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Daily and Seasonal Movements of Brown Pelicans in the Bahía Grande Wetland Complex: Technical Report

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COLLEGE STATION, TEXAS

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Federal Highway Administration and the
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16. Abstract

This research project implemented a series of studies that investigated the daily and seasonal movements of brown pelicans in the Bahía Grande Wetland Complex (BGWC) of South Texas. The project was motivated by brown pelican mortality that occurs along a stretch of highway (State Highway 48 [SH 48]) that links Brownsville, Texas, to Port Isabel, Texas. Brown pelican mortality is a conservation concern but is also a risk to the traveling public. The research undertaken in this project tracked individual pelicans using global positioning system devices. Researchers also undertook a banding and resight study, and other field methods employed to monitor pelicans in the region. These field methods were used to develop mathematical and statistical models that provide a holistic view of the movement ecology of pelicans in the region, and help explain the frequency of SH 48 crossings, and SH 48 pelican mortality events.

The study illuminates key roost and loafing sites used by pelicans in the BGWC as well as major flight corridors that connect them. These sites include pelican habitat within the BGWC that largely explain why pelicans regularly attempt crossings across SH 48. The analysis of field data collected during this project also identified the important seasonal migration trends of pelicans in the region and the temporal variation in the size of the BGWC population. Statistical models of pelican mortality show that, in addition to the daily and seasonal movements of pelicans in the region, mortality is associated with cold fronts that result in strong northwestern winds that create unfavorable flight conditions for pelicans crossing SH 48.

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DAILY AND SEASONAL MOVEMENTS OF BROWN PELICANS IN THE BAHÍA GRANDE WETLAND COMPLEX: TECHNICAL REPORT

by

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DISCLAIMER

This research was performed in cooperation with the Texas Department of Transportation (TxDOT) and the Federal Highway Administration (FHWA). The contents of this report reflect the views of the authors, who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official view or policies of FHWA or TxDOT. This report does not constitute a standard, specification, or regulation.

This report is not intended for construction, bidding, or permit purposes. The researcher in charge of this project was Andrew Birt.

The United States Government and the State of Texas do not endorse products or manufacturers. Trade or manufacturers' names appear herein solely because they are considered essential to the object of this report.

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In addition to these agencies, many other individuals also took part in surveys and banding efforts. These include Alicia Cavasos, Andrew Orgill, Bob Severson, Boyd Bilhovde, Dr. Tom DeMaar, Edna Goette, Jason Fry, Javi Gonzalez, Jessica Castillo, Jessica Pohl, Jim Chapman, Jolaine Lanehart, Justin LeClaire, Kat Shupe, Larry Johnson, M. Lee Brown, Marco Limon, Megan Villarreal, Michele and Rob Gardner, Miranda Butler-Valverde, Nicole and Rick Ekstrom, Nike Pappas, Renee Lockett, Richard Moore, Shelby Bessette, Stan Sterba, Stephanie Bilodeau, Tommy Saenz, Tony Henehan, Victor Worrell. The authors apologize for any names that are missing – the eagerness of the general public to participate in the research study and help pelican crossing was outstanding and demonstrates the importance of this wildlife crossing problem to the local community.

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LIST OF ABBREVIATIONS

AADT	Annual Average Daily Traffic
AIC	Akaike Information Criterion
AL	Alabama
ASCBC	Audubon Society Christmas Bird Count
BGWC	The Bahía Grande Wetland Complex
BSC	Brownsville Ship Channel
CJS	Cormack-Jolly-Seber Model
CTB	Concrete Traffic Barrier
DDT	Dichlorodiphenyltrichloroethane
DOT	Department of Transportation
ESA	Endangered Species Act
FHWA	Federal Highway Administration
FL	Florida
GIS	Geographical Information System
GPS	Global Positioning System
HMM	Hidden Markov model
LA	Louisiana
MM	Minta-Mangel Estimator
MX	Mexico
NA	Not Available/Not Applicable
NOAA	National Oceanic and Atmospheric Administration
NTIS	National Technical Information Service
PI	Port Isabel
PWS	Project Wind Station
RMSE	Root Mean Squared Error
SH	State Highway
STARS II	Statewide Traffic Analysis and Reporting System
TPWD	Texas Parks and Wildlife Department
TTI	Texas A&M Transportation Institute
TX	Texas
TxDOT	Texas Department of Transportation
USEPA	United States Environmental Protection Agency
USFWS	United States Fish and Wildlife Service
WRD	Wind Risk Duration
WRV	Wind Risk Velocity
ZIP	Zero-Inflated Poisson Regression Model

CHAPTER 1. INTRODUCTION

The brown pelican (*Pelecanus occidentalis*) is currently a common resident of coastal habitats along the Gulf of Mexico. However, between 1940 and 1970, their numbers declined because of pesticide residues that affected survival and reproduction. From the 1950s through 1974, approximately 50 brown pelicans remained in Texas (King et al. 1985). This precipitous decline led to the brown pelican being listed as an endangered species in 1970. Efforts to recover the population in North America, including banning the use of DDT, were successful, and the population recovered. As a result, brown pelicans were removed from the federal endangered species list in 2009 and have since become a symbol of conservation success in the United States.

The brown pelican is currently listed as being of "Least Concern." It now occupies a large geographic range, and its population has increased since it became protected (BirdLife International 2018). The population of the eastern subspecies in the United States was estimated at approximately 35,000–44,000 breeding pairs per year during 2007–2013, with approximately 65 percent of the population occurring along the Gulf of Mexico coast (Shields 2014).

Although populations are increasing, brown pelicans still face natural and anthropogenic threats. Many islands that support roosting and nesting colonies erode over time (hurricanes can cause islands to erode especially quickly) and thereby reduce habitat (Walter et al. 2013). Cold winter temperatures can affect prey availability and survival (McEachron et al. 1994; Lamb 2016). Increases in coastal development result in disturbances that can negatively influence the behavior of brown pelicans (Wright et al. 2007). Pelicans may also ingest lead fishing lures (Franson et al. 2003) and become entangled with fishing lines and other marine debris (Laist 1997). Other disturbances include wind farms (Graham and Hudak 2011, Lamb et al. 2018a) and oil spills (Lamb et al. 2018b).

This report deals with an unusual source of pelican mortality that exists on the Brownsville-Port Isabel Highway (State Highway [SH] 48) located in the Bahía Grande Wetland Complex (BGWC) near the southern Gulf Coast of Texas (Figure 1). Along a section of SH 48 that borders the south side of the Bahía Grande, cold fronts result in wind conditions that cause brown pelicans to crash-land on the roadway. To a lesser extent, similar mortality occurs at the Jamie Zapata Bridge approximately two miles to the west. Once on the roadway, pelicans have difficulty regaining flight, and many are hit by passing vehicles. Previous studies of the phenomenon (Birt et al. 2018) have identified several interacting factors that cause pelicans to crash-land on the road. These factors include:

- Strong north winds that affect the ability of brown pelicans to fly into the Bahía Grande.
- The influence of an elevated roadway and concrete safety barriers that perturb wind conditions over SH 48.

- The proximity of SH 48 to key brown pelican habitat, which includes the Bahía Grande and the Brownsville Ship Channel.

The SH 48 brown pelican crossing events (hereafter referred to as *pelican events*) have been observed since 2011 and formally recorded since 2013. Figure 2 illustrates the pulsed, periodic nature of brown pelican mortality on SH 48 since records of the mortality began to be kept (these data illustrate mortality recorded before the initiation of this project).

The periodic mortality of brown pelicans in the region has attracted concern from various state and federal agencies, including the Texas Department of Transportation (TxDOT), the United States Fish and Wildlife Service (USFWS), and Texas Parks and Wildlife Department (TPWD). Local conservationists and news channels have also documented the issue. In particular, the coincidence of pelican events with predictable and forecasted weather events has resulted in an active community of volunteers who assemble on SH 48 to save birds that have crash-landed (hereafter referred to as *downed* birds) from traffic. These pelican events also represent a considerable public safety risk. The volunteers are required to enter the roadway to save birds, and this practice often occurs during low light and poor visibility due to rainy, foggy, and windy conditions. In addition, downed pelicans have the potential to cause drivers to brake forcefully or erratically swerve—again under potentially hazardous driving conditions.

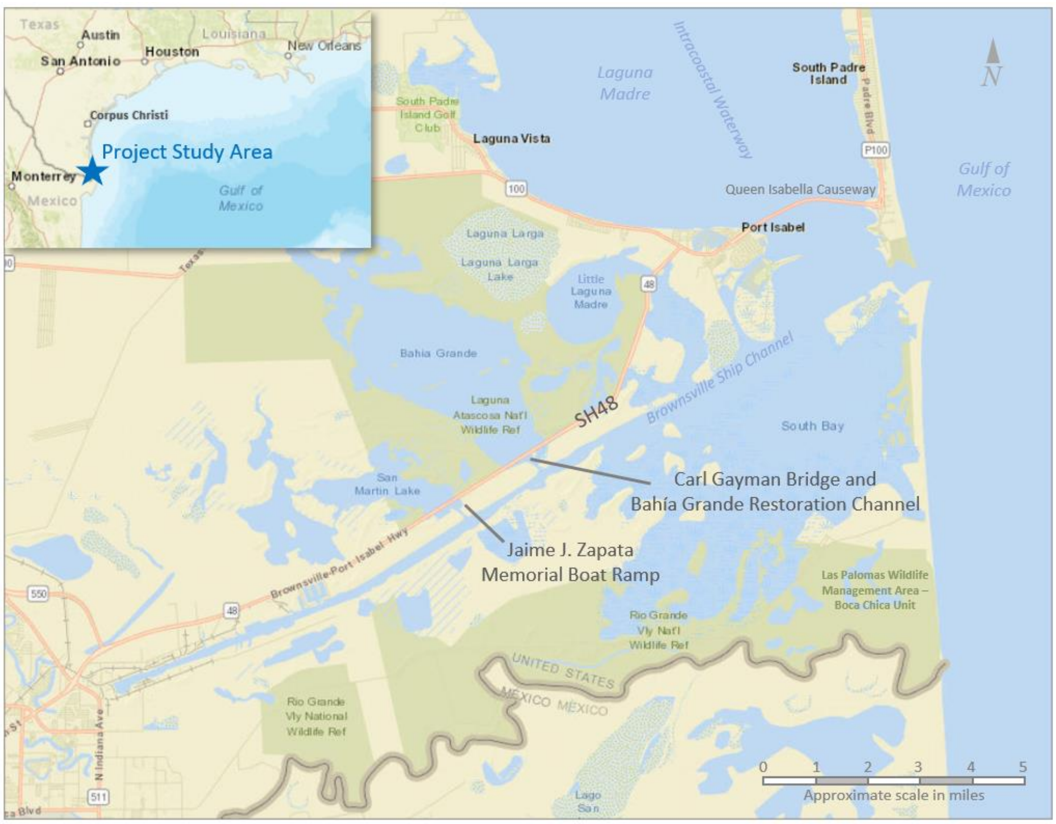


Figure 1. Map of the Project Study Area and the BGWC.

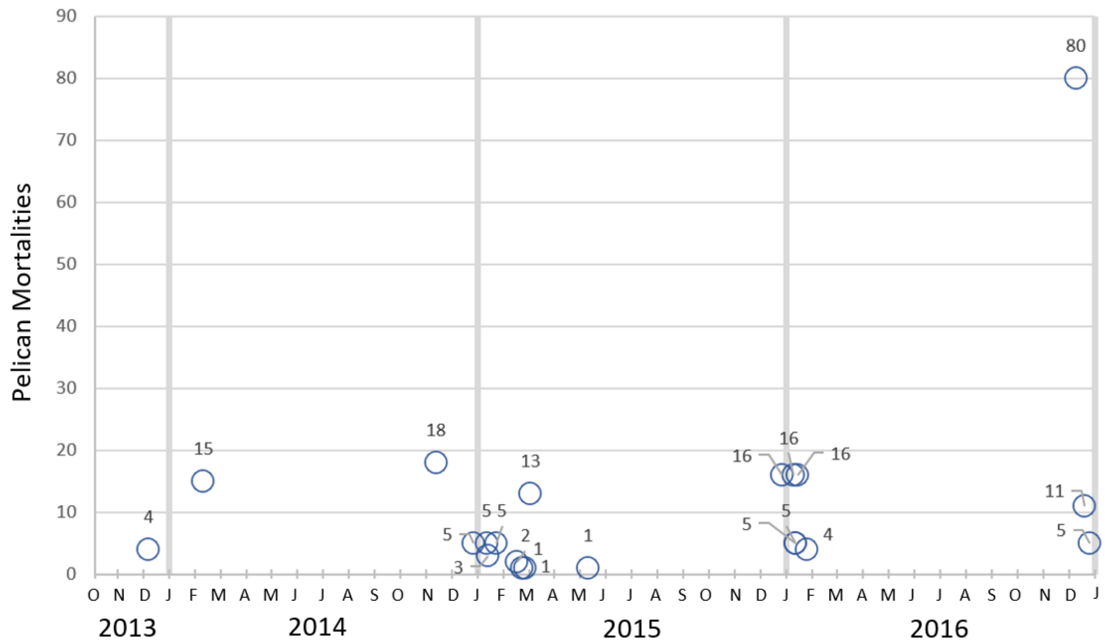


Figure 2. Counts of Pelican Mortalities (December 2013 through 2016). The number for each circle represents the number of pelicans killed in single day.

PROJECT GOALS AND RATIONALE

As the state agency primarily responsible for transportation in the region, TxDOT has a responsibility to provide efficient and safe transportation for the traveling public. It also has a responsibility to reduce the negative environmental consequences of transportation.

Although previous research has identified factors that likely contribute to the pelican–vehicle interactions on SH 48 and mitigative measures have been taken, the problem persists. While previous research has focused on understanding the interactions among pelican events, local weather conditions, and roadway infrastructure, relatively little is known about the ecology of brown pelicans in the region—in particular, their population abundance and their daily and seasonal movements that ultimately drive the conservation and safety issues associated with this problem.

The goal of this research project is to investigate daily and seasonal movements of brown pelicans in the BGWC. The rationale for the project is that this information will be useful to develop cost-effective solutions to mitigate pelican–vehicle interactions on SH 48 and elsewhere. It follows logically that the elimination or reduction of pelican crash landings on SH 48 will prevent further pelican mortality, remove the need for volunteer conservationists to enter the roadway to save birds, and generally improve driver safety on SH 48.

The remainder of this introductory chapter provides a history of the pelican events, a detailed description of the study area, the roadway design, the outcomes of previous research, and brown pelican ecology. The chapter concludes with a specific set of objectives for the study and a roadmap that describes how the research undertaken during this study will contribute to providing information useful for mitigating pelican events.

THE BAHÍA GRANDE WETLAND COMPLEX STUDY AREA

The focus of this study is a population of brown pelicans that overwinter in and around the Lower Laguna Madre of South Texas. The Laguna Madre is a hypersaline lagoon that extends approximately 130 miles (209 km) from Corpus Christi to Brownville, Texas, and is bordered on the east by South Padre Island (Figure 1). The cities of Port Isabel, South Padre Island, and Laguna Vista are situated on the southern coast of the Laguna Madre and are popular tourist destinations year-round. The cities contain several marinas and boat ramps used for commercial and recreational fishing and other recreational activities. The city of Brownsville is located further inland but is connected to the Laguna Madre and the Gulf by the Brownsville Ship Channel. To the west of the Laguna Madre, the land is largely privately owned and used for ranching, agriculture, and wind farms. The Intracoastal Waterway passes through the Laguna Madre, and the Laguna Atascosa National Wildlife Refuge is located at its southern end. Six natural islands occur in the Laguna Madre, and hundreds of other islands were created during the dredging of the Gulf Intracoastal Waterway. Many of the islands are used by colonial nesting waterbirds, including brown pelicans. Islands are owned and managed by entities that include the Texas General Land Office, Padre Island National Seashore, Audubon Texas, and Coastal Bend Bays & Estuaries Program. The Laguna Madre is connected to the Gulf of Mexico via ship channels in Corpus Christi, Port Mansfield, and Brownsville.

The BGWC is a series of inland lagoons that are hydrologically linked to the Laguna Madre and the Gulf of Mexico via the Brownsville Ship Channel. The Bahía Grande wetlands encompass approximately 10,000 acres and comprise the Bahía Grande, Little Laguna Madre, and Laguna Larga lagoons. SH 48 runs parallel to the Brownsville Ship Channel such that an approximately 1.2-mile section borders the Bahía Grande.

At two locations on SH 48, bridges cross channels that link the Bahía Grande wetlands to the ship channel. The westernmost bridge (San Martin Bridge) spans a channel that links the ship channel to San Martin Lake and is close to a recreational boat ramp (Jamie Zapata Memorial Boat Ramp). The San Martin Bridge is the source of minor but consistent mortality on SH 48. The easternmost bridge (Carl Gayman Bridge) crosses the Carl “Joe” Gayman Channel midway along the Bahía Grande. This section of SH 48 has historically been the foci of pelican events, although mortality is known to occur all along the section of SH 48 that borders the Bahía Grande. Anecdotal field observations suggest that mortality may be concentrated at the bridge because of the tendency of pelicans to fly low along the Carl Gayman Channel as they move from the ship channel to the Bahía Grande.

Since the 1990s, pelican mortality has also occasionally been observed on the Queen Isabella Causeway (linking Port Isabel to South Padre Island), but the characteristics (severity and periodic nature) of these mortalities are quite different than the mortality currently occurring on SH 48 (Owens and James 1991, Shafer and Jasek 1997).

Restoration of the Bahía Grande Wetlands

Over the last 100 years, the BGWC has undergone considerable change. The current wetland was effectively destroyed in 1936 following the construction of the Brownsville Ship Channel. In the 1950s, SH 48 was developed parallel to the ship channel. These constructions cut off water flow between the Laguna Madre and the BGWC. Isolation of the Bahía Grande and other lagoons resulted in large changes in the hydrology and wildlife of the region. In a relatively short time, the Bahía Grande was transformed into a salty dustbowl that impacted local structures, machinery, and humans and provided limited habitat for waterfowl.

Restoration of the Bahía Grande began unofficially in 1983 when a local shrimper (Carl "Joe" Gayman) dug a small channel between the ship canal and the lagoon bed. Although these initial efforts were halted, an official restoration plan was initiated in 1999 when the U.S. Fish and Wildlife Service (USFWS), the Nature Conservancy, and the Conservation Fund purchased the Bahía Grande and the surrounding land. TxDOT assisted the USFWS and its partners with the channel restoration project and, in 2007, completed construction of a new four-lane highway and widened and extended Carl Gayman Bridge. The channel improvements restored tidal flow to the Bahía Grande and surrounding lagoons. These efforts have successfully restored the BGWC from a degraded, seasonal dryland/wetland system to a natural wetland system made up of interconnected hypersaline lagoons, including islands that provide critical habitats for a variety of bird life (including brown pelicans).

Thus far, the restoration efforts have been hailed as an environmental and social success and as an internationally acclaimed example of successful coastal wetland restoration. The restoration efforts have transformed 10,000 acres of land into a dynamic, natural landscape of national and international importance. In line with the restoration of the physical environment, the wetland has resulted in the re-establishment of native flora and fauna. The newly restored Bahía Grande system has provided considerable benefits to the local economy, including increased opportunities for fishing, hunting, and wildlife watching, and improved environmental conditions (principally a reduction in suspended dust)[1].

Figure 3 and Figure 4 provide Google Earth aerial images from 2004 (before the official restoration plan was implemented) and 2017 (Google Earth's most recent aerial image of the area), respectively. In each figure, the lower panel provides an inset view of the yellow box in the upper image. The approximate dimensions of the width of the highway and channel are also

[1] https://www.fws.gov/refuge/laguna/about/bahia_grande_unit.html

provided to help illustrate the highway and channel improvements. Figure 5 provides a view of the Bahía Grande Restoration Channel from the eastbound lane of SH 48.

Figure 3. Google Earth Aerial Images (2004) of SH 48, the Carl Gayman Bridge, and Channel prior to Restoration. The lower image provides the inset view of the bridge showing highway and undeveloped drainageway width prior to the Bahía Grande Channel Restoration Project.

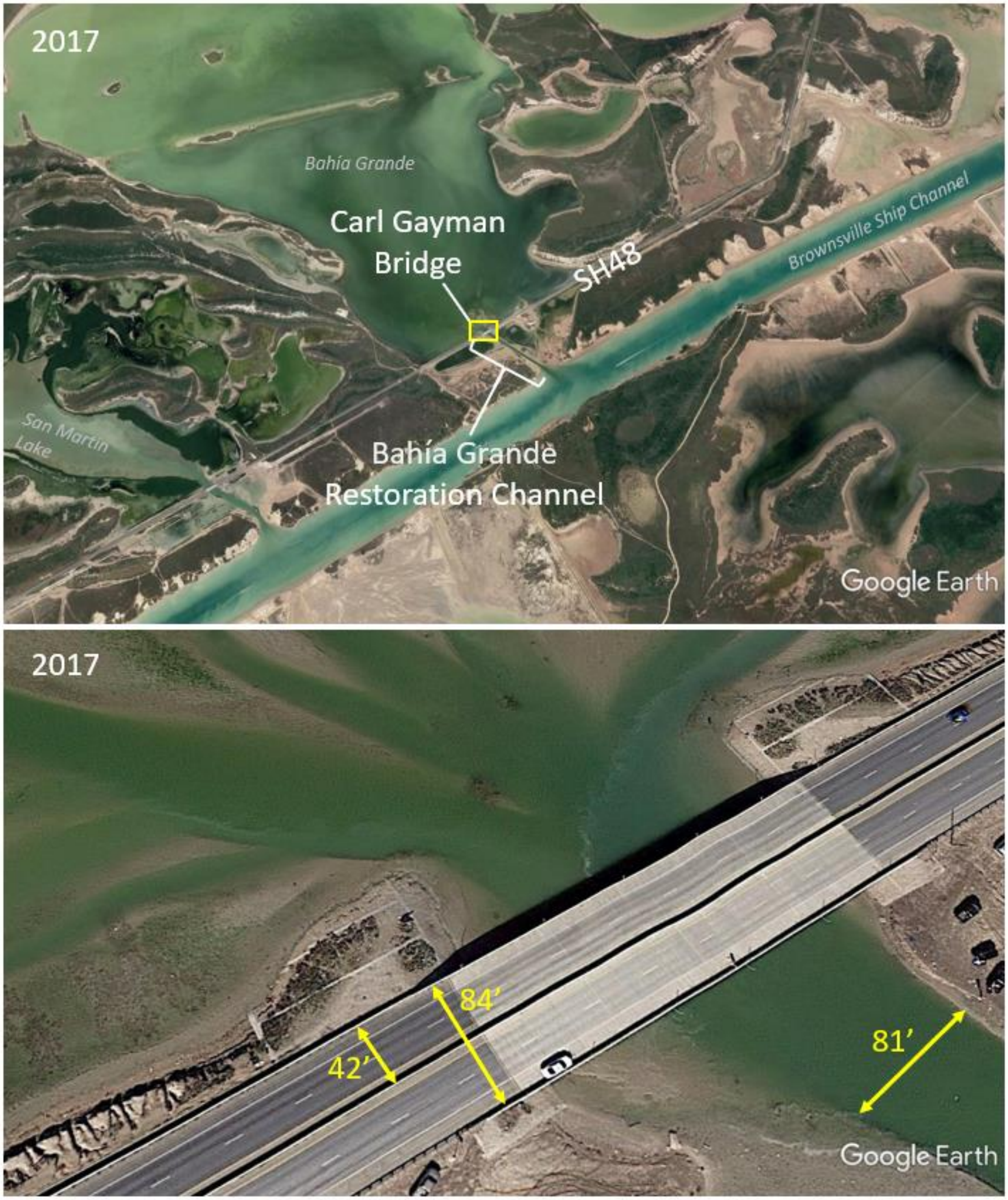


Figure 4. Google Earth Aerial Images (2017) of SH 48, the Carl Gayman Bridge, and Channel after Construction. The lower image provides the inset view of the bridge showing highway width and Bahía Grande Restoration Channel width after the improvements.

Figure 5. Google Street View of the Carl Gayman Bahía Grande Restoration Channel from Eastbound Lane of SH 48. The Brownsville Ship Channel is located 0.4 miles away at end of the channel. The pelican poles mounted on the 36-inch-high concrete traffic barriers (CTBs) extend 12 feet above the bridge pavement. The yellow arrow on the map indicates approximate photo location and direction (image captured July 2019, view to the southeast).

Description of SH 48—Road Infrastructure

Improvements to SH 48 in 2007 included roadway widening and the modification (lengthening) of two bridges to span the two channels that hydrologically link the lagoons to the Brownsville Ship Channel (Bahía Grande Restoration Channel and the San Martin Lake Channel adjacent to the Zapata Memorial Boat Ramp). Most of the current SH 48 roadway is a four-lane, concrete barrier-divided highway with speed limits of 75 mph, peak traffic volumes of approximately 300 vehicles per hour, and an average daily volume of approximately 11,480 vehicles (2016 data accessed from the TxDOT STARS II system). The hourly traffic volumes are illustrated in Figure 6. As illustrated in Figure 3 and Figure 4, the existing highway consists of two eastbound and two westbound 12-ft-wide travel lanes with 10-ft-wide paved outside shoulders and 8-foot-wide inside shoulders in each direction. Along most of its length, the roadway is elevated approximately 6 ft above the water level. The Carl Gayman Bridge has a span of approximately 250 feet and a water-to-deck height of between 4 and 8 ft (depending on the tide).

At most locations, the roadway is divided by 42-inch CTBs between the eastbound and westbound lanes to prevent head-on vehicle crashes (Figure 7). Thirty-six-inch-high CTBs also protect the shoulders of the Carl Gayman and San Martin Bridges (though the latter does not have a median barrier). Sections of the roadway that border the Bahía Grande are equipped with 36-inch CTBs to protect vehicles from exiting the road into the lagoon.

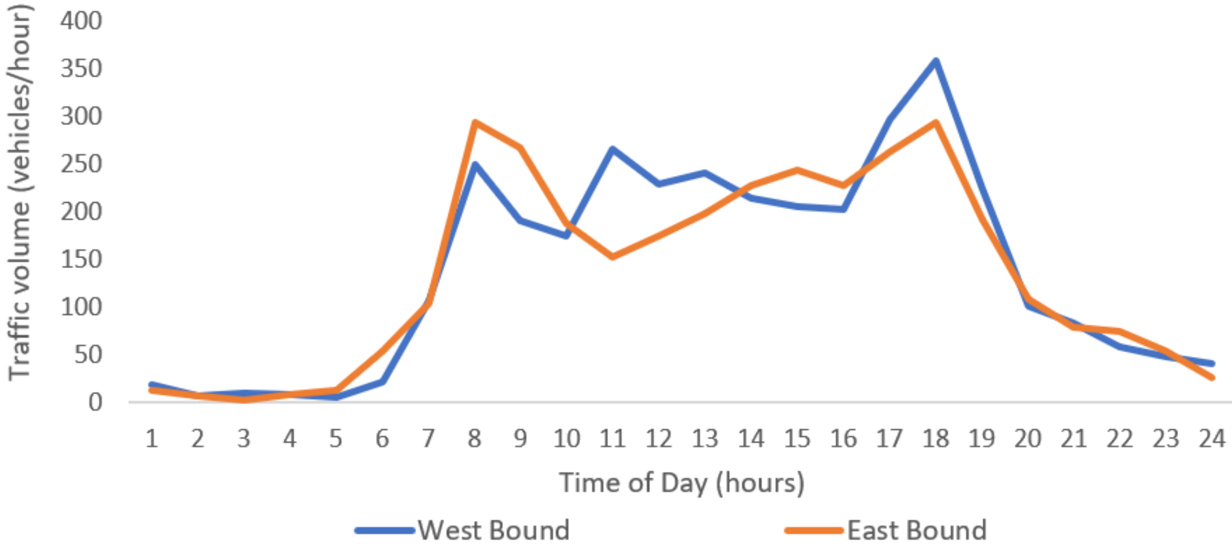


Figure 6. Traffic Volumes on SH 48.

Figure 7. Google Street View of Westbound SH 48 Just East of the Carl Gayman Bridge over the Bahía Grande Restoration Channel. Bahía Grande is on the right. The view shows the 48-inch-high center CTB, and the 36-inch-high north (right) and south (far left) outer traffic barriers. The 12-foot high, barrier-mounted pelican poles are visible on both sides of the bridge. The yellow arrow on the map indicates approximate photo location and direction (image captured June 2019).

Current Engineering-Based Mitigation Solutions

TxDOT has implemented several engineering efforts to mitigate pelican mortalities on SH 48 (separate from this project). TxDOT's Pharr District has led efforts to reduce pelican mortalities along SH 48.

Pelican Poles

In early 2015, work was completed on installing 12-foot vertical metal poles along the Carl Gayman Bridge (Figure 8), with additional poles installed southeast of that site on the San Martin Bridge near the Jamie J. Zapata Memorial Boat Ramp (Figure 9). The poles are designed to encourage pelicans to fly at higher altitudes over the bridge and are located near these two channels because of the tendency of pelicans to follow the channels low to the water before adjusting altitude in order to cross over the bridge. The pelican poles on the bridge portion of SH 48 appear to have reduced mortality; however, episodic mortality events still occur.

Figure 8. South Side View of the Carl Gayman Bridge along SH 48 Showing Pelican Poles and the Relatively Low Height from the Tidal Water Surface to the Bottom of the Bridge Deck Structure. The CTB-mounted pelican poles are visible on the side of the bridge. The yellow arrow on the map indicates approximate photo location and direction.

Figure 9. Google Street View of the Jaime K. Zapata Memorial Boat Ramp from the Eastbound Lane of SH 48. The view shows three pelican poles mounted on the south CTB. The Brownsville Ship Channel is located approximately 0.4 miles away at the far end of the channel. The yellow arrow on the map indicates approximate photo location and direction (image captured July 2019).

The Influence of Concrete Traffic Barriers on Pelican Crossings

In 2017, TxDOT commissioned a study to investigate the effect of SH 48's CTBs on pelican mortality (Birt et al. 2018). The study was initiated in response to observations that the CTBs might be causing pelican crossing difficulties. In the study, TTI researchers conducted wind tunnel testing of a scale model of the bridge, adjacent roadway, and various CTB configurations. The results from the wind tunnel experiments were used to understand patterns of airflow (changes in speed and direction) around the bridge deck and CTB. Figure 8 presents a side view of the bridge as it was configured for the wind tunnel initial model to represent the bridge (Figure 10).

Figure 10. View of SH 48 Bridge Scale Model and Smoke Wand Test in Wind Tunnel.

The results from the wind tunnel testing confirmed that the bridge, highway, and CTBs influence air patterns over the roadway. In subsequent studies, researchers also used computational fluid dynamic models to evaluate local wind conditions relative to the existing roadway infrastructure and to evaluate several alternative barrier designs that could be employed along the roadway to mitigate the air flow effects and therefore reduce the severity of pelican events.

The computational fluid dynamics and wind tunnel modeling studies indicated that replacement of the CTBs on the Bahía Grande side of SH 48 (and on both sides of Carl Gayman Bridge) with a railing type design could help to reduce the adverse air flow patterns over the bridge. However, the study's conclusions also cautioned that, irrespective of the CTBs, the elevated design of SH 48's bridges and adjacent roadways also has a large effect on airflow over the road.

Following these studies (circa 2017, and just after the initiation of this project) TxDOT initiated a project to replace the existing outer CTBs on the section of roadway bordering the Bahía Grande with a railing design barrier (type T2P) designed to improve airflow over the road. Both outer barriers were replaced on the Carl Gayman Bridge and the side outer barrier was replaced along the roadway bordering the Bahía Grande. The median barriers were left in place. No modifications were made at the San Martin Bridge. The construction began in fall 2019 and was finished in spring 2020. Figure 11 illustrates the new barrier arrangement.

Figure 11. View of New Guard Rails Installed on the Carl Gayman Bridge. View to the southwest along westbound SH 48. Left image shows the space between each horizontal crossbar on the railing. The right image shows the reinstalled pelican poles and a new transmission line on the south side of the highway (image captured January 2021).

BROWN PELICAN ECOLOGY

The brown pelican is a large, long-lived coastal seabird found along coasts from southern North America to northern South America. It is the smallest of seven pelican species worldwide and is a charismatic resident of coastal, nearshore habitats. Taxonomically, the brown pelican includes five subspecies: (a) *P. o. occidentalis*, which breeds in the Greater and Lesser Antilles, Bahamas, West Indies, Colombia, Venezuela, and Trinidad and Tobago; (b) *P. o. californicus*, which breeds along the West Coast of North America; (c) *P. o. urinator*, whose range includes the Galapagos Islands; (d) *P. o. murphyi*, which breeds along the coast of western Colombia to Ecuador; and (e) *P. o. carolinensis*, the eastern brown pelican, which is the focus of this study.

The eastern brown pelican occupies a breeding range along the Atlantic and Gulf Coasts of the United States, along Caribbean coasts, and along the Pacific coast of Honduras, Costa Rica, and Panama. Nonbreeding pelicans range from New York to Venezuela[2].

Brown pelicans occupy coastal habitats and are the only truly marine pelican species in the world. Primary foraging areas are shallow (<500 ft or 150 m depth) waters of estuaries and the continental shelf, typically within 20 km of the shore (Briggs 1983). Brown pelicans forage most often in the early morning and evening during rising tides but also occasionally forage at night

[2] https://www.audubon.org/field-guide/bird/brown-pelican

(Shields, 2014). Major food items are small, surface-schooling fish, including menhaden (*Brevoortia* spp.*)*, and mullet (*Mugil* spp.*)* (Fogarty et al. 1981). They are plunge-divers, feeding by diving headfirst into the water to trap fish, and are one of only two pelican species to use this foraging method. Brown pelicans are highly social year-round and reach sexual maturity at 3–5 years of age, with the oldest known pelican being 43 years of age[3].

When traveling to and from roosting and foraging areas, pelicans will typically fly in flocks in a line or V-formation, often gliding just above the water's surface to save energy by reducing drag—a phenomenon known as the ground effect (Hainsworth, 1988). Based on anecdotal reports from pelican events, this propensity of pelicans to follow coastlines and channels, often at low altitude, may be one of the factors that affect mortality at the two bridges on SH 48. Brown pelicans also use slope lifts and thermals to conserve energy while in flight. Taking off from the ground or water can be awkward for this large bird because they need sufficient space and energy to raise and spread the wings while pushing off with the feet and lowering the anterior portion of the body. They will also frequently use wind-lift to increase the efficacy of this maneuver. The physical challenge of initiating flight may be another reason why pelicans that crash-land on SH 48 are so vulnerable to vehicle-induced mortality.

RESEARCH OBJECTIVES AND OUTLINE

As previously stated, the goal of this project is to document the daily and seasonal movements of brown pelicans in the BGWC. The rationale for the study is that this knowledge will provide information that will be useful to illuminate the magnitude of the current pelican-traffic interaction problem; highlight locations where, without significant planning, future pelican-traffic interactions may occur; and most importantly, lead to effective mitigation solutions on SH 48.

The most significant challenge of studying a wild animal population such as the brown pelican lies in the range and mobility of the species. Put simply, it is not possible to design a single research approach or experiment that can provide a complete view of the ecology of pelicans in the region. Moreover, since the rationale of the project is to mitigate pelican events on SH 48, it is essential that information on the ecology of pelicans in the region be presented in a form that ensures that it can be used to practically manage existing and potential pelican-traffic problems. To achieve the project goals, the TTI and TxDOT research team have designed a research plan that uses a variety of field-based research techniques to independently evaluate different components of the pelican problem. Throughout the research project, modeling approaches are used to translate field observations into information that is more directly useful for mitigating pelican mortality and protecting public safety.

[3] https://www.allaboutbirds.org/guide/Brown_Pelican/overview#

To this end, this research report is organized around eight interdependent chapters that illuminate different areas of the pelican problem:

- Chapter 2 describes a study that provides high resolution information on the movements of individual BGWC pelicans fitted with global positioning system (GPS) devices. The information from this chapter details both the seasonal range of pelicans that overwinter in the BGWC as well as key pelican habitats in the BGWC.
- Chapter 3 describes a banding study that provides a population-level view on the survival and seasonal movements of BGWC pelicans. This chapter builds upon the findings of Chapter 2, but since the method tracks a larger number of pelicans, it provides a more general view of seasonal movements and survivability.
- Chapter 4 integrates existing knowledge of the life history of brown pelicans and the information obtained from Chapters 2 and 3 to provide a detailed picture of the population of BGWC pelicans. This chapter also includes a detailed literature review of life history and population trends.
- Chapter 5 describes methods used to estimate the abundance of BGWC pelicans using information obtained from the previous chapters. The abundance information is useful for understanding the proportion of the pelican population that likely crosses SH 48 and therefore understanding the potential for pelican mortality.
- Chapter 6 presents information on wind conditions on SH 48 relative to local weather stations. The chapter discusses the potential utility of being able to predict pelican events using real-time data from local weather stations and of developing consistent weather data useful for modeling pelican mortality events.
- Chapter 7 models the incidence of SH 48 pelican mortality in relation to local weather conditions—especially wind. The motivation for this chapter is to determine the relative importance of different weather variables in driving pelican events and, in so doing, explore the predictability of events as a trigger for potential traffic engineering solutions to the problem.
- Chapter 8 integrates and summarizes the key research undertaken for the project and presented in the previous chapters, provides the conclusions to the project, and offers suggestions for future research.

The research team has also developed a supplementary report that contains a full history of pelican movements as determined by GPS study, a full history of brown pelican GPS data that has been made available from a previous brown pelican study, and a full history of pelican events in relation to weather conditions. In addition to this supplementary material, the main report contains five appendices that include information referred to in the main chapter of the report. Appendix I details a stakeholder workshop that was conducted at the beginning of the project and was designed to identify existing knowledge of brown pelicans in the region and to notify stakeholders of the project. Appendix II provides a complete description of all the field methods used in the project. Appendix III provides a summary of the daily and seasonal movements of each brown pelican tracked during the study. Appendix IV describes methods used to generate mark-resight data that are used to test and validate the mark-resight models described in Chapter 3. Finally, Appendix V describes simulation and mathematical models of vehicles and pelican collisions useful for understanding traffic induced mortality.

CHAPTER 2. FINE-SCALE DAILY AND SEASONAL MOVEMENTS OF BROWN PELICANS

Between December 2017 and February 2019, 35 BGWC brown pelicans were captured at loafing sites in the lower Laguna Madre area—in the vicinity of Port Isabel, SH 48, and South Padre Island—and fitted with a GPS transmitter. The goal of this GPS study (and the subsequent mark-resight study described in Chapter 3) was to determine the seasonal and daily movements of the lower Laguna Madre brown pelican population, especially the location of overnight roost sites, loafing and feeding areas, major flight paths, and the use of habitats outside of the BGWC (including seasonal migrations and breeding sites).

METHOD AND ANALYSIS

The GPS transmitters that were fitted on the 35 brown pelicans tracked during this study recorded the movements of individual pelicans at approximately 15- to 30-minute intervals. Figure 12 provides a chronology of the capture and tracking of each pelican during the study period. On average, each GPS-fitted pelican provided GPS data for approximately 136 days (median 51 days). Appendix II provides details of the field methods used to capture pelicans and fit the GPS devices.

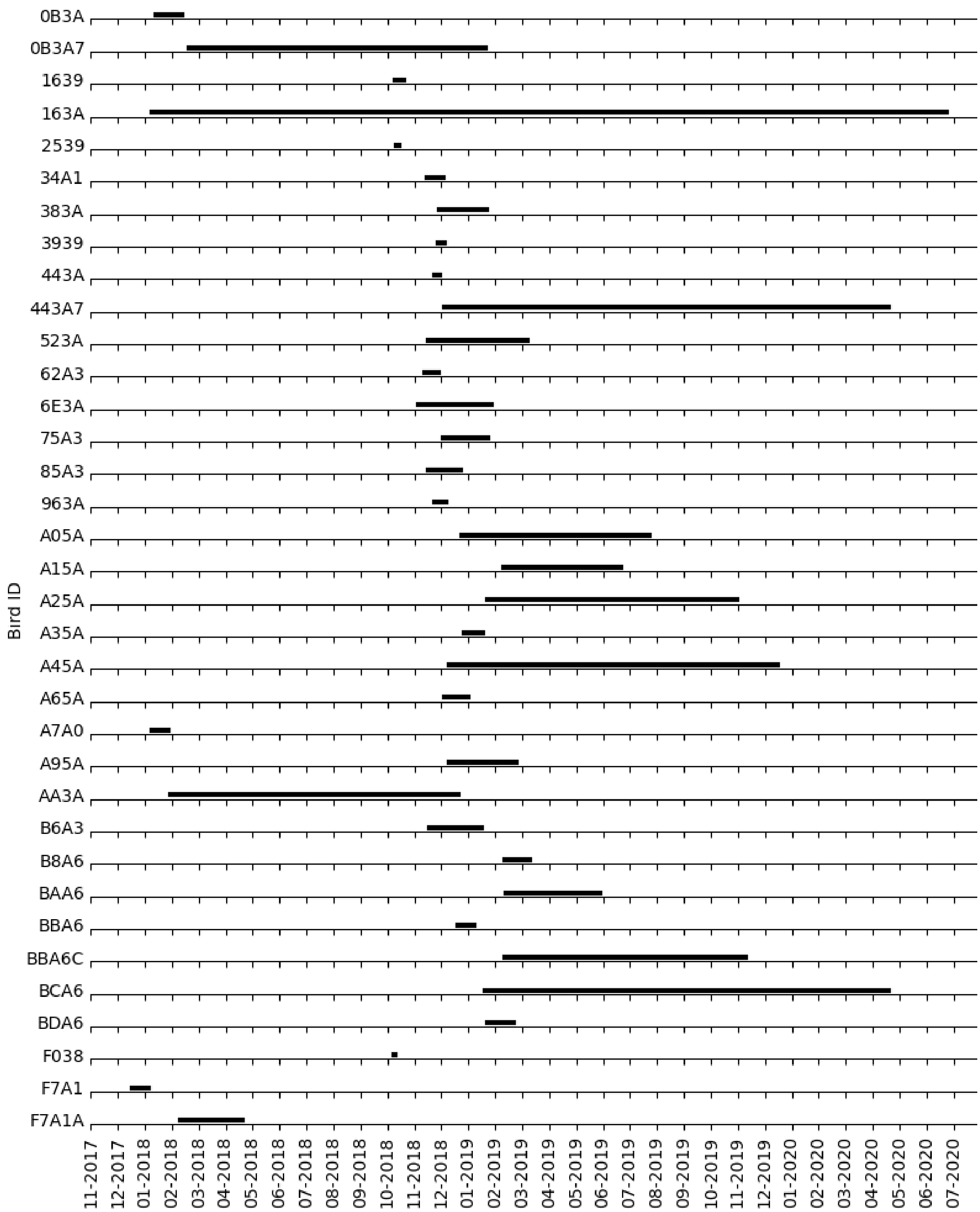


Figure 12. Dates of Capture and Duration of Valid GPS Transmissions for Each Pelican Monitored during the Study.

GPS Data and Distribution

The GPS transmissions provided a large quantity of pelican location data from the pelicans tracked during the study. Figure 13 illustrates the density of GPS points recorded and the geographic range of the tracked pelicans throughout the Gulf Coast area. The red shaded areas indicate the highest density of GPS data points; the blue shaded areas indicate the lowest density of GPS data points (on a relative scale). The map illustrates the pelicans' preference for coastal habitats. High-density point areas tend to coincide with features such as lagoons, islands, canals, and coastal population centers such as fishing ports. The high density of points in the BGWC reflects the general location where the pelicans were caught. The blue shaded areas show that the range of these birds clearly extends along the Gulf Coast from southern Mexico to Mobile, Alabama.

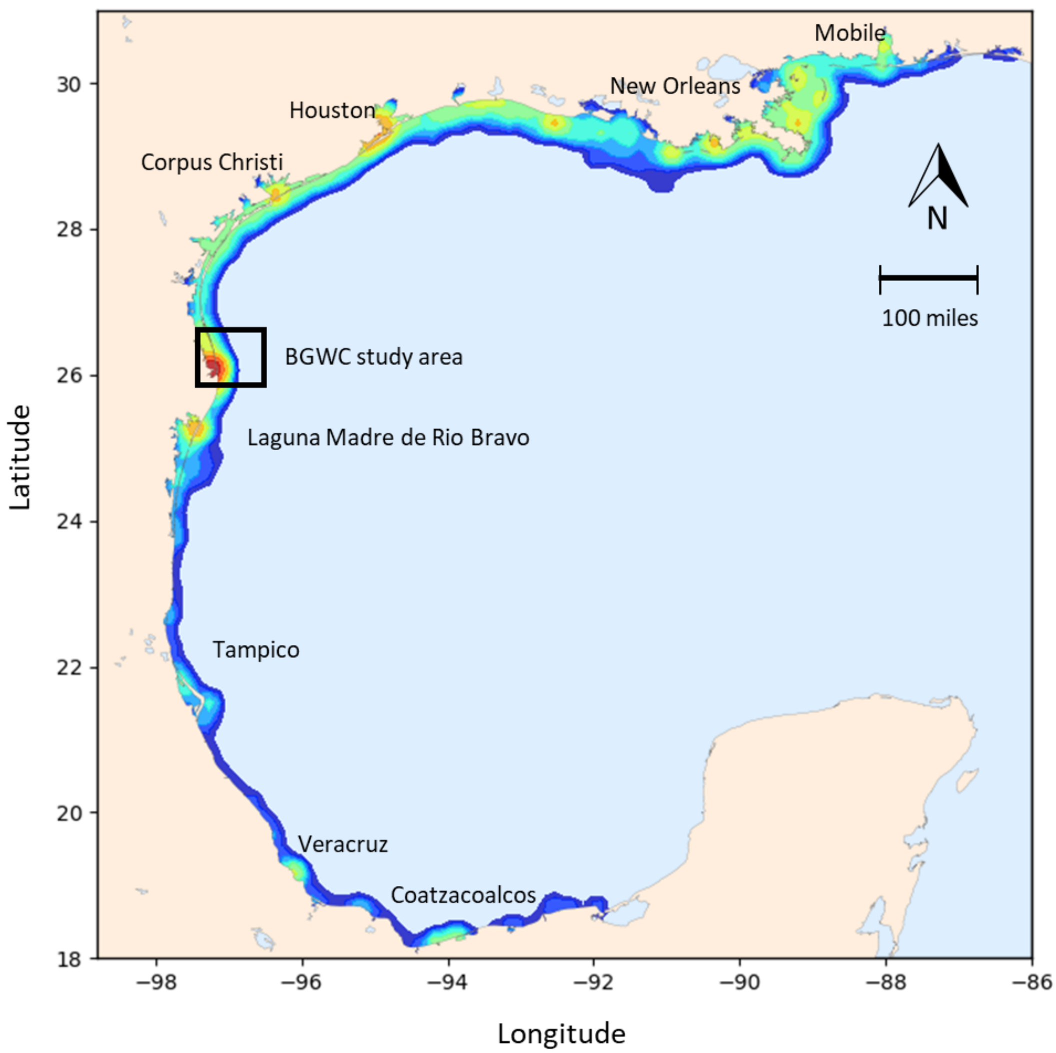


Figure 13. Map Showing GPS Point Density for All Pelican GPS Data Collected during the BGWC Study.

GPS Limitations

The pelican GPS units provide a detailed record of pelican movement that would be difficult to obtain by any other research method. However, there are limitations to the technology. Physically, the units are invasive to the pelicans and may affect pelican behavior or mortality. The units are also costly and are unlikely to be recovered. GPS data signals can be intermittent, and maintenance cannot be performed on the GPS units once fitted onto the pelicans. As previously mentioned, the GPS units were fitted onto a small sample of adult pelicans—limiting any behavioral observations to this demographic group.

Interpretation of movement using GPS data has some limitations as well. Pelican movement pathways are represented as straight lines between GPS data points collected at 15-minute intervals. Fifteen-minute GPS intervals are effective if the pelican's movement is in one direction for a time greater than the GPS interval, such as during migration or long-distance flight. However, local movements may not be represented accurately when the movement duration or direction is less than the GPS's data collection interval. Pelicans that briefly stop or turn will affect the GPS's interpretation of speed and/or direction.

SEASONAL MOVEMENT

Prior to the initiation of this project, little was known about the timing of seasonal movements or breeding sites used by BGWC pelicans. Existing knowledge of brown pelican ecology prior to this project indicated that the BGWC study area is an important overwintering habitat for Gulf Coast brown pelicans and that the summer population declines considerably when pelicans migrate to summer breeding grounds. Despite regular surveys of breeding birds in the area, there are few recent historical records of brown pelicans nesting or successfully breeding in the BGWC.

The GPS data collected during this project supports the idea that the BGWC pelicans are an overwintering and/or transitory migrant population comprising birds that occupy a large geographic range along the Gulf Coast—from southern Mexico to Mobile, Alabama (see Figure 13).

Figure 14 shows the seasonal movements of BGWC pelicans by showing the location of tracked pelicans throughout the study. To generate this figure, the research team delineated the Gulf coast region into 14 distinct zones running approximately south–north. The zones are shown in Figure 15 and were chosen based on the density of points in Figure 13 (itself an indicator of important habitat). The research team then determined the location of each pelican relative to these 14 zones throughout the course of the study (i.e., by date). In Figure 14, each colored line corresponds to the location (*y*-axis) and date (*x*-axis) of each pelican tracked during the study. Only pelicans that were tracked long enough to determine migration behavior were included in this analysis. Table 1 provides a descriptive summary of the migratory movements of all pelicans tracked during the study (including those that were not tracked for enough time to determine seasonal movements). The pelicans are listed in the order they were fitted with GPS transmitters. Appendix III provides a summary of the movements of each tracked pelican, while the supplementary report provides a full graphical history of each captured pelican's movement over the course of the study.

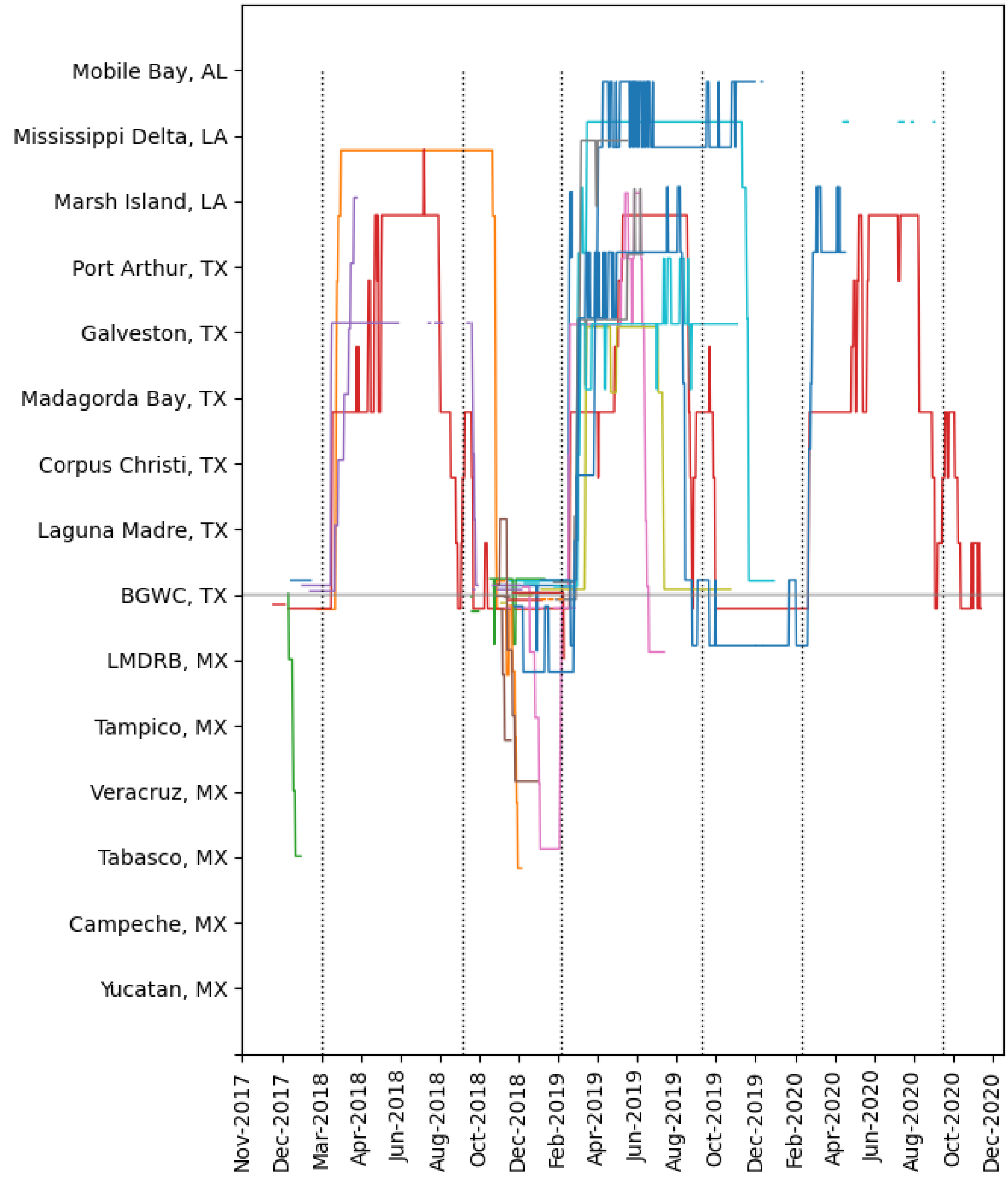


Figure 14. Migration Pattern of Individual Pelicans by Gulf Coast Zone (*y*-axis) and Dates (*x*-axis). The *x*-axis represents dates of the survey. The vertical dotted lines delineate March 1 and September 1 of each year during the survey. The color lines represent individual pelicans.

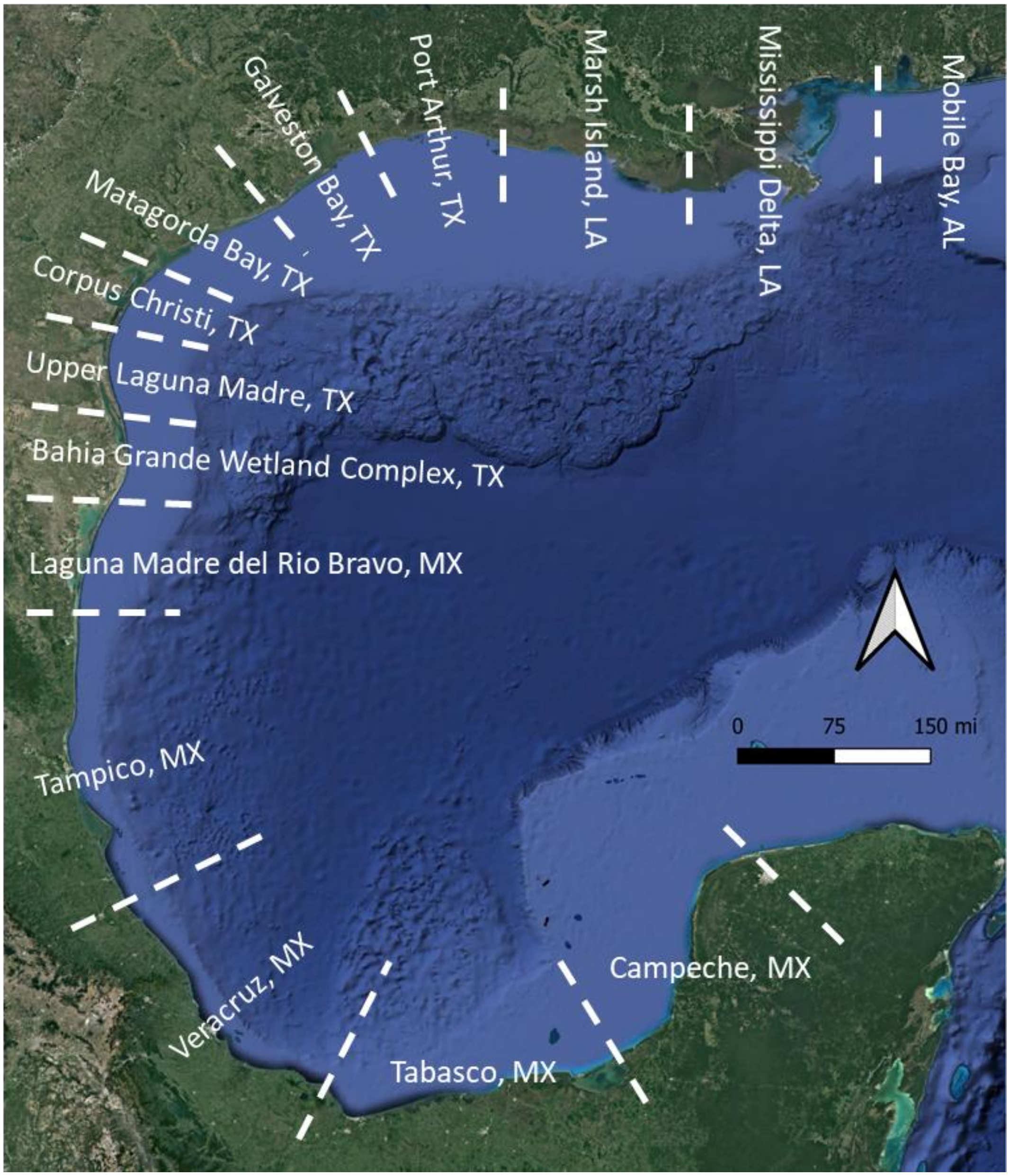


Figure 15. Map Showing the Coastal Zones Used to Define the Pelican Migration Patterns. The points represent selected habitats frequently used by pelicans as intermediate stops during their migration or as seasonal destinations. The lines between the points indicate the boundary between each coastal zone.

Table 1. Summary of Major Seasonal Migrations.

Pelican ID	Active From	Active To	Migrated	Emigration Date	Immigration Date	Signs of Breeding	Notes
F7A1	Dec. 18, 2017	Jan. 01, 2018	NA	-	-	-	-
163A	Jan. 10, 2018	Nov. 23, 2020	2018 North	Mar. 16	Sept. 27–Oct. 27	No	Summer range included Galveston Bay to Mississippi Delta. Very mobile through summer. Moved up and down the coast. Returned to BGWC on Sept. 27 but then emigrated to Matagorda Bay until Oct. 21.
			2019 North	Mar. 14	Sept. 16–Oct. 21	No	Moved extensively throughout a summer range that included Galveston Bay, TX, Port Arthur, TX, and the Mississippi Delta. Returned to study area on Sept. 12 but stayed only 1 day before moving north to Matagorda Bay, TX. Returned permanently Oct. 21, 2020.
			2020 North	Mar. 11	Sept. 19–Oct. 28	No	Moved extensively throughout a summer range that included Galveston Bay, TX, Port Arthur, TX, and the Mississippi Delta. Returned to study area on Sept. 19 before moving north to Corpus Christi, TX. Returned permanently Oct 28, 2020.
A7A0	Jan. 10, 2018	Jan. 24, 2018	2018 South	Jan. 11, 2018	Did not return	No	Migrated in winter to southern Mexico and did not return (emigrated Jan 11, 2018).
0B3A	Jan. 14, 2018	Feb. 12, 2018	NA	-	-	-	-
AA3A	Jan. 31, 2018	Dec. 26, 2018	2018 North	Mar. 16	Oct. 22	Possibly	Summered in Galveston, TX. High site fidelity (North Deer Island). Possibly bred but did appear to switch roost sites within the breeding period. Intermittently faulty transmitter.
F7A1A	Feb. 12, 2018	Apr. 22, 2018	2018 North	Mar. 24	Did not return	No	Moved to the Mississippi Delta. Lost transmission while in the Delta.

Pelican ID	Active From	Active To	Migrated	Emigration Date	Immigration Date	Signs of Breeding	Notes
0B3A7	Feb. 22, 2018	Jan. 22, 2019	2018 North	Mar. 23	Nov. 23	Possibly	Mississippi Delta. Returned to same roost (or nest) site between May 2 and Jun. 24. After Jun. 24, used a greater variety of roost islands in the Delta. Remained in the Delta until Nov. 19 before a 3-day journey back to BGWC.
F038	Oct. 15, 2018	Oct. 15, 2018	NA	-	-	-	-
1639	Oct. 16, 2018	Oct. 25, 2018	NA	-	-	-	-
2539	Oct. 18, 2018	Oct. 20, 2018	NA	-	-	-	-
6E3A	Nov. 13, 2018	Jan. 31, 2019	NA	-	-	-	Moved longer daily distances, often 100 km (approximately 62 miles) or more between the Bahía Grande roost island, the Rio Grande estuary region, and the Mar Negro wetlands, MX, sometimes returning within the same day.
62A3	Nov. 19, 2018	Dec. 3, 2018	NA	-	-	-	-
34A1	Nov. 22, 2018	Dec. 6, 2018	NA	-	-	-	-
523A	Nov. 23, 2018	Mar. 12, 2019	2018 North	Mar. 12, 2019	-	-	Migrated for 1 day before losing transmission.
85A3	Nov. 24, 2018	Dec. 28, 2018	NA	-	-	-	-
B6A3	Nov. 25, 2018	Jan. 18, 2019	2019 South	Dec. 16, 2018	Did not return.	-	Migrated southwards (Veracruz, MX). Did not return.
963A	Nov. 30, 2018	Dec. 9, 2018	2018 South	Dec. 02, 2018	Did not return.	-	Migrated south (Laguna Madre, MX). Did not return.
443A	Nov. 30, 2018	Dec. 4, 2018	NA	-	-	-	-
3939	Dec. 5, 2018	Dec. 9, 2018	NA	-	-	-	-

Pelican ID	Active From	Active To	Migrated	Emigration Date	Immigration Date	Signs of Breeding	Notes
383A	Dec. 6, 2018	Jan. 29, 2018	NA	-	-	-	-
75A3	Dec. 10, 2018	Jan. 28, 2018	NA	-	-	-	-
A65A	Dec. 12, 2018	Dec. 30, 2018	2018 South	Dec. 17, 2018	Did not return.	-	Migrated southwards to Cuidad del Carmen, MX.
443A7	Dec. 12, 2018	Aug. 13, 2020	2019 North	Mar. 23, 2019	Dec. 11, 2019	Possibly	Mississippi Delta southeast of New Orleans, LA. Stopped between Port Arthur, TX, and Lake Charles, LA, on the northward trip. High roost site fidelity from Apr. 16 to Jun. 5.
			2020 North	Unknown	Last signal Aug. 13, 2020	-	The transmitter signal was lost between Jan 15, 2020, and May 4, 2020. Signal resumed in Mississippi Delta. Intermittent coverage thereafter.
A45A	Dec. 18, 2018	Dec. 20, 2019	2019 South then North	Mar. 18, 2019	Did not return. Last signal was Dec. 20 south of Mobile, AL	Unlikely	Initially moved south to Laguna Madre. Summer grounds were mostly east of the Mississippi Delta. Stops on northbound journey at Corpus Christi, TX, and Matagorda Bay, TX. High roost site fidelity but not for long enough to suggest breeding occurred.
A95A	Dec. 18, 2018	Mar. 2, 2019	NA	-	-	-	-
BBA6	Dec. 27, 2018	Jan. 10, 2019	NA	-	-	-	-
A05A	Jan. 1, 2019	Aug. 3, 2019	2019 South	Jan. 12, 2019	Mar. 6, 2019	-	Spent Jan. 31 to Feb. 22 in Coatzacoalcos, MX, before returning to BGWC.
			2019 North	Mar. 12, 2019	Passed through Jul. 11, 2019	No	Summered between Houston, TX, and the Mississippi Delta. Traveled south through the BGWC study area to Laguna Madre, MX.
A35A	Jan. 4, 2019	Jan. 23, 2019	NA	-	-	-	-
BCA6	Jan. 28, 2019	May. 1, 2020	2019 North	Mar. 25, 2019	Sept. 8, 2019	-	Summered between Houston, TX, and Mississippi Delta. Low roost site fidelity.

Pelican ID	Active From	Active To	Migrated	Emigration Date	Immigration Date	Signs of Breeding	Notes
			2020 North	Feb. 21, 2020	Did not return.	-	Left BGWC study region south, moving toward Laguna Madre, MX. Then traveled north (Mar. 10, 2020) through study region to coast between Houston, TX, and Mississippi Delta.
A25A	Jan. 30, 2019	Nov. 10, 2019	2019 North	Apr. 6, 2019	Aug. 6, 2019	No	Summered in Galveston Bay, TX, and Matagorda Bay, TX. High roost site fidelity in Galveston Bay but not enough to suggest breeding.
BDA6	Jan. 30, 2019	Feb. 28, 2019	NA	-	-	-	Intermittent transmission.
A15A	Feb. 18, 2019	Jun. 27, 2019	2019 North	Mar. 21, 2019	Did not return.	No	Summered Galveston Bay, TX. Relatively low roost site fidelity. Last location Port Arthur, TX.
B8A6	Feb. 19, 2019	Mar. 21, 2019	NA	-	-	-	-
BBA6C	Feb. 19, 2019	Nov. 20, 2019	2019 North	Mar. 26, 2019	Did not return. Lost transmission Nov. 20, 2019, in Houston, TX.	No	Summered between Corpus Christi, TX, and Houston, TX. Low roost site fidelity.
BAA6	Feb. 21, 2019	Jun. 5, 2019	2019 North	Mar. 24, 2019	Did not return. Last transmission Jun 5, 2019, in the Mississippi Delta.	No	Mississippi Delta. High roost site fidelity between Apr. 27 and Jun. 05; then, signal was lost.

NA = Not applicable.
[1] Pelicans that did not leave the BGWC study region are indicated by NA in the fourth column (Migrated). GPS tracking for these pelicans ended before the typical migration window ended. Whether these pelicans would have migrated or remained local is not known.

The following observations can be made regarding the seasonal movements of the tracked pelicans:

- Eighteen of the 35 pelicans were not tracked long enough to show seasonal migrations. However, none of the tracked pelicans remained in the BGWC through summer (although one pelican with a malfunctioning device was observed in the BGWC over summer).

- Seventeen pelicans migrated from the BGWC. Four pelicans (AA3A, 0B3A7, A05A, and A25A) were tracked over one migration. Ten migrating pelicans were tracked for less than one season (Pelicans A7A0, F7A1A, 523A, B6A3, 963A, A65A, A45A, A15A, BBA6C, and BAA6). The remaining three pelicans were successfully tracked for longer than one migration:
    - Pelican 163A was tracked over three annual migrations.
    - Pelican 443A7 was tracked over two migrations.
    - Pelican BCA6 was tracked over one summer and winter migration, followed by another summer migration (after which the GPS device provided no more recordings).
- The summer range of the BGWC pelicans included Matagorda Bay, Galveston Bay, locations close to the Louisiana-Texas border (the Port Arthur, TX, and Marsh Island, LA, locations marked in Figure 15), the Mississippi Delta, and Mobile Bay, AL. Some of the tracked pelicans showed high site fidelity in locations such as Matagorda Bay and Galveston Bay for several weeks before heading further north to the Mississippi Delta.
- Based on approximately 60-day periods of high roost site fidelity (indicating that the pelicans were likely sitting on nests), four pelicans may have nested. These pelicans were 163A, 0B3A7, BCA6, and BAA6. Two of the likely nest sites were in the Mississippi Delta (Pelicans 0B3A7 and BAA6), one was in Calcasieu Lake south of Lake Charles, LA (Pelican BCA6), and one was in Matagorda Bay (Pelican 163A).
- Spring migrations occurred within a relatively short time window in March (i.e., March 10 to March 26). The dates of the returning fall migrations were much more variable. Fall migrations were initiated between August and November. In general, while the spring migrations were relatively direct (i.e., with few stops at other locations during their journeys), the fall migrations were less direct, often involving multiday or multiweek stops in suitable coastal habitats along the Gulf Coast. Pelicans returned to the BGWC study area between September 8 and December 11.
- The pelicans that were tracked over multiple years used similar summer ranges each year and undertook migrations on similar dates each year.
- The pelicans that overwintered in the BGWC also used overwintering habitat in the Laguna Madre del Rio Bravo. These pelicans moved regularly between these habitats during the winter.
- Four pelicans captured in the BGWC in the fall and early winter undertook southern migrations to overwintering locations in southern Mexico (such as Veracruz and Tabasco) between late December and January. One of these pelicans left the study area on January 12, 2019, and briefly returned to the BGWC study area the following spring (March 6, 2019) before undertaking a spring migration to the northern Gulf. Tracking of the other three pelicans stopped during the winter, which suggests that several pelicans that temporarily visit the BGWC in fall and winter also overwinter in more southern locations.

- Every bird tracked during the study used migratory flyways along the Gulf Coast—that is, none undertook migrations across the open waters of the Gulf.
- One pelican (A7A0) captured in the BGWC on January 10, 2018, undertook an unusual winter migration towards southern Mexico and then attempted to cross the Isthmus of Tehuantepec toward Guatemala on the Atlantic coast. The pelican began its journey on January 11, reached Coatzacoalcos, Mexico, January 21, and then spent two days inland on the Isthmus of Tehuantepec before returning to the Gulf Coast just before the GPS tracker stopped recording data. Figure 16 shows the GPS movements recorded for A7A0.

