to other behaviors as the season progressed, and the difference in the behavior chosen to sacrifice by Hooded and Whooping Cranes could be a reflection of a vast difference in the ecologies of their respective wintering grounds.

Whooping Cranes sleep and nest in the middle of shallow open bodies of water, increasing their ability to receive auditory cues of potential incoming predators (Folk *et al.* 2014); therefore, it is very possible that the amount of time Whooping Cranes spend on alert is at least partially driven by water level. In fact, the amount of time spent on alert in winter 2016 was highly correlated to shifts in bay water levels; when water level was particularly low in February compared to January and March, the cranes spent significantly more time on alert. This could possibly be explained by the cranes needing

to spend more of their time on alert when there was less standing water in the marsh to act as their alarm system. Regardless of the drivers behind the elevated amount of time spent on alert in February 2016, there was also a significant decrease in time spent resting that month, possibly due to the increased amount of time dedicated to alert.

The trend of adults spending more time on alert than juveniles has also been observed in wintering Hooded Cranes (Li *et al.* 2015; Zhou *et al.* 2010) and Common Cranes (Avilés 2003). In contrast to this study, wintering juvenile Hooded Cranes and Common Cranes spent significantly more time foraging than adults (Avilés 2003; Zhou *et al.* 2010). In the Li *et al.* (2015) study of Hooded Cranes, adults spent significantly more time on alert than juveniles during one winter (2013-2014), but not the other (2012-2013). In addition, the juveniles only spent significantly more time foraging than adults during the winter where they spent significantly less time on alert (2013-2014; Li *et al.* 2015). In all the instances of juveniles both spending less time on alert and significantly more time foraging than the adult birds across these three studies, there was a great discrepancy between the amount of time spent on alert between the two age groups, affording the juveniles more time to forage instead. In this study of Whooping Cranes, the juveniles spent significantly less time on alert but did not spend significantly more time foraging, but the discrepancy between the amounts of time spent on alert across the two age groups was much smaller.

Apart from the amount of time spent foraging, the general lack of differences in behavior between juvenile and adult Whooping Cranes in this study may also be an effect of the behavioral samplings being conducted in the second half of their wintering season (January, February, March). While juvenile Hooded Crane behavior was significantly

different from that of the adults early in the wintering season, there was not a significant behavioral difference between the two age groups by the end of the season (Zhou *et al.* 2010).

Of the six behavior categories, sampling month had a significant effect on juvenile Whooping Crane behavior on two behaviors: the amount of time spent in locomotion in 2016 and alert in 2017. The significantly different amount of time spent in these two behavior categories across months did not, however, sequentially increase or decrease as the winter season progressed, indicating that the transition of winter to spring was not the primary driver of the change in amount of time dedicated to these behaviors. The lack of obvious trends and/or significant differences between adult and juvenile behavior through time may be explained by the consistently small sample sizes of juveniles observed each month. The significantly different amount of time dedicated to alert and locomotion by juveniles across months was not reflected in analyses of behavior through time when all birds observed (combined adults and juveniles) were included. Therefore, if the discrepancy in the amount of time spent on alert and locomotion by juveniles was driven by an environmental factor instead of time, one would expect to see a similar response in the behavior of the adults, which was not the case. This supports the notion that juvenile sample size was simply too small. To enhance the juvenile sample size in the future, observations could be conducted on Matagorda Island, as the Blackjack Peninsula of the Aransas NWR can only provide territories for a limited number of mated pairs and therefore fewer juveniles.

Many of the behavioral trends of Whooping Cranes observed in their natural winter territories in this study have been seen in other wintering crane species. Deviations

in behavior from what has been observed in other wintering crane species often correlated to hydrological changes in the estuary. This illustrates that while wintering Whooping Cranes do share certain behavioral trends observed in other wintering crane species, the extraordinarily dynamic wintering grounds of the AWBP can sometimes skew their behavior into deviating from these trends. While we cannot control water level in the greater estuary, humans can manage the discharge of freshwater into the system. Here, enhanced freshwater inflows to coastal systems are critical to facilitate the availability of critical Whooping Crane resources and to stabilize the ecology of their saltmarsh territories, which influences their overall behavior while in their wintering grounds.

Acknowledgments

We thank the Earthwatch Institute for funding this research through a grant to J. Wozniak. We also thank the 54 citizen scientist volunteers who participated in the “Protecting Whooping Cranes and Coastal Habitats” Earthwatch expeditions of 2016 and 2017; the extent of data collected for this project would not have been possible without their hard work and dedication to conservation. We greatly acknowledge L. Smith and R. Kirkwood for their consistent dedication to supplementing our volunteer education programs. This project would not have been possible without the support of the US Fish and Wildlife Service at the Aransas National Wildlife Refuge through the allowance of permits and use of research facilities.

Literature Cited

- Alonso, J. C. and J. A. Alonso. 1992. Daily activity and intake rate patterns of wintering Common Cranes *Grus grus*. ARDEA 80: 343-351.
- Alonso, J. C., J. A. Alonso, L. M. Bautista and R. Muñoz-Pulido. 1995. Patch use in cranes: a field test of optimal foraging predictions. Animal Behaviour 49: 1367-1379.
- Avilés, J. M. 2003. Time budget and habitat use of the Common Crane wintering in dehesas of southwestern Spain. Canadian Journal of Zoology 81: 1233-1238.
- Bautista, L. M., J. C. Alonso and J. A. Alonso. 1998. Foraging site displacement in Common Crane flocks. Animal Behaviour 56: 1237-1243.
- Burnham, J., J. Barzen, A. M. Pidgeon, B. Sun, J. Wu, G. Liu and H. Jiang. 2017. Novel foraging by wintering Siberian Cranes *Leucogeranus leucogeranus* at China's Poyang Lake indicates broader changes in the ecosystem and raises new challenges for a critically endangered species. Bird Conservation International 2017: 1-20.
- Canadian Wildlife Service and U.S. Fish and Wildlife Service (CWS and USFWS). 2005. International recovery plan for the Whooping Crane. Ottawa: Recovery of Nationally Endangered Wildlife (RENEW), and U.S. Fish and Wildlife Service, Albuquerque, New Mexico. 162 pp.
- Chavez-Ramirez, F. 1996. Food availability, foraging ecology, and energetics of Whooping Cranes wintering in Texas. ProQuest Dissertations and Theses.
- Díaz, M., E. González, R. Muñoz-Pulido and M. A. Naveso. 1996. Habitat selection patterns of Common Cranes *Grus grus* wintering in Holm Oak *Quercus ilex*

- dehesas of central Spain: effects of human management. *Biological Conservation* 75: 119-123.
- Folk, M. J., A. R. Woodward and M. G. Spalding. 2014. Predation and scavenging by American alligators on Whooping Cranes and Sandhill Cranes in Florida. *Southeastern Naturalist* 13: 64-79.
- Gil de Weir, K. (2006). Whooping Crane (*Grus americana*) demography and environmental factors in a population growth simulation model. PhD dissertation. Texas A&M University.
- Gil de Weir, K. C., W. E. Grant, R. D. Slack, H. -H. Wang, and M. Fujiwara. 2012. Demography and population trends of Whooping Cranes. *Journal of Field Ornithology* 83:1-10.
- Jia, Y., S. Jiao, Y. Zhang, Y. Zhou, G. Lei and G. Liu. 2013. Diet shift and its impact on foraging behavior of Siberian Crane (*Grus leucogeranus*) in Poyang Lake. *PLoS One*. 8: e65843.
- Lafever, K. E. 2006. Spatial and temporal winter territory use and behavioral responses of Whooping Cranes to human activities. Master's thesis. Texas A&M University.
- Lee, S. D., P. G. Jabłoński and H. Higuchi. 2007. Wintering foraging of threatened cranes in the Demilitarized Zone of Korea: behavioral evidence for the conservation importance of unplowed rice fields. *Biological Conservation* 138: 286-289.
- Li, C., L. Zhou, L. Xu, N. Zhao and G. Beauchamp. 2015. Vigilance and activity time-budget adjustments of wintering Hooded Cranes, *Grus monacha*, in human-dominated foraging habitats. *PLoS ONE* 10: e0118928.

- Stehn, T. V. and F. Prieto. 2010. Changes in winter Whooping Crane territories and range 1950-2006. North American Crane Workshop Proceedings. University of Nebraska – Lincoln.
- United States Army Corps of Engineers (USACE). 2004. Waterborne commerce of the United States, Part 2. Waterways and Harbors Gulf Coast, Mississippi River System and Antilles. Institute for Water Resources. Alexandria, VA: U.S. Army Corps of Engineers, 344p.
- Wang, Z., Z. Li, G. Beauchamp and Z. Jiang. 2011. Flock size and human disturbance affect vigilance of endangered Red-crowned Cranes (*Grus japonensis*). Biological Conservation 144: 101-105.
- Wozniak, J. R., T. M. Swannack, R. Butzler, C. Llewellyn and S. E. Davis III. 2012. River inflows, estuarine salinity, and Carolina Wolfberry fruit abundance: linking abiotic drivers to Whooping Crane food. Journal of Coastal Conservation 16: 345-354.
- Zhou, B., L. Zhou, J. Chen, Y. Cheng and W. Xu. 2010. Diurnal time-activity budgets of wintering Hooded Cranes (*Grus monacha*) in Shengjin Lake, China. Waterbirds. 33: 110-115.

CHAPTER III

Environmental Assessment of Coastal Saltmarsh Habitat Quality

This thesis follows the style and format of *Waterbirds*.

Abstract

The saltmarshes of the San Antonio-Guadalupe River estuary on the Texas Gulf Coast provide critical wintering grounds to the Aransas-Wood Buffalo population of Whooping Cranes (*Grus americana*), the last remaining natural population of the endangered species. The mean sea level and salinity of the San Antonio Bay play a large role in dictating the distribution and availability of vital Whooping Crane resources, such as Blue Crabs (*Callinectes sapidus*), Carolina Wolfberry (*Lycium carolinianum*) and fresh drinking water. This study in part investigated how Whooping Crane food resources and water quality varied through time across the Aransas National Wildlife Refuge landscape from January through March in 2016 and 2017. Inter-site variability significantly exceeded intra-site variability in marsh pond salinity, but not in Blue Crab or red Carolina Wolfberry fruit density. Significant shifts in marsh pond salinity and Blue Crab density occurred over individual winter seasons during the study. When sites were pooled into regions along the Blackjack Peninsula, some sites within regions were hydrologically similar, however this trend was not consistent for all sample intervals. Future geospatial modeling of the region will be necessary to better understand which structural saltmarsh components yield profitable Whooping Crane habitat.

KEY WORDS: Aransas National Wildlife Refuge, Blackjack Peninsula, *Callinectes sapidus*, *Grus americana*, *Lycium carolinianum*, marsh hydrology, saltmarsh, San Antonio Bay, Whooping Crane.

Environmental Assessment of Coastal Saltmarsh Habitat Quality

Introduction

Estuarine ecology. Estuaries form a transition zone between riverine and marine environments, where freshwater runoff from the land mixes with the saltwater in the ocean and bays (Morrison and Greening 2011). Along the coastal margin, river outputs supply freshwater, sediment, nutrients, and organic matter to nearshore environments while the shallow waters create ideal conditions for a wide range of primary producers (Day *et al.* 2007). For this reason, estuaries are one of the most biologically productive ecosystems in the world, and are therefore relied upon heavily by both humans and a wide variety of other organisms (Day *et al.* 2013). For example, many aquatic species, including multiple fish and crab species, rely upon the relatively shallow, productive, sheltered waters of the estuary in order to complete their life cycle, while a diverse array of avian species call estuaries their home either seasonally, in passing during migration, or year-round. Estuaries possess a high diversity of habitat types and a rich community of specialized niches which support a broad distribution of many different types of birds. Environmental factors such as water depth and vegetation cover directly influence habitat type and result in birds selecting specific habitats based on their preferred food resources and foraging method along the tidal gradient (Takekawa *et al.* 2011).

Humans have colonized deltas and floodplains for thousands of years, exploiting their nutrient rich soils and easy access to freshwater for agriculture (Kennett and Kennett 2006). In 2011, it was calculated that 39% of the United States' population, approximately 123 million people, dwelled within coastal counties, which comprise less

than 10% of the area of the contiguous United States (United States Census Bureau 2011; NOAA 2012). To provide freshwater to these large coastal communities and growing populations further inland in the watershed, increased volumes of freshwater are being extracted for municipal and agricultural purposes year in and year out, with the global human population using an estimated 50% of the readily available freshwater runoff (Montagna *et al.* 2002). In addition to the previously mentioned linkages to estuarine health, freshwater inflows have a direct impact on estuarine salinity regimes, nutrient concentrations, and sediment transport into the system (Longley 1994). When freshwater inflows are diminished, hypersaline conditions can have detrimental effects on the aquatic organisms within the estuarine system, directly inhibiting primary production and subsequently impact food web dynamics at higher trophic levels throughout the estuary (Longley 1994). Coastal ecosystems are among both the most highly biologically productive and biodiverse areas in the world. The anthropogenic impacts and pressures imposed by urbanization (e.g., freshwater extraction, water column pollution, and coastal habitat loss) on estuaries threaten an astounding abundance and diversity of species globally.

Saltmarsh hydrology. A saltmarsh is a type of wetland characterized by halophytic grasslands emerging from deposited sediments along a saline body of water, which experiences regular fluctuations in water level (Mitsch and Gosselink 2007). In a coastal saltmarsh, the most substantial and regular fluctuations in water level are predominately driven by tides in the adjacent saline water body. For example, saltmarshes situated along a bay receive saltwater inputs from the bay when tides increase water levels; vice versa, an inundated, or hydrologically connected saltmarsh,

experiences outflow of marsh-waters when the tide turns and bay water levels recede. The salinity of the bay at time of inundation will dictate whether the saltmarsh receives an increase or decrease in water column salinity as a result of hydrological connectivity. Bay salinity is driven by a combination of factors, including freshwater inflows and internal circulation patterns. Once the saltmarsh is hydrologically disconnected from the bay, local precipitation events and evapotranspiration processes dictate the freshening or salinization of open marsh waters, respectively.

Study site. Along the Gulf Coast of Texas there are 7 major bay and estuarine systems (National Wildlife Federation 2004), all varying in the volume of freshwater inflow, watershed size and the degree of anthropogenic influence. Previous studies have shown that levels of freshwater inflows are the defining factor in dictating biological productivity within these Texas estuaries (Copeland 1966; Armstrong 1987). Generally, there is a predominantly diminishing precipitation gradient as you move from east to west within the state of Texas (Daly *et al.* 2008). Therefore, in Texas estuaries south of Galveston Bay, evaporation rates often exceed precipitation rates, resulting in exaggerated hypersaline conditions (Bianchi *et al.* 1999). In addition, the influence of urban growth in Texas has had a pronounced influence on coastal systems. The appropriation of freshwater permits within watersheds by the state of Texas can result in diminished freshwater flows reaching the coastline (National Wildlife Federation 2004), which has evoked great debate within the state on the necessity and ecological requirements for adequate freshwater inflows on the coast. This had lead the Texas Commission on Environmental Quality (TCEQ) to form the Basin and Bay Area Stakeholder Committee (BBASC) and the Basin and Bay Area Expert Science Team

(BBEST) which are tasked with the creation of Environmental Flows Recommendation Reports for several Texas estuaries.

Established as a National Wildlife Refuge by the US Fish and Wildlife Service in 1937, the coastal marshes of the Aransas National Wildlife Refuge (NWR) are part of an estuarine system receiving freshwater inflows from the Guadalupe and San Antonio River watersheds into the San Antonio Bay. The highly heterogeneous coastal landscape of the refuge is comprised of saltwater ponds, open bays, tidal creeks and high elevation marsh habitats, all experiencing unique fluctuations in hydrological connectivity to the estuary (Wozniak *et al.* 2012). The mean sea level of the San Antonio Bay is the main driver of the level of hydrological connectivity between the bay and coastal saltmarshes, and the salinity of the San Antonio Bay is largely influenced by freshwater inflows.

The hydrologically dynamic coastal marshes of the Aransas NWR and surrounding areas along the Texas Gulf Coast make up the sole wintering grounds of the Aransas-Wood Buffalo population of Whooping Cranes (*Grus americana*). In their wintering grounds, mated Whooping Crane pairs actively defend large territories averaging 172 ha in area (Stehn and Prieto 2010). Whooping Cranes along the Texas Gulf Coast have been observed to opportunistically feed on a wide array of food items, such as Blue Crabs (*Callinectes sapidus*), Carolina Wolfberry fruit (*Lycium carolinianum*), Razor Clams (*Tagellus plebius*), snails (*Melampus coffeus*), acorns (*Quercus virginiana*), crayfish (*Cambarus hedgpethi*) and assorted insects (Chavez-Ramirez 1996; Greer 2010; Hunt and Slack 1989).

Carolina Wolfberry fruit abundance peaks in the fall when the cranes first arrive at their wintering grounds and are eaten in large quantities; these berries provide the

cranes with an abundant food source that requires little foraging effort to obtain, which is much needed after completing an approximately 4,000 km migration (Chavez-Ramirez 1996; Greer 2010). Studies have shown that early in the wintering season Whooping Cranes primarily feed upon Carolina Wolfberry fruit as they are widely abundant at that time in the season (Chavez-Ramirez 1996; Lafever 2006; Wozniak *et al.* 2012). Even though Carolina Wolfberry plants are evenly distributed in Aransas NWR coastal salt marshes, different sites along the peninsula have been known to vary significantly in berry production (Butzler 2006). Wolfberry plants produce more fruit during the winter of years when mean summer salinities (June, July, August) were relatively low, which emphasizes the need to maintain substantial freshwater inflows into the San Antonio Bay year-round (Wozniak *et al.* 2012).

While they are known to consume many different types of food items, the Blue Crab is considered to be the most important source of protein and biomass for wintering AWB Whooping Cranes (Chavez-Ramirez 1996; Greer 2010). Blue Crabs are an especially important resource towards the end of the wintering season before the cranes migrate back to Wood Buffalo NP (Chavez-Ramirez 1996; Greer 2010); one study showed a significant non-linear relationship between low Blue Crab abundance towards the end of the winter season (March) and heightened mortality of Whooping Cranes (Pugesek *et al.* 2013). Relatively low salinities in the estuary are necessary to sustain the local Blue Crab population through the facilitation of larvae development and survival (Sandoz and Rogers 1944). While the cranes primarily utilize salt marsh habitat for foraging, it has also been widely observed that they will forage for clams in open bays, eat roasted acorns after a prescribed burn in upland habitats, foraging in adjacent

agricultural fields, and visit game feeders in nearby urban sites (Chavez-Ramirez 1996; Lavever 2006; Stehn 1992).

As the Whooping Cranes are not breeding during their time in coastal Texas, their daily activities revolve around consuming and storing as much energy as possible before their spring migration back to Canada (Chavez-Ramirez 1996). Since the act of flight is a very energetically expensive behavior (Chavez-Ramirez 1996), Whooping Cranes typically stay within the bounds of their saltmarsh territories; they most often leave to obtain resources that cannot be provided by their own territories. To enable individuals of the population to store sufficient amounts of energy during the winter season, it is crucial for their saltmarsh territories to exceed their daily energy requirements. Whooping Cranes at the Aransas NWR are also reliant upon sufficient freshwater inflows to provide relatively fresh drinking water, especially during periods of drought.

Objectives and hypotheses. The primary objective is to expand our knowledge on which combination of factors create high quality wintering Whooping Crane habitat. Due to microtopographic variations in elevation, large-scale hydrological events throughout the greater estuary can yield highly variable effects in different areas across the saltmarsh landscape. As the population of this territorial species continues to increase in population size and expand spatially across the region, more land will need to be acquired and protected to ensure their continued success and eventual downlisting. The identification of which saltmarsh territories consistently provide abundant food resources and fresh drinking water to Whooping Cranes throughout the winter season could contribute to the future prioritization of which areas should be acquired, maximizing the Whooping Crane conservation benefits gained per investment.

Question: How does salinity and the abundance of Blue Crab and Carolina Wolfberry fruit (critical Whooping Crane food resources) vary spatially and temporally throughout the winter season in coastal marshes at the Aransas NWR?

Hypotheses:

1. Inter-site variability in habitat quality will be greater than intra-site variability at a given point in time.
2. Habitat quality at a given site will change through time.
3. Overall habitat quality is patchy and will therefore vary spatially.

Methods

To assess the habitat quality of a given coastal saltmarsh territory, a habitat assessment was conducted at the location of a previous Whooping Crane behavioral survey conducted along the Blackjack Peninsula of the Aransas NWR. Each coastal territory was revisited within 5 days of the behavioral observation, performed opportunistically when the cranes were not currently utilizing that given area. Habitat assessments consisted of Carolina Wolfberry fruit, Blue Crab, water quality surveys, and data gathering of conditions in the greater estuary from public access sources (e.g., mean sea level, bay salinity, freshwater inflow rate, air temperature, monthly precipitation).

Carolina Wolfberry survey protocol. Carolina Wolfberry fruit abundance was surveyed by employing a combination of transect and quadrat sampling methods. The abundance of green and red wolfberry fruit was counted at each sampling point along a transect, each sampling point spaced 15m apart. Random sampling at each sampling point

along the transect line was achieved through the use of three, 1m² PVC quadrats spaced 10m apart (Fig. 6). This specific method, optimally performed with four people (persons “A”, “B”, “C” and a recorder), was developed as a rapid assessment technique to capture the variability/patchiness of wolfberry plants within each coastal territory. On average, each site could be surveyed in ~45 minutes. First, Persons A, B and C unraveled the pre-measured nylon rope and space themselves 10m apart from each other. Knots in the rope indicated the two ends and center of a given sampling point. Persons A, B, and C then placed their 1m² quadrats on the ground, lining up the center of their quadrat with their corresponding knot in the rope. Person B was responsible for relaying the GPS coordinates to the recorder. Persons A, B, and C then counted the number of red and green Carolina Wolfberry fruits within their 1 m² quadrat and reported the counts to the recorder. Person B then held one end of a measuring tape while the recorder walked out 15m straight ahead with the other end to determine the subsequent sampling point along the transect line. Persons A, B and C then advanced the 15m forward and repeated the sampling protocol at the next sampling point. Berry abundance was counted at a minimum of five sampling points along the transect, yielding a minimum of 15 samples per site as berry abundance was counted within three quadrats at each sampling point.

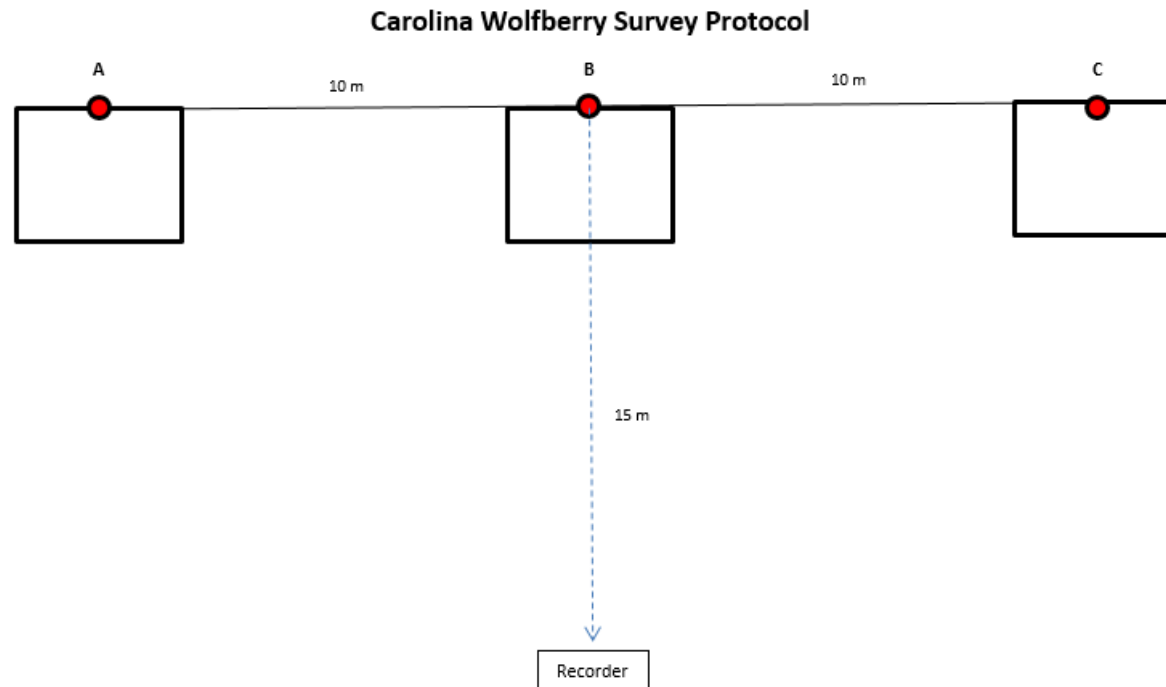


Figure 6. Conceptual diagram of Carolina Wolfberry fruit survey protocol, with the four people involved labeled as “A”, “B”, “C”, and “Recorder”. Persons A, B, and C, spaced 10m apart, count fruit abundance within their 1m² quadrat per replication, with the recorder documents their fruit abundance and GPS coordinates at each sampling point along the transect. Sampling points occur every 15m, with a minimum of 5 sampling points along a transect line per site

Blue Crab survey protocol. The availability of Blue Crabs within each coastal territory was assessed by a visual walking survey method along pond or tidal creek edges in sites where Whooping Crane behavioral surveys were previously conducted. At each site, a minimum of 300m of pond or tidal creek edge was surveyed. This method was employed most efficiently with three people (two surveyors and one recorder). The number of crabs along each waterbody edge were classified by size according to carapace width (small: <6cm, medium: 6-10 cm, or large: >10cm; Fig. 7). One surveyor was positioned 1m into the water from the edge while the other surveyor walked 1m out from the pond edge. Surveyors walked side by side at the same pace while conducting a survey. The recorder walked a few feet behind the surveyors and continuously measured the distance of pond edge surveyed at each site. In the case of small ponds (<100m), the whole pond was surveyed. The recorder walked behind the surveyors so to not influence the behavior of crabs prior to being surveyed.



Figure 7. Blue Crab size difference between each size class as measured by carapace width (left to right): large (>10 cm), medium (6-10 cm) and small (<6 cm).

Water quality sampling. The water quality (temperature, salinity, conductivity, and pH) of each saltmarsh waterbody surveyed for Blue Crabs was recorded using a YSI 556 handheld submersible sonde (YSI Incorporated, Yellow Springs, Ohio, USA). Water quality measurements were always collected at the end of a Blue Crab survey, to avoid creating an unnecessary source of disturbance prior to a Blue Crab survey. A total of 197 water quality samplings were measured across 55 sites throughout the study, averaging 3-4 water quality samplings per site.

Estuarine hydrology and local weather data collection. Mean sea level (m) data was collected by a remote water sampling station in Rockport, Texas (Station ID: 8774770) and retrieved from a NOAA public-access data base (tidesandcurrents.noaa.gov). Average Guadalupe River discharged rate (ft^3/s) near Spring Branch, Texas (Station ID: 08167500) data was sourced from a USGS data base (waterdata.usgs.gov). San Antonio Bay salinity (ppt) data was collected by a remote water sampling station at the Aransas NWR (GBRA1) operated by TCOON. Regional weather data, such as precipitation (cm), wind speed (m/s), and air temperature (C), was retrieved from Wunderground.com and collected by weather stations in Port Lavaca, Texas.

Data analysis. The relationship between estuarine water levels and average saltmarsh pond salinity/crab density during both winters was analyzed through multiple regression. As the data was not normally distributed, Kruskal-Wallis tests were used to compare inter-site versus intra-site variability in berry density, Blue Crab density, and salinity. To analyze how the habitat quality of a specific site changed through time, three sites per winter were identified which were consistently sampled during each month of a

given year. Kruskal-Wallis tests were then used to investigate shifts in berry density, Blue Crab density, and salinity throughout the winter at each of these sites. Lastly, to investigate the patchiness in habitat quality along the Blackjack Peninsula, salinity (ppt), conductivity (mS/cm) and water temperature (C) data gathered at each Blue Crab survey per site each month was Z-score transformed and plotted in PCA. The average PCA1 (x-axis) and PCA2 (y-axis) scores of each sample at a given site per month were then averaged to plot a PCA analysis of the average values at each site. To compare the similarity in habitat assessment results across sites each month, I calculated the distance between each site's average point on the 2D PCA plot ($\sqrt{((x_2-x_1)^2+(y_2-y_1)^2)}$). Sites less than 1 unit distance apart on the averaged PCA each month were deemed hydrologically similar and clustered together.

Results

Mean sea level (m) varied across months during both winters of the study, but mean sea level was only negative during environmental sampling periods during the months of February 2016 and February 2017 (Fig. 8, 9). Guadalupe River discharge rates ranged from 175-500 ft³/sec across sampling months (Jan-Mar) in 2016 and ranged 200-1,100 ft³/sec during 2017 sampling months (Fig. 10). During sampling months of 2016 and 2017, total monthly precipitation in the region ranged 1-6.65cm (Fig. 11). Average monthly temperatures of minimum, mean, and maximum daily temperature recordings revealed that each corresponding month in 2017 was slightly warmer than in 2016 (Fig. 12).

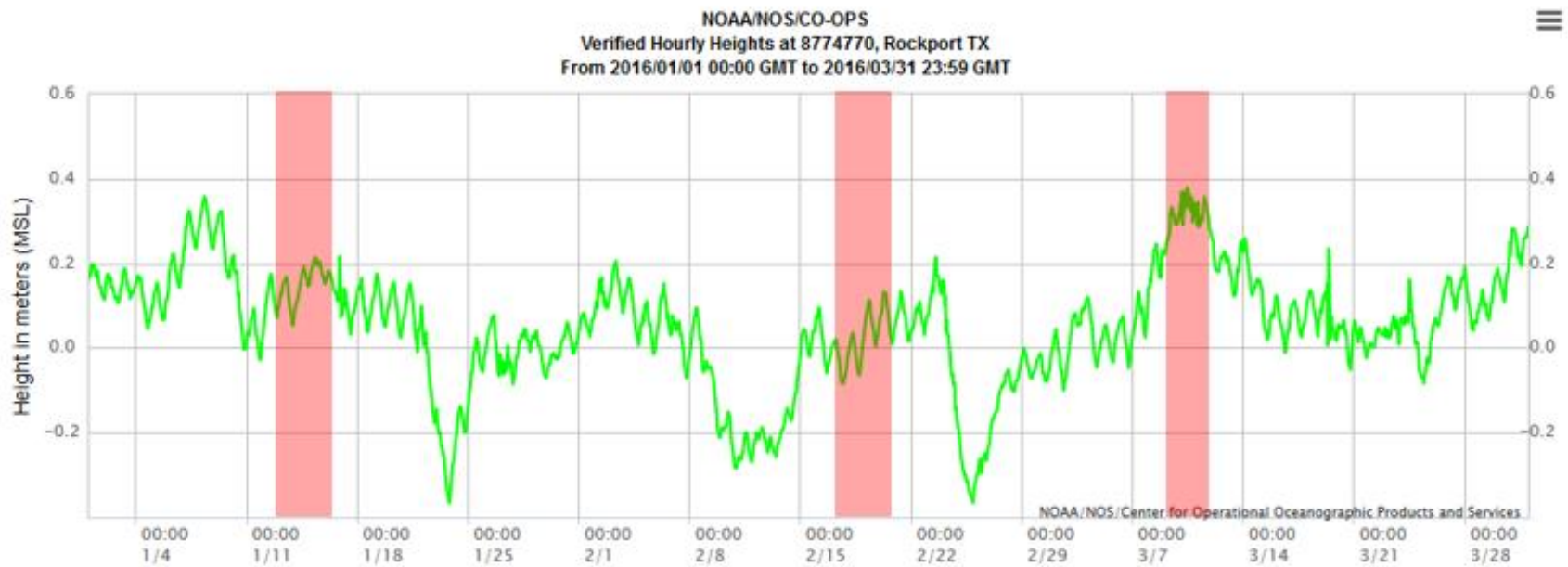


Figure 8. Mean sea level (m) of the San Antonio Bay as recorded at the NOAA water data collection station in Rockport, Texas (station ID#8774770) from January 1st-March 31st, 2016. Approximate monthly saltmarsh environmental data collection dates for this study are shaded in red.

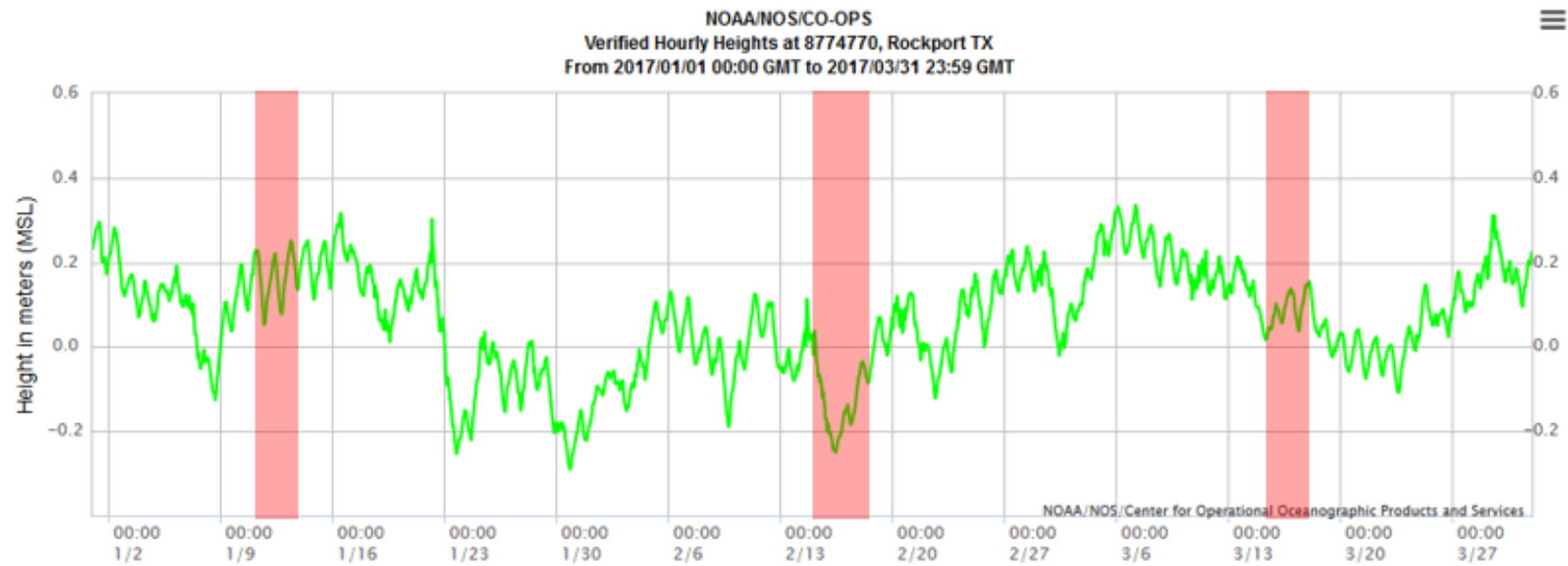


Figure 9. Mean sea level (m) of the San Antonio Bay as recorded at the NOAA water data collection station in Rockport, Texas (station ID#8774770) from January 1st-March 31st, 2017. Approximate monthly saltmarsh environmental data collection dates for this study are shaded in red.

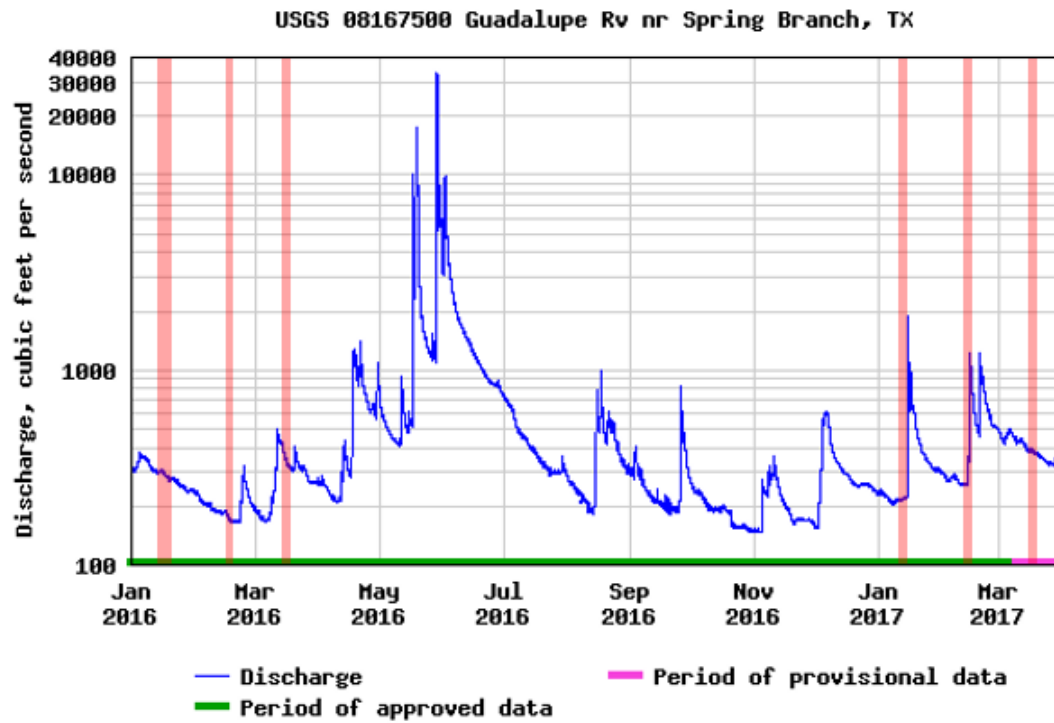


Figure 10. Daily average discharge rate of the Guadalupe River (ft^3/sec) from January 2016 to April 2017 as recorded by the USGS water data collection station in Spring Branch, Texas (Station ID#8167500). Approximate monthly saltmarsh environmental data collection dates for this study are shaded in red.

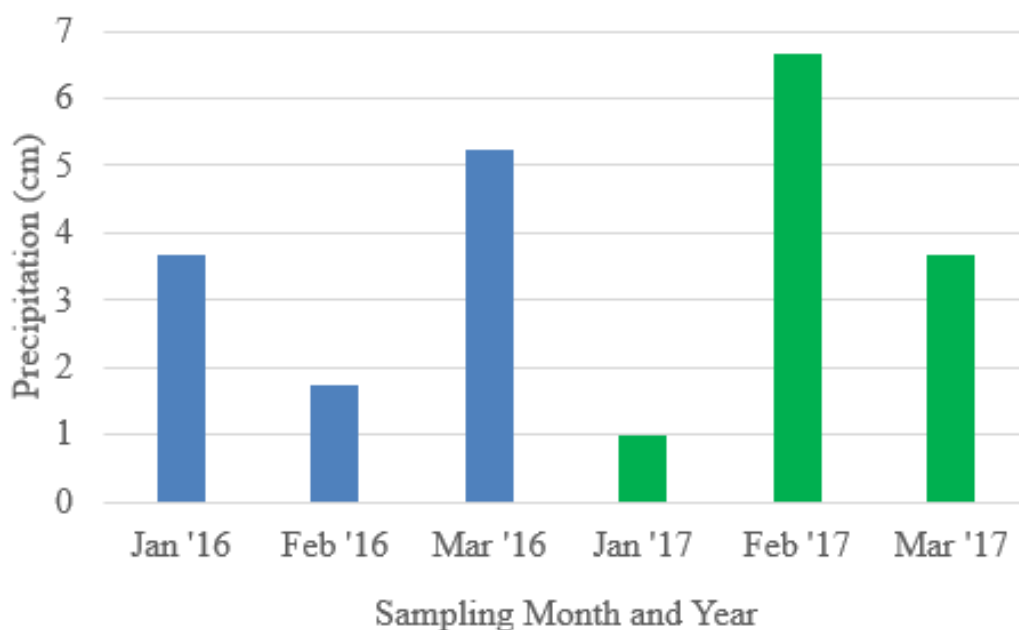


Figure 11. Total monthly (Jan-March) precipitation in Port Lavaca, Texas in 2016 and 2017 as reported by Weather Underground.

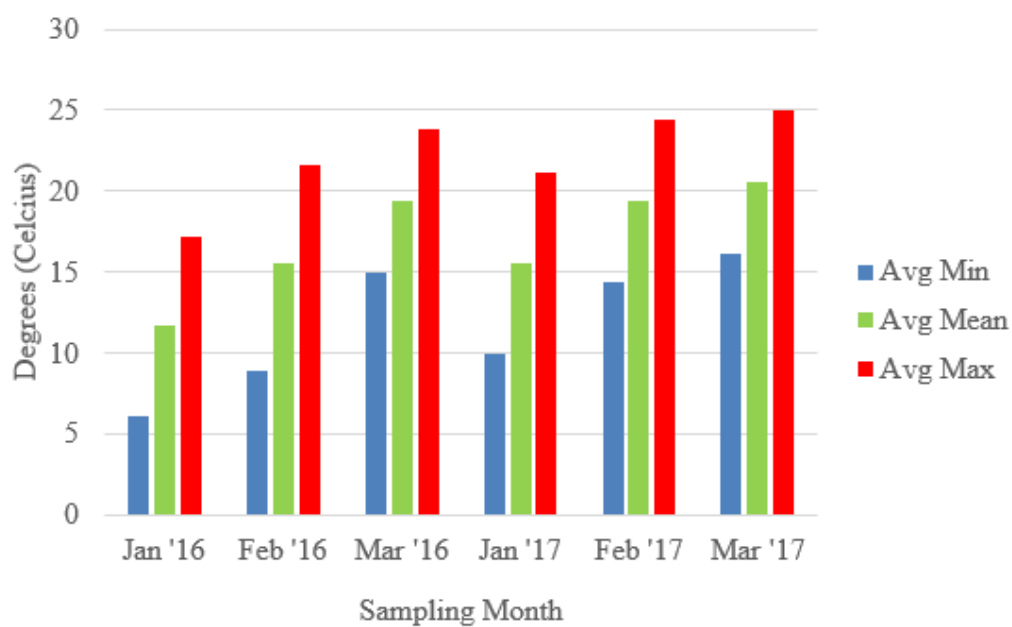


Figure 12. Monthly (Jan-March) average of daily minimum (blue), mean (green) and maximum (red) temperatures in 2016 and 2017 as recorded in Port Lavaca, Texas by Weather Underground.

In 2016, environmental assessments were conducted at 8 unique sites in January, at 10 sites February, and 9 sites in March (Fig. 13). In 2017, environmental assessments were conducted at 8 unique sites in both January and February, and 11 sites were sampled in March (Fig. 13). Three sites were repeatedly sampled during both 2016 (Boat Ramp, Rattlesnake Island, Dunham Marsh) and 2017 (Boat Ramp, South Sundown Bay, Ayer's Island; Fig. 14).

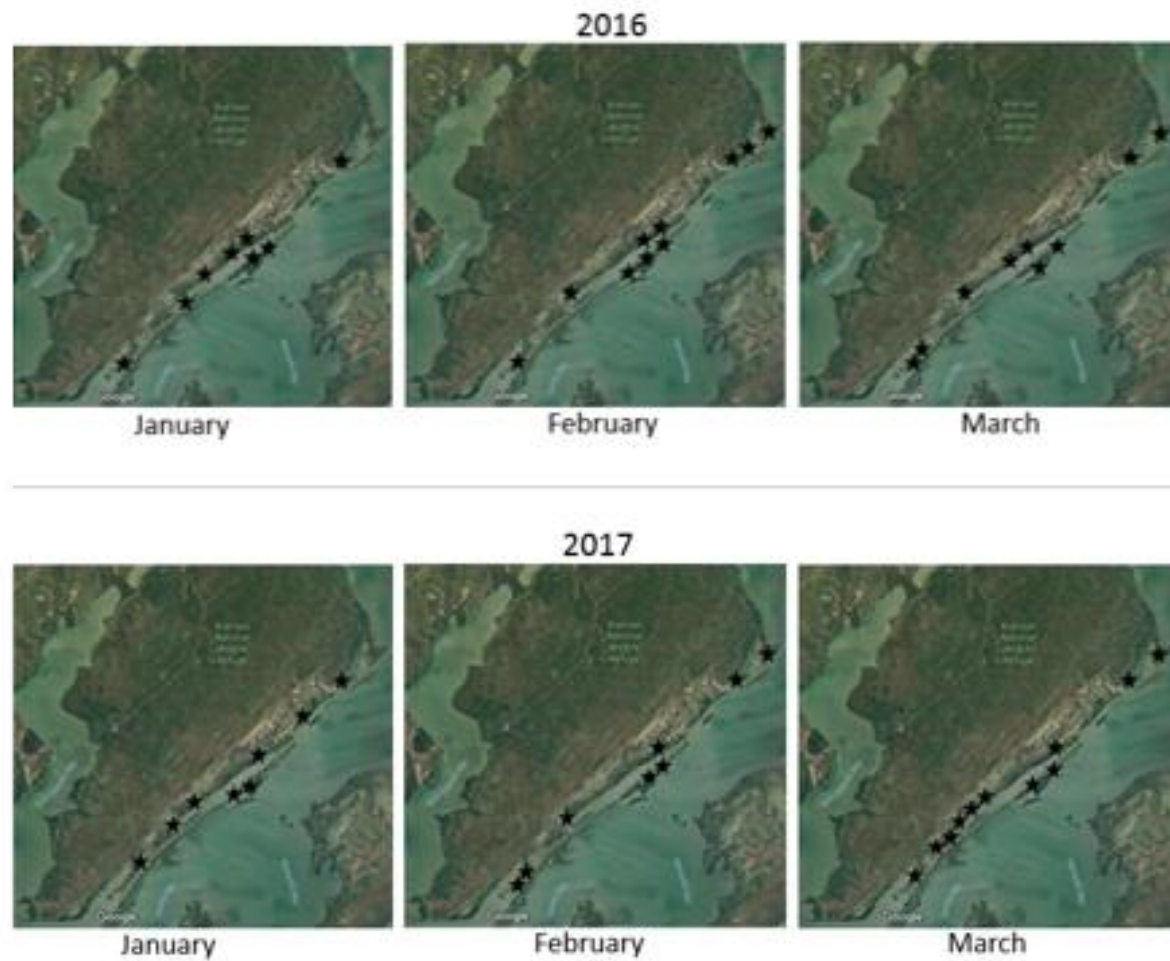


Figure 13. Location of sites where environmental assessments were conducted each month in 2016 and 2017.

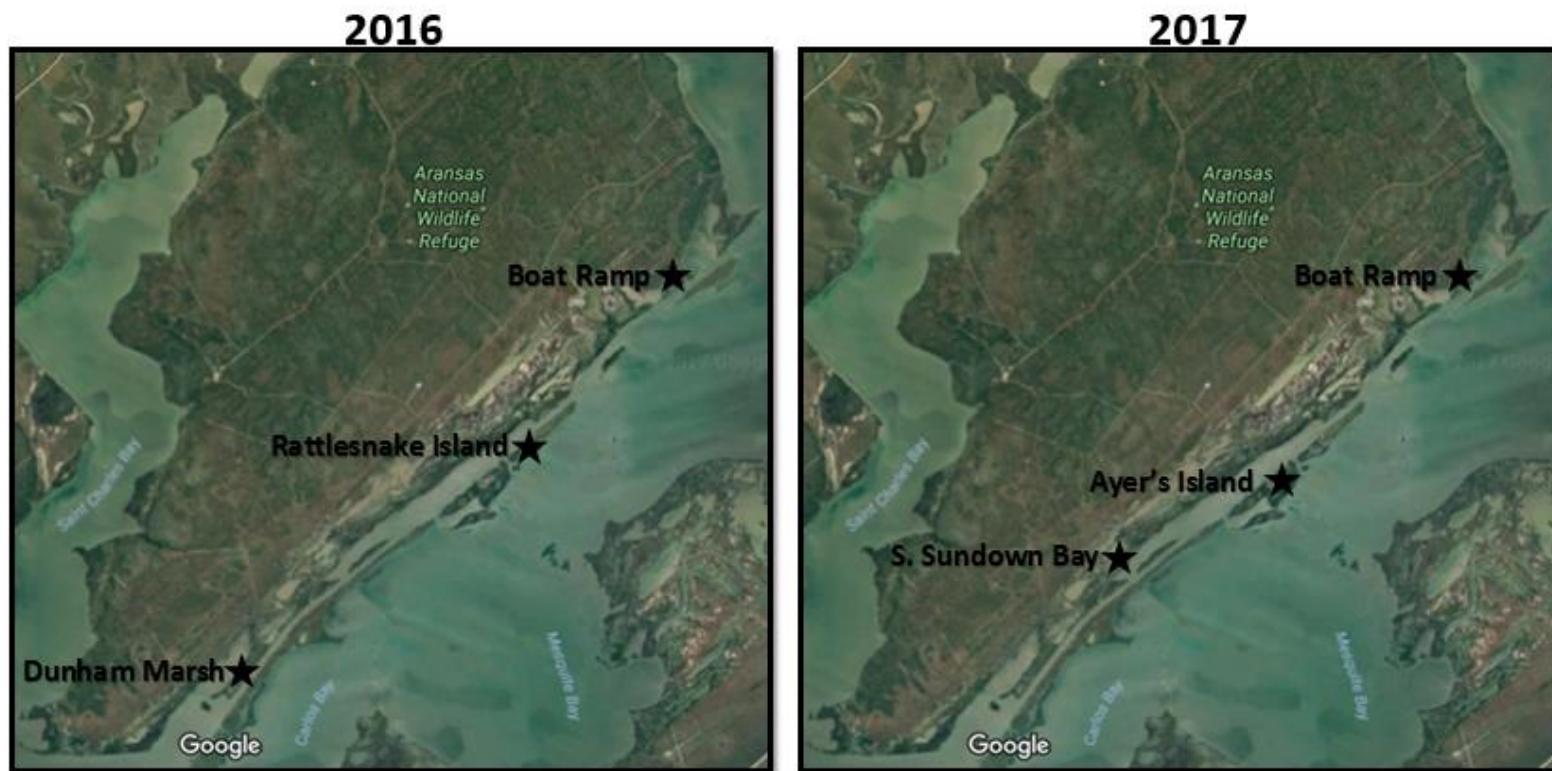


Figure 14. Name and location of the three sites in 2016 (left) and 2017 (right) that were repeatedly sampled each month (January, February and March) of that given year.

Inter-site versus intra-site variation. Of the six sampling months, inter-site variation in Blue Crab density per 100 meters was only significantly greater than intra-site variability during two months (January and February 2016), and inter-site variation in red Carolina Wolfberry fruit per square meter only exceeded intra-site variability during one sampling month (January 2016). Inter-site marsh pond salinity variabilities, however, were significantly greater than intra-site variability during every sampling month except March 2017 (Table 7).