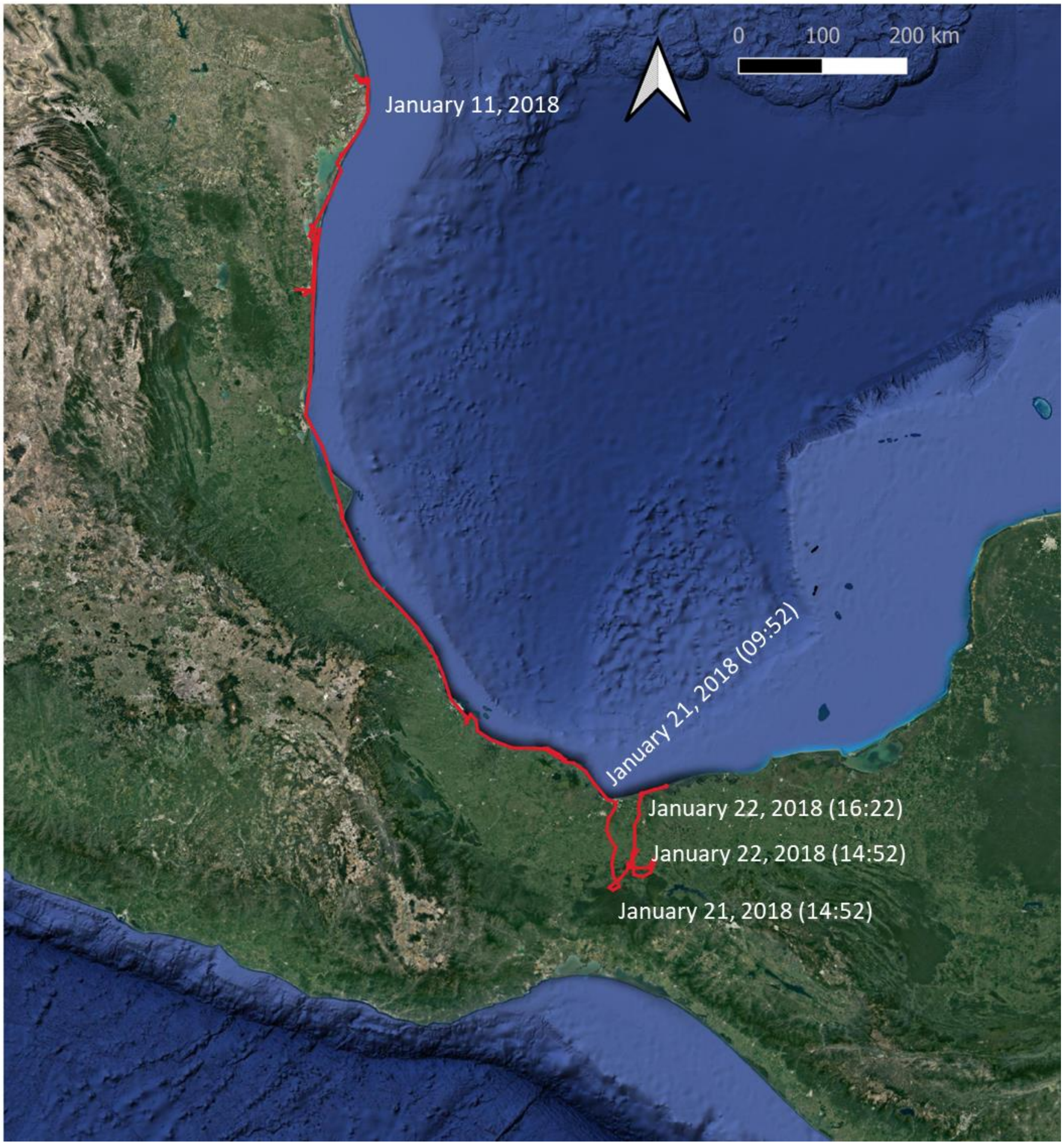


Figure 16. Map of Winter Migration of Pelican A7A0 from the BGWC (capture location) to Coatzacoalcos, Mexico, and an Attempted Crossing of the Yucatan Peninsula.

DAILY MOVEMENTS

The daily movements of brown pelicans in the BGWC can be conceptualized as a series of activities centered around roost sites (overnight habitat), loafing sites (habitat chosen by the pelicans for daytime resting, usually out of the water), and feeding sites. Generally, the daily movements of overwintering populations in the BGWC focus on a few key roost habitats and a series of movements throughout the day to favored loafing habitat. Observations of pelican activity in the field (by the study team) and analysis of GPS data suggest that, in the BGWC and during overwintering, foraging *tends* to occur opportunistically as pelicans move to and from individual loafing sites throughout the day—although distinct foraging locations do exist, particularly in the Laguna Madre and on the coastal shelf of the Gulf of Mexico.

In summer, the GPS data show a slightly different pattern. Pelicans still move to and from loafing sites during each day, but they also appear to spend much more time on the water—either resting or actively feeding.

In the following sections, the research team use the conceptual framework of roost sites, loafing sites, and movements of pelicans between them to generalize the movements of the BGWC population. Because the focus of this project is mortality on SH 48, the review focuses on the activities of pelicans overwintering in the BGWC.

Roost Sites

Figure 17 shows all the roost sites identified from the GPS data. To delineate roost sites, the research team developed algorithms that identified all points where pelican displacements between successive GPS fixes (usually occurring every 15 to 30 minutes) were less than 100 meters and occurred between 9 p.m. and 5 a.m. A clustering algorithm was used to translate each point to one distinct location. This process allowed the research team to identify a distinct overnight location for each pelican (i.e., a single day's roost location). In Figure 17, the size of the circle indicates the number of pelican days spent at each site (aggregated for all pelicans). The map shows many roost sites were used during the course of the study and over the seasonal range of the pelicans. However, it also highlights a subset of highly preferred locations—especially in areas where pelicans remained for extended periods (i.e., locations with high GPS point densities).

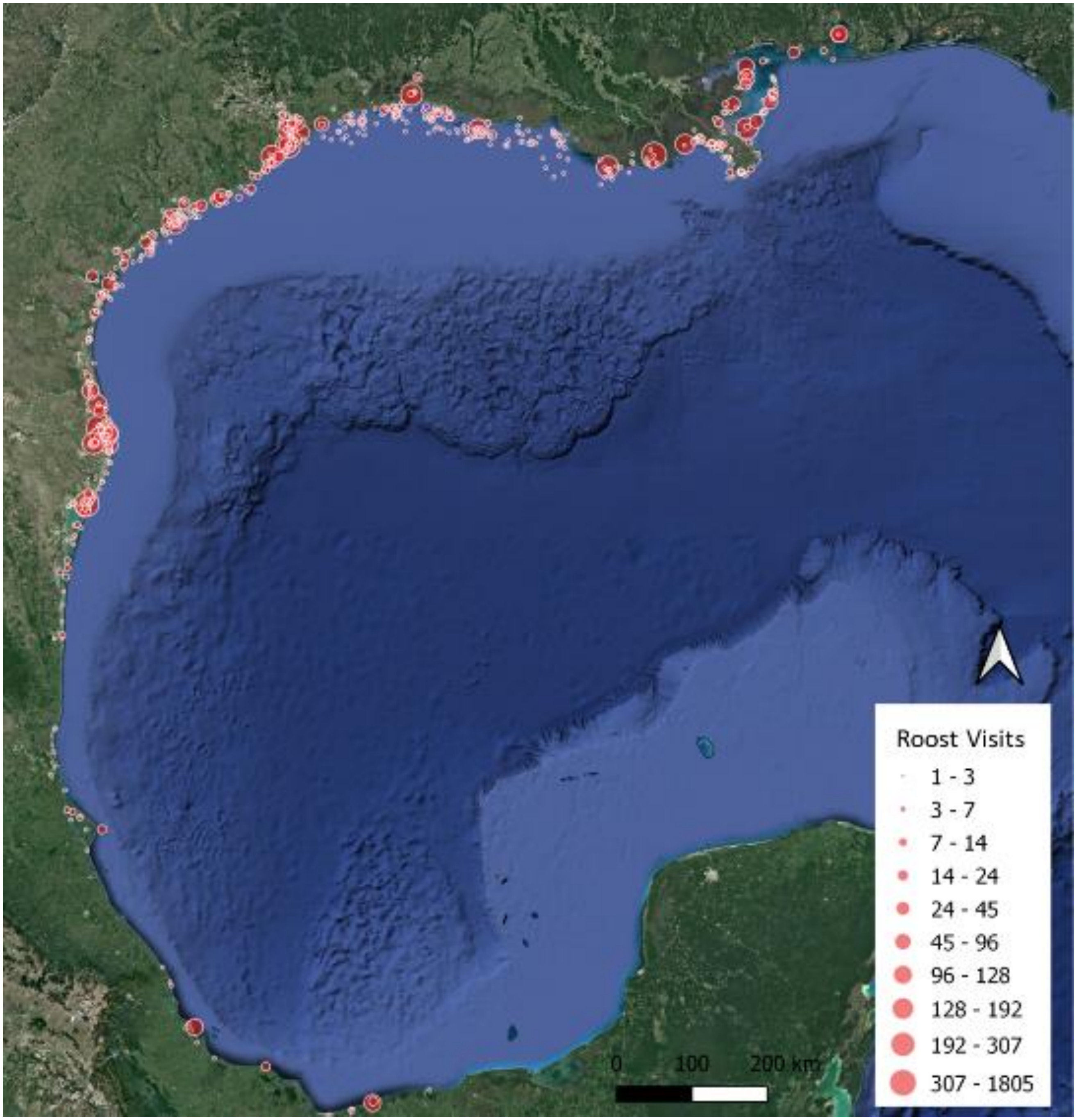


Figure 17. Roost Sites Visited by Pelicans Tracked During the Study. The size of the circle represents the number of overnight roosts at that location.

Figure 18 shows the key roost sites within the extended BGWC study area, including the Laguna Madre del Rio Bravo in Mexico and the upper Laguna Madre in Texas. The most frequently used roost sites were on specific spoil islands in the lower Laguna Madre, at marinas in Port Isabel and the Laguna Madre side of South Padre Island, on two islands in the Bahía Grande, islands in the Brownsville Ship Channel, and at a series of shrimp docks on the western end of the Brownsville Ship Channel.

Figure 18. Image Location Map and Aerial Images of Two Major Roost Sites within the BGWC. These roost sites include a group of dredge spoil islands in the Laguna Madre located roughly one mile from shore (Image A) and four islands within the Bahía Grande (Image B). The roost sites in the Bahía Grande are located approximately 1.7 (Location 1 in Image B) and 2.8 miles (Location 3 in Image B) north to northwest of the Carl Gayman Bridge and Channel. Locations 1, 2, and 4 in Image B are associated with a former railroad crossing that now consists of railbed subgrade material and abandoned support pilings.

Figure 19 and Figure 20 provide supplementary views of roost locations based on daily transitions between sites on consecutive days. In these figures, the size of each circle indicates the number of times pelicans returned to the same roost site on consecutive nights, while the thickness of the lines indicates the number of transitions between different roost sites on consecutive nights. In Figure 19, these transitions were calculated directly from the aggregated movement history of each pelican. However, this method of determining transition history is influenced by how long each pelican was tracked (pelicans that were tracked for longer will have a large influence on the transitions). Figure 20 shows the same information, but in this figure the transition probabilities for each pelican are normalized according to the number of days that the pelican was tracked. Both figures show the roost site transitions diagrammatically such that they link consecutive roost locations rather than showing the full set of daytime movements that occur between locations. In general, the following observations can be made:

- The most popular roost site is on a spoil island located approximately 1 mile northeast of the city of Laguna Vista.
- Pelicans show a high degree of roost site fidelity such that, on most days, pelicans return to the same roost site (indicated by the size of the black circles in Figure 19 and Figure 20).
- Transitions between different roost sites occur relatively frequently (although not as frequently as pelicans returning to the same roost site on consecutive days). The most important transitions occur between the Laguna Madre roost site and marinas in Port Isabel, islands in the Bahía Grande, and the shrimp basin located at the western end of the Brownsville Ship Channel.
- Overwintering BGWC pelicans also use roost sites in the Laguna Madre del Rio Grande in Mexico and the Upper Laguna Madre in Texas, suggesting that these locations can be considered an extension of the overwintering range of BGWC pelicans.
- Although not explicitly illustrated by Figure 19 and Figure 20, a number of other islands located in the Lower Laguna Madre were never used for roosting by any of the tracked pelicans.

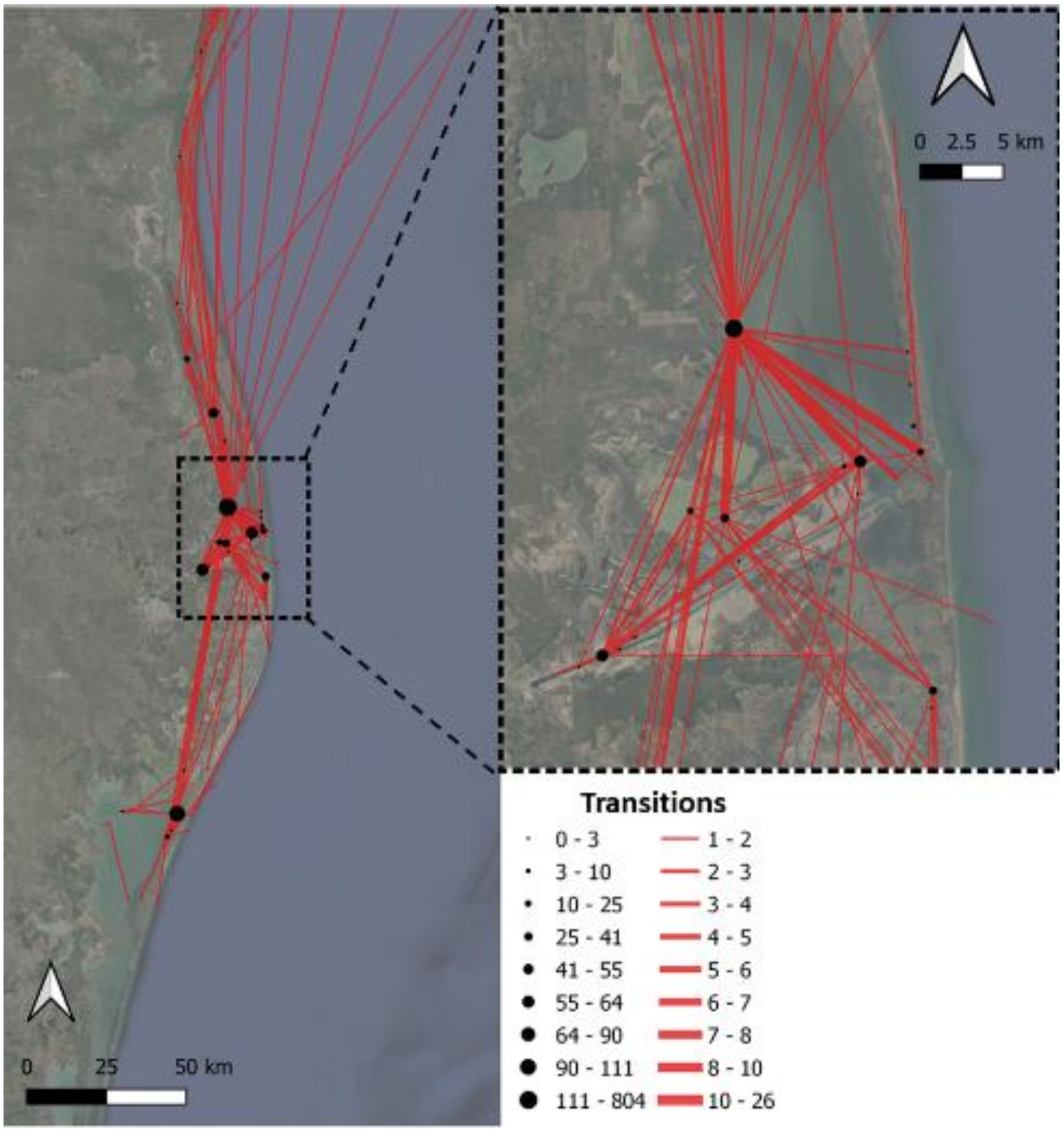


Figure 19. Pelican Transitions among Roost Sites in the Study Area. The left map shows roost site transitions in the broader study area (encompassing the Laguna Madre, BGWC, and the Laguna Madre de Rio Bravo, Mexico). The map on the right shows detailed transitions in the Bahía Grande/Laguna Madre study area. The size of the circles indicates the number of times pelicans returned to the same roost site on consecutive nights. The thickness of the red lines shows the number of transitions between distinct roost sites.

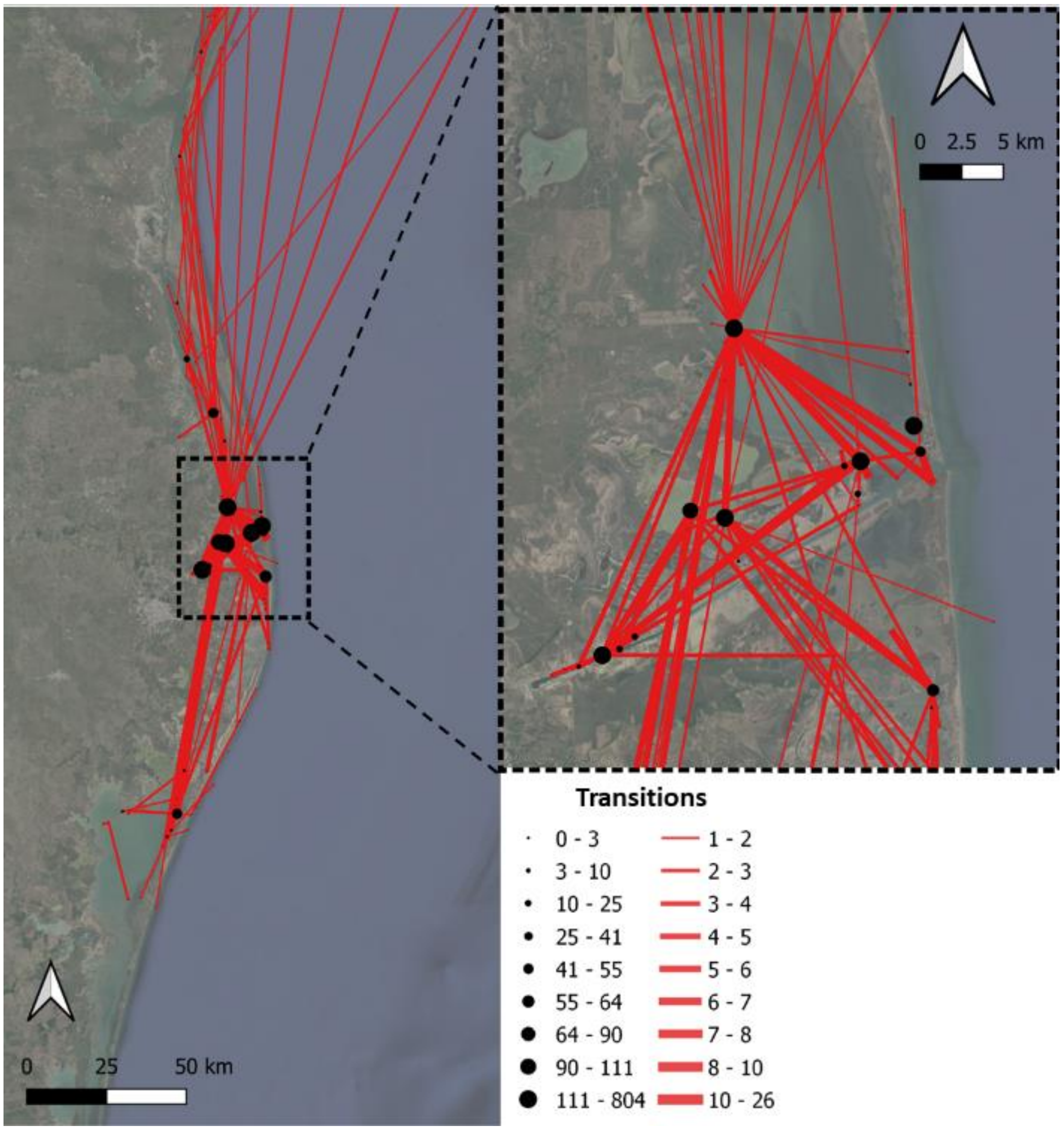


Figure 20. Pelican Transitions between Roost Sites in the Study Area Normalized According to the Number of Days that the Pelicans Were Tracked. The left map shows roost site transitions in the broader study area (encompassing the Laguna Madre, BGWC, and the Laguna Madre de Rio Bravo, Mexico). The map on the right shows detailed transitions in the Bahía Grande/Laguna Madre study area. The size of the circles indicates the number of times pelicans returned to the same roost site on consecutive nights normalized to the number of days the pelicans were tracked. The thickness of the red lines shows the normalized number of transitions between distinct roost sites.

Figure 21 and Figure 22 show the time-of-day pelicans left and returned to roost sites, respectively, for each month of the study. Figure 21 shows the cumulative probability of all pelicans tracked leaving roost sites by a specific hour of the day in each month of the study. The black line shows the cumulative probability of pelicans that left the roost sites before 12 p.m. (midday). The gray line shows the cumulative probability of pelicans leaving the roost site for all pelicans. The solid red line shows a cumulative normal distribution fitted to the time of emergence (for pelicans moving before 12 p.m.). The gray areas delineate the hours before sunrise. Figure 21 shows that pelicans leave from their roost sites as early as two hours before sunrise. By sunrise, approximately 50 percent of the pelicans leave their overnight roosts. The gray line suggests that some pelicans remain in close proximity to roost sites for extended periods of the day (such that roost sites are also used as loafing sites). This general behavior is consistent for each month of the year.

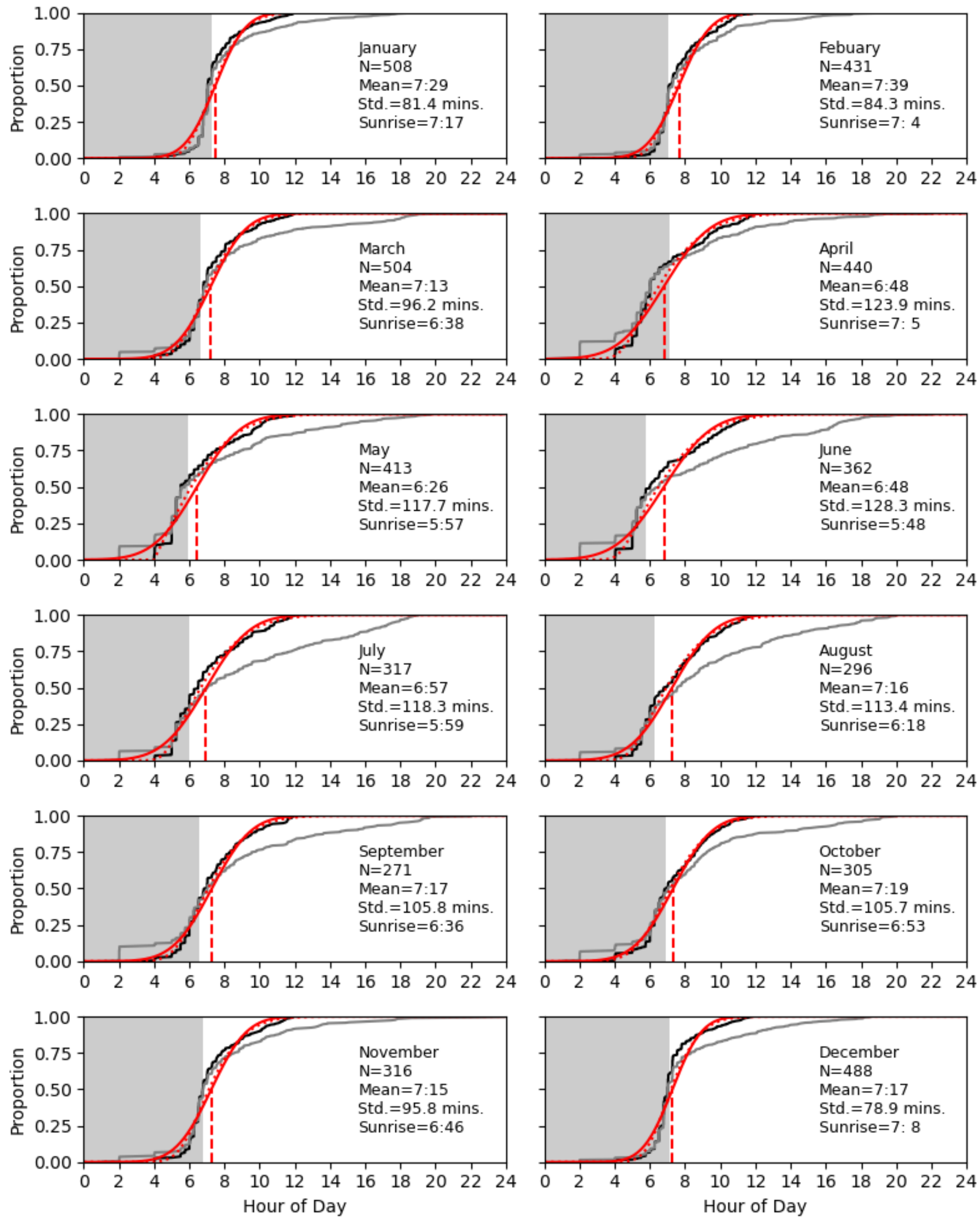


Figure 21. Timing of Daily Movements from Overnight Roost Sites to Daytime Feeding and Loafing Sites across the BGWC Study Area. Each graph shows data for all pelicans (aggregated) by month (January through December). The black line shows the timing of roost site dispersal for pelicans that left their roost site before 12 p.m. The gray line shows the timing of roost movements for all pelicans. The solid red line shows the cumulative probability of movement (by time) modeled using a normal distribution (the mean value is shown as the vertical red dashed line). The gray area delimits nighttime hours (hours before sunrise).

Figure 22 shows the timing of pelican movement to roost sites for each month of the study. In these graphs, the black line shows the cumulative probability of pelicans returning to the roost sites by hour of the day but only includes pelicans returning after 12 p.m. (midday). The gray line shows the cumulative probability of pelicans returning to the roost sites by hour of the day for all pelicans. The solid red line shows a cumulative normal distribution fitted to the time of returns (for pelicans returning after 12 p.m.). The gray areas delineate time after sunset. Figure 22 shows that (depending on the month) between 50 and 75 percent of the pelicans tracked returned to their roost sites before sunset. In January, February, March, and December, 50 percent or more of the pelicans returned to the roost site after sunset.

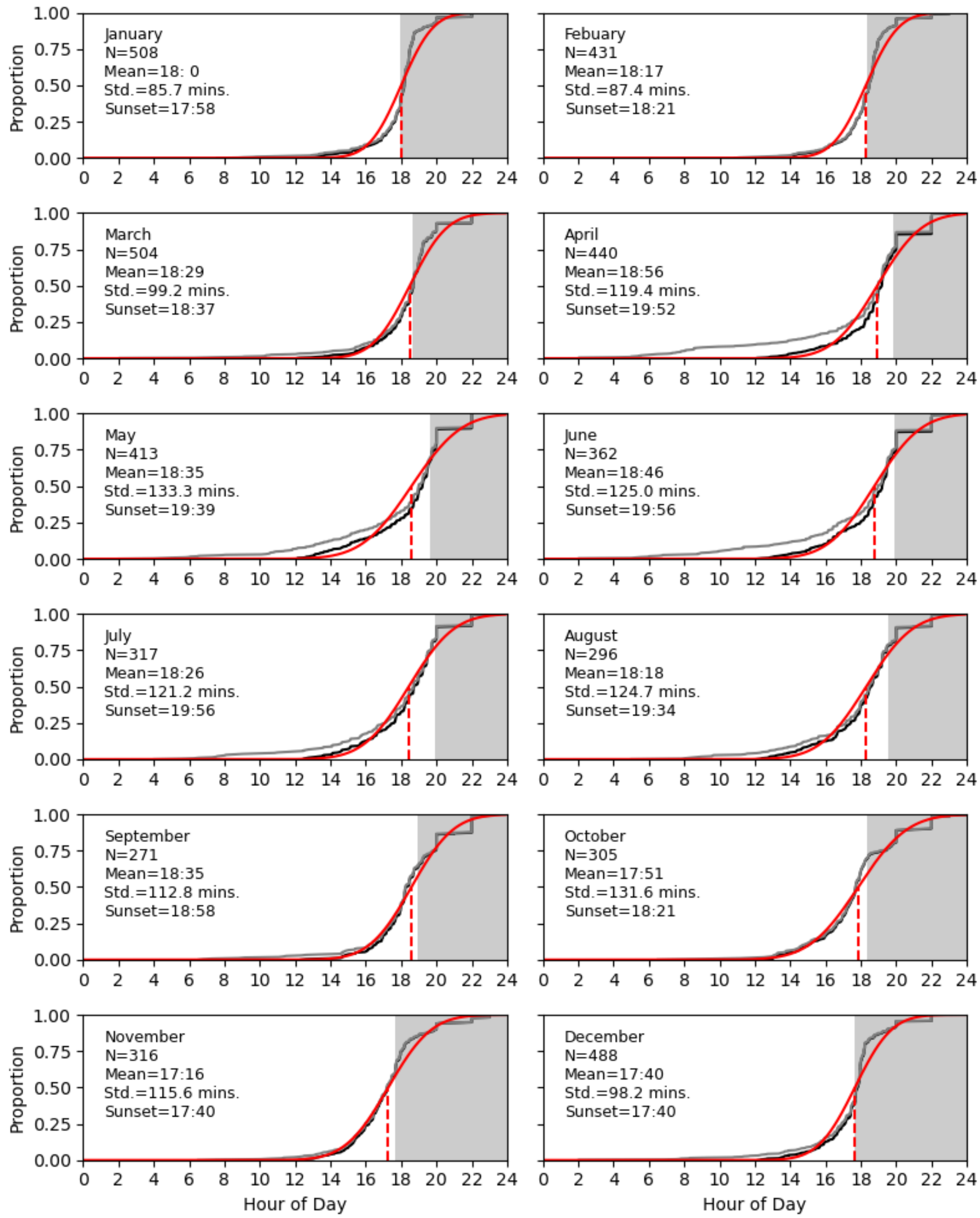


Figure 22. Timing of Daily Movements to Overnight Roost Sites from Daytime Feeding and Loafing Sites across the BGWC Study Area. Each graph shows data for all pelicans aggregated by month (January through December). The black line shows the timing of movements to roost sites for pelicans that entered the roost site after 12 p.m. The gray line shows the timing of roost movements for all pelicans. The solid red line shows the cumulative probability of movement (by time) modeled using a normal distribution (the mean value is shown as the vertical red dashed line). The gray area delimits nighttime hours (hours after sunset).

Loafing Sites

Figure 23 shows the location of major loafing sites in the BGWC. The maps show loafing sites that are used for durations of one, two, four, and six hours. The size of the circles illustrates the number of recorded visits to each site (aggregated across all tracked pelicans). The researchers defined loafing sites as locations where displacements between consecutive GPS fixes were less than 100 meters after an initial movement (greater than 500 meters) from the overnight roost location. A clustering algorithm was then used to delineate discrete loafing locations. Figure 24 shows how many of the tracked pelicans used each loafing site.

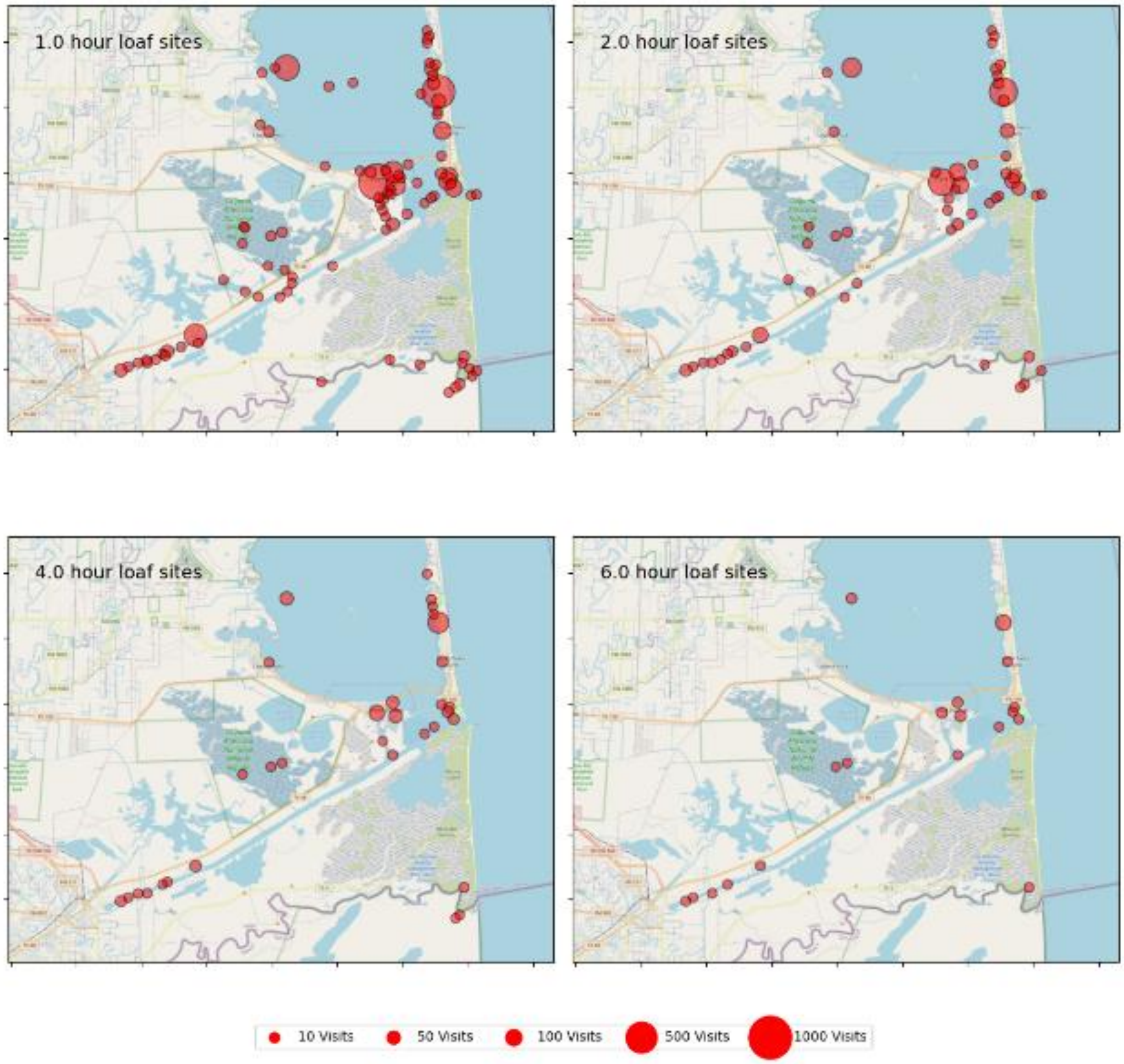


Figure 23. Pelican Loafing Sites within the Study Area Measured by Number of Visits. Each circle represents a unique loafing site as determined by a clustering algorithm. The size of the circles indicates the number of times each unique loafing site was used by pelicans tracked during the study. The four maps show the use of the loafing sites for durations equal to or greater than 1, 2, 4, and 6 hours.

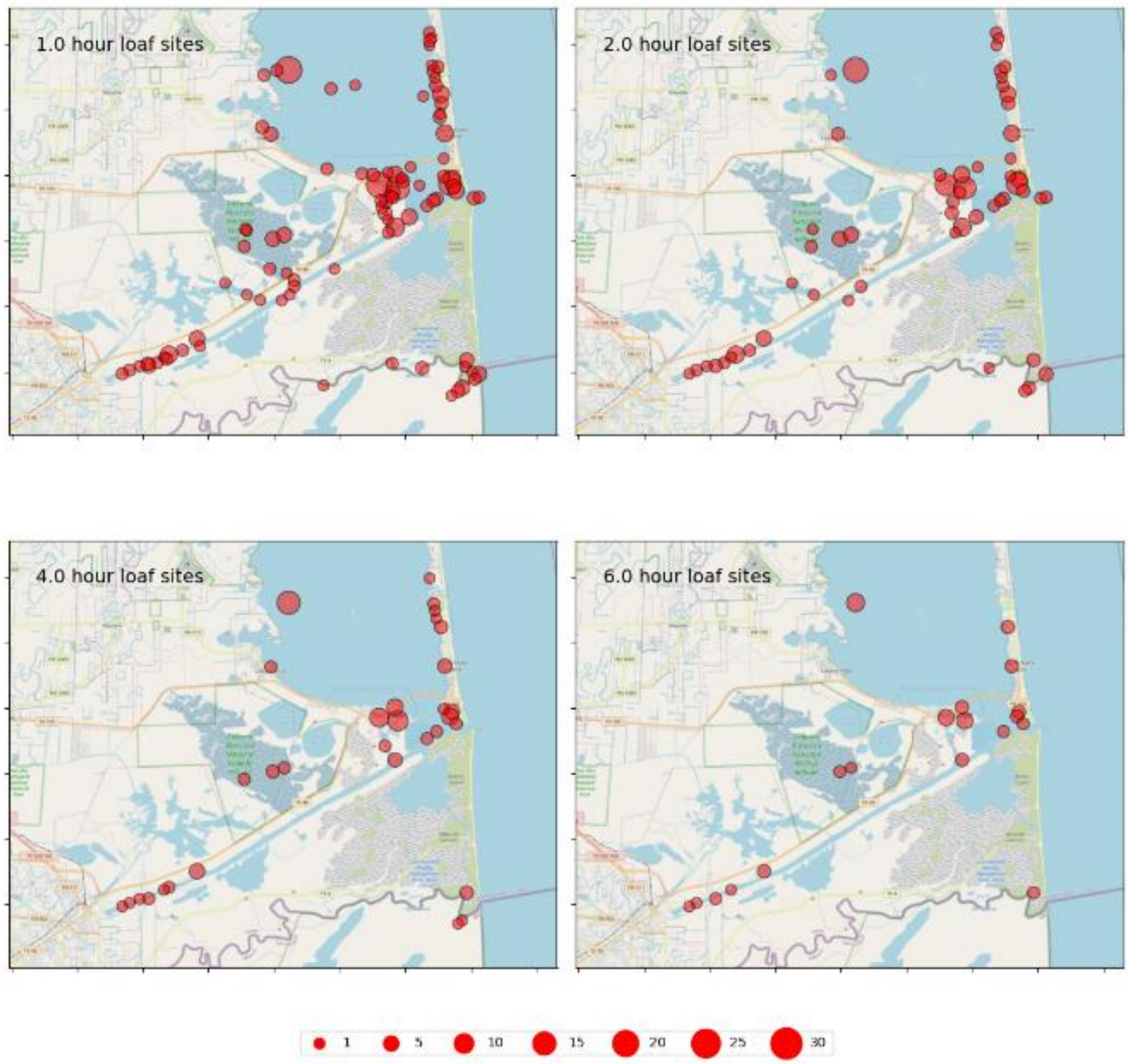


Figure 24. Pelican Loafing Sites within the Study Area Measured by Number of Visits by Unique Birds. Each circle represents a unique loafing site as determined by a clustering algorithm. The size of the circles shows the number of individual pelicans tracked during the study that visited the sites. The four maps show the use of the loafing sites for durations equal to or greater than 1, 2, 4, and 6 hours.

Figure 25 provides a location map and aerial images of the key loafing sites within the BGWC based on the number of pelican visitations during the study.

Figure 25. Image Location Map and Aerial Images of Key Loafing Sites within the BGWC Based on the Number of Pelican Visitations. The key loafing sites include docks and structures in the Parrot Eyes Restaurant area (Image A), near the Painted Marlin Grill area (Image B), the U.S. Coast Guard station (Image C), Port Isabel, specifically the Port Isabel Channels (Location 1 in Image D), structures near the west end of the Queen Isabella Causeway Bridge (Location 2 in Image D), the island within the Port Isabel Channel (Location 3 in Image D), the Laguna Madre roost island (see Figure 18 for aerial photograph), the Brownsville Ship Channel (Image F), and the area near the Rio Grande River outfall to the Gulf of Mexico (Image G).

Figure 26 shows the cumulative number of discrete loafing sites identified during the study. The top panel shows the cumulative number of one-hour loafing site locations identified. The middle and lower panels show the same information for two- and four-hour loafing sites, respectively. For example, initially, the research team identified approximately 50 discrete one-hour loafing sites from January to April 2018. Because the tracked pelicans left the study area over summer, no additional loafing sites were detected until the following overwintering season (October 2018 to April 2019). In the third overwintering season (October 2019 to January 2020), relatively few new loafing sites were detected, which can be attributed to a relatively short tracking season, or it may also indicate that after three years of study, most of the major loafing sites used by pelicans in the BGWC have been identified.

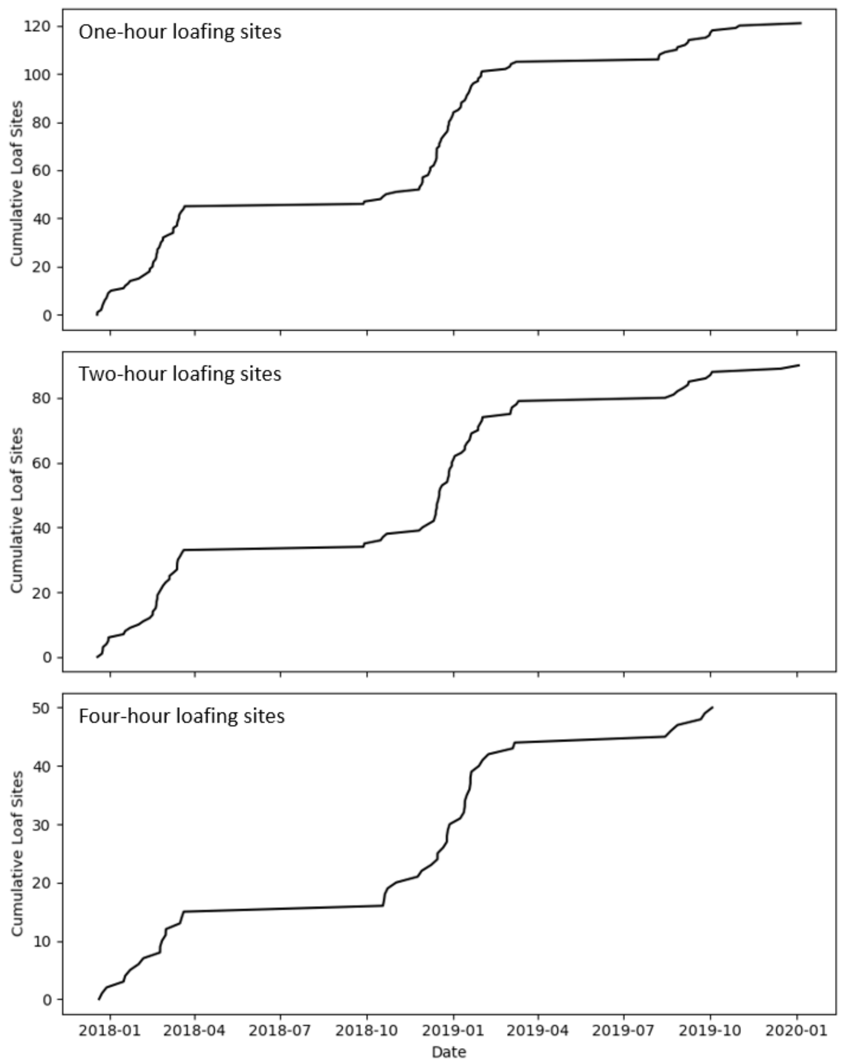


Figure 26. Distinct Loafing Sites Identified during the Study. The top graph shows the cumulative number of one-hour loafing sites identified during the study. The middle and bottom graphs show the same information for two- and four-hour loafing sites, respectively.

The following general observations can be made about loafing sites:

- Most loafing sites are located north of the Brownsville Ship Channel (or on the southern bank of the channel).
- The most popular loafing sites are at the marinas in Port Isabel and on the Laguna Madre side of South Padre Island. The shrimp basin situated at the western end of the Brownsville Ship Channel is also extensively used for loafing.
- Loafing also occurs frequently on previously identified roost sites on the Laguna Madre spoil islands and in the Bahía Grande.
- Some consistent but less frequent loafing occurs at the mouth of the Rio Grande on the Mexico-Texas border and at several inland locations along the Rio Grande. No loafing sites were identified in South Bay or the Boca Chica wetlands (i.e., the contiguous area of tidal wetlands that occur south of the Brownsville Ship Channel and north of the Rio Grande—though field excursions have identified brown pelicans loafing in this region).
- The two measures of loafing site use—total pelican visits and the number of tracked pelicans that visited the loafing site—provide a consistent view of the key loafing locations in the BGWC study area. The location of loafing sites by the duration of loafing also helped to identify the most important loafing sites in the study area.

Movement Patterns

Figure 27 shows the frequency distribution of loafing by duration in the BGWC study area. The modal loafing duration is for one hour, but pelicans occasionally remain at distinct loafing sites for periods up to 11 hours.

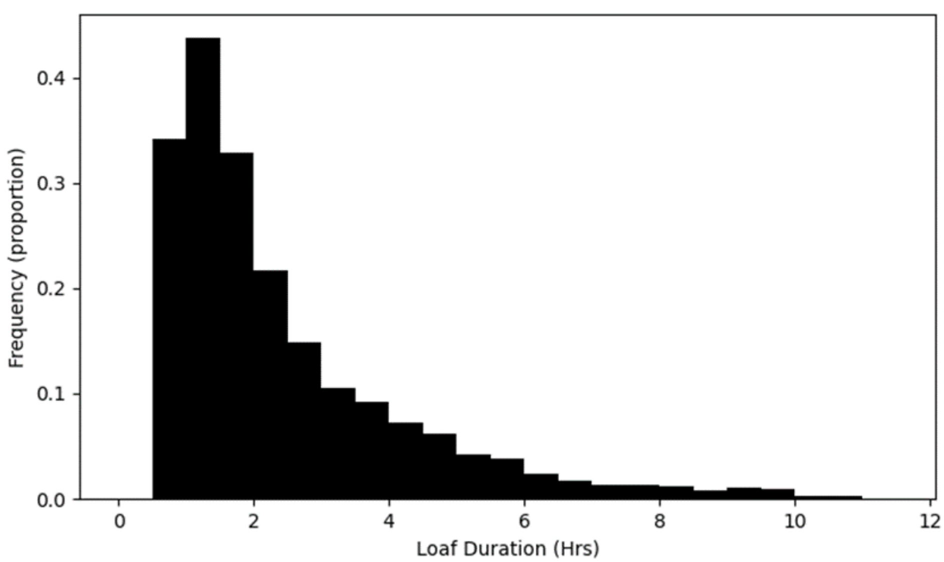


Figure 27. Frequency Distribution for the Duration of Loafing Time Observed in the BGWC Study Area.

Figure 28 shows the frequency of one-hour duration loafing activities by time of day. The figure shows a peak in one-hour loafing activity between 7 a.m. and 8 a.m. and that one-hour loafing occurs consistently during daylight hours. The figure also shows that one-hour loafing activity decreases between 4 p.m. and 8 p.m.

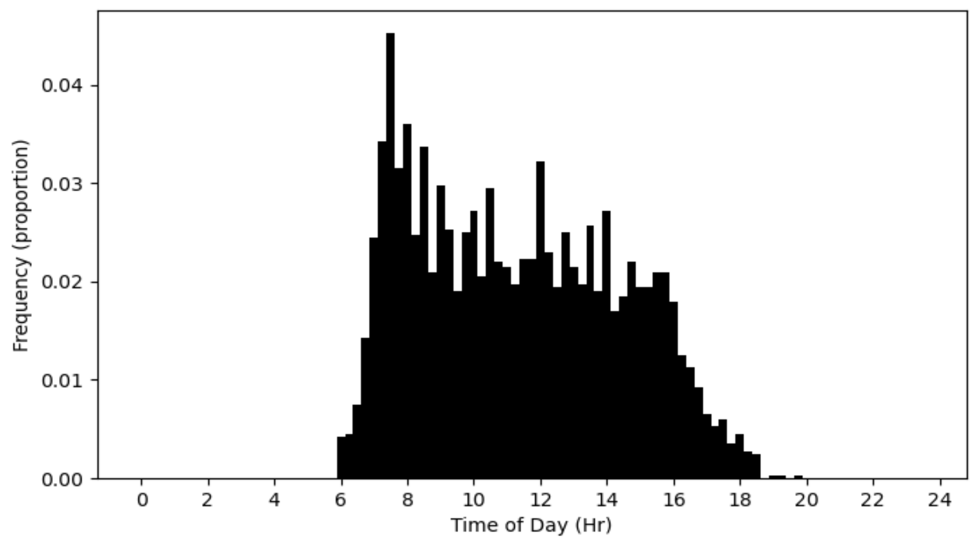


Figure 28. Frequency of One-Hour Loafing Activities Observed in the BGWC by Time of Day.

Figure 29 shows the daily movement patterns of the tracked pelicans by illustrating the displacements measured in kilometers per hour by time of day and month. For the BGWC overwintering period (November through March) two peak displacements occur. The first occurs between 6 a.m. and 8 a.m. as the tracked pelicans leave from their roost sites. A second peak in displacements occurs between 4 p.m. and 6 p.m. as the tracked pelicans return to their roost sites.

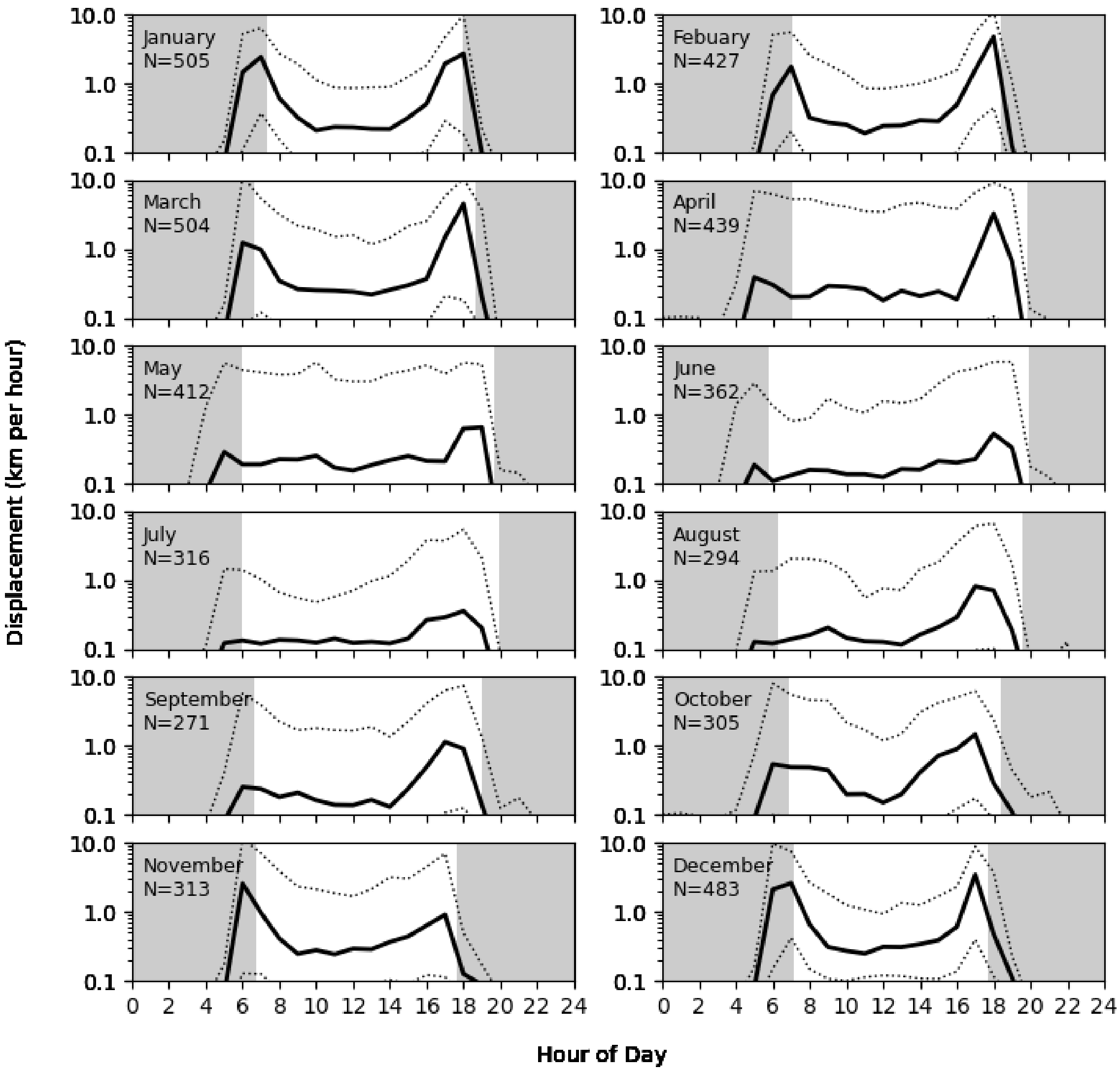


Figure 29. Daily Movement (km) of Pelicans by Hour of Day and Month. The solid line shows the median distance (km) moved per hour over 24 hours. The dashed lines show upper and lower 95 percentiles of hourly movement. The shaded areas indicate representative sunrise and sunset times (October to March show BGWC sunrise/sunset times, April to October show Mississippi Delta sunrise/sunset times).

Figure 30 shows the cumulative displacement of the tracked pelicans by month. The figure supports the previous analysis that showed that the pelicans typically begin to leave their roost sites just before sunrise and typically return to their roost sites at sunset (where the cumulative displacement curves reach an asymptote). Figure 30 shows that the cumulative mean displacement (or distance moved per day) is fairly consistent through each month of the year, at approximately 80 km per day.

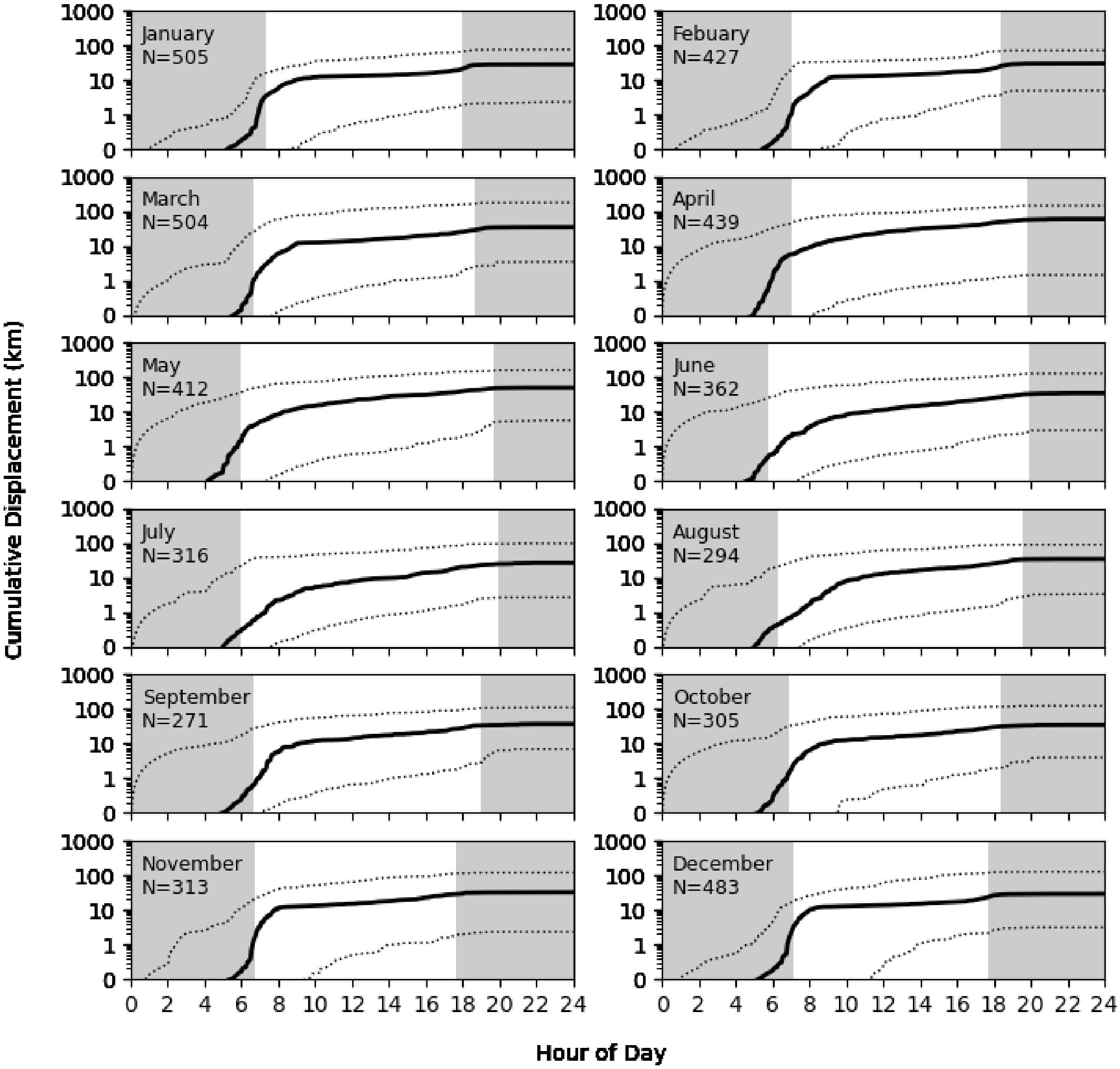


Figure 30. Cumulative Daily Movement (km) of Pelicans by Hour of Day and Month. The solid line shows the median distance (km) moved per hour over 24 hours. The dashed lines show upper and lower 95 percentiles of hourly movement. The shaded areas indicate representative sunrise and sunset times (October to March show BGWC sunrise/sunset times, April to October show Mississippi Delta sunrise/sunset times).

Figure 31, Figure 32, and Figure 33 explore the daily variation in the total movement of each pelican tracked by day for the winters of 2017–2018, 2018–2019, and 2019–2020, respectively. The gray dots in each of these figures shows significant variation that is masked by the average movement for the season and the daily average movement for all pelicans tracked.

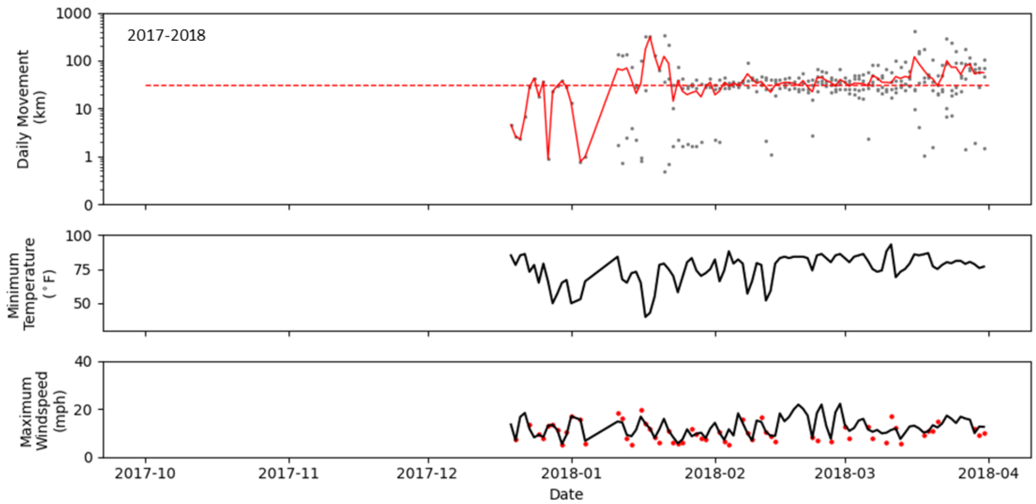


Figure 31. Total Daily Movement (km) of Pelicans Tracked during Winter 2017–2018. The graphs show daily movement (top), minimum daily temperature (middle), and maximum daily wind speed (bottom). In the daily movement graph, the dashed horizontal red line illustrates the average movement for the season, the solid red line illustrates the daily average (all pelicans tracked on that day), and the gray dots show movements of individual pelicans. The maximum wind speed graph illustrates maximum daily wind speed (solid black line) and maximum northern wind speed (red dots).

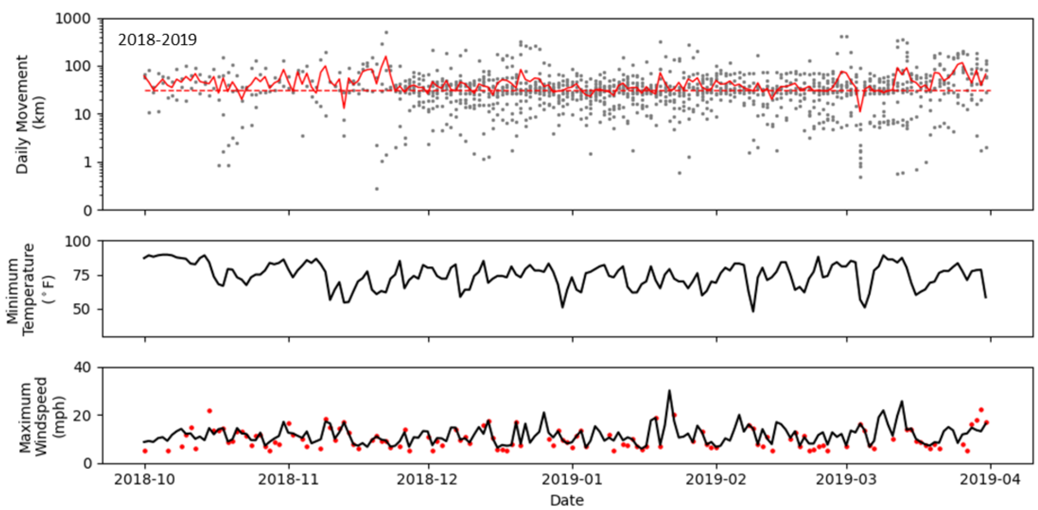


Figure 32. Total Daily Movement (km) of Pelicans Tracked during Winter 2018–2019. The graphs show daily movement (top), minimum daily temperature (middle), and maximum daily wind speed (bottom). In the daily movement graph, the dashed horizontal red line illustrates the average movement for the season (all pelicans tracked that season), the solid red line illustrates the daily average (all pelicans tracked on that day), and the gray dots show movements of individual pelicans. The maximum wind speed graph illustrates maximum daily wind speed (solid black line) and maximum northern wind speed (red dots).

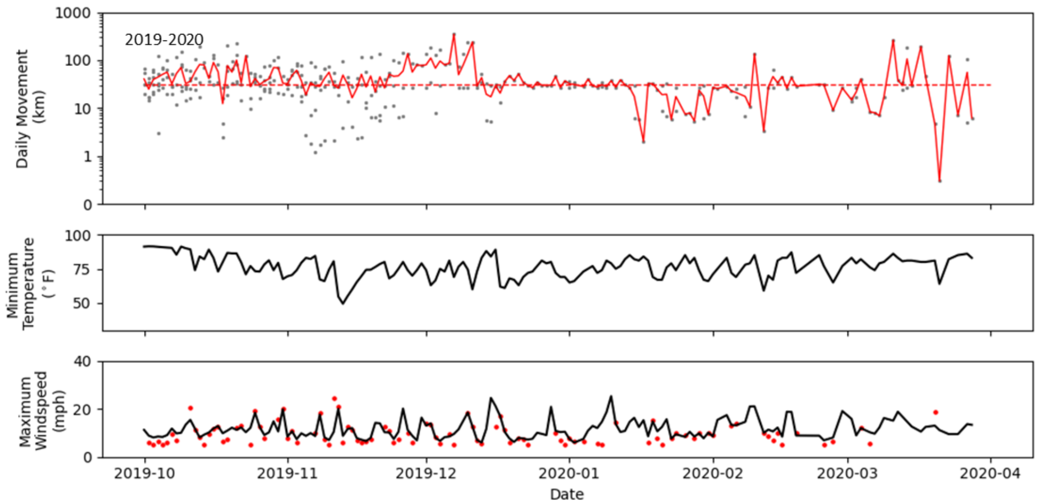


Figure 33. Total Daily Movement (km) of Pelicans Tracked during Winter 2019–2020. The graphs show daily movement (top), minimum daily temperature (middle), and maximum daily wind speed (bottom). In the daily movement graph, the dashed horizontal red line illustrates the average movement for the season, the solid red line illustrates the daily average (all pelicans tracked on that day), and the gray dots show movements of individual pelicans. The maximum wind speed graph illustrates maximum daily wind speed (solid black line) and maximum northern wind speed (red dots).

Finally, Figure 34 illustrates the distance (in kilometers) that pelicans moved during inclement (as identified in Chapter 7) versus ambient weather conditions. The box plot (left) shows no clear difference between the daily distance traveled on days when a cold front entered the area versus normal (non-cold front) days. Similarly, the scatter plot shows no correlation between the pelicans' daily movement and the minimum daily temperatures.

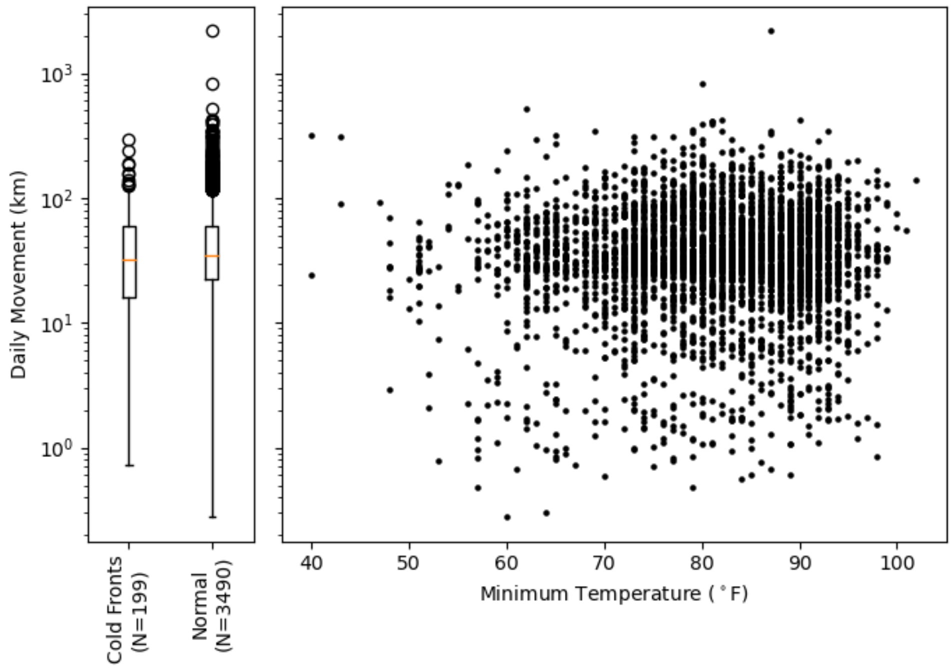


Figure 34. Plots Illustrating No Clear Difference in Distance Moved by Pelicans during Inclement versus Ambient Weather Conditions. The box plot (left) shows the difference between daily distance traveled on cold front versus non-cold front days. The scatter plot shows the relationship between daily movement and minimum daily temperatures.

FLIGHT TRAJECTORIES

Figure 35 shows the trajectories and altitudes of sustained flights undertaken by the pelicans tracked during the study. These flight trajectories were created by linking consecutive GPS points, where both points indicated a pelican in flight. As such, these trajectories *mostly* represent periods of sustained, directional flight (rather than trajectories that link loafing sites, for example). Figure 35 shows that the main flight paths within the study area include the Brownsville Ship Channel, the Gulf Coast of South Padre Island and Boca Chica, and the Laguna Madre.