Table 7

Kruskall-Wallis results comparing inter versus intra site variability in Blue Crab density (crabs/100m), red Carolina Wolfberry fruit density (red berries/square meter), and marsh pond salinity (ppt).

Month	Blue Crab Density P value	Red Fruit Density P value	Marsh Pond Salinity P value
Jan 2016	0.006**	0.023*	<0.001***
Feb 2016	0.034*	0.349	<0.001***
March 2016	0.301	0.344	<0.01**
Jan 2017	0.396	0.1375	0.014*
Feb 2017	0.2523	NA	0.029*
March 2017	0.2897	NA	0.4324

Note. * $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$.

Shifts in habitat quality over a winter season. The number of Blue Crab, water quality, and Carolina Wolfberry fruit density surveys varied at each site varied on a monthly basis (Appendix B). In 2016, Blue Crab density was elevated in the month of February at all three sites repeatedly sampled, but only significantly at Boat Ramp and Dunham Marsh ($P=0.017$ and $P=0.043$, respectively; Fig. 15, Table 8). In addition, marsh pond salinities were significantly higher at all three sites repeatedly sampled in February (Fig. 15, Table 8). Due to the small numbers of red Carolina Wolfberry fruit density in January and complete lack of red fruit in February and March at all three sites, red fruit density did not significantly vary by month (Fig. 15, Table 8).

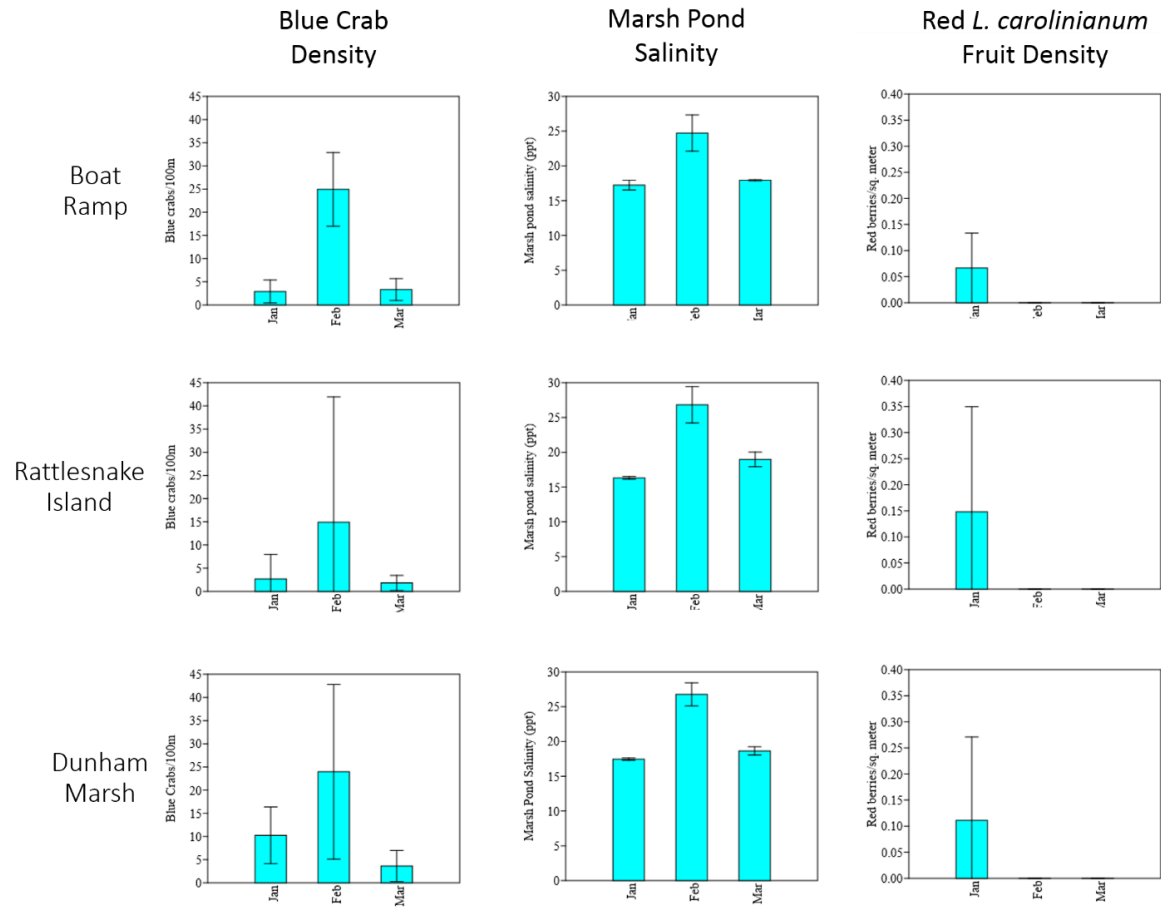


Figure 15. Bar charts with 95% CI of habitat quality through time (January, February, March) in 2016 at Boat Ramp, Rattlesnake Island, and Dunham Marsh sites. Refer to Figure 18 for the location of these sites, and the below table (Table 8) for statistical analysis.

Table 8

Kruskall-Wallis significance values for differences in Blue Crab density (crabs/100m), marsh pond salinity (ppt) and red Carolina Wolfberry fruit density (berries/meter²) for three sites that were assessed each sampling month (January, February, March) in 2016.

Site	Blue Crab Density	Marsh Pond Salinity	Red Fruit Density
Boat Ramp	P=0.017*	P=0.012*	P=0.183
Rattlesnake Island	P=0.667	P=0.005**	P=0.206
Dunham Marsh	P=0.043*	P=0.003**	P=0.148

Note. Sample sizes of each environmental parameter at each site per month are located in Appendix B.

Of the three sites repeatedly sampled each month in 2017, the Boat Ramp and South Sundown Bay sites saw significant changes in all three environmental parameters (Blue Crab density, marsh pond salinity, red fruit density), while the Ayer's Island site experienced no significant monthly variation in any of the environmental parameters. Marsh pond salinities were higher in January and February than in March at Boat Ramp and South Sundown Bay (P=0.30 and P=0.049, respectively); the two sites did not, however, experience similar monthly shifts in Blue Crab density (Fig. 16, Table 9). While both Boat Ramp and South Sundown Bay had higher Blue Crab densities in January than in March, not a single Blue Crab was counted during February surveys at South Sundown Bay, which is when Boat Ramp had the highest average Blue Crab density (Fig. 16). Even though there were no red Carolina Wolfberry fruit found at any of the sites repeatedly sampled during the months of February and March, as observed in 2016, relatively high red fruit densities observed in January at Boat Ramp and South Sundown Bay resulted in statistically significant monthly variation in that metric at both sites (P=0.007 and P<0.001, respectively; Fig. 16, Table 9).

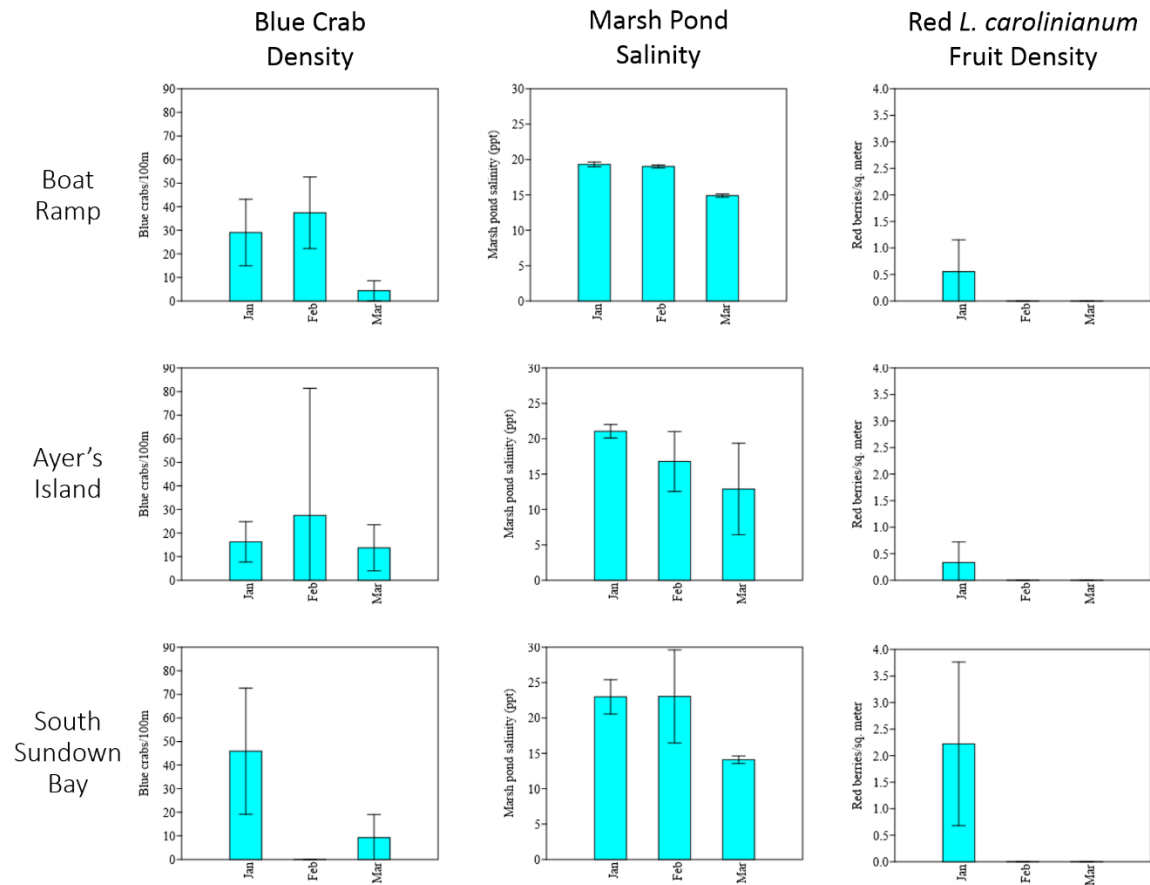


Figure 16. Bar charts with 95% CI of habitat quality through time (January, February, March) in 2017 at Boat Ramp, Ayer's Island and South Sundown Bay Sites. Refer to Figure 18 for the location of these sites, and the below table (Table 9) for statistical analysis.

Table 9

Kruskall-Wallis significance values for differences in Blue Crab density (crabs/100m), marsh pond salinity (ppt) and red Carolina Wolfberry fruit density (berries/meter²) for three sites that were assessed each sampling month (January, February, March) in 2017.

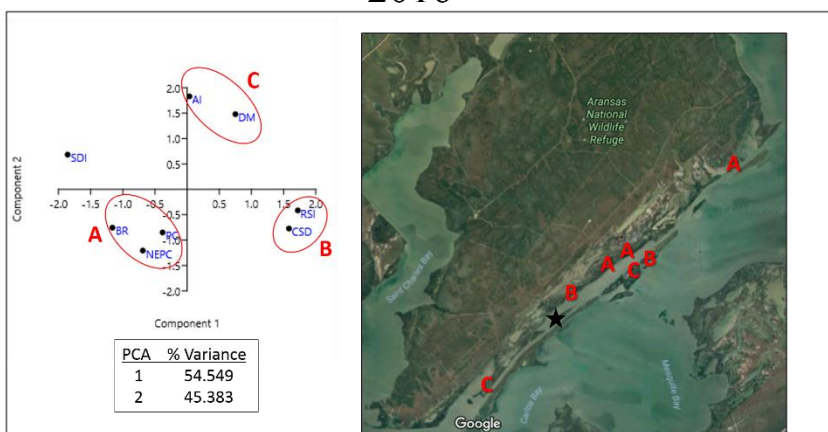
Site	Blue Crab Density	Marsh Pond Salinity	Red Fruit Density
Boat Ramp	P=0.039*	P=0.030*	P=0.007**
Ayer's Island	P=0.704	P=0.103	P=0.057
South Sundown Bay	P=0.024*	P=0.049*	P<0.001***

Note. Sample sizes of each environmental parameter at each site per month are located in Appendix B.

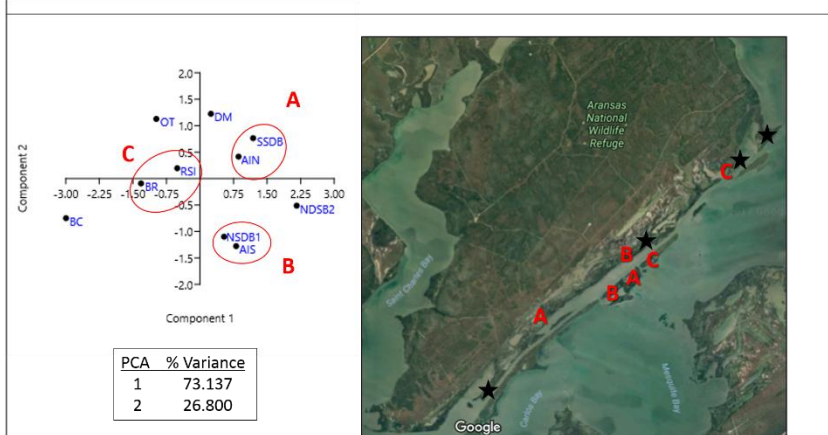
Water quality patchiness along the Blackjack Peninsula. The number of water quality samplings at each site per study month can be found in Appendix B. For this hypothesis, it was assumed that sites in close proximity to each other would be similar in habitat quality due to relatively shared distances from freshwater inflows into the bay, microtopography and the level of protection from the bay, but this was not always the case (Fig. 17, 18).

2016

Jan



Feb



Mar

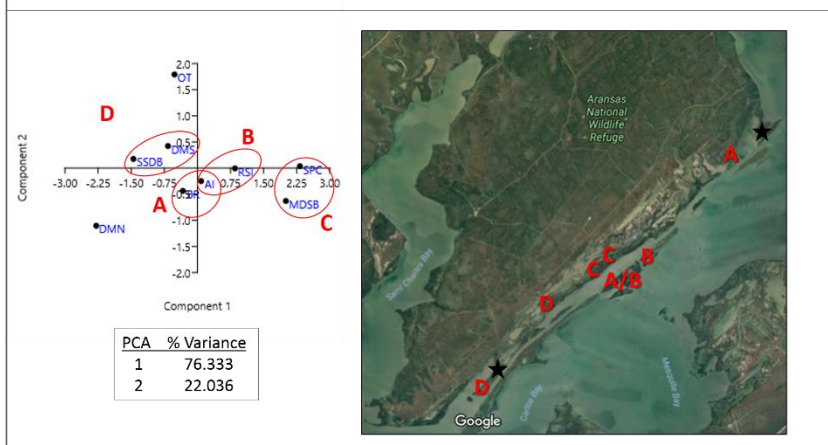
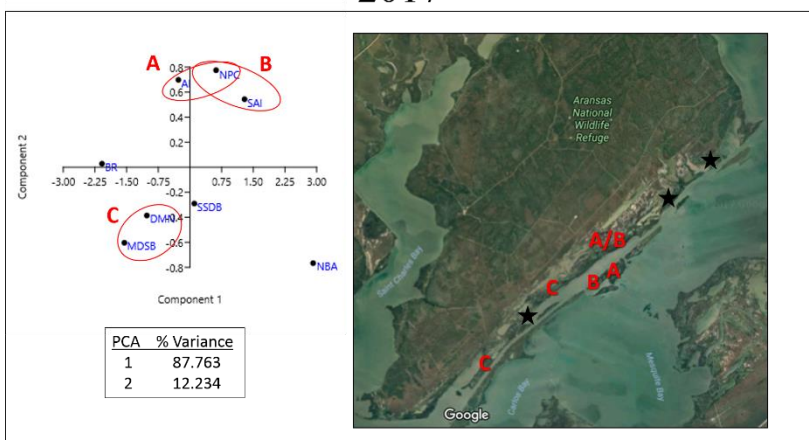


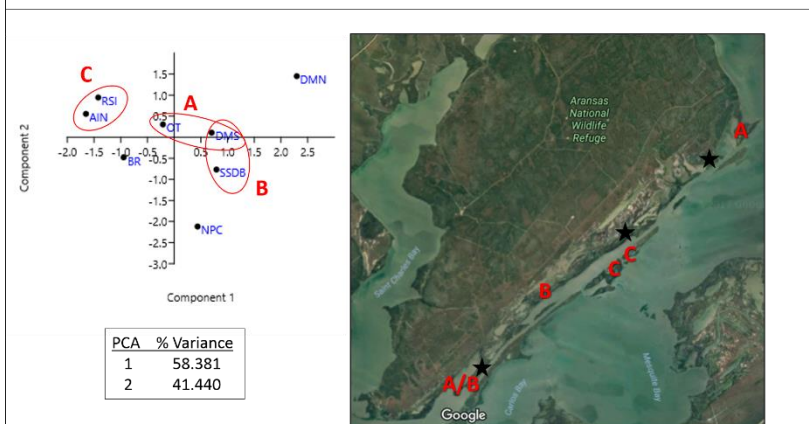
Figure 17. PCA of water quality (salinity, temperature, and conductivity) derived from averaged PCA1 (x-axis) and PCA2 (y-axis) values per site sampled each month in 2016, with sites having <1 unit distance between them circled and given an alphabetical cluster label (left), paired with the location of each site in a given cluster (sites not part of a cluster labeled as “X”; right). Water quality data in original PCA’s were Z-score transformed. The sample size at each site and site abbreviations per month can be found in Appendix C.

2017

Jan



Feb



Mar

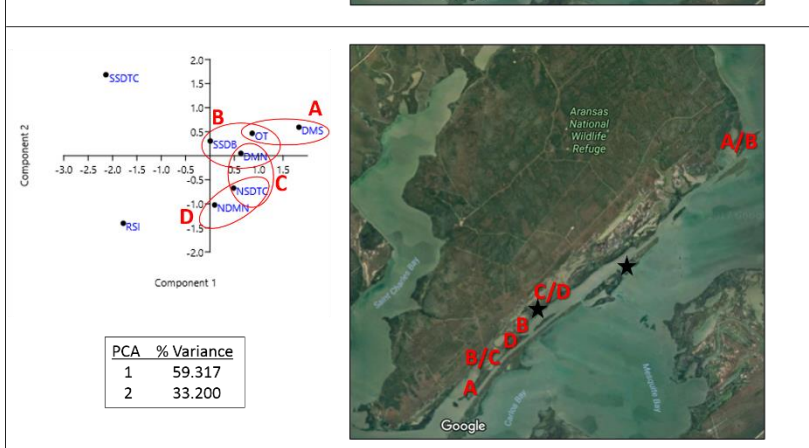


Figure 18. PCA of water quality (salinity, temperature, and conductivity) derived from averaged PCA1 (x-axis) and PCA2 (y-axis) values per site sampled each month in 2017, with sites having <1 unit distance between them circled and given an alphabetical cluster label (left), paired with the location of each site in a given cluster (sites not part of a cluster labeled as “X”; right). Water quality data in original PCA’s were Z-score transformed. The sample size at each site and site abbreviations per month can be found in Appendix C.

Across the six data collection months, five interesting results occurred more than once, with their locations described in Figure 19: the northeast half of Ayer's Island was not the most hydrologically similar to the southwest half of Ayer's Island, and the two halves were instead more similar to sites immediately across the GIWW in the Pump Canal region (Feb. 2016 and Jan. 2017; Fig. 19.1), adjacent sites within the Pump Canal region were most similar to each other (Jan. 2016 and Mar. 2016; Fig. 19.2), Boat Ramp, the northeastern-most site, was the most hydrologically similar to Dunham Marsh, the southwestern-most site (Feb. 2017 and Mar. 2017; Fig. 19.3), adjacent Rattlesnake and Ayer's islands were hydrologically similar to each other (Jan. 2016 and Feb. 2017; Fig. 19.4) and Dunham Marsh was hydrologically similar to the adjacent Sundown Bay Region (Mar. 2016, Jan. 2017, Feb. 2017 and Mar. 2017; Fig. 19.5).

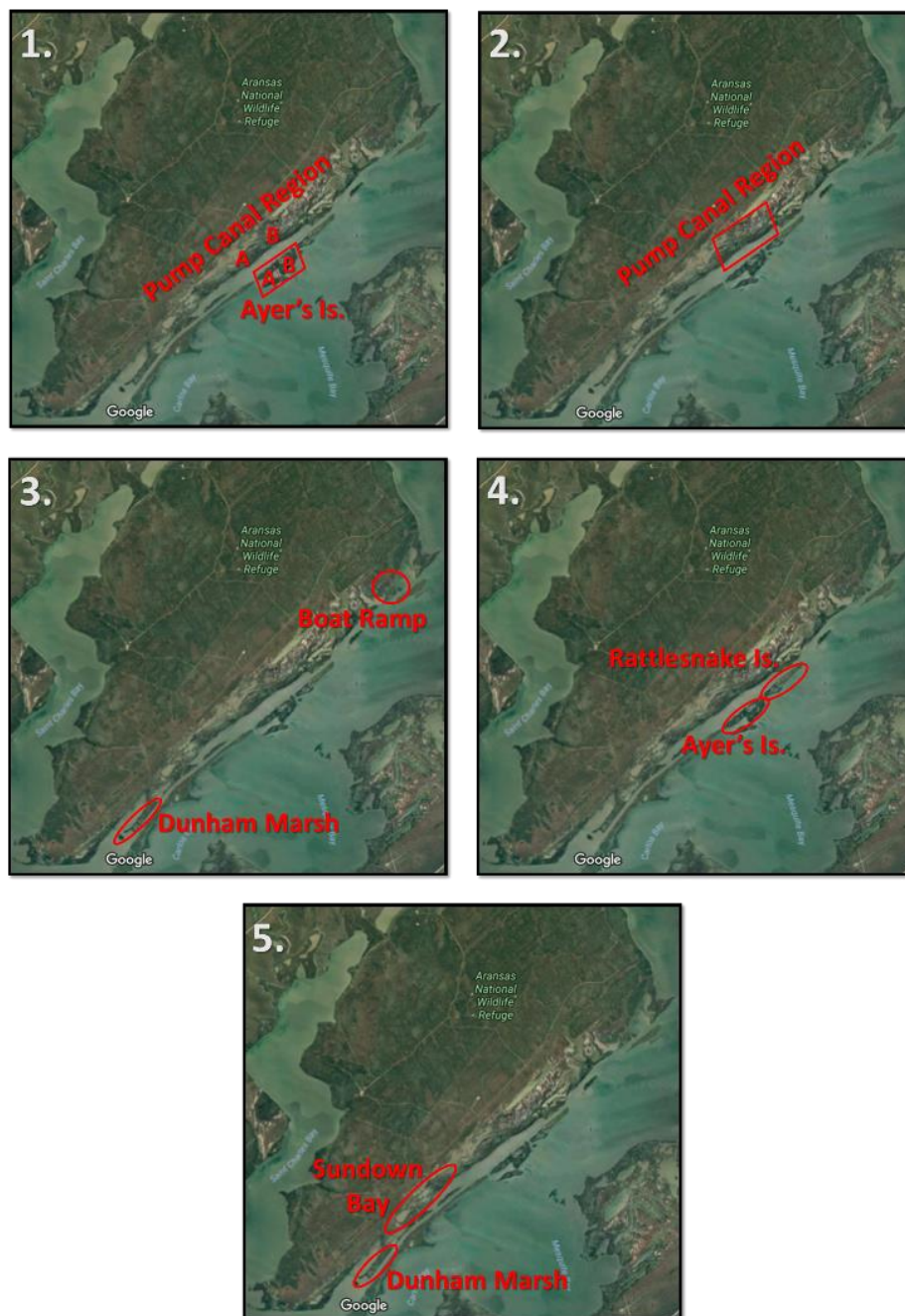


Figure 19. The locations of sites/regions where five notable trends of similar or dissimilar water quality parameters occurred during more than one of the six sampling months. 1) the northeast half of Ayer's Island was not the most hydrologically similar to the southwest half of Ayer's Island, and the two halves were instead more similar to sites immediately across the GIWW in the Pump Canal region, 2) adjacent sites within the Pump Canal region were most similar to each other, 3) Boat Ramp, the northeastern-most site, was the most hydrologically similar to Dunham Marsh, the southwestern-most site, 4) adjacent Rattlesnake and Ayer's islands were hydrologically similar to each other, and 5) Dunham Marsh was hydrologically similar to the adjacent Sundown Bay Region.

Discussion

Variability in pond salinity across sites is likely a result of the heterogeneous nature of the saltmarsh landscape. Physical pond attributes such as the hydrological classification, size, depth, distance from the bay, and pond edge/berm elevation can greatly impact evaporation rates, hydrological connectivity, and surface water quality. Significant variability in marsh pond salinities at different sites along the Blackjack Peninsula have also been observed in prior studies (Pugesek *et al.* 2008; Wozniak *et al.* 2012). The lack of variability in red Carolina Wolfberry fruit across sites corresponds to previous findings of generally similar marsh plant community composition across the Aransas NWR, and may also be an effect of the sampling occurring relatively late in its fruiting season, at a time when overall berry density is historically low (Butzler and Davis 2006). Even during peak fruiting season (October, November), sites along the Aransas NWR have not significantly varied in berry abundance in the past (Butzler 2006).