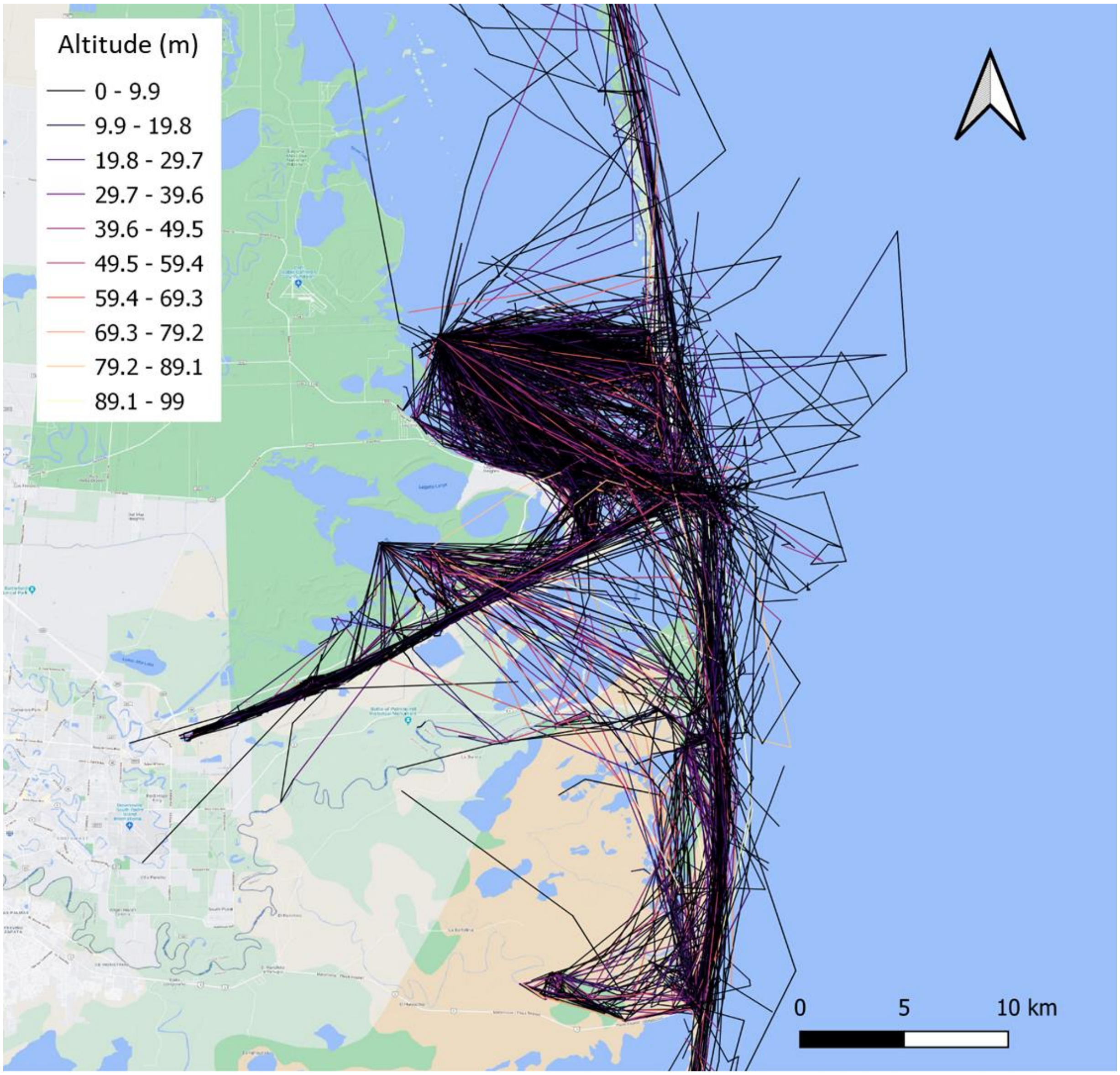


Figure 35. Plot of Flight Trajectories and Altitudes in the BGWC.

The flight trajectories that traverse the Laguna Madre are somewhat predictable given the importance of the spoil island roost sites and loafing sites in Port Isabel and on South Padre Island. Pelicans flying across the Laguna Madre have been observed to undertake (a) direct flights in which they often fly in formation and low to the water surface toward a destination, and (b) more tortuous paths during which they forage (plunge-dive). Although the size of the Laguna Madre makes it difficult to follow individual pelicans over long distances, the dual role of the Laguna Madre as a flight corridor and feeding area may explain why the spoil islands are such a popular roost site. The size of the Laguna Madre may also explain the peaks in activity (measured by displacement) that were illustrated in Figure 29. Consequently, the flight trajectories across the Laguna Madre appear to show one major movement path connecting the spoil islands to marinas on South Padre Island and another major path that links the spoil islands to Port Isabel.

The movement trajectories over Port Isabel follow the major channels that bisect the city, which highlights the tendency of pelicans to follow waterways during flight. The channels within Port Isabel also link directly to the Brownsville Ship Channel—another major flight corridor.

The final major flight corridor occurs along the Gulf Coast of South Padre Island and Boca Chica. Field observations suggest that this corridor enables pelicans to take advantage of uplift created when offshore winds are forced upward by dunes along the Gulf Coast beaches. The research team postulated that these uplifts provide an efficient flight path for pelicans moving longitudinally along the coast, which may explain why relatively few directional flights occur over the land between the ship channel and loafing sites at the mouth of the Rio Grande.

Figure 35 also shows a set of more tortuous flight trajectories extending to approximately 10 km (6 miles) offshore. This coastal flight corridor may facilitate efficient foraging in this area. Field researchers have observed pelicans using the uplift that occurs over the coastal dunes to make foraging trips into the surf zone.

Although the constructed GPS trajectories do not indicate a ***major*** flight corridor over SH 48, the research team identified three patterns in the data that indirectly highlight the importance of SH 48 crossings for the connectivity of pelican habitat:

- The proximity of the Bahía Grande roost islands to the Brownsville Ship Channel emphasizes the importance of SH 48 crossings for the continuity and connectivity of pelican habitat in the study area. The analysis of roost and loafing sites (Figure 17 and Figure 23) highlight the potential importance of SH 48 crossings for pelican habitat connectivity.
- The paucity of direct, uninterrupted flights between Bahía Grande and habitat in the Laguna Madre—especially the Laguna Madre spoil islands—highlights the importance of SH 48 crossings. The GPS data suggest that most pelican movements into and out of the Bahía Grande occur over SH 48 and onto the Brownsville Ship Channel flight corridor to loafing and feeding destinations across the study area. These movement patterns occur despite the presence of large bodies of open water between the Bahía Grande and the Laguna Madre. Significant human development (including SH100) occurs along the western edge of the Laguna Madre coastline, which may be one reason why there may be few flights over this area.
- The trajectories in Figure 35 link consecutive GPS fixes that indicate pelicans in flight. As such, the visible paths across SH 48 do not show a complete, uninterrupted trajectory of pelicans crossing SH 48. These crossings may be much more concentrated along paths that minimize flights across land. It is also possible that pelicans crossing in the Bahía Grande temporarily loaf in areas along the Brownsville Ship Channel and along the Carl

Gayman Channel before beginning directional flight into the Bahía Grande. In the latter case, the crossings will be underrepresented by the sustained flight trajectories in Figure 35.

Figure 36 shows the distribution of pelican flight speeds recorded by the GPS devices during the study. The flight speeds recorded by a GPS device are based on an instantaneous measure of displacement derived from the satellite GPS signal. Across all months, the mean instantaneous flight speed of the pelicans is relatively constant, at approximately 35 km/hour (22 mph). However, two factors should be considered in interpreting these results:

- The instantaneous flight speed (as recorded by the GPS device) is affected by the fine-scale flight behavior of the individual pelicans. In other words, low flight speeds may occur if the timing of the GPS signal coincides with pelicans taking off, landing, soaring, or undertaking severe directional changes in flight. Field observations suggest that these stages of flight occur often in the field. For example, loafing pelicans often engage in short duration flights that will likely register as low-speed flights.
- The instantaneous flight speed measurements refer to ground speeds—the distance covered per unit time measured relative to the surface of the earth. In reality, the flight speed of pelicans (or any bird) is dictated by air speed—the relative speed of the bird relative to the air passing over the wing.

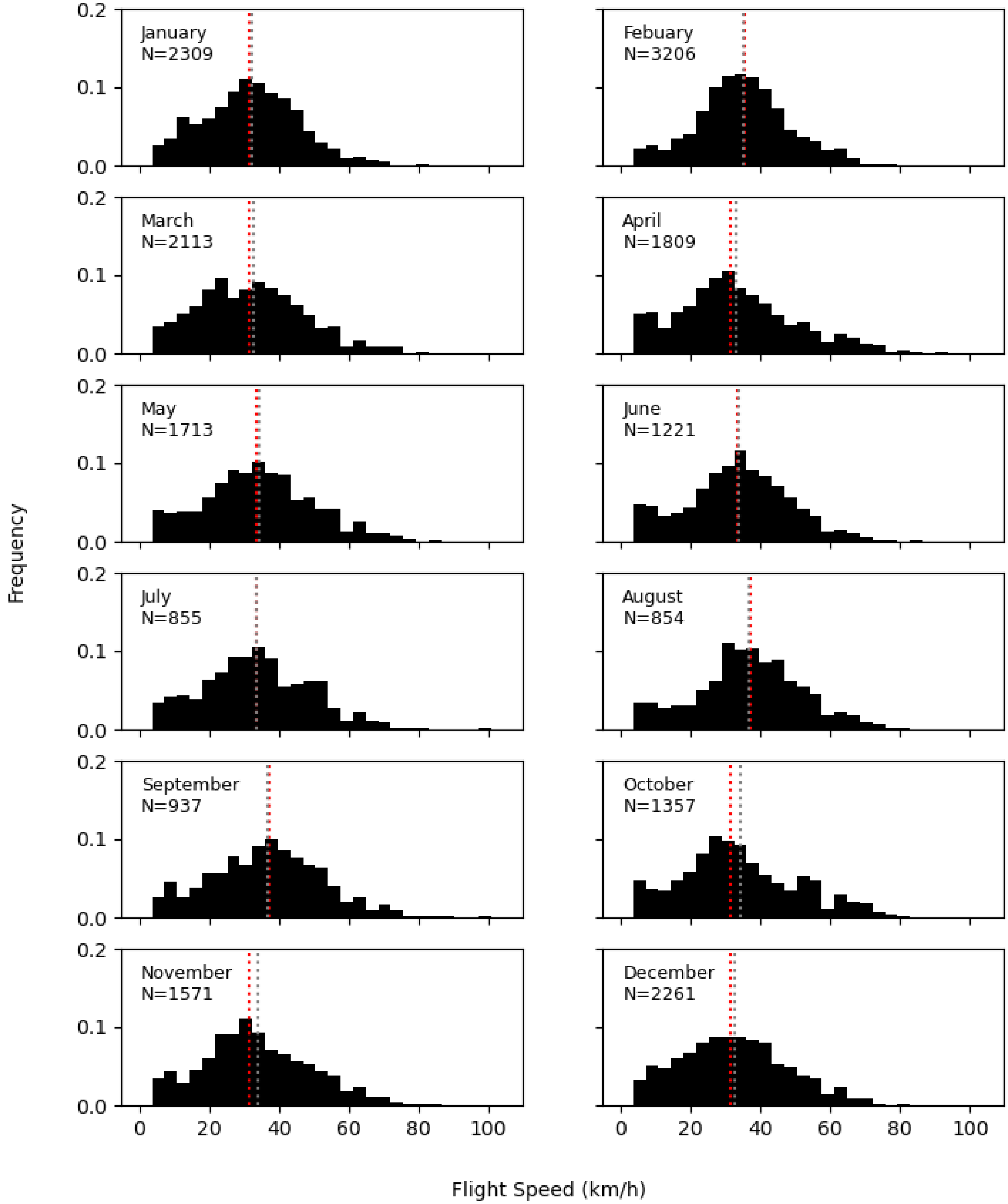


Figure 36. Frequency Distributions of Flight Speed Directly Recorded by the GPS Devices. The red and gray dashed lines show median and mean values, respectively.

Figure 37 shows the distribution of pelican flight altitudes collected by the GPS devices during the study. These altitudinal measurements are made relative to GPS satellites, and the research team noted considerable error in the raw altitudinal data measured by the devices. For example, some measurements indicated altitudes greater than 8 km (5 miles), despite the fact that they were estimated based on multiple GPS satellite fixes.[4] Nonetheless, the consistency of altitudinal measurements provides corroborating evidence to support the preference of brown pelicans to fly at relatively low altitudes.

[4] GPS devices use measurements called horizontal and vertical dilution of precision (HDOP and VDOP, respectively) to determine the measurement error of horizontal and vertical positioning. This measurement is based on the number and position of GPS satellites available. The GPS devices used in this study occasionally reported unreasonable altitudinal measurement even though the VDOP measurements signified accurate readings.

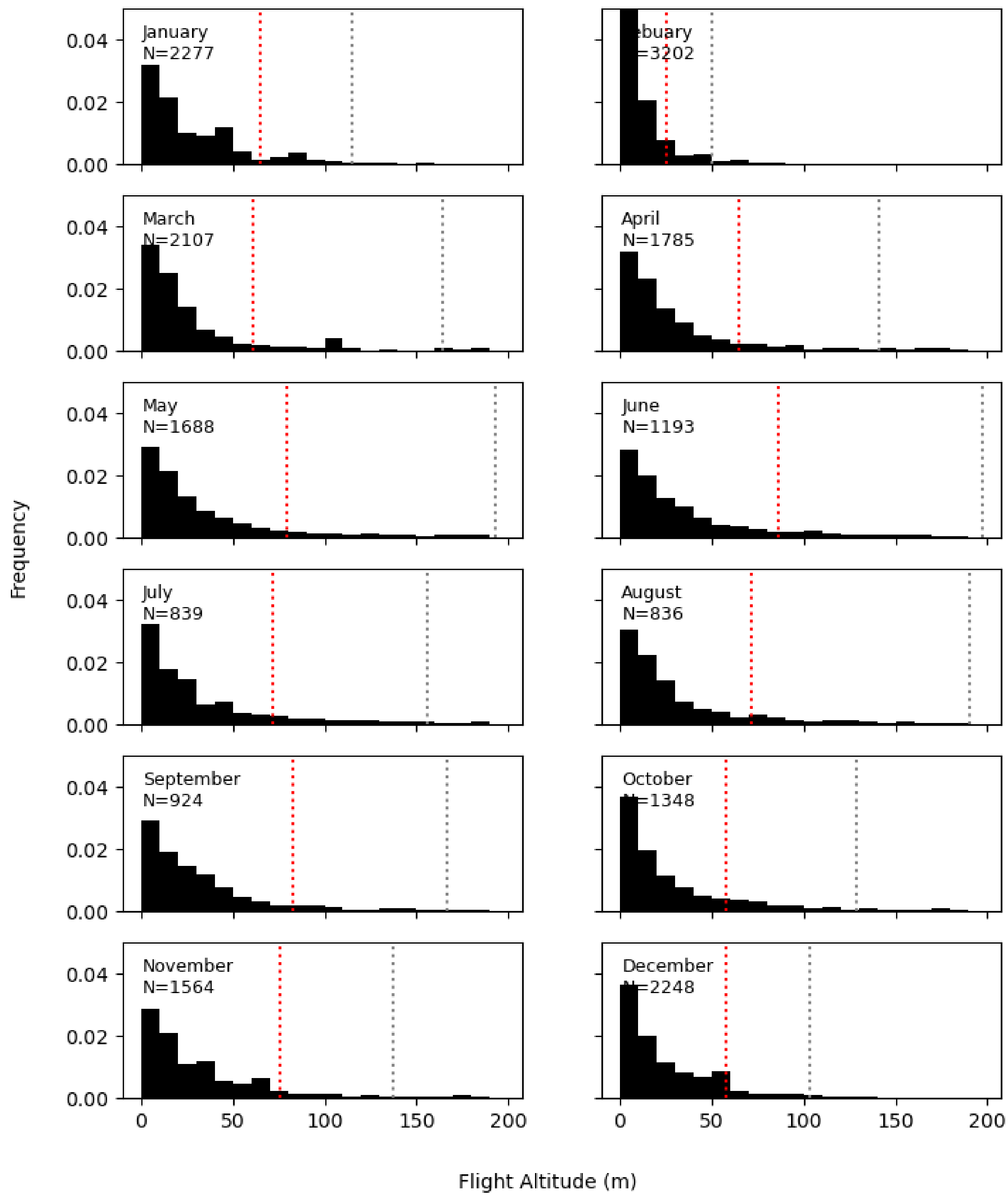


Figure 37. Frequency Distributions of Flight Altitude Recorded by GPS Devices. The red and gray lines show median and mean values, respectively.

CONCLUSIONS

This chapter detailed the daily and seasonal movements of 35 brown pelicans that overwinter in the BGWC of South Texas. Each pelican was fitted with a GPS device that recorded locations (longitude and latitude) at approximately 15- to 30-minute intervals, as well as data such as movement speed and altitude. The GPS data collected from the study provide essential information on the location of key roost and loafing sites within the region, major movement (flight) trajectories, and the seasonal migration of BGWC pelicans.

Based on detailed analysis of the GPS data, the daily movement of pelicans in the study area consists of a daily cycle of movements to and from one of several key roost sites, interspersed by visits to a larger number of preferred loafing sites in the region. Pelicans typically return to the same roost site on consecutive evenings. Although movement from and to roost sites generally coincides with sunset or sunrise, pelicans also remain active before sunrise and after sunset. Major roost sites in the region are larger islands (protected from inundation by tides). Roosting may also occur on protected docks and occasionally on sandbanks temporarily exposed by low tides.

Throughout daylight hours, BGWC pelicans successively visit a number of loafing sites in the region. Although pelicans use a large number of distinct loafing sites (especially relative to roost sites), the most popular loafing sites are at the marinas in Port Isabel and marinas on the Laguna Madre side of South Padre Island. The shrimp basin situated at the western end of the Brownsville Ship Channel is also used for loafing. Loafing also occurs frequently on previously identified roost sites on the Laguna Madre spoil islands and in the Bahía Grande. Pelicans typically remain at a loafing site between one and six hours before moving to a new location.

The research team found that the cumulative mean displacement (or distance moved per day) by the tracked pelicans was consistent, at approximately 50 miles (80 km) per day, irrespective of the month. Furthermore, the research team found no clear difference between the daily distance traveled on days when a cold front entered the area versus normal (non-cold front) days. Similarly, no correlation was found between the pelicans' daily movement and the minimum daily temperatures.

Finally, the main pelican flight paths identified within the study area include the Brownsville Ship Channel, the Gulf Coast of South Padre Island and Boca Chica, and the Laguna Madre. In the context of SH 48 crossings, the Brownsville Ship Channel appears to represent an especially important movement corridor because it links important roosts sites in the Bahía Grande to other local roost sites—especially the spoil islands in the Laguna Madre. If the GPS data are representative of the entire BGWC pelican population, the lack of direct "as the crow flies" movements from Bahía Grande roosts suggests that virtually all pelicans will enter and leave the Bahía Grande by crossing SH 48.

CHAPTER 3. MIGRATION AND SURVIVAL OF BROWN PELICANS USING MARK-RESIGHT METHODS

This chapter describes a mark-resight experiment and subsequent data analysis designed to infer survival and migration information for pelicans in the BGWC study area.

Mark-resight methods provide a way of estimating key life history parameters for a species of interest, especially birds. Mark-resight experiments involve capturing a sample of a population and marking them in some way (for example with bands) so that individuals can be readily identified in the field. The marked individuals are then released, and surveys are undertaken to resight the marked individuals. The resulting resight data consist of a history of sightings (resights) associated with pelicans banded during the study. These resight data can be analyzed to infer population- and individual-level ecological parameters of interest such as survival and seasonal movement (e.g., MacClintock and White 2012).

The mark-resight study for brown pelicans in the BGWC was initiated in 2017 and roughly coincided with the GPS study described in the previous chapter. In contrast to the GPS study, the mark-resight study was less invasive, cheaper to undertake, and captured data from a larger sample of the pelicans in the BGWC population. Although the resulting mark-resight data are coarser in resolution than the GPS data, the rationale is that larger sample sizes will help infer key life history processes that are more representative of the entire BGWC population (rather than to the 35 adult pelicans sampled during the GPS study).

The research team collected and analyzed mark-resight data to address the following questions:

1. What are the typical survival rates of pelicans in the BGWC?
2. How many pelicans migrate to and from the BGWC to summer breeding grounds each year (seasonal movements)?
3. When does the BGWC pelican population undertake this seasonal migration?

METHODS AND RESULTS

Between November 2017 and February 2019, the research team captured and banded 310 brown pelicans in and adjacent to the BGWC study area. Bands were maroon leg bands displaying three white alphanumeric characters. Between November 2017 and March 2020, the research team undertook regular resight surveys with the purpose of identifying banded pelicans in the study area. The regular resight surveys were conducted at regular survey locations. At each location, field researchers spent a fixed period counting pelicans present at that location. Data from the regular resight surveys were also supplemented with opportunistic resights made during other fieldwork and by data submitted to the U.S. Geological Survey Bird Banding Laboratory.

All resighted pelicans were recorded, along with the date, location (longitude and latitude), and as much uniquely identifiable information as was possible. Typically, if a band could be seen on a pelican using the naked eye or low-powered binoculars, the full three-digit alphanumeric code could be discerned with a 10 to 30 times magnification binocular or spotting scope.

Figure 38 shows the cumulative number of pelicans banded during the study, and the cumulative number of resights (from all sources). Figure 39 shows the pattern of resights obtained for each pelican. In Figure 39, each row of the figure represents a uniquely identifiable pelican, and the date at which the pelican was caught and banded is shown with the leftmost square on that row. For data analysis, resights were aggregated to 5-day sample periods (because field surveys were not conducted each day of the study, this step was included to standardize resight effort). Subsequent resights (following capture) are shown by black squares.

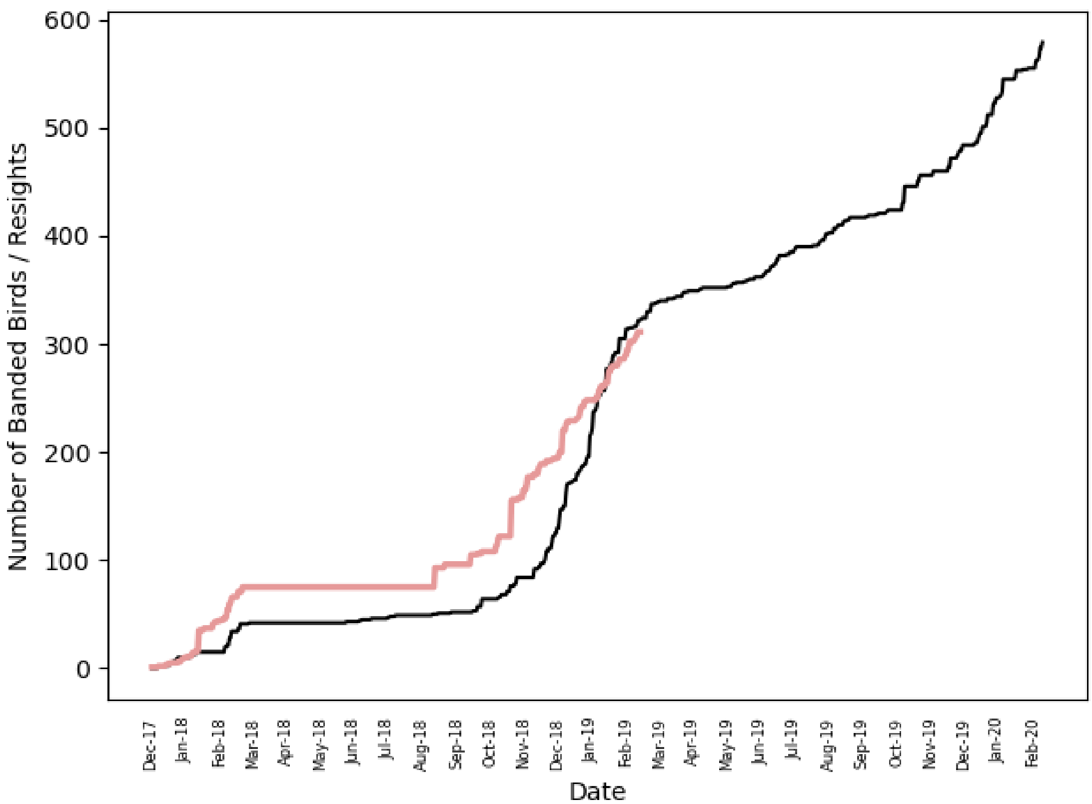


Figure 38. Cumulative Captures (red line) and Resights (black line) of Brown Pelicans during the Mark-Resight Study.

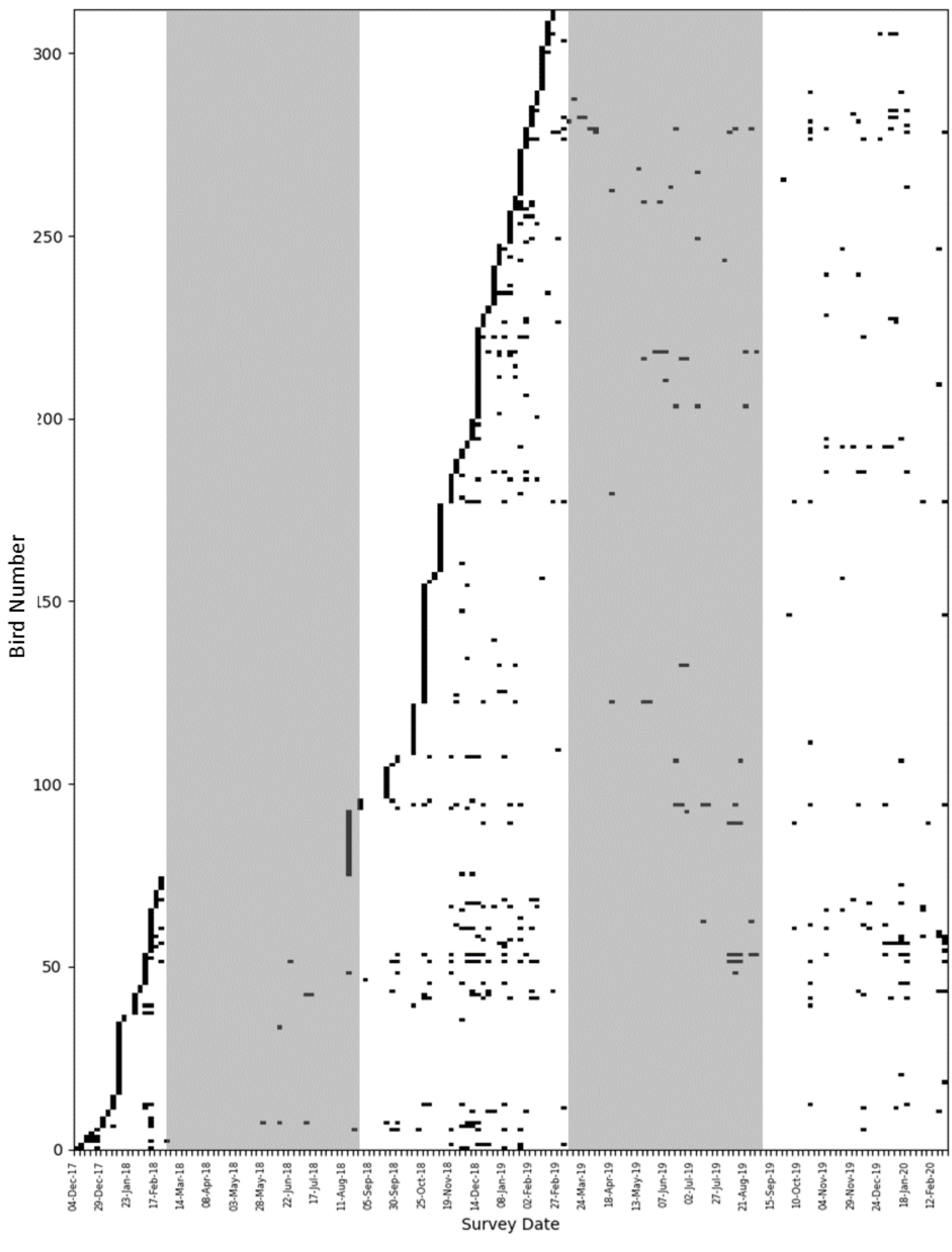


Figure 39. Capture History (the date that pelicans were banded) and Resight Data for Brown Pelicans Banded during the Study. Each row of data (*y*-axis) represents a single pelican (initial banding date and subsequent resights). Approximate spring-summer periods (March to September) are shown as shaded regions.

Cormack-Jolly-Seber Mark-Resight Analysis

Figure 39 illustrates the statistical and ecological challenges associated with deriving useful life history parameters from mark-resight data. Essentially, mark-resight surveys yield data that describe whether a pelican was sighted or not during a resight survey period. They are useful when it is practically not possible to track all pelicans directly and completely within a population.

Mark-resight methods assume that the probability of a pelican being resighted depends on two factors: (1) whether it was alive and present in the general study area, and (2) whether it was detected during location-specific sample surveys. For example, it is possible that a pelican was present in the study area but was not detected during a sample interval. In this case, one of two conclusions can be made about the status of the pelican at that sample interval: the pelican has died, or the pelican is alive but was undetected. In the latter case, any resights in subsequent surveys would confirm that the pelican was alive during previous sample intervals during which it was not resighted.

Fundamentally, the mark-resight analysis uses a complete history of resights of individual pelicans to simultaneously estimate two key parameters: the probability of a pelican (or other animal) surviving between sample intervals (S), and the resight probability (P) of any banded pelican during location and time-constrained resight surveys.

The Cormack-Jolly-Seber (CJS) model is one of the most popular ways to analyze mark-resight data. The CJS model estimates two parameters from mark-resight data: apparent survival (Phi) and P. Both parameters (Phi and P) are defined by the sample period used in the study—so P represents the probability of a pelican being sighted during a sample interval *t*, and Phi is defined as the probability of survival between sample interval *t* and *t*+1. The term Phi is used because the CJS does not explicitly account for migration into or out of a closed population. Instead, Phi confounds migration and survival because pelicans that leave the area and do not return are impossible to observe and cannot be distinguished from pelicans that have actually died.

The standard CJS model uses maximum likelihood methods to fit best estimates of Phi and P to a sequence of binary resight data for each pelican through time and for each pelican in the population. Figure 39 provides a pictorial representation of mark-resight data prior to analysis. In simple terms, the CJS model assesses the likelihood of observing a particular sequence of sighting histories (sighted or not sighted) for each marked pelican over the course of a mark-resight experiment. Since resight histories of each pelican are independent, the goal is to find the parameter values for Phi and P that maximize the likelihood of observing the resight sequences for all pelican sightings (and non-sightings) in the sample of resights. To this end, parameters Phi and P represent population-level statistics—that is, they represent the average or typical life history responses of the studied population.

The standard CJS model can be extended to include covariates to address whether estimates of Phi and P differ between demographic classes (e.g., sex, age) or to investigate whether Phi or P vary through time (an approach that the researchers used in this study). When covariates are included in CJS, it is common to use a model competition approach to assess whether the addition of a covariate is statistically supported by the data. Model competition involves proposing multiple (competing) CJS models, each formulated with a different representation of how Phi and P are affected by covariates (such as sex, age, or time). Each model is then fit to the same resight data, and the statistical likelihoods (naïve goodness of fit) for each model are translated into an information criterion such as the Akaike Information Criterion (AIC). The purpose of the AIC is to assess the goodness of fit of a proposed model while also accounting for the complexity of the model (i.e., the number of parameters). The AIC provides a way of selecting the relative quality of a statistical model relative to competing models with different levels of complexity.

CJS Analysis of Brown Pelican Data

The TTI researchers used CJS models for an initial analysis of the brown pelican mark-resight data collected during this study. The CJS method was initially chosen because the method is implemented in a variety of software packages and programming libraries, which enabled the TTI researchers to efficiently explore the data before undertaking the analyses described in this chapter.[5] Following data exploration and guided by the seasonal migration patterns uncovered during the GPS study, the CJS models were formulated to illuminate survival and migratory life history processes. Specifically, the models were designed to explore changes in Phi and P over time and extrapolate the effects of these changes on survival and migration processes. The TTI researchers developed five competing CJS models to fit the data:

- Model 1—Constant P and constant Phi. This model assumes that Phi and P remain constant throughout the study. The model is essentially the standard CJS model (with only two parameters).
- Model 2—Phi is assumed to be constant, while the month of the year is used as a covariate for P. This model assumes that survival remains constant throughout the year, but P varies by month (resulting in 13 parameters—one Phi parameter and 12 P parameters).
- Model 3—P is assumed constant, while Phi varies by month. This model assumes that survival varies by month, but P remain constant throughout the year (resulting in 13 parameters).
- Model 4—Both Phi and P vary by month (resulting in 24 parameters).
- Model 5—Constant survival throughout the year. For P, two parameters were introduced to describe the timing of immigration and emigration (by month). Two P parameters—

[5] After some exploration of the data, the research team found that using the CJS models with demographic covariates did not yield useful results.

P_{summer} and P_{winter}—were formulated to represent P between these migration dates (resulting in five parameters—one for Phi and four representing P).

All CJS model analyses were performed using the RMark[6] library of R statistical software (version 3.6.0).

Testing Analyses Using Simulation Data

The unique design of the pelican mark-resight experiment dictates custom analyses. To support the analysis of the field data, the research team used simulated mark-resight data to ensure that all analyses provided statistically accurate and ecologically interpretable outputs.

The idea behind using simulated data is to generate (via simulation) a mark-resight data set that is similar to the one collected during field observations. These simulated data can then be used to test the statistical analyses that were custom designed for field data. Since, by definition, the simulated data were generated using known parameters (i.e., parameters chosen by a researcher), the technique provides a way of assessing whether the statistical analysis is theoretically and practically capable of back estimating the known parameters of the simulated data set. This step in the analysis process is useful to help build evidence that the custom statistical analyses developed for this study can provide useful and ecologically interpretable parameter estimates. Full methods for simulating the fates and resights of banded pelicans are provided in Appendix IV.

The parameters used to generate the simulated data detailed in this study are listed in Table 2. The simulated mark-resight data were generated for 300 banded birds over a two-and-a-half-year period (i.e., mimicking the sample size and duration of the field experiment).

Table 2. Parameters Used to Generate Simulated Mark-Resight Data.

Parameter	Symbol	Simulated Value
Survival probability or Apparent Survival probability[1]	S or Phi	0.99
Resight probability	P	0.05
Migration probability (proportion of the population that migrate)	M	0.9
Date of emigration	Emdate	March 1
Date of immigration	Imdate	October 1
Duration of emigration	Emduration	30 days
Duration of immigration	Imduration	30 days

[1] The data were generated assuming a closed population—thus, the use of survival probability.

[6] https://cran.r-project.org/web/packages/RMark/RMark.pdf

Results—CJS-Based Mark-Resight Estimators

Table 3 shows the results of the CJS model competition. A lower AIC indicates a better model. The models with the lowest AICs were Model 4 and Model 2. The next best model is a variant of Model 5—a model with an emigration month of March and an immigration month of September. Table 3 also lists some parametrizations of Model 5 that yield competitive model fits.

Table 3. Summary of Parameters and Best-Fit Metrics of CJS-Based Mark-Resight Methods. The shaded rows show the best fitting models.

Model	Parameter Phi		Parameter P		AIC	Number of Parameters
Model 1—Constant Phi and constant P	constant	0.986	Constant	0.032	3456.77	2
Model 2—Constant Phi, monthly P	constant	0.986	Jan	0.077	3231.44	13
			Feb	0.046		
			Mar	0.027		
			Apr	0.005		
			May	0.002		
			Jun	0.007		
			Jul	0.007		
			Aug	0.010		
			Sep	0.010		
			Oct	0.035		
			Nov	0.032		
			Dec	0.087		
Model 3—Monthly Phi and P	Jan	1.000	Constant	0.036	3407.45	13
	Feb	0.932				
	Mar	0.939				
	Apr	1.000				
	May	1.000				
	Jun	1.000				
	Jul	1.000				
	Aug	1.000				
	Sep	1.000				
	Oct	1.000				
	Nov	1.000				
	Dec	0.979				
Model 4—Monthly Phi and P	Jan	0.953	Jan	0.093	3213.30	24
	Feb	0.977	Feb	0.059		
	Mar	0.981	Mar	0.035		
	Apr	1.000	Apr	0.007		
	May	1.000	May	0.003		
	Jun	1.000	Jun	0.008		
	Jul	1.000	Jul	0.007		
	Aug	1.000	Aug	0.010		
	Sep	1.000	Sep	0.010		
	Oct	1.000	Oct	0.030		
	Nov	0.967	Nov	0.028		
	Dec	0.945	Dec	0.089		
Model 5—Psummer and Pwinter, March emigration, September immigration	constant	0.986	Pwinter	0.050	3273.19	4
	constant		Psummer	0.007		
Model 5—Psummer and Pwinter, February emigration, September immigration	constant	0.986	Pwinter	0.057	3282.27	4
	constant		Psummer	0.011		
Model 5—Psummer and Pwinter, February emigration, October immigration	constant	0.986	Pwinter	0.060	3294.16	4
	constant		Psummer	0.013		
Model 5—Psummer and Pwinter, February emigration, November immigration	constant	0.986	Pwinter	0.067	3292.11	4
	constant		Psummer	0.015		
Model 5—Psummer and Pwinter, March emigration, November immigration	constant	0.986	Pwinter	0.056	3307.79	4
	constant		Psummer	0.013		
Model 5—Psummer and Pwinter, February emigration, August immigration	constant	0.986	Pwinter	0.051	3316.46	4
	constant		Psummer	0.011		
Model 5—Psummer and Pwinter, March emigration, August immigration	constant	0.986	Pwinter	0.046	3301.17	4
	constant		Psummer	0.006		

Figure 40 shows estimates of Phi and P using Model 1 to 4 of the CJS analysis. Each panel of the figure shows estimates of Phi (top graph) and P (lower graph). Graphs with horizontal lines for Phi or P indicate that these parameters were held constant for that model. The dashed lines in each graph indicate 95 percent confidence level intervals for the estimated parameter value. The lower confidence intervals for Phi of Models 3 and 4 are large (so large that they cannot be shown on the graph), suggesting that the field data did not provide enough information to provide useful inferences for Phi.

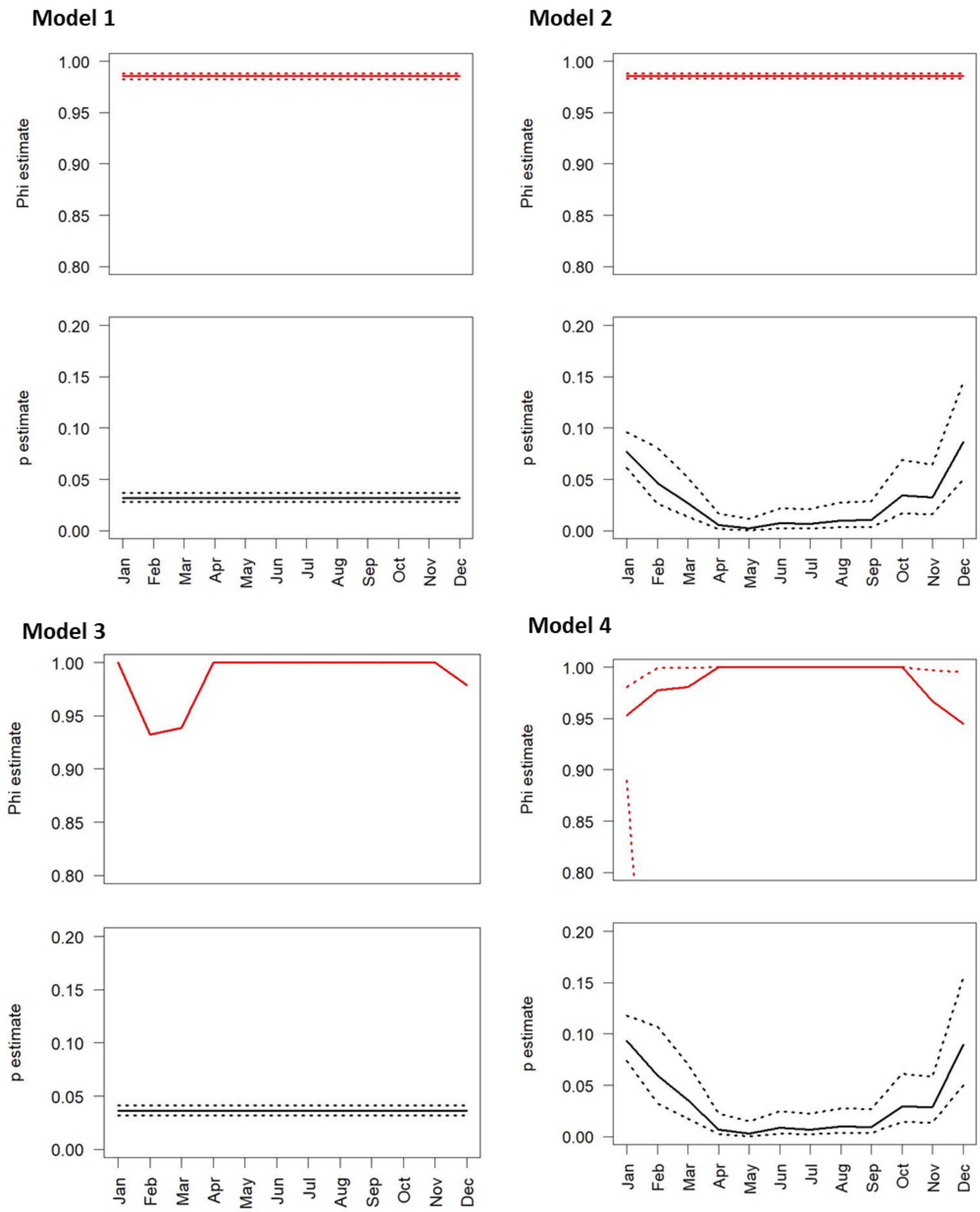


Figure 40. Monthly Phi and P Using Time-Dependent Mark-Resight Methods Estimated from Field Data. Each panel shows the estimated Phi (top graph in each panel) and p (lower graph in each panel) for Models 1 to 4. In all figures, the solid line shows the best estimate of the parameter (for a given month on the *x*-axis), while the dashed lines show 95-percent confidence intervals.

Figure 41 shows the results of fitting variants of Model 5 to the data. Panel A shows the month-dependent parameter estimates of P (in Model 5, survival was assumed constant through the year). The best fitting model estimated a major break in P in March, and another in September (i.e., two distinct P's representing periods from March to September and October to February). Panel B shows the result of fitting Model 5 using different values for the resight breakpoint. The shaded contours show areas of equal maximum likelihood. The plot suggests that resight breakpoints of March to February and September to November also result in likelihoods close to the best fitting model. These variants of Model 5 are also listed in Table 3.

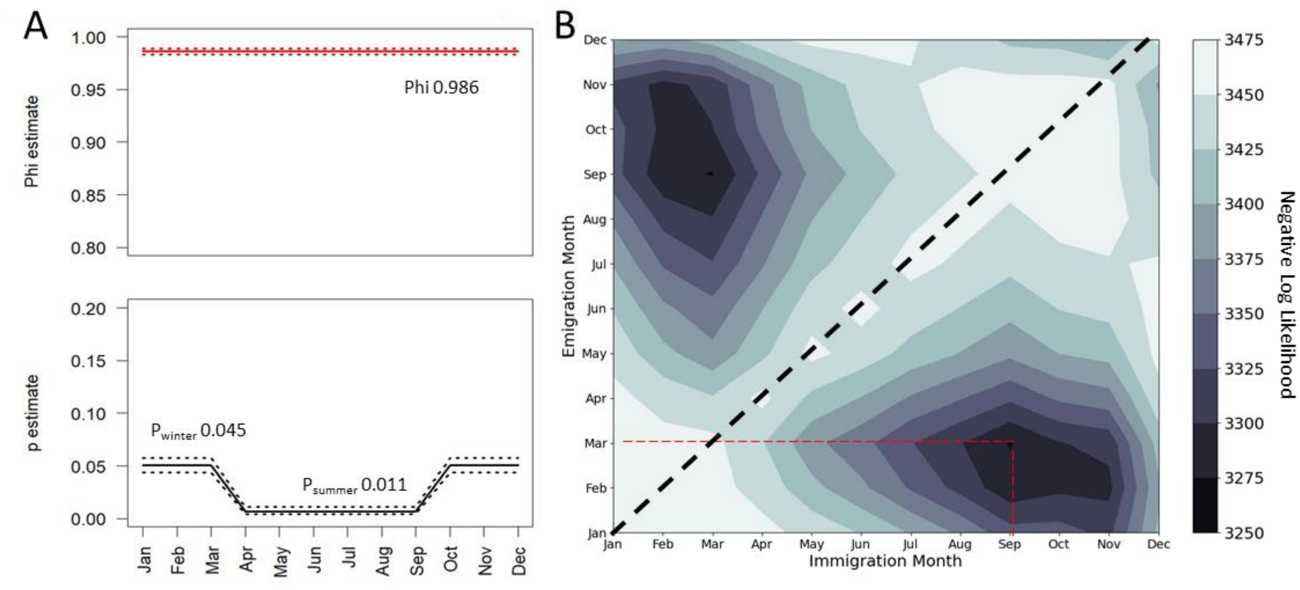


Figure 41. Best fitting Estimates of Phi, P_{summer}, P_{winter}, and Immigration and Emigration Months Using Simple Mark-Resight Method with Migration, Estimated from Field Data. Panel A shows best estimates of Phi (constant for each month), and P_{summer} and P_{winter} delineated by emigration and immigration dates (March and September, respectively). Panel B shows the statistical likelihood of the P_{summer} and P_{winter} mark-resight model assuming different emigration and immigration dates. The darker regions show areas of lowest negative likelihood (models that best fit the data). The black dashed line indicates that the likelihood surface is symmetrical if emigration and immigration dates are switched.[7] The red dashed line shows the best fitting model is for an emigration date of March and an immigration date of September (corresponding to the monthly specific Phi and P estimates shown in Panel A). Note that the likelihood is similar for any immigration dates between September to November.

CJS Model Results—Simulated Data

The TTI researchers tested the ability of the five CJS models to accurately model mark-resight data generated by simulation. The rationale of this analysis was to ensure that the models (and

[7] Note that the graph is symmetrical because switching immigration and emigration dates and P_{summer} and P_{winter} results in essentially the same mark-resight model.

statistical methods used to fit the models) work. This assessment was made by comparing the parameters estimated using the CJS models with the parameters that were used to generate a simulated mark-resight data set (Table 2).

Figure 42 shows the parameter estimates of Models 1 to 4 when fitted to the simulated mark-resight data. Figure 42 is directly analogous to Figure 40, which shows the same parameter estimates derived from field data. All models (Models 1–4) fitted to the simulated data capture estimates of Phi well (the true value for Phi was 0.99). In Model 1, estimates of P are lower than the value used to generate the simulated resight data (0.05). Model 2 shows an accurate estimate for Phi, but a significant decrease in P during the summer months, coinciding with the period that birds were simulated to move away from the study area (to summer breeding sites—March to October). Model 4 shows a similar response to the resight estimate. Time (month)-dependent estimates of Phi (Models 3 and 4) both show a decrease in Phi that coincides with the simulation parameter that dictates emigration from the study area.

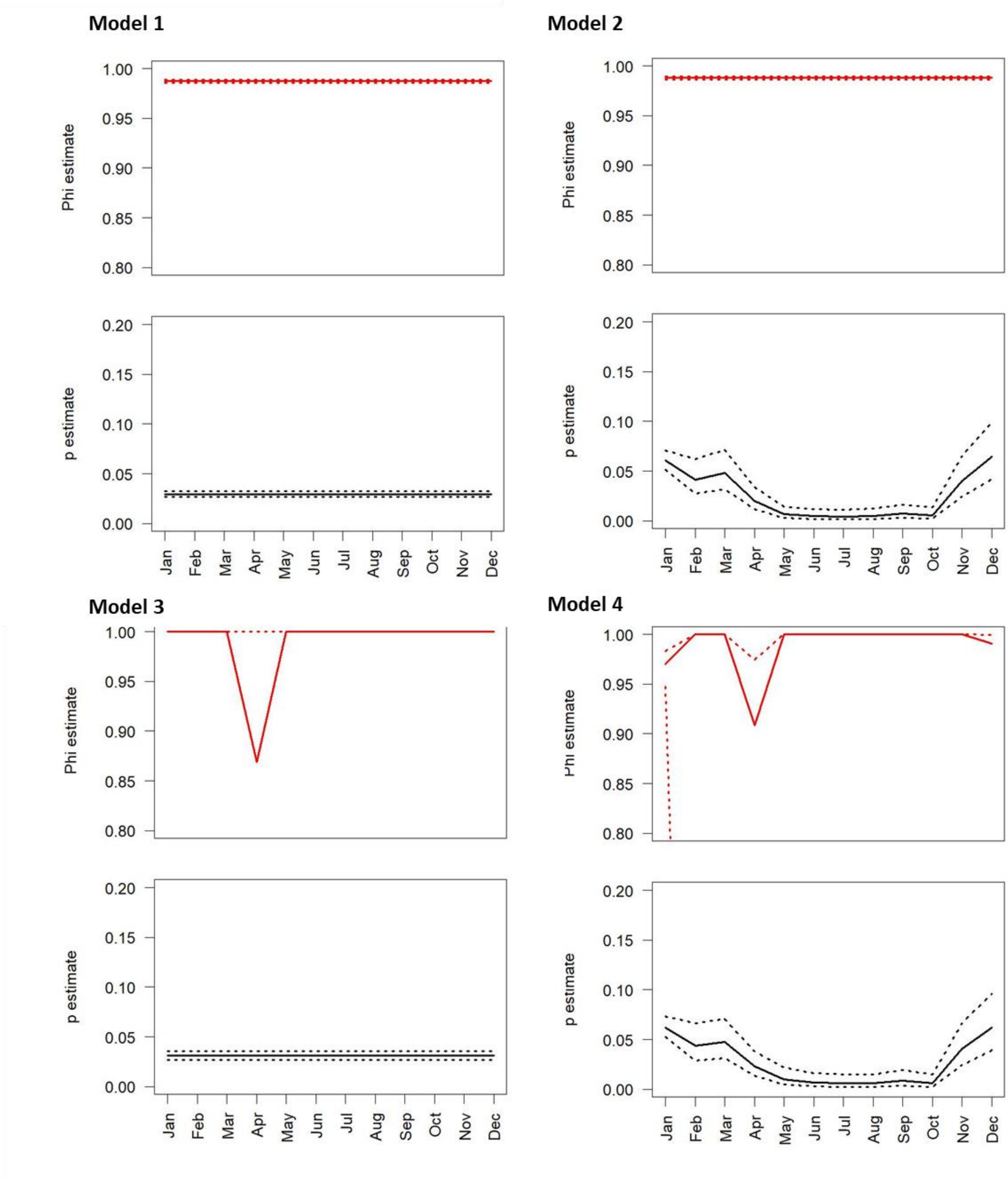


Figure 42. Monthly Phi and P Using Time-Dependent Mark-Resight Methods Estimated from Simulated Data. Each panel shows the estimated Phi (top graph in each panel) and P (lower graph in each panel) for Models 1 to 4. In all figures, the solid line shows the best estimate of the parameter (for a given month on the *x*-axis), while the dashed lines show 95-percent confidence intervals.

Figure 43 shows the results of fitting Model 5 to simulated data (analogous to Figure 41, which shows the same information for the field data). Like Models 2 and 4, Model 5 illustrates a drop in P that occurs during the period migratory birds in the simulation were outside the (virtual) study area. Panel B of Figure 43 shows the goodness of fit attained from Model 5 using different estimates for the breakpoint between P's. The simulation defined a migratory period between March and September, with migration occurring over a 1-month period. The breakpoints of the best fitting model are February and September (which correspond closely to the migration periods defined in the simulation of March and September). Although the same graph derived from the field data shows a relatively large region of similar likelihoods for breakpoints defined by adjacent months, the results from the simulated data show a relatively well-defined region of the likelihood for these breakpoint parameters (the simulated data modeled immigration and emigration occurring over one month).

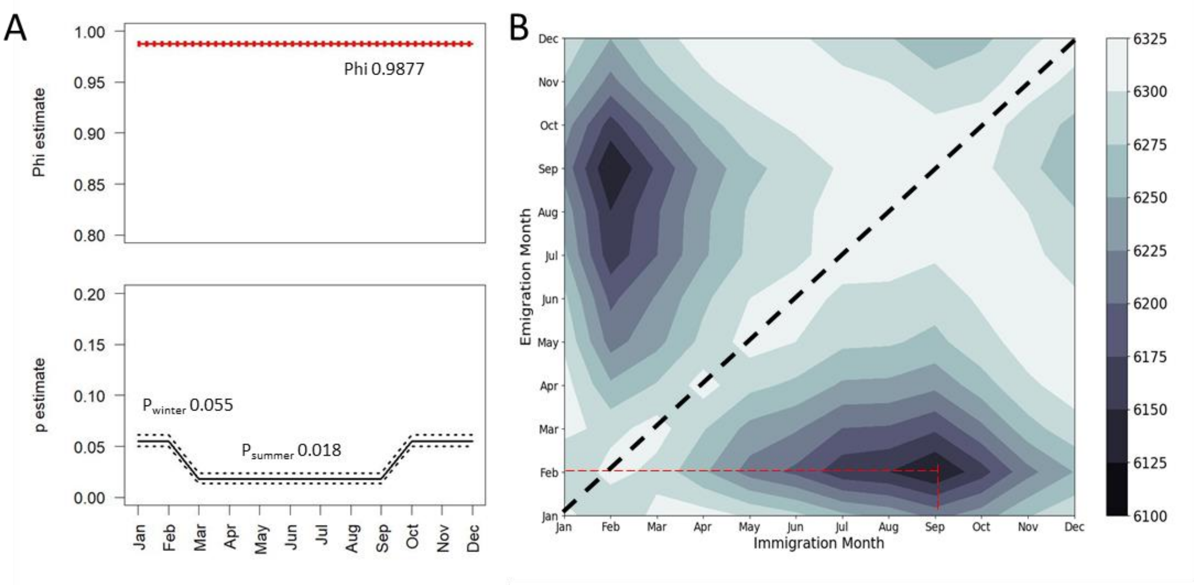


Figure 43. Best Fitting Estimates of Phi, P_{summer}, P_{winter}, and Immigration and Emigration Months Using Simple Mark-Resight Method with Migration, Estimated from Simulated Data. Panel A shows best estimates of Phi (constant for each month), and P_{summer} and P_{winter} delineated by emigration and immigration dates (February and September, respectively). Panel B shows the statistical likelihood of the P_{summer} and P_{winter} mark-resight model assuming different emigration and immigration dates. The darker regions show areas of lowest negative likelihood (models that best fit the data). The black dashed line indicates that the likelihood surface is symmetrical if emigration and immigration dates are switched.[8] The red dashed line shows the best fitting model is for an emigration date of February and an immigration date of September (corresponding to the monthly specific Phi and P estimates shown in Panel A).

[8] Note that the graph is symmetrical because switching immigration and emigration dates, and P_{summer} and P_{winter} results in essentially the same mark-resight model.

Inferring Migration Processes

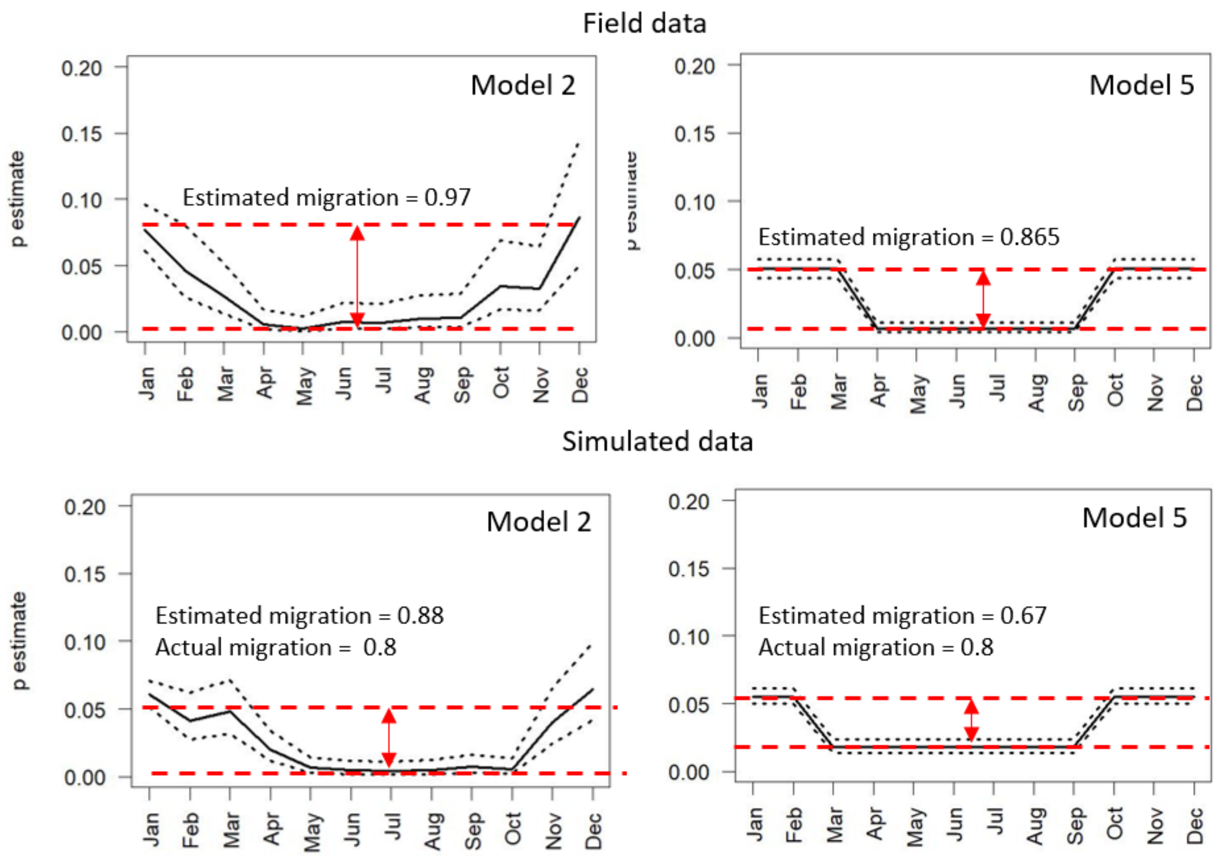
As mentioned previously, standard CJS models do not explicitly model migration. However, the model competition approach outlined above was designed to provide some information about these processes. One reason why the Phi estimate in CJS is called apparent survival rather than (true) survival is that the standard CJS model is unable to distinguish between the two real-life states of *dead* and *outside the study area*. In other words, if a pelican migrates from the study area, it is classified as dead by the model. Extending this logic, the extent to which migration affects survival depends in large part on whether migrating pelicans return to the study area or whether they never return (either because they remain alive but permanently outside the study area, or actually die outside the study area). In other words, if no resight data are collected outside the study area (as is the case for the CJS analyses shown above), then the model is unable to differentiate between pelicans that permanently migrate from the study area and pelicans that die within the study area.

However, the following behaviors of CJS models do allow results to be used to approximately estimate migration. For example:

- If one-way emigration occurs from the study area and some of these pelicans never re-enter the study area (either because of permanent migration or because they die), then migration influences the estimate of true survival rates.
- If migration occurs but all pelicans return to the study area, then it will mostly affect estimates of resight probability.

In the case of the brown pelican study, the GPS study informs that migration outside of the BGWC study area does occur throughout the year, but most of these migrations are short in duration, temporary, and result in pelicans returning to the study area. The GPS also demonstrates that the most dominant migratory process is a seasonal migration to summer breeding grounds, with considerable evidence that most pelicans return following this migration. In theory then, this predominately seasonal migratory process should affect resight estimates. Specifically, the probability of resighting pelicans should decrease during this migratory period (while pelicans are at summer breeding grounds rather than within the study area) and should increase when the pelicans return to the study area. Furthermore, the reduction in resight probability over the year should contain some information about the proportion of pelicans that undergo these migrations.

Figure 44 shows the calculations necessary to infer migration processes from the CJS models using both field and simulated data. The left-hand panels show resight probabilities using Model 2 results, and the right-hand panel shows results using Model 5. The proportion of pelicans migrating is estimated as the representative values for P during the summer period relative to the winter period (i.e., $1 - P_{summer}/P_{winter}$).



Field data
Model 2
Estimated migration = 0.97
p estimate
0.20
0.15
0.10
0.05
0.00
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Model 5
Estimated migration = 0.865
Simulated data
Model 2
Estimated migration = 0.88
Actual migration = 0.8
Model 5
Estimated migration = 0.67
Actual migration = 0.8

Figure 44

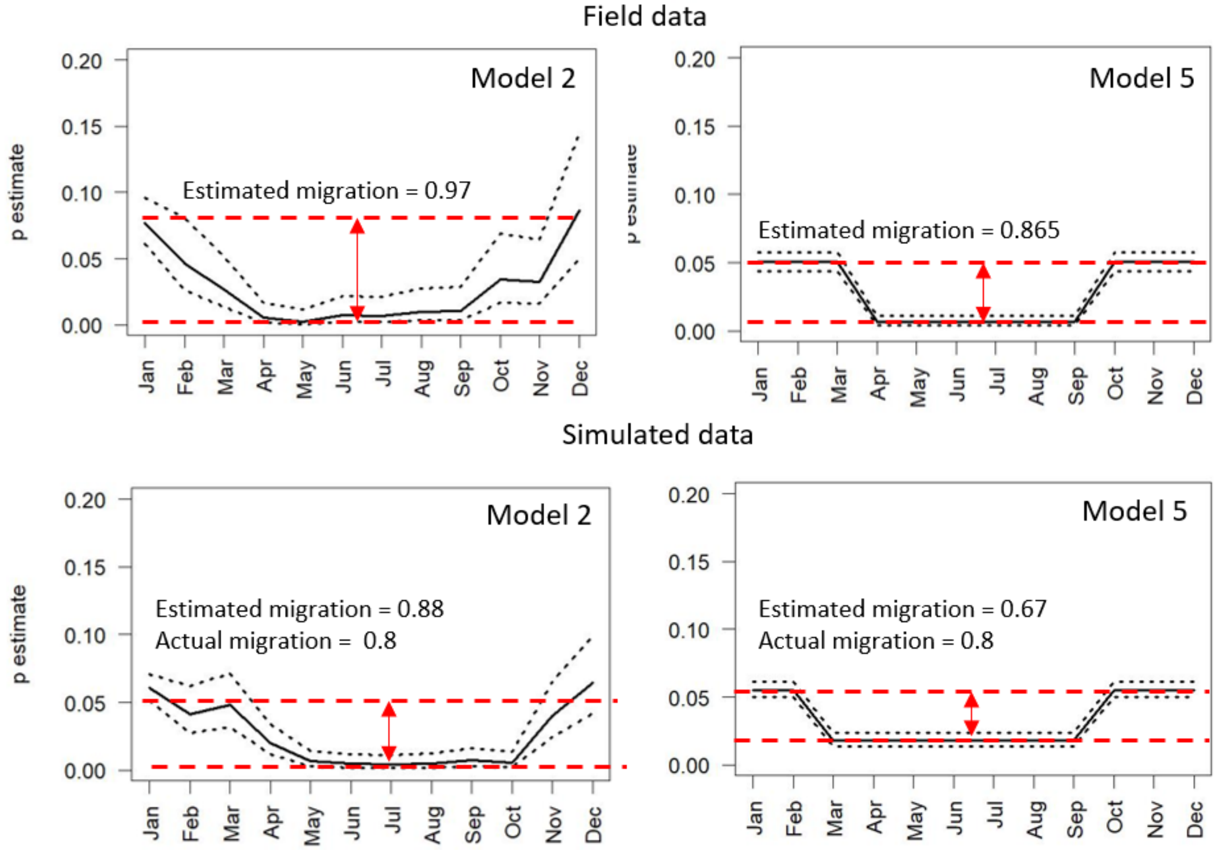


Figure 44. Estimates of the Proportion of Brown Pelicans Undertaking Seasonal Migration Using Simple Mark-Resight Models. The top graphs illustrate calculations using results from field data. The lower graphs show results from simulated data. The left-hand graphs show results from Model2, and the right-hand graph show results using Model 5. The dashed red lines show upper and lower resight probabilities estimated using the best fitting mark-resight models. The proportional difference between these values provides a rough indication of the number of pelicans migrating to and from the study region each year.

The field data suggest that between 87 to 97 percent of brown pelicans undergo round-trip seasonal migrations—typically emigrating from the study area between January and March and returning between September and December. The simulated data confirm the validity of using this method on field data, although the estimates should be considered approximate.[9]

The difference between Model 2 and Model 5 is the way the migration process is modeled. Model 2 uses a different value of Phi for each month and suggests that migratory processes occur throughout late winter and early spring, with immigration occurring over a similar duration in fall and early winter. Model 5 was designed to represent a shorter (month-long) migratory period for both emigration and immigration. Model 5 suggests peak migration occurs in February, and

[9] The research team undertook further exploration of this method by running the model using simulated data with various migratory parameters.

peak immigration occurs in September. Comparison between the two model results is useful because migration estimates from Model 2 may be affected by uncertainty in monthly estimates of P (note the wider confidence intervals for Model 2 estimates). On the other hand, Model 5's parameterization of resights is more constrained and assumes that migration occurs over a relatively short month-long period. Since the AIC results show that these added constraints statistically affect the ability of the model to fit the data, the research team concludes that the field data suggest that migration (emigration and immigration) typically occurs over greater than one month and possibly occurs continually throughout the late winter-early spring (emigration) and fall-early winter (immigration).

Another key feature of parameters derived from both the field and simulated data is the temporary reduction in survival that occurs in Models 3 and 4. In the simulated data, this temporary reduction occurs within the same month that emigration is simulated. According to the theory presented above, it corresponds to the reduction in survival that may be caused by the pelicans that emigrate from the study area (real or virtual), but that never return (i.e., die outside the study area).

Hidden Markov Model Analysis of Mark-Resight Data

The CJS analysis presented in the previous section provides a useful method to infer key brown pelican survival and migration life history parameters. However, CJS models do not explicitly represent migration. Furthermore, while it is possible to modify the standard CJS model to incorporate migration, the statistical methods required to do so become unwieldy. In this section, the research team introduces another method of modeling resight data—the Hidden Markov model (HMM). Hidden Markov models are less frequently used to model mark-resight data. However, they provide a way of modeling complex life history processes and benefit from being relatively transparent and easy to implement.

Hidden Markov models are a class of statistical models that can be used to infer states and transitions of a Markov chain from observations that do not measure these states and transitions directly. In the context of the pelican mark-resight study, the fate of individual pelicans in the population can be described by a Markov chain that describes whether pelicans are in one of several states (e.g., alive and within the BGWC study area, alive and outside the BGWC study area, or dead). These states are linked by transition probabilities (e.g., probability of death, probability of migration). The fundamental problem posed by mark-resight analyses is that the states of the studied population cannot be observed directly. Instead, these hidden states must be inferred using data that can be observed directly (i.e., resights).

In Hidden Markov terms, the states of pelicans during the study (alive or dead and in or outside the study area) represent *hidden states*. Hidden Markov models provide a statistically robust method of inferring the hidden states and transitions of a Markov chain using incomplete observations (resight data). The data used to infer hidden layer processes are often called the observation layer.

Figure 45 illustrates a simplified version of the HMM used in this study. The hidden layer comprises three states (pelicans that are alive and within the study area, pelicans that are alive and outside the study area, and pelicans that are dead; Table 4). The solid arrows in Figure 45 illustrate ecological processes (transition probabilities) that link these states. For example, within any observational time period, any pelican may die (with a certain but as yet unknown probability), may remain alive (either within or outside of the study area), or may migrate to or from the study area). If a pelican dies, ecological intuition suggests that the pelican will remain in that state (i.e., it cannot come back to life).

The lower half of Figure 45 (circled states and dashed lines) represents the observation layer. It describes the processes that lead to the mark-resight observations observed in the field. The probability of a pelican within the study area being resighted during a sample interval is described by the parameter P (therefore the probability of it not being resighted *despite* being in the study area is 1-P). Assuming field observations are only made within the study area, there is zero probability of resighting a pelican that is either dead or alive and outside the study area (i.e., a probability of 1 that it is not observed during a sample period).

Given a proposed structure for the hidden and observational layers of a HMM, it is possible to use mark-resight data and HMM algorithms to estimate the transition probabilities that link the dynamics of pelicans between the hidden states (solid lines in Figure 45) and to infer the parameters of the observation layer (dashed lines in Figure 45) that lead to the pattern of resight observed during a study.