In general, Blue Crab density, water quality (salinity, conductivity, temperature), and Carolina Wolfberry fruit density varied across months at the three sites each year that were consistently sampled. As mentioned earlier, the habitat surveys in this study occurred relatively late in the Carolina Wolfberry's fruiting season, at a time when most of the plants are denuded of berries (Butzler and Davis 2006). Even though density was low, red berries were present at all three sites both years in the month of January, and no red berries were present at any of the sites in February or March either year. January red fruit density was only statistically higher compared to February and March when average January red fruit density exceeded 0.5 red berries/m² at Boat Ramp and South Sundown

Bay in 2017. If sampling had started in the fall during peak fruiting season (~September-November), a more obvious effect of time on fruit density may have been present across a sampling year, as has been previously observed (Butzler 2006).

In 2016, Blue Crab density (crabs/100m) was elevated in February at all three sites, but only significantly at two of the sites (Boat Ramp and Dunham Marsh). In addition, marsh pond salinities (ppt) were significantly higher at all three sites in February. In 2016, the three sites sampled each month generally experienced similar monthly shifts in Blue Crab density and marsh pond salinity, which were largely driven by fluctuations in the mean sea level in the estuary. When mean sea level was at its lowest point in February 2016, average marsh pond salinity and Blue Crab density increased at all three sites as a result of the disconnection with the San Antonio Bay. While the low water levels in February 2016 decreased the total area of inhabitable marsh for the Blue Crabs, effectively increasing their average density and making them easier to find and capture by the Whooping Cranes, the coinciding increase in marsh water salinity exceeded the threshold of suitable drinking water (~19-23ppt; E. Smith, personal communication) at all three sites. Therefore, even though the crabs became isolated and increased in density in saltmarsh territories, many of the cranes likely had to fly inland to access suitable drinking water from freshwater habitats, possibly nullifying any energetic gain from the increase in crab availability.

Multiple regression revealed that marsh pond salinities across all sites in 2016 correlated the strongest with mean sea level and San Antonio Bay salinity, and the salinity of marsh ponds at sites sampled in 2017 was primarily driven by bay salinity. While we cannot directly manage the water level of the San Antonio Bay, we can manage

the volume of freshwater inputs into the estuary. Leaving their saltmarsh territories in search of fresh water is energetically expensive and results in the cranes spending time in relatively unfamiliar habitats, increasing their vulnerability to predation. For Whooping Cranes to truly benefit from increased Blue Crab availability when water levels are low, the bay water inundating the marshes prior to the hydrological disconnection event must be fresh enough to be able to remain below 19-23ppt once isolated and susceptible to evapotranspiration until sea level rises again.

Data analysis found that sites in the Dunham Marsh area were most similar in water quality to sites in the adjacent Sundown Bay region during four of the six sampling months, and sites within the centrally located Pump Canal region were most similar to each other during two of the six sampling months. Also, adjacent Ayer's and Rattlesnake Islands were most similar in water quality in two of the sampling months. While these three trends may seem to roughly support the hypothesis, the Boat Ramp (northeastern-most) site was most comparable to Dunham Marsh (the southwestern-most site) and the northern half of Ayer's Island was dissimilar to the southern half of the island, with both phenomena observed two of the six months. This lack of a consistent general trend in water quality along the Aransas NWR coastal marshes indicates that inter-site structural variability does not necessarily occur along a linear gradient across the peninsula, and this structural variability may have a greater influence on water quality than an individual site's position along the Gulf Intracoastal Waterway.

Intra-seasonal shifts in mean sea level and salinity in the San Antonio Bay cause dramatic changes in the hydrological dynamics of coastal saltmarshes, largely dictating the distribution and availability of resources crucial to Whooping Cranes. To investigate

which structural components make one saltmarsh territory more plentiful in Whooping Crane resources than another, future geospatial modeling of the microtopographic variations along the Aransas NWR could be paired with the food density (Carolina Wolfberry fruit and Blue Crab) and marsh pond salinity data from this study. These environmental indicators of enhanced habitat quality could be applied to future land purchase, protection of existing lands, environmental easement, and restoration decisions. These steps may lead to the long-term conservation of coastal resources and preservation of key winter habitats throughout the region to support this increasing population of Whooping Cranes.

Acknowledgments

We thank the Earthwatch Institute for funding this research through a grant to J. Wozniak. We also thank the 54 citizen scientist volunteers who participated in the “Protecting Whooping Cranes and Coastal Habitats” Earthwatch expeditions of 2016 and 2017; the extent of data collected for this project would not have been possible without their hard work and dedication to conservation. We greatly acknowledge L. Smith and R. Kirkwood for their consistent dedication to supplementing our volunteer education programs. This project would not have been possible without the support of the US Fish and Wildlife Service at the Aransas National Wildlife Refuge through the allowance of permits and use of research facilities.

Literature Cited

- Armstrong, N. E. 1987. The ecology of open-bay bottoms of Texas: A community profile. Biological Report No. 85 (7.12). National Wetlands Research Center, Fish and Wildlife Service, US Department of the Interior.
- Bianchi, T. S., J. R. Pennock and R. R. Twilley. 1999. Biogeochemistry of Gulf of Mexico Estuaries. John Wiley and Sons, Inc. New York, New York.
- Butzler, R. E. 2006. Spatial and temporal patterns of *Lycium carolinianum* Walt, the Carolina Wolfberry, in the salt marshes of Aransas National Wildlife Refuge, Texas. Master's Thesis, Texas A&M University.
- Chavez-Ramirez, F. 1996. Food availability, foraging ecology, and energetics of Whooping Cranes wintering in Texas. ProQuest Dissertations and Theses.
- Copeland, B. J. 1966. Effects of decreased river flow on estuarine ecology. *Estuarine Ecology* 38: 1831-1839.
- Daly, J. W., M. Halbleib, J. I. Smith, W. P. Gibson, M. K. Doggett, G. H. Taylor, J. Curtis and P. P. Pasteris. 2008. Physiographically sensitive mapping of climatological temperature and precipitation across the conterminous United States. *International Journal of Climatology* 28: 2031-2064.
- Day, J. W., J. D. Gunn, W. J. Folan, A. Yáñez-Arancibia and B. P. Horton. 2007. Emergence of complex societies after sea level stabilized. *EOS Transaction, American Geophysical Union* 88: 169-170.
- Day, J. W., W. M. Kemp, A. Yáñez-Arancibia and B. C. Crump. 2013. *Estuarine Ecology*, 2nd edition. Hoboken, New Jersey: Wiley-Blackwell.

- Greer, D. M. 2010. Blue Crab population ecology and use by foraging Whooping Cranes on the Texas Gulf Coast. PhD dissertation, Texas A&M University.
- Hunt, H. E. and R. D. Slack. 1989. Winter diets of whooping and Sandhill Cranes in South Texas. *Journal of Wildlife Management* 53: 1150-1154.
- Kennett, D. J. and J. P. Kennett. 2006. Early state formation in Southern Mesopotamia: sea levels, shorelines, and climate change. *Journal of Island and Coastal Archaeology* 1: 67-99.
- Lafever, K. E. 2006. Spatial and temporal winter territory use and behavioral responses of Whooping Cranes to human activities. Master's thesis. Texas A&M University.
- Longely, W. L., ed. 1994. Freshwater inflows to Texas bays and estuaries: ecological relationships and methods for determination of needs. Texas Water Development Board and Texas Parks and Wildlife Department, Austin, TX. 386 pp.
- Mitsch, W. J. and J. G. Gosselink. 2007. *Wetlands*, 4th ed. John Wiley and Sons, Inc., Hoboken, New Jersey.
- Montagna, P. A., M. Alber, P. Doering and M. S. Connor. 2002. Freshwater inflow – Science, policy, management: *Estuaries* 25: 1243-1245.
- Morrison, G. and H. Greening. 2011. Chapter 6: Freshwater Inflows. Integrating Science and Resource Management in Tampa Bay, Florida. USGS.
- National Oceanic and Atmospheric Administration (NOAA). 2012. Spatial Trends in Coastal Socioeconomics. Demographic Trends Database: 1970-2010. Woods and Poole Economics, Inc. Projections Database 1970-2040. Available from: coastalsocioeconomics.noaa.gov.

- National Wildlife Federation (NWF). 2004. Bays in Peril: A Forecast for Freshwater Flows to Texas Estuaries. www.nwf.org.
- Pugesek, B. H., M. J. Baldwin and T. Stehn. 2013. The relationship of Blue Crab abundance to winter mortality of Whooping Cranes. *Wilson Journal of Ornithology* 125: 658-661.
- Sandoz, M. and R. Rogers. 1944. The Effect of Environmental Factors on Hatching, Moulting, and Survival of Zoea Larvae of the Blue Crab *Callinectes Sapidus* Rathbun. *Ecology* 25: 216-228.
- Stehn, T. V. 1992. Unusual movements and behaviors of color-banded Whooping Cranes during winter. *North American Crane Workshop Proceedings* 6: 95-101.
- Stehn, T. V. and F. Prieto. 2010. Changes in winter Whooping Crane territories and range 1950-2006. *North American Crane Workshop Proceedings*. University of Nebraska – Lincoln.
- Takekawa, J. Y., I. Woo, R. Gardiner, M. Casazza, J. T. Ackerman, N. Nur, L. Liu and H. Spautz. 2011. Avian communities in tidal salt marshes of San Francisco Bay: a review of functional groups by foraging guild and habitat association. *San Francisco Estuary and Watershed Science Journal* 9: 1-24.
- United States Census Bureau. 2011. Census 2010. Available from: factfinder2.census.gov/faces/nav/jsf/pages/index.xhtml.
- Wozniak, J. R., T. M. Swannack, R. Butzler, C. Llewellyn and S. E. Davis III. 2012. River inflows, estuarine salinity, and Carolina Wolfberry fruit abundance: linking abiotic drivers to Whooping Crane food. *Journal of Coastal Conservation* 16: 345-354.

CHAPTER IV

Does Wintering Whooping Crane Behavior Reflect Shifts in Habitat Quality?

This thesis follows the style and format of *Waterbirds*.

Abstract

The last remaining natural population of endangered Whooping Cranes (*Grus americana*) exclusively overwinter in saltmarsh territories along the Texas Gulf Coast. The primary objective of this study was to identify relationships between Whooping Crane habitat quality (primary food item density and marsh pond salinity) and observed behavior, with the goal of determining a non-invasive method to determine overall habitat quality through behavioral observations. Whooping Crane behavioral surveys were paired with habitat assessments of resource availability during the winters 2016 and 2017 at the Aransas National Wildlife Refuge. Whooping cranes observed in territories similar in resource availability did not consistently display similar behaviors, nor did their behavior consistently reflect shifts in resource availability across a given winter season. Whooping Crane behavior also did not significantly reflect time of day, observation distance, air temperature, or wind speed in the same manner across sampling months. Geospatial modeling of historically profitable Whooping Crane territories could provide an alternative method to help further define which saltmarsh structural features yield prime wintering habitats.

KEY WORDS: Aransas National Wildlife Refuge, behavioral ecology, *Callinectes sapidus*, *Grus americana*, time activity budgets, Whooping Crane.

Does Wintering Whooping Crane Behavior Reflect Shifts in Habitat Quality?

Introduction

Wading bird foraging success and hydrology. The term “wading birds” is used to define the group of birds that forage for food by wading in shallow water, which includes egrets, cranes, herons, ibises, storks and spoonbills. Water levels at which a particular wading bird species can forage in is largely a function of their leg length (Custer and Osborn 1978), and increasing water levels can result in loss of foraging habitat for shorter-legged species, and potentially decrease prey capture rates by increasing water turbidity (Kushlan 1981). An increase in aquatic prey density due to seasonal decreases in water levels often provide necessary heightened food availability for many different wading birds (Kushlan 1986). It has been well documented that wading bird foraging success increases with the heightened aquatic prey density associated with decreased water levels (Kahl 1964; Kushlan 1986; Dimalexis and Pyrovetsi 1997; Russell *et al.* 2002; Matsinos *et al.* 2012). Increasing water levels can decrease the area of suitable foraging habitat to wading birds (Dimalexis and Pyrovetsi 1997), and they have been observed to leave foraging patch when prey density decreases (Gawlik 2002). The sensitivity of wading birds to their aquatic environment has even led to them being labeled as useful indicators of ecological change (Kushlan 1993).

Links between habitat and behavior in other wintering crane species.

Winter foraging ecology studies have been conducted on Common (*Grus grus*) and Siberian (*Grus leucogeranus*) cranes (Alonso *et al.* 1995; Bautista *et al.* 1998; Burnham *et al.* 2017; Jia *et al.* 2013). Alonso *et al.* (1995) tested the marginal value

theorem in Common Cranes in northeastern Spain to see if the time spent in a foraging patch would increase with patch quality. However, the Common Cranes only supported the marginal value theorem when a given patch could not provide the sufficient intake rates to fulfill an individual's daily energy requirements, and also left higher quality patches earlier than expected (Alonso *et al.* 1995). A study of kleptoparasitism within the same population by Bautista *et al.* (1998) rooted in optimal foraging theory hypothesized and supported that wintering Common Cranes would steal food items from conspecifics when an individual's food intake rate was lower than that required for survival, and that cranes with above average intake rates would be targeted. A complete shift in the selection of foraging habitat following a severe flood event has been documented in Siberian Cranes wintering at Poyang Lake, China (Burnham *et al.* 2017; Jia *et al.* 2013). When the availability of *Vallisneria* tubers drastically declined throughout their preferred mudflat and shallow water habitats as a result of the flood, the Siberian Cranes adopted a novel foraging strategy and fed on *Potentilla limprichtii* in adjacent wet meadows (Burnham *et al.* 2017; Jia *et al.* 2013). While the alternative food source obtained in the wet meadows during the high-water conditions secured the population's survival that winter, there was an observed decrease in reproductive success during the following breeding season, which emphasizes the importance of sustaining high *Vallisneria* availability at Poyang Lake (Burnham *et al.* 2017).

Winter Whooping Crane behavior and ecology. The sole remaining natural flock of endangered Whooping Cranes (*Grus americana*) exclusively winter along the Texas Gulf Coast in the saltmarshes of Matagorda Island, the Aransas National Wildlife Refuge (NWR), San Jose Island, Welder Flats and Lamar Peninsula (Stehn and Prieto

2010). As a result of excessive hunting and habitat loss, the Whooping Crane narrowly avoided extinction when there was an estimated low of about 16 individual birds in 1941. As the current size of this Aransas-Wood Buffalo population is still less than half of that required for downlisting, extensive conservation efforts in their breeding and wintering grounds by a wide range of governmental, academic, and non-profit agencies are ongoing (CWS and USFWS 2005). Multiple detailed studies of the wintering behaviors of the Aransas-Wood Buffalo population of Whooping Cranes have been published since the 1990's.

Chavez-Ramirez (1996) provided extensive information regarding wintering Whooping Crane habitat use, foraging behaviors, time activity budgets, and energy requirements at the Aransas NWR. It was observed that on average the population spent 87% of their time in saltmarsh habitats, with an increased use of saltmarsh vegetation early in the season when Carolina Wolfberry (*Lycium carolinianum*) fruit are abundant, and a shift to open water habitats later in the season as Carolina Wolfberry fruit are diminished (Chavez-Ramirez 1996). The cranes were observed to venture out of their typical saltmarsh habitat when Blue Crab (*Callinectes sapidus*) densities were low and when clam abundance was high in the San Antonio Bay (Chavez-Ramirez 1996). Mated pairs of Whooping Cranes typically establish and defend saltmarsh territories in their wintering grounds, and groups of non-familial birds were most often observed in upland habitats during both years of the study (Chavez-Ramirez 1996). Cranes exhibited different time activity budgets across different habitat types (saltmarsh vegetation, saltmarsh open water, bay, upland) during the first year but not the second year of the study (Chavez-Ramirez 1996). Cranes in upland habitats spent very little time foraging

and an abnormally high amount of time resting compared to when in other habitats (Chavez-Ramirez 1996). Through the construction of a wintering Whooping Crane energy budget, Chavez-Ramirez (1996) concluded that 88% of an individual's total energy is derived from the consumption of Blue Crabs, and that at least 5.26 crabs must be consumed per day to meet their daily energy requirements.

Lafever (2006) found that Whooping Cranes spent an average of 63% and 66% of their time activity budget foraging, and 15% of their time on alert. Adults spent more time on alert than juveniles in January and February, and instances of flight were highest in November and December, likely due to the delineation of territory boundaries after arrival (Lafever, 2006). As mentioned earlier, an increase in disturbance can result in more time spent on alert, effectively decreasing the amount of time cranes can spend foraging. As the Gulf Intracoastal Waterway (GIWW) runs the length of the Aransas NWR, there was interest in the impact of the high level of human activity (e.g., recreational fishing, barge traffic) on wintering Whooping Crane behavior. However, Lefever (2006) concluded that the current levels of activity within the GIWW were not detrimental to the cranes with bordering territories.

Historical territory and range data from 1950-2006 was compiled and used by Stehn and Prieto (2010) to deduce average territory size and project the future area of protected habitat required to support a population large enough to warrant the downlisting of the species (1000 individuals or 250 breeding pairs; CWS and USFWS 2005). Their analysis revealed that newly-paired male cranes typically establish their territory near the territory of his parents (Stehn and Prieto 2010). They calculated the minimum territory size at the Aransas NWR to be 101 ha and the overall average minimum territory size

across all wintering locations to be 172 ha (Stehn and Prieto 2010). The study ultimately projected that there was currently not enough protected suitable habitat for the population to reach the recovery goal as a result of continued development of coastal lands and sea level rise (Stehn and Prieto 2010).

Objective and hypotheses. As the AWB population of Whooping Cranes continues to increase and expand spatially across the Texas Gulf Coast, more land will need to be allocated to accompany their increase with a sufficient area of available winter territories. The objective of this study is determine the linkages between environmental conditions (regional and local/territory scale) to Whooping Crane behavior, for the ultimate purpose of deducing the habitat quality at a given site (in reference to Whooping Crane needs) through behavioral observation surveys. This may provide a relatively non-invasive method of surveying Whooping Crane habitat quality at a given site, which could in turn ultimately inform our currently limited knowledge of which elements make one saltmarsh territory more profitable than another, and be useful in future land acquisition decisions.

Hypotheses:

- 1) Observed Whooping Crane time activity budgets will be similar at coastal marsh territories with similar habitat parameters.
- 2) Shifts in habitat quality will correlate to shifts in Whooping Crane behavior.

Methods

Study area. Established as a National Wildlife Refuge by the US Fish and Wildlife Service in 1937, the coastal marshes of the Aransas National Wildlife Refuge (NWR) are part of an estuarine system receiving freshwater inflows from the Guadalupe

and San Antonio Rivers into the San Antonio Bay. The highly heterogeneous coastal landscape of the refuge is comprised of saltwater ponds, open bays, tidal creeks and high elevation marsh habitats, all experiencing unique fluctuations in hydrological connectivity to the estuary (Wozniak *et al.* 2012). Behavioral surveys of birds in natural saltmarsh territories were conducted at the Aransas NWR along ~12 miles of coastal saltmarshes of the Blackjack Peninsula and the barrier islands of the Gulf Intracoastal Waterway (GIWW). The GIWW, a shipping channel along the coast of the Blackjack Peninsula, is heavily utilized by an estimated 50,000 shipping vessels annually (USACE 2004), commercial fisheries, and recreational boaters. Behavioral surveys of Whooping Cranes in their saltmarsh territories were conducted by boat from the GIWW.

Behavioral Sampling. Whooping Crane behavior was sampled monthly from January-March of 2016 and 2017. This research was funded by Earthwatch Institute, and data was collected with the assistance of a total of 54 Earthwatch citizen scientists. To sample Whooping Crane behavior we employed a modified version of a previously established time-activity budget sampling protocol (Chavez-Ramirez 1996). Each behavioral survey occurred over a twenty minute period, with Whooping Crane behavior category recorded every 15 second interval. The first step was to locate a group of Whooping Cranes (either an individual, a pair, a family group, or sub-adult group) in either a natural coastal saltmarsh or urban upland site where they are close enough to be accurately observed yet far away enough to not be disturbed by our presence (optimal range ~200-400m). Once observable cranes were located, metadata (e.g., air temperature, wind speed, wind direction, GPS location, observation range and compass heading to birds) was collected prior to initiation of the behavior survey (see Appendix A). During

each 20 minute observational “snapshot” interval, the main categories that were recorded include the following: foraging, resting, alert, comfort/maintenance, locomotion, and interaction (Fig. 20). The *foraging* category refers to any action related to searching for, obtaining, processing or consuming a food item. The *comfort/maintenance* category involves behaviors such as scratching, stretching, preening and ruffling of feathers. *Locomotion* refers to walking, running, or flying. Locomotion can be distinguished from active foraging by the position of the head- during foraging, the crane is slowly walking with its head down while it is actively searching for food, compared to walking/running where the neck is erect and the head is in the upright position, facing in the direction of transit. *Interaction* refers any action in response to other cranes or organisms, and antagonistic behaviors towards other Whooping Cranes for the purpose of territory defense was specifically noted. The *alert* behavior category is characterized by a stiff neck as the crane investigates for any possible threats. The *resting* category is most easily identified by a relaxed, more “S” shaped neck, and is characterized by a complete lack of noticeable movement. If a crane becomes nonvisible during the behavior survey, “ND” for No Data was documented for each interval until the bird became visible again. Any unusual occurrences during a behavior survey, such as a disturbance or interaction was documented in detail in the comments section of that given survey. As the majority of the Whooping Cranes along the Blackjack Peninsula are not banded, we differentiated pairs and family groups by general territory location. An IACUC exemption was approved by Sam Houston State University, as no vertebrates were handled or collected during this study (ID#16-03-16-1020-10-01).

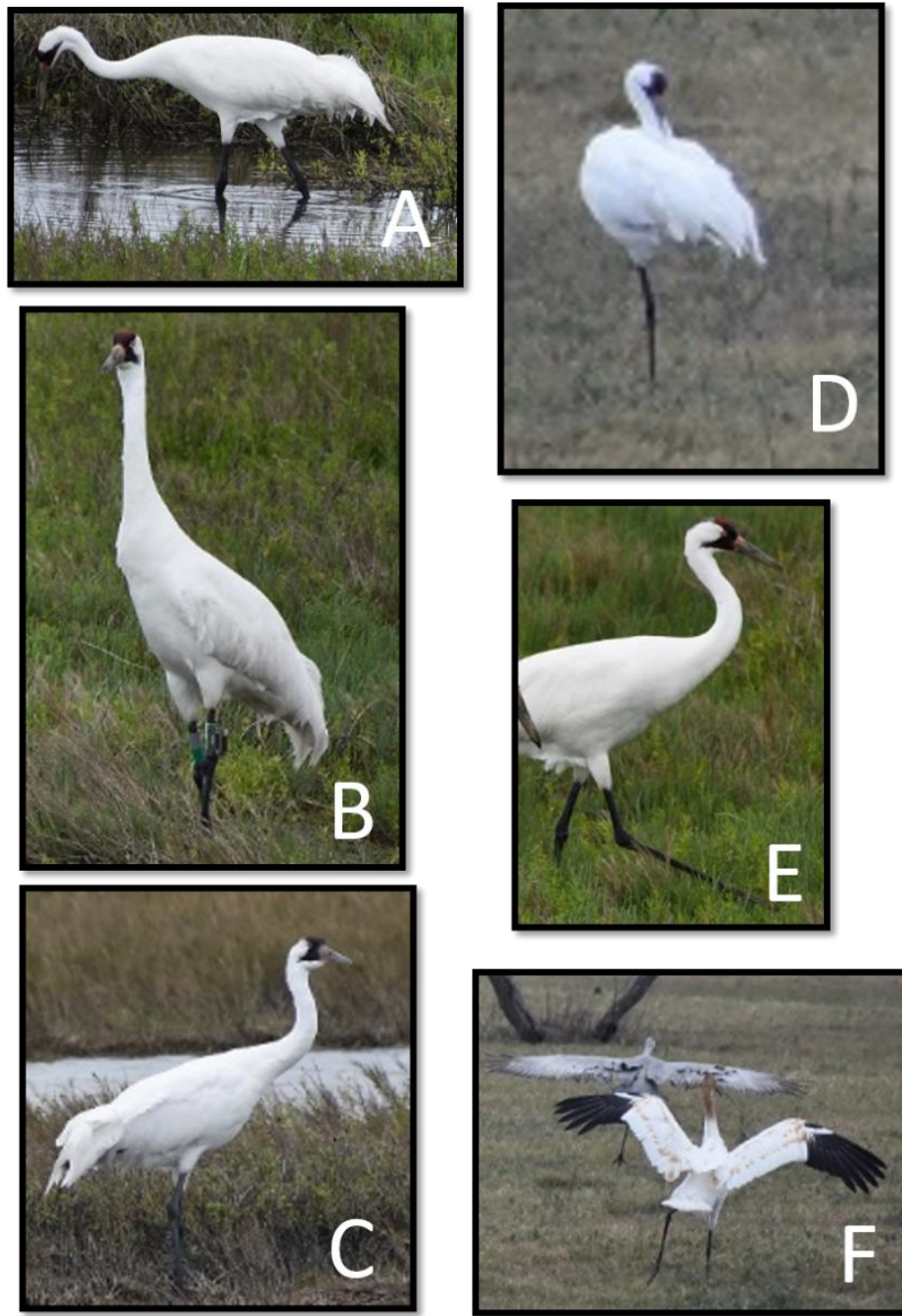


Figure 20. Images of Whooping Cranes displaying each behavioral category used during observational surveys: Foraging (A), Alert (B), Rest (C), Comfort/Maintenance (D), Locomotion (E), and Interaction (F).