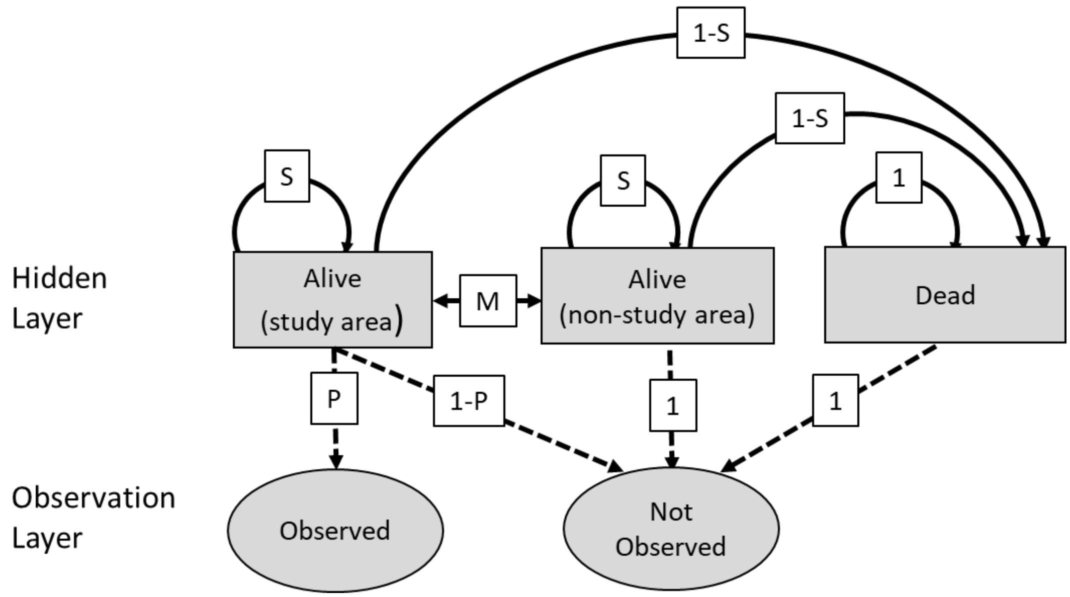


Figure 45. Conceptual Diagram of the HMM. The hidden layer (grayed square boxes) comprises the states of each pelican in the study: alive and within the study area, alive and outside the study area, and dead. The solid lines and attached boxes represent processes or transitions between hidden states: survival (S), mortality (1-S) and migration (M). The ellipses represent the observational layer: a pelican is observed (within the study area) or not observed during a sample period. The dashed arrows represent the processes that link the hidden layer states to the observations—i.e., probability of resight (P) or probability of no resight (1-P). The HMM provides a way of estimating the nonobservable (hidden) states of the pelicans and the transitions between these states using only the resight data of banded pelicans.

Table 4. Parameterization of the Hidden Layer Transition Matrix.

		End state (t+1)		
		Study Area (Alive)	**Non-Study Area (Alive)**	**Dead**
Begin state (t)	**Study Area (Alive)**	S*(1-M)	S*M	1-S
	Non-Study Area (Alive)	S*M	S	1-S
	Dead	0	0	1

Hidden Markov Model Analysis of Pelican Data

Figure 45 simplifies the important ecological processes involved in predicting the fates of pelicans assuming simple constant migration. However, the GPS study (and the previously described CJS analysis) showed that migration in the BGWC pelican population tends to be seasonal, pelicans tend to emigrate from the study area in spring (and move to the northern gulf over an extended summer period), and then consistently return in fall to overwinter in the region.

To account for this, the M parameter in Figure 45 and Table 4 was augmented with four parameters that describe the first date of emigration (Em_{date}), the first date of immigration (Im_{date}), and the duration of the immigration and emigration processes ($Im_{duration}$ and $Em_{duration}$). Note that these duration parameters are intended to describe the duration of population-level migration (i.e., the time taken, relative to the start of the migration process, for all migrating pelicans to complete their immigration or emigration process and return to or leave the study area). To accommodate migration durations of different durations, the migration parameter for each 5- day sample period was defined as:

$$log_e M_t = log_e(M)/Em_{duration} \quad \text{Equation 1}$$

For the emigration process, and:

$$log_e M_t = log_e(1)/Im_{duration} \quad \text{Equation 2}$$

For the immigration process. Equation 1 assumes that the number of pelicans emigrating during each model time interval was modeled as an exponential decay function (defined by the start and duration of the emigration process). Equation 2 assumes that all the pelicans that emigrated (minus those that died outside the study region) returned to the study region (modeled as a cumulative exponential function). Table 5 describes the full set of parameters used in the Hidden Markov analysis.

Table 5. Table of Parameters Estimated Using the HMM.

Parameter	Symbol	Notes
Survival of pelicans during the study.	S	Survival is assumed to be the same for pelicans within and outside the study area.
Probability of resighting pelicans in the study region.	P	Assumes that only resights within the study region are used in the model.
Proportion of population migrating.	M	Assumes that pelicans that emigrate from the study region return to the study region (if they survive).
Date of emigration (day of the year).	Em_{date}	The date that defines the start of the population-level emigration process (movement from the study area to summer range).
Duration of emigration in days.	$Em_{duration}$	The duration of the population-level emigration process that starts on the date described by Im_{date}.
Date of immigration (day of the year).	Im_{date}	The date that defines the start of the population-level immigration process (movement from summer range to study area).
Duration of immigration in days.	$Im_{duration}$	The length of the population-level emigration process that starts on the date described by Im_{date}.

Although HMMs have not been widely used to analyze mark-resight data, they are popular methods used in other data science domains. As such, several standard algorithms to estimate HMM processes are well described in the literature. The TTI researchers used the *forward algorithm* to assess the fit of a resight history to a specified set of HMM parameters. The forward algorithm assesses the likelihood of a resight history for each banded pelican and for each pelican in the sample (the forward algorithm is analogous to the multinomial likelihoods used in the CJS analyses described previously). The researchers used the Metropolis-Hastings algorithm to fit the most likely set of HMM parameters to the mark-resight data. The Metropolis-Hastings algorithm is a robust and tractable algorithm that can be used to derive the best fitting parameters for a specified model and data set. The Metropolis-Hastings algorithm usefully provides the best fitting parameters and confidence intervals for these parameters.

The TTI research team implemented all HMM methods using custom code developed using the Python programming language. The research team also used the simulated data described previously to test the ability of the HMM analysis (models and methods) to provide meaningful and interpretable life history parameter estimates.

Hidden Markov Model Results—Field Data

Figure 46 shows the brown pelican life history parameters estimated from field data. The HMM estimates a survival rate of 0.9875 per 5-day survey period (0.997 per day), and a probability of resight of 0.067 per survey period. The HMM estimates that approximately 80 percent of the banded pelicans undertook a seasonal migration. The first pelicans begin to emigrate from the region beginning close to February 1, and they immigrate back to the BGWC in late September. The HMM model predicts that the duration of both emigration and immigration lasts for around

70 days (i.e., the data suggest that the first pelicans to migrate start leaving/entering the area on the emigration/immigration date, and the last pelicans leave/enter 70 days later).

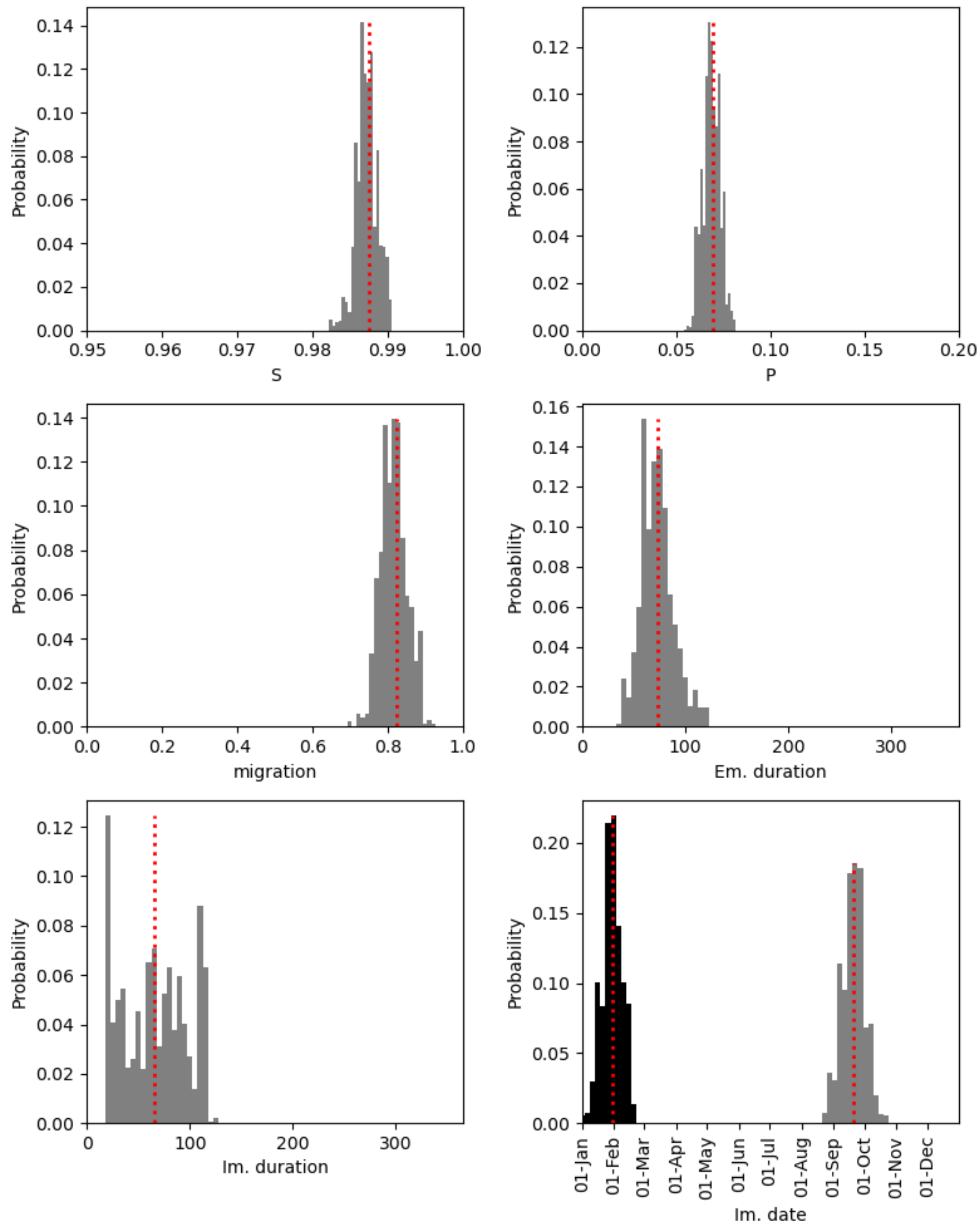


Figure 46. HMM Parameters Estimated Using Field Data. The histograms show the distribution of parameter estimates after convergence of the Metropolis-Hastings algorithm. The dashed red line shows the mean of these estimates. See Table 5 for a description of the parameters.

Figure 47 shows the fates of banded pelicans predicted by the parameters from the HMM. The upper plot includes only seasonal migration processes, while the lower plot includes survival and seasonal migration processes. In these plots, each line is generated by effectively reversing the hidden states and transitions of the HMM to predict the fates of banded pelicans (survival, and migration). Each line represents the fate of pelicans predicted using values for survival and migration parameters drawn from the distributions shown in Figure 46. Therefore, each line represents a plausible prediction for the fate of banded pelicans resighted during the study.

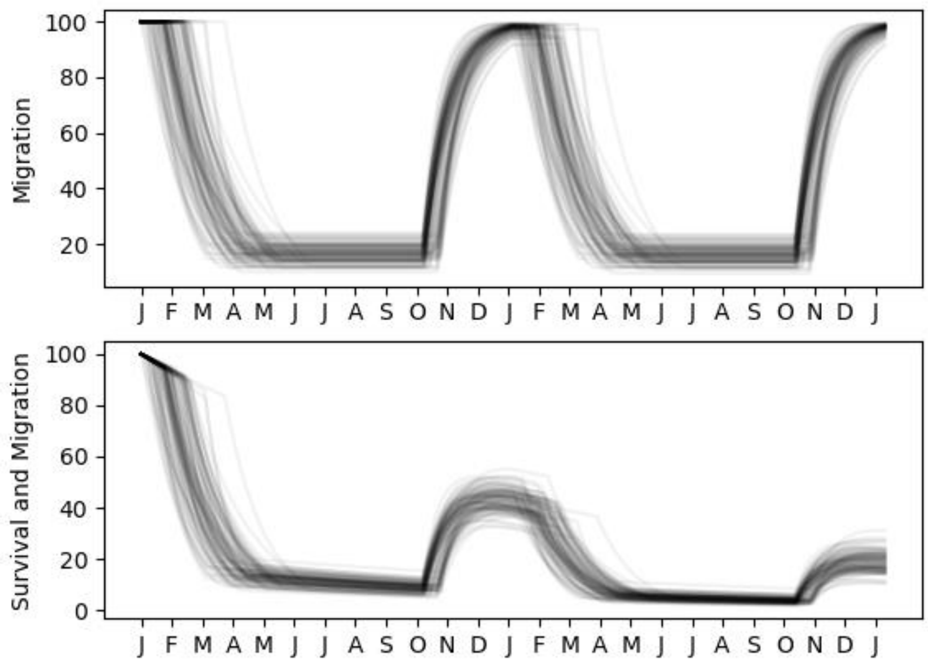


Figure 47. Simulated Band Fates through Time Using Parameters Derived from the HMM.

Figure 48 shows the convergence plot of the negative log likelihood for the Metropolis-Hastings algorithm that fitted the HMM to the field data. Figure 49 shows convergence plots for all parameters. The convergence plots provide useful information on the ability of the HMM to fit the field data—in other words, the ability of the algorithm to find a unique set of parameters. In this case, the plot provides evidence that the fitting algorithm converged, yielding a set of estimated parameters that provide meaningful statistical and ecological interpretation. A possible exception to this is the parameter ($Im_{duration}$), which does not converge to values that are as well defined as the other parameter. Because the strength of convergence and the variance of the distribution obtained from the Metropolis-Hastings algorithm (Figure 49) indicate how well the data support model parameters, it is reasonable to conclude that the field data provide the least informational support for this parameter relative to others. Nevertheless, the research team is confident that the estimated parameter $Im_{duration}$ does provide some useful and usable information on pelican life history.

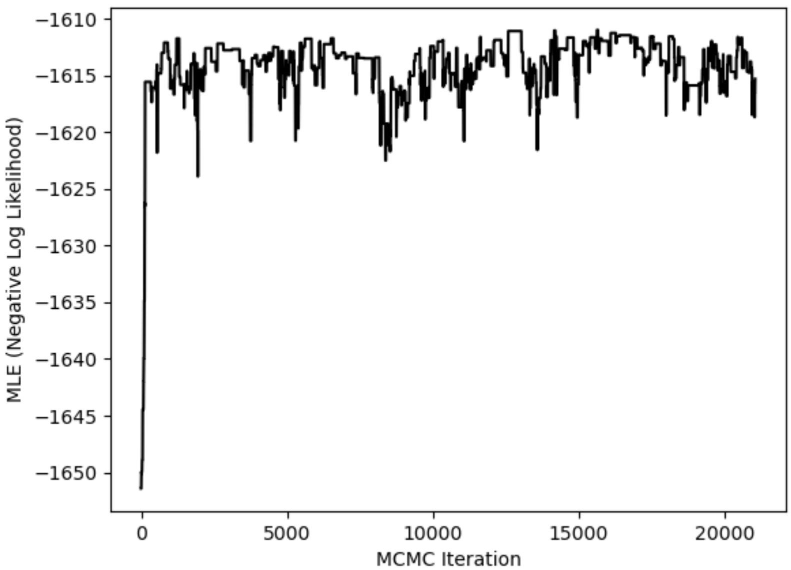


Figure 48. Convergence Plot of Model Fit for HMM and Metropolis-Hastings Algorithm Applied to Field Mark-Resight Data.

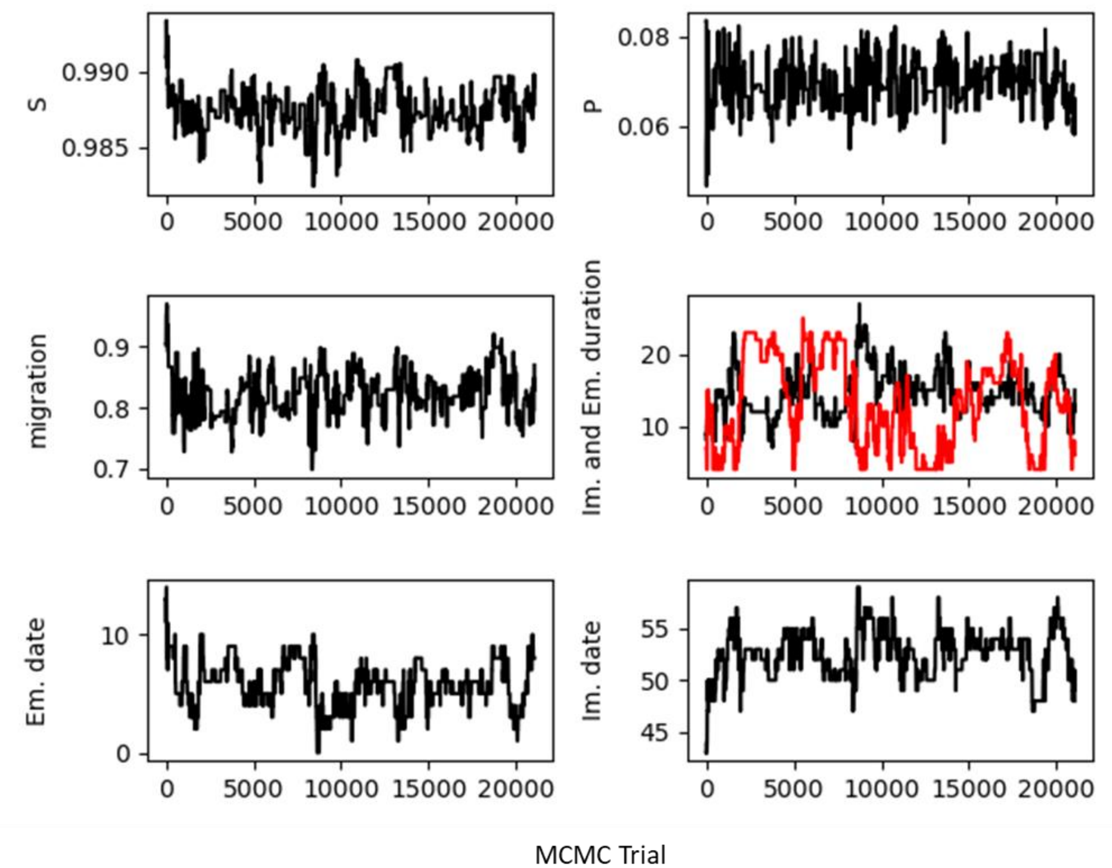


Figure 49. Convergence Plots for HMM Parameters Estimated from Field Mark-Resight Data.

Hidden Markov Model Results—Simulated Data

The research team used the HMM models and algorithms described above to test their ability to back estimate parameters of a simulated data set. Figure 50 shows the parameters estimated by the HMM when applied to the simulated mark-resight data. This figure is analogous to Figure 46, which provides the same results but for parameters estimated from field data. Because Figure 50 shows the estimates from simulated data (for which the parameters that generated the data are known), these true (known) parameters have been added to the plots to show the agreement between known and estimated parameters. The parameters $Im_{duration}$ and $Em_{duration}$ were estimated with the least accuracy by the HMM. For all other parameters, the HMM estimated the parameters that were used to generate synthetic data with considerable accuracy. Figure 51 and Figure 52 show the convergence plots of the HMM model. The plots show that the model converges well for all parameters.

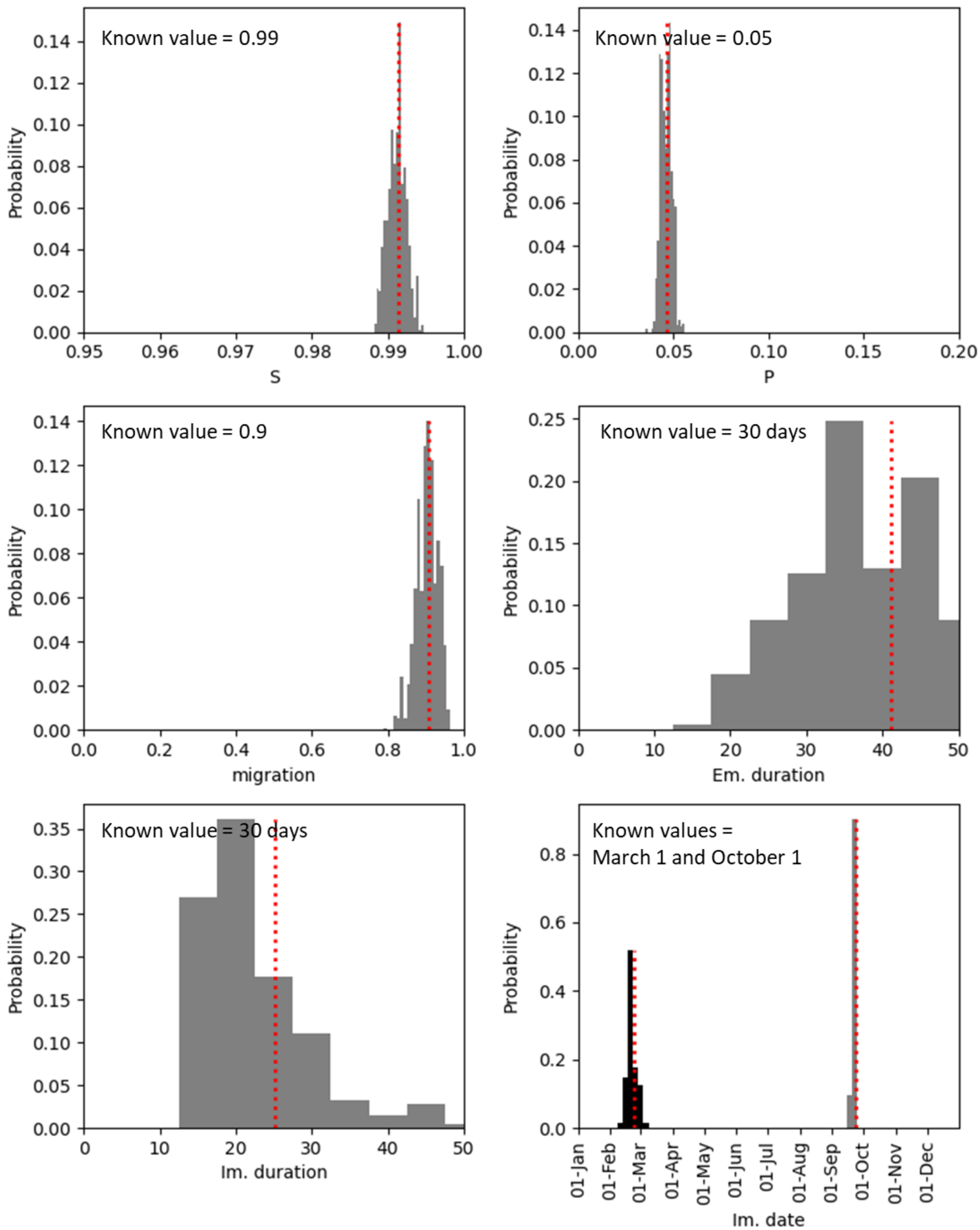


Figure 50. Hidden Markov Model Parameters Estimated Using Simulated Data. The histograms show the distribution of parameter estimates after convergence of the Metropolis-Hastings algorithm. The dashed red line shows the mean of these estimates. The known values correspond to the values of the parameters that were used to generate the simulated data.

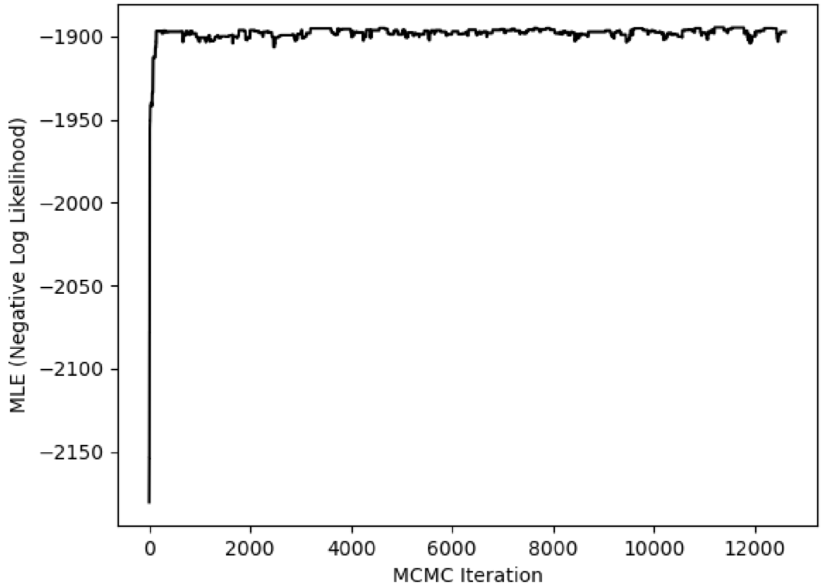


Figure 51. Convergence Plot of Model Fit for HMM and Metropolis-Hastings Algorithm Applied to Simulated Mark-Resight Data.

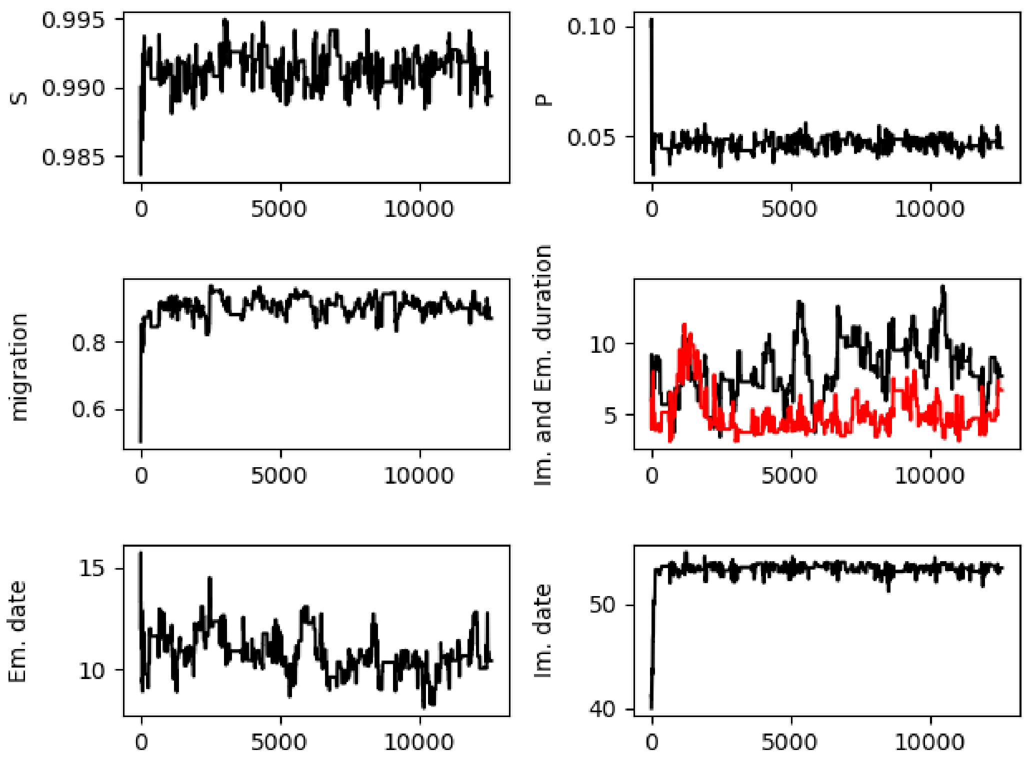


Figure 52. Convergence Plots for HMM Parameters Estimated from Simulated Mark-Resight Data.

DISCUSSION

This chapter provides details and results from the analysis of mark-resight data collected during this project. The mark-resight data were collected and analyzed to mine information on the survival and movement of brown pelicans in the BGWC. The study and analysis were designed to increase the information gathered from the GPS study described in Chapter 2. While the GPS study provides detailed, fine-scale movements of 35 pelicans (many of which provided limited information on seasonal movements), the mark-resight study provides information on a greater number of pelicans. Despite the inherent coarseness of these data, the analyses outlined in this chapter provide useful and robust information on the daily and seasonal movements of brown pelicans, which significantly adds to the information obtained from the GPS study.

Pelican Migration

The HMM mark-resight analyses suggest that approximately 80 percent of the pelicans that overwinter in the BGWC study area undertake a seasonal migration to summer ranges. The analyses suggest that individual pelicans in the area begin to emigrate (out of the study area) during February, and pelicans continue to leave the area through March and early April. Pelicans begin to immigrate back to the area in mid-September and continue to return to the area as late as mid-November.

Typical Pelican Survival Rates

In addition, the data and analyses estimate survival rates of approximately 0.997 per day. These parameters are most easily conceptualized through Figure 47, which shows seasonal movement with and without survival parameters.

The GPS study provides information on seasonal migrations of 14 pelicans (pelicans that remained active for long enough to provide information on seasonal movements) over 2 seasons. Figure 53 shows pelican fates predicted by the mark-resight data overlaid by the migratory behavior mined from the GPS study. The top graph shows patterns of summer migration derived from the GPS study alongside the patterns mined from the mark-resight study. The dashed lines represent cumulative immigration and emigration (by date) as derived from immigration and emigration dates mined from the GPS study (N = 16 for the timing of emigration, and N = 9 for the timing of immigration). The thin lines show different combinations of pelican fates predicted by the mark-resight analyses (this information is identical to the upper graph of Figure 47). Given that the experiments were effectively independent of each other, the correspondence between information from both methods is remarkably consistent. The lower graph of Figure 53 shows the predicted fate of pelicans overlaid with information from winter migration mined from the GPS study. Only four pelicans monitored during the GPS study provided information on winter migrations (i.e., southward), and none of these pelicans returned to the study region.

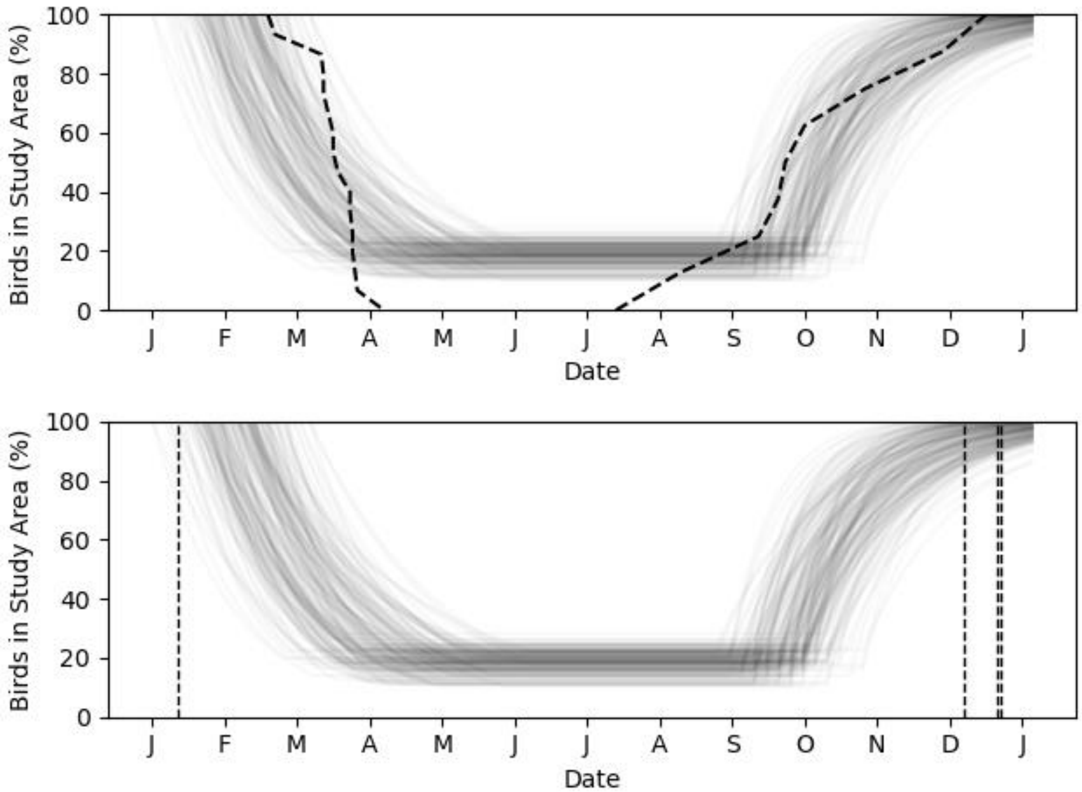


Figure 53. Graphs Showing Migration Patterns Measured during the GPS Study versus Mark-Resight Study. Both graphs show 100 simulated patterns of annual migration using parameters obtained from the HMM (solid lines). Each line shows a different possible pattern of population-level migration based on parameter uncertainty. The top graph shows the timing of migration to northern habitats (dashed line showing an empirically derived cumulative emigration and immigration). The bottom graph shows the timing of southern migrations by four pelicans observed during the GPS study.

One difference between seasonal movements inferred from the GPS data and those inferred using the mark-resight process lies in the number of pelicans that migrate. None of the pelicans fitted with active GPS units spent the summer in the BGWC study area (although one pelican with an inactive transmitter was regularly spotted in the BGWC during the summer). However, the HMM mark-resight analyses suggest that 20 percent of pelicans remained in the study area during the summer. Given the migration parameter estimated by mark-resight and the small number of GPS pelicans (N = 10 pelicans that provided seasonal migration data), it is reasonable that, by chance alone, none of the pelicans in the GPS study were explicitly seen to spend summer in the BGWC.[10] This argument rationalizes the collection of mark-resight data. As discussed in the introduction, the mark-resight data, although of a relatively coarse resolution,

[10] The research team suggests an approximate calculation of 0.8^{10}—an approximately 11 percent chance of selecting 10 migrating individuals and zero nonmigrating intervals, assuming 80 percent of the population migrate.

provide life history estimates that are much more representative of the pelican population than the small sample sizes imposed by the GPS study.

During the analysis of the mark-resight data, the research team used an approach that focused on inferring information from competing models, and in the case of the HMM, a novel analysis method. The CJS approach of fitting useful models provided useful evidence on the survival and migration of pelicans, but these processes could not be inferred directly due to known limitations in the CJS approach. The CJS models motivated the HMM methods. HMM methods are useful because they enable the modeler to easily specify or suggest a model structure (states and transitions) assumed to be relevant to a problem and then easily test this model against the data. One of the drawbacks of the HMM approach is the computational effort required to fit the models to data (in comparison, CJS methods are fast and robust). However, the TTI researchers note that the process of fitting HMM models to data, although computationally expensive, necessarily involves effort from the modeler that results in a thorough understanding of the information inherently contained in the raw mark-resight data.

The HMM methods developed here could easily be extended to include more states and therefore more transitions. In line with statistical theory, the addition of more transitions usually requires larger data sets to derive statistically relevant processes. Originally, one of the motivations for the HMM approach was to use it to include sightings inside and outside the study area. This effort would require an additional resight probability estimate but would also be useful to fully tease apart survival and migration processes. For this study, there were not enough resights outside of the study area to support this approach, but it is possible that these ideas can be revisited as additional resight data become available (it is possible that pelicans will be resighted years after the current study is complete).

CONCLUSIONS

- The HMM mark-resight analyses suggest that approximately 80 percent of the pelicans that overwinter in the BGWC study area undertake a seasonal migration to summer ranges. The analyses suggest that individual pelicans in the area begin to emigrate (out of the study area) during February, and pelicans continue to leave the area through March and early April. Pelicans begin to immigrate back to the area in mid-September and continue to return to the area as late as mid-November.
- Moreover, the data and analyses estimate survival rates of approximately 0.997 per day. These parameters are most easily conceptualized through Figure 47, which shows seasonal movement with and without survival parameters.

CHAPTER 4. MODELING THE BROWN PELICAN POPULATION DYNAMICS IN THE BAHÍA GRANDE WETLAND COMPLEX

This chapter describes a population dynamics model (also referred to as the population model) of Bahía Grande brown pelicans developed by the research team. The purpose of the model is to integrate life history information obtained from this study (described in the previous chapters) with data and information from the scientific literature to illuminate the population dynamics of brown pelicans in the BGWC.

The rationale for the population dynamics model is that free-ranging, wild populations are often difficult to observe directly and holistically. Animal populations consist of multiple individuals that interact with each other and with their environment, often in complex ways. Instead of direct observation, sampling or reductionist experiments are required to understand and measure distinct population processes (e.g., survival, reproduction, development, and migration). Population dynamics models help integrate these population processes and population samples into mathematical formulations that present a more holistic view of the population under study and can be analyzed to infer the importance of each life history process to the population. In doing so, population dynamics models provide a tool to assess whether:

- Reductionist life history processes can be integrated such that their resulting population dynamics reasonably match with knowledge of limited population dynamics observed in the field, or
- Life history processes that are not directly observable can be estimated from population metrics (population size, growth, demography) sampled in the field.

The goal of the research team was to develop a population dynamics model that integrates pelican life history processes (survival, reproduction, migration) into a systematic view of BGWC brown pelican population dynamics. The model was developed using data generated through this project (notably survival and migration estimates) as well as information mined from the scientific literature. The model was developed, in part, to facilitate other studies undertaken during this project (most notably the chapter on estimating population abundance). However, the model is also directly useful for addressing the following questions:

1. How do the survival and migration life history processes quantified in previous chapters and the scientific literature affect the growth (or decline) of the BGWC brown pelican population?
2. Which brown pelican life history processes are most important for maintaining a sustainable BGWC population?
3. How is the BGWC brown pelican population affected by traffic-induced mortalities on SH 48?

This chapter is organized into three further sections. In the next section (Methods and Results), the research team describes the development and analysis of the population model. This section includes a review of pelican life history and population dynamics as reported in the scientific literature. The Discussion section and Conclusions section present these findings in the context of traffic-induced mortality in the BGWC region and past, present, and future brown pelican populations.

METHODS AND RESULTS

Population dynamics models can be implemented in several ways, such as, for example, using matrix algebra differential equations or using computational-based methods. Methods are most often chosen based on factors such as the availability of data, complexity of modeled population processes, and tractability and ease of analysis. In this study, the researchers used an individual-based modeling approach. This approach allows complex ecological processes to be incorporated into the model relatively easily and intuitively and enabled the research team to represent the life history of brown pelicans at a level of complexity and detail concurrent with the availability of data, which enables these life history processes to be easily parameterized. However, relative to mathematical approaches, individual-based models are more difficult to analyze and require computer-intensive methods (virtual experiments) to assess the implications of changes in life history parameters on key population metrics (e.g., population growth rates, demography).

Brown Pelican Population Model

The researchers designed a pelican population model around the key life history processes of survival, development, reproduction, and migration. The model was designed to represent BGWC pelicans and especially to integrate estimates of survival and migration obtained in previous chapters of this report into population-level statistics such as population growth.

The individual-based model represents each simulated pelican of a defined population by a set of state variables that describe the status of that individual at each time step of the model. The state variables used in the model are age (in days), alive or dead, and location (either within or outside of the BGWC study area). At the beginning of a simulation, time is set to zero, and a specified number of virtual pelicans are created (to represent a virtual population). The simulation proceeds by iterating the state variables of each bird within the simulation according to simple rules that determine whether an individual remains alive, dies, reproduces, or migrates. If an individual reproduces, each of its virtual offspring is added to the existing virtual population. Dead pelicans are removed from the population. The simulation runs on a time scale of a single day such that each virtual pelican is iterated once a day. After each daily timestep, the simulation aggregates the number of birds by age, class, and location, and outputs the results to text files for analysis. Table 6 describes the states and life history parameters used in the simulation.

Table 6. Summary of State Variables and Parameters Used in the Population Dynamics Model.

State Variable	Symbol	Description
Dead or alive	**na**[1]	Binary state variable describing whether the pelican is alive or dead. All dead pelicans are removed from the simulation.
Age	**na**	Age of the bird in days. This state variable is used to track whether the pelican is old enough to breed and age-specific survival.
Location	**na**	Whether the bird is located within or outside the BGWC study region. This state variable is updated according to the migration parameters.
Parameter	**Symbol**	**Description**
Survival of juveniles and adults	S_{adult}	Stage- and location-dependent daily survival of pelicans that have left the nest.
Survival of eggs and chicks	S_{nest}	Survival of pelicans (eggs and chicks) within the nest (up until the time of fledge).
Time to fledge	FLEDGE	Time taken for pelicans to develop from egg to free-flying juvenile birds.
Reproduction	$R_{location}$	Clutch size per nest. The number of eggs per nest is defined according to the location of the pelican (within or outside of the study area). The location subscript enables a different value of egg production to be defined for within the study area versus outside the study area.
Reproductive age	RAGE	Age at first reproduction (years).
Date of reproduction	RDATE	Day of year reproduction occurs (day of year).
Migration probability	M	Controls whether the pelican is a migrator (i.e., leaves the study area during summer) or whether it stays in the BGWC over summer. All migrations are assumed to be round trips.
Date of emigration	EMIG	Date at which the first pelican in the population emigrates from the BGWC study area (conditional on whether the bird is a migrator).
Date of immigration	IMM	Date at which the first pelican in the population immigrates into the BGWC study area (conditional on whether the pelican is a migrator).

[1] Note: na indicates not applicable – i.e., that no symbol is necessary

The following pseudocode describes the logic of the model.

For each simulated day:

1. Simulation time is incremented by one day. Then, for each pelican in the virtual population:

    a. Survival of the virtual pelican is assessed by checking the stage and daily survival rate against a uniform random (interval [0,1]). If the random number is less than the survival rate (S_{adult} or S_{nest}), the pelican survives, and its age (in days) is incremented. Otherwise, the virtual pelican dies and is removed from the simulation. If a pelican survives, its age (in days) is incremented.

b. Migration is determined probabilistically by the population-level parameter that defines the number of pelicans that undergo a seasonal (summer) migration. If the pelican is determined to be a migrator, emigration occurs on the date of emigration (EMIG), and immigration occurs on the date of immigration (IMM). Both dates are defined by day of the year (1 to 365). Pelicans that migrate have their location state variable changed to signify that they are either within the BGWC study area or outside the BGWC study area.
c. Virtual pelicans reproduce if the age of the pelican is greater than the population-level reproductive age (RAGE) and the date of the simulation is equal to the date of reproduction (RDATE). Each modeled pelican produces a number of eggs defined by the parameter $R_{location}$, which specifies the number of eggs per female for the BGWC study area or non-study area. Note that if the value of $R_{location}$ for a location (e.g., BGWC study area) is set to zero, the virtual pelicans currently modeled at that location will not produce any eggs.

2. After the states of all the simulated pelicans have been iterated, the simulation counts the number of individuals in each simulated location (inside or outside the BGWC study area) and aggregates them into 12 specified age classes. The 12 age classes are ‘eggs and chicks’, juveniles (fledglings up to one year of age), nine subsequent age classes corresponding to the age of the bird in year increments, and a final class that includes all birds greater than 10 years old. The ‘egg and chick’ stage is determined by egg hatch time and fledge time. Thereafter, stages are defined by the age of the bird in years.

Parameterizing the Model

Data presented in the previous mark-resight analysis chapter were used to parameterize the migration and adult survival life history components of the model. The remaining life history parameters relating to chick, hatchling, and fledgling survival; reproduction; and the timing of various life-stages were parameterized using information mined from the literature. Table 6 provides the parameters used in the base version of the model, with justification and reference to the source of the information. When mining parameters from the literature, care was taken to ensure that the field experiments were relevant to the current brown pelican population. For example, many brown pelican studies were undertaken in response to the decline of the Gulf Coast population in the 1970s. Therefore, quantities such as egg production or egg survival reported from these studies may be lower than for the current population. Care was also taken to ensure the consistency of time units used in rate-based parameters such as survival rate. Where possible, the researchers translated the survival rates reported in a study to the daily rates used by the model (although in some cases, time-based information was not reported).

Adult and Juvenile (Post-Fledgling) Survival

Independent, scientifically collected data on the survival and longevity of pelicans are not common in the literature. Many ornithology guides state that average lifespans are over 10 years, and often as long as 30 years. However, it is unclear whether these values are intended to represent typical pelican longevities rather than a true scientific average (which may include mortality from environmental stress). Using long-term banding data, Schreiber and Mock (1988) estimate that only 30 percent of birds survive their first year of life after banding, while less than 2 percent live beyond 10 years of age, and only 0.11 percent (three pelicans out of 2,519 banded pelicans) survive beyond 20 years. These estimates are consistent with daily survival rates of approximately 0.999 (first year), and 0.9995 (post 1 year). Henny (1972) reported a first-year mortality rate of 69.5 percent, and an overall mortality rate of 42 percent per year for pelicans banded in Florida between 1927 and 1934. These values translate to daily survival rates of approximately (0.998).

The literature does not present any firm data on differences in survival by age (post-fledgling). Intuitively, the survival rates of most species vary with age. For example, experienced animals often have higher survival rates than immature animals because they are more capable of evading predation or finding resources. Similarly, survival rates tend to decrease as individuals age past their peak. Brandt (1984) observed greater foraging efficiency in adults relative to juvenile birds and attributed these differences to skill rather than habitat selection. However, the author did not assess whether this extra foraging efficiency translates to differences in survival rates. Despite the intuition that potential survival should vary with age, field populations that are subject to considerable environmental stress often exhibit relatively high and non-age-specific mortality. In the case of brown pelicans, such stressors include predation, entanglement in fishing lines, poisoning, and low-temperature mortality.

One of the objectives of this study was to assess how the survival rates determined from the mark-resight experiment confer to population performance. In line with this goal, the research team used the age-independent survival rate derived from the mark-resight experiment as a base model parameter value. In the mark-resight experiment, the survival estimate (0.985) was based on a five-day analysis period. The upper graph in Figure 54 translates this estimate to the proportional survival of a pelican cohort over time (years) and provides the corresponding 1-day (0.997) and 1-year survival rates. In the absence of other evidence, a single rate is assumed for all post-fledgling pelicans (irrespective of age). The research team notes that this estimate is lower than the values presented in the literature (a significant goal of the population model is to evaluate the effects of the mark-resight estimate of survival on population dynamics). Figure 54 also details alternative survival curves within the range reported in the literature (note that the third graph shows survival rates similar to those reported by Schreiber and Mock [1988]).

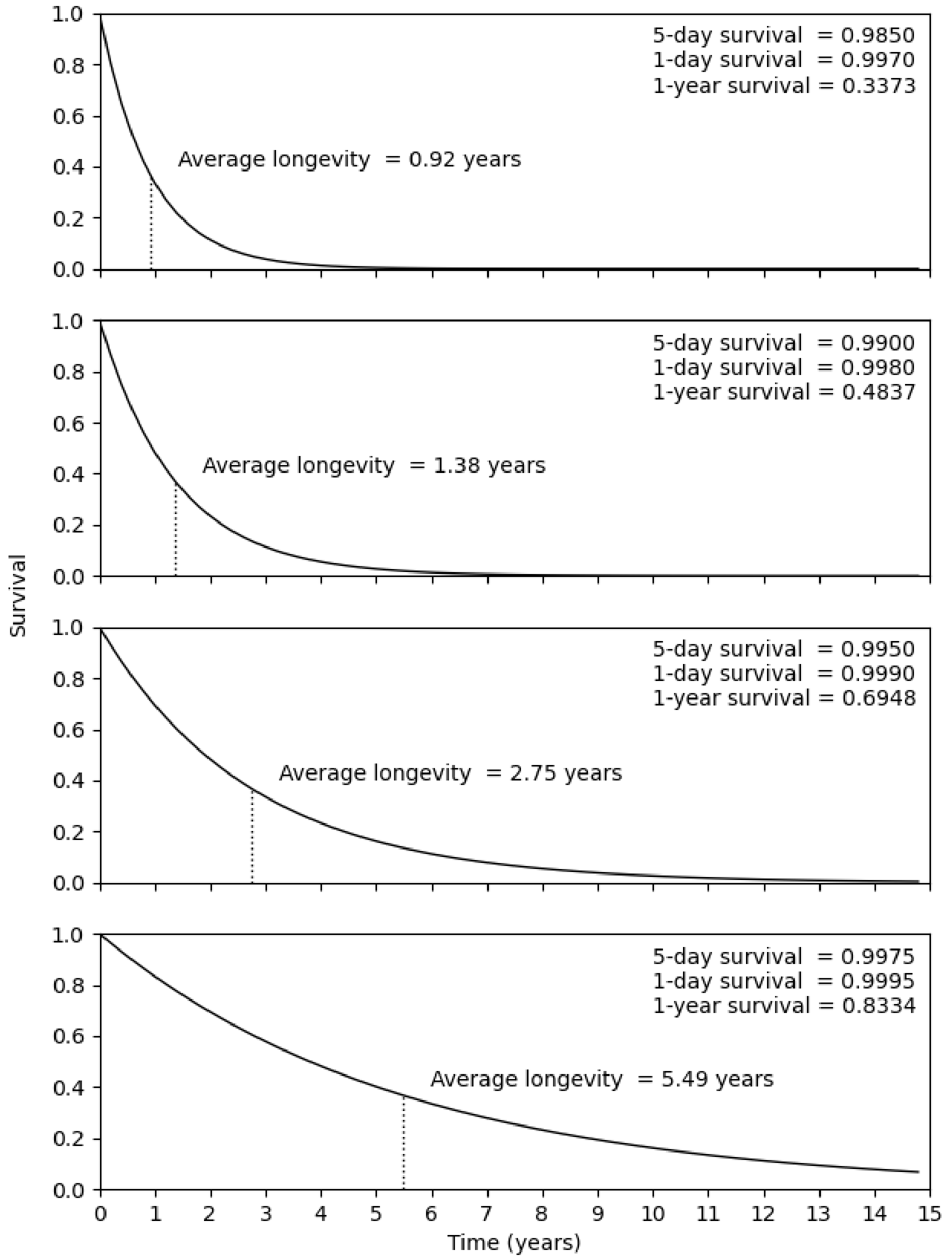


Figure 54. Comparison of Survival Curves for Different Daily Survival Rates. The top graph shows the immature and adult survival curve estimated using the mark-resight analysis. The subsequent graphs show survival curves for incremental increases in survival (from 0.998, 0.990, 0.995 and 0.9975). The second graph shows survival curves for the upper estimates obtained from the mark-resight study. Each graph also displays the 1-day and 1-year survival rates equivalent to the 5-day rate, and the mean longevity of the survival curve.

Migration

The mark-resight and GPS studies that were undertaken during this project estimate that approximately 80 percent of BGWC pelicans undergo a round-trip migration to summer breeding grounds. Pelicans begin leaving the BGWC study area in February through April and return to the study area between September and December.

For the base model parameterization, the statistics from the mark-resight experiment were used to simulate the seasonal summer migration. The model assumes that migrating pelicans are selected randomly (from all adult individuals in the population) and that nonmigrating pelicans do not reproduce.[11] Intuitively, then, migration (specifically the number of pelicans that migrate) will affect population growth (since brown pelicans do not breed in the study area, pelicans that do not migrate will forego breeding opportunities). However, studies also indicate that lower migration rates might not necessarily result in a lower population growth rate. For example, oversummering shorebirds have been found to have higher survival, which may compensate for the loss of breeding opportunity in terms of population growth (Tavera et al. 2020). This deferred migration may be beneficial due to the low reproductive success in younger pelicans. The research team investigated these assumptions in the subsequent analysis of the model.

Several authors have studied brown pelican migration. King et al. (2013) tracked 18 brown pelicans captured on Grand Isle, Louisiana, and observed pelicans crossing the Gulf of Mexico to the Yucatan peninsula, as well as undertaking migrations along the southern Gulf Coast. Lamb (2016) captured pelicans at nesting colonies ranging from Alabama to Texas and tracked movements using GPS. Due to the significance of Lamb's study to this project, a detailed summary of the GPS data is presented in the supplemental material that accompanies this research report. In Lamb's study, pelican migration varied considerably among the pelican colonies, between approximately 35 and 75 percent. The author found a positive correlation between the density of breeding colonies and the distance the pelicans moved and that migrant birds of both sexes were smaller (assessed by a shorter culmen) than nonmigratory birds. The author's models also suggested that these factors interacted such that smaller pelicans and females were more likely to migrate *per se* but were increasingly likely to migrate with increases in colony size.

[11] Only a single active nest was found throughout all the field work undertaken during this project. This includes regular sampling of Laguna Madre roost islands that are the most popular roost sites for pelicans in the region. The sole nest site was discovered on a small island in the Brownsville Ship Channel.

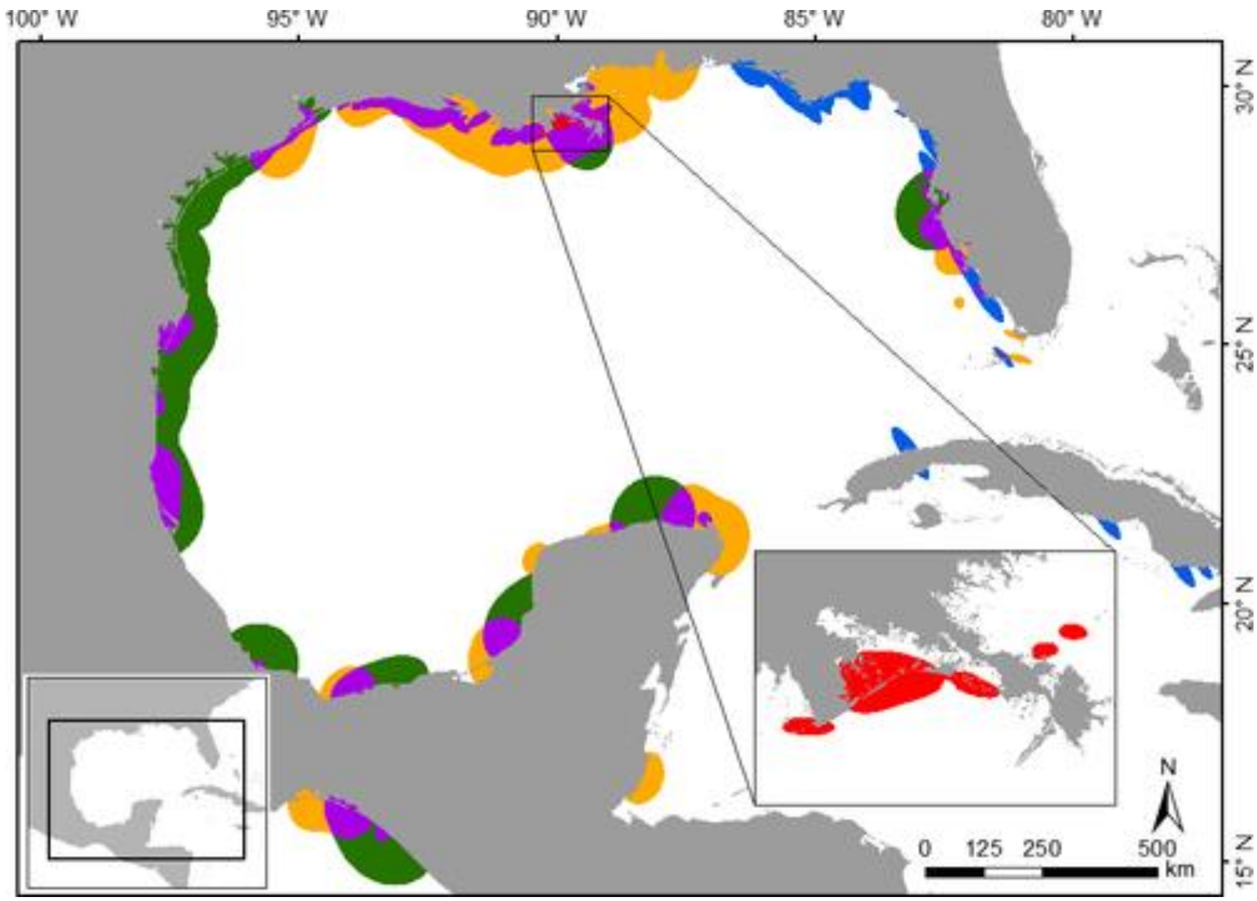


Figure 55. 95 Percent Kernel-Density Estimates for Locations of Brown Pelicans Originally Captured at Breeding Colonies in the Eastern (blue), Central (orange), and Western (green) Breeding Colonies, 2013–2015. The map shows a high degree of range overlap by birds natal to eastern, central, or western breeding colonies.

Development and Aging

Pelicans lay oval, chalky white eggs that are incubated by both parents for 28 to 30 days (Bartholomew and Goldstein 1984). The growth and physical development of nestlings take place over approximately 71 to 88 days (Henny 1972), resulting in a total time to fledge of approximately 110 days. Pelicans hatch as helpless (altricial) pink chicks that weigh approximately 45 to 80 grams.[12] Because they are poorly developed, newly hatched chicks lack the ability to thermoregulate independently. After approximately 10 days, chicks develop downy feathers, and after 30 days, scapular feathers appear. Parents continuously attend eggs and young chicks less than 20 days old (Sachs and Jodice 2009). Beyond 20 days post-hatch, attendance rates decline such that one parent is present on the nest 90 percent of the time, but two parents are almost never in attendance at once, which suggests that the rapidly growing chicks require

[12] Among marine birds, altricial chicks are unique to the order *Pelicaniformes*. This lack of development may be advantageous in the sense that each egg requires a small initial energy investment, but if food resources are available, chicks may grow rapidly.

adults to forage continuously. When a pelican reaches 3 to 5 weeks of age, most permanently leave their nest and form pods. Although pelicans are capable of flight at approximately 60 days, they normally fledge at 11 to 12 weeks (77 to 84 days) post-hatch (Blus 1982). By the fledgling stage, pelicans are typically the same weight and size as adults, suggesting that physiologically at least, they are equipped to forage independently.

After leaving the nest (fledging), the next significant stage of pelican development is sexual maturity. Pelicans usually retain a distinct immature plumage until the bird is about 14 to 15 months old (Bent 1922), and the transition to sexual maturity occurs most visibly through changes in plumage. Adult breeding plumage consists of a brownish-black venter, gray dorsum, white head (yellow at start of breeding season) and a chestnut neck and a white stripe. Pelicans gradually transition to this full adult plumage from the mottled brown immature plumage. Intermediate plumage stages include a gray or light brown neck, indistinct neck stripe, and a mottled head or venter. Importantly, many authors note that full adult plumage is not a prerequisite for breeding, and successful breeding has variously been observed in pelicans with immature plumage. Full adult plumage is usually evidence that pelicans are over 3 years old.

Reproduction

Clutch size is consistently reported in the literature as approximately three eggs per nest for adult pelicans. Immature breeders generally have smaller clutches (closer to two eggs per nest). Blus and Keahey (1978) reported an average clutch size for immature nests of 2.16 eggs versus 2.85 for adult nests. In their studies, clutch size ranged from one to three for immature birds, and two to four for adults. Four egg clutches were rare (only five out of 2,400 nests observed during South Carolina nest surveys in 1975), while five clutch nests are extremely rare (observed only three times in approximately 10,000 nests during surveys of South Carolina pelican nests from 1969 through 1975). Robinson and Dindo (2011) observed nesting success in Alabama and found the largest clutch size was three eggs (also the most common clutch size).

Most authors report that pelicans reach reproductive age at three years of age, but that most pelicans reproduce at four years or older. Williams and Joanen (1974) observed three-year-old pelicans nesting successfully in Grand Terre, Louisiana (the pelicans had been relocated from Florida as fledglings, so their age could be reliably determined). The nesting three-year-olds were reported to be in an advanced subadult plumage (similar to full adult plumage but lacking the bright yellow crown and throat markings). However, the authors also noted that nesting immatures were not present during surveys in Florida and suggest that the age of first reproduction may vary according to factors such as food supply or competition for nest sites. During surveys of Marsh Island, Cape Romain National Wildlife Refuge, South Carolina, approximately 30 percent of nests were tended by pelicans in immature plumage (Blus and Keahey 1978).

Pelicans are reported to initiate nests between March and June (Robinson and Dindo, 2011). Lamb (2013) captured pelicans on the nest between April 24 (Florida) to July 2 (Louisiana). Birds in full adult plumage tend to arrive at nest sites earlier than younger birds. The more experienced birds select premium nest sites (usually sites with less vegetation and away from tidal areas that pose a flood risk). Nests are most often constructed on the ground or at elevations of less than 2 meters in low vegetation, such as Black Mangrove (*Avicennia nitida*). Some authors suggest that some vegetation cover helps chicks thermoregulate while in the nest.

Reproductive Success—Egg and Chick Survival

Brown pelicans reproduce in colonies, usually on islands with no mammalian predators. Avian predation has been recorded at nest sites. However, as noted in the section on development, brown pelican chicks are nearly always attended by at least one parent until they are approximately 30 days old, a factor that may reduce the risk of predation.

Most authors report that favorable nesting sites within colonies are limited, but pelicans will nest in marginal areas if space is limited. Marginal sites include those sites that offer no vegetative shade or are prone to tidal flooding. Parents also cause egg and chick mortality while entering and exiting the nest, especially at crowded nests or if access to nests is difficult (e.g., nests in low vegetation). Because brown pelican chicks are altricial and unable to fully thermoregulate until they reach the downy feather stage, young chicks may be prone to extreme heat or cold stress. As they grow, their rapid development requires increasing food resources from parents.

Several authors have studied the reproductive success of brown pelicans. Henny (1972) reported a recruitment rate (number of fledged birds per breeding pair) of 0.32 to 1.67 (mean = 0.85). Robinson and Dindo (2011) measured egg success (proportion of an individual surviving from egg to fledgling) in Alabama over two breeding seasons (2007–2008). Egg success ranged between 0.0 and 0.659, depending on the physical conditions at the nest site. Egg success was positively correlated with earlier nesting dates, low elevation nests, and moderate vegetation cover but negatively correlated with nest density. The authors noted that ground nests are preferred because they minimize egg damage by adults, enable chicks to temporarily leave the nest to avoid predation, and provide thermoregulatory benefits. Blus and Keahey (1978) studied nesting success within a nesting colony on Marsh Island, Cape Romain National Wildlife Refuge, South Carolina, between 1969 and 1975. In this study, flooding was the major source of egg and chick mortality. They reported survival rates of eggs to fledgling of 16 and 34 percent (for immatures and adults, respectively) for unflooded nests. The authors attributed the lower reproductive success of immature nesters to their use of poorer quality nest sites—especially those prone to flooding (immature pelicans tend to arrive at nest colonies later than adults and therefore have fewer nest site choices).

During a 1969–70 study of nests in Boca Ciega Bay, St. Petersburg, Florida, Schreiber and Risebrough (1972) reported hatching success of between 29 and 84 percent. They found that hatching success was greater for undisturbed nests (those checked less frequently during their surveys). Most unhatched eggs were caused by slight physical damage to the egg (8–65 percent of mortalities); between 3 and 16 percent of eggs failed to hatch but were not destroyed; and 0–5 percent had been crushed. The two largest causes of damaged eggs were from predators (especially avian predators) and from adult pelicans entering or leaving the nest (especially when disturbed). Given the timing of this study, it is possible that mortality rates were affected by the thinner shells caused by DDT poisoning.

Schreiber (1976) reported that the first chick to hatch in a multi-egg clutch (or a single chick) has a greater chance of survival than younger siblings, and the survival of second and third hatchlings varied by year (for example, during 1971, only 1 out of 8 second or third hatched chicks died, while in 1970, 9 out of 25 died). These findings suggest the importance of food availability for growing pelicans and that, in addition to competition for space, pelican chicks may face competition for food from their siblings. Brood reduction due to sibling-induced mortality, known as siblicide, is common in several species of the pelican family, with brown pelican sibling aggression being found in almost all multi-egg clutches (Johnston 2018). Siblicide in brown pelicans is thought to occur because of food scarcity but has occurred even when food resources are equally distributed by parents and no food shortages exist. These findings suggest that younger chicks may provide insurance value if an older chick dies or that larger clutches provide extra reproductive value when food resources are abundant (Ploger 1992).

Figure 56 summarizes egg and chick survival rates reported in the literature. The figure shows the survival to fledge expressed as daily survival rates (survival curves). Where necessary, a time-to-fledgling of 110 days and an average clutch size of 2.85 is assumed to convert the proportion of surviving pelicans to daily survival. The rate of 0.9962 reported by Robinson and Dindo (2011) is used in the base model because it is the most recent rate and is therefore unlikely to be affected by DDT issues.

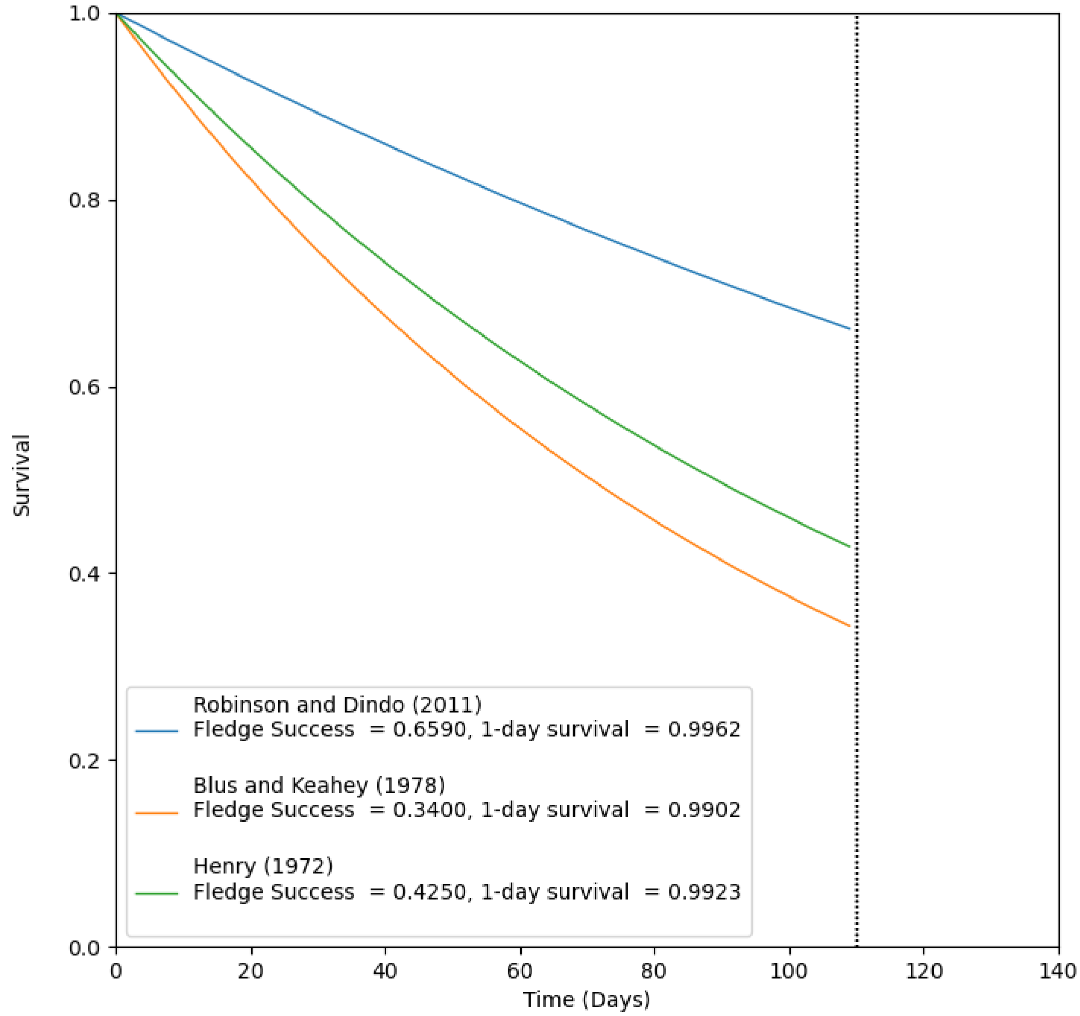


Figure 56. Summary of Egg and Chick Survival Curves Reported in the Literature. The original values reported in the literature have been converted to daily survival rates. The dashed vertical line represents fledgling time (110 days).

Population Dynamics

The eastern brown pelican population has recently recovered following declines in the population between 1940 and 1970.[13] These declines were caused by exposure to pesticides and other human-induced mortality (such as hunting). The decline in Texas populations has been attributed to organochloride pesticide poisoning (Holm et al 2003). However, in Louisiana, population decline is more often attributed to direct mortality and reduction in prey caused by endrin contamination (Blus et al. 1975; Blus et al. 1979).

[13] Prior to these dates, the brown pelicans were hunted for their feathers (for the millinery trade), and they were one of the reasons the U.S. National Wildlife Refuge System was established (the first reserve was established on Pelican Island, Florida, on March 14, 1903).

Historical estimates of brown pelican population sizes in Louisiana and Texas have varied considerably, no doubt because of the difficulty of estimating populations and the natural dynamics of populations. Bailey (1920) reported that an estimated 50,000 brown pelicans used the Mississippi Delta. Pearson (1919, 1921) estimated the Texas brown pelican population at approximately 5,000 birds and estimated the Gulf Coast population (Texas to Florida) to be 65,000. Lowery (1955) estimated the Louisiana population to be 12,000 to 85,000 pelicans, while Schreiber (1980) estimated that, historically, 50,000 pelicans would have occupied Texas and Louisiana combined. Oberholser (1938) listed brown pelicans as an abundant permanent resident in Louisiana, and during a survey of the coast in June 1933 estimated at least 5,500 nests and a population of at least 14,000 adults.

Despite the historical abundance of brown pelicans in Texas and Louisiana, in 1961, less than 50 adults remained in Texas (King et al. 1977). In Louisiana, the population was extirpated by 1963 (Williams and Martin 1968). In contrast to the population declines in Texas, numbers in Florida have remained relatively stable (Williams and Martin 1968; Kushlan and Frohring 1985; Wilkinson et al. 1994).

Two pieces of legislation are responsible for the recovery of the brown pelican population. The brown pelican was first declared endangered in 1970 under the Endangered Species Preservation Act, a precursor to the current Endangered Species Act, where it remained until it was delisted in 2009. The ESA afforded pelicans direct protection from human-induced mortality. In 1972, the United States Environmental Protection Agency (USEPA) banned the use of DDT[14], Eldrin, and other organochloride pesticides. Over the previous decades, these pesticides were increasingly linked to lower egg survival (DDT especially is synonymous with eggshell thinning that is thought to have reduced breeding success). Recovery of the brown pelican occurred through reintroductions and natural spread of remnant populations, particularly Florida populations. Between 1968 and 1980, the Louisiana Department of Wildlife and Fisheries established new brown pelican colonies by relocating birds from Florida, while Texas populations may have recovered through natural recolonization.

Given that the population in Texas and Louisiana was virtually extirpated during the 1960s and 1970s, it is reasonable that the population growth experienced by pelicans during their recovery were unencumbered by intraspecific competition or other density-dependent effects. Data on the long-term trends in pelican populations during this recovery period can therefore provide information on the potential for population growth in the species. Figure 57 shows the change in the number of pelican nests in Florida, Louisiana, and Texas between 1970 and 2002, estimated from annual aerial and ground surveys (Holm et al. 2003). Assuming that the number of nests is a good index of population abundance, average population growth rates during recovery were between 1.26 per year for the Louisiana population, and 1.30 for the Texas population. The data

[14] Note that Mexico only ceased lawful production of DDT in 1997 and stopped using it in 2000.

suggest that the Florida population was stationary during this period. Figure 58 shows the change in the number of nesting colonies in Florida, Louisiana, and Texas between 1970 and 2002 (Holm et al. 2003).

Figure 59 shows the annual change in the annual population growth rate for Texas and Louisiana during the same period. The data suggest that population growth rates are decreasing through time—most likely a result of density dependence effects. Holm et al. (2003) also noted that some intraspecific variation in growth rates could be explained by environmental disturbances. For example, in 1990 and 1996, freezing temperatures during the preceding winters caused a significant drop in the number of nests reported in Louisiana, while the drop in numbers between 1999 and 2000 coincided with high estuarine salinity along the coast.

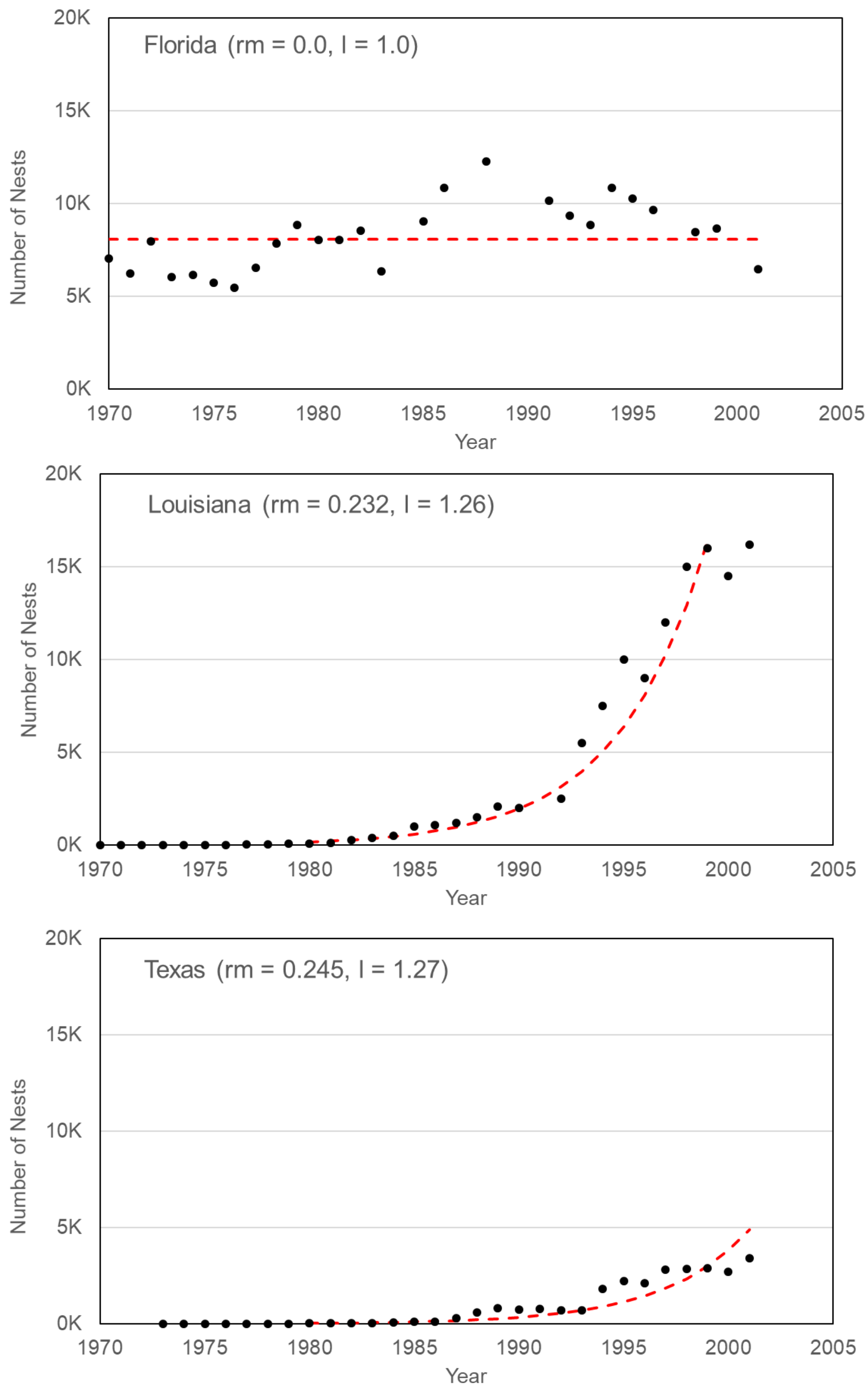


Figure 57. Trends in Number of Nests in the Gulf Coast of Florida (top), Louisiana (middle), and Texas (bottom) between 1970 and 2002. The solid circles show field estimates, and the red line illustrates an exponential model fitted to the counts. Rates of increase (r_m and λ) are listed in the plot titles.

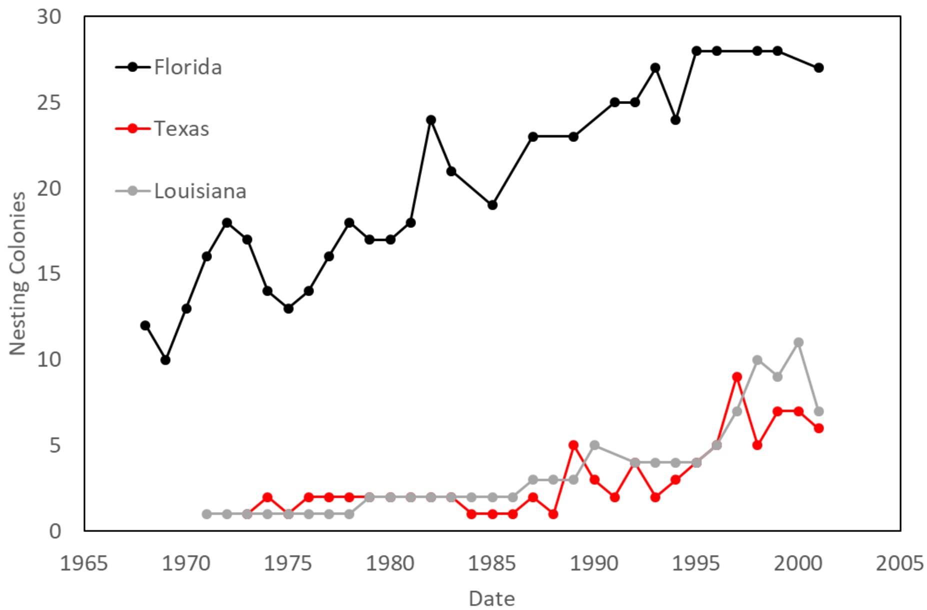


Figure 58. Trends in Number of Nesting Colonies in the Gulf Coast of Florida (top), Louisiana (middle), and Texas (bottom) between 1970 and 2002.

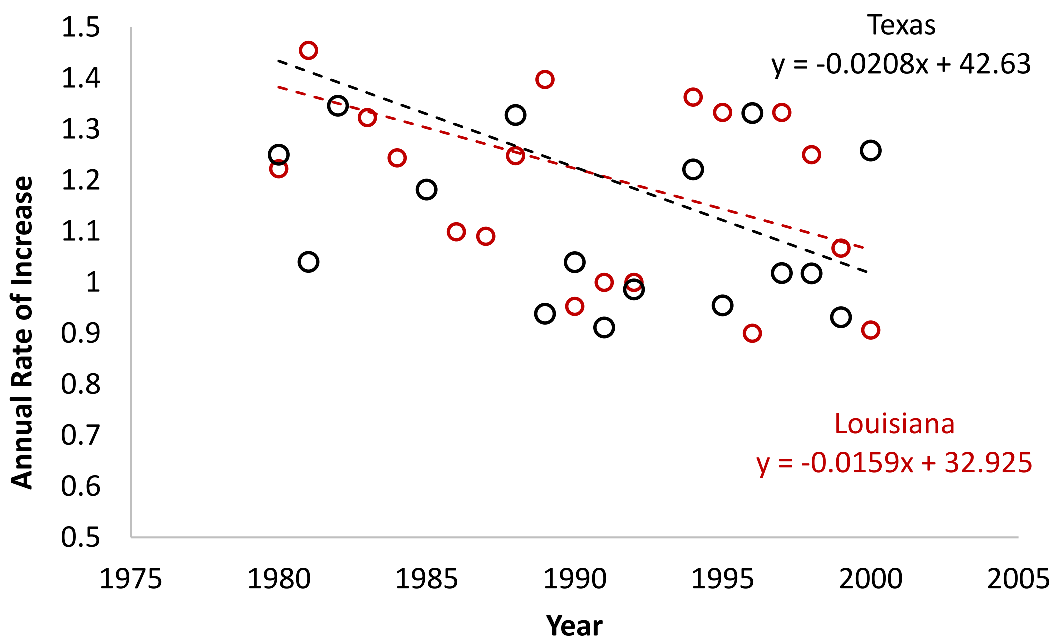


Figure 59. Annual Rates of Increase of Brown Pelican Nests by Year (data from Holm et al. 2003). Red circles show data (annual change in number of nests) for Louisiana, and black circles show the same metric for Texas. The red and black dashed lines show trends for the Louisiana and Texas populations, respectively.

The National Audubon Society Christmas Bird Count (ASCBC) program also provides data on the recovery of the brown pelican population (http://www.christmasbirdcount.org, accessed

December 1, 2020). The ASCBC program is a long-running citizen science project in which volunteers undertake simultaneous counts of all species observed in a circular study area within a 15-mile radius. Counts are repeated at the same locations annually. Figure 60, Figure 61, and Figure 62 show changes in the number of brown pelican sightings per observer for a number of count circles between 1980 and 2019. Figure 63 shows the locations of the ASCBC circles along the Gulf of Mexico, and each numbered location corresponds to a subplot shown in Figure 60, Figure 61, and Figure 62.

According to the ASCBC data[15], between 1980 and 2019, brown pelican sightings have increased in Texas and the northern Gulf Coast. In Florida, however, sightings have either remained consistent or even declined in some locations (e.g., Fort Myers). When used as a population index, the data indicate annual population growth rates between 1.05 and 1.1 in most locations. Population growth rates along the northern Gulf Coast (Louisiana, Mississippi, Alabama, and the Florida panhandle) tend to be lower than in Texas, but overall, suggest an increasing population. Population counts along Florida's east coast show approximately static or slightly declining population trends.

[15] National Audubon Society (2020). The Christmas Bird Count Historical Results [Online]. Available http://www.christmasbirdcount.org [accessed September 2020]

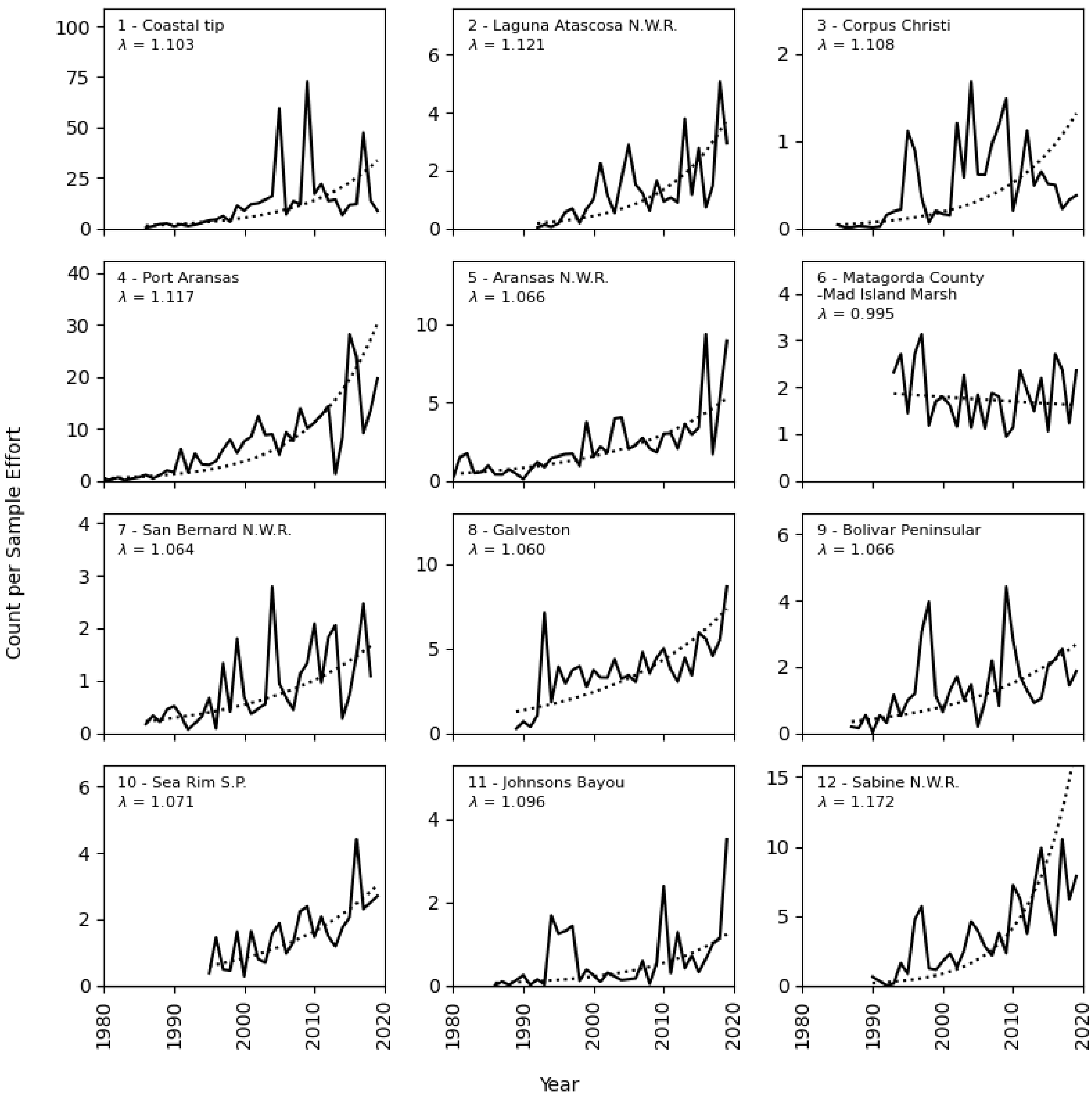


Figure 60. The Annual Change in Brown Pelican Abundance from 1980 to 2019 Observed at 12 National Audubon Society Christmas Count Survey Locations on the Texas-Louisiana Gulf Coast. The abundance estimate is the number of pelicans observed normalized by survey effort. The dashed line shows an exponential curve fitted to each location. The title in each graph shows the location number (referencing to Figure 63) and the name of the survey location.

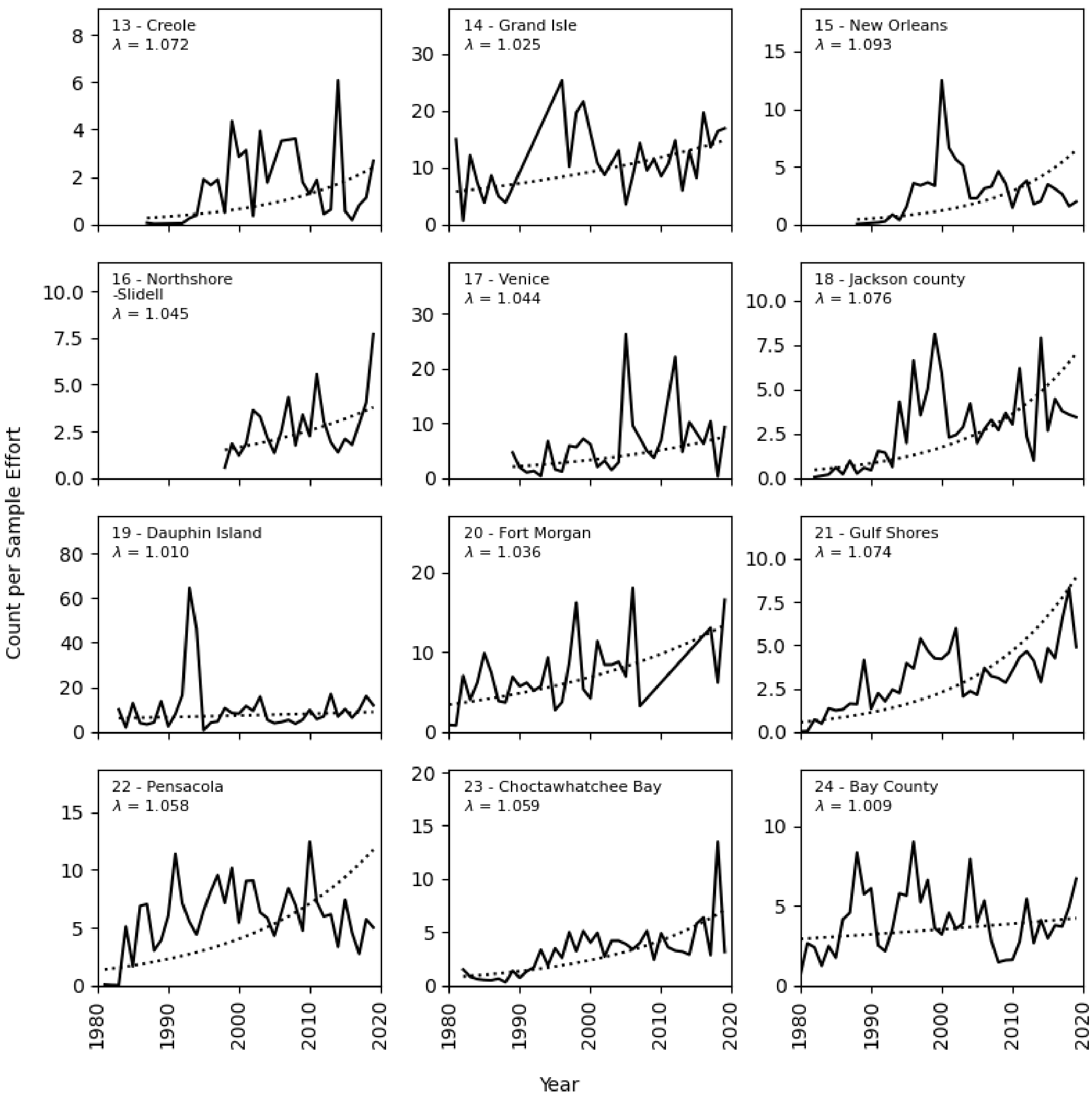


Figure 61. The Change in Brown Pelican Abundance from 1980 to 2019 Observed at 12 National Audubon Society Christmas Count Survey Locations on the Gulf Coast between Texas and the Florida Panhandle. The abundance estimate is the number of pelicans observed normalized by survey effort. The dashed line shows an exponential curve fitted to each location. The title in each graph shows the location number (referencing to Figure 63) and the name of the survey location.

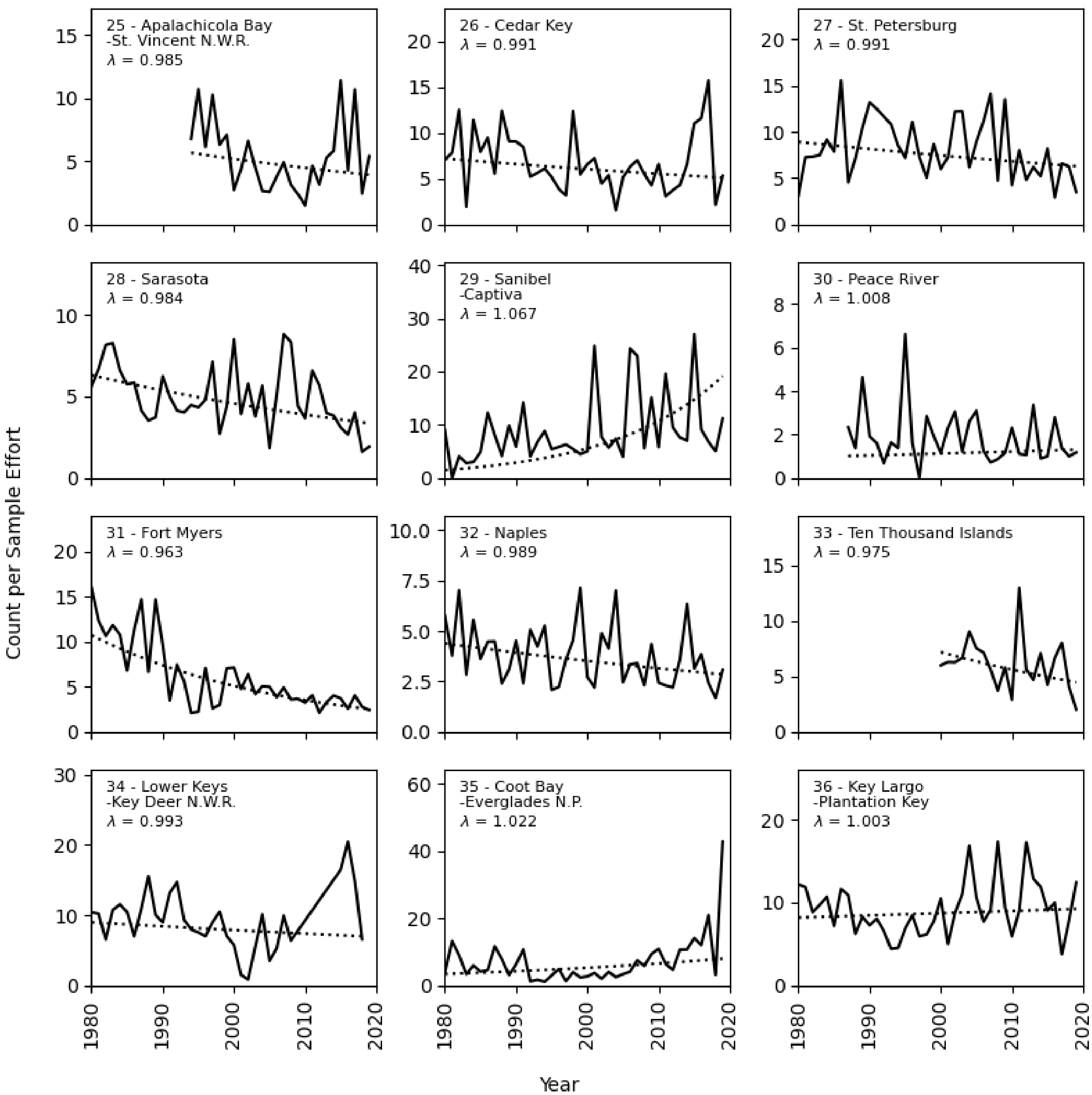
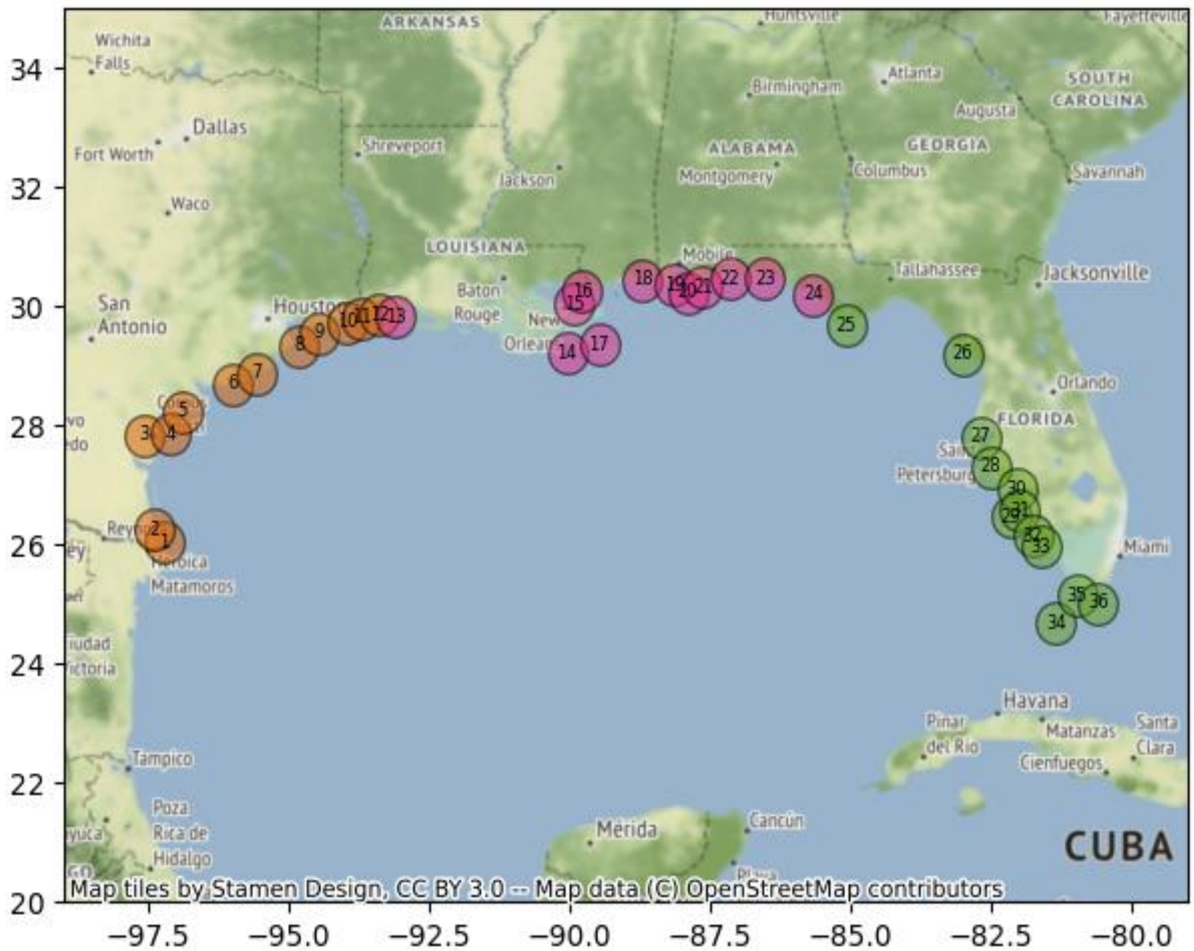


Figure 62. The Change in Brown Pelican Abundance from 1980 to 2019 Observed at 12 National Audubon Society Christmas Count Survey Locations along Florida's Gulf Coast. The abundance estimate is the number of pelicans observed normalized by survey effort. The dashed line shows an exponential curve fitted to each location. The title in each graph shows the location number (referencing to Figure 63) and the name of the survey location.



1: Coastal tip
2: Laguna Atascosa N.W.R.
3: Corpus Christi
4: Port Aransas
5: Aransas N.W.R.
6: Matagorda County-Mad Island Marsh
7: San Bernard N.W.R.
8: Galveston
9: Bolivar Peninsular
10: Sea Rim S.P.
11: Johnsons Bayou
12: Sabine N.W.R.
13: Creole
14: Grand Isle
15: New Orleans
16: Northshore-Slidell
17: Venice
18: Jackson county
19: Dauphin Island
20: Fort Morgan
21: Gulf Shores
22: Pensacola
23: Choctawhatchee Bay
24: Bay County
25: Apalachicola Bay-St. Vincent N.W.R.
26: Cedar Key
27: St. Petersburg
28: Sarasota
29: Sanibel-Captiva
30: Peace River
31: Fort Myers
32: Naples
33: Ten Thousand Islands
34: Lower Keys-Key Deer N.W.R.
35: Coot Bay-Everglades N.P.
36: Key Largo-Plantation Key

Figure 63. National Audubon Society Christmas Count Survey Locations Used to Estimate Change in Pelican Abundance.[16]

[16] The difference in colors corresponds to the different figure panels used to show the temporal abundance estimates.

Summary of Life History Parameters

The review of pelican life history and population dynamics suggests that during their recovery, brown pelican populations have increased at rates of approximately 10–20 percent per year (population growth: λ = 1.1 to 1.2). Many of the life history processes of pelicans have been studied by at least two researchers; thus, alternative measurements can be compared. There is general agreement among researchers that pelicans may nest at three years of age, but most probably nest at four years. The number of eggs per clutch is also consistently reported at approximately three (average 2.85). Migration characteristics are also consistent between those derived from this project (Chapters 2 and 3 detailing GPS movements and mark-resight analysis, respectively), and data provided by Lamb (2016).

The life history processes with the least information are the survival rates of fledged birds (juveniles and adults), eggs, and chicks. The latter has received considerable study, but most authors report that nest survival is particularly variable between locations and years and may even represent the major form of density dependence in the species. Adult survival has been less well studied. In the current project, the TTI team estimated the survival rate of 0.997 per day based on banding data and mark-resight analysis (see Chapter 3).

The research team parameterized a version of the population dynamics model using data from the review above. Table 7 summarizes the life history parameter values used in a base population model parameterization, along with ranges that bound reasonable estimates of these parameters. The base model uses the survival rate determined in the mark-resight study and the median of egg and chick survival rates reported in the literature. In light of the life history review, the main uncertainties in model parameterization concern the survival rates of pelicans (nest stages and fledged stages). The base population model was defined for the purposes of exploring the effect of changes in life history parameters on population growth.

Table 7. Life History Parameters Used in the Base Population Model.

Parameter	Symbol	Base Model Value	Range	Description
Adult Survival	S_{adult}	0.997	0.99–0.9995	Daily survival of fledged individuals and adults.
Egg and Chick Survival	S_{nest}	0.9962	0.2–0.99	Daily survival of eggs and chicks.
Egg to Fledgling Time	F_{time}	110 days	NA	
Time to first reproduction	R_{time}	4 years	2–4 years	
Eggs per Nest	R_{loc}	2.85	2.15–3.5	Average number of eggs per nest, defined according to the location of the bird (within or outside of the study area).
Date of reproduction	R_{date}	April 1 to June 1	NA	Day of year reproduction occurs.
Migration probability	M_{prob}	0.8	0.5–1	Controls whether the bird is a migrator (all migrations assumed to be round trips).
Emigration Date	EM_{date}	Feb 1 to April 1	NA	Timing of immigration or emigration conditional on whether the bird is a migrator.
Immigration Date	IM_{date}	Sep 1 to Dec 1	NA	Timing of immigration or emigration conditional on whether the bird is a migrator.

NA = Not applicable

Model Analysis—Population Growth Rate

The research team analyzed the simulation model by assessing the sensitivity of model parameters on population growth rate. The research team analyzed the population dynamics model by repeating simulations using a different set of parameter values within the ranges specified in Table 7. Specifically, each parameterization of the model involved choosing one of the parameters at random and changing that parameter value while all others were kept at the base rate documented in Table 7. At the end of each simulation, the intrinsic rate of increase was calculated by regressing the logarithm of the total population size at each daily time step against time.

All simulations were run using an initial population size of 500 pelicans allocated across different age classes using a representative age distribution (note that the initial population size does not affect population growth estimates unless it is very small—an element explained in more detail in the following sections). This representative age distribution was obtained by running the base model for 50 years until the distribution of each age class converged to a near stable ratio.[17] Each simulation was run for 10 years. Initializing the model with a near-stable age distribution produced consistent estimates of population growth rate after simulations lasting only five years (simulations are computationally expensive).

Figure 64 shows the relationship between base model parameters and population growth rate. Each graph shows the relationship between changes in one of the key model parameters and λ, assuming that all other parameter values are held constant (using the base rates in Table 7). The population growth rate in each graph is plotted as λ, representing the growth (or decline) of the population per year. The dashed horizontal line (at $\lambda = 1$) illustrates a stationary population (constant through time). Population growth rates less than 1 indicate a declining population, and growth rates greater than 1 indicate an increasing population. The growth rate units are years, so $\lambda = 1.1$ means that the population is predicted to grow at a rate of 10 percent per year ($\lambda = 0.9$ means it decreases by 10 percent after a year). The vertical dashed line in each graph shows the parameter value used in the base parameterization (Table 7).

Figure 64 illustrates that the base model parametrization does not result in population growth. Under this base parametrization, the modeled population is expected to decline at a rate of 50 percent per year. According to this base parametrization, the only way in which the modeled population can grow (or remain stable) is through an increase in the survival rate of adults. If all other parameter values are fixed at the base rates, population growth can only occur if adult survival increases to approximately 0.999 per day (relative to the 0.997 used in the base parameterization).

Because the base parametrization did not result in population growth, a second version of the model was parameterized using a daily survival rate of 0.999 (approximate to the rate reported by Schreiber and Mock [1988]). Figure 65 illustrates the result of repeating the sensitivity

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[17] Theoretically, as a population grows or declines from an arbitrary starting population (composed of different age classes), it will initially grow at variable rates (i.e., different growth rates per time period). Over an extended time period, it converges to a stable age distribution in which the proportion of individuals in each age or stage class remains constant over time. As the stage or age distribution of the population converges, the population also exhibits less variability in growth rate and eventually converges to a time invariant population growth rate often referred to as finite rate of increase (λ) or intrinsic rate of increase (r_m).

analysis using an adult survival value of 0.999. This new value results in population growth (λ) approximately equal to 1.02 (i.e., a population that increases at 2 percent per year).

The sensitivity analysis indicated that the modeled population growth rate is most sensitive to the survival rate of adults. The model has approximately equal sensitivity to egg and chick survival, migration, and eggs per clutch. As expected, population growth is positively related to each of these parameters but is negatively related to the time to first reproduction parameter.

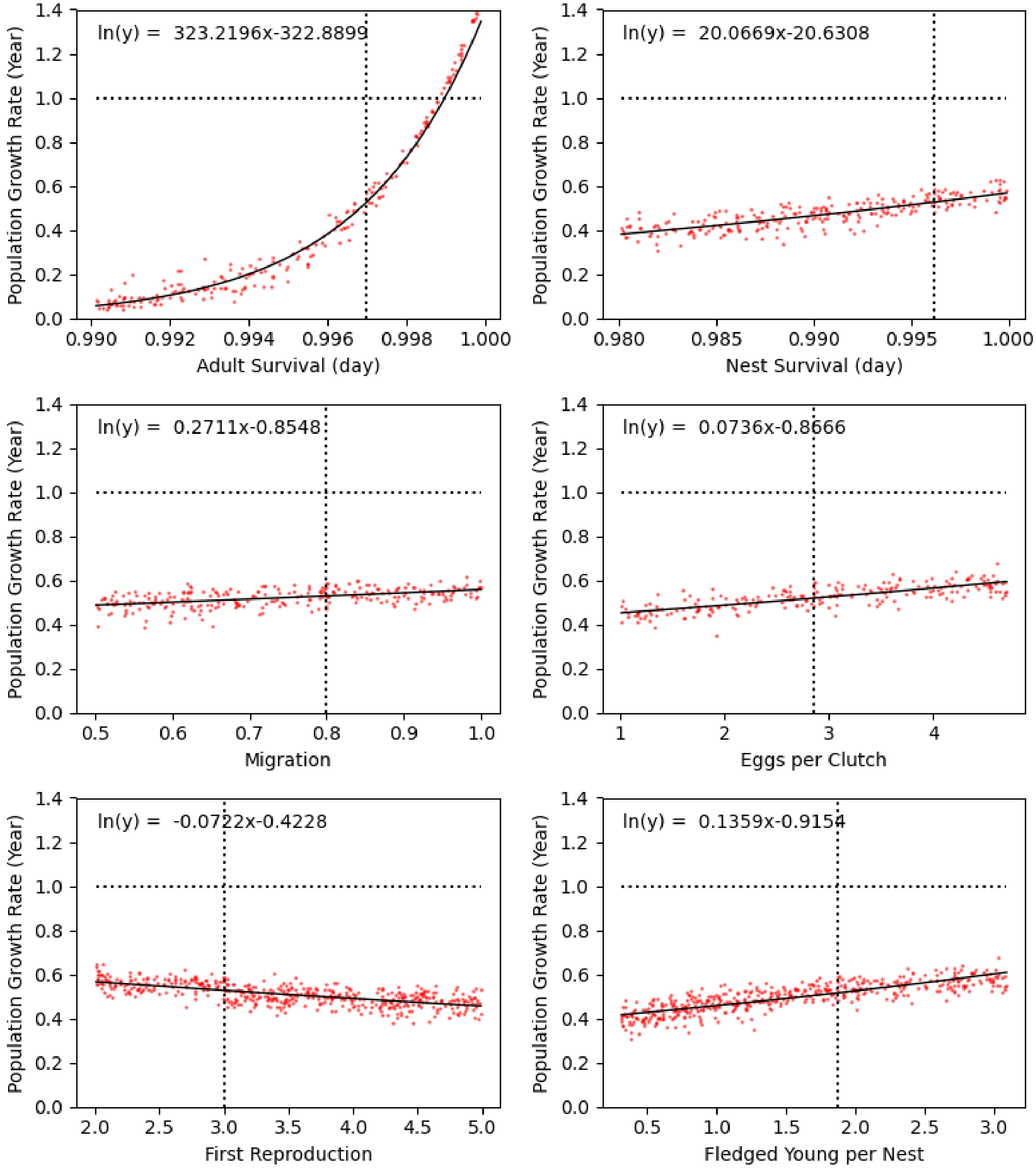


Figure 64. Sensitivity of Base Population Model to Key Life History Parameters. Each graph shows the relationship between population growth rate and changes to the parameter value, assuming all other parameters are kept equal (held at base values). The horizontal dashed line marks the threshold of population growth (greater than 1.0). The vertical dashed lines show the base value of each parameter. The equations indicate the relationship between changes in the parameter value and population growth.

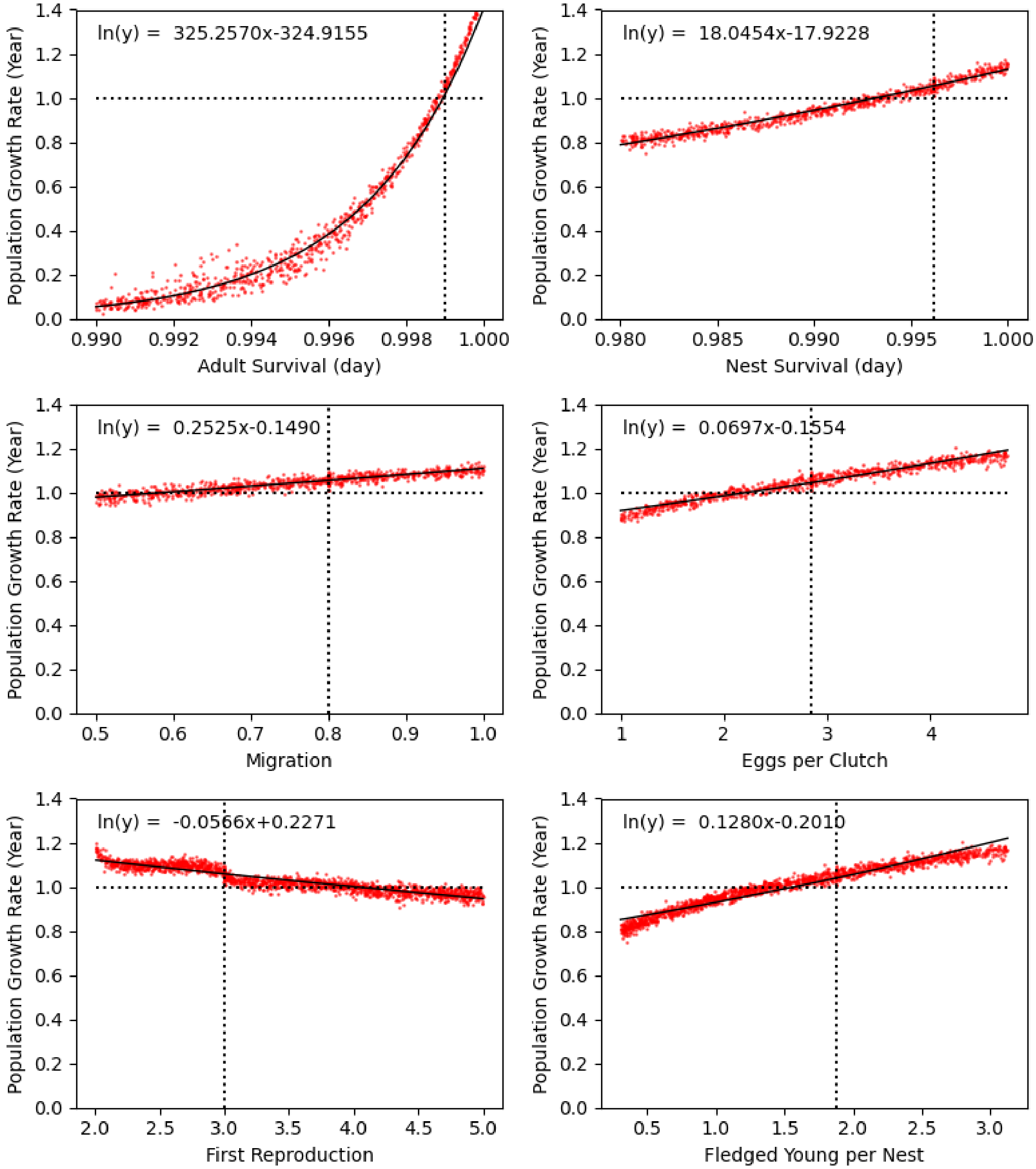


Figure 65. Sensitivity of Adjusted Population Model with Higher Survival Rate to Key Life History Parameters. Each graph shows the relationship between population growth rate and changes to the parameter value, assuming all other parameters are kept at base values but with adult survival changed to a rate of 0.999 per day. The horizontal dashed line marks the threshold of population growth (greater than 1.0). The vertical dashed lines show the base value of each parameter. The equations indicate the relationship between changes in the parameter value and population growth.

Model Analysis—Temporal Population Dynamics

Figure 66 shows the temporal dynamics of the two model parametrizations over 20 years. As determined during the sensitivity analysis, the population of the base model declines precipitously over time, and the population becomes extinct in less than 10 years. In contrast, the increased survival model results in a population that grows exponentially, and true to population dynamics theory, converges to approximately a stable age distribution.

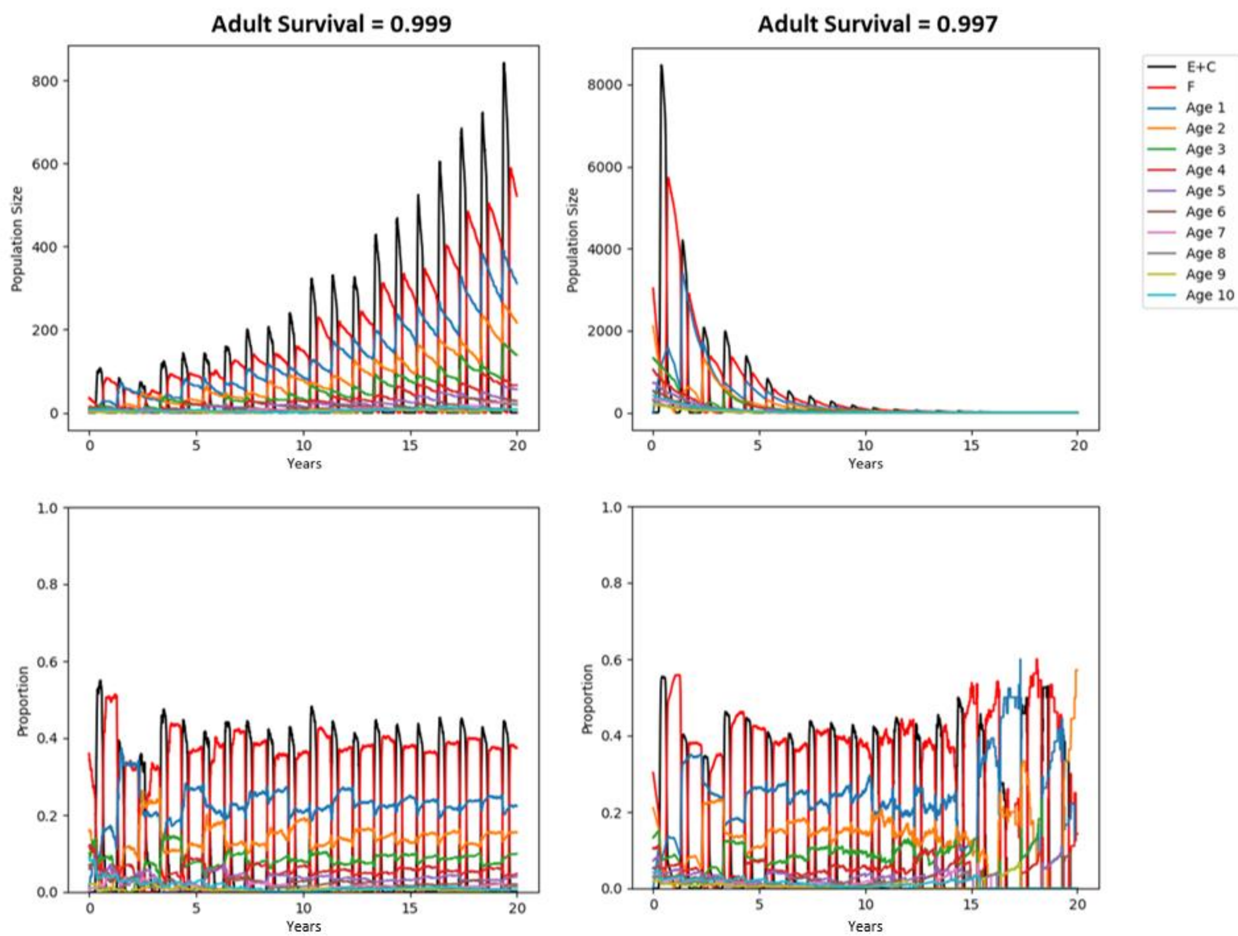


Figure 66. Temporal Dynamics of the Model Base and Improved Survival Parameterizations over 20 Years. The upper graphs show total population size, while the lower graphs show age distributions (proportion of each pelican in each modeled stage).

Figure 67 provides a simplified view of the modeled population dynamics over a single year. The three graphs in each panel show the dynamics of the population in the study area (top), outside the study area (middle), and for the total population. Moreover, the population has been reduced to four discrete stages that approximately correspond to stages that are discernable by sight in the field (eggs and chick, yearlings, immatures, and adults). In both models, reproduction only occurs outside of the BGWC study area, so the egg and chick stages do not appear in the upper graphs of each panel. The models indicate that the number of immature and yearling pelicans in the population are approximately equal, and each represents approximately 40 percent of the population, while full adult individuals constitute approximately 20 percent of the population. Due to the 80 percent migration rate in the base model, the population dynamics show a significant reduction in the BGWC population during summer, followed by a return to the area in fall.[18]

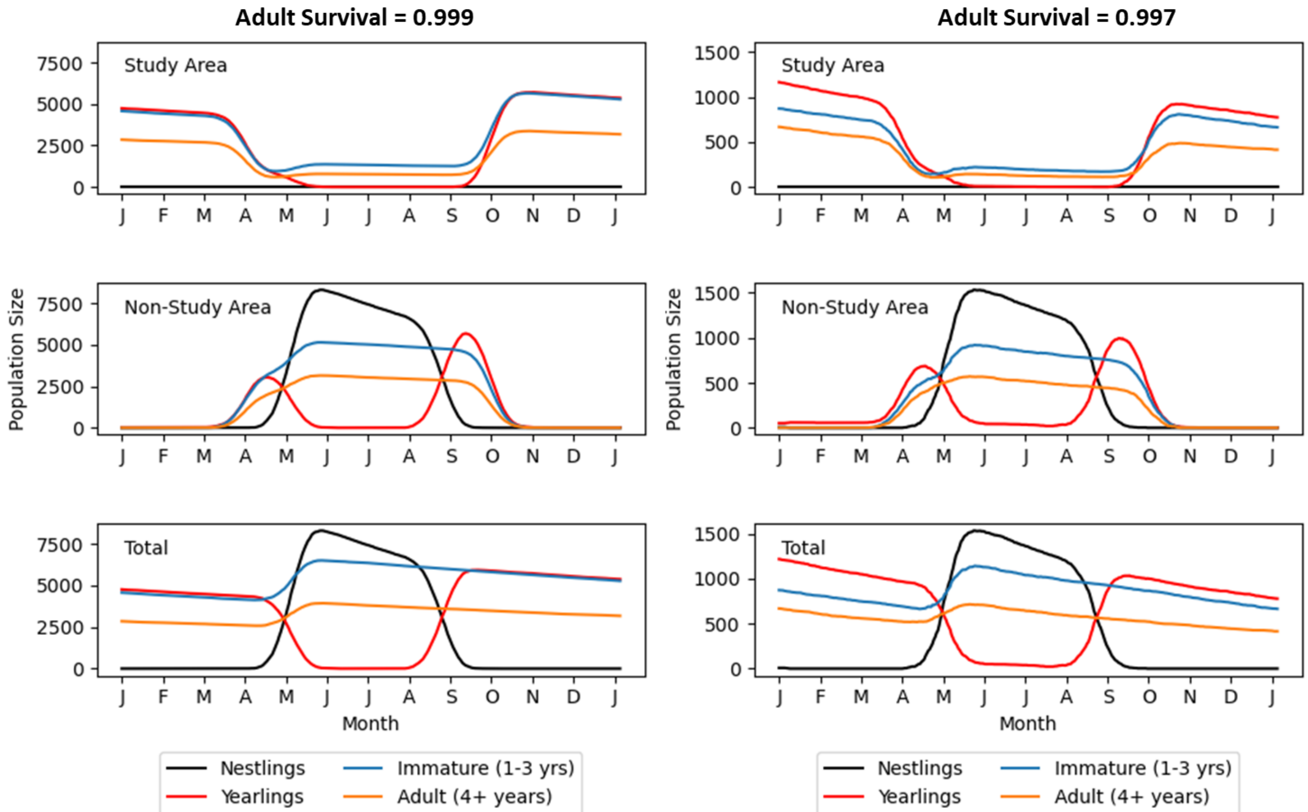


Figure 67. Annual Dynamics of the Base and Improved Survival Models.

Model Analysis—Effects of External Mortality on Population Growth

The previous analyses illustrate the importance of adult survival on population growth rate. The models demonstrate that a survival rate of 0.997 (as reported in the mark-resight chapter) is not sufficient to enable the BGWC to be sustainable. On the other hand, a survival rate of 0.999 does result in a growing, sustainable population. These survival rates correspond to the normal survival rates of pelicans—roughly defined as rates from natural mortality agents. Essentially, the survival rates assume that each pelican experiences the same rate of mortality (fixed for the population). For this reason, the population growth rates reported by the model are largely independent of population size. (In theory, except for stochastic events that may occur in smaller

[18] Note that although the model includes migration, it represents only the BGWC population. For this reason, the middle graphs suggest that all individuals leave the non-study area in fall. In reality, these locations may be occupied by pelicans from other subpopulations.

populations, the population growth rate in a population with a stable age distribution and no density dependence is independent of time and population size.)

To analyze the potential impacts of external mortality sources (such as traffic mortality on SH 48) the research team modified the improved survival version of the model to include extra mortality similar to the mortality that occurs on SH 48 during cold front events. To achieve this, the simulation was run repeatedly over 10-year periods. For each run, the research team defined a single rate of mortality per year (independent of population size), and at the beginning of each year, simulated this “pulsed mortality event” by randomly removing pelicans (older than 1 year) from the simulation. For each run of the simulation, the initial size of the population was set (randomly) between 100 and 5,000 pelicans. The results (growth rates) from each simulation run were analyzed to derive the average response of the model to a specified initial population and mortality rate.

Figure 68 shows the relationships among population size, external mortality, and population growth rate. In the figure, the colored surface represents population growth rates achieved for simulations with initial population size (*x*-axis) and annual mortality (*y*-axis). The dashed black contour shows the threshold between models that resulted in growth versus decline (i.e., marks the region where population growth is equal to 1.0). The red contour marks the region where the combination of mortality and initial population size are indistinguishable from the model run with zero mortality.

The analysis shows that when mortality is independent of population size, important interactions occur between the size of the population and the amount of mortality. In simple terms, small populations are more at risk from such perturbations than large populations. Modeled populations greater than 1,000 individuals are relatively unaffected by pulsed mortality of the order of 25 individuals per year and are not expected to decline unless mortality is greater than 75 individuals per year. Populations greater than 2,000 individuals are buffered against external mortalities up to 50 individuals per year and are not at risk of decline if external mortality is less than approximately 175 individuals per year.

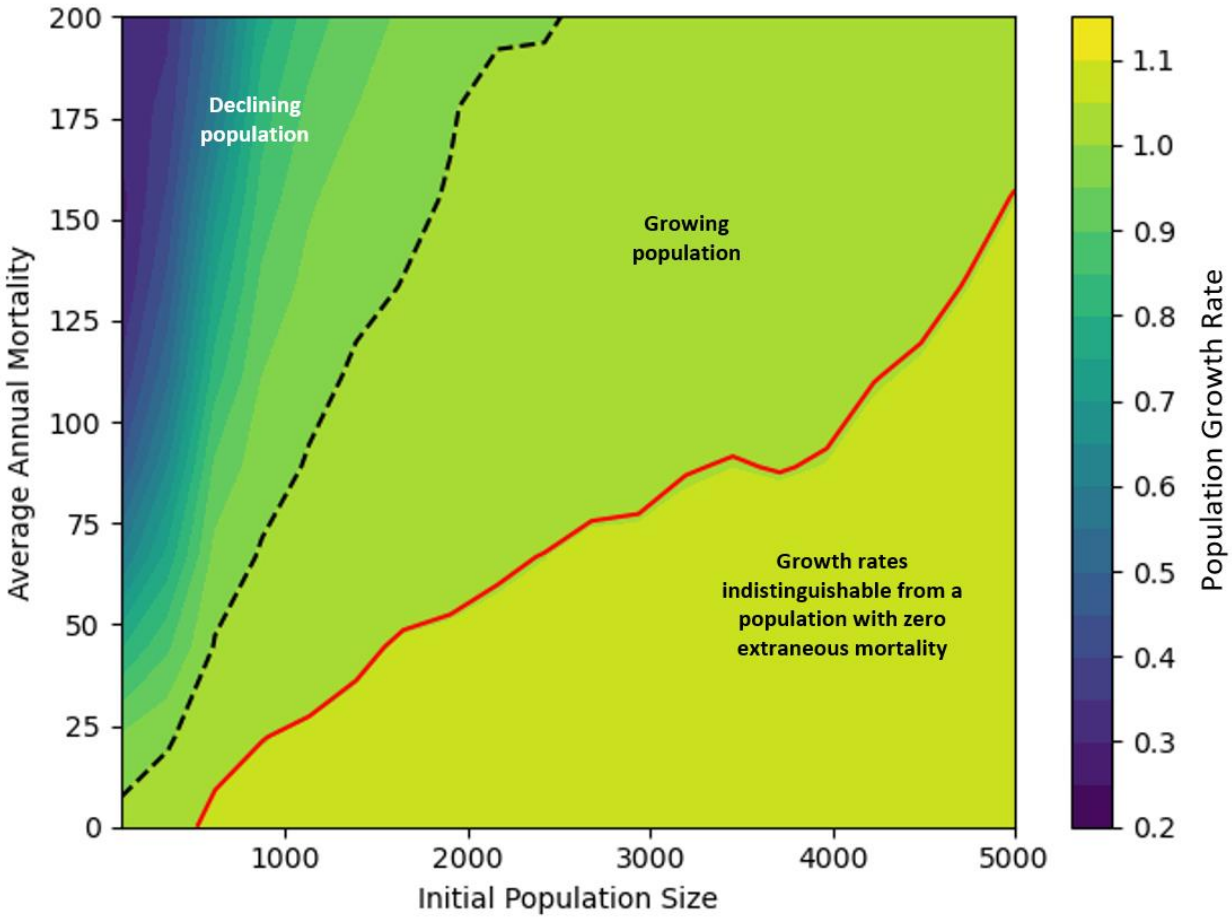


Figure 68. Effects of Initial Population Size and External Mortality on the Modeled Population Growth Rate. The colored surface plot shows estimated population growth rates for different combinations of initial population size and extraneous mortality. The dashed black contour shows the threshold between population decline and population growth ($\lambda = 1$). The solid red line shows the contour representing the growth rate of the base population model with no extraneous mortality.

DISCUSSION

This chapter describes a population dynamics model developed by the research team that integrates pelican life history processes (survival, reproduction, migration) into a systematic view of pelican population dynamics in the BGWC. The research literature contains considerable information on the life history processes of the brown pelicans. Most of those studies have focused on measuring and understanding isolated components of brown pelican biology (for example, egg production, nesting success, or migration). Useful information is also available on the long-term population growth rates of pelicans. The population dynamics model developed in this chapter integrates these life history data into a complete population dynamics model that, under a specific set of assumptions concerning adult survival, yields population growth rates consistent with those reported in the literature.

One of the objectives of this study was to use the population model to assess the adult survival rate obtained from the mark-resight experiment on the population growth rate. The calculated growth rate based on the mark-resight study was approximately 0.5, indicating a declining population. On the other hand, survival rates derived from long-term banding data (e.g., average longevity of 2.75 years) yield a population growth rate of 1.05 per year. This population growth rate is consistent with independently derived population growth rates reported in the literature, which indicates one of the following conclusions is true:

1. The survival rate reported in the mark-recapture study does not represent the true survival rate of the population.
2. The BGWC population is not a self-sustaining, viable population and remains stable because of an influx of pelicans from other more successful Gulf Coast populations (source populations).

Based on the modeling exercise and the review of pelican life history, it is the view of the research team that the population within the BGWC is sustainable (or nearly so), and the survival rate obtained in the mark-resight analysis is too low relative to the true survival rates. Specifically, the research team proposes that the survival rates from the mark-resight analysis are biased because of the transient nature of pelicans in the BGWC.

The migratory nature of the Gulf Coast pelican population makes it difficult to study the BGWC independently of the broader population. The review of life history information suggests that the Gulf Coast population is partially migratory meaning that some pelicans within a population migrate while others do not and that different subpopulations have different migration rates and different migratory destinations. According to the GPS data and banding data collected during this project, approximately 80 percent of the BGWC undertake round-trip migrations to northern summer habitats every year. However, this view of the BGWC population is an oversimplification of the migratory process and is largely a result of observing pelicans in the BGWC study area. Instead, the life history review presented in this chapter illuminates a situation where a portion of the BGWC pelican population are only temporary visitors in the sense that the study area is a stopping-off point on migrations to overwintering sites further south. For example, at least 17 percent (six of 35 pelicans) tracked in this study were captured in the BGWC in fall or winter and then migrated to more southern overwintering ranges soon after they were caught. Furthermore, 19 pelicans tracked by Lamb (2016) passed through the BGWC study area on the way to winter habitats further south, while only three used the BGWC as a winter habitat. Assuming that the BGWC represents only a portion of potential winter pelican habitat along the Gulf Coast and that most pelicans that overwinter north of the Yucatan Peninsula migrate along the coast (rather than across the gulf), it is likely that during this migratory period, many transient pelicans will pass through the BGWC study area on their way to more southern overwintering sites.

Figure 69 illustrates these population dynamics conceptually. Figure 69 represents the seasonal dynamics of populations as described by the population model (Figure 67) but with the addition of an extra class of pelicans (northbound and southbound migrators), as illustrated by the dashed green lines. Intuitively, the relative proportion of transient pelicans in the population at any time depends on the number of pelicans that pass through the study area and the average length of time they reside in the BGWC study area before they move further south. GPS data suggest that the southbound migrations (resulting in fall transients) occur over a longer period than the northbound migrations (spring transients). Southbound migrations are characterized by a gradual movement of pelicans southward, possibly in response to colder temperatures. In many cases, pelicans that migrate through the BGWC or overwinter there temporarily reside in coastal lagoons north of the BGWC (e.g., Galveston Bay, Matagorda Bay, Corpus Christi Bay, Baffin Bay, the BGWC, and the Laguna Madre del Rio Bravo) before they reach their ultimate overwintering habitat. In contrast, the northward spring migration is more direct. The review of life history information provides additional context here—most authors report nest site preference and that birds that arrive early and occupy these nest sites tend to be more successful at raising young.

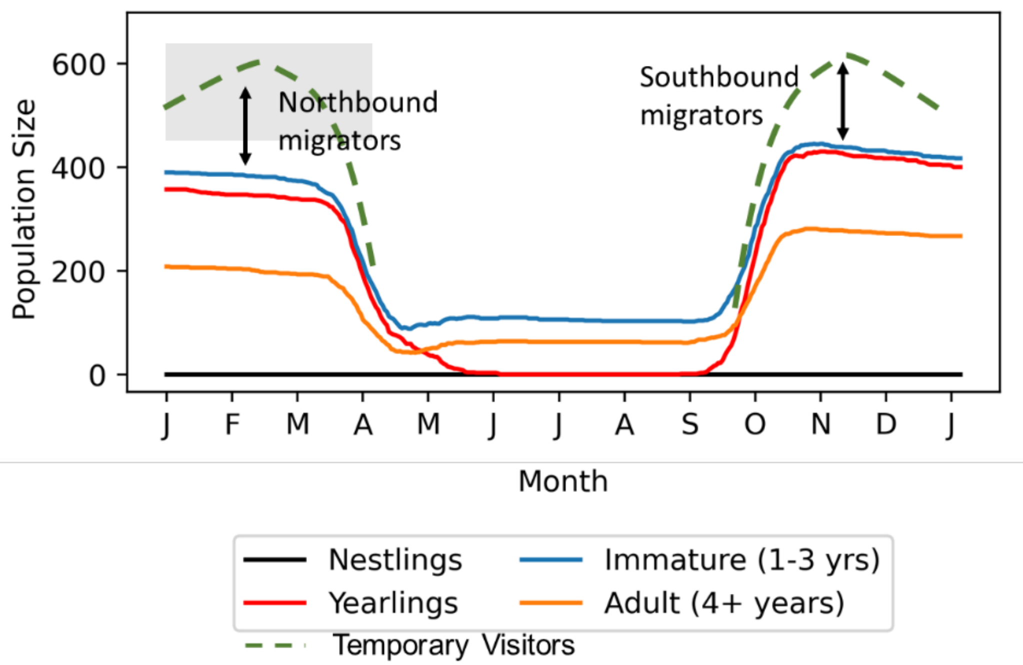


Figure 69. Intra-annual Population Dynamics within the BGWC Study Region.

The view of population dynamics presented in Figure 69 is a product of the life history review and population modeling process undertaken in this study. The research team proposes that this informed view of BGWC population dynamics has important implications for SH 48 mortality. Most pelican mortality occurs in the fall and coincides with cold fronts that bring strong winds.

Figure 68 illustrates the implications of SH 48 mortality on the BGWC population, assuming that the population is sustainable (i.e., survival rates consistent with those reported in the literature). The analysis explicitly assumes that extraneous mortality is independent of population size. In other words, it is designed to dissociate (partition) extraneous mortality (such as traffic mortality), from natural (or baseline) pelican mortality in the region. The figure is designed to assess the potential impact of SH 48 mortality on the sustainability of the BGWC population.

CONCLUSIONS

The migratory behavior of Gulf Coast brown pelicans makes it difficult to independently model subpopulations such as those that overwinter in the BGWC and generally makes the interpretation of population size difficult. Nevertheless, the population dynamics model has resulted in some insights important for understanding the dynamics of pelicans in the BGWC.

- The literature review of pelican life history and population dynamics suggests that during their recovery, Gulf Coast brown pelican populations have increased at rates of approximately 10–20 percent per year.
- Migration characteristics derived from the literature review are consistent with those derived from this project.
- This study identified a situation wherein a portion of the BGWC pelican population are only temporary visitors in the sense that the study area is a stopping-off point on migrations to overwintering sites further south. GPS data suggest that the southbound migrations (fall transients) occur over a longer period than the northbound migrations (spring transients). Southbound migrations are characterized by a gradual movement of pelicans southward, possibly in response to colder temperatures.
- The adult survival rate derived from the mark-resight analysis ***does not*** result in a sustainable BGWC population. However, the survival rates reported from the literature review ***do*** result in population growth rates commensurate with independently reported population trends. Based on the evidence from this review, the research team proposes that it is most likely that the mark-resight experiment and analysis has resulted in a biased (lower) survival rate that has been biased because of the use of transient pelicans in the mark-resight analysis.
- Adult survival process is the most important of the life history process for maintaining a sustainable BGWC population. In this study, the researchers used an individual-based modeling approach to allow complex ecological processes to be incorporated into the model. The research team analyzed the model by assessing the sensitivity of simulation model parameters on population growth rate. The sensitivity analysis indicates that the modeled population growth rate is most sensitive to the survival rate of adults.
- Assuming that traffic-induced mortality on SH 48 is independent of population size, important interactions occur between the size of the population and the amount of extraneous mortality. Modeled populations greater than 1,000 individuals are relatively

unaffected by extraneous mortality of up to about 25 individuals per year and are not expected to decline unless mortality is greater than 75 individuals per year. Modeled populations of greater than 2,000 individuals are buffered against external mortalities up to 50 individuals per year and are not at risk of decline if external mortality is less than approximately 175 individuals per year.

CHAPTER 5. ESTIMATING BROWN PELICAN POPULATION ABUNDANCE IN THE BAHÍA GRANDE WETLAND COMPLEX

In the previous chapters, the researchers estimated seasonal movement and survival of brown pelicans in the BGWC. The analyses suggest the size of the BGWC pelican population varies considerably throughout any given year and that specifically pelicans are most abundant in the BGWC during the winter months (November to March). In the spring, approximately 80 percent of pelicans migrate from the BGWC to summer breeding grounds in the northern Gulf. The results of the GPS study suggest that these northern breeding grounds include barrier island-protected lagoons around Corpus Christi and Houston and islands and shallow waters of the Mississippi Delta. Pelicans begin to migrate back to the BGWC in late summer, reaching the study area by November.

Although the results from previous chapters provide essential information on timing, location, and magnitude of migration, they do not provide quantitative information on the abundance and population density of pelicans in the BGWC. This chapter discusses how the research team estimated the size of the brown pelican population in the BGWC—the core study area of this project. Estimating population size is essential to effectively managing wildlife. In the case of the BGWC pelicans, population size estimates provide key context for:

- Assessing local mortality in the context of the total size of the population in the BGWC.
- Determining the relationships among population size, the numbers of pelicans crossing SH 48, and the number of crashed and killed pelicans on SH 48.

METHODS AND RESULTS

The research team estimated BGWC brown pelican population abundance using three methods:

- Mark Resight methods that calculate abundance based on the ratio of banded to unbranded birds observed in the population.
- Field counts of the number of pelicans crossing SH 48 observed during year-round surveys.
- Surveys to estimate the number of pelicans roosting at a key roost site location.

The methods and results are described in the following sections.

Mark Resight Methods

Mark-resight or mark-recapture methods have been widely used as a method of estimating population size from survey data. Classical mark-resight/recapture studies proceed as follows:

1. A focal study area is defined (i.e., an area that contains the population of interest).

2. A discrete capture session is organized during which animals are trapped, marked with either a unique identifying mark (such as by putting a band with an alphanumeric letter sequence on a leg) or marks that can be used to determine whether the individual has been caught previously (or has never been caught).
3. A series of resight or recapture surveys are undertaken during which the number of unmarked and marked individuals are recorded. In mark-recapture studies, unmarked individuals caught during subsequent surveys are often also marked before being returned to the focal study area. However, mark-resight surveys usually involve a single capture period, followed by subsequent resight-only surveys (i.e., no animals are marked subsequent to the original capture period).

The foundation of mark-resight analysis is estimates of the total size of the population using the ratio of marked to unmarked individuals observed during sampling:

$$\frac{S_{marked}}{S_{total}} = \frac{N_{marked}}{N_{total}} \quad \text{Equation 5.1}$$

Where:

$\mathbf{N_{total}}$ is the estimated total population size,

$\mathbf{N_{marked}}$ is the number of marked individuals in the population,

$\mathbf{S_{total}}$ is the total number of individuals (i.e., marked + unmarked) during a subsequent resight survey, and

$\mathbf{S_{marked}}$ is the number of those total sighted individuals that were marked (i.e., resighted individuals).