Environmental sampling. To assess the habitat quality of a given coastal saltmarsh territory, a habitat assessment was conducted at the location of a previous Whooping Crane behavioral survey. Each coastal territory was revisited within 5 days of the behavioral observation, performed opportunistically when the cranes were not currently utilizing that given area. Habitat assessments consisted of Carolina Wolfberry (*Lycium carolinianum*) fruit, Blue Crab (*Callinectes sapidus*), and water quality surveys.

Carolina Wolfberry fruit abundance was surveyed by employing a combination of transect and quadrat sampling methods. The abundance of green and red wolfberry fruit was counted at each sampling point along a transect, each sampling point spaced 15m apart. Random sampling at each sampling point along the transect line was achieved through the use of three, 1m² PVC quadrats spaced 10m apart (Fig. 21). This specific method, optimally performed with four people (persons “A”, “B”, “C” and a recorder), was developed as a rapid assessment technique to capture the variability/patchiness of wolfberry plants within each coastal territory. On average, each site could be surveyed in ~45 minutes. First, Persons A, B and C unraveled the pre-measured nylon rope and space themselves 10m apart from each other. Knots in the rope indicated the two ends and center of a given sampling point. Persons A, B, and C then placed their 1m² quadrats on the ground, lining up the center of their quadrat with their corresponding knot in the rope. Person B was responsible for relaying the GPS coordinates to the recorder. Persons A, B, and C then counted the number of red and green Carolina Wolfberry fruits within their 1 m² quadrat and reported the counts to the recorder. Person B then held one end of a measuring tape while the recorder walked out 15m straight ahead with the other end to determine the subsequent sampling point along the transect line. Persons A, B and C

then advanced the 15m forward and repeated the sampling protocol at the next sampling point. Berry abundance was counted at a minimum of five sampling points along the transect, yielding a minimum of 15 samples per site as berry abundance was counted within three quadrats at each sampling point.

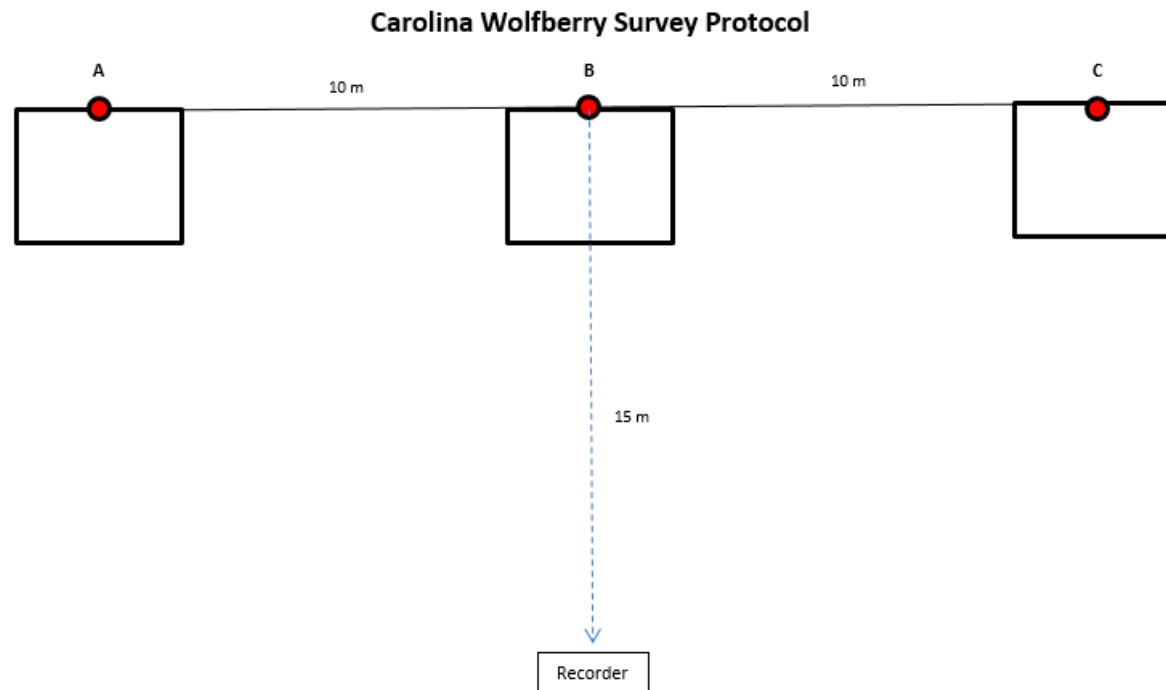


Figure 21. Conceptual diagram of Carolina Wolfberry fruit survey protocol, with the four people involved labeled as “A”, “B”, “C”, and “Recorder”. Persons A, B, and C, spaced 10m apart, count fruit abundance within their 1m² quadrat per replication, with the recorder documents their fruit abundance and GPS coordinates at each sampling point along the transect. Sampling points occur every 15m, with a minimum of 5 sampling points along a transect line per site.

The availability of Blue Crabs within each coastal territory was assessed by a visual walking survey method along pond or tidal creek edges in sites where Whooping Crane behavioral surveys were previously conducted. At each site, a minimum of 300m of pond or tidal creek edge was surveyed. This method was employed most efficiently with three people (two surveyors and one recorder). The number of crabs along each waterbody edge were classified by size according to carapace width (small: <6cm, medium: 6-10 cm, or large: >10cm; Fig. 22). One surveyor was positioned 1m into the water from the edge while the other surveyor walked 1m out from the pond edge. Surveyors walked side by side at the same pace while conducting a survey. The recorder walked a few feet behind the surveyors and continuously measured the distance of pond edge surveyed at each site. In the case of small ponds (<100m), the whole pond was surveyed. The recorder walked behind the surveyors so to not influence the behavior of crabs prior to being surveyed.



Figure 22. Blue Crab size difference between each size class as measured by carapace width (left to right): large (>10 cm), medium (6-10 cm) and small (<6 cm).

The water quality (temperature, salinity, conductivity, and pH) of each saltmarsh waterbody surveyed for Blue Crabs was recorded using a YSI 556 handheld submersible sonde (YSI Incorporated, Yellow Springs, Ohio, USA). Water quality measurements were always collected at the end of a Blue Crab survey, to avoid creating an unnecessary source of disturbance prior to a Blue Crab survey. A total of 197 water quality samplings were measured across 55 sites throughout the study, averaging 3-4 water quality samplings per site.

Data analysis. XY plots with standard error bars of Blue Crab density and marsh pond salinity at each site were used to compare Whooping Crane resource availability across sites each month. When the error bars of a site during a given month intersected with another site, those two sites were paired and classified as similar in resource availability. PCA's of the average Whooping Crane time activity budget (arcsine transformed) at each site per month were then employed to see whether the cranes acted most similarly in the sites classified as similar in resource availability. Bray-Curtis NMDS was used to investigate the influence of shifts in habitat quality (Blue Crab density, marsh pond salinity, and red fruit density data was Z-score transformed) on the average Whooping Crane time activity budget (arcsine transformed) at the sites which were repeatedly sampled each month (January, February, March) of a given year and experienced significant changes in habitat quality (Chapter 3, hypothesis 2). Lastly, multiple regression was used to investigate the influence of the other factors measured in this study (i.e. time of day, wind speed, air temperature, observation distance to the birds, San Antonio Bay water levels) on Whooping Crane behavior.

Results

Comparison of crane behavior between sites similar in habitat quality. In January 2016, one pair of sites was concluded to be similar in resource availability, and four pairs of sites were deemed similar in resource availability in both February and March 2016 (Fig. 23). In 2017, there were 3 pairs of sites deemed similar in January, 2 pairs in February, and 8 pairs in March (Fig. 24).

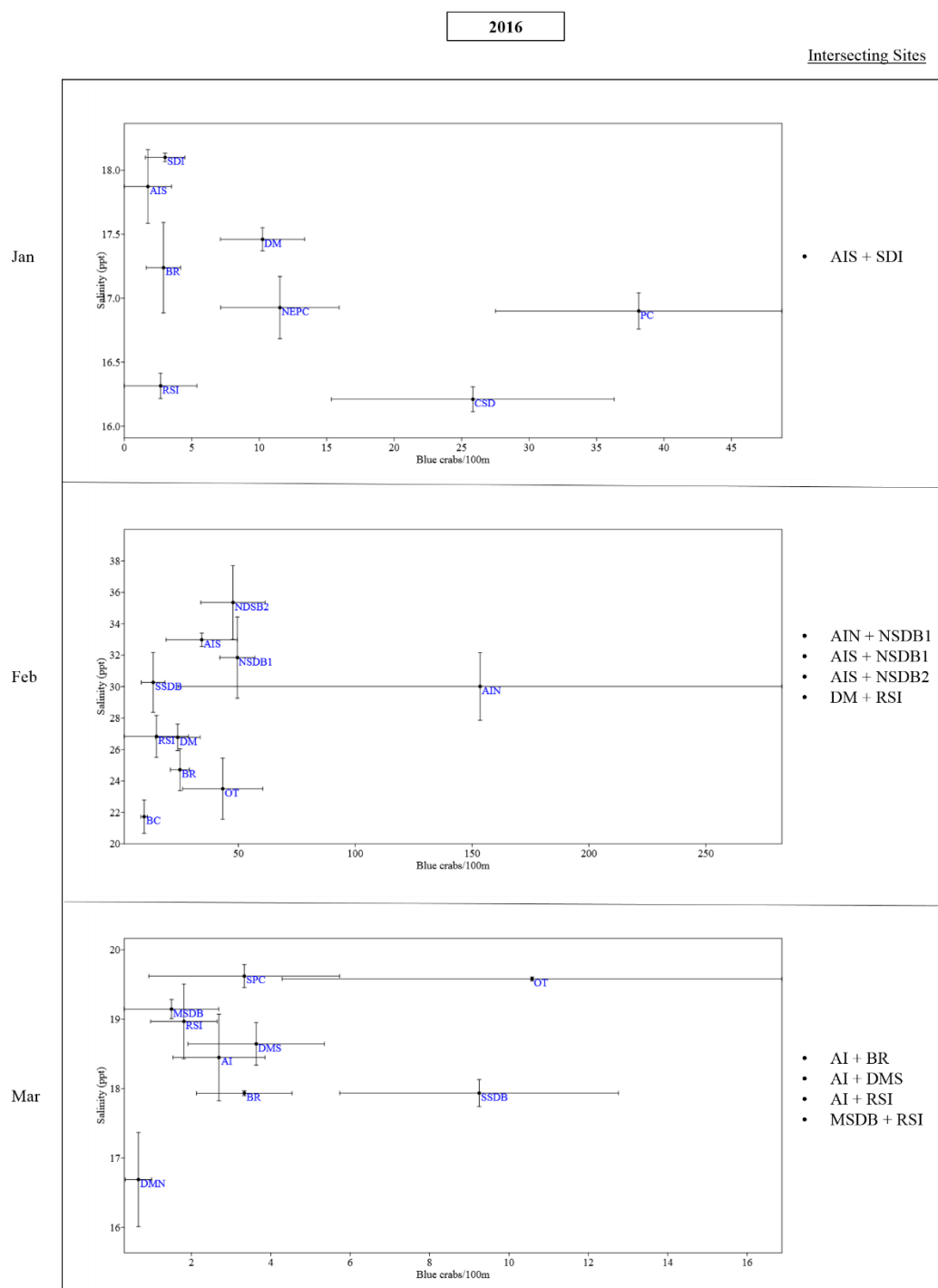


Figure 23. Monthly XY plots with SE of Blue Crabs/100m (x) and marsh pond salinity (y) at sites sampled in 2016. An intersection of error bars between any two sites each month resulted in the two sites being classified as similar in Whooping Crane resource availability (right).

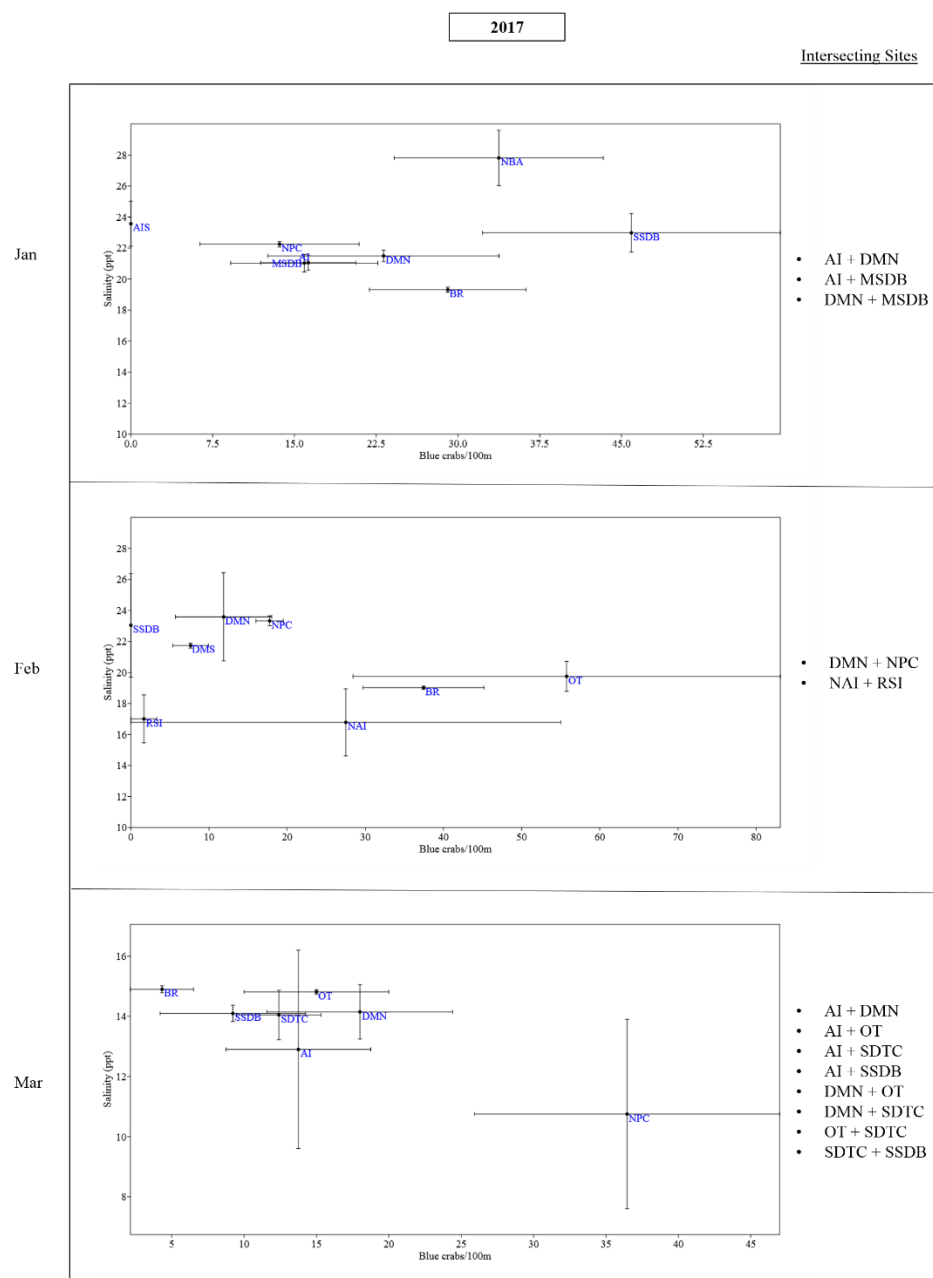


Figure 24. Monthly XY plots with SE of Blue Crabs/100m (x) and marsh pond salinity (y) at sites sampled in 2017. An intersection of error bars between any two sites each month resulted in the two sites being classified as similar in Whooping Crane resource availability (right)

A total of 22 sites were concluded to be similar in Blue Crab density and marsh pond salinity across the six sampling months (Appendix F; Fig. 23, 24). The average time activity budget of Whooping Cranes observed at each site per month was then analyzed through PCA, with the behavior in sites deemed similar in resources each month symbolized by either shared color (red, green purple) or symbol (dot, square, filled square, X), and sites not concluded to be similar to any other site that given month symbolized by a black dot (Fig. 25, 26). Of the 22 sites similar in Blue Crab density and marsh pond salinity over the six months, behavior at only four of those site pairings were most similar to each other (Appendix F; Fig. 25, 26).

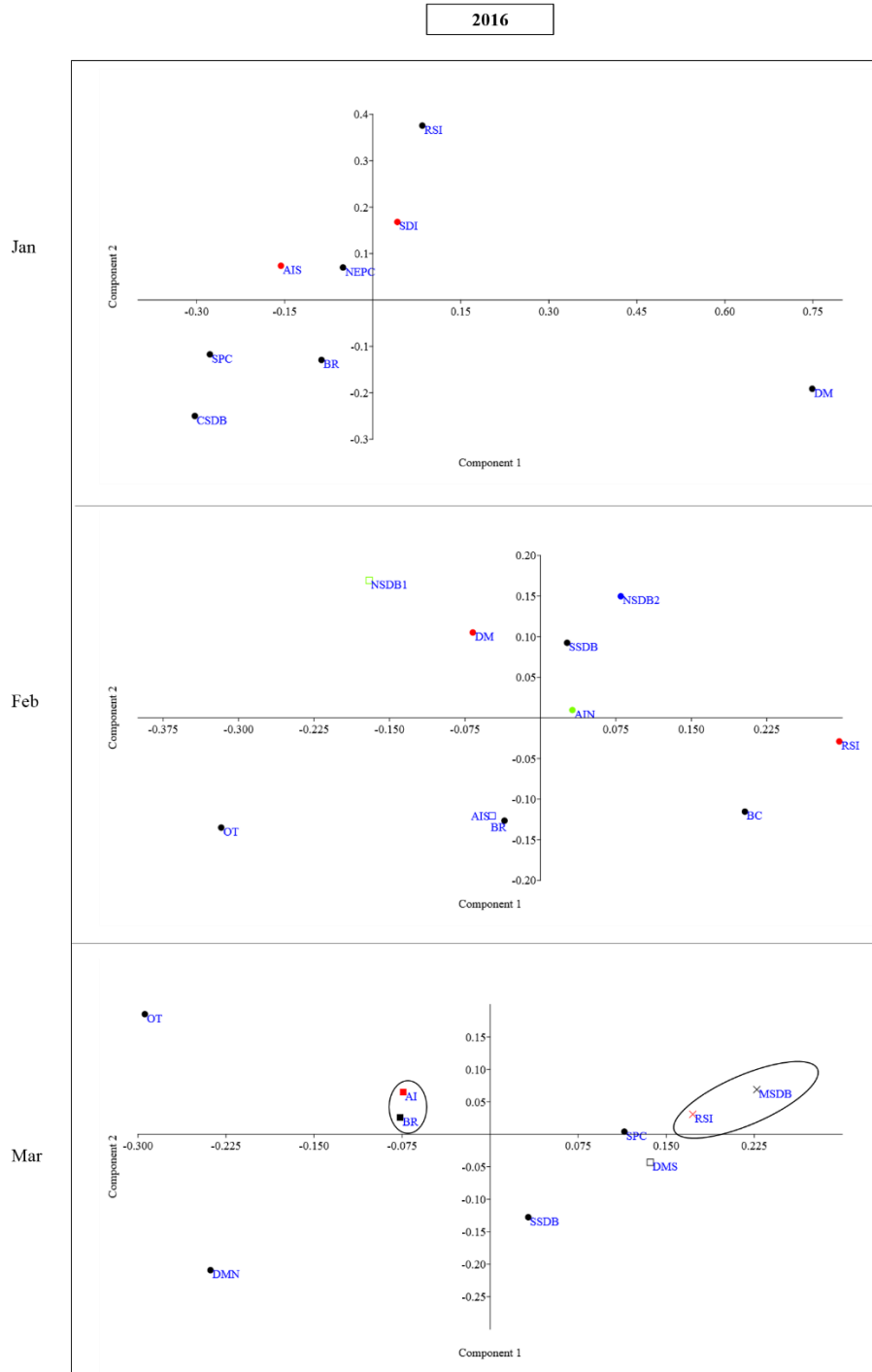


Figure 25. PCA of average Whooping Crane time activity budget per site each month of 2016, with sites deemed similar in resource availability designated by either shared color (red, green, purple) or symbol (dot, square, filled square, X). Sites which were not similar to any other site in resource availability (Blue Crabs/100m and marsh pond salinity) during a given month are represented by a black dot. Sites similar in both resource availability and behavior are circled, and a complete list of sites paired in resource availability can be found in the Appendix (F). Behavior data was arcsine transformed.

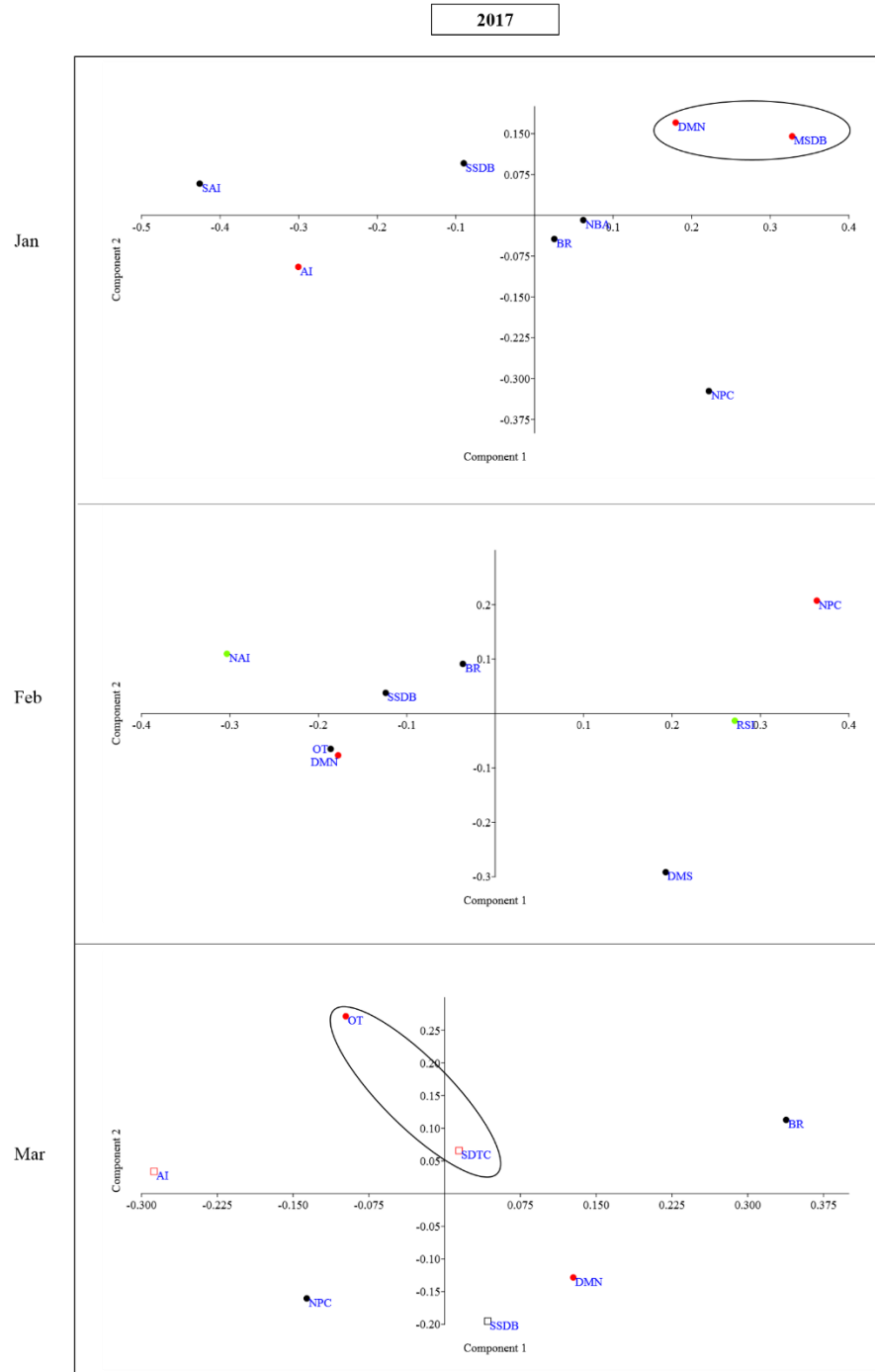


Figure 26. PCA of average Whooping Crane time activity budget per site each month of 2017, with sites deemed similar in resource availability designated by either shared color (red, green, purple) or symbol (dot, square, filled square, X). Sites which were not similar to any other site in resource availability (Blue Crabs/100m and marsh pond salinity) during a given month are represented by a black dot. Sites similar in both resource availability and behavior are circled, and a complete list of sites paired in resource availability can be found in the Appendix (F). Behavior data was arcsine transformed.

Shifts in behavior in response to changing habitat quality. The Boat Ramp, Rattlesnake Island, and Dunham Marsh sites were repeatedly sampled each month (January, February, March) in 2016, while Boat Ramp, South Sundown Bay, and Ayer's Island were sampled each month in 2017. As sampling occurred relatively late in the Carolina Wolfberry's fruiting season, very little to no red fruit were present during monthly environmental assessments; therefore, red berry density was excluded from the NMDS analysis.