It is also useful to define two additional quantities:

$\mathbf{S_{unmarked}} = \mathbf{S_{total}} - \mathbf{S_{marked}}$ is the number of observed birds that were unmarked, and

$\mathbf{N_{unmarked}} = \mathbf{N_{total}} - \mathbf{N_{marked}}$ is the estimated number of birds in the total population that were unmarked.

Although not used in the equation above, these added terms are useful for the remainder of this section. Equation 5.1 can be rearranged to calculate the total population's size (N_{total}):

$$N_{total} = \frac{N_{marked} * S_{total}}{S_{marked}} \quad \text{Equation 5.2}$$

Equation 5.2 is known as the Lincoln-Peterson estimator and is the simplest method by which to estimate population size using mark-resight data.

Another way of framing Equation 5.1 is:

$$N_{total} = \frac{N_{marked}}{SP_{marked}} \qquad \text{Equation 5.3}$$

Where:

SP_{marked} is the proportion of marked (or banded) birds sighted during a survey (i.e., the number of banded birds divided by the total number of sightings).

Equation 5.3 states that the total number of birds in the population can be found by knowing (or having estimates of) two fundamental pieces of information:

1. The number of marked birds in the population, and
2. The ratio or proportion of marked to total sighted birds obtained through resight sampling.

The Lincoln-Peterson index generally requires a specific set of assumptions to be met for it to be a statistically reliable method for estimating population size. Table 8 lists these assumptions in the context of this brown pelican study. Although none of these assumptions are completely true for the BGWC brown pelican study population, the simplicity of the Lincoln-Peterson method makes it a useful way of exploring the pelican resight data before more advanced methods are used.

Table 8. Assumptions of the Lincoln-Peterson Method Compared to Analogous Characteristics of the Study Data.

Assumption	Pelican Study
Animals occur in a spatially and demographically closed population (i.e., one where there are no births, deaths, or movement in or out of a study area); or the time between capturing (banding) occasions and resight survey is small enough such that the assumption of a closed population is practically true.	Pelicans are known to migrate to and from the study area, and since the abundance sampling occurred over greater than one year, births and deaths are also likely to have occurred.
Individually marked animals are equally likely to be resampled following capture (i.e., there is no avoidance or other behaviors such as aggregation that make some individuals more likely to be resighted than others).	For pelicans, this concept may be true and is a useful simplifying assumption. However, pelicans do aggregate, and habitat selection may also lead to breaking the assumption of random mixing (equal catchability).
The number of marked animals in the population is exactly known. In other words, animals do not migrate (first assumption above), and marks are permanent and do not fall off animals.	Pelicans were marked (banded) over a year-long period and resighted over a subsequent year-long period. Since the pelican population is demographically and spatially open, it is not possible to know the number of bands in the population at any point in time.

Open-Population Lincoln-Peterson Method

Pelican resight surveys were conducted at multiple sample locations over an approximately 12-month period. The research team modified Equation 5.3 to estimate population size for each survey location and survey date, specifically:

$$N_{total_{[date,location]}} = \frac{N_{marked_{[date]}}}{SP_{marked_{[date,location]}}} \qquad \text{Equation 5.4}$$

Where:

The date and location subscripts correspond to individual measurements taken at each survey location on each date.

The N_{marked} term in Equation 5.4 only has a date subscript because the term represents the estimate of the number of banded individuals in the entire study area. The date and location subscripts for N_{total} indicate that Equation 5.4 estimates the total study area population for a specific date but is derived from sighting data collected at one specific survey location. The SP_{marked} variable is subject to sample error—i.e., there is inherent variation in the total number of birds, and the number of banded birds encountered at a specific survey location (similar variation should also be expected by date). To offset variation between locations, the researchers also pooled the S_{total} and S_{marked} estimates (Equation 1) across locations to yield a best estimate of the population size on a given sample date:

$$N_{total_{[date]}} = \frac{N_{marked_{[date]}}}{SP_{marked_{[date]}}} \qquad \text{Equation 5.5}$$

Where:

The denominator is the sum of S_{marked} (for all locations on a sample date), divided by the sum of S_{total} observed at all sample locations.

Equations 5.4 and 5.5 require an estimate of the number of $N_{marked[date]}$ or the number of banded birds in the study area population on a specified survey date. During this study, 310 banded pelicans were introduced into the population over approximately one year, and resight sampling occurred for a year thereafter. Since the pelican population is demographically and spatially open, it is not reasonable to assume that all the original banded birds remain in the study area. Therefore, the research team employed the data and analyses from the previously described mark-resight study to estimate the number of banded pelicans in the study area population at each resight survey. The models were simulated stochastically to give 100 permutations of the possible number of bands within the population throughout the resight surveys. For the simple Lincoln-Peterson method, the mean of the estimated number of banded pelicans is used to estimate N_{marked} in Equations 5.4 and 5.5.

Minta-Mangel Estimator

The Lincoln-Peterson Index provides a simple way of determining population size using banding and resight data. However, it lacks statistical rigor. To overcome this, the research team analyzed the resight survey data using a modified form of an analysis method described by Minta and Mangel (1989). The original Minta-Mangel (MM) estimator uses Monte Carlo simulation to estimate the number of unmarked animals in a population based on the number of observed sightings (S_{total}, S_{marked}, and $S_{unmarked}$) and a theoretical or empirical probability distribution describing the probability of resighting marked individuals a specified number of times throughout the survey period.

The MM estimator proceeds by performing a Monte Carlo simulation a specified number of times, generating a different population estimate (N_{total}) after each iteration. The resulting distributions of N_{total} estimate are then used to determine statistical properties such as the mean, median, and confidence intervals associated with the population estimate.

In simple terms, the MM estimator method assumes that, on average, every sighted unmarked bird is associated with an average number of sighted marked birds. The Monte Carlo simulation estimates the many different numbers of unmarked birds that *might* have been generated given two essential pieces of information:

1. The number of marked and unmarked birds sighted during a survey.
2. Assumptions about how often individual birds are sighted (i.e., the resight frequency probability distribution).

The sight ability of banded animals (described through a resight frequency probability distribution) is important for determining population size, and the effects of sightability on population estimates have been well studied. The simplest assumption about sightability is that all banded individuals are equally likely to be sighted during a given survey. In other words, banded individuals are well mixed (randomly distributed) within the greater population. In this case, the number of banded sightings out of S_{total} sightings should be (approximately) binomially distributed with the probability of sighting a banded bird ($p = N_{marked}/N_{total}$). In such cases, simple estimators such as the Lincoln-Peterson method can provide accurate, unbiased estimates of population size—especially when sample sizes are large.

On the other hand, if banded individuals do not have equal probabilities of being sighted, estimates of population size can be biased. For example, if subsets of a population prefer different habitats and these factors are not adequately covered by sampling locations, considerable differences in sightability among individuals may exist. In such a case, the equality shown in Equation 5.1 may no longer hold, and the total population size will be under- or overestimated. The MM method was designed to incorporate information on the sightability of individuals into the population estimate (through the resight frequency probability distribution), which makes it a useful estimator that can be used to explore the effect of resight probability on population estimates.

Like other abundance estimators, the original MM estimator assumes a closed population (with repeated resight surveys). The research team modified the original method to make it suitable for estimating the seasonal population dynamics of pelicans in the BGWC.

The modification (like the open-population modification of the Lincoln-Peterson method) involves using the original MM estimator to estimate abundance using data relevant to defined subperiods within the total survey period. Each subperiod is defined by a start date and a duration (in days). Since each subperiod is small (relative to the larger survey period), a closed population is assumed, and the original MM estimator is used to estimate population size. A single iteration of the modified MM estimator involves estimating the population size for each consecutive subperiod of the entire sample period. This process was repeated 1000 times, with each iteration of the Monte Carlo simulation using a different sequence (defined by start date and duration) of subperiods. As in the previously described Lincoln-Peterson-based method, the number of banded birds in the population at each sample date was estimated using data and models described in the previous mark-resight chapter.

Testing Abundance Estimation Methods Using Simulated Data

Due to the constraints of the experimental design used in this study, the research team tested the Lincoln-Peterson and MM population estimation methods using simulated data. Simulated population data were generated using the population dynamics model described in Chapter 4. An additional module was added to the model to simulate the addition of banded birds to the virtual pelican population, followed by the generation of abundance survey data (S_{marked} and S_{total} counts) taken at five locations and uniform five-day intervals during a (simulated) year-long virtual survey period. On each sampling occasion, and at each virtual survey location, a Poisson distributed random sample of S_{total} birds were selected from the simulated population. The number of virtually banded birds within this S_{total} was then calculated. In this way, the simulation assumed equal sightability of banded birds in the population such that all samples (S_{total} and S_{marked}) were taken from the population without replacement (as if replicate daily surveys were conducted simultaneously). The simulated total population, the number of banded birds, and abundance survey data were saved to files.

Finally, the Lincoln-Peterson and MM algorithms described above were tested on the simulated data. Specifically, the objective was to assess the ability and accuracy of the algorithms to estimate the known simulated population (N_{total}) from the simulated resight survey data (N_{marked}, S_{total}, S_{marked}). The results of these tests are provided in Appendix V.

Mark -Resight Field Observations

Figure 70 shows the actual number of pelicans sighted through the survey period. In this graph, the black dots show the total number of birds sighted during each 30-minute survey. The red dots, paired with the black dots, show the number of banded pelicans sighted during the same surveys. Figure 71 shows the proportion of banded birds (relative to the total number of sighted birds) calculated for each survey.

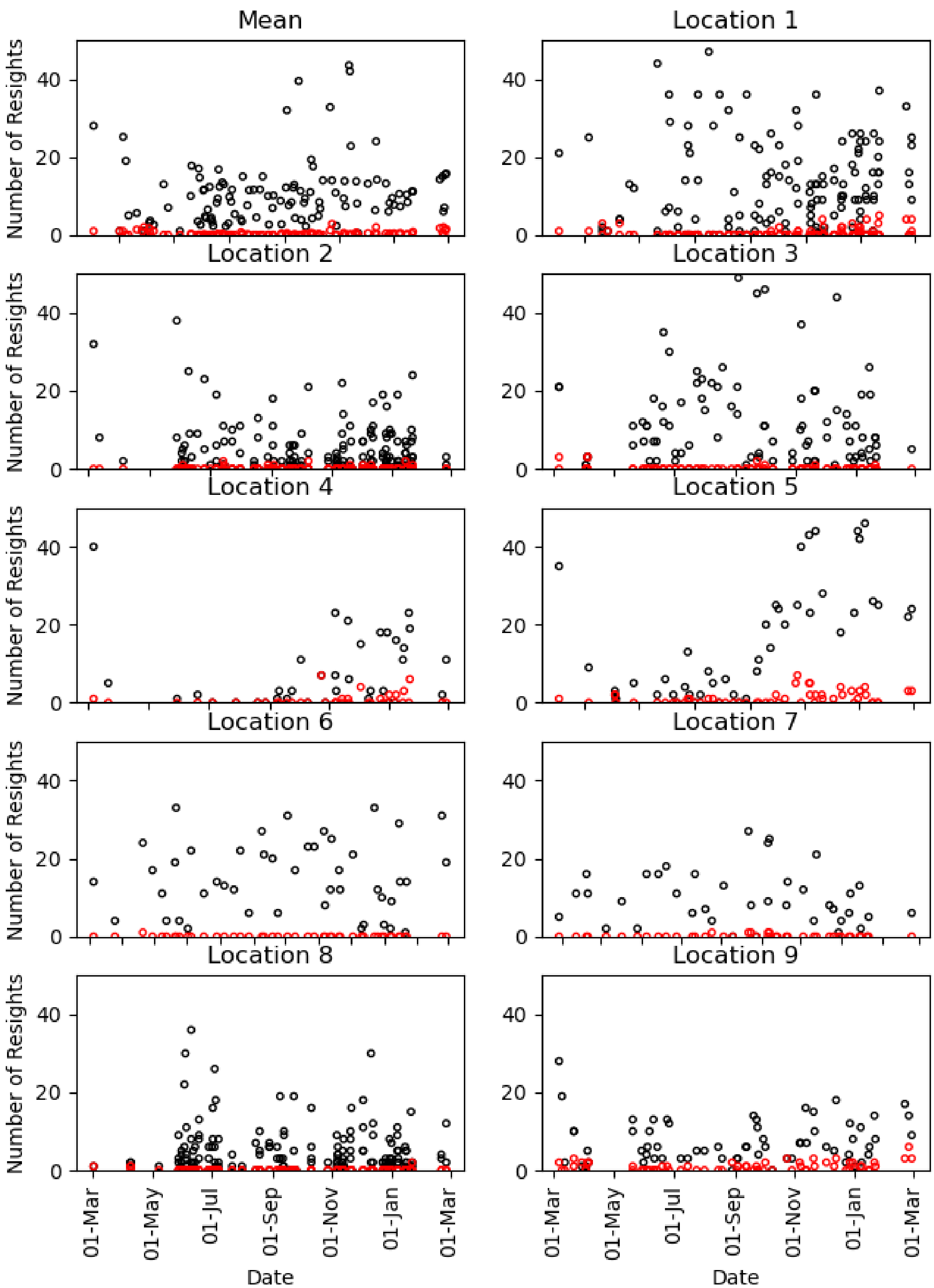


Figure 70. Plots of Total and Banded Sightings during Regular Surveys between March 2019 and March 2020. The open black dots show total pelicans observed during the survey period, while the red circles show the number of banded resights. The top left graph shows data aggregated as a mean across all survey locations. Each subsequent graph shows data for each survey location.

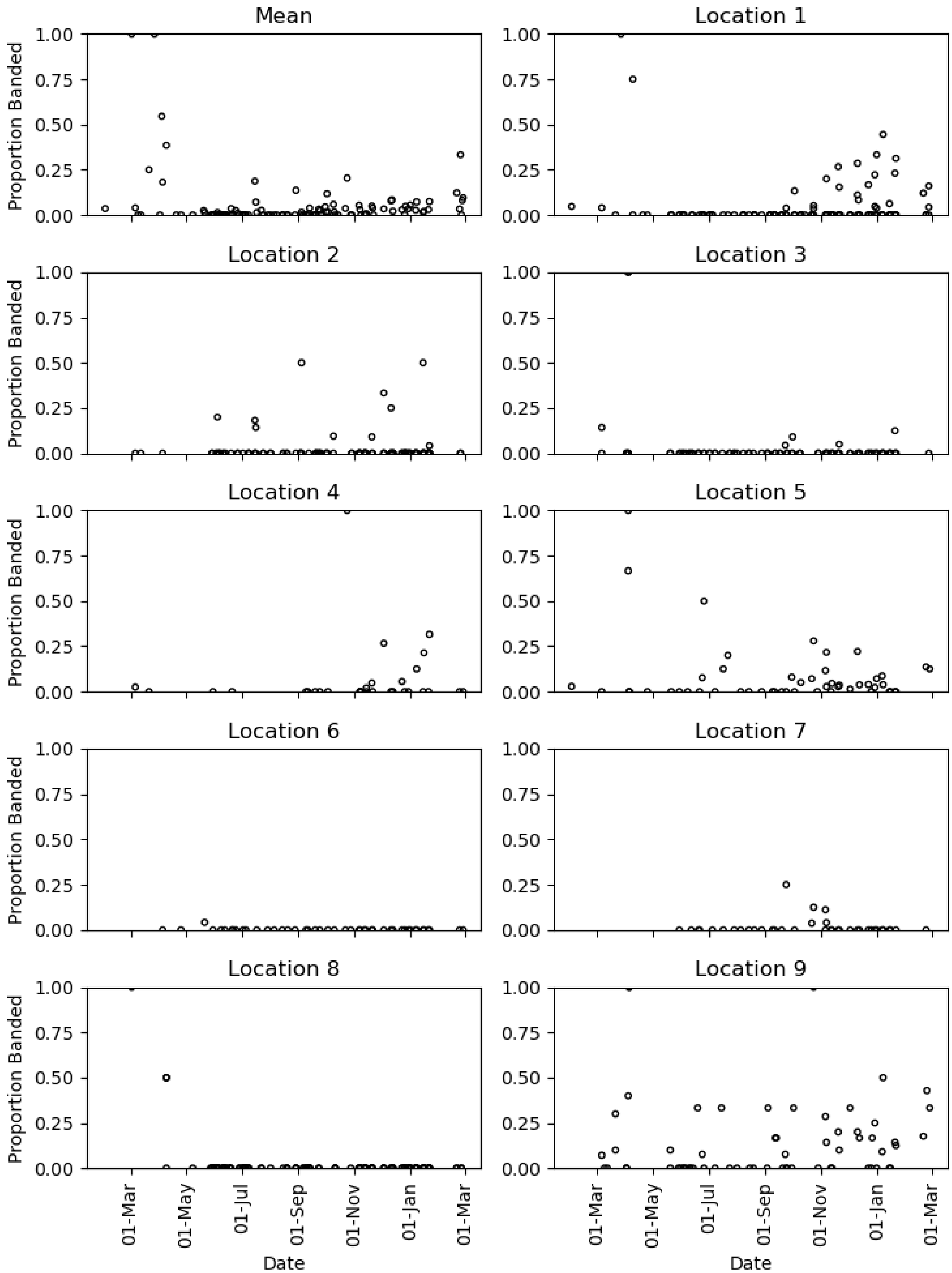


Figure 71. Plots Showing the Proportion of Banded Pelican Sightings during Regular Surveys between March 2019 and March 2020. The top left graph shows data aggregated across all survey locations. Each subsequent graph shows data for each survey location.

Figure 72 shows the frequency distribution of resights of individual birds during the abundance surveys. These frequency distributions represent the proportion of the marked population that were sighted a specified number of times throughout the study period. In this figure, the solid black line shows the frequency distribution observed during the study (i.e., the probability or frequency with which individually marked birds were resighted). The red line shows the frequency distribution that would be expected assuming equal sightability of each bird in the population (i.e., a binomial distribution). The empirically derived frequency distribution is like the theoretical binomial case, although there is some evidence that resights were not equally probable among all birds (i.e., some birds were resighted more frequently than others).

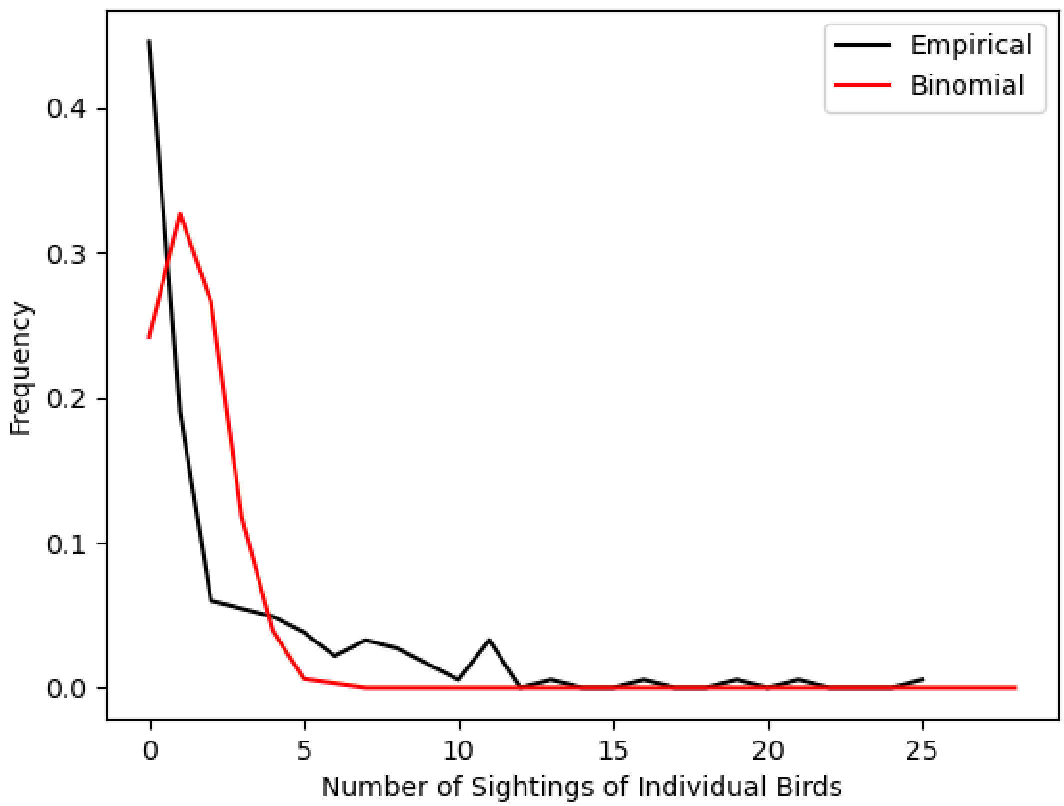


Figure 72. Sighting Frequencies of Birds Banded during the Study. The graph illustrates the frequency (*y*-axis) that uniquely identified birds were sighted the number of times specified by the *x*-axis. The black line shows the sighting frequencies derived from the sample data. The red line shows sighting frequencies assuming all banded birds are sighted with equal probability (i.e., a binomial distribution).

Figure 73 shows temporal pelican abundance estimated using the Lincoln-Peterson method described above. The figure on the left shows the population size estimated for each sample day (using data from all survey locations). The right-hand graph shows the monthly average of these population estimates. Using monthly averages, the estimates show a pattern of relatively large populations in the winter months, with populations beginning to increase in August and climb to approximately 3,000 pelicans by November. In summer, the data and models suggest populations of approximately 1,000 pelicans.

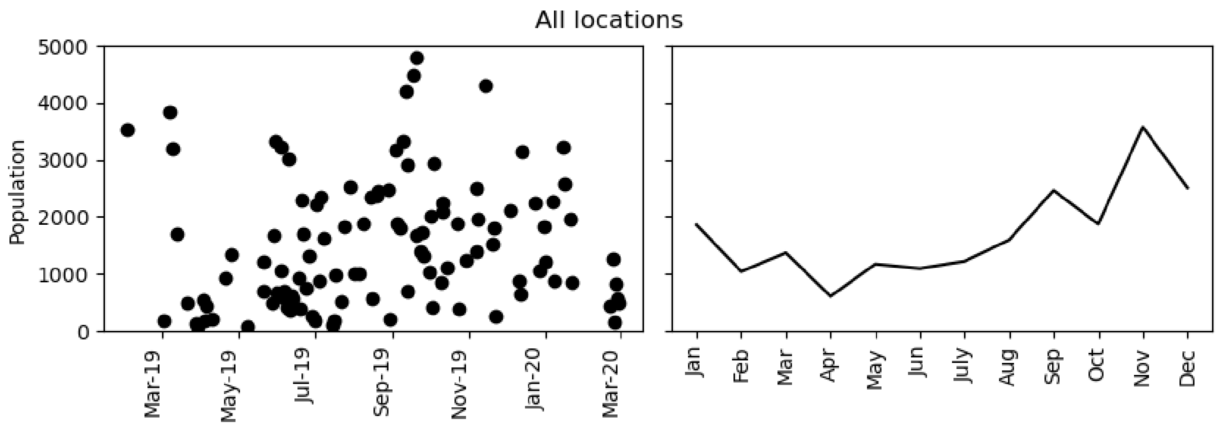


Figure 73. Lincoln-Peterson-Based Estimate of Brown Pelican Population Size in the Study Area by Month. The left graph shows the population size estimated for each sample day using data from all survey locations. The right-hand graph shows the monthly average of these population estimates.

Figure 74 shows the temporal pelican abundance estimated using the modified MM method. This method estimates a peak population abundance of approximately 1,000–2,000 pelicans between November and March and approximately 400 pelicans in midsummer. The associated confidence intervals provide statistical bounds for these estimates.

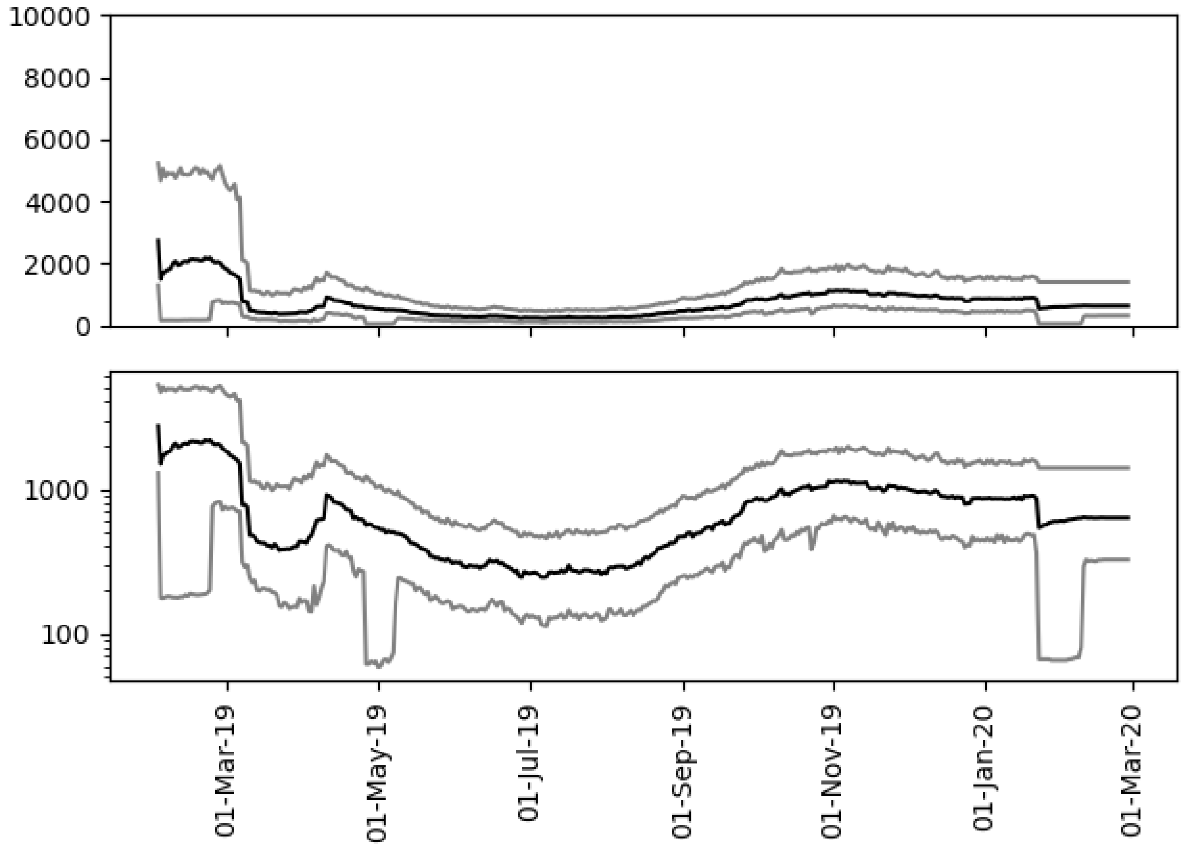


Figure 74. Modified MM-Derived Estimates of Temporal Changes in Abundance of Brown Pelicans in the Study Area. The top graph shows populations on a conventional scale. The lower graph shows the same information on a log scale. The solid black line represents the average population (estimated for the time period shown on the *x*-axis). The gray lines delineate approximate 95 percent confidence intervals.

SH 48 Crossings and Roost Site Use

In addition to the mark-resight methods, the research team undertook regular count surveys of pelicans flying over SH 48 at different times of the day, and year. The GPS data outlined in Chapter 2 indicate that all the pelicans that roost in the Bahia Grande enter and exit these roost sites by crossing SH 48 (e.g., Figure 35). Intuitively then, assuming that roost site choice is relatively constant[19], the total size of the BGWC brown pelican population can be estimated using the following information:

1) The number of pelicans crossing SH 48

2) The number of proportion of pelicans that use Bahia Grande roost sites.

[19] The proportion of the total pelican population that use different roost sites is relatively constant through time.

To furnish this estimate of population abundance the research team surveyed SH 48 pelican crossings between November 2017 and March 2021. Each survey consisted of pelican counts over a 30 minute to 3-hour period during which time field scientists recorded the number of pelicans crossing SH 48 including information on the direction of travel (north or south), altitude, time of crossing, group size (i.e., number of individuals crossing in formation), and the location of crossing. Crossing surveys were conducted throughout all months of the project, and to cover each daylight hour. However, a greater proportion of surveys were conducted in the morning and evening when crossing activity is highest. Approximately 250 crossing surveys (approximately 300 hours) were undertaken during the study.

Figure 75 shows the number of pelicans crossing SH 48 by month and time of day where crossings are described by a crossing rate (pelicans crossing per hour of an individual survey). These figures include data for north and south crossings. The figure illustrates that most crossings occur in the morning and evening, while crossings during the day tend to be less frequent. South crossings tend to occur in the mornings as pelicans emerge from roosts in the Bahia Grande, while evening crossings tended to comprise pelicans moving towards the Bahia Grande roost sites. Figure 75 also shows observed symmetry in terms of the number of pelicans crossing SH 48 in the mornings versus evening.

The data in Figure 75 are raw field counts expressed as a crossing rate (number of pelicans observed to cross SH 48 divided by the length of the survey). Care must be taken in interpreting this data directly because each survey occurred at different times of the day and because the durations of surveys were not equal. As such, it is possible that a high crossing rate was measured because, by chance, a relatively large number of pelicans crossed SH 48 during the survey. Conversely a low crossing rate may occur if, again by chance, relatively few pelicans cross during a survey period.

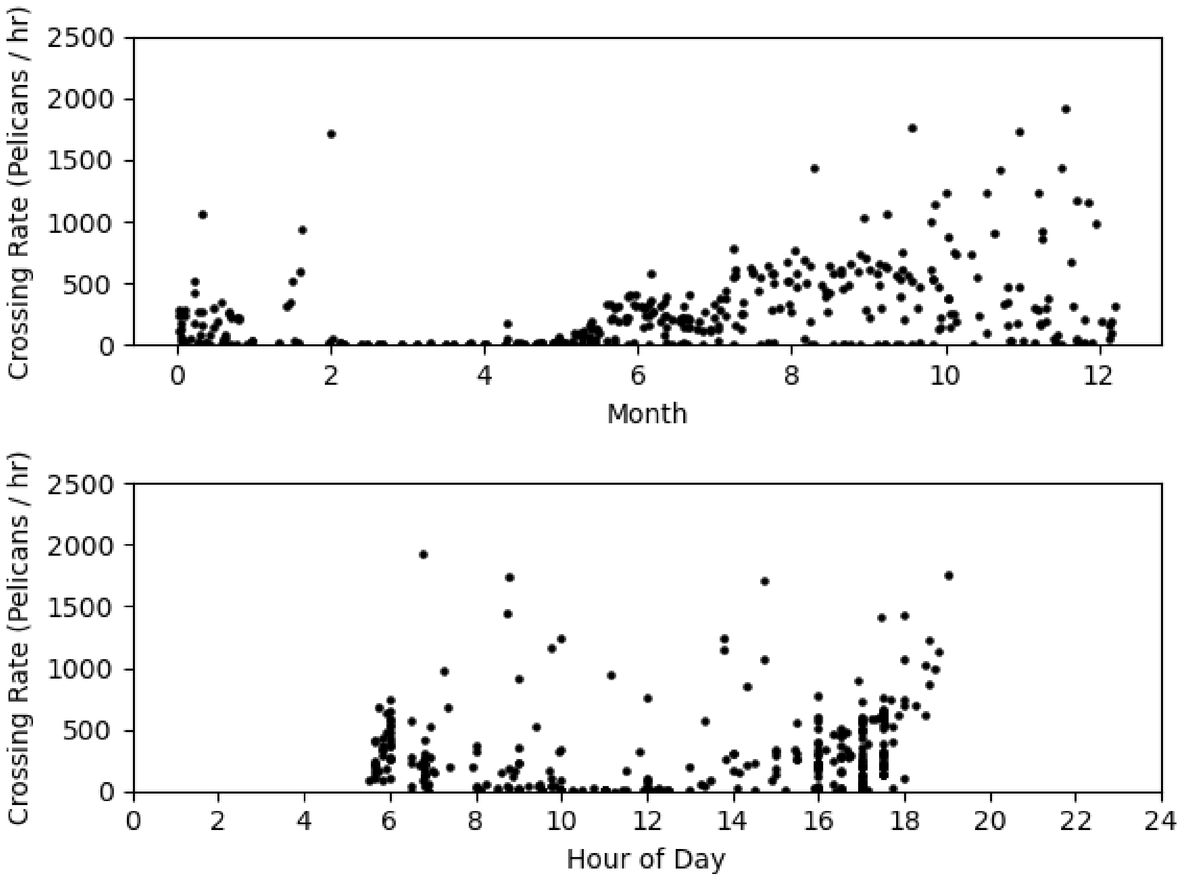


Figure 75. Observed Rates (per hour) of Pelicans Crossing SH 48 by Time off Day and Month.

Figure 76 and Figure 77 show the results of extrapolating the crossing rate data (Figure 75) into estimates of total daily crossings for each month of the year. The estimates were obtained using data from the GPS study detailing the timing of movement from and to roost sites (Chapter 2, Figure 21). In Chapter 2, the timing of movements to roost sites was shown to follow a normal distribution where the mean arrival time at roost sites is equal to the time of sunset, and the standard deviation is equal to approximately 90 minutes. Movement from roost sites followed a similar distribution with a mean corresponding to sunrise, and similar standard deviations. The rate data shown in Figure 75 were extrapolated to daily crossings by calculating the proportion of total daily crossings that would be expected to cross in a given survey period according to the probability distributions derived from the GPS study. Estimated total crossings were then calculated by dividing the number of pelicans that crossed during the sample period by this proportion. For example, a survey period extended from 2 pm to sunset should, according to data from the GPS study account for an average of half the pelicans crossing in a specified direction on any day. Therefore, if 1000 pelicans were observed to cross within this survey, then the estimate of total crossings is 1000 multiplied by 0.5, or 2000 individuals[20]. This procedure was undertaken for all surveys (defined by their start and end time, and the number of individuals observed to have crossed SH 48) that fell within the range of the time to roost data obtained from the GPS study. For example, data from surveys that started after 12 pm were used to estimate daily northbound crossings (from counts of pelicans moving northwards) while surveys completed before 12 pm were used to estimate daily southbound crossings from counts of pelicans moving southwards.

Figure 76 shows estimates of daily crossings by month based on survey counts of northward crossings and estimated using the extrapolation method described above. Figure 77 shows the same information for southward crossings. In these figures, the solid black line shows the mean daily estimated crossing rate for a specific month. The dashed lines show the 95th percentile confidence limits, while each point represents an extrapolation from an individual survey. Given the methods of extrapolation, the variation in total crossings should be interpreted as a combination of error associated with the extrapolation technique and inherent variation in the actual number of pelicans crossing SH 48 on different days. Both figures suggest a similar pattern of increased SH 48 crossings between June and February, with peak crossings occurring in August, September, and October. Interestingly, estimates of total crossing in December are relatively low in both figures (although Figure 75 shows that surveys in late November yielded crossing rates of over 1000 pelicans per hour). Another striking feature of both figures is the consistency in estimates of northward and southward crossings. Figure 76 shows a peak of approximately 2500 northbound crossings per day (on average), while Figure 77 shows a peak of approximately 2000 total southbound crossings

[20] Suggesting that the other 50% of daily crossings occurred after sunset in line with the GPS study data.

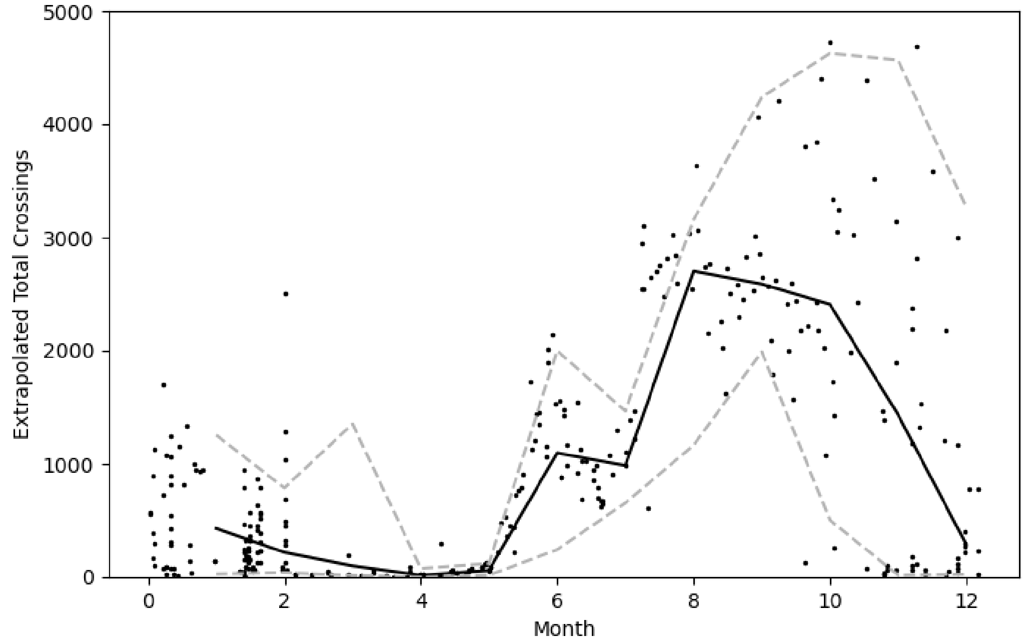


Figure 76.Estimated Monthly Evening (Northbound) Brown Pelican Crossings Over SH 48. The solid black line shows the median number of estimated crossings per month calculated by extrapolating from individual field counts (black dots). The dashed lines show the 5th and 95th percentile of crossing estimates.

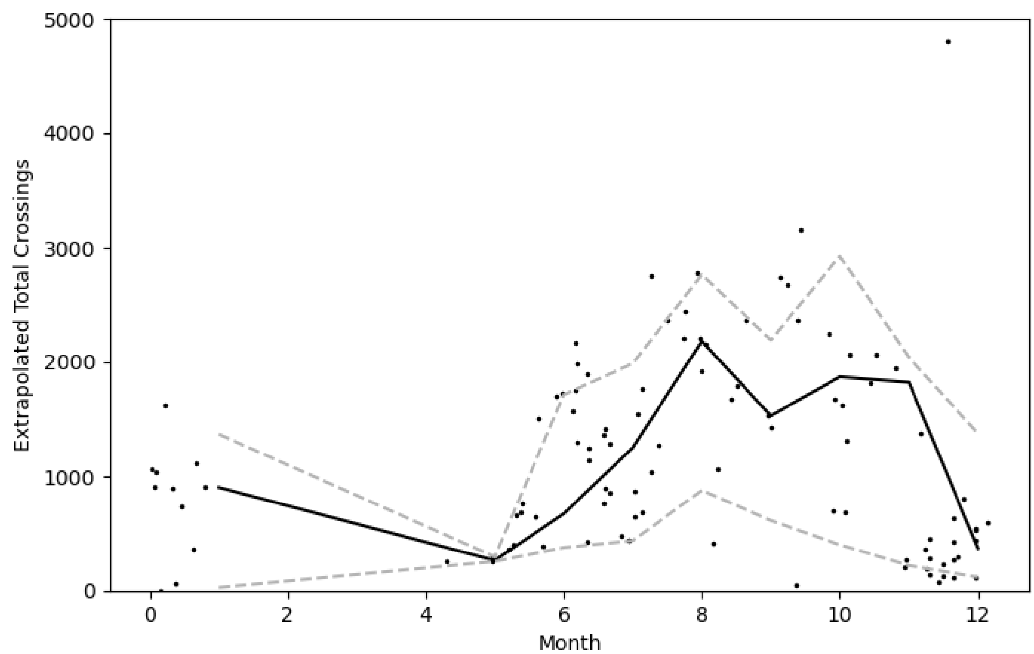


Figure 77.Estimated Monthly Morning (Southbound) Brown Pelican Crossings Over SH 48. The solid black line shows the median number of estimated crossings per month calculated by extrapolating from individual field counts (black dots). The dashed lines show the 5th and 95th percentile of crossing estimates.

Use of Bahia Grande Roost Sites

Figure 79, Figure 80 and

Figure 81 illustrate the proportion of visits to key roost sites in the BGWC. In these figures the roost sites (x-axis) have been simplified into the following locations: BG = Bahia Grande, BSC Island = Brownsville Ship Channel Island, LM = Laguna Madre, LM-RB = Laguna Madre Rio Bravo (south of the Mexico border), South Wetlands = wetlands adjacent to the BGWC south of the Mexico border, Swing Bridge = Port Isabel Swing Bridge Island, and all other roost sites. Figure 78 shows these roost site locations.

Figure 79 shows the proportional visits to different roost sites by individual pelicans tracked using GPS. Figure 80 shows the relative use of different roost sites by month of the year (with all pelicans aggregated into a single statistical population).

Figure 81 shows proportional roost site use by individual pelican and by month. In Figure 79 and Figure 80, the series of markers associated with each roost site is a result of a bootstrap analysis that investigates the effect of sample size (the number of pelican days included in the analysis) on estimates of roost site use. The markers associated with Bahia Grande roost sites are colored red. The bootstrap approach ensures that interpretation of the data accounts for the effect of unequal sample sizes in the underlying data. For example, Figure 80 shows that no GPS tracked pelicans were present in the area during May and June, and that few individuals were present in April and August. Because of this, the error associated with estimating roost site use in April and August is high because there were very few records of BGWC roost site use during these months.

This detailed analysis of roost site use confirms the findings presented in Chapter 2 – that the roost site in the Laguna Madre is by far the most used roost site. Figure 79 illustrates that most birds tracked during the study consistently used the Laguna Madre roost site and only two individuals used the Bahia Grande roost sites frequently. These two pelicans spent between 10 to 50 percent of nights in Bahia Grande roosts. Figure 80 indicates that the use of different roost sites remains relatively constant by month.

Figure 81 indicates that there is no discernable interaction between the seasonal use of roost sites and individual pelicans.

Estimating Abundance from SH 48 Crossings and Roost Site Use

Assuming SH 48 crossings are proportional to total population size, the total size of the population can be estimated by dividing the total number of SH 48 Crossings by the proportional use of Bahia Grande Roost sites (i.e., the number of nights spent roosting in the Bahia Grande as a proportion of the total number of roost nights measured for the entire population.

Using this logic, the seasonal peak in daily crossing is approximately 2500 individuals. The proportional use of Bahia Grande roosts sites is more difficult to interpret. The GPS data collected from 35 individuals suggests an upper limit of approximately 10 percent of all roosts occurred in the Bahia Grande (although this number varies by individual).

This simple logic yields a peak population estimate of 2500 / 0.1 = 25,000 pelicans. This number is clearly much greater than the population estimate derived from mark-resight estimates. The validity of the estimate is discussed in the discussion section.

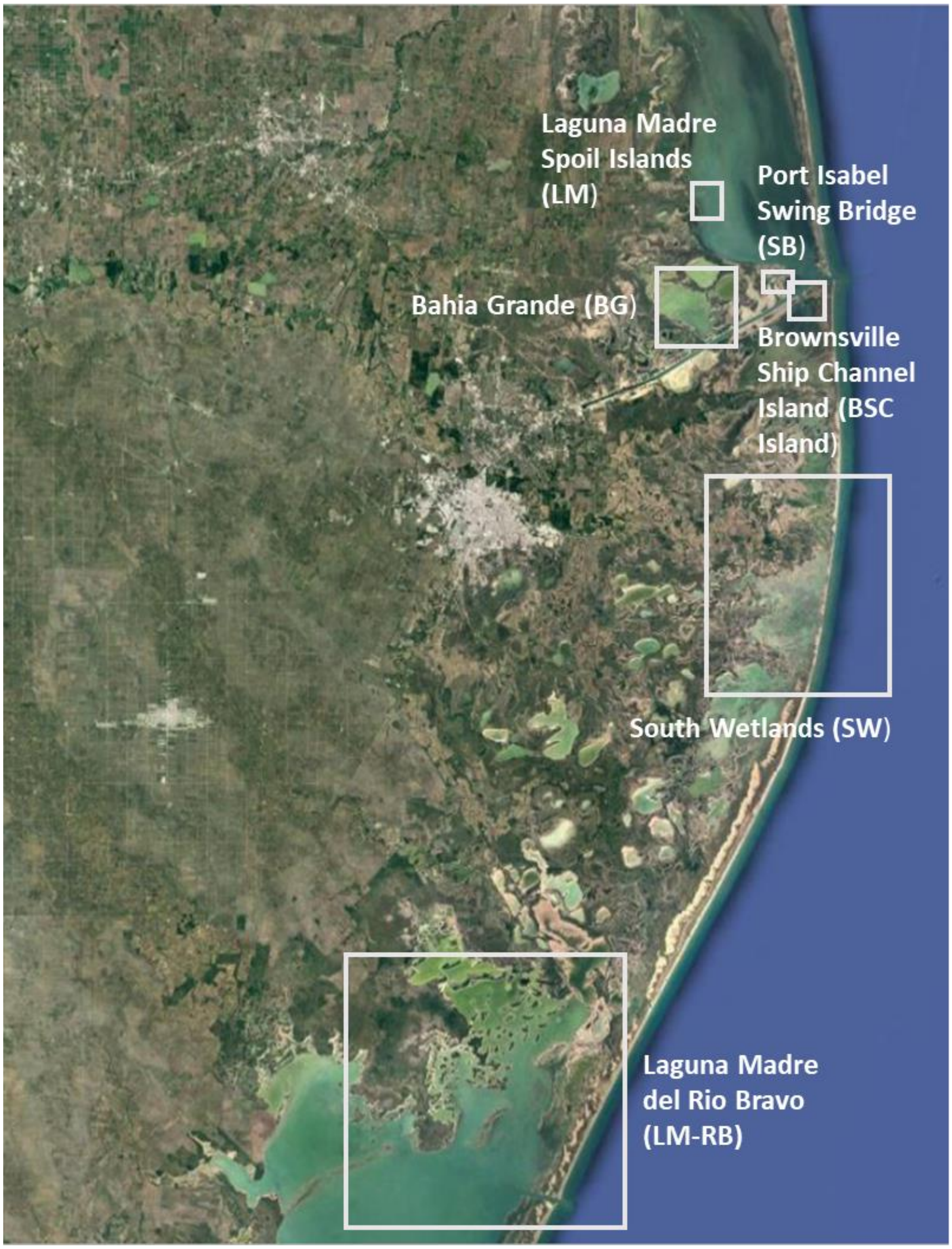


Figure 78. Location of Key Roost Sites used by BGWC Pelicans.

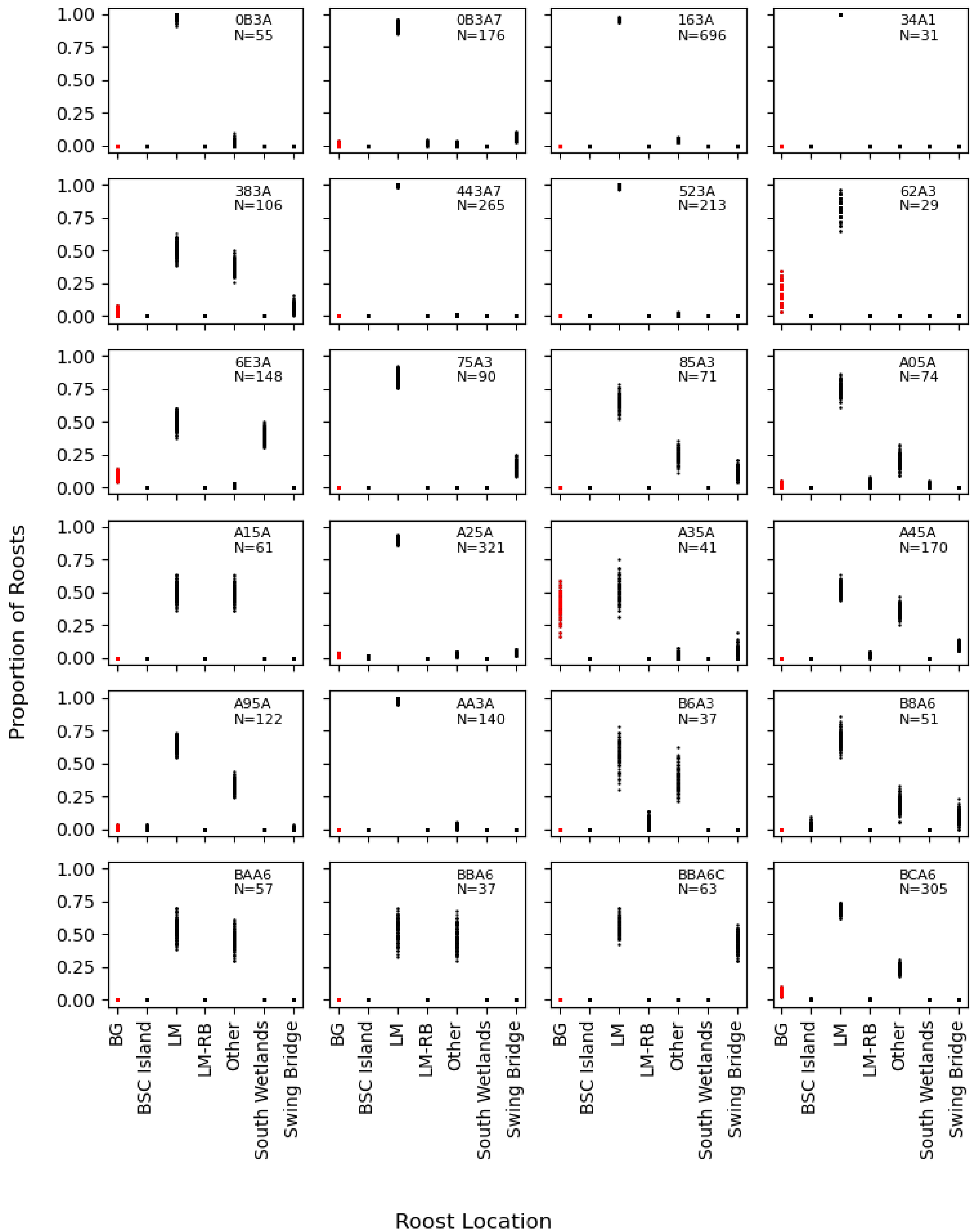


Figure 79. Proportional use of BGWC Roost Sites by Individual Pelicans. The symbols show the use of different roost sites grouped by month.

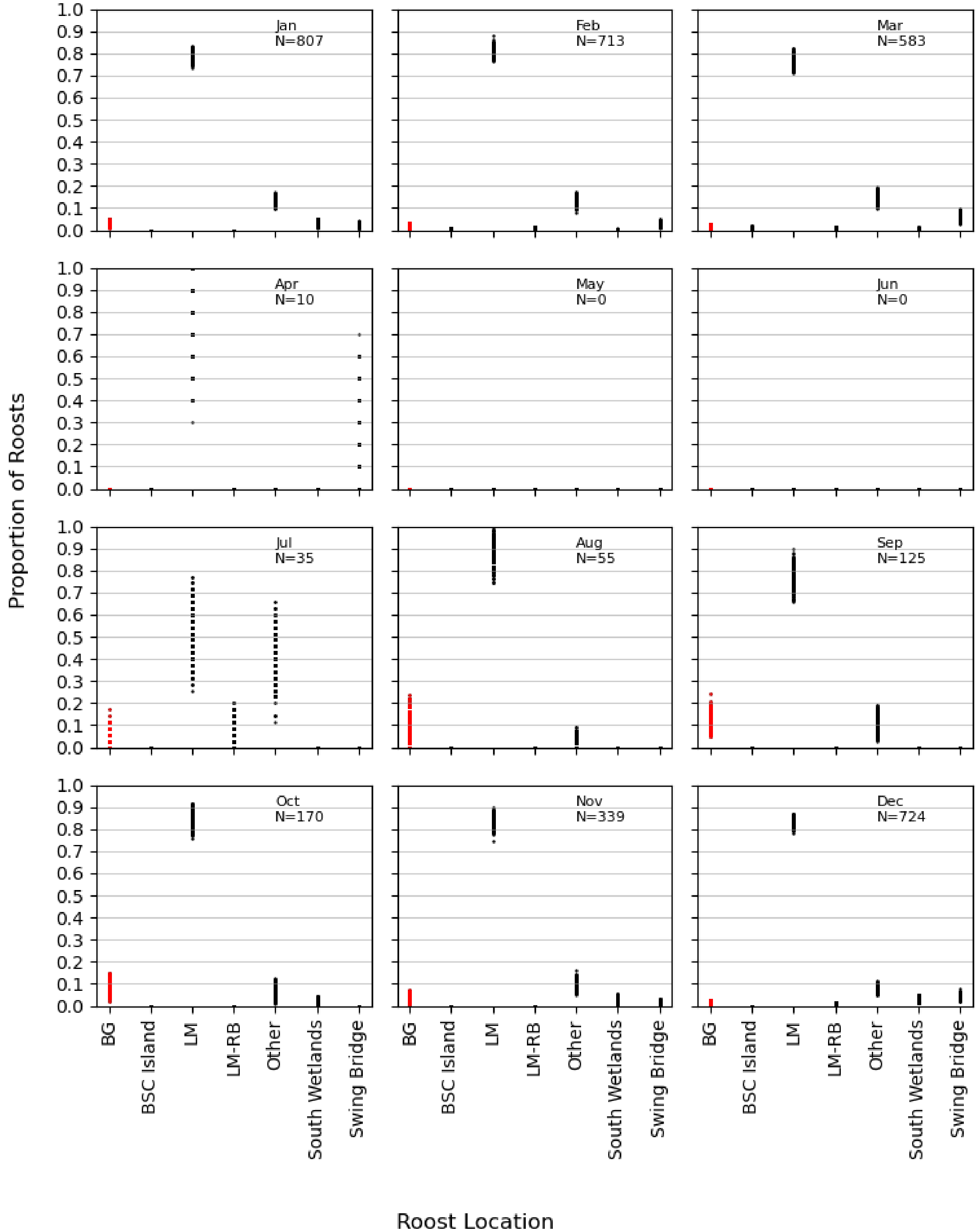


Figure 80. Proportional Use of BGWC Roost Sites by Month.

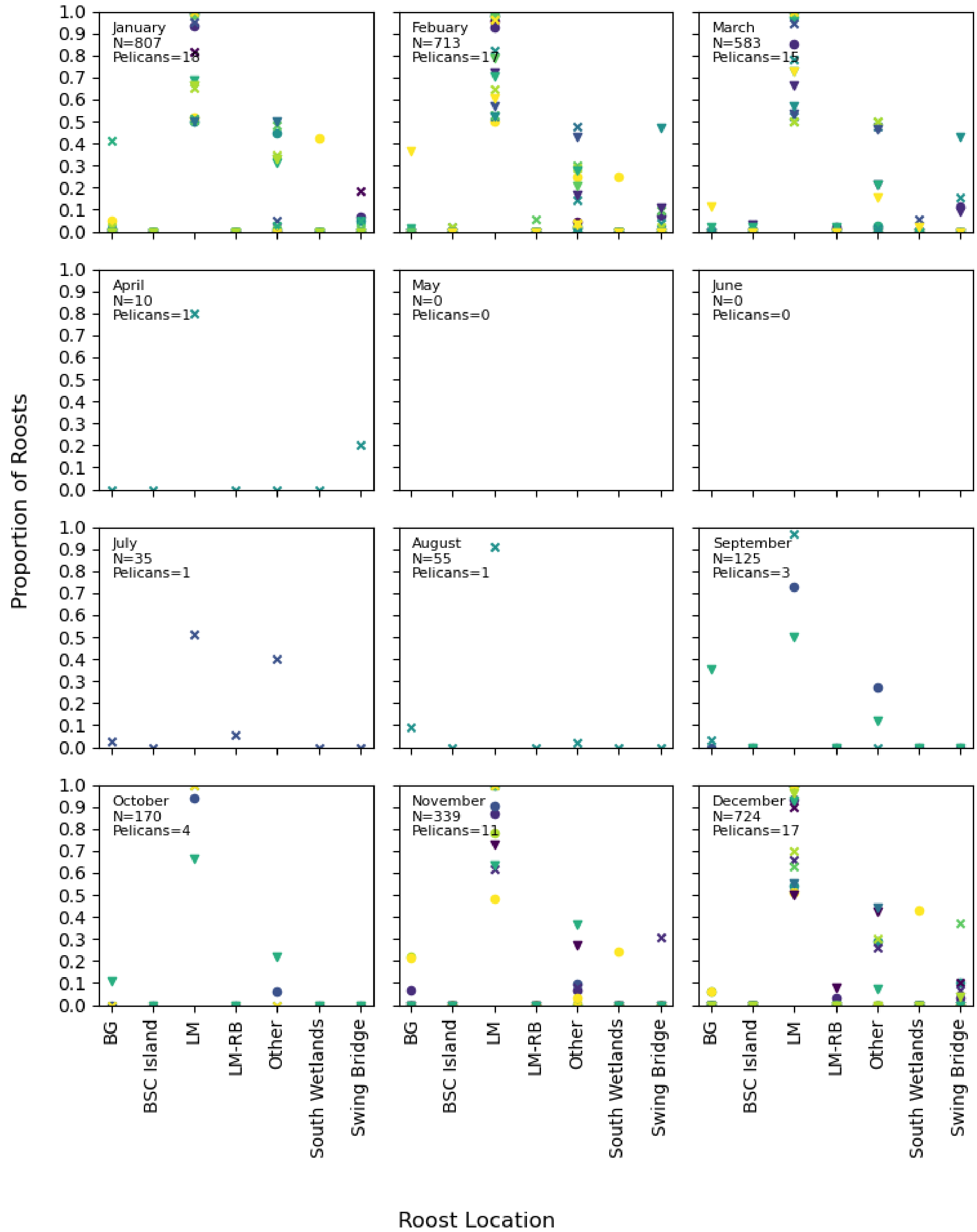


Figure 81. Proportional Use of BGWC Roost Sites by Month and Unique Pelican. Each graph shows the proportion of nights pent in each roost site, the color and marker symbols denote unique pelicans (symbols and colors of each pelican are held consistent for all months).

Roost Island Surveys

The research team's final method of estimating BGWC pelican abundance was through boat surveys of the key pelican roost site – the Laguna Madre spoil islands situated approximately a mile north east of the City of Laguna Vista. Surveys were conducted between July 20, 2020 and January 2021. Each survey was conducted as close to first light as practically possible. During each survey researchers circled the roost island multiple times and made visual counts of all Brown Pelicans remaining on the island (or in its vicinity) at the time of the survey.

Figure 82 shows the number of pelicans observed during each boat survey. The blue symbols show direct counts made during the survey. The orange symbols show estimates of the total number of pelicans that used the site based on the direct counts and the temporal extrapolation method discussed earlier (based on the GPS derived estimates of temporal movements away from the roost site). The figure indicates that between 1000 and 2000 pelicans roost on the Laguna Madre roost island between the months of July and December. Peak count occurred in October (2020) indicating that up to 7000 individuals used the Laguna Madre roost site.

Following the logic outlined in the previous section on SH 48 crossings, an estimate of total population size can be obtained by dividing the number of pelicans using the roost site by the proportional roost site use derived from the GPS data (Figure 79, Figure 80 and

Figure 81). From this data approximately 75 percent of roosts occur on the Laguna Madre spoil islands. This yields a population estimate of approximately 2000 / 0.75 or approximately 2700 individuals through most of the winter months, and a peak abundance of approximately 9500 in October.

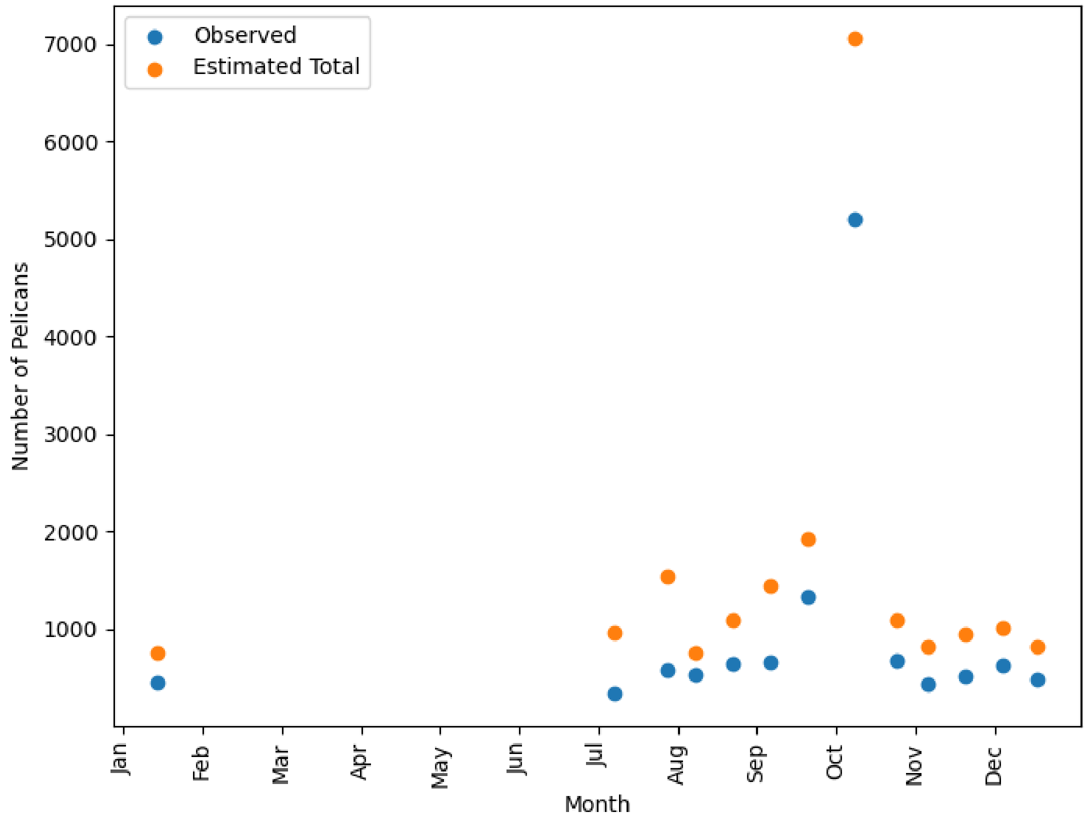


Figure 82. Number of Brown Pelicans Roosting on the Laguna Madre Spoil Islands Estimated using Boat Surveys.

DISCUSSION

In this chapter, the research team estimated the size of the brown pelican population in the BGWC using three methods:

- A mark-resight method that estimates population size based on the proportion of banded to unbanded pelicans observed during multiple field surveys. The peak total population estimated using this method is 2,000 – 3,000 individuals.
- A method that estimates total population size using counts of pelicans crossing SH 48 along with independent estimates of roost site use. This method yields a typical average winter population of 25,000 individuals
- A method that uses counts of pelicans occupying the Laguna Madre roost site along with independent estimates of roost site use. This method yields average winter populations of 2,700 individuals with a peak of 9,500 individuals.

Interpreting these estimates of population size requires some care. All estimates are based on some key assumptions. For the mark resight method, the key assumption is that the probability of resighting a banded versus unbanded bird is equal for all individuals in the population. For the methods based on SH 48 crossings and roost site counts, the major assumption is that the GPS data provides an unbiased estimate of roost site use for all pelicans in the BGWC population.

More generally then, each of the estimation methods rely on an assumption that the population under study is a single population made up of individuals that behave similarly. It is this assumption that may explain some of the discrepancies in the estimates of abundance produced by each method. While the methods based on mark-resight and roost island surveys produce similar total population estimates, the estimate based on SH 48 crossings is almost ten times greater. One plausible explanation for this is that the small sample size associated with the GPS study has resulted in biases in the estimates of relative roost site use. It is plausible that, by chance alone, the 35 birds captured and fitted with GPS units did not use the Bahia Grande roost site as often as they should, relative to a population average.

Another plausible explanation for the inconsistency in abundance estimates is that the BGWC brown pelican population might be better understood as comprising multiple meta-populations. In other words, that the BGWC comprises multiple populations, each of which comprise individuals that use the BGWC and surrounding landscape in different ways. For example, the GPS study highlights the tendency for most of the GPS tracked individuals to operate in and around the marinas and docks of Port Isabel and South Padre Island. It is plausible that in addition to pelicans that have become habituated to these locations, a sub-population of pelicans exists that tend to forage in other areas and are not as well represented by the GPS or banding studies. This idea becomes increasingly plausible given the seasonal movements of pelicans. As discussed in the previous chapter, in fall and spring it is likely that the BGWC consists of transient individuals that pass through the area on their way to winter and spring grounds, and it is possible that these individuals behave differently than those that are more permanent BGWC winter residents. Similarly, the population dynamics and life-history of the species suggest that every year, the BGWC population will be inundated with large numbers of juvenile pelicans that may also exhibit behavioral differences relative to established BGWC individuals.

The research team acknowledge that the methods used to estimate BGWC populations depend on key assumptions that affect their accuracy. The methods based on counts of SH 48 crossings and roost island surveys also lack statistical rigor but are nonetheless simple to understand and interpret. The method based on SH 48 counts partially compensate for a lack of statistical rigor by providing information on SH 48 crossings which are independently important for understanding pelican mortality on SH 48. Irrespective of statistical analysis, field researchers regularly counted over 1000 pelicans crossing SH 48 to roost sites in the Bahia Grande.

In contrast to the SH 48 crossing and roost island count methods of estimating total population size, the mark resight population estimates are based on a robust method that was designed to overcome limitations in experimental design. The principal experimental design limitation centers on the fact that, due to the difficulty of capturing pelicans, banded pelicans were introduced to the population gradually. With this principal limitation, it is not possible to assume that the population is closed (a major assumption of most mark-resight studies). To overcome these difficulties, the research team tested analyses using synthetic data to ensure, theoretically at least, that they were able to accurately estimated population. The fact that Figure 215 and Figure 216 (Appendix V) both show a good agreement between estimated and simulated population size provides strong empirical evidence that the mark-resight population estimation methods developed for this study are capable of providing accurate population estimates.

CONCLUSIONS

In this chapter, the research team estimated the size of the brown pelican population in the BGWC—the core study area of this project. The abundance survey and estimation methods suggest that the BGWC brown pelican population includes between 2,000 and 3,000 birds during the winter period. In summer, the study area population may be fewer than 1,000 birds. This population estimate is essential to effectively manage wildlife. In the case of the BGWC pelicans, the population estimates provide key context for subsequently assessing local mortality in the context of the total size of the population in the BGWC and for determining the relationships of the population size, the numbers of pelicans crossing SH 48, and the number of crashed and killed pelicans on SH 48.

CHAPTER 6. ANALYSIS OF WIND STATION DATA

This chapter provides an analysis and overview of wind conditions on SH 48—the primary location of traffic-induced pelican mortality. The analysis compares detailed wind data measurements collected using a wind station installed for this project and compares these SH 48 measurements to data collected at local National Oceanic and Atmospheric Administration (NOAA) weather stations. One of the practical applications of this analysis is to develop a consistent weather data record that can be used to model past and future pelican events on SH 48. To this end, the application of data from permanent NOAA stations may help to make in situ forecasts and traffic mitigation options, such as automatic warning signs, practically possible.

DESCRIPTION OF THE PROJECT WEATHER STATION

On November 28, 2017, a project wind station (PWS) was installed on SH 48 at the Carl Gayman Bridge to a telegraph pole provided by TxDOT. Figure 83 illustrates the installation. The wind station consists of two anemometers to measure wind speed and direction, situated approximately 21 and 12 feet above the road surface. The upper anemometer includes a wind vane to measure wind direction. The lower anemometer is mounted on a bracket that extends 38 inches from the pole, which is greater than 3.5 times the diameter (approximately 11 inches) of the pole. This configuration minimizes the influence of the pole on the anemometer readings from wind blowing from the direction of the pole. A data logger logs all data from the sensing equipment. The data logger is mounted inside a water- and shock-proof case secured 7 feet above ground level. The data logger is powered by batteries only (i.e., no solar panel) and writes data to a memory card. The data logger is checked by field scientists twice a week. At each visit, batteries are replaced, and data are moved to a permanent data repository.

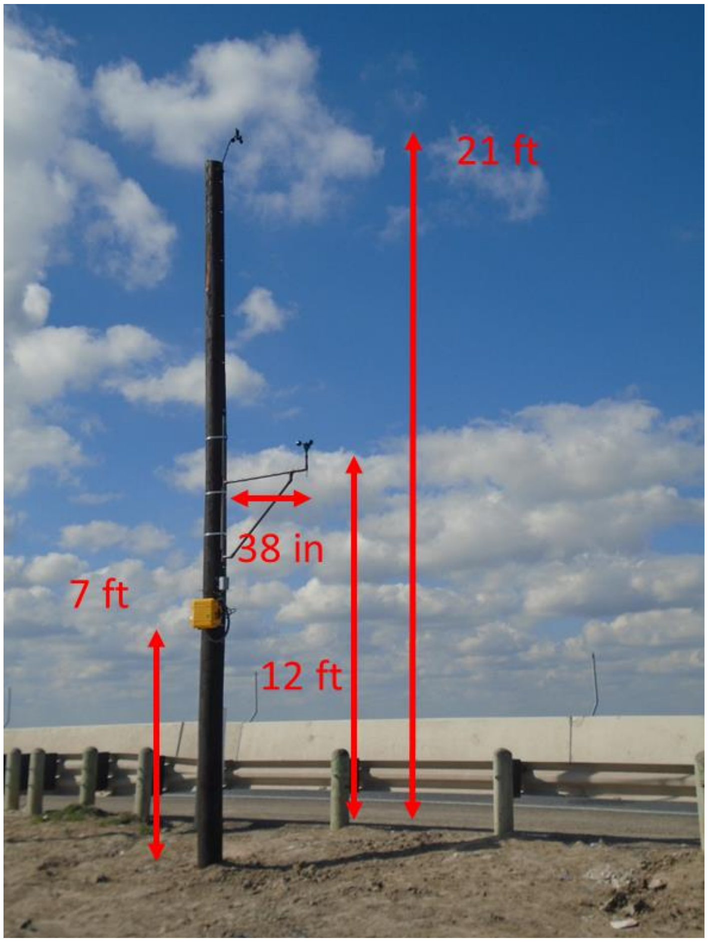


Figure 83. Wind Station Located on SH 48.