In 2016, the three sites repeatedly sampled each month experienced elevated Blue Crab densities and marsh pond salinities in the month of February, and similarly lower Blue Crab densities and pond salinities in January and March (Fig. 27, right). If their behavior were to shift in correlation to this shift in the availability of those two resources, one would expect the January (dot) and March (X) data points of each site to cluster together, away from the February (square) data point in the NMDS plot; this, however, was not the case (Fig. 27, left). Whooping Crane behavior at sites repeatedly sampled in 2017 also did not shift in correlation to observed monthly shifts in Blue Crab density and marsh pond salinity (Fig. 28).

2016

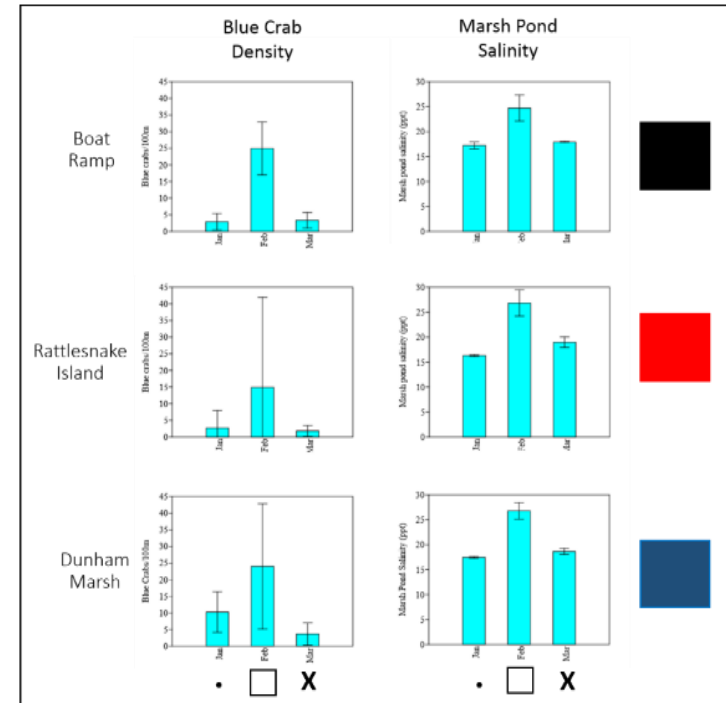
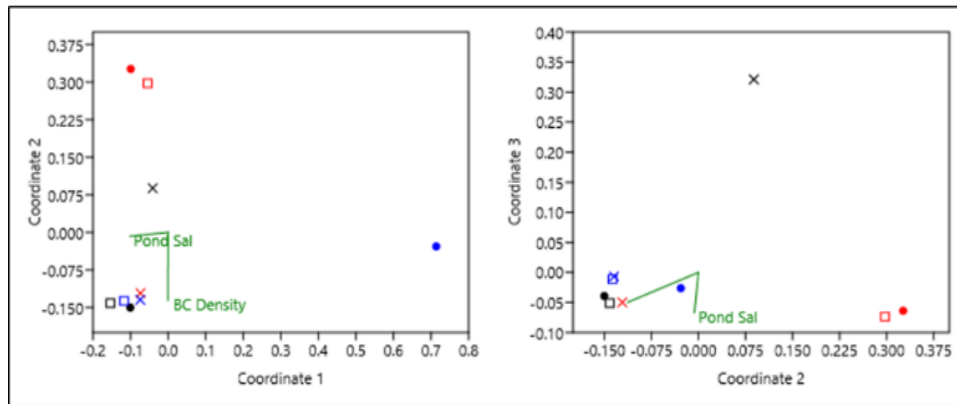


Figure 27. (Left) Bray-Curtis NMDS plots of the influence of marsh pond salinity and Blue Crab density on monthly Whooping Crane time activity budgets at sites repeatedly sampled (Boat Ramp=black, Rattlesnake Island=red, Dunham Marsh=blue) in January (dots), February (squares) and March (X's) of 2016. (Right) Monthly shifts in Blue Crab density and marsh pond salinity at the three sites. Blue Crab density and pond salinity data per site was averaged and Z-score transformed. Average fraction of time spent in each behavior per site was arcsine transformed.

2017

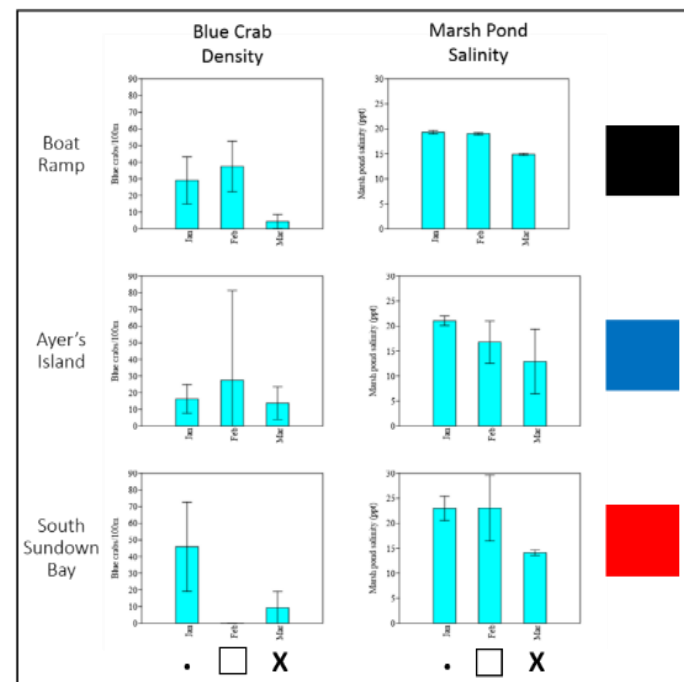
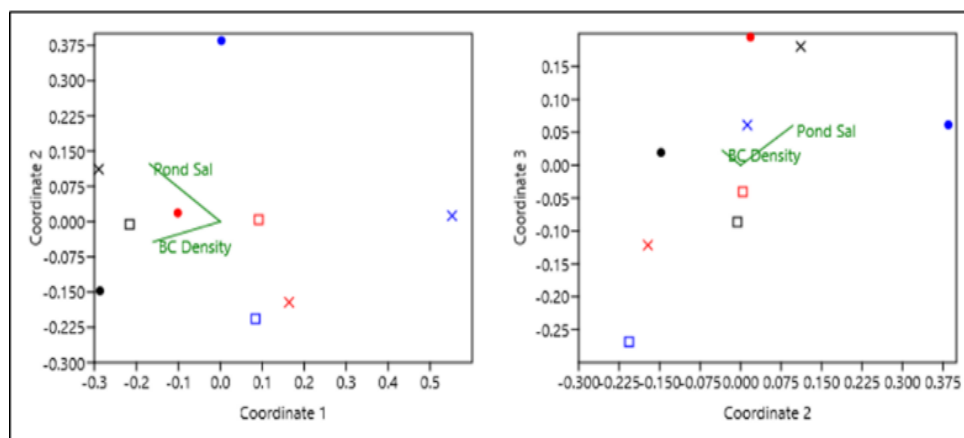


Figure 28. (Left) Bray-Curtis NMDS plots of the influence of marsh pond salinity and Blue Crab density on monthly Whooping Crane time activity budgets at sites repeatedly sampled (Boat Ramp=black, Ayer's Island=blue, South Sundown Bay=red) in January (dots), February (squares) and March (X's) of 2017. (Right) Monthly shifts in Blue Crab density and marsh pond salinity at the three sites. Blue Crab density and pond salinity data per site was averaged and Z-score transformed. Average fraction of time spent in each behavior per site was arcsine transformed.

Further investigation of the drivers of Whooping Crane behavior. Analyses for the two hypotheses of this objective revealed that Blue Crab density and marsh pond salinity alone were not strong indicators of wintering Whooping Crane behavior at the Aransas NWR. Therefore, multiple regression was used to investigate how other environmental factors (observation distance to bird, wind speed, air temperature, time of day, bay water level, red Carolina Wolfberry fruit density) correlated with observed Whooping Crane behavior in 2016 and 2017. No multiple regression of any behavior category during either sample year was significant ($P > 0.05$), and R^2 did not exceed 0.445 (Appendix D, E).

A few individual factors within the multiple regressions, however, did relatively correlate strongly to behavior. In 2016, the multiple regression of the six environmental factors concluded that time spent foraging correlated the closest to time of day ($P = 0.038$, $\beta = -0.036$) and red Carolina Wolfberry fruit density ($P = 0.037$, $\beta = 0.32$), time spent on alert correlated most closely with bay water level ($P = 0.039$, $\beta = -0.502$), and amount of time in comfort/maintenance correlated to time of day ($P = 0.014$, $\beta = 0.040$) and red fruit density ($P = 0.034$, $\beta = -0.332$). In 2017, comfort/maintenance correlated the strongest to observation distance to the birds ($P = 0.018$, $\beta = -0.001$) and time spent in interaction correlated to time of day ($P = 0.011$, $\beta = 0.016$).

Discussion

Across the six sampling months, 22 pairs of sites were determined to be statistically similar in Blue Crab and marsh pond salinity. Of these 22 similar pairs, there was only four instances when bird behavior resulted in similar time activity budgets.

Interestingly, a similarity in Blue Crab density and marsh pond salinity alone did result in the exhibition of similar Whooping Crane time activity budgets.

The behavior of cranes observed at the three sites that were repeatedly sampled each month were used to investigate whether significant changes in habitat quality are reflected in Whooping Crane behavior. As mentioned earlier, the three sites consistently sampled in 2016 experienced elevated Blue Crab densities and marsh pond salinities in the month of February, and similarly lower Blue Crab densities and pond salinities in January and March. If their behavior were to shift in correlation to this change in the availability of those two resources, one would expect the behavior of the cranes to change as well. Specifically, behavior at each site in January was expected to be similar to how they behaved in March and in contrast to February, when Blue Crab density and pond salinity was significantly higher, which was not the case. Whooping Crane behavior at sites repeatedly sampled in 2017 also did not shift in correlation to observed monthly shifts in Blue Crab density and marsh pond salinity.

Whooping Crane behavior was not frequently observed to be most comparable between sites similar in Blue Crab density and marsh pond salinity, nor did it shift in correlation to monthly shifts in the same two environmental metrics. Therefore, Blue Crab density and marsh pond salinity alone were not strong indicators of monthly Whooping Crane behavior across the Aransas NWR. While Blue Crabs are their primary food source while wintering at the Aransas NWR, their overall opportunistic feeding habits may be partially responsible for the lack of significance in this model. Also, due to the lack of an elevation platform during behavioral observations, it was not possible to view and record fine-scale foraging behavior data, such as differentiating between

searching for, processing, and consuming food items. This model also did not scale Blue Crab density to the area of open water habitat in a given territory. Even though two sites may be similar in Blue Crab density, they may vary significantly in the actual area of crab habitat present, which would yield a dramatic discrepancy in the total number of crabs present between the two sites.

As Blue Crab density and marsh pond salinity alone did not sufficiently correlate to Whooping Crane behavior, multiple regression was used to investigate how other environmental factors (observation distance to bird, wind speed, air temperature, time of day, bay water level, red Carolina Wolfberry fruit density) correlate with observed Whooping Crane behavior in 2016 and 2017. No multiple regression using this new set of environmental factors significantly correlated to the amount of time spent in any behavior category during either sample year. A few individual factors within the multiple regressions, however, did correlate significantly with behavior, but these relationships were not consistent seen across the two winters.

Interestingly, in 2016, the amount of time spent foraging and in comfort/maintenance both most strongly correlated to time of day and red fruit density, but in an opposite nature. The Whooping Cranes generally spent less time foraging as the day progressed, and those at sites with relatively higher red Carolina Wolfberry fruit density spent more time foraging; conversely, the opposite relationship between these two factors and time spent in comfort/maintenance was observed. As foraging is an “obligate” behavior necessary for survival and comfort/maintenance behaviors are considered “elective” behaviors (not directly pertinent to survival), this phenomenon may be exhibiting a tradeoff between an obligate and elective behavior: when/where the

cranes spent more of their time foraging, which is crucial to their survival, less time was partitioned to non-essential comfort/maintenance activities. Wintering Common Cranes have also exhibited a tradeoff between the time of day they spend foraging and in comfort/maintenance, with the peak time of day spent in either behavior having a negative correlation to the peak time of day spent in the other (Alonso and Alonso 1992). However, neither time of day nor red fruit density correlated to time spent foraging or in comfort/maintenance in 2017; the lack of influence on red fruit density on behavior in 2017 is likely resultant of the complete lack of red fruit in February and March, which was not the case in 2016. The cranes generally spent more time on alert as bay water levels decreased in 2016. As Whooping Cranes are known to rely on standing water to relay auditory cues of incoming predators, they may have had to spend more of their time being vigilant themselves when water levels were lower. However, the relationship between water level and time on alert was not observed in 2017, when bay water levels during sampling periods were much lower than in 2016.

Whooping Crane behavior did not consistently reflect Blue Crab density, marsh pond salinity, time of day, water level, observation distance, wind speed, air temperature or red Carolina Wolfberry fruit density across the two winters of this study. Shifts in the large-scale hydrological conditions throughout the greater estuary, however, continuously changed water quality and food resource availability in the Whooping Cranes' saltmarsh territories throughout a winter season. The frequent changes in estuarine hydrology, which do not necessarily influence the habitat quality at different sites in the same way, both during and across winter seasons makes it extremely difficult to find consistent relationships between Whooping Crane behavior and environmental conditions.

Geospatial modeling of historically profitable Whooping Crane territories could provide an alternative method to help further define which saltmarsh structural features yield prime wintering habitats.

Acknowledgments

We thank the Earthwatch Institute for funding this research through a grant to J. Wozniak. We also thank the 54 citizen scientist volunteers who participated in the “Protecting Whooping Cranes and Coastal Habitats” Earthwatch expeditions of 2016 and 2017; the extent of data collected for this project would not have been possible without their hard work and dedication to conservation. We greatly acknowledge L. Smith and R. Kirkwood for their consistent dedication to supplementing our volunteer education programs. This project would not have been possible without the support of the US Fish and Wildlife Service at the Aransas National Wildlife Refuge through the allowance of permits and use of research facilities.

Literature Cited

- Alonso, J. C. and J. A. Alonso. 1992. Daily activity and intake rate patterns of wintering Common Cranes *Grus grus*. ARDEA 80: 343-351.
- Alonso, J. C., J. A. Alonso, L. M. Bautista and R. Muñoz-Pulido. 1995. Patch use in cranes: a field test of optimal foraging predictions. Animal Behaviour 49: 1367-1379.
- Bautista, L. M., J. C. Alonso and J. A. Alonso. 1998. Foraging site displacement in Common Crane flocks. Animal Behaviour 56: 1237-1243.
- Burnham, J., J. Barzen, A. M. Pidgeon, B. Sun, J. Wu, G. Liu and H. Jiang. 2017. Novel foraging by wintering Siberian Cranes *Leucogeranus leucogeranus* at China's Poyang Lake indicates broader changes in the ecosystem and raises new challenges for a critically endangered species. Bird Conservation International 2017: 1-20.
- Canadian Wildlife Service and U.S. Fish and Wildlife Service (CWS and USFWS). 2005. International recovery plan for the Whooping Crane. Ottawa: Recovery of Nationally Endangered Wildlife (RENEW), and U.S. Fish and Wildlife Service, Albuquerque, New Mexico. 162 pp.
- Chavez-Ramirez, F. 1996. Food availability, foraging ecology, and energetics of Whooping Cranes wintering in Texas. ProQuest Dissertations and Theses.
- Dimalaxis, A. and M. Pyrovetsi. 1997. Effect of water level fluctuations on wading bird foraging habitat use at an irrigation reservoir, Lake Kerkini, Greece. Colonial Waterbirds 20: 244-252.
- Gawlik, D. E. 2002. The effects of prey availability on the numerical response of wading

- birds. *Ecological Monographs* 72: 329-346.
- Jia, Y., S. Jiao, Y. Zhang, Y. Zhou, G. Lei and G. Liu. 2013. Diet shift and its impact on foraging behavior of Siberian Crane (*Grus leucogernanus*) in Poyang Lake. *PLoS One* 8: e65843.
- Kahl, M. P. 1964. Food ecology of the Wood Stork (*Mycteria americana*) in Florida. *Ecological Monographs* 34: 97-117.
- Kushlan, J. A. 1981. Resource use strategies of wading birds. *The Wilson Bulletin* 93: 145-163.
- Kushlan, J. A. 1986. Responses of wading birds to seasonally fluctuating water levels: strategies and their limits. *Colonial Waterbirds* 9: 155-162.
- Kushlan, J. A. 1993. Colonial waterbirds as bioindicators of environmental change. *Colonial Waterbirds* 16: 223-251.
- Lafever, K. E. 2006. Spatial and temporal winter territory use and behavioral responses of Whooping Cranes to human activities. Master's thesis. Texas A&M University.
- Stehn, T. V and F. Prieto. 2010. Changes in winter Whooping Crane territories and range 1950-2006. *North American Crane Workshop Proceedings*. University of Nebraska – Lincoln.
- United States Army Corps of Engineers (USACE). 2004. Waterborne commerce of the United States, Part 2. Waterways and Harbors Gulf Coast, Mississippi River System and Antilles. Institute for Water Resources. Alexandria, VA: U.S. Army Corps of Engineers, 344p.
- Wozniak, J. R., T. M. Swannack, R. Butzler, C. Llewellyn and S. E. Davis III. 2012. River inflows, estuarine salinity, and Carolina Wolfberry fruit abundance: linking

abiotic drivers to Whooping Crane food. *Journal of Coastal Conservation* 16: 345-354.

CHAPTER V

Summary

Wintering Whooping Crane behavior

Natural saltmarsh territories versus urban upland sites. Whooping Cranes occupying their natural territories interact with a heterogeneous landscape, where microtopographic variations in elevation dictate the distribution of water and composition of vegetation across the marsh. In contrast, cranes visiting urban upland sites are on relatively flat land above the tidal zone, largely surrounded by a monoculture of grass in a privately owned parcels of land. On average, the Whooping Cranes observed in natural saltmarsh territories in 2016 and 2017 spent 66.2% and 60.1% of their time foraging, 9.6% and 10.1% on alert, 6.4% and 9.8% resting, 2.8% and 3.8% in comfort/maintenance, and 12.2% and 13.6% in locomotion, respectively. The average time activity budget of cranes observed near urban game feeders at urban upland sites in 2016 and 2017 dedicated 8.1% and 25.4% to foraging, 12% and 5.9% on alert, 33.5% and 36.3% resting, 35.3% and 23.2% in comfort/maintenance, and 7.5% and 5.1% in locomotion. The average percent of time spent in interaction was <1% in both habitat types either year.

Wintering Red-crowned Cranes have been observed to spend more time on alert when utilizing highly populated urban areas (Wang *et al.* 2011). The Whooping Cranes spending time in urban upland sites in this study, however, did not spend more time on alert than the cranes observed in their natural saltmarsh territories. Cranes in urban upland sites are in close proximity to people, cars, dogs and cattle, but the vegetation of the generally flat residential properties is relatively short and often maintained by

mowing, allowing them a clear view of their surroundings. Cranes in their natural saltmarsh territories are also subjected to sporadic vehicular traffic, but in the form of boats and barges along the Gulf Intracoastal Waterway. While cranes in their natural territories are not in such close proximity to humans nor encounter domestic dogs and cattle, they are always susceptible to predation by their natural predators (e.g., coyotes, bobcats), and are in habitats with relatively higher vegetation and variable elevation. Unlike the cranes at urban upland sites, those in their natural territories have the ability to utilize auditory cues of incoming predators relayed by standing water in the marsh. The similar amount of time spent on alert by cranes in urban upland sites and natural territories may indicate that while the types of disturbances, predators, and predator detection mechanisms vary between the two habitat types, they are overall matched in the level of security as perceived by the cranes.

The time activity budgets of wintering Whooping Cranes observed in their saltmarsh territories in this study were comparable to earlier studies conducted in a similar fashion at the Aransas NWR (Chavez-Ramirez 1996; Lafever 2006). Cranes observed in their natural saltmarsh territories spent more time foraging and in locomotion, two energy consumptive behaviors, than those visiting game feeders in urban upland sites. Whooping cranes occupying their natural territories must actively forage for food items throughout the dynamic saltmarsh landscape. In contrast, cranes visiting game feeders at urban upland sites are provided corn every time the feeder dispenses, which is quickly and easily consumed. With much less of their time being dedicated to foraging, the cranes in urban upland sites spent significantly more time resting and in comfort/maintenance activities, two relatively energy conservative behaviors, than those

in their natural territories. As the feeders are situated in the homogenous lawns of residential properties, it is likely that there are not many other food items for the cranes to find and eat as they wait for the corn to be dispensed again. Therefore, foraging for non-corn resources between dispenses is likely to consume more energy than would be gained. Wintering Common Cranes exploiting cereal farmlands in Spain were observed to leave a foraging patch when their energy intake rate decreased below that required to meet their daily energy requirements (Alonso 1995). This observation in Common Cranes, in addition to the consistent use of and long duration of time spent sitting by game feeders in urban upland sites, could indicate that the cranes visiting these sites are meeting their daily energy requirements, even when the flight to and from the game feeder is energetically costly. However, energetically speaking, spending the day at a game feeder may not be worth the trip for cranes with territories that are not in close proximity to the urban upland sites. Also, it is important that wintering AWB Whooping Cranes exceed their daily energy requirements, not simply meet them.

A crane's net daily energy budget dictates how much energy is stored as fat, and these energy reserves are necessary for successful spring migration, and can influence that year's subsequent reproductive effort (Gil de Weir 2006; Gil de Weir *et al.* 2012). By foraging less and devoting more time to energy conservative activities, cranes in urban upland sites expended less energy than those in natural sites. Even though they are reducing their daily energy expenditure by sitting at game feeders in urban upland sites, the cranes in their natural saltmarsh territories are consuming a larger variety of food items, which are likely to be of higher nutritional value than the corn dispensed from the feeders. As the majority of the birds observed at the urban sites are not banded, it is

impossible to monitor which individuals are visiting the game feeders and at what frequency, and whether these individuals experience any negative consequences after they leave their wintering grounds.

Siberian Cranes have been documented to forage in novel habitats when their preferred food item is not available (Burnham *et al.* 2017; Jia *et al.* 2013); are Whooping Cranes visiting the urban game feeders due to low food availability within their own territory, or simply because their territories are close by? Like the Whooping Cranes at game feeders in this study, Siberian Cranes also exhibited a decrease in the amount of time spent foraging while visiting unconventional habitats compared to when they are in their historically preferred foraging habitats (Jia *et al.* 2013), and there was an observed decrease in the number of juveniles that arrived at their wintering grounds the following year (Burnham *et al.* 2017). Therefore, there is increased merit in future efforts to band the individuals visiting the game feeders to investigate their subsequent reproductive success. If individuals spending their winter days at a game feeder experience a significant decrease in fecundity, this information could be considered in future population management decisions. Without these birds being banded, there is currently no way to track which territory they return to at the end of the day.

Behavior as winter transitions to spring. On average, the amount of time spent foraging while occupying their natural saltmarsh habitats consistently increased each sampling month both years (63.2% in January, 66% in February, and 69.8% in March of 2016; 49.9% in January, 62.6% in February, and 69.2% in March of 2017). Sampling month did not show a consistent effect on the fraction of time spent in any other the other behaviors besides foraging, and the increased time spent foraging each month was not

significant in 2016. While behavior trends through time were not consistent across the two sampling years, there were, however, significant differences in the amount of time spent in certain behavior categories within a given year.

Like the wintering Whooping Cranes observed in this study, an increase in the amount of time spent foraging as the winter season progresses and spring migration nears has also been observed in Hooded Cranes (Zhou *et al.* 2010). This phenomenon could be driven not only by the looming energetically expensive migration, but could also be a result of a decrease in food item density as the amount of time the cranes have foraged in their territory increases. The increased amount of time spent foraging each month by the wintering Hooded Cranes coincided with a sequential decrease in the amount of time spent on alert each month (Zhou *et al.* 2010). The significant increase in foraging through time by the Whooping Cranes observed in this study in 2017 coincided with a significant decrease in time spent resting each that year. As the cranes increased the amount of time spent foraging each month, it is logical that they had increasingly less time to devote to other behaviors as the season progressed, and the difference in the behavior chosen to sacrifice by Hooded and Whooping Cranes could be a reflection of a vast difference in the ecologies of their respective wintering grounds.

Whooping Cranes nest (in their breeding groups) and sleep (year-round) in the middle of shallow open bodies of water, increasing their ability to receive auditory cues of potential incoming predators (Folk *et al.* 2014). Therefore, it is very possible that the amount of time Whooping Cranes spend on alert is partially driven by water level. In fact, the amount of time spent on alert in winter 2016 was highly correlated to shifts in bay water levels; when water level was particularly high in February compared to

January and March, the cranes spent significantly more time on alert. This may be explained by the cranes needing to spend more of their time on alert when there was less standing water in the marsh to act as their alarm system. Regardless of the drivers behind the elevated amount of time spent on alert in February 2016, there was also a significant decrease in time spent resting that month, possibly due to the increased amount of time dedicated to alert.

Juvenile versus adult behavior. In 2016, behavioral surveys were conducted on 64 adult and 13 juvenile individuals in natural saltmarsh habitat, and 66 adults and 22 juveniles were observed in 2017. As the “juvenile” age group only refers to cranes born earlier that year, the large disparity in sample sizes between the two age groups was unavoidable. Analyses of the comparison between overall adult and juvenile Whooping Crane behavior showed that overall behavior was statistically different between the two age groups in both 2016 and 2017. However, Kruskal-Wallis tests of each individual behavior category between the two age groups revealed that the only specific behavior in which they significantly varied was the time spent on alert, with adults consistently spending more time on alert than juveniles both years.