The PWS was installed to provide in situ wind speed and direction measurements throughout the project and records data every 10 seconds. The upper anemometer is a Davis Instruments' Davis 6410 Vantage Pro2; the lower anemometer is an APRS World APRS6504. Both anemometers are connected to an APRS World data logger (APRS6000). The wind vane on the upper anemometer points 50 degrees relative to north. The wind station collects data at two heights to assess possible changes in the speed or direction of air at different altitudes. Figure 84 shows the geographic location of the PWS (latitude 26.015151, longitude −97.275976) relative to SH 48.

Figure 84. Location of the Wind Station Installed on SH 48. The red dot in the aerial image (top) highlights the wind station with reference to the Bahía Grande, and the Carl Gayman Bridge and channel. The lower aerial imagery shows a finer scale view of the telegraph pole on which the wind station is affixed (marked by the red arrow).

Local NOAA Weather Stations

One objective of this chapter is to provide an assessment of the characteristics of wind patterns on SH 48 relative to those recorded elsewhere in the region. To this end, NOAA operates several full-time weather stations in the region. Each NOAA station collects different types of wind measurements (e.g., wind, temperature, precipitation, humidity), at different temporal scales (e.g., daily, hourly) depending on the purpose of the station. In addition, the historic record of data collected at each station may differ according to the age of the station, reliability, or upgrades in technology.

The research team identified two NOAA stations for analysis. The Brownsville–South Padre Island International Airport[21] (herein Brownsville) station is located approximately 20 miles southwest of the project wind station (latitude = 25.9141, longitude = −97.4230, elevation = 24 ft, or 7.3 m) and provides, among other measurements, dry- and wet-bulb temperature measurements, hourly wind direction, and wind speed. Historical weather data from the Brownsville site were downloaded from the NOAA Local Climatological Data website.[22] The research team also used historical weather data obtained at an NOAA Tides and Currents station located close to Port Isabel (station identifier = 8779770, latitude = 26.05194, longitude = −97.2025). The Port Isabel station measures air temperature, wind speed and direction, and water temperature among other variables, typically at a temporal resolution of six minutes. The Port Isabel data were downloaded from the NOAA Tides and Currents data access portal.[23] Figure 85 maps the location of the Brownsville and Port Isabel NOAA stations relative to the project wind station.

[21] Weather stations connected to national or global networks are usually identified by a code. Brownsville-South Padre Island International Airport code is WBAN: 72250012919 (KBRO).
[22] https://www.ncdc.noaa.gov/cdo-web/datatools/findstation
[23] https://tidesandcurrents.noaa.gov/stationhome.html?id=8779770.

Figure 85. Location of NOAA Brownsville and Port Isabel Weather Stations Relative to the Project Study Area and the Project Weather Station (SH 48 wind station).

METHODS

The TTI researchers converted the raw data logged by the project wind station (pulses per second in the case of wind speed, and potentiometer voltages in the case of wind direction) into wind direction in degrees and wind speed in miles per hour (mph). Specification from the manufacturers of the anemometers were used to convert pulses and potentiometer readings to these metrics. Table 9 provides the formula used to translate raw anemometer measurements to wind direction and wind speed. The data logger used in the study provided the data as individual files—each representing a day of wind measurements. The data from individual files were aggregated into a single database of values—with each record 10-second measurements of wind direction (at 21 feet), and wind speed at 21 feet (upper anemometer) and at 12 feet (lower anemometer).

Table 9. Formulas Used to Convert Raw Anemometer Data to Wind Speed and Direction Values.

Device	Input measurement	Conversion formula
Upper anemometer	pulses	pulses/10 seconds*2.25
Wind vane	potentiometer volts	(Volts/5) * 360
Lower anemometer	pulses	pulses/10 seconds*0.857 + 0.725

Following consolidation of the project wind data, the research team developed algorithms to convert the 10-second wind measurements obtained from the PWS to means relevant to any temporal measurement period (e.g., one minute, one hour).

The research team used the standard meteorological method for averaging wind direction. This method converts wind direction (in degrees) to two vector quantities—representing the strength of wind in the south to north direction and the strength of wind in the west to east direction—through the following formulas:

$$VS = \cos(\theta) \quad VW = \sin(\theta) \qquad \text{Equation 6.1}$$

Where VS is the relative magnitude of wind speed in the south to north direction, V_W is the relative magnitude of wind speed in the west to east direction, and θ is the wind direction in degrees or radians.

The conversion of wind direction in degrees to these vectors is necessary to overcome the problem of wind direction occurring in the interval zero to 360 degrees. After converting wind direction to vectors, the research team used the arithmetic means of each vector VW and VS to derive the average strength of these vector components for a chosen averaging period. Averages of the unit vectors (Equation 6.1) yields the average wind direction alone. However, it is also useful to work with the absolute strength of these directional vectors (simply the unit vector multiplied by wind speed), as shown; that is:

$$VS = \cos(\theta) * v \quad VW = \sin(\theta) * v \qquad \text{Equation 6.2}$$

Where v is the velocity of the wind speed (e.g., in miles per hour).

The averages of unit or absolute vectors VW and VS can be transformed back to an average wind direction (in degrees) and wind speed using the following formulas:

$$\theta = \text{atan2}(VS, VW) \qquad \text{Equation 6.3}$$

$$v = \sqrt{VS^2 + VW^2} \qquad \text{Equation 6.4}$$

Equation 6.1 to 6.4 were used to convert the original 10-second interval wind station data to wind speed and direction measurements between one minute and one hour in duration.

Modeling Hourly Wind Speed and Direction

The wind station provides high-precision, 10-second interval wind speed and direction data representative of the location on SH 48 where pelican mortality occurs. To assess characteristics of wind conditions on SH 48 relative to the broader BGWC study area, the research team modeled the relationships between hourly wind data collected at the project wind station and NOAA weather stations.

The research team used simple regression models to relate the average wind speed and direction on SH 48 to those of the NOAA station(s):

$$VS_{WS} = (VS_{NOAA} * a) + b \qquad \text{Equation 6.5}$$

$$VW_{WS} = (VW_{NOAA} * a) + b \qquad \text{Equation 6.6}$$

Where VS_{WS} and VW_{WS} are the wind vector components at the wind station, and VW_{NOAA} and VS_{NOAA} are the same components measured at either the Brownsville or Port Isabel stations; last, *a* and *b* are fitted parameters (slope and intercept parameters). Figure 86 shows the modeled and observed relationships for both wind vector components. Table 10 shows the parameters derived by fitting the regression model to the data. The figures show a strong correlation between the absolute hourly wind vector components (including wind speed) measured at the wind station and at the two NOAA stations (Brownsville data are shown in black, Port Isabel data in red). The figures also show a greater range of velocities for the south-north versus west-east components, which suggests that prevailing winds at all stations (NOAA and wind stations) predominately blow north to south or south to north.

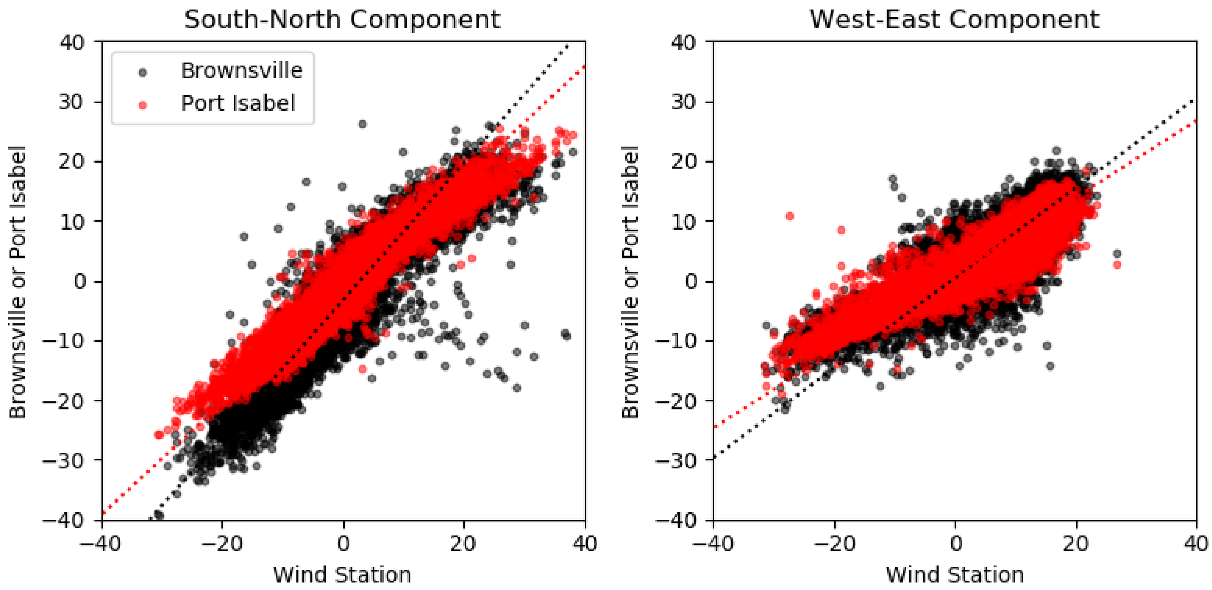


Figure 86. Relationships among Wind Vector Components from Wind Station versus Brownsville or Port Isabel NOAA Stations.

Table 10. Regression Parameters to Predict Wind Station Wind Component Vectors Using NOAA Data (Brownsville or Port Isabel). All coefficients are highly significant ($p < 0.00$).

Model	Brownsville		Port Isabel	
	***b* coefficient (intercept)**	***a* coefficient (slope)**	***b* coefficient (intercept)**	***a* coefficient (slope)**
VS	2.960	0.872	1.898	1.065
VW	−0.502	1.326	−1.543	1.554

Figure 87 shows the accuracy of the regressions in terms of predicting wind direction and wind speed on SH 48 using NOAA station data. In these figures, the vector components have been converted back to wind speed and angular direction. The left-hand panels show actual versus observed wind direction[24] (top) and actual and observed wind speeds (bottom). The right-hand panels show the probability distribution functions of the prediction residuals (difference between predicted versus actual values). Overall, the figures show that NOAA data provide an accurate way of estimating average wind conditions on SH 48. Approximately 95 percent of all predictions using NOAA data and the appropriate model fall within 5 mph and 30 degrees of the wind speeds and direction measured on SH 48. Overall, the Port Isabel station provides the best prediction accuracy, but the differences are marginal.

[24] Note the difficulty of representing wind direction predictions in a conventional two-dimensional graph (top left panel of Figure 87). The cluster of points in the top left and bottom right of the figure show data points that were close in terms of degrees of difference (degrees), but whose absolute values plotted on a linear scale are far apart (e.g., a predicted value of 355 versus an observed value of 2 degrees represents only a 7-degree difference but appears much different [353 degrees] when plotted on a linear scale.)

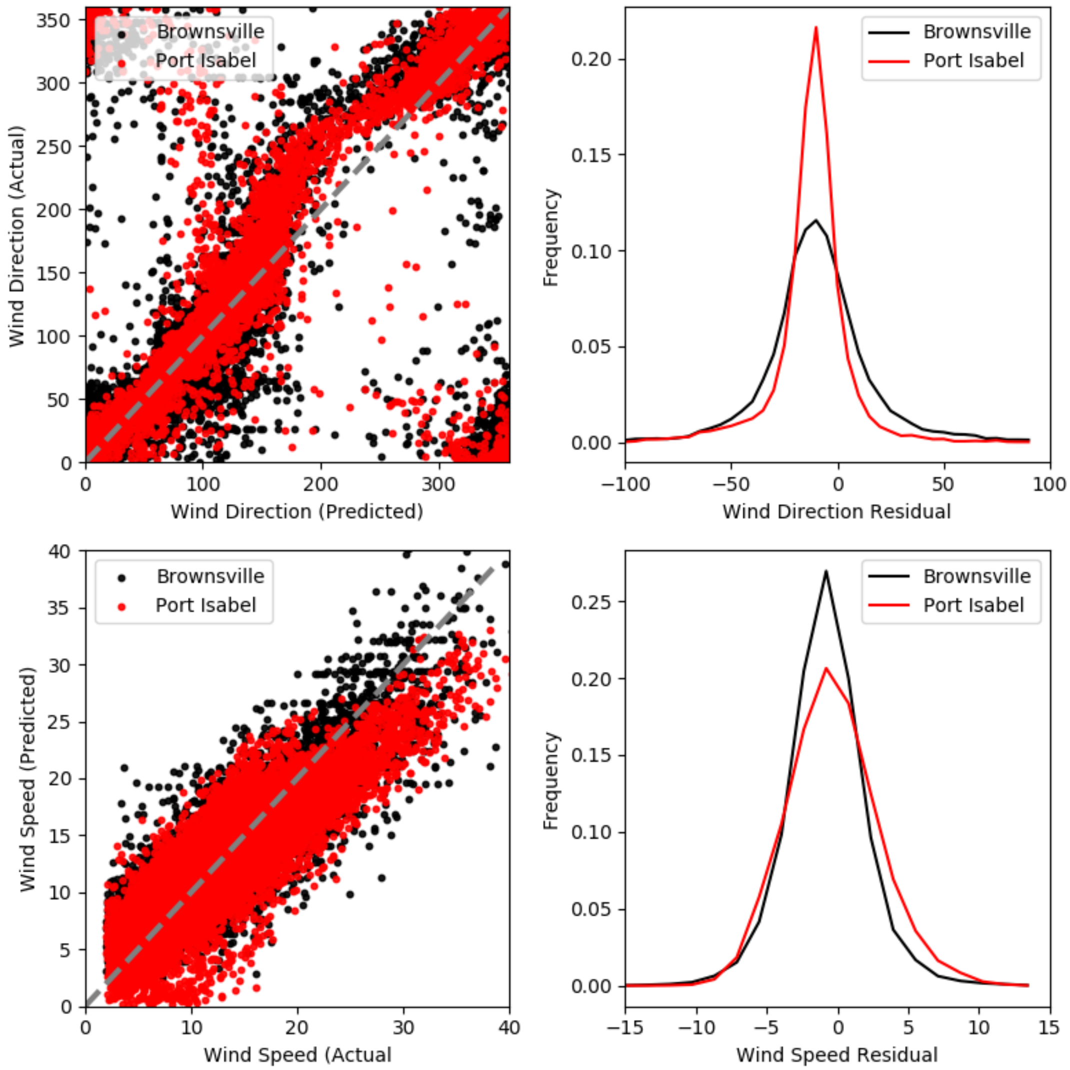


Figure 87. Wind Direction and Speed on SH 48 Modeled Using Data from the Brownsville and Port Isabel NOAA Weather Stations.

The research team also investigated using the same methods to predict wind station component vectors using *both* Brownsville and Port Isabel components through the following regression:

$$VS_{ws} = VS_{Brownsville} \cdot a + VS_{PortIsabel} \cdot b + c \quad \text{Equation 6.7}$$

$$VW_{ws} = VW_{Brownsville} \cdot a + VW_{PortIsabel} \cdot b + c \quad \text{Equation 6.8}$$

Where the subscripts of the vector components VW and VS correspond to Brownsville and Port Isabel values explicitly, and *a*, *b*, and *c* are fitter parameters. Figure 88 illustrates the accuracy of wind station predictions using data from both these stations. Table 11 shows the coefficients obtained from the regression model. The model that uses data from both stations provides slightly more accurate predictions of the wind on SH 48.

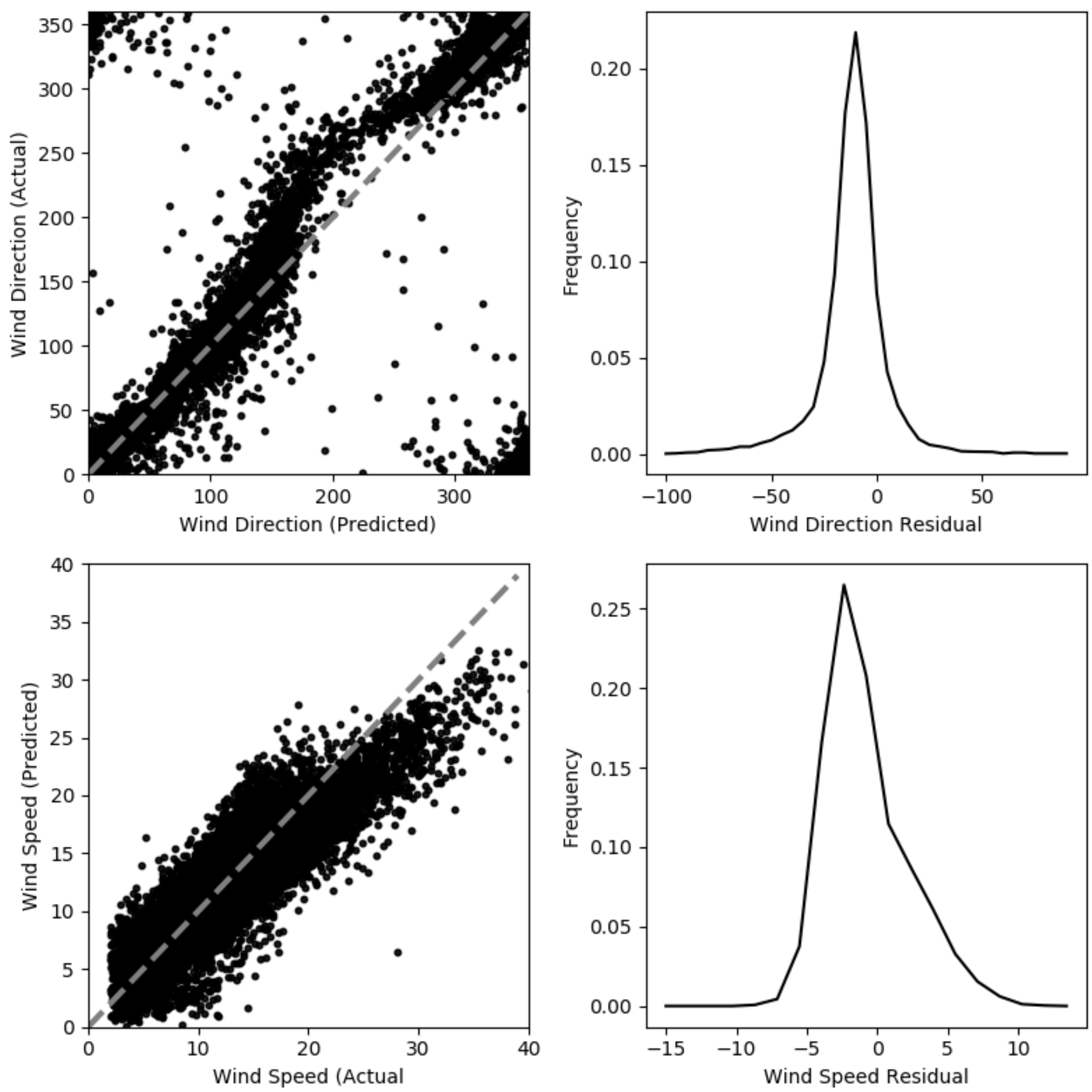


Figure 88. Wind Direction and Speed on SH 48 Modeled Using Combined Data from the Brownsville and Port Isabel NOAA Weather Stations.

Table 11. Regression Parameters to Predict Wind Station Wind Component Vectors Using Brownsville and Port Isabel Data Simultaneously. All coefficients are highly significant ($p < 0.00$).

Model	***a* coefficient (Brownsville)**	***b* coefficient (Port Isabel)**	***c* coefficient (Intercept)**
VS	0.162	0.892	2.147
VW	0.463	1.133	−1.6327

Prevailing Wind Conditions

The preceding section illustrates that, at least at the scale of 1-hour measurements, wind conditions measured on the bridge can be accurately estimated using data from local NOAA weather stations. In turn, this suggests that the prevailing weather patterns on SH 48 (at the site of pelican mortality) are not considerably different from those in the surrounding landscape. In this section, the research team characterizes these prevailing wind patterns.

Figure 89 shows the frequency of wind directions and speeds measured by the wind station, averaged over 1-minute, 5-minute, 30-minute, and 1-hour periods. The figure shows that the most frequent prevailing winds on SH 48 are from the southeast and between 7 and 20 mph. This prevailing wind direction is at an angle almost perpendicular to the eastbound lane (south side of SH 48).

The next most common wind directions and speeds are from the northwest, between an angle of approximately 310 and 330 degrees, and at velocities of 10 to 25 mph. These winds occur less frequently than the southeast winds and are often associated with cold fronts. These northwesterly winds occur at an angle almost perpendicular to SH 48 from the north.

Winds between 180 and 270 degrees (i.e., from the northeast) are rare but not as uncommon as winds from the southwest.

Figure 90 shows information on prevailing wind direction using hourly wind data from NOAA stations and the project wind station. In this figure, SH 48 wind measurements over 20 mph have been extracted from the larger wind measurement data set and modeled using data from the NOAA stations (as described in the previous section). The figure shows that wind greater than 20 mph is restricted to the northeast and southwest directions. The figure also suggests that SH 48 wind speeds above 20 mph can be predicted from NOAA data with relatively high accuracy.

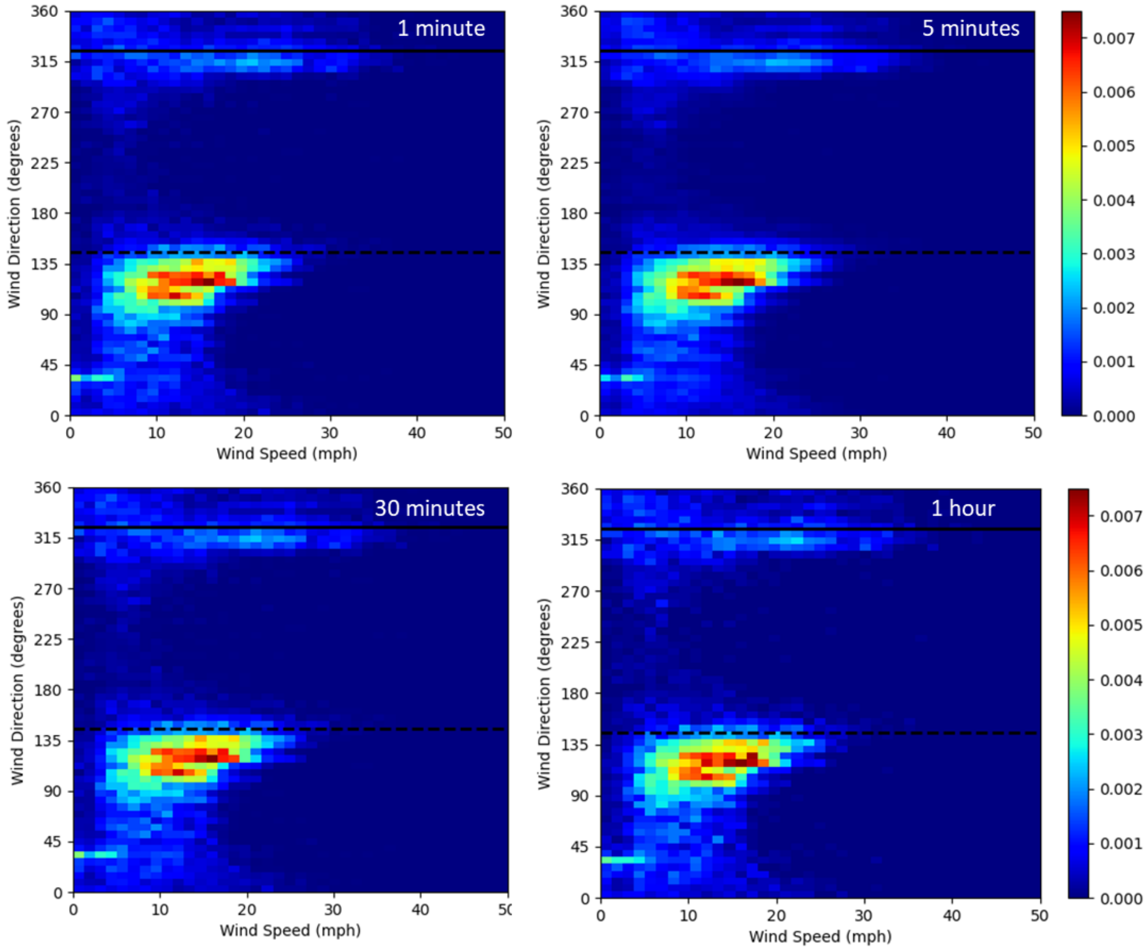


Figure 89. Frequency (percentages) of Average Wind Speed and Direction Measured by the Project Weather Station and Averaged over Periods of One Minute to One Hour. The solid and dashed horizontal lines show the angle at which wind is approximately perpendicular to the north and south sides (westbound and eastbound lanes) of SH 48, respectively.

Figure 90. Schematic of Prevailing and Cold Front Winds Measured at the Wind Station on SH 48.

Example Wind Conditions on SH 48

Figure 91 shows the daily pattern of weather conditions on SH 48 leading to and during a cold front that resulted in pelican mortality (October 10, 2018). The cold front arrived at approximately 2 p.m., at which time the temperature dropped precipitously (over 25 degrees in an hour), wind direction changed from the prevailing southeast to a northwest direction (i.e., from the northwest), and the hourly average wind speed increased dramatically at the Brownsville NOAA station and as measured by the two anemometers on the bridge. Before the cold front, the wind speeds measured at the two SH 48 anemometers were similar to those speeds measured at the NOAA station. After the winds shifted to blow from the northwest, the wind speed measured at the upper anemometer increased relative to the lower anemometer reading.

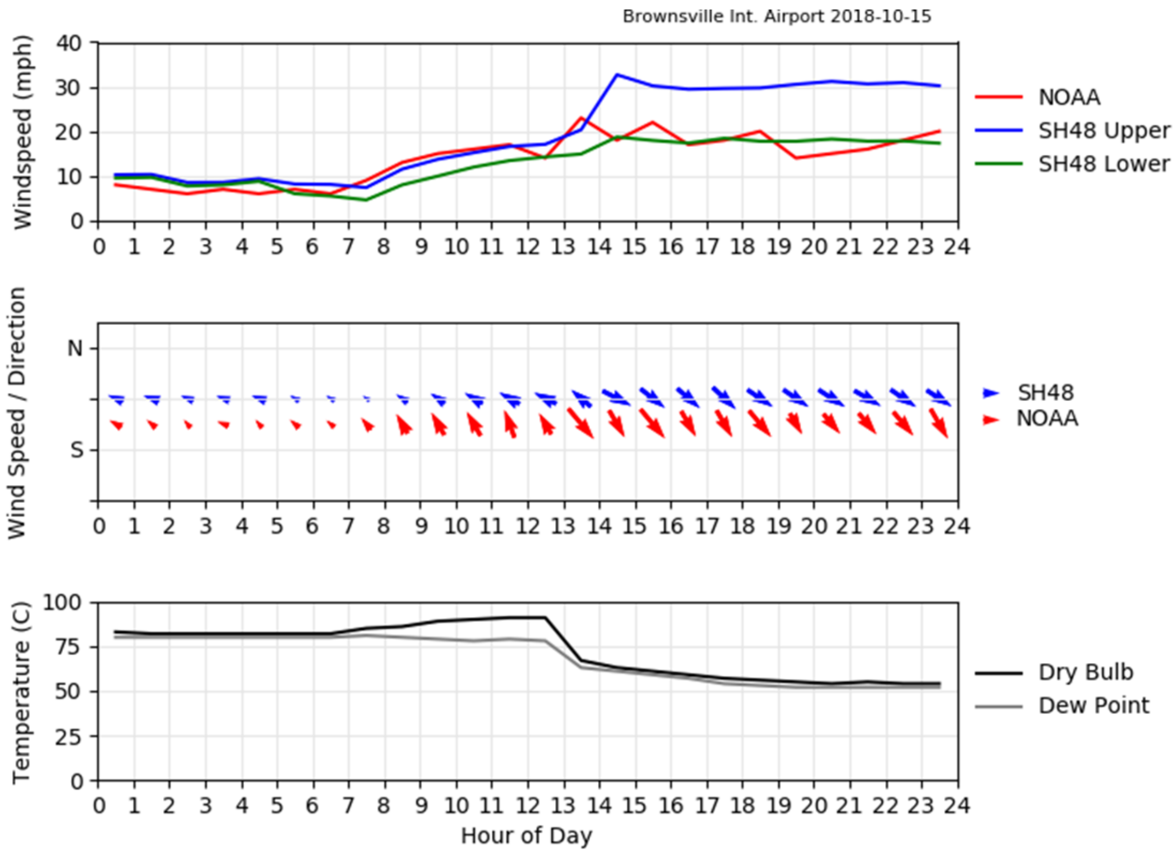


Figure 91. Wind Speed and Wind Direction Data from the PWS (labeled SH 48 in the legend) versus the Same Measurements from Brownsville International Airport (labeled NOAA in the legend) on October 15, 2018. The bottom panel shows dry bulb temperatures and dew point temperatures measured from the NOAA station.

Figure 92 shows the temporal variation in wind speed averages for the same cold front event as measured by the SH 48 wind station. The figure illustrates that 60-, 30- and 15-minute wind speed averages are relatively consistent through time. Most variation in the pattern occurs at a temporal scale of one minute such that one-minute average periods often deviate from the more stable 60-minute average by up to +/− 5 degrees.

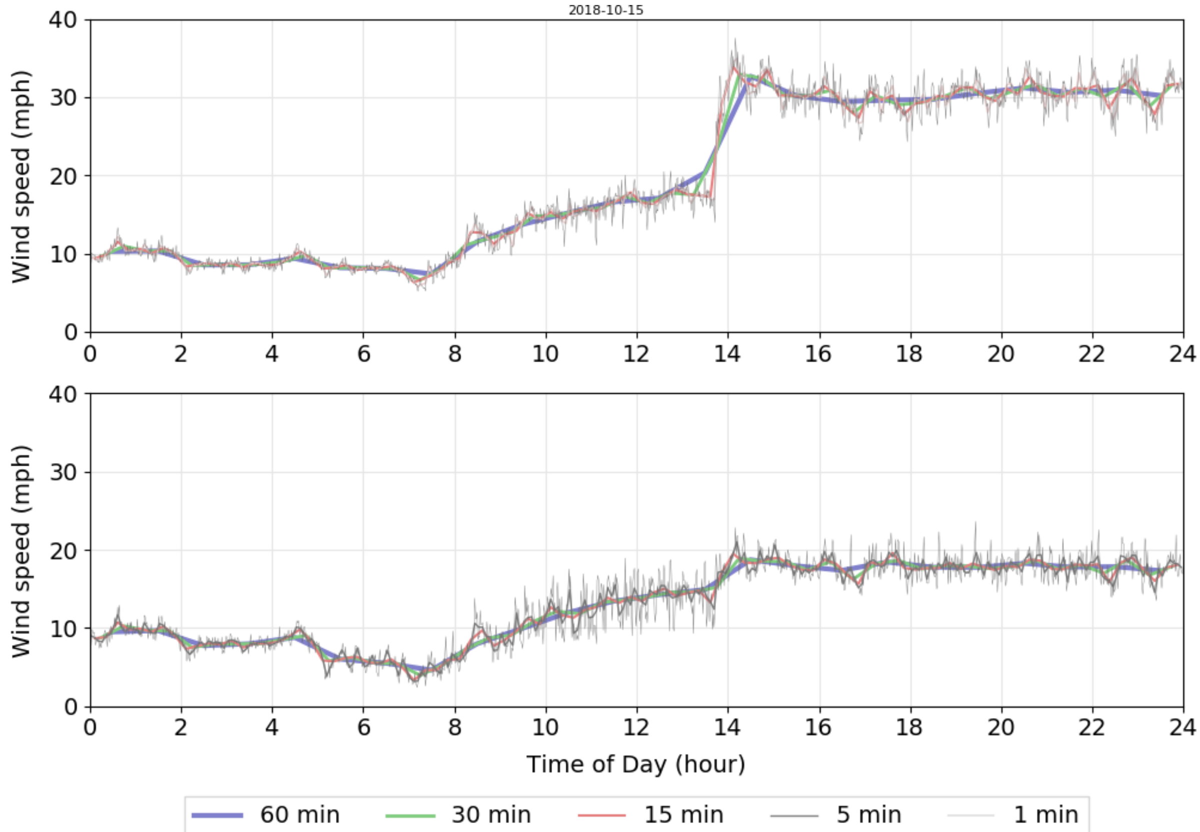


Figure 92. Temporal Variation in Upper (top) and Lower (bottom) Anemometer Readings during a Mortality Event (October 15, 2018). Each line shows the measured wind speed averaged over a specified time period (60, 30, 15, 5, or 1 minute).

Figure 93 and Figure 94 show another example of changes in conditions during a cold front event occurring on December 5, 2017. This time, the cold front occurs later in the day (approximately 8 p.m.). Typically, wind speeds in the area increase gradually during the day and then dissipate at night, as shown in the temporal pattern before 8 p.m. However, the arrival of the cold front at 8 p.m. is marked by a sudden shift in wind direction, a slight drop in temperature, and an almost 20 mph increase in wind speed within an hour.

The temporal patterns of weather illustrated by Figure 92 to Figure 94 are typical of those that occur during most cold fronts and pelican events on SH 48. The weather patterns that occurred on known pelican events will be further explored in the next chapter.

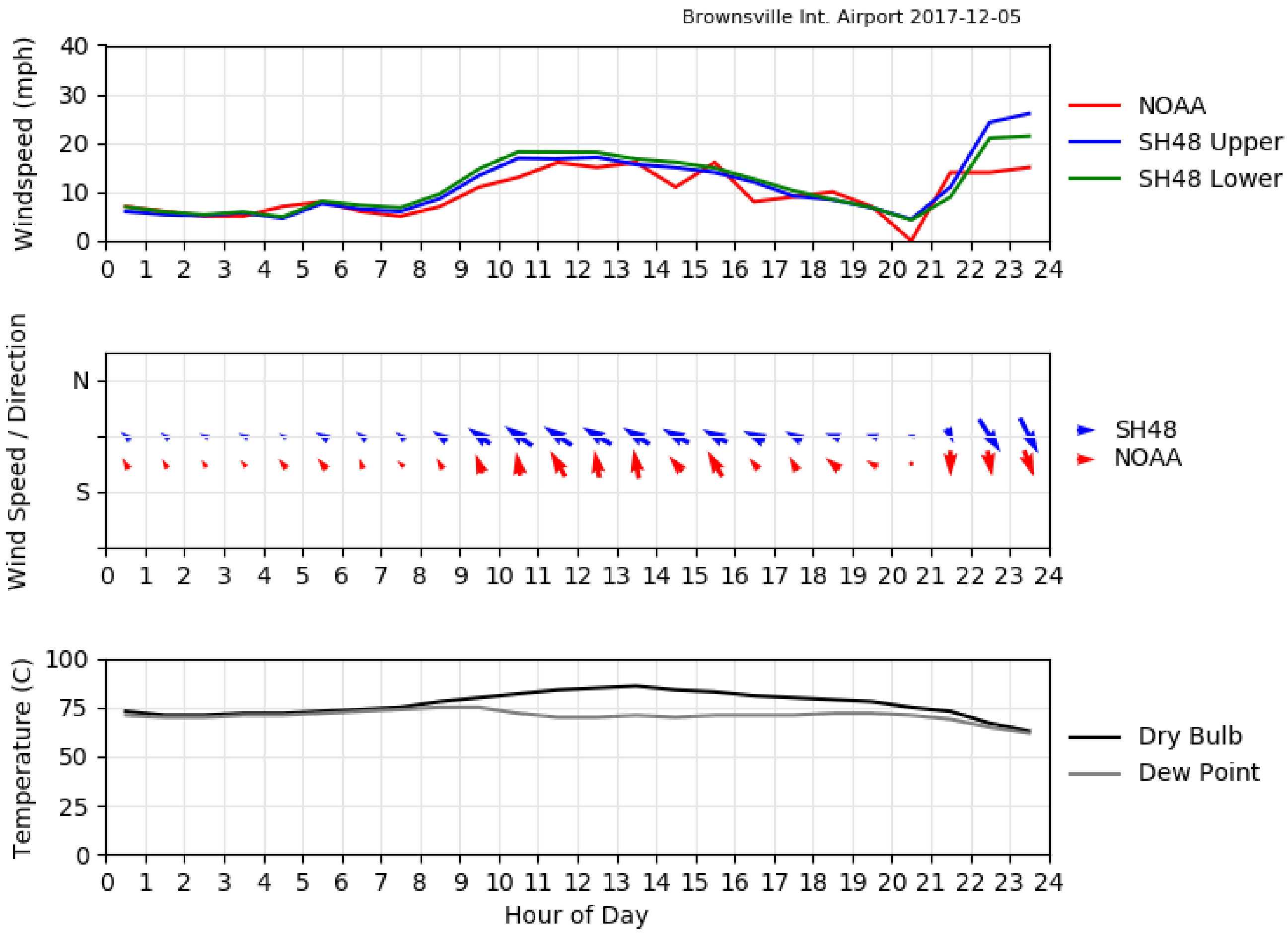


Figure 93. Wind Speed and Wind Direction Data from the PWS (labeled SH 48 in the legend) versus the Same Measurements from Brownsville International Airport (labeled NOAA in the legend) on December 5, 2017. The bottom panel shows dry bulb temperatures and dew point temperatures measured from the NOAA station.

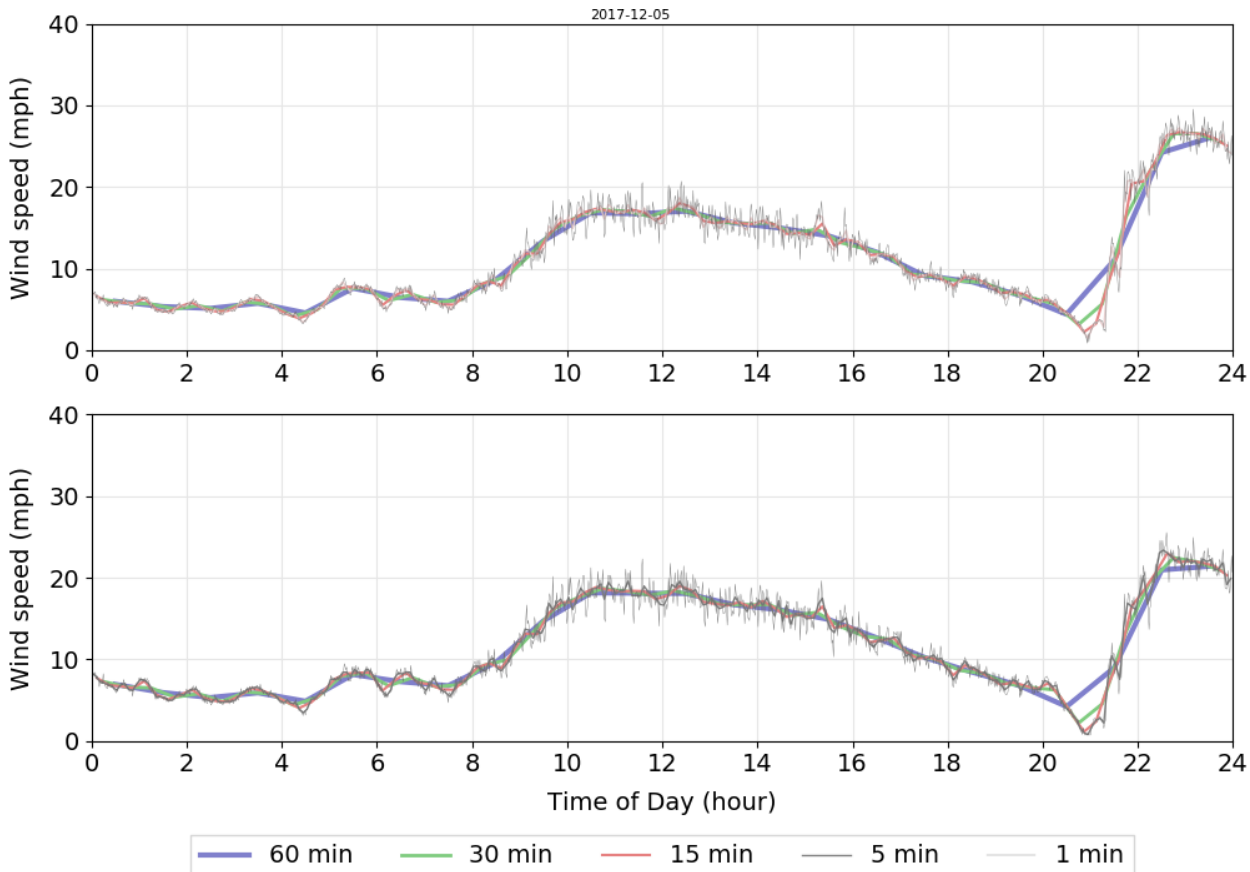


Figure 94. Temporal Variation in Upper (top) and Lower (bottom) Anemometer Readings during a Cold Front (December 5, 2017). Each line shows the measured wind speed averaged over a specified time period (60, 30, 15, 5, or 1 minute).

Influence of SH 48 Road Infrastructure on Vertical Wind Profile

The graphical summaries of wind speed and direction shown in the previous section show a consistent pattern of faster wind measured by the upper anemometer on the PWS relative to the lower anemometer. Figure 95 provides a more detailed view of this phenomenon for all wind speeds and directions recorded by the SH 48 wind station. Figure 95 shows the percent difference between wind speeds measured by the upper anemometer relative to the lower anemometer for a range of averaging periods (1, 5, 15, 30, and 60 minutes). South winds that are perpendicular to SH 48 are marked on the figure using a dashed line (145-degree wind), while the north perpendicular direction is marked with a solid horizontal line (i.e., 320 degrees).

Figure 95 suggests that for all averaging periods, winds become vertically stratified over SH 48 during north winds. The research team hypothesized that this stratification is caused by the roadway infrastructure, including the height of the roadway (either the bridge infrastructure or the raised road infrastructure) and CTBs that form bluffs above the road surface. Because the wind station is situated on the south side of SH 48, the stratification is only detected or measured with north winds. South winds (which are not obstructed by the road before reaching the PWS) show minor differences in lower and upper measurements. East and west winds (that blow parallel to the relevant section of SH 48) are relatively uncommon and result in similar upper and lower anemometer measurements. Figure 96 shows these angles relative to the wind station and surrounding topography.

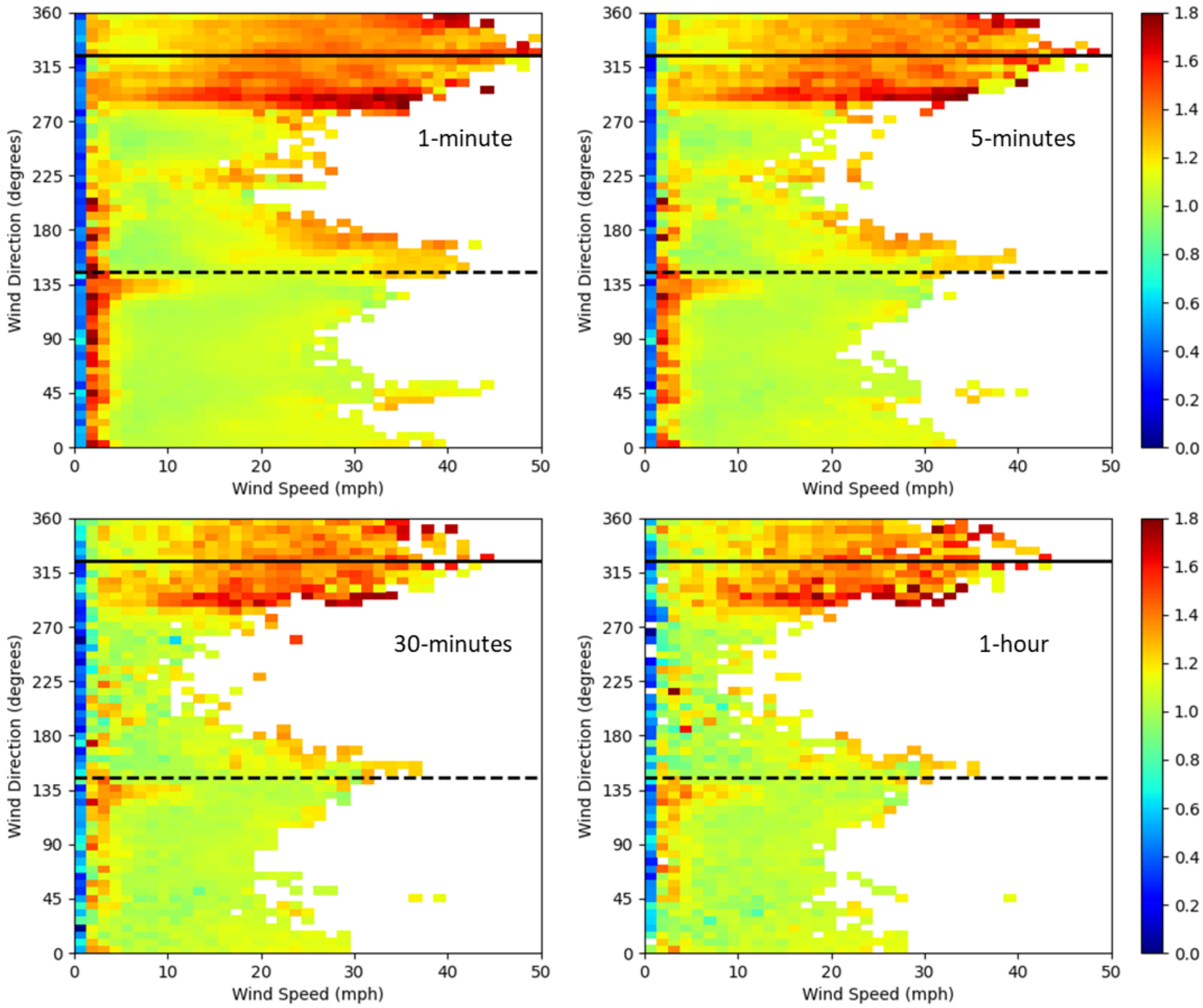


Figure 95. Percentage Difference in Wind Speeds Measured by Upper and Lower Anemometers Plotted by Wind Direction and Wind Speed. Percentage difference is shown by color (scale indicated by the color bar). White areas of the plot show no data. For each wind speed and direction combination, percentage differences were calculated using 1-minute wind speed averages. The solid and dashed horizontal lines show the angle at which wind is approximately perpendicular to the north (solid) and south (dashed) sides of SH 48.

Figure 96. Schematic of Wind Directions That Result in Largest Vertical Differences in Wind Profile Measured by the SH 48 Wind Station.

DISCUSSION

This chapter discusses analyses of wind speed and direction measurements obtained from the PWS installed on SH 48. The PWS indicates that under typical weather conditions, wind in the BGWC blows from the southeast at a velocity between 5 to 20 mph. These conditions translate to winds that blow perpendicular to the south edge of SH 48, and toward the Bahía Grande. During cold fronts, the wind direction on the bridge changes by 180 degrees and blows from the northwest. The switch in wind direction during cold fronts also tends to result in 5- to 10-mph increases in wind speed (typical northwestern winds range between 10 to 25 mph). Northwestern winds blow perpendicular to the northern edge of SH 48. During these conditions, pelicans flying into the Bahía Grande (i.e., to roost sites) will experience strong headwinds. During northwestern winds, the PWS also indicates faster wind speeds measured at an altitude of 21 feet above the roadway versus 12 feet above the roadway. Because these wind speed differentials do not occur during southeastern winds, they are most likely driven by the nature of the topography on the northern side of SH 48. This topography includes the smooth water surface of the Bahía Grande, the berms separating the Bahía Grande from the elevated road (or bridge sections), and the northside and median CTBs installed on the road (comprising a 36-inch northside CTB, and a 42-inch median CTB). Pelicans flying into the Bahía Grande during cold fronts will therefore experience strong headwinds in addition to a stratified wind profile. An additional analysis of the fine-scale wind measurements obtained by the PWS does not reveal evidence of significant wind gusts that could further affect pelican flight over SH 48.

In addition to this analysis of wind conditions on the bridge, the research team have developed models that are able to accurately predict wind speed conditions on SH 48 from local NOAA weather stations. The accuracy of these predictions is on the order of 15 degrees and 5 mph and these errors are unbiased. In the context of the SH 48 pelican problem, the ability to accurately model SH 48 wind speeds from the local NOAA stations is important because of the following:

1. They enable the TTI researchers to model historical pelican events (i.e., those events recorded before the inception of this project and installation of the PWS) and events monitored during this project using the same unified wind data (these mortality models are described in next chapter).
2. The NOAA wind stations can be used as a cost-effective, reliable source of wind data for real-time predictive models that can be linked to a variety of dynamic traffic management scenarios (such as dynamic warning lights, community announcements or even road closures) to be used as potential mitigation options. Although a dedicated, specialized wind station installed on SH 48 (such as an improved version of the PWS) is also capable of providing this information, such a solution is likely too costly to install and maintain. In contrast, existing NOAA stations provide data of a comparable accuracy but have the benefit of already being in place and maintained by dedicated weather scientists.

CHAPTER 7. MODELING PELICAN EVENTS ON SH 48 IN RELATION TO WEATHER AND OTHER ENVIRONMENTAL VARIABLES

This chapter discusses the investigation into the interactions among pelican mortality (and pelicans that crash-landed) on SH 48 relative to local weather conditions. As defined previously, days or periods during which multiple brown pelicans crash-land on SH 48 (and may be subsequently injured or killed by passing vehicles) are referred to as pelican events. The purpose of this chapter is to analyze pelican events in the context of environmental conditions during these events relative to baseline (or prevailing environmental conditions).

Pelicans that crash on SH 48 may be subject to several outcomes. They may regain flight independently (and survive), be rescued by volunteers (and survive), or they may be hit by vehicles—usually fatally (mortalities). The pelican event terminology used in this chapter acknowledges that SH 48 is subject to relatively rare periods during which multiple pelicans crash on the road while attempting to fly over SH 48. These pelican events occur over the course of one or two days, typically during inclement weather (a factor suspected of causing these events).

Between December 2013 and November 2017, TxDOT recorded pelican mortalities on SH 48 following known pelican events. These data provide a record of pelican events on SH 48 that precedes the current research project. During this research project, additional pelican event data were collected. The presence of TTI researchers at these events has led to a more detailed account of downed and/or killed pelicans on SH 48. These additional data include details on the physical measurements, age, and location of pelicans downed or killed on SH 48.

In the following Methods and Results section, detailed records of pelican events on SH 48 observed during this study are analyzed by the researchers to illuminate the spatial location and physiology of downed and killed pelicans. The second part of this analysis discusses the statistical model the TTI research team developed to predict pelican events using the full history of pelican events available to the researchers (i.e., pelican events prior to and during this project). The chapter concludes with a discussion of all the analyses.

METHODS AND RESULTS

Between October 2017 and January 2021, TTI field researchers monitored and recorded the number of crashed and killed pelicans on SH 48 that occurred during all cold front events or other inclement weather in the BGWC.

During all monitored pelican events, field researchers were stationed on SH 48, usually close to the Carl Gayman Bridge and channel. During most pelican events, local conservation-minded individuals were also present. These local conservation volunteers (the pelican conservation group) have assembled since 2014 (independently of the research project) to rescue pelicans that crash-land in the roadway and to monitor pelican mortality on SH 48. At the beginning of this research project, the research team attended a local stakeholder meeting to coordinate with this local pelican conservation group, which included collaboratively implementing safety procedures (high-visibility vests) and encouraging the presence of local law enforcement. During events, the volunteers also coordinated with the TTI field scientists to report estimates of crashed and killed pelicans (this stakeholder meeting is documented in Appendix I).

In conjunction with the pelican conservation group, TTI researchers monitored the number of downed, injured, and killed pelicans during each event. When possible, researchers recorded details of the location, sex, and age (adults or juveniles) of pelicans. The TTI field researchers also checked the roadway for carcasses on days following cold fronts and whenever the researchers were present on SH 48 performing other field surveys (e.g., mark-resight, wind station monitoring).

The TTI field researchers and TxDOT project team installed 20-foot poles on the edge of the highway as reference points to help determine crossing altitude and location. Figure 97 provides a schematic of these survey areas. Whenever possible, efforts were made to record the precise location (longitude and latitude) of carcasses found on the road, as well as the lane from which it was recovered. For pelicans that were immediately removed from the roadway, it was often only possible to allocate the pelican to one of the sections illustrated in Figure 97.

Notes on the Quality of Mortality Data

Several factors prevented a complete record of downed or killed pelicans to be recorded in full detail during this study. First, pelicans crash-land and are killed over a stretch of SH 48 that extends east from the San Martin Bridge to the portion of SH 48 that borders the Bahía Grande (close to a 3-mile stretch of road). Second, visibility on the road is often hampered by poor weather and shortened daylength—large numbers of pelicans cross SH 48 after dark. Third, the traffic conditions and roadway design hamper full observations. Most of SH 48 is a four-lane highway with speed limits of 60 to 70 mph and relatively high traffic volumes. At most locations, the roadway is divided by a 48-inch median CTB that prevents full visibility across east and westbound lanes and prevents volunteers from crossing the entire roadway safely. Finally, the pelican events are inherently chaotic and traumatic—they occur during high winds, cold, and often wet conditions. The most severe events involve graphic scenes of distressed pelicans, distressed volunteers, pelican mortality, and concern for the traveling public.

In addition to pelican events recorded during this research project, between 2013 and 2017, TxDOT collected data on dead pelicans on SH 48 following cold front events. Usually, surveys were undertaken the day after cold front events, during which time the number of dead pelicans were counted (since there were no field workers on site to observe crashed pelicans).

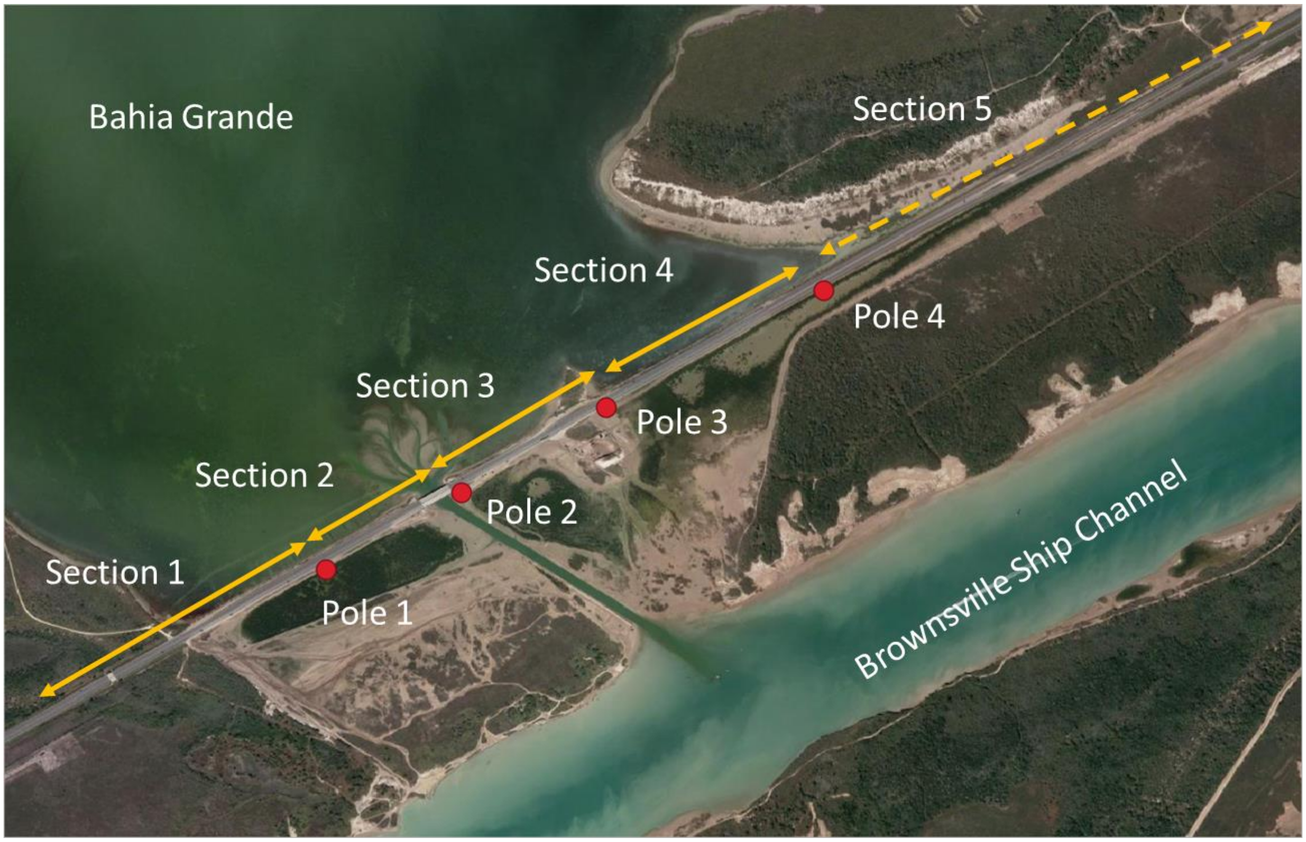


Figure 97. Sample Locations on SH 48.

As mentioned earlier, the statistical models of pelican mortality presented in this chapter rely on the pooling of pelican event data collected between 2013 and 2017 with more detailed measurements taken during this study. The rationale for pooling the data is that pooling provides a longer record of pelican events and therefore more accurate statistical models. However, the pooled data has some consequences for the interpretation of analyses and results. First, the pre-2017 data only contain mortalities, and the timing of these mortalities relative to observation dates may be slightly skewed (i.e., carcasses that were observed in driving surveys a day after mortality). Data collected post-2017 include both downed and killed pelicans. However, in both cases, but especially post-2017, the number of pelicans that died during each cold front event was affected by the presence of volunteers saving pelicans that landed on the roadway (i.e., the success of this endeavor).

ANALYSIS OF PELICAN EVENT DATA COLLECTED DURING THE STUDY

Figure 98 through Figure 103 provide summaries of the location, timing, and physical characteristics of pelicans that crashed on SH 48. Most of the detailed data come from observations taken after the fall of 2017 (i.e., during this research project).

Data recorded by TxDOT and the pelican conservation group indicate that a total of 263 pelicans were killed on SH 48 prior to the start of this research project (48 months between December

2013 and November 2017), averaging approximately 66 pelicans killed per year. During this research project (38 months from December 2017 through January 2021), TTI researchers have recorded an additional 636 pelicans that crashed on SH 48, and of those, 198 pelicans were killed (with an average of 63 pelican per year killed). The total for all pelican events (December 2013 through January 2021) is 899 downed pelicans, with 461 deaths. The supplemental report provided with this research report provides a comprehensive and detailed record of the association among weather variables and recorded pelican events between 2013 and 2021.

Figure 98 shows that pelicans were killed or downed along the entire length of SH 48 that borders the Bahía Grande, although downed/killed pelicans tend to be concentrated adjacent to the Carl Gayman Bridge. The annotations in the lower map show the location of traffic barriers on SH 48. A 48-inch-high central barrier occurs along the entire length of the visible section (the red line in the figure illustrates the extent of the center barrier, not the location). The yellow lines illustrate the extent of CTBs[25] on the north side of the road (westbound carriage ways). The Carl Gayman Bridge also has a 36-inch barrier installed on its south side, with its extent indicated by the pale orange line. Although difficult to verify statistically, a change in the spatial pattern of mortalities appears to occur adjacent to the small peninsula marked **A** on the map. Adjacent to this area, mortality appears to be restricted to the eastbound (southern) lane and possibly occurs less frequently. This result may be a consequence of the topography and road infrastructure but may also occur because it is a relatively easy place for volunteers to be stationed during cold fronts (thereby possibly increasing the rescue rate at this location). Figure 99 summarizes the location of crashed and killed pelicans by the sections shown in Figure 97.

[25] Prior to 2013 and up to fall 2019, these barriers were 36-inch CTBs. In fall 2019 (construction lasting until spring 2020), they were replaced with a railing design.

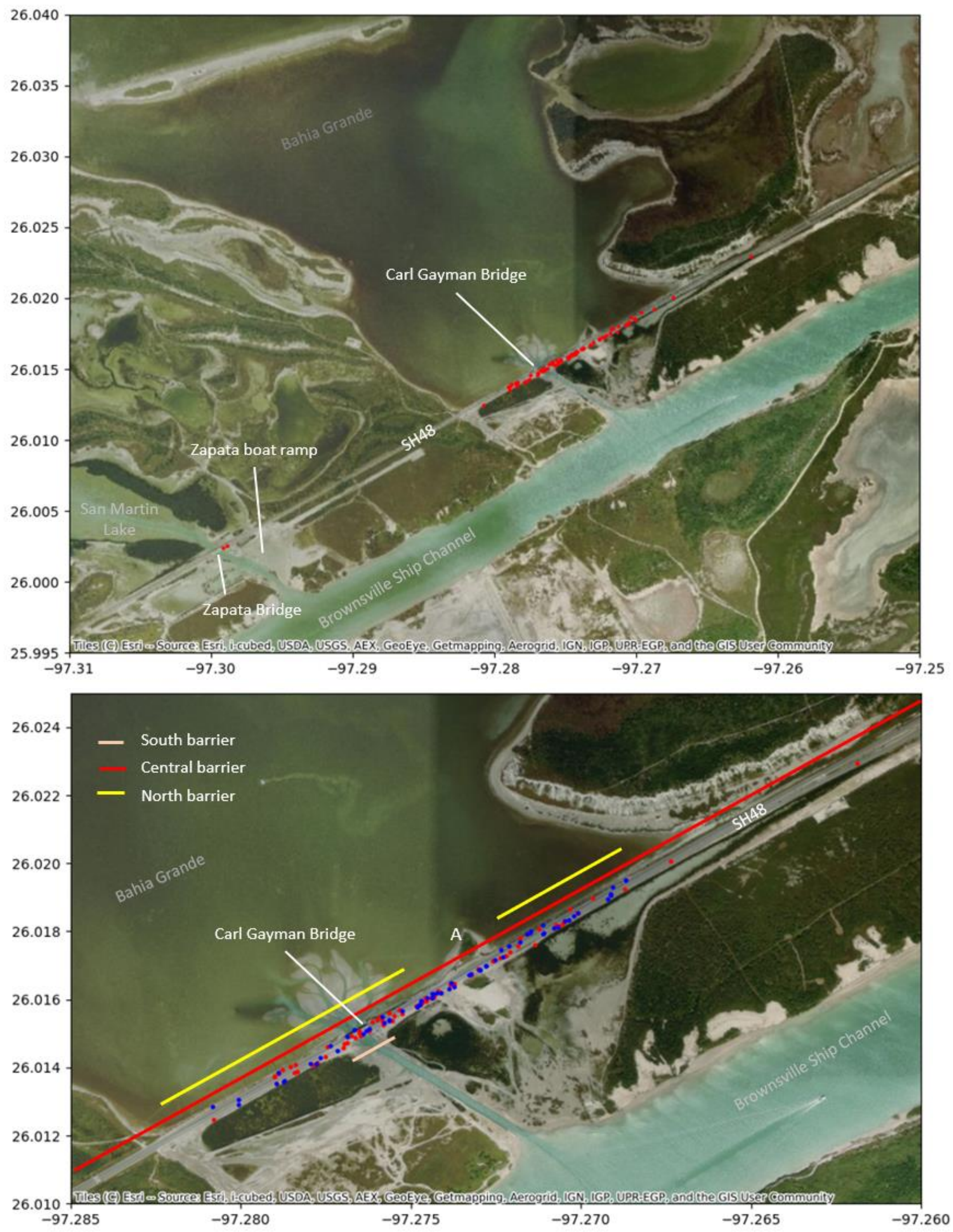


Figure 98. Location of Carcasses Retrieved from SH 48 (2017–2021) during and following Cold Front Events. The upper plot shows all carcasses found between the Zapata boat ramp and the east end of the Bahía Grande. The lower graph shows carcasses adjacent to Carl Gayman Bridge colored by age (red = juveniles, blue = adults) and the physical extent of the traffic barriers (not actual location).

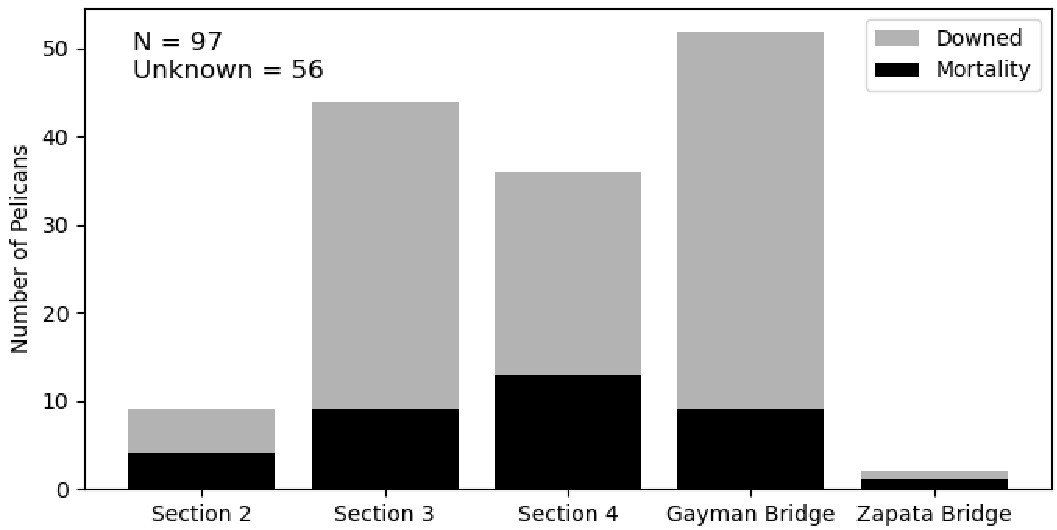


Figure 99. Number of Pelicans Crashed and Killed on Different Sections of SH 48.

Figure 100 shows the distribution of downed and killed pelicans by time. Pelican mortalities and crash landings occur most frequently in the afternoon and evening. It should be noted that this graph only contains information for events that were directly observed by field workers. As mentioned previously, during serious (large) pelican mortality events, pelicans may crash-land after sunset. It should also be noted that since each cold front event affects a different number of pelicans, the data in these graphs may be skewed by the timing of mortality on these specific, high mortality events.

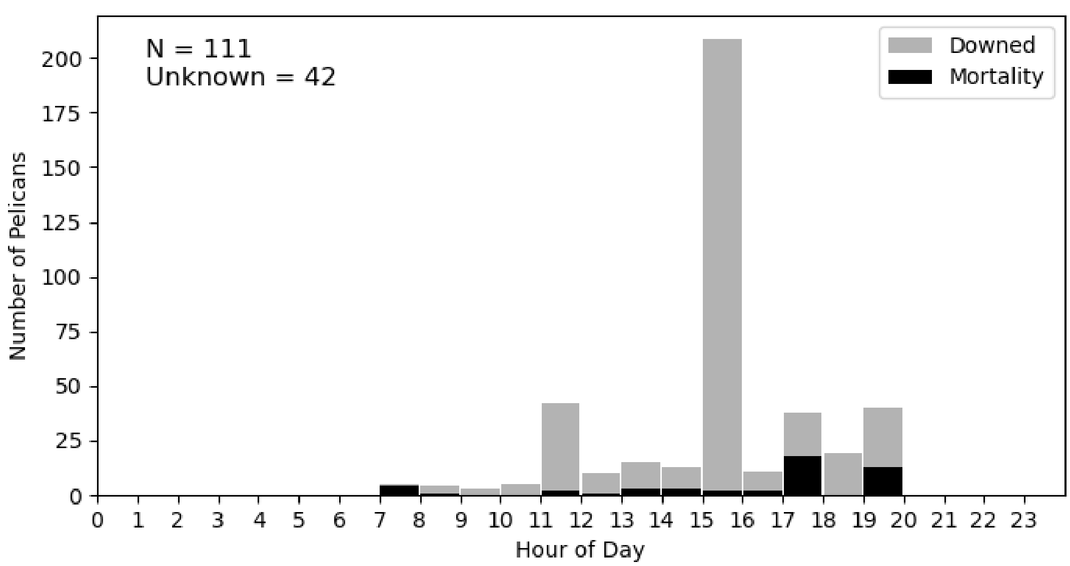


Figure 100. Number of Pelicans Crashed or Killed on SH 48 by Time of Day.