The trend of adults spending more time on alert than juveniles has also been observed in wintering Hooded Cranes (Li *et al.* 2015; Zhou *et al.* 2010) and Common Cranes (Avilés 2003). In contrast to this study, wintering juvenile Hooded Cranes and Common Cranes spent significantly more time foraging than adults (Avilés 2003; Zhou *et al.* 2010). In the Li *et al.* (2015) study of Hooded Cranes, adults spent significantly more time on alert than juveniles during one winter (2013-2014), but not the other (2012-2013). In addition, the juveniles only spent significantly more time foraging than adults

during the winter where they spent significantly less time on alert (2013-2014; Li *et al.* 2015). In all the instances of juveniles both spending less time on alert and significantly more time foraging than the adult birds across these three studies, there was a great discrepancy between the amount of time spent on alert between the two age groups, affording the juveniles more time to forage instead. In this study of Whooping Cranes, the juveniles spent significantly less time on alert but did not spend significantly more time foraging, but the discrepancy between the amounts of time spent on alert across the two age groups was much smaller.

Apart from the amount of time spent foraging, the general lack of differences in behavior between juvenile and adult Whooping Cranes in this study may also be an effect of the behavioral samplings being conducted in the second half of their wintering season (January, February, March). While juvenile Hooded Crane behavior was significantly different from that of the adults early in the wintering season, there was not a significant behavioral difference between the two age groups by the end of the season (Zhou *et al.* 2010).

Juvenile behavior through time. Of the six behavior categories, sampling month had a significant effect on juvenile Whooping Crane behavior on two behaviors: the amount of time spent in locomotion in 2016 and alert in 2017. The significantly different amount of time spent in these two behavior categories across months did not, however, sequentially increase or decrease as the winter season progressed, indicating that the transition of winter to spring was not the primary driver of the change in amount of time dedicated to these behaviors. The lack of obvious trends and/or significant differences between adult and juvenile behavior through time may be explained by the consistently

small sample sizes of juveniles observed each month. The significantly different amount of time dedicated to alert and locomotion by juveniles across months was not reflected in analyses of behavior through time when all birds observed (combined adults and juveniles) were included. Therefore, if the discrepancy in the amount of time spent on alert and locomotion by juveniles was driven by an environmental factor instead of time, one would expect to see a similar response in the behavior of the adults, which was not the case. This supports the notion that juvenile sample size was simply too small. To enhance the juvenile sample size in the future, observations could be conducted on Matagorda Island, as the Blackjack Peninsula of the Aransas NWR can only provide territories for a limited number of mated pairs and therefore fewer juveniles.

Conclusion. Many of the behavioral trends of Whooping Cranes observed in their natural winter territories in this study have been seen in other wintering crane species. Deviations in behavior from what has been observed in other wintering crane species often correlated to hydrological changes in the estuary. This illustrates that while wintering Whooping Cranes do share certain behavioral trends observed in other wintering crane species, the extraordinarily dynamic wintering grounds of the AWBP can sometimes skew their behavior into deviating from these trends. While we cannot control water level in the greater estuary, humans can manage the discharge of freshwater into the system. Here, enhanced freshwater inflows to coastal systems are critical to facilitate the availability of critical Whooping Crane resources and to stabilize the ecology of their saltmarsh territories, which influences their overall behavior while in their wintering grounds.

Coastal saltmarsh habitat quality

Inter-site versus intra-site variation. Of the six sampling months, inter-site variation in Blue Crab density per 100 meters was only significantly greater than intra-site variability during two months (January and February 2016), and inter-site variation in red Carolina Wolfberry fruit per square meter only exceeded intra-site variability during one sampling month (January 2016). Inter-site marsh pond salinity variability, however, was significantly greater than intra-site variability in five of the six sampling months.

Variability in pond salinity across sites is likely a result of the heterogeneous nature of the saltmarsh landscape. Physical pond attributes such as the hydrological classification, size, depth, distance from the bay, and pond edge/berm elevation can greatly impact evaporation rates, hydrological connectivity, and surface water quality. Significant variability in marsh pond salinities at different sites along the Blackjack Peninsula have also been observed in prior studies (Pugesek *et al.* 2008; Wozniak *et al.* 2012). The lack of variability in red Carolina Wolfberry fruit across sites corresponds to previous findings of generally similar marsh plant community composition across the Aransas NWR, and may also be an effect of the sampling occurring relatively late in its fruiting season, at a time when overall berry density is historically low (Butzler and Davis 2006). Even during peak fruiting season (October, November), sites along the Aransas NWR have not significantly varied in berry abundance in the past (Butzler 2006).

Shifts in habitat quality over a winter season. Sites repeatedly sampled each month (January, February, March) of the same year (2016 and 2017) were used to investigate how a particular site may change in habitat quality across a winter season. In

general, Blue Crab density, water quality (salinity, conductivity, temperature), and Carolina Wolfberry red fruit density varied across months at the three sites each year that were consistently sampled.

As mentioned earlier, the habitat surveys in this study occurred relatively late in the Carolina Wolfberry's fruiting season, at a time when most of the plants are denuded of berries (Butzler and Davis 2006). Even though density was low, red berries were present at all three sites both years in the month of January, and no red berries were present at any of the sites in February or March either year. January red fruit density was only statistically higher compared to February and March when average January red fruit density exceeded 0.5 red berries/m² at Boat Ramp and South Sundown Bay in 2017. If sampling had started in the fall during peak fruiting season (~September-November), a more obvious effect of time on fruit density may have been present across a sampling year, as has been previously observed (Butzler 2006).

In 2016, Blue Crab density (crabs/100m) was elevated in February at all three sites, but only significantly at two of the sites (Boat Ramp and Dunham Marsh). In addition, marsh pond salinities (ppt) were significantly higher at all three sites in February. In 2016, the three sites sampled each month generally experienced similar monthly shifts in Blue Crab density and marsh pond salinity, which were largely driven by fluctuations in the mean sea level in the estuary. When mean sea level was at its lowest point in February 2016, average marsh pond salinity and Blue Crab density increased at all three sites as a result of the disconnection with the San Antonio Bay. While the low water levels in February 2016 decreased the total area of inhabitable marsh for the Blue Crabs, effectively increasing their average density and making them easier to

find and capture by the Whooping Cranes, the coinciding increase in marsh water salinity exceeded the threshold of suitable drinking water (~19-23ppt; E. Smith, personal communication) at all three sites. Therefore, even though the crabs became isolated and increased in density in saltmarsh territories, many of the cranes likely had to fly inland to access suitable drinking water from freshwater habitats, possibly nullifying any energetic gain from the increase in crab availability.

Multiple regression revealed that marsh pond salinities across all sites in 2016 correlated the strongest with mean sea level and San Antonio Bay salinity, and the salinity of marsh ponds at sites sampled in 2017 was primarily driven by bay salinity. While we cannot directly manage the water level of the San Antonio Bay, we can manage the volume of freshwater inputs into the estuary. Leaving their saltmarsh territories in search of fresh water is energetically expensive and results in the cranes spending time in relatively unfamiliar habitats, increasing their vulnerability to predation. For Whooping Cranes to truly benefit from increased Blue Crab availability when water levels are low, the bay water inundating the marshes prior to the hydrological disconnection event must be fresh enough to be able to remain below 19-23ppt once isolated and susceptible to evapotranspiration until sea level rises again.

Water quality patchiness along the Blackjack Peninsula. I hypothesized that sites in close proximity to each other would be comparable in water quality (salinity, conductivity, temperature) due to their generally shared distance from freshwater inputs and assumed similarity in microtopography. Data analysis found that sites in the Dunham Marsh area were most similar in water quality to sites in the adjacent Sundown Bay region during four of the six sampling months, and sites within the centrally located

Pump Canal region were most similar to each other during two of the six sampling months. Also, adjacent Ayer's and Rattlesnake Islands were most similar in water quality in two of the sampling months. While these three trends may seem to roughly support the hypothesis, the Boat Ramp (northeastern-most) site was most comparable to Dunham Marsh (the southwestern-most site) and the northern half of Ayer's Island was dissimilar to the southern half of the island, with both phenomena observed two of the six months. This lack of a consistent general trend in water quality along the Aransas NWR coastal marshes indicates that inter-site structural variability does not necessarily occur along a linear gradient across the peninsula, and this structural variability may have a greater influence on water quality than an individual site's position along the Gulf Intracoastal Waterway.

Conclusion. Intra-seasonal shifts in mean sea level and salinity in the San Antonio Bay cause dramatic changes in the hydrological dynamics of coastal saltmarshes, largely dictating the distribution and availability of resources crucial to Whooping Cranes. To investigate which structural components make one saltmarsh territory more plentiful in Whooping Crane resources than another, future geospatial modeling of the microtopographic variations along the Aransas NWR could be paired with the food density (Carolina Wolfberry fruit and Blue Crab) and marsh pond salinity data from this study. These environmental indicators of enhanced habitat quality could be applied to future land purchase, protection of existing lands, environmental easement, and restoration decisions. These steps may lead to the long-term conservation of coastal resources and preservation of key winter habitats throughout the region to support this increasing population of Whooping Cranes.

Relationships between Whooping Crane behavior and habitat quality

Comparison of crane behavior between sites similar in habitat quality. It was hypothesized that if two Whooping Crane territories were comparable in food (Blue Crab) density and freshwater availability, then the cranes observed in those two sites would exhibit similar time activity budgets. Once determining which sites each month were statistically similar in Blue Crab density and marsh pond salinity, PCA was then used to determine which sites were most comparable in behavior. Across the six sampling months, 22 pairs of sites were determined to be statistically similar in Blue Crab and marsh pond salinity. Of these 22 similar pairs, there was only four instances when bird behavior resulted in similar time activity budgets. Interestingly, a similarity in Blue Crab density and marsh pond salinity alone did result in the exhibition of similar Whooping Crane time activity budgets.

Shifts in behavior in response to changing habitat quality. The behavior of cranes observed at the three sites that were repeatedly sampled each month were used to investigate whether significant changes in habitat quality are reflected in Whooping Crane behavior. As mentioned earlier, the three sites consistently sampled in 2016 experienced elevated Blue Crab densities and marsh pond salinities in the month of February, and similarly lower Blue Crab densities and pond salinities in January and March. If their behavior were to shift in correlation to this change in the availability of those two resources, one would expect the behavior of the cranes to change as well. Specifically, behavior at each site in January was expected to be similar to how they behaved in March and in contrast to February, when Blue Crab density and pond salinity was significantly higher, which was not the case. Whooping Crane behavior at sites

repeatedly sampled in 2017 also did not shift in correlation to observed monthly shifts in Blue Crab density and marsh pond salinity.

Whooping Crane behavior was not frequently observed to be most comparable between sites similar in Blue Crab density and marsh pond salinity, nor did it shift in correlation to monthly shifts in the same two environmental metrics. Therefore, Blue Crab density and marsh pond salinity alone were not strong indicators of monthly Whooping Crane behavior across the Aransas NWR. While Blue Crabs are their primary food source while wintering at the Aransas NWR, their overall opportunistic feeding habits may be partially responsible for the lack of significance in this model. Also, due to the lack of an elevation platform during behavioral observations, it was not possible to view and record fine-scale foraging behavior data, such as differentiating between searching for, processing, and consuming food items. This model also did not scale Blue Crab density to the area of open water habitat in a given territory. Even though two sites may be similar in Blue Crab density, they may vary significantly in the actual area of crab habitat present, which would yield a dramatic discrepancy in the total number of crabs present between the two sites.

Further investigation of the drivers of Whooping Crane behavior. As Blue Crab density and marsh pond salinity alone did not sufficiently correlate to Whooping Crane behavior, multiple regression was used to investigate how other environmental factors (observation distance to bird, wind speed, air temperature, time of day, bay water level, red Carolina Wolfberry fruit density) correlate with observed Whooping Crane behavior in 2016 and 2017. No multiple regression using this new set of environmental factors significantly correlated to the amount of time spent in any behavior category

during either sample year. A few individual factors within the multiple regressions, however, did correlate significantly with behavior, but these relationships were not consistent seen across the two winters.

Interestingly, in 2016, the amount of time spent foraging and in comfort/maintenance both most strongly correlated to time of day and red fruit density, but in an opposite nature. The Whooping Cranes generally spent less time foraging as the day progressed, and those at sites with relatively higher red Carolina Wolfberry fruit density spent more time foraging; conversely, the opposite relationship between these two factors and time spent in comfort/maintenance was observed. As foraging is an “obligate” behavior necessary for survival and comfort/maintenance behaviors are considered “elective” behaviors (not directly pertinent to survival), this phenomenon may be exhibiting a tradeoff between an obligate and elective behavior: when/where the cranes spent more of their time foraging, which is crucial to their survival, less time was partitioned to non-essential comfort/maintenance activities. Wintering Common Cranes have also exhibited a tradeoff between the time of day they spend foraging and in comfort/maintenance, with the peak time of day spent in either behavior having a negative correlation to the peak time of day spent in the other (Alonso and Alonso 1992). However, neither time of day nor red fruit density correlated to time spent foraging or in comfort/maintenance in 2017; the lack of influence on red fruit density on behavior in 2017 is likely resultant of the complete lack of red fruit in February and March, which was not the case in 2016. The cranes generally spent more time on alert as bay water levels decreased in 2016. As Whooping Cranes are known to rely on standing water to relay auditory cues of incoming predators, they may have had to spend more of their time

being vigilant themselves when water levels were lower. However, the relationship between water level and time on alert was not observed in 2017, when bay water levels during sampling periods were much lower than in 2016.

Conclusion. Whooping Crane behavior did not consistently reflect Blue Crab density, marsh pond salinity, time of day, water level, observation distance, wind speed, air temperature or red Carolina Wolfberry fruit density across the two winters of this study. Shifts in the large-scale hydrological conditions throughout the greater estuary, however, continuously changed water quality and food resource availability in the Whooping Cranes' saltmarsh territories throughout a winter season. The frequent changes in estuarine hydrology, which do not necessarily influence the habitat quality at different sites in the same way, both during and across winter seasons makes it extremely difficult to find consistent relationships between Whooping Crane behavior and environmental conditions. Geospatial modeling of historically profitable Whooping Crane territories could provide an alternative method to help further define which saltmarsh structural features yield prime wintering habitats.

Importance of continued waterbird conservation efforts.

As lake and wetland water levels and the distribution of waters are expected to be greatly influenced by climate change due to shifting precipitation and evaporation regimes (Meyer *et al.* 1999), there is merit in using earlier studies of wading bird responses to fluctuating water levels to infer potential future responses of wading birds to global climate change. An early materialization of this concept utilized previous studies describing how water level dictates nesting and foraging behaviors of wading birds to comment that their continued future in North America is going to depend upon their

ability to behaviorally adapt to the effects of habitat loss resultant of human development and sea level rise (Butler and Vennesland 2000). As wading birds largely rely upon seasonally abundant prey sources for their subsequent reproductive success, Butler and Vennesland (2000) conclude that their continued survival is going to be a function of the availability of suitable foraging habitat. Therefore, future research regarding how wading birds cope with climate variability and how they will habituate to increasing levels of human impairment on their natural habitats is crucial (Butler and Vennesland 2000).

Models in Chavez-Ramirez and Wehtje's (2012) exploration of the future impacts of global climate change on whooping cranes predict an average 20% increase in annual precipitation at the Aransas-Wood Buffalo flock's summer wetland breeding grounds in North Central Canada (Chavez-Ramirez and Wehtje 2012). During these extreme rainfall events, Whooping Crane chicks could possibly drown in their nests built in the middle of ponds (Chavez-Ramirez and Wehtje 2012). However, low water levels have historically been associated with increased Whooping Crane chick predation (Kuyt 1981), and Chavez-Ramirez and Wehtje (2012) predict that a modest increase in precipitation will generally stimulate prey populations, both of which indicate a possible increase in Whooping Crane fitness in response to climate change. However, if aquatic invertebrates and frogs start their life cycles earlier in the year and become desynchronized with crane chick development, prey items may be too large for consumption by young Whooping Crane chicks (Chavez-Ramirez and Wehtje 2012).

Past and current research of how wading birds of different sizes, foraging methods, and nesting periods are affected by fluctuating water levels can definitely be considered useful in the context of how wading birds may be affected by environmental

variability. Alteration in water column mixing and the magnitude and timing of seasonal runoff schedules will successively shift the nutrient loading regime of a system, as well as change habitat availability for aquatic organisms (Meyer *et al.* 1999). For example, global climate can influence the primary and secondary productivity of aquatic systems, shown through increases in population instability and dramatic changes in community structure (Meyer *et al.* 1999; O'Reilly *et al.* 2003; Winder and Schindler 2004; Winder *et al.* 2009).

O'Reilly *et al.* (2003) found that climate change has actually decreased the overall productivity of Lake Tanganyika, Africa by 20% through increased thermal water column stability and decreased wind velocity and subsequent mixing. Their study also estimated an approximate 30% decrease in fish yields in response to this decrease in lake primary productivity (O'Reilly *et al.* 2003). While this study did not specifically explore the possible implications of decreased fish populations on animals at higher trophic levels other than humans, it is clearly an example of how global climate change has the ability to negatively impact aquatic populations of wading bird prey species.

A study of Lake Washington, USA showed that as water temperature has increased over time, effectively extending the duration of the yearly growing season of the lake, a copepod species (*Leptodiaptomus ashlandi*) has increased their number of reproductive efforts per year (Winder *et al.* 2009). This switch in voltinism resulted in the desynchronization of a previously predictable seasonality of copepod recruitment and peak lake production (Winder *et al.* 2009). The increase in generations per year also resulted in less stable population dynamics of *Leptodiaptomus ashlandi* (Winder *et al.* 2009). This intriguing study does, however, stop short of implying possible consequences

of this change in secondary producer population dynamics on organisms higher up in the food web, such as the fish that feed upon them, as well as the subsequent predators of those fish. As migratory birds often arrive at their breeding/wintering grounds in synchronization with seasonally available food resources, seasonal desynchronization and/or increased population instability at lower trophic levels due to global climate change could potentially result in a lack of available food items during peak nesting season or when migrants first arrive at their seasonal destination (Both *et al.* 2006; Robinson *et al.* 2009). Seasonal desynchronization of food availability and breeding behaviors of migrants could result in great losses in overall avian fitness, as migratory breeding birds rely upon the seasonal availability of these food items to meet the feeding requirements of their growing offspring (Both and Visser 2001). Therefore, there is much merit in future research regarding how shifts in population dynamics at lower trophic levels are possibly having bottom-up limits on their predator populations in higher trophic levels as an effect of global climate change in aquatic ecosystems.

While there is currently a limited amount of primary literature specifically exploring the potential future impacts of climate change on wading bird populations in aquatic ecosystems, previous and recent studies of the effect of water level fluctuations on their foraging and nesting success, as well literature documenting the recent spread of avian diseases can be useful indicators of how wading birds may respond to the continued progression of global climate change. However, there is currently a large gap in knowledge of the severity of the impact of novel arbovirus diseases on waterbird populations, as well as a gap in knowledge regarding how changing aquatic population dynamics at lower trophic levels induced by climate change will affect migratory wading

birds. By expanding our knowledge of how large scale global climate change impacts are threatening wading birds in aquatic habitats, we can potentially learn how to direct future water management projects in attempt to mitigate the severity of these negative impacts.

REFERENCES

- Allen, R. P. 1952. The Whooping Crane. Research Report No. 3 by the National Audubon Society.
- Alonso, J. C. and J. A. Alonso. 1992. Daily activity and intake rate patterns of wintering Common Cranes *Grus grus*. ARDEA 80: 343-351.
- Alonso, J. C., J. A. Alonso, L.M. Bautista and R. Muñoz-Pulido. 1995. Patch use in cranes: a field test of optimal foraging predictions. Animal Behaviour 49: 1367-1379.
- Armstrong, N. E. 1987. The ecology of open-bay bottoms of Texas: A community profile. Biological Report No. 85 (7.12). National Wetlands Research Center, Fish and Wildlife Service, US Department of the Interior.
- Avilés, J. M. 2003. Time budget and habitat use of the Common Crane wintering in dehesas of southwestern Spain. Canadian Journal of Zoology 81: 1233-1238.
- Banks, R. 1978. The size of the early Whooping Crane populations. Unpublished Report. USFW files. 10 pp.
- Bautista, L. M., J. C. Alonso and J. A. Alonso. 1998. Foraging site displacement in Common Crane flocks. Animal Behaviour 56: 1237-1243.
- Bianchi, T. S., J. R. Pennock and R. R. Twilley. 1999. Biogeochemistry of Gulf of Mexico Estuaries. John Wiley and Sons, Inc. New York, New York.
- Binkley, C. S. and R. S. Miller. 1980. Survivorship of the Whooping Crane. Ecology 61: 434-437.
- Binkley, C. S. and R. S. Miller. 1988. Recovery of the Whooping Crane. Biological Conservation 45:11-20.

- Both, C. and M. Visser. 2001. Adjustment to climate change is constrained by arrival date in a long-distance migratory bird. *Nature* 411: 296-298.
- Both, C., S. Bouwhuis, C. M. Lessells and M. E. Visser. 2006. Climate change and population declines in a long distance migratory bird. *Nature Letters* 44: doi: 10.1038.
- Brown, W. M., R. C. Drewien and E. G. Bizeau. 1987. Mortality of cranes and waterfowl from powerline collisions in the San Luis Valley-Colorado. 1985 Crane Workshop. Platte River Whooping Crane Habitat Maintenance Trust and USFWS, Grand Island, Nebraska. 128-136.
- Burnham, J., J. Barzen, A. M. Pidgeon, B. Sun, J. Wu, G. Liu and H. Jiang. 2017. Novel foraging by wintering Siberian Cranes *Leucogeranus leucogeranus* at China's Poyang Lake indicates broader changes in the ecosystem and raises new challenges for a critically endangered species. *Bird Conservation International* 2017: 1-20.
- Butler, R. W. and R. G. Vennesland. 2000. Integrating climate change and predation risk with wading bird conservation research in North America. *The International Journal of Waterbird Biology* 23: 535-540.
- Butzler, R. E. 2006. Spatial and temporal patterns of *Lycium carolinianum* Walt, the Carolina Wolfberry, in the salt marshes of Aransas National Wildlife Refuge, Texas. Master's Thesis, Texas A&M University.
- Butzler, R. E. and S. E. Davis. 2006. Growth patterns of Carolina wolfberry (*Lycium carolinianum* L.) in the salt marshes of Aransas National Wildlife Refuge, Texas USA. *Wetlands* 26: 845-853.

- Canadian Wildlife Service and U.S. Fish and Wildlife Service (CWS and USFWS). 2005. International recovery plan for the Whooping Crane. Ottawa: Recovery of Nationally Endangered Wildlife (RENEW), and U.S. Fish and Wildlife Service, Albuquerque, New Mexico. 162 pp.
- Chavez-Ramirez, F. 1996. Food availability, foraging ecology, and energetics of Whooping Cranes wintering in Texas. ProQuest Dissertations and Theses.
- Chavez-Ramirez, F. and R. D. Slack. 1995. Differential use of coastal marsh habitats by nonbreeding wading birds. *Colonial Waterbirds* 18: 166-171.
- Chavez-Ramirez, F. and W. Wehtje. 2012. Potential impact of climate change scenarios on Whooping Crane life history. *Wetlands* 32: 11-20.
- Copeland, B. J. 1966. Effects of decreased river flow on estuarine ecology. *Estuarine Ecology* 38: 1831-1839.
- Custer, T. W. and R. G. Osborn. 1978. Feeding habitat use by colonially-breeding herons, egrets, and ibises in North Carolina. *The Auk* 95: 733-734.
- Daly, J. W., M. Halbleib, J. I. Smith, W. P. Gibson, M. K. Doggett, G. H. Taylor, J. Curtis and P. P. Pasteris. 2008. Physiographically sensitive mapping of climatological temperature and precipitation across the conterminous United States. *International Journal of Climatology* 28: 2031-2064.
- Darnell, T. M. and E. H. Smith. 2004. Avian use of natural and created salt marsh in Texas, USA. *Waterbirds* 27: 355-361.
- David, P. G. 1994. Wading bird use of Lake Okeechobee relative to fluctuating water levels. *The Wilson Bulletin* 106: 719-732.

- Day, J. W., J. D. Gunn, W. J. Folan, A. Yáñez-Arancibia and B. P. Horton. 2007. Emergence of complex societies after sea level stabilized. EOS Transaction, American Geophysical Union 88: 169-170.
- Day, J. W., W. M. Kemp, A. Yáñez-Arancibia and B. C. Crump. 2013. Estuarine Ecology, 2nd edition. Hoboken, New Jersey: Wiley-Blackwell.
- Díaz, M., E. González, R. Muñoz-Pulido and M. A. Naveso. 1996. Habitat selection patterns of Common Cranes *Grus grus* wintering in Holm Oak *Quercus ilex* dehesas of central Spain: effects of human management. Biological Conservation 75: 119-123.
- Dimalaxis, A. and M. Pyrovetsi. 1997. Effect of water level fluctuations on wading bird foraging habitat use at an irrigation reservoir, Lake Kerkini, Greece. Colonial Waterbirds 20: 244-252.
- Ellis, D. H., S. R. Swengel, G. W. Archibald and C. B. Kepler. 1998. A sociogram for the cranes of the world. Behavioural Processes 43: 125-151.
- Folk, M. J., A. R. Woodward and M. G. Spalding. 2014. Predation and scavenging by American alligators on Whooping Cranes and Sandhill Cranes in Florida. Southeastern Naturalist 13: 64-79.
- Gawlik, D. E. 2002. The effects of prey availability on the numerical response of wading birds. Ecological Monographs 72: 329-346.
- Gil de Weir, K. 2006. Whooping Crane (*Grus americana*) demography and environmental factors in a population growth simulation model. Dissertation, Texas A&M University, College Station, Texas.
- Gil de Weir, K. C., W. E. Grant, R. D. Slack, H. -H. Wang and M. Fujiwara 2012.

- Demography and population trends of Whooping Cranes. *Journal of Field Ornithology* 83:1-10.
- Greer, D. M. 2010. Blue Crab population ecology and use by foraging Whooping Cranes on the Texas Gulf Coast. PhD dissertation, Texas A&M University.
- Hunt, H. E. and R. D. Slack. 1989. Winter diets of whooping and Sandhill Cranes in South Texas. *Journal of Wildlife Management* 53: 1150-1154.
- Jia, Y., S. Jiao, Y. Zhang, Y. Zhou, G. Lei and G. Liu. 2013. Diet shift and its impact on foraging behavior of Siberian Crane (*Grus leucogeranus*) in Poyang Lake. *PLoS One* 8: e65843.
- Johns, B. W., J. P. Goossen, E. Kuyt and L. Craig-Moore. 2005. Chavez-Ramirez, F. ed. *Proceedings of the Ninth North American Crane Workshop*, Jan 17-20, 2003. Sacramento, California: North American Crane Working Group. Pp. 117-126.
- Kahl, M. P. 1964. Food ecology of the Wood Stork (*Mycteria americana*) in Florida. *Ecological Monographs* 34: 97-117.
- Kennett, D. J. and J. P. Kennett. 2006. Early state formation in Southern Mesopotamia: sea levels, shorelines, and climate change. *Journal of Island and Coastal Archaeology* 1: 67-99.
- Klassen, J. A., D. E. Gawlik and P. C. Frederick. 2016. Linking wading bird prey selection to number of nests. *The Journal of Wildlife Management* DOI: 10.1002/jwmg.21141.
- Kushlan, J. A. 1981. Resource use strategies of wading birds. *The Wilson Bulletin* 93: 145-163.
- Kushlan, J. A. 1986. Responses of wading birds to seasonally fluctuating water levels:

- strategies and their limits. *Colonial Waterbirds* 9: 155-162.
- Kushlan, J. A. 1993. Colonial waterbirds as bioindicators of environmental change. *Colonial Waterbirds* 16: 223-251.
- Kuyt, E. 1981. Population status, nest site fidelity, and breeding habitat of whooping cranes. *Crane Research around the World. Proceedings of the International Crane Symposium, Sapporo Japan, 1980.* Robinson, Fort Collins: 119-125.
- Lafever, K. E. 2006. Spatial and temporal winter territory use and behavioral responses of Whooping Cranes to human activities. Master's thesis. Texas A&M University.
- Lee, S. D., P. G. Jabłoński and H. Higuchi. 2007. Wintering foraging of threatened cranes in the Demilitarized Zone of Korea: behavioral evidence for the conservation importance of unplowed rice fields. *Biological Conservation* 138: 286-289.
- Li, C., L. Zhou, L. Xu, N. Zhao and G. Beauchamp. 2015. Vigilance and activity time-budget adjustments of wintering Hooded Cranes, *Grus monacha*, in human-dominated foraging habitats. *PLoS ONE* 10: e0118928.
- Longely, W. L., ed. 1994. Freshwater inflows to Texas bays and estuaries: ecological relationships and methods for determination of needs. Texas Water Development Board and Texas Parks and Wildlife Department, Austin, TX. 386 pp.
- Matsinos, Y. G., W. F. Wolff and A. Moustakas. 2011. Adapting foraging to habitat heterogeneity and climate change: an individual-based model for wading birds. *Ethology Ecology and Evolution* 24: 209-229.
- Meyer, J. L., M. J. Sale, P. J. Mulholland and N. L. R. Poff. 1999. Impacts of climate change on aquatic ecosystem functioning and health. *Journal of American Water Resources Association* 35: 1373-1386.

- Mitsch, W. J. and J. G. Gosselink. 2007. *Wetlands*, 4th ed. John Wiley and Sons, Inc., Hoboken, New Jersey.
- Montagna, P. A., M. Alber, P. Doering and M. S. Connor. 2002. Freshwater inflow – Science, policy, management: *Estuaries* 25: 1243-1245.
- Morrison, G. and H. Greening. 2011. Chapter 6: Freshwater Inflows. *Integrating Science and Resource Management in Tampa Bay, Florida*. USGS.
- National Wildlife Federation. 2004. *Bays in Peril: A Forecast for Freshwater Flows to Texas Estuaries*. www.nwf.org.
- National Oceanic and Atmospheric Administration (NOAA). 2012. *Spatial Trends in Coastal Socioeconomics. Demographic Trends Database: 1970-2010. Woods and Poole Economics, Inc. Projections Database 1970-2040*. Available from: coastalsocioeconomics.noaa.gov.
- O' Reilly, C. M., S. R. Alin, P. D. Plisnier, A. S. Cohen and B. A. McKee. 2003. Climate change decreases aquatic ecosystem productivity of Lake Tanganyika, Africa. *Nature* 424: 776-768.
- Pugesek, B. H., M. J. Baldwin and T. Stehn. 2013. The relationship of Blue Crab abundance to winter mortality of Whooping Cranes. *Wilson Journal of Ornithology* 125: 658-661.
- Robinson, R. A., H. Q. P. Crick, J. A. Learmonth, I. M. D. Maclean, C. D. Thomas, F. Bairlein, M. C. Forchhammer, C. M. Francis, J. A. Gill, B. J. Godley, J. Harwood, G. C. Hays, B. Huntley, A. M. Hutson, G. J. Pierce, M. M. Rehfish, D. W. Sims, M. Begoña Santos, T. H. Sparks, D. A. Stroud and M. E. Visser. 2009. *Travelling*

- through a warming world: climate change and migratory species. *Endangered Species Research* 7:87-99.
- Russell, G. J., O. L. Bass Jr. and S. L. Pimm, S.L. 2002. The effect of hydrological patterns and breeding-season flooding on the numbers and distribution of wading birds in Everglades National Park. *Animal Conservation* 5: 185-199.
- Sandoz, M. and R. Rogers. 1944. The Effect of Environmental Factors on Hatching, Moulting, and Survival of Zoea Larvae of the Blue Crab *Callinectes Sapidus* Rathbun. *Ecology* 25: 216-228.
- Stehn, T. V. 1992. Unusual movements and behaviors of color-banded Whooping Cranes during winter. *North American Crane Workshop Proceedings* 6: 95-101.
- Stehn, T. V and F. Prieto. 2010. Changes in winter Whooping Crane territories and range 1950-2006. *North American Crane Workshop Proceedings*. University of Nebraska – Lincoln.
- Takekawa, J. Y., I. Woo, R. Gardiner, M. Casazza, J. T. Ackerman, N. Nur, L. Liu and H. Spautz. 2011. Avian communities in tidal salt marshes of San Francisco Bay: a review of functional groups by foraging guild and habitat association. *San Francisco Estuary and Watershed Science Journal* 9: 1-24.
- Tischendorf, L. 2004. The Whooping Crane: population viability and critical habitat in the Wood Buffalo National Park area NT/AB Canada. *Elutis Modelling and Consulting Inc.* Ottawa, Canada.
- United States Army Corps of Engineers (USACE). 2004. Waterborne commerce of the

- United States, Part 2. Waterways and Harbors Gulf Coast, Mississippi River System and Antilles. Institute for Water Resources. Alexandria, VA: U.S. Army Corps of Engineers, 344p.
- United States Census Bureau. 2011. Census 2010. Available from: factfinder2.census.gov/faces/nav/jsf/pages/index.xhtml.
- United States Fish and Wildlife Service (USFWS). 2017. Whooping Crane Survey Results: Winter 2016-2017. Available at: fws.gov.
- Wang, Z., Z. Li, G. Beauchamp and Z. Jiang. 2011. Flock size and human disturbance affect vigilance of endangered Red-crowned Cranes (*Grus japonensis*). *Biological Conservation* 144: 101-105.
- Winder, M. and D. E. Schindler. 2004. Climate change uncouples trophic interactions in an aquatic ecosystem. *Ecology* 85: 2100-2106.
- Winder, M., D. E. Schindler, T. E. Essington and A. H. Litt. 2009. Disrupted seasonal clockwork in the population dynamics of a freshwater copepod by climate warming. *Limnology and Oceanography* 54: 2493-2505.
- Wozniak, J. R., T. M. Swannack, R. Butzler, C. Llewellyn and S. E. Davis III. 2012. River inflows, estuarine salinity, and Carolina Wolfberry fruit abundance: linking abiotic drivers to Whooping Crane food. *Journal of Coastal Conservation* 16: 345-354.
- Zhou, B., L. Zhou, J. Chen, Y. Cheng and W. Xu. 2010. Diurnal time-activity budgets of wintering Hooded Cranes (*Grus monacha*) in Shengjin Lake, China. *Waterbirds* 33: 110-115.

APPENDIX A

Whooping Crane behavioral observation data collection sheet.

FRONT

Whooping Crane Focal Bird Sampling Data Sheet

Date: _____ Site: _____ Team Members: _____

F=Foraging (Pond or Vegetation) C=Comfort/maintenance L=Locomotion (note if Flying)

I=Interaction (note if Territory Defense) A=Alert R=Resting

Start Time: _____ Bird #1					Start Time: _____ Bird #2				
Bands:			Observer:		Bands:			Observer:	
Int #	Obs	Comments	Int #	Obs	Comments	Int #	Obs	Comments	
1			41			1			
2			42			2			
3			43			3			
4			44			4			
5			45			5			
6			46			6			
7			47			7			
8			48			8			
9			49			9			
10			50			10			
11			51			11			
12			52			12			
13			53			13			
14			54			14			
15			55			15			
16			56			16			
17			57			17			
18			58			18			
19			59			19			
20			60			20			
21			61			21			
22			62			22			
23			63			23			
24			64			24			
25			65			25			
26			66			26			
27			67			27			
28			68			28			
29			69			29			
30			70			30			
31			71			31			
32			72			32			
33			73			33			
34			74			34			
35			75			35			
36			76			36			
37			77			37			
38			78			38			
39			79			39			
40			80			40			

APPENDIX B

Number of Blue Crab, water quality, and Carolina Wolfberry fruit surveys conducted at each site that was sampled all three months of the same year (2016 and 2017).

Site	Month and Year	Blue Crab/ water quality survey (n)	Carolina Wolfberry fruit survey (n)
Boat Ramp	Jan 16	6	15
	Feb 16	4	24
	Mar 16	3	27
Rattlesnake Island	Jan 16	4	27
	Feb 16	5	21
	Mar 16	4	21
Dunham Marsh	Jan 16	4	27
	Feb 16	5	24
	Mar 16	5	27
Boat Ramp	Jan 17	5	18
	Feb 17	3	15
	Mar 17	3	27
Ayer's Island	Jan 17	3	18
	Feb 17	3	18
	Mar 17	2	15
South Sundown Bay	Jan 17	3	18
	Feb 17	3	15
	Mar 17	3	15

Note. Water quality was sampled after each Blue Crab survey, which explains the shared sample size between those two parameters. A minimum total of 300m of open water edge was sampled for Blue Crabs at each site, with each body of water included in the survey counting as one sample. Carolina Wolfberry fruit survey sample size was calculated by the number of repetitions that occurred at each site multiplied by three, as three sampled were taken during each replicate along the transect line.

APPENDIX C

The site location name, associated acronym, and number of independent Blue Crab/water quality surveys that were conducted at each site sampled by month in 2016 and 2017.

Month and Year	Site Name	Site Acronym	Blue Crab/Water Quality Survey Sample Size
Jan 2016	Central Sundown Bay	CSD	4
	Rattlesnake Island	RSI	4
	Boat Ramp	BR	6
	N.E. Pump Canal	NEPC	6
	South Pump Canal	SPC	4
	Sundown Island	SDI	4
	Ayer's Island	AI	4
	Dunham Marsh	DM	4
Feb 2016	Boat Canal	BC	4
	Rattlesnake Island	RSI	5
	Boat Ramp	BR	4
	Ayer's Island South	AIS	7
	Observation Tower	OT	5
	South Sundown Bay	SSDB	6
	Ayer's Island North	AIN	5
	Dunham Marsh	DM	5
	N. Sundown Bay 1	NSDB1	4
	N. Sundown Bay 2	NDSB2	6
Mar 2016	Boat Ramp	BR	3
	South Sundown Bay	SSDB	4

(continued)

Month and Year	Site Name	Site Acronym	Blue Crab/Water Quality Survey Sample Size
Jan 2017	Dunham Marsh N.	DMN	3
	Dunham Marsh S.	DMS	5
	Ayer's Island	AI	6
	Observation Tower	OT	4
	Rattlesnake Island	RSI	4
	Mid Sundown Bay	MSDB	4
	South Pump Canal	SPC	3
	Dunham Marsh N.	DMN	3
	South Sundown Bay	SSDB	3
	Ayer's Island	AI	3
	Mid Sundown Bay	MSDB	3
	Boat Ramp	BR	5
	N. Bowling Alley	NBA	2
	North Pump Canal	NPC	3
	South Ayer's Island	SAI	3
Feb 2017	Boat Ramp	BR	3
	North Pump Canal	NPC	2
	North Ayer's Island	NAI	3
	Rattlesnake Island	RSI	3
	Dunham Marsh N.	DMN	3
Mar 2017	Observation Tower	OT	5
	South Sundown	SSD	3
	Dunham Marsh S.	DMS	3
	Rattlesnake Island	RSI	1
	South Sundown Bay	SSDB	3

(continued)

Month and Year	Site Name	Site Acronym	Blue Crab/Water Quality Survey Sample Size
	Dunham Marsh N.	DMN	4
	N. Dunham Marsh N.	NDMN	2
	N. Pump Canal	NPC	2
	Ayer's Island	AI	2
	S. Sundown TC	SSDTC	1
	Observation Tower	OT	2
	N. Sundown TC	NSDTC	3
	S. Dunham Marsh	SDM	1
	Boat Ramp	BR	3

Note. Each sample varies in the length (m) of water body edge surveyed, with samples totaling a minimum of 300m surveyed per site.

APPENDIX D

Multiple regression results of the influence of observation distance (m), wind speed (m/s), air temperature (C), time of day, bay water level (m), and red Carolina Wolfberry fruit density (fruit/meter²) on each behavior category across all sites sampled in 2016.

Behav.		df	SS	MS	F	Signif. F	R ²
Forage	Regress.	6	0.158	0.026	1.208	0.352	0.312
	Resid.	16	0.348	0.022			
	Total	22	0.506				
Alert	Regress.	6	0.157	0.026	2.229	0.094	0.445
	Resid.	16	0.188	0.012			
	Total	22	0.345				
Rest	Regress.	6	0.112	0.019	0.983	0.468	0.269
	Resid.	16	0.305	0.019			
	Total	22	0.417				
Comfort	Regress.	6	0.167	0.028	1.489	0.244	0.358
	Resid.	16	0.299	0.019			
	Total	22	0.467				
Loco.	Regress.	6	0.071	0.012	1.078	0.416	0.288
	Resid.	16	0.176	0.011			
	Total	22	0.248				
Interact.	Regress.	6	0.001	0.000	1.002	0.458	0.273
	Resid.	16	0.004	0.000			
	Total	22	0.005				

APPENDIX E

Multiple regression results of the influence of observation distance (m), wind speed (m/s), air temperature (C), time of day, bay water level (m), and red Carolina Wolfberry fruit density (fruit/meter²) on each behavior category across all sites sampled in 2017.

Behav.		df	SS	MS	F	Signif. F	R ²
Forage	Regress.	6	0.087	0.015	0.490	0.805	0.174
	Resid.	14	0.414	0.296			
	Total	20	0.501				
Alert	Regress.	6	0.016	0.003	0.128	0.991	0.052
	Resid.	14	0.292	0.021			
	Total	20	0.308				
Rest	Regress.	6	0.044	0.007	0.300	0.927	0.114
	Resid.	14	0.343	0.244			
	Total	20	0.387				
Comfort	Regress.	6	0.147	0.024	1.720	0.189	0.424
	Resid.	14	0.199	0.014			
	Total	20	0.346				
Loco.	Regress.	6	0.063	0.010	0.480	0.813	0.171
	Resid.	14	0.305	0.022			
	Total	20	0.367				
Interact.	Regress.	6	0.028	0.005	1.851	0.160	0.442
	Resid.	14	0.035	0.003			
	Total	20	0.063				

Note. Analysis result of the average value of each metric per site. Average fraction of time spent in each behavior category was arcsine transformed.

APPENDIX F

List of sites designated as similar in resources each month and whether Whooping Crane time activity budgets were also similar between the two sites.

Month & Year	Sites Similar in Resources	Sites Similar in Behavior? (Yes/No)
Jan 2016	AIS & SDI	No
Feb 2016	AIN & NSDB1	No
	AIS & NSDB1	No
	AIS & NSDB2	No
	DM & RSI	No
Mar 2016	AI & BR	Yes
	AI & DMS	No
	AI & RSI	No
	MSDB & RSI	Yes
Jan 2017	AI & DMN	No
	AI & MSDB	No
	DMN & MSDB	Yes
Feb 2017	DMN & NPC	No
	NAI & RSI	No
Mar 2017	AI & DMN	No
	AI & OT	No
	AI & SDTC	No
	AI & SSDB	No
	DMN & OT	No
	DMN & SDTC	No
	OT & SDTC	Yes
	SDTC & SSDB	No

Note. Blue Crab density and marsh pond salinity were used to determine Whooping Crane resource availability at each site. A complete list of sites sampled each month and their associated acronyms can be found in Appendix C.

APPENDIX G

Catalogue of Acronyms

AI: Ayer's Island

AIN: Ayer's Island North

AIS: Ayer's Island South

AWB: Aransas-Wood Buffalo population

BBASC: Basin and Bay Area Stakeholder Committee

BBEST: Basin and Bay Area Expert Science Team

BC: Boat Canal

BR: Boat Ramp

COSEWIC: Committee on the Status of Endangered Wildlife in Canada

CSD: Central Sundown Bay

CWS: Canadian Wildlife Service

DM: Dunham Marsh

DMN: Dunham Marsh North

DMS: Dunham Marsh South

EMP: Eastern Migratory Population

GBRA1: Guadalupe Bay River Authority 1 (?)

GIWW: Gulf Intracoastal Waterway

IUCN: International Union for Conservation of Nature

MSDB: Mid Sundown Bay

NAI: North Ayer's Island

NBA: North Bowling Alley

NDMN: North Dunham Marsh North

NEPC: Northeast Pump Canal

NOAA: National Oceanic and Atmospheric Administration

NP: National Park

NPC: North Pump Canal

NSDB1: North Sundown Bay 1

NSDB2: North Sundown Bay 2

NSDTC: North Sundown Tidal Creek

NWR: National Wildlife Refuge

OT: Observation Tower

RMP: Rocky Mountain Population

RSI: Rattlesnake Island Site

SAI: South Ayer's Island

SDI: Sundown Island

SDM: South Dunham Marsh

SPC: South Pump Canal

SSD[B]: South Sundown Bay

SSDTC: South Sundown Tidal Creek

TCEQ: Texas Commission on Environmental Quality

TCOON: Texas Coastal Ocean Observation Network

USACE: United States Army Corps of Engineers

USFWS: US Fish and Wildlife Service

USGS: United States Geological Survey

WCEP: Whooping Crane Eastern Partnership

WCRP: Whooping Crane Recovery Plan

WLWCA: White Lake Wetlands Conservation Area

VITA

Lindsey A. Tiegs

Fall 2017

Sam Houston State University
Department of Biological Sciences
Huntsville, Texas 77341-2116
E-mail: tiegs@shsu.edu

EDUCATION

Master of Science, December 2017

Biological Sciences

Sam Houston State University, Huntsville, TX

GPA: 3.87

Bachelor of Science, May 2014

Biological Sciences

University of Wisconsin-Milwaukee, Milwaukee, WI

GPA: 3.65

PROFESSIONAL ENGAGEMENTS

Field Team Leader: Summer 2015, 2016 & 2017

Co-managed three summer research trips for high school students. The foundation of each two-week expedition was rooted in estuarine ecology. EarthWatch Ignite: Waterbirds of Coastal Texas, The EarthWatch Institute. PI's: Jeffrey R. Wozniak and Julia C. Buck.

Graduate Teaching Assistant: January 2015 – May 2017

Botany lab (Spring 2015-Summer 2016) and Zoology lab (Fall 2016-Spring 2017) instructor. Department of Biological Sciences, Sam Houston State University.

Field Team Leader: Winter (Jan-Mar) 2016 & 2017

Co-managed six teams of adult volunteers during weeklong research expeditions. Protecting Whooping Cranes and Coastal Habitats in Texas, The EarthWatch Institute. PI: Jeffrey R. Wozniak.

Avian Captive Technician: Summer 2014

Provided daily care for juvenile captive-reared eastern loggerhead shrikes, a critically endangered songbird. Also performed daily behavioral observations of captive birds, conducted walking surveys to monitor newly released birds, and wrote reports for the program. Eastern Loggerhead Shrike Recovery Program, Wildlife Preservation Canada.

ACADEMIC PRESENTATIONS

- Tiegs, L.A., E. Smith and J.R. Wozniak. 2017. Habitat quality and behavior of wintering Whooping Cranes along the Texas Gulf Coast. Annual Meeting of the Waterbird Society. Reykjavik, Iceland. [Oral Presentation]
- Tiegs, L.A., E. Smith and J.R. Wozniak. 2017. Comparison of whooping crane behavior in natural saltmarsh and urban upland habitats. Texas Bays and Estuaries Meeting. Port Aransas, Texas. [Poster Presentation]
- Tiegs, L.A. 2016. The cost of parenthood: understanding the relationship between adult and juvenile whooping crane behavior. Texas A&M University-Corpus Christi Student Research Forum. Corpus Christi, Texas. [Oral Presentation]
- Tiegs, L.A., E. Smith and J.R. Wozniak. 2016. Analysis of wintering whooping crane behavior along the Texas Gulf Coast. 40th Anniversary Meeting of The Waterbird Society. New Bern, North Carolina. [Oral Presentation]
- Tiegs, L.A. 2016. The impacts of the global pet trade on amphibians. Sam Houston State University Herpetology Symposium. Huntsville, Texas. [Oral Presentation]
- Tiegs, L.A., J.R. Wozniak and E. Smith. 2016. Assessment of whooping crane behavior and coastal habitat quality along the Texas Gulf Coast. Annual Meeting of The Society of Wetland Scientists. Corpus Christi, Texas. [Oral Presentation]
- Tiegs, L.A. and J.R. Wozniak. 2015. An event-based approach to assessing coastal habitat quality: linking hydrological drivers to whooping crane behavior. Coastal & Estuarine Research Federation Biennial Conference. Portland, Oregon. [Poster Presentation]
- Tiegs, L.A. and G. Höbel. 2014. Do male Gray treefrogs choose calling perch based upon color? Biological Sciences Symposium, University of Wisconsin-Milwaukee. Milwaukee, Wisconsin. [Poster Presentation]

HONORS AND AWARDS

- Graduate Teaching Award, Department of Biological Sciences. Sam Houston State University, 2016.
- Graduation Honors: Magna Cum Laude, University of Wisconsin – Milwaukee, 2014.
- First Place Undergraduate Poster in Ecology, Evolution, and Behavior. Biological Sciences Symposium, University of Wisconsin - Milwaukee, 2014.
- Dean's List, University of Wisconsin - Milwaukee, 2012-2014.

SCHOLARSHIPS AND GRANTS

- The Waterbird Society Student Travel Grant, 2017. **\$250**
- The Waterbird Society Student Travel Grant, 2016. **\$100**
- Texas A&M University-Corpus Christi Student Research Forum Travel Grant, 2016. **\$400**
- Ruth I. Walker Memorial Scholarship, 2014. **\$200**
- Ted Krzynski and Harlan Murray College Scholarship Recipient, 2010-2011. **\$5,000**

VOLUNTEER/OUTREACH

- Travis Elementary 2nd Grade Forest Festival 2016 & 2017: represented the Audubon Society of Huntsville and educated local children about the birds of southeast Texas. Huntsville, TX.
- Undergraduate Research Symposium: volunteered as a graduate student moderator and evaluated undergraduate research presentations. Sam Houston State University, Huntsville, TX. April 23, 2016.
- Project Sunshine Field Day: ran an activity table to educate adults and children with cognitive challenges about the fundamentals of botany. Huntsville, TX. March 3, 2016.
- Whooping Crane Festival 2016: volunteered for the International Crane Foundation and educated the general public about the whooping crane recovery story and struggles of other cranes around the world. Port Aransas, Texas. February 25-28, 2016.

SOCIETY MEMBERSHIPS

- The Waterbird Society, 2016 to present.
- Wilson Ornithological Society, 2016 to present.
- Association of Field Ornithologists, 2015 to present.
- Society of Wetland Scientists, 2015 to present.
- Biological Sciences Graduate Student Organization, Sam Houston State University, 2015 to present.
- Texas Academy of Science, 2015-2016.
- Coastal & Estuarine Research Federation, 2015-2016.