Figure 101 shows the distribution of pelicans crashed and killed by the month of the year. The top graph in this figure provides a view of pelican events for the entire data record (between 2013 and 2021). The middle figure shows the record for the period prior to the current research project (2013 to fall 2017), while the bottom graph shows data collected during the current research project. All pelican events (except one) have occurred between September and March. Peak pelican events occur in December and January.

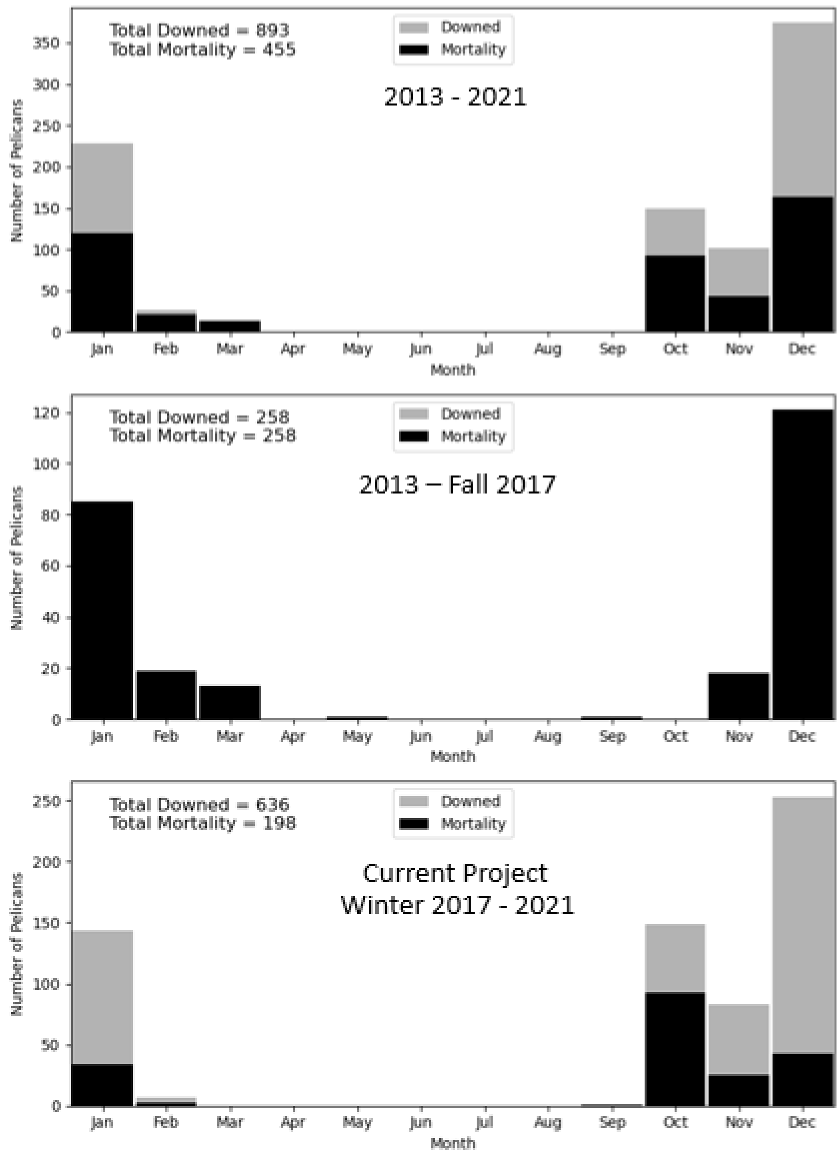


Figure 101. Number of Pelicans That Crashed or Were Killed by Month between 2013 and 2021. The top graph shows the distribution of pelican events for the entire period. The middle graph shows pelican events between 2013 and 2017 (before the current research project was initiated). The bottom graph shows events during the current research project.

Figure 102 and Figure 103 illustrate the physical characteristics of pelicans rescued from the bridge or of pelican carcasses recovered from the bridge (if the carcasses were in a state suitable to make such measurements). Figure 102 compares the morphology of adults and juveniles recovered on SH 48 with a control group. The control group measurements are those taken during the capture of BGWC pelicans throughout the GPS and mark-resight (banding) studies undertaken in this chapter. Figure 102 suggests that there are no clear differences in the morphology of pelicans that crash-land on SH 48 relative to the control group. Figure 103 shows the same information broken down into age and sex. Again, there is no evidence of morphological differences between pelicans recovered on SH 48 and the control group.

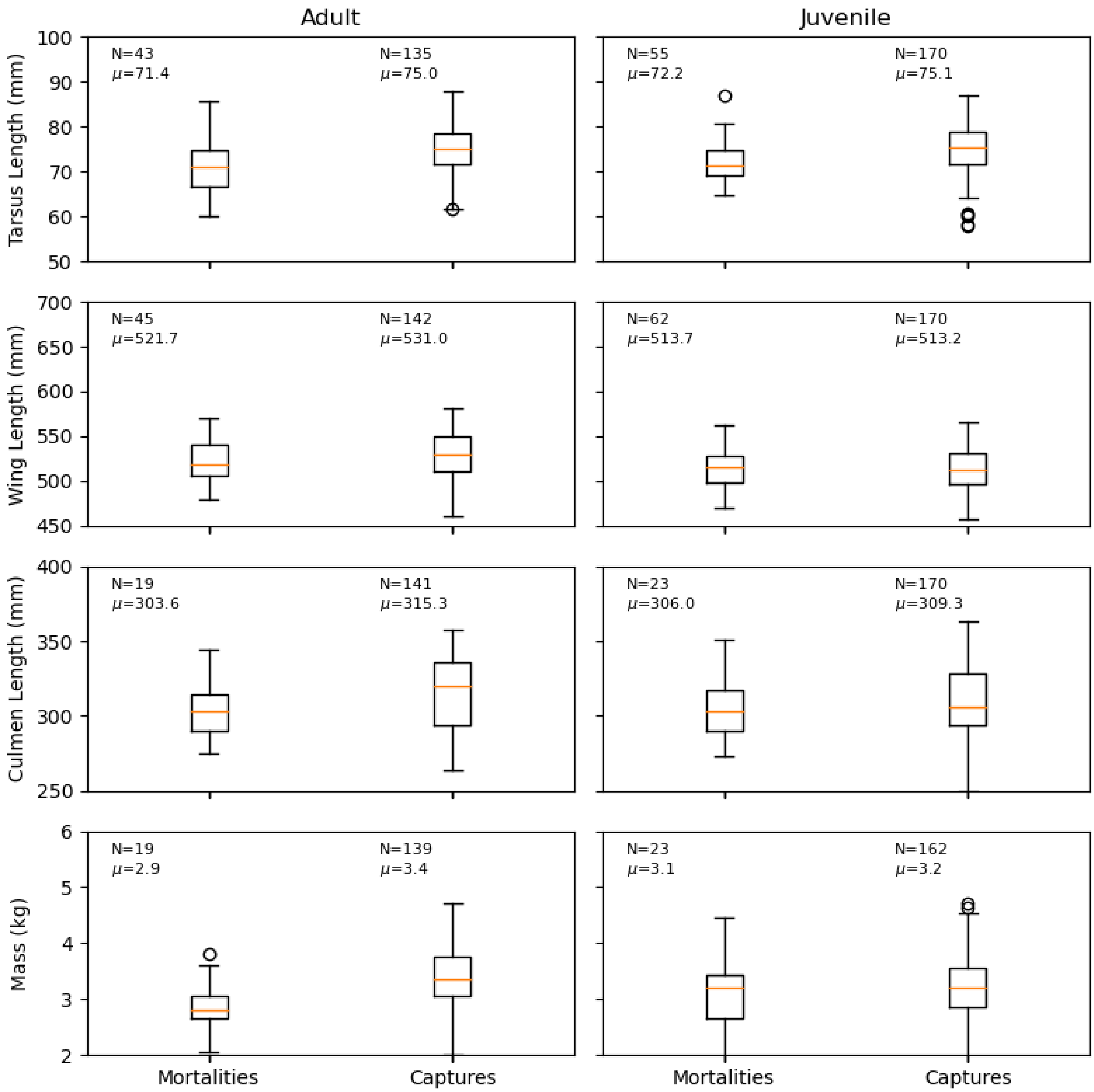


Figure 102. Body Measurements of Adult and Juvenile Pelicans Killed on SH 48 Relative to Control Group Pelicans. In the charts, N represents the number of samples, and μ (mu) represents the mean value (orange line).

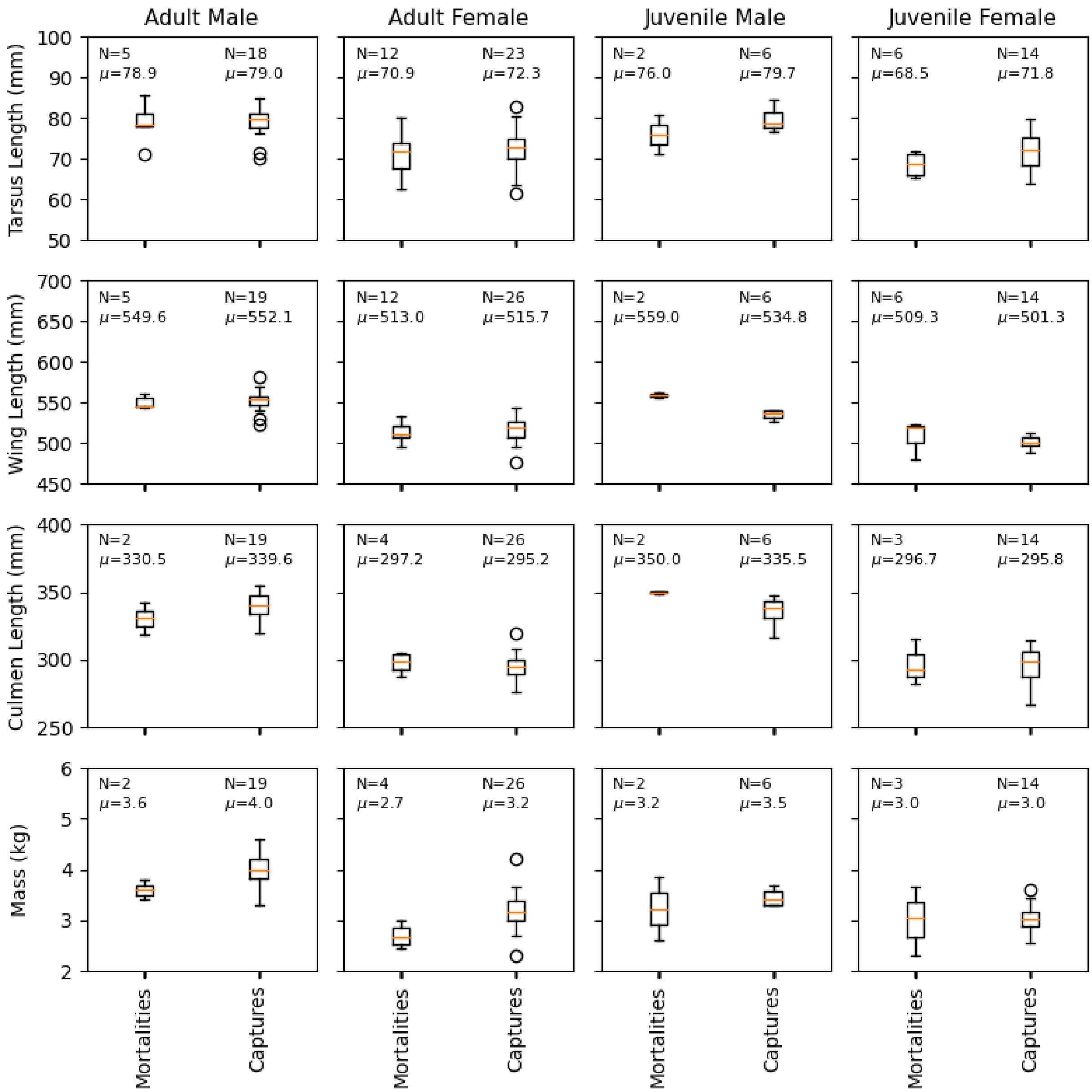


Figure 103. Body Measurements of Pelicans Killed on SH 48 Relative to Control Group Pelicans Categorized by Age and Sex.

QUALITATIVE SUMMARY OF MORTALITY EVENTS

This section provides a detailed description of the weather associated with pelican events on SH 48. Previous research, field observations, and anecdotal reports indicate that cold fronts are the principal driver of pelican events—specifically, the cold fronts that result in a change in wind direction from prevailing southeasterly to winds originating from the north-northwest. Cold fronts are also associated with an abrupt drop in temperature, an increase in wind speed and often precipitation. Weather data were collected from two NOAA weather stations (Brownsville and Port Isabel) and from the on-site project weather station located adjacent to the Carl Gayman

Bridge and canal that was set up specifically for this project. In this section, TTI researchers qualitatively review the incidence of pelican events relative to prevailing weather conditions using a subset of selected pelican events.

Severe Pelican Events

The five most severe pelican events recorded from 2013 through January 2021 resulted in a total of 524 crashed pelicans (approximately 58 percent of crashed or killed pelicans recorded from 2013 through January 2021), with 199 of them killed before they could recover from the crash landing (43 percent). The five most severe pelican events are:

1. December 6–8, 2017—233 crashed pelicans, 31 killed (Figure 104).
2. October 15–18, 2018—83 crashed pelicans, 59 killed (Figure 105).
3. January 10, 2021—91 crashed pelicans, 19 killed (Figure 106).
4. December 9, 2016—80 pelicans killed (crashed pelicans that survived were not recorded; Figure 107).
5. October 11, 2019—37 crashed pelicans, 10 killed (Figure 108).

The following five figures provide the temperature, wind speed, and wind direction for these weather events. With few exceptions, severe pelican events are associated with a rapid drop in temperature, an abrupt 180-degree shift in wind direction (from the prevailing southeastern to winds originating from the northwest), and an increase in wind speed. Of these phenomena, the shift in wind direction appears the most consistent indicator of a change in weather conditions that results in pelican events. The time of day of the cold fronts varies across examples (approximately 8 p.m. on the December 5–9, 2017, event; 3 p.m. on the October 14–17, 2018, event; approximately noon on January 10, 2021; about 10 a.m. on December 8, 2017; and 2 p.m. on October 10–13, 2019).

In most cases, the winds are strongest close to the onset of the cold front. The increase in wind speed associated with the beginning of the cold front also coincides with the largest number of crashed pelicans (Figure 105, Figure 106, and Figure 108). The December 5–9, 2017, event (Figure 104) is somewhat different in the sense that the highest winds (and the days with the highest mortality) occur a day after the onset of the cold front. For the December 8, 2016, event (shown in Figure 107), the project weather station was not in place, and the mortalities, as assessed during post-event surveys, may have occurred on either of two days (December 7 or 8, 2016).

The increase in wind speeds (before and after the onset of cold fronts) requires some careful interpretation. Although it is true that most cold fronts do result in an increase in wind speeds, the actual difference between maximum wind speeds during ambient versus cold front wind conditions is relatively small (for NOAA station measurements, the relative difference is typically less than 5 mph).

One feature of wind velocity seen in all graphs is the difference in NOAA measurements versus the project wind station measurements for northwestern winds. In Figure 104 through Figure 108, the shift to north winds results in an increase in wind speed measured at the project weather station (especially the upper anemometer) relative to the NOAA stations, often by as much as 5 mph.

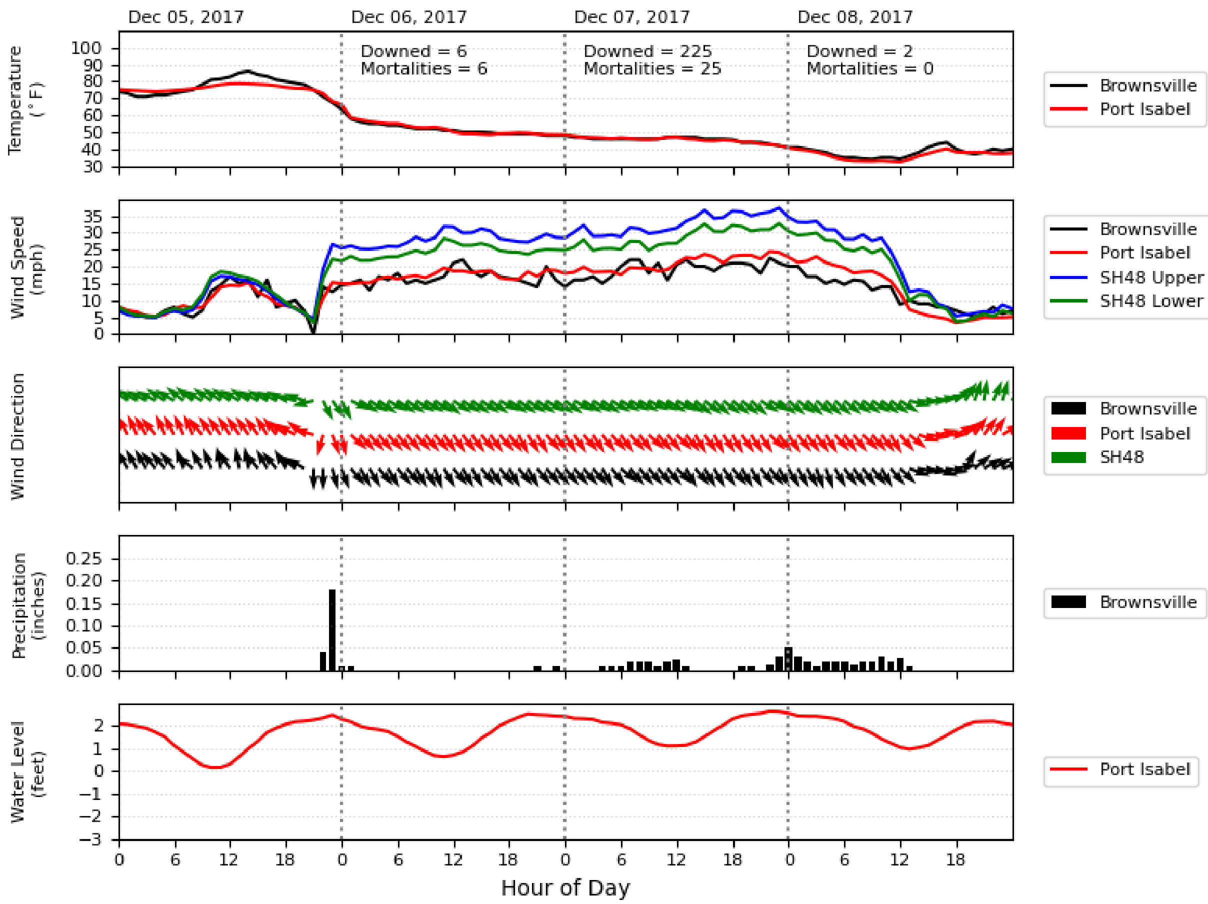


Figure 104. Hourly Weather (and water levels) Associated with a Severe Pelican Event (233 pelicans) Occurring in December 2017.

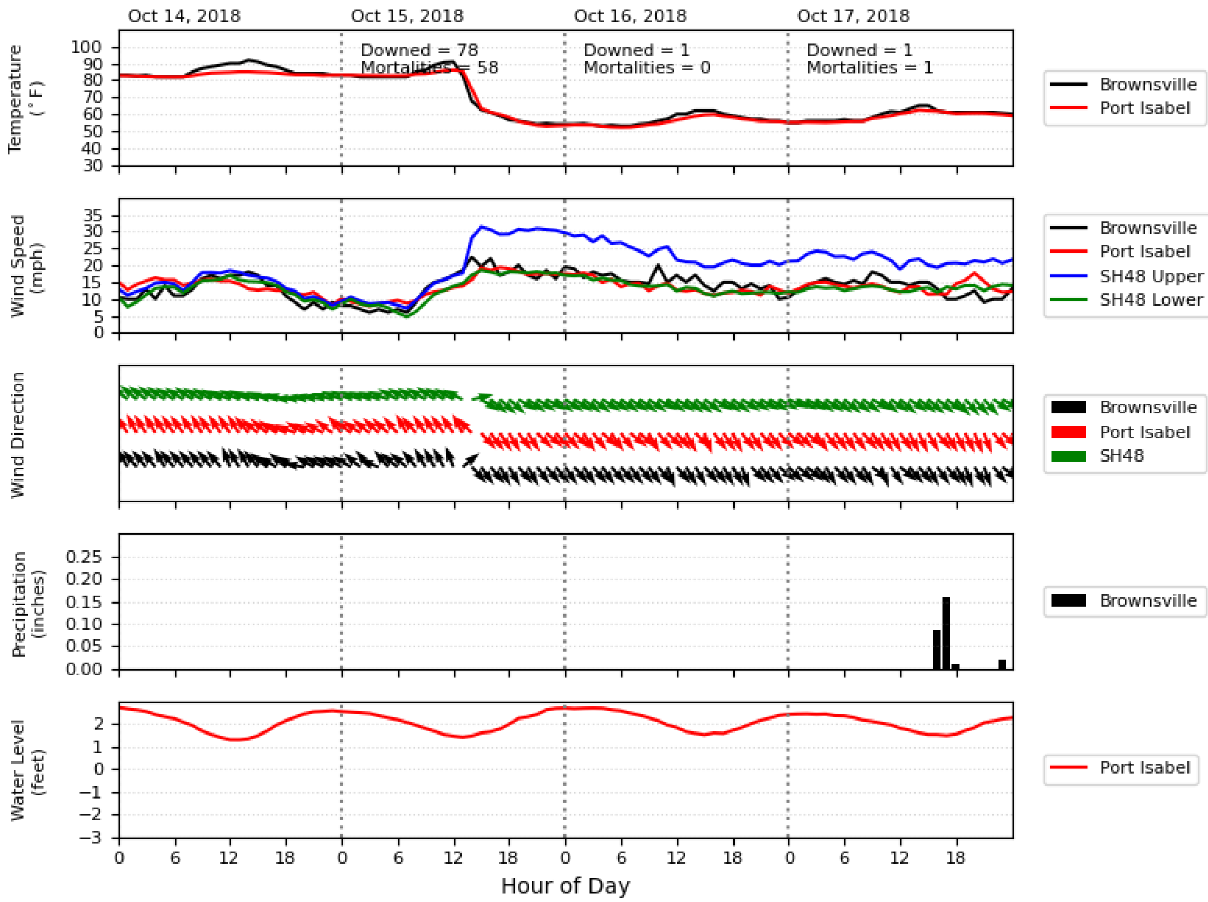


Figure 105. Hourly Weather (and water levels) Associated with a Severe Pelican Event (83 pelicans) Occurring in October 2018.

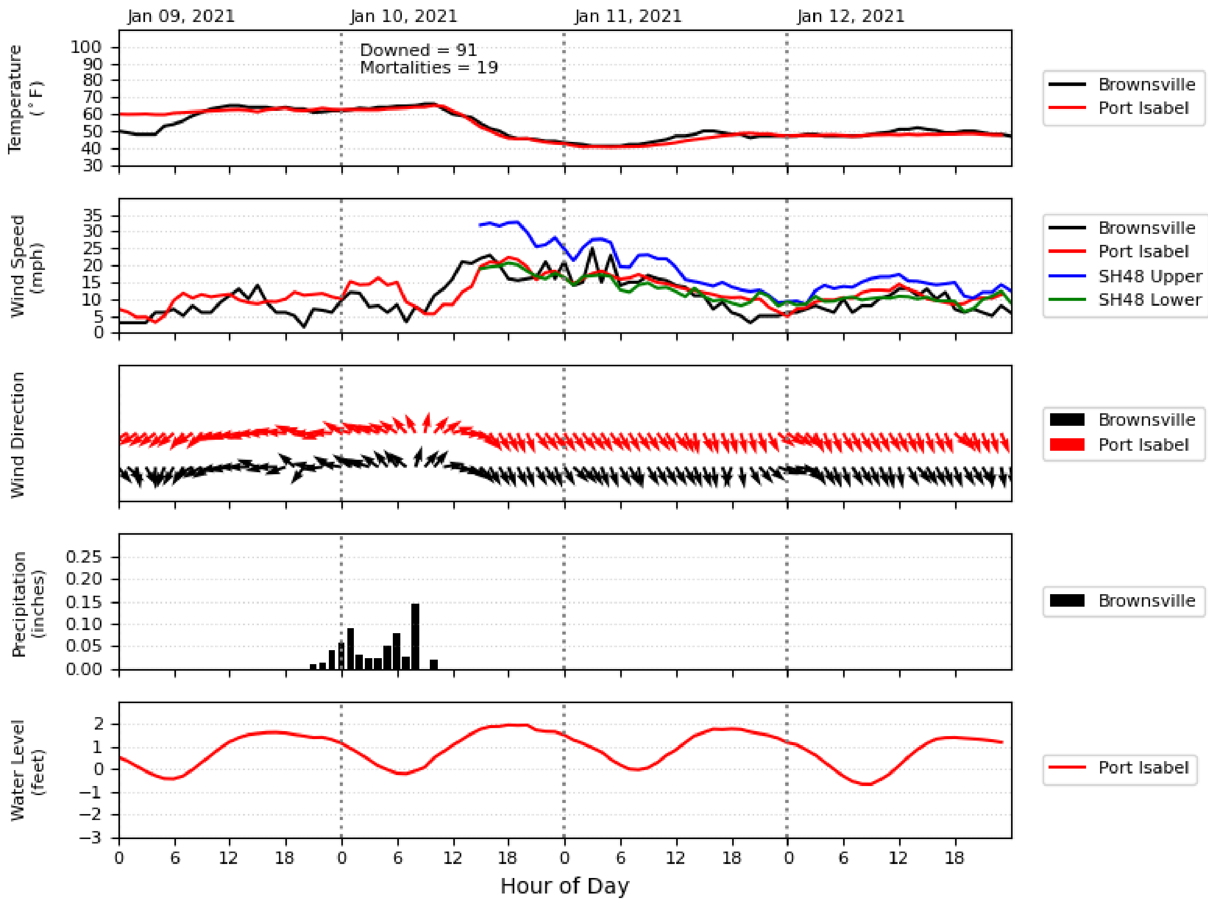


Figure 106. Hourly Weather (and water levels) Associated with a Severe Pelican Event (91 pelicans) Occurring in January 2021.

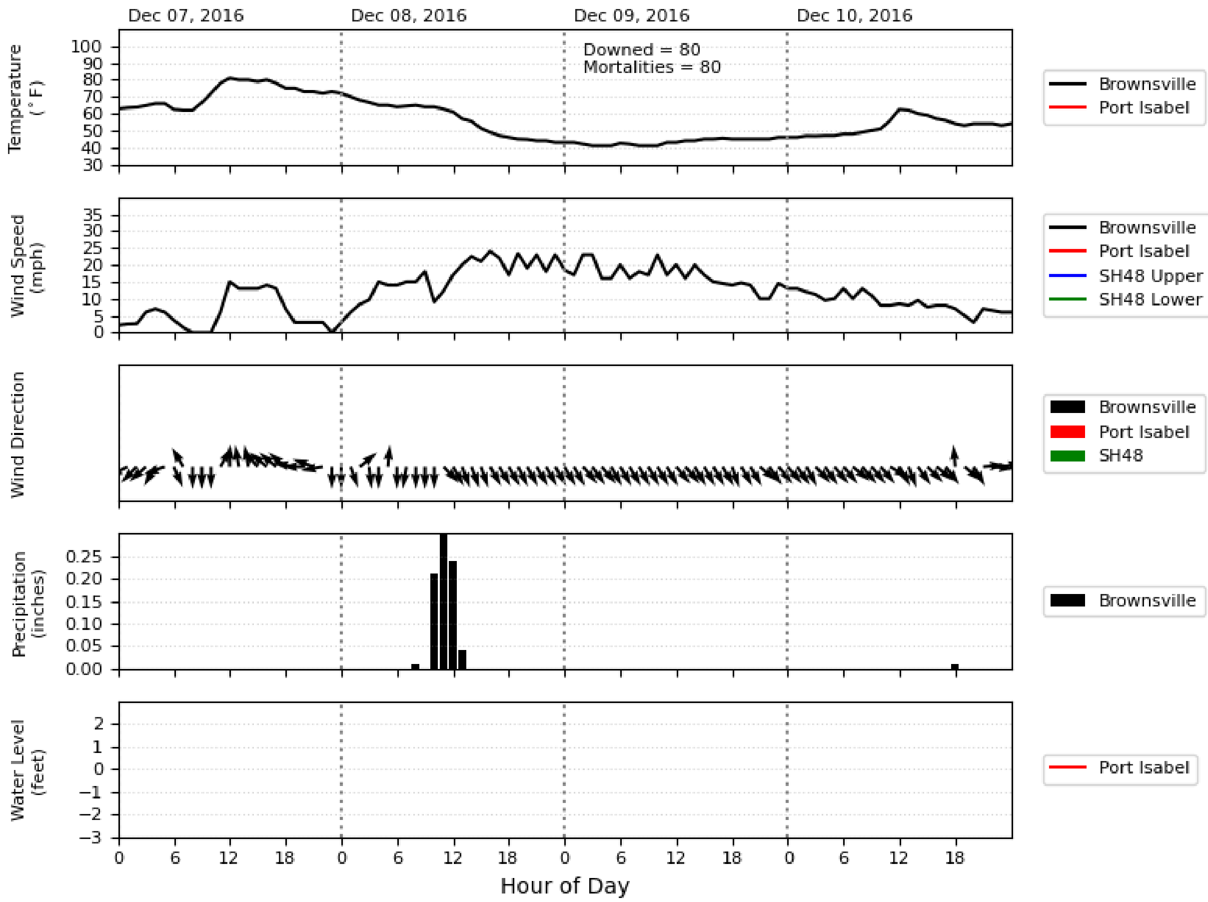


Figure 107. Hourly Weather Associated with a Severe Pelican Event (80 pelicans) Occurring in December 2016. Project weather (SH 48) station data and crashed pelican counts were not available.

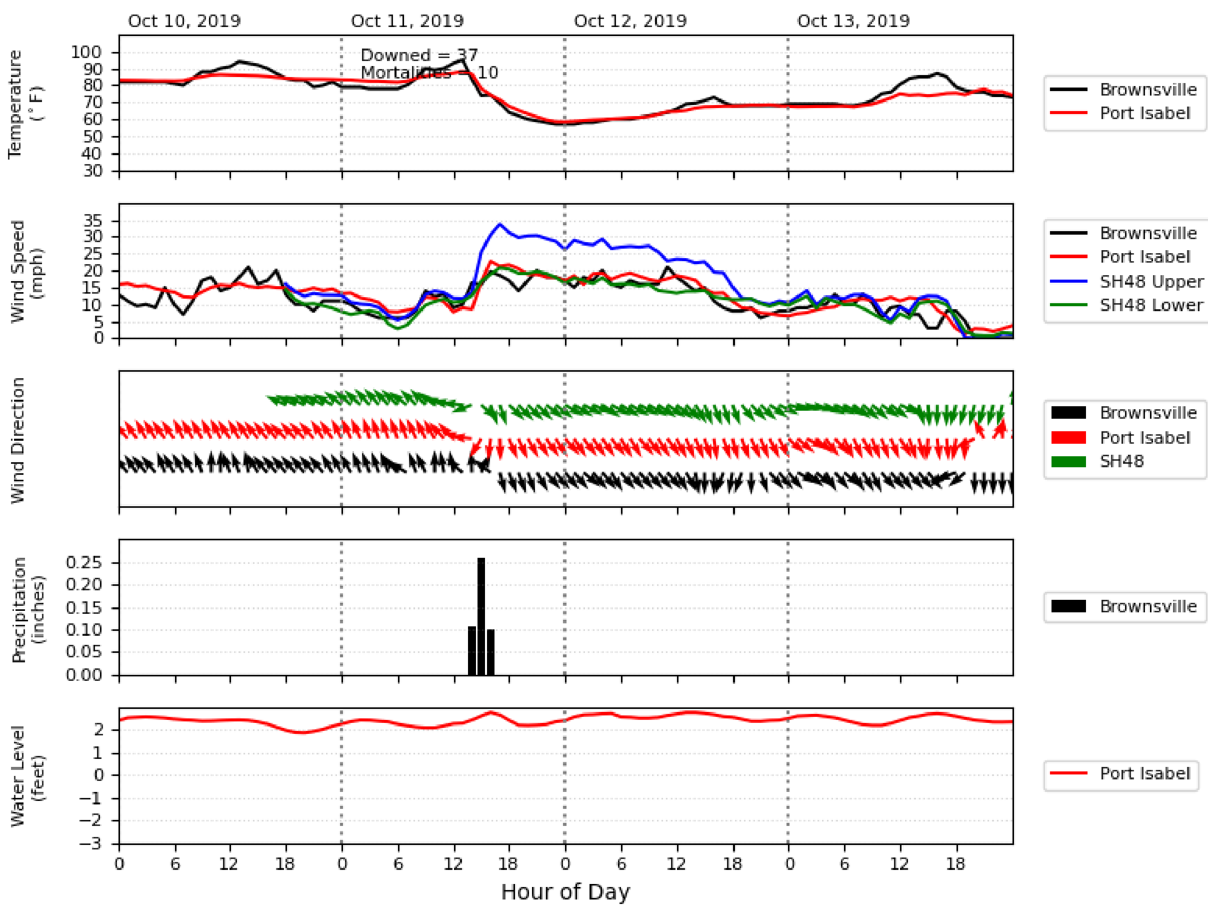


Figure 108. Hourly Weather (and water levels) Associated with a Severe Pelican Event (37 pelicans) Occurring in October 2019.

Minor Events

Figure 109 through Figure 112 present weather variables consistent with pelican events of medium or low severity. The four minor pelican events represented here are:

- February 11, 2018—Seven crashed pelicans, two killed (Figure 109),
- October 25, 2019—Six crashed pelicans, three killed (Figure 110),
- January 11, 2018—Two crashed pelicans, both killed (Figure 111), and
- January 23, 2019—One crashed pelican that was killed (Figure 112).

As is the case for the severe pelican events, downed/killed pelicans occur in association with a pronounced change in wind direction, wind speed, and temperature characteristic of cold fronts. Again, the timing of cold fronts is variable—in the February 11, 2018, event (Figure 109), the cold front arrives at approximately 12 p.m., which also coincides with the highest wind speeds. Unlike the more severe events presented in the previous section, high-velocity winds remain only for the remainder of the day (although the northern direction persists for several days). A similar pattern can be seen in the October 25, 2018, event (Figure 110). In this case, the cold front occurs at approximately 1 p.m., leading to a sudden and large change in wind speeds. High wind speeds occur for a day but then diminish to less than 20 mph the next day (again the wind remains from the north). The January 11, 2018, event (Figure 111), coincides with an early afternoon cold front and very high wind speeds on SH 48 between the hours of 2p.m. and 6 p.m. but a considerable reduction in wind speed the following day. The pelican event of January 23, 2019, highlights the importance of wind direction on mortality events. The day prior to pelican mortality is characterized by high winds (above 25 mph) from the southeast that resulted in no (recorded) pelican mortality. The following day, a cold front occurred at approximately 5 a.m., resulting in early morning northeasterly winds greater than 25 mph and one mortality (Figure 112).

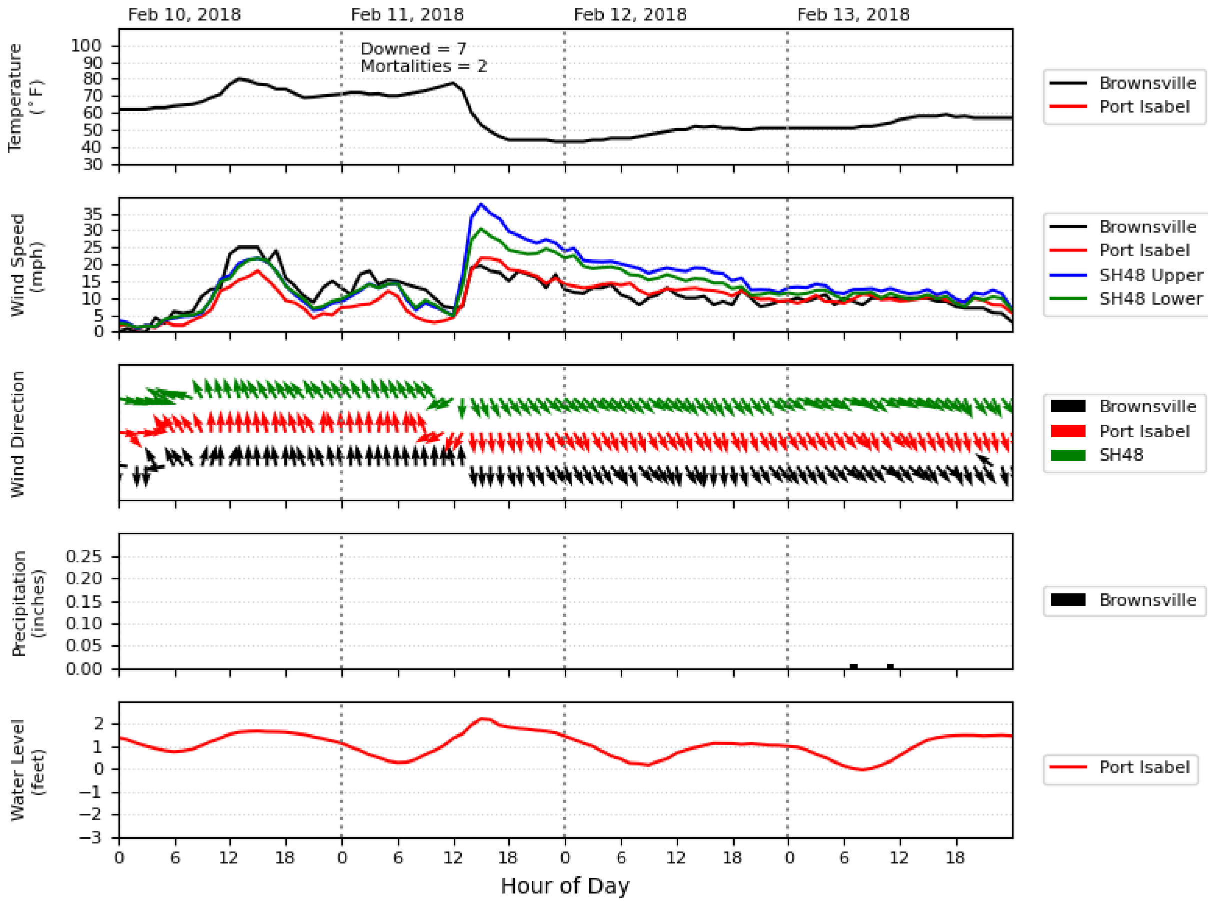


Figure 109. Hourly Weather (and water levels) Associated with a Minor Pelican Event (seven pelicans) Occurring in February 2018.

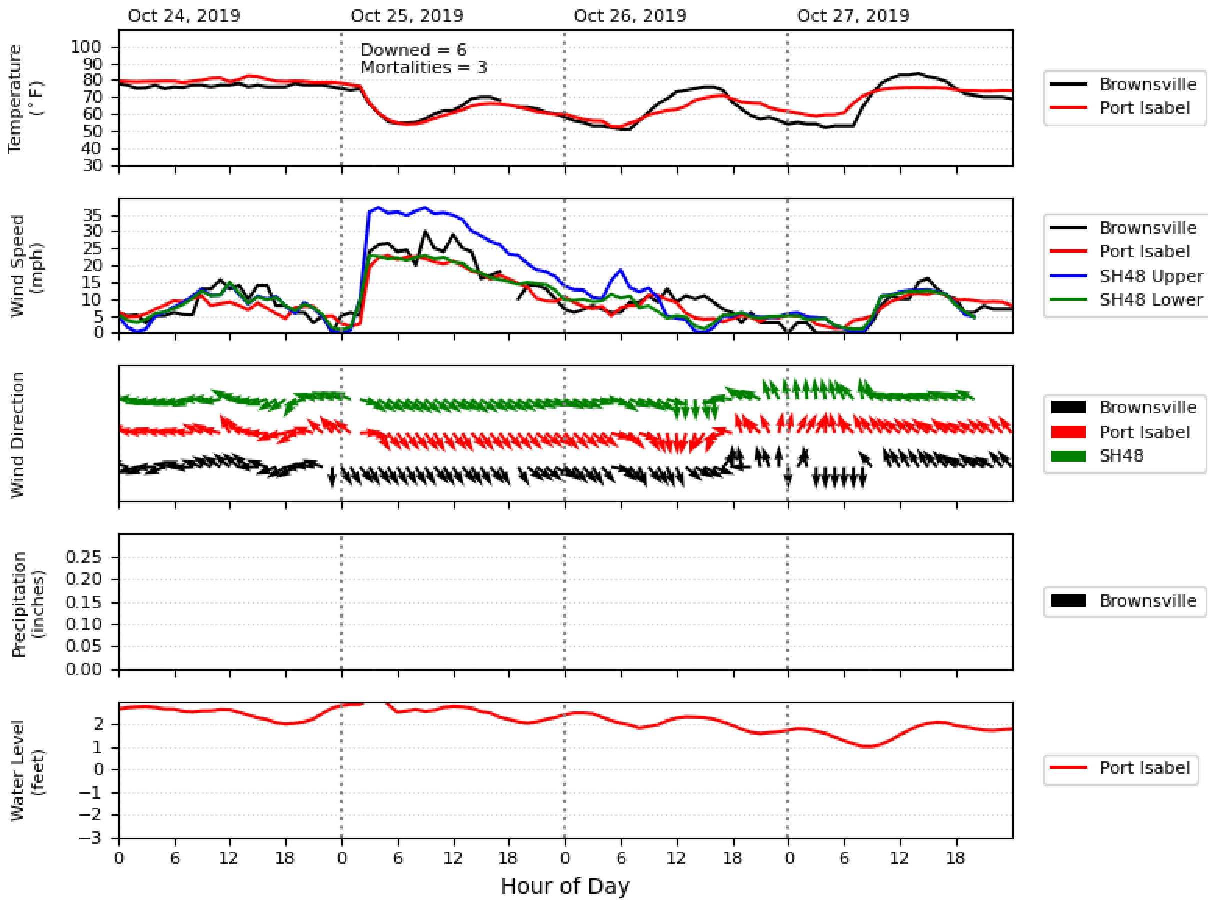


Figure 110. Hourly Weather (and water levels) Associated with a Minor Pelican Event (six pelicans) Occurring in October 2019.

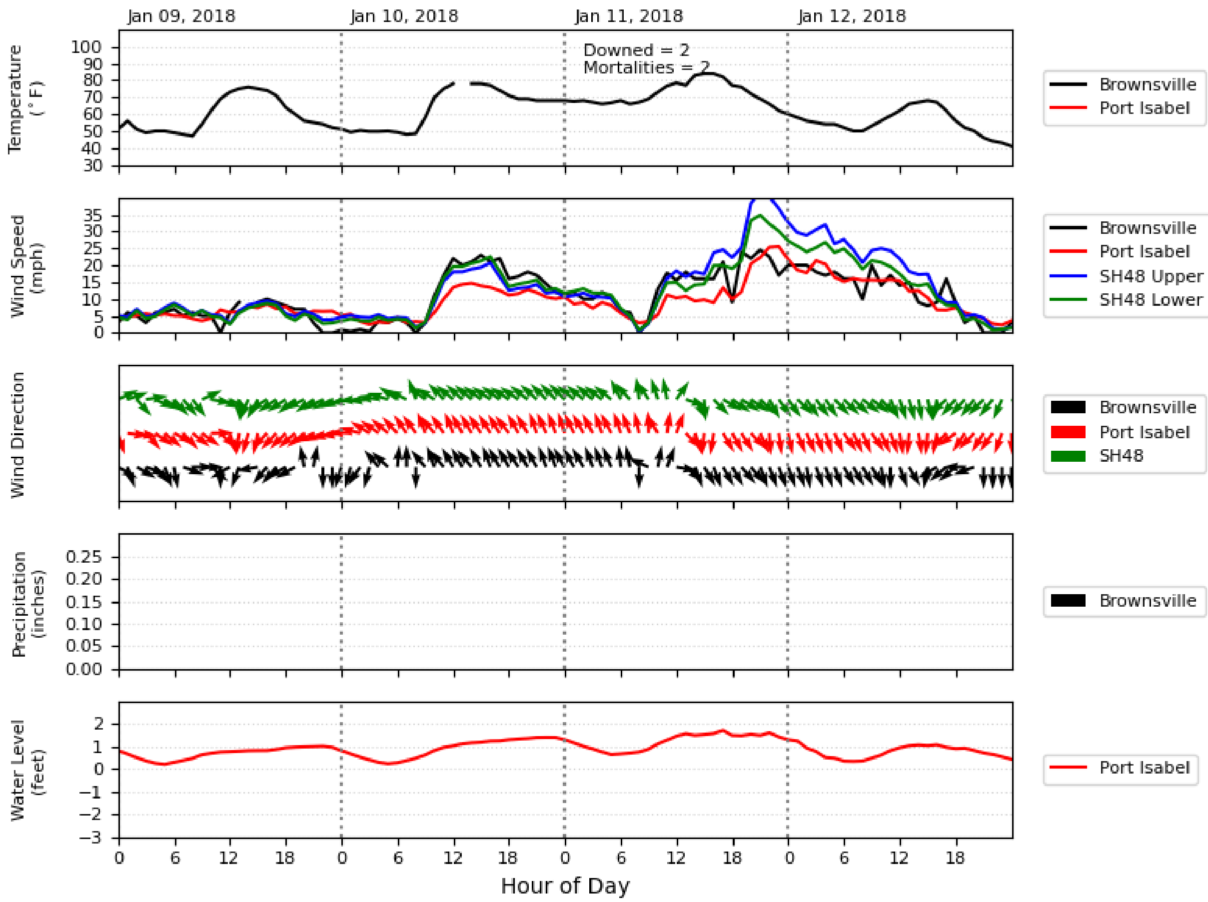


Figure 111. Hourly Weather (and water levels) Associated with a Minor Pelican Event (two pelicans) Occurring in January 2018.

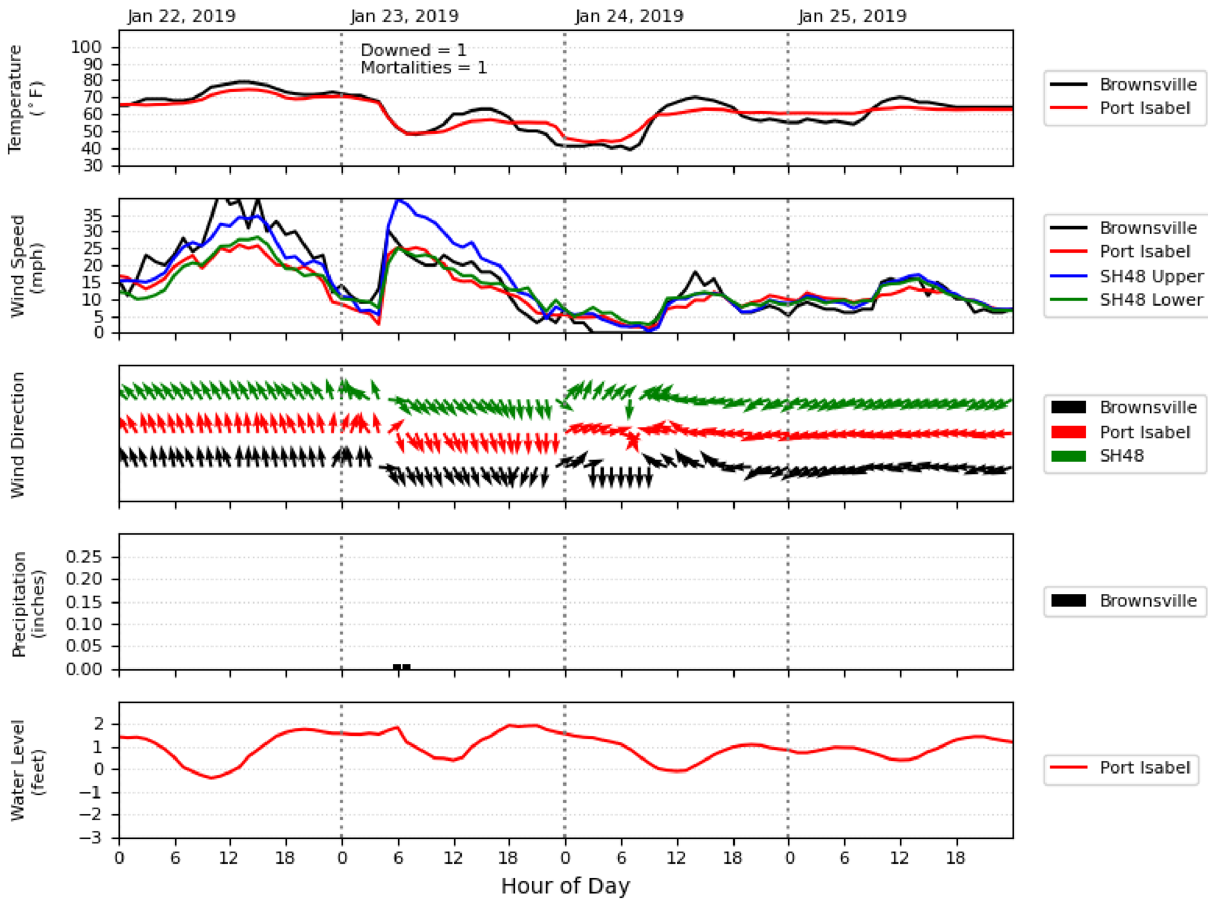


Figure 112. Hourly Weather (and water levels) Associated with a Minor Pelican Event (one pelican) Occurring in January 2019.

Overview

The subset of pelican mortality events described above, and the more comprehensive review provided in the supplemental report provide insights into the factors that drive pelican events. Based on the qualitative review, the research team tentatively concluded that strong (greater than 20 mph) northwestern winds are the most common factor associated with all pelican events. These winds generally only occur with cold fronts. In most cases, the strongest winds occur at the beginning of the cold front. Generally, the figures suggest that the duration of abnormally high northern winds drives the severity of pelican events.

Figure 113 to Figure 115 summarize the record of pelican events between 2013 and 2021. Figure 113 shows the full temporal pattern of daily pelican events for the fall season (October 1 to December 31) for each year of pelican mortality data (2013 to 2020). The figure also shows the incidence of the following weather conditions: minimum daily temperature less than 55 degrees, the occurrence of a northwestern wind direction (during any time of the day), wind speeds (measured at NOAA stations) greater than 17.5 mph., and days in which all these weather factors occurred (indicated by the colored horizontal bands that signify whether the weather condition occurred on any given day). Figure 114 shows the same information for the spring season (January 1 to March 31). Figure 115 shows the summer season (April 1 to September 30).

In general, these semi-quantitative summaries highlight that pelican events coincide with the temperature conditions when northern winds exceed approximately 17.5 mph (as measured at NOAA stations). The graphs illustrate several examples when lower velocity northern winds occur but with no pelican events. In addition, there are cases where strong northern winds occur, but pelican events do not (at least recorded events). While the fall and spring graphs illustrate a large number of potential and actual events, the summer graphs illustrate that while wind speeds greater than 17.5 miles an hour are common during summer, northwestern winds are rare.

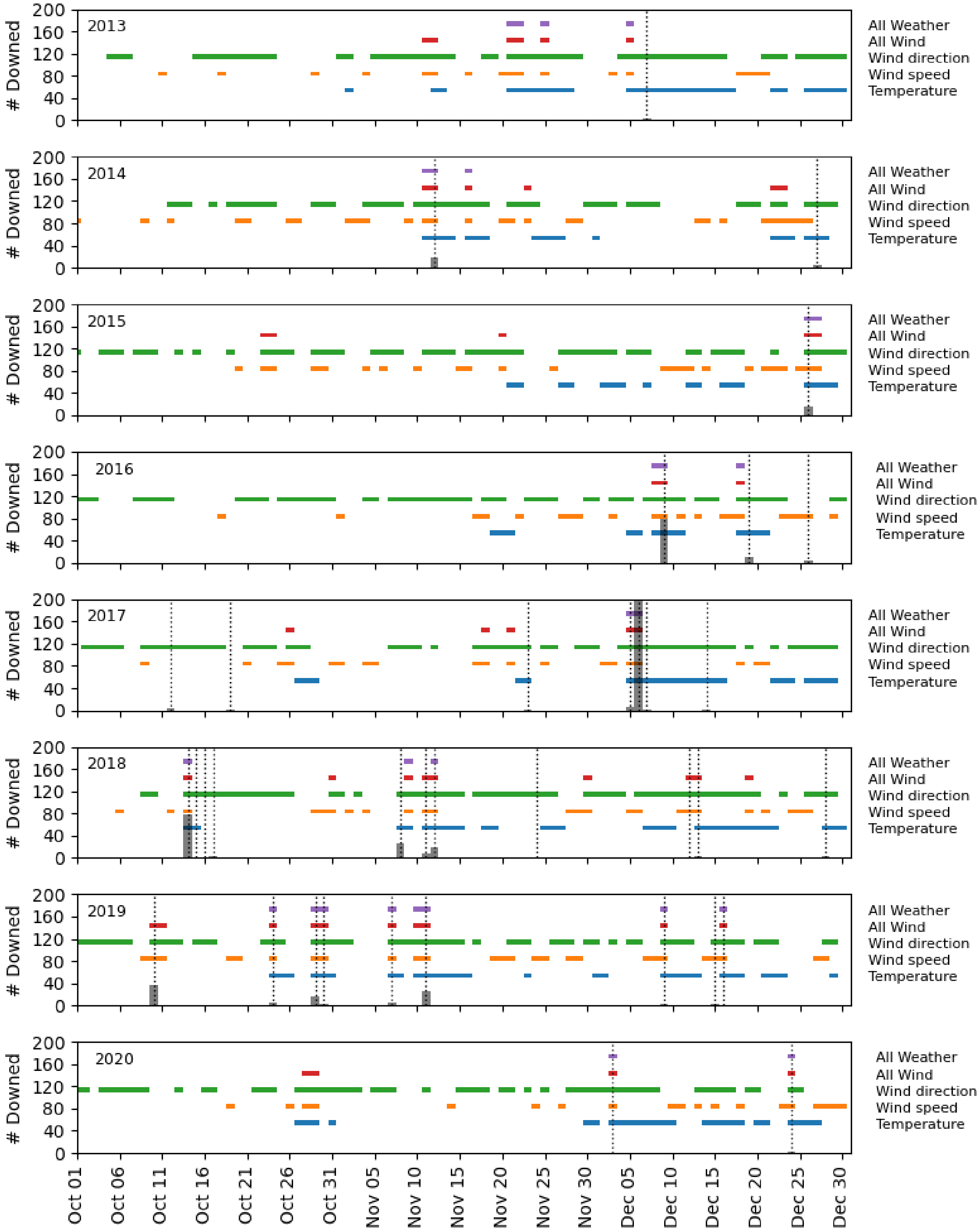


Figure 113. Timing of Cold-Front-Like Weather Variables in Fall with Associated SH 48 Pelican Events. Each vertical bar shows the number of crashed pelicans (*y*-axis) on days shown on the *x*-axis. The dashed lines mark all pelican events irrespective of size. The colored horizontal bars show days when the thresholds for different environmental variables are exceeded (listed on the secondary *y*-axis).

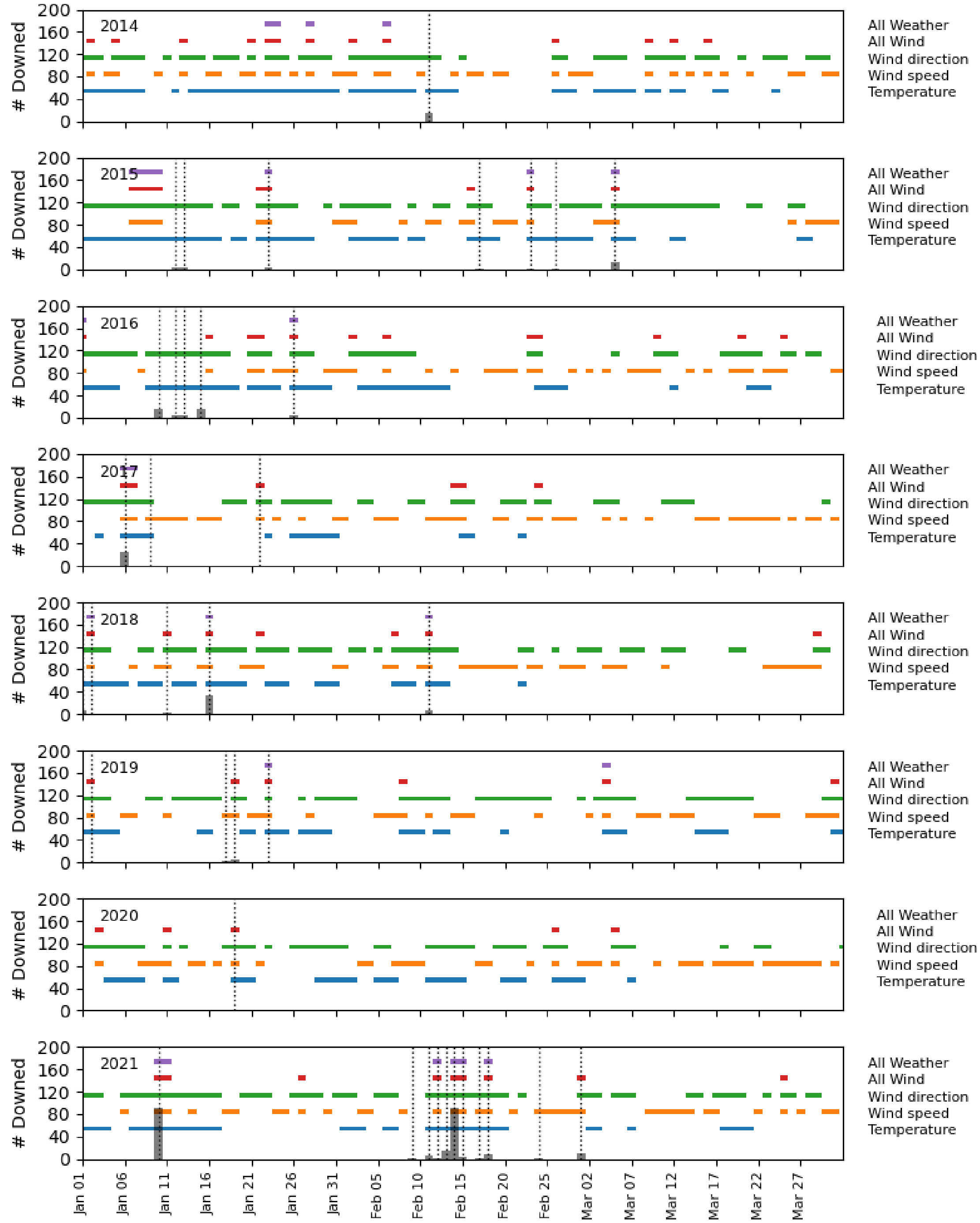


Figure 114. Timing of Cold-Front-Like Weather Variables in Spring with Associated SH 48 Pelican Events. Each vertical bar shows the number of crashed pelicans (*y*-axis) on days shown on the *x*-axis. The dashed lines mark all pelican events irrespective of size. The horizontal bars show days when the thresholds for different environmental variables are exceeded (listed on the secondary *y*-axis).

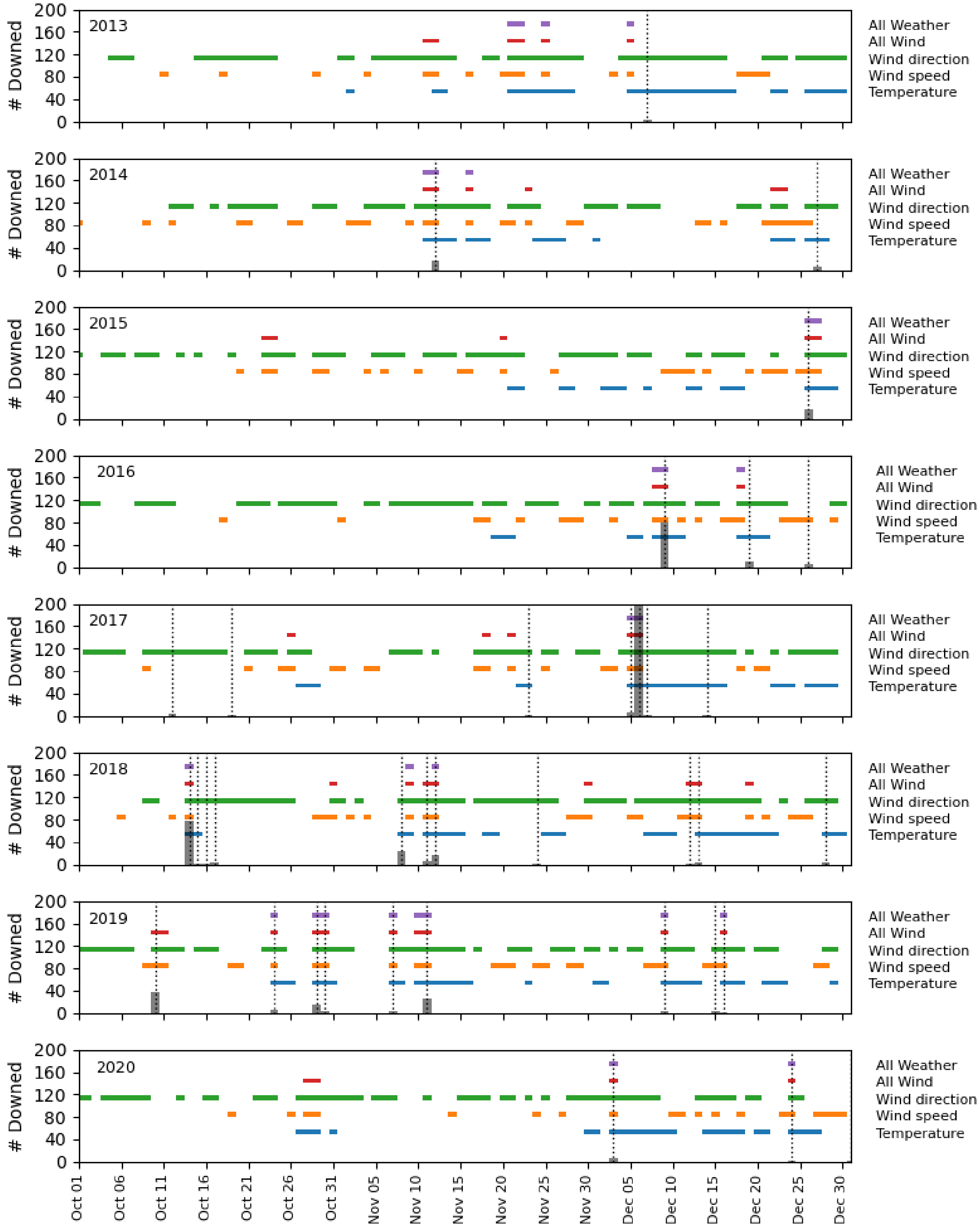


Figure 115. Timing of Cold-Front-Like Weather Variables in Summer. Each vertical bar shows the number of crashed pelicans (*y*-axis) on days shown on the *x*-axis. The dashed lines mark all pelican events irrespective of size. The horizontal bars show days where the thresholds for different environmental variables are exceeded (listed on the secondary *y*-axis).

STATISTICAL MODELING

This section discusses the development of a statistical model by the research team to predict pelican events on SH 48 using environmental variables (wind speed and direction, precipitation, temperature, and local water level). The previous sections provide a detailed quantitative review of the occurrence of crashed or killed pelicans relative to local environmental conditions. The objective of the statistical model is to quantify these relationships and formally (statistically) assess which environmental variables drive pelican events on SH 48.

To maximize the data available for statistical modeling, the model uses pelican event data collected both before this project (2013 to 2017) and data collected during this project (2017–2021). As discussed previously, the data record between 2013 and 2017 only includes the number of pelicans killed (as assessed during post-event surveys). In contrast, the data collected during this project include estimates of both the number of crashed pelicans (per day) and the total number of killed pelicans. For the purposes of the statistical modeling, the number of crashed pelicans (per day) is used as the dependent variable in the model because, in the view (and experience) of the research team, it represents the most consistent index of the severity of a pelican event given that volunteers are often present to save crashed pelicans from being hit by cars (mortality).

For independent variables, the research team used weather data downloaded from the two NOAA weather stations (Brownsville and Port Isabel) described previously. Hourly NOAA data were used in preference to the project weather station data for the following reasons:

1. The NOAA data from Brownsville provide hourly data from 2013 to 2021, while the project weather station only contains data from 2017. Using the Brownsville data enables the model to include pelican events that occurred before 2017.
2. The research team have already demonstrated the ability to model wind on SH 48 from local stations, thereby demonstrating the equivalence and consistency of such measurements.
3. If the model is to be used operationally, it will be useful for it to be calibrated to conditions at an existing, professionally maintained weather station.

Model Development

The previous sections of this chapter highlight the apparent association between pelican events and local weather conditions—particularly the presence of cold fronts that result in a sudden drop in temperature, a shift in wind direction (from the prevailing southeast to northwest), and, in most cases, an increase in wind speed. These qualitative analyses suggest that wind speed and direction are the most consistent indicators of pelican events on SH 48. Moreover, based on the detailed analysis of pelican events and some mechanistic understanding of airflow over SH 48, it is reasonable to assume that the number of pelican crash landings per day is related to the number of hours of inclement wind conditions on a particular day.

The research team used a three-step statistical analysis. The first step of the analysis was to calculate two plausible indices of *daily* wind risk based on hourly weather data (from the NOAA station). These indices were founded on the idea (hypothesis) that the probability of crashed pelicans on any given day is proportional to the number of hours per day that the hourly wind direction falls within 30 degrees (plus or minus) of a critical wind direction (denoted by the unknown parameter $\theta_{critical}$) and hourly wind speed exceeds a critical velocity threshold (denoted by the unknown parameter $v_{critical}$). In turn, these parameters were used to derive two daily indices of pelican event risk from hourly wind data, namely wind risk duration (WRD) and wind risk velocity (WRV), derived as follows:

- WRD is the number of hours per day (expressed as a proportion) where wind direction falls within +/− 30 degrees of $\theta_{critical}$ and exceeds the velocity $v_{critical}$.
- WRV is the mean velocity of wind calculated using each hour that wind direction falls within +/− 30 degrees of $\theta_{critical}$ and exceeds the velocity $v_{critical}$.

The second step of the model used a zero-inflated Poisson (ZIP) regression model to predict the number of pelicans that crashed on each ***day*** of the historical record based on the two aforementioned daily indices WRD and WRV (in turn derived using the parameters $\theta_{critical}$ and $v_{critical}$). The outcome of the ZIP model is a goodness of fit statistic (negative log likelihood) that measures the ability of the model to predict pelican events for a specified combination (pair) of parameters: $\theta_{critical}$ and $v_{critical}$. The ZIP model is defined by two statistical processes known as the inflation term and the Poisson term, respectively. The inflation term dictates the probability, P, of a pelican event occurring on any given day, assuming a set of predictor variables and coefficients (β_i), and takes the form of a logistic regression:

$$P = \text{logit}^{-1} (\beta_1 + \beta_2 WRD + \beta_3 WRV) \qquad \text{Equation 7.1}$$

The Poisson term predicts the magnitude of the event (conditional on an event occurring) as follows:

$$N = \beta_4 + \beta_5 WRD + \beta_6 WRV \qquad \text{Equation 7.2}$$

In this way, the expected number of crashed pelicans is derived by multiplying the probability of occurrence (Equation 7.1) by the count of expected events (Equation 7.2).

The final (third) step of the modeling process was to derive the values for the parameters $\theta_{critical}$ and $v_{critical}$ that result in the most predictive ZIP model and to assess whether the best fitting model provides useful (i.e., statistically significant) predictions. This step was achieved by iteratively running Steps 1 and 2 using different combinations of $\theta_{critical}$ and $v_{critical}$ within reasonable potential ranges (i.e., via a direct search method)—namely, 0–360 degrees (i.e., all possible cardinal wind directions) in 5-degree intervals—and assessing $v_{critical}$ for wind velocities ranging from 5 to 30 mph in 1 mph increments.

Model Results—Critical Wind Direction and Speed

Figure 116 summarizes the results of a direct search on the parameters $\theta_{critical}$ and $v_{critical}$. The figure shows a contour plot of the model log likelihood (goodness of fit) that results, assuming different values of $\theta_{critical}$ and $v_{critical}$ are used to derive the daily indices $WR_{duration}$ and $WR_{velocity}$. The yellow areas show relatively high model likelihood (goodness of fit), while the darker areas indicate a ZIP model with poorer goodness of fit or predictive accuracy. Specifically, the highest goodness of fit occurs for a model that assumes a critical wind angle of 300 degrees (+/− 30 degrees) and a critical wind velocity threshold of 15 to 17 mph (mean hourly wind speeds).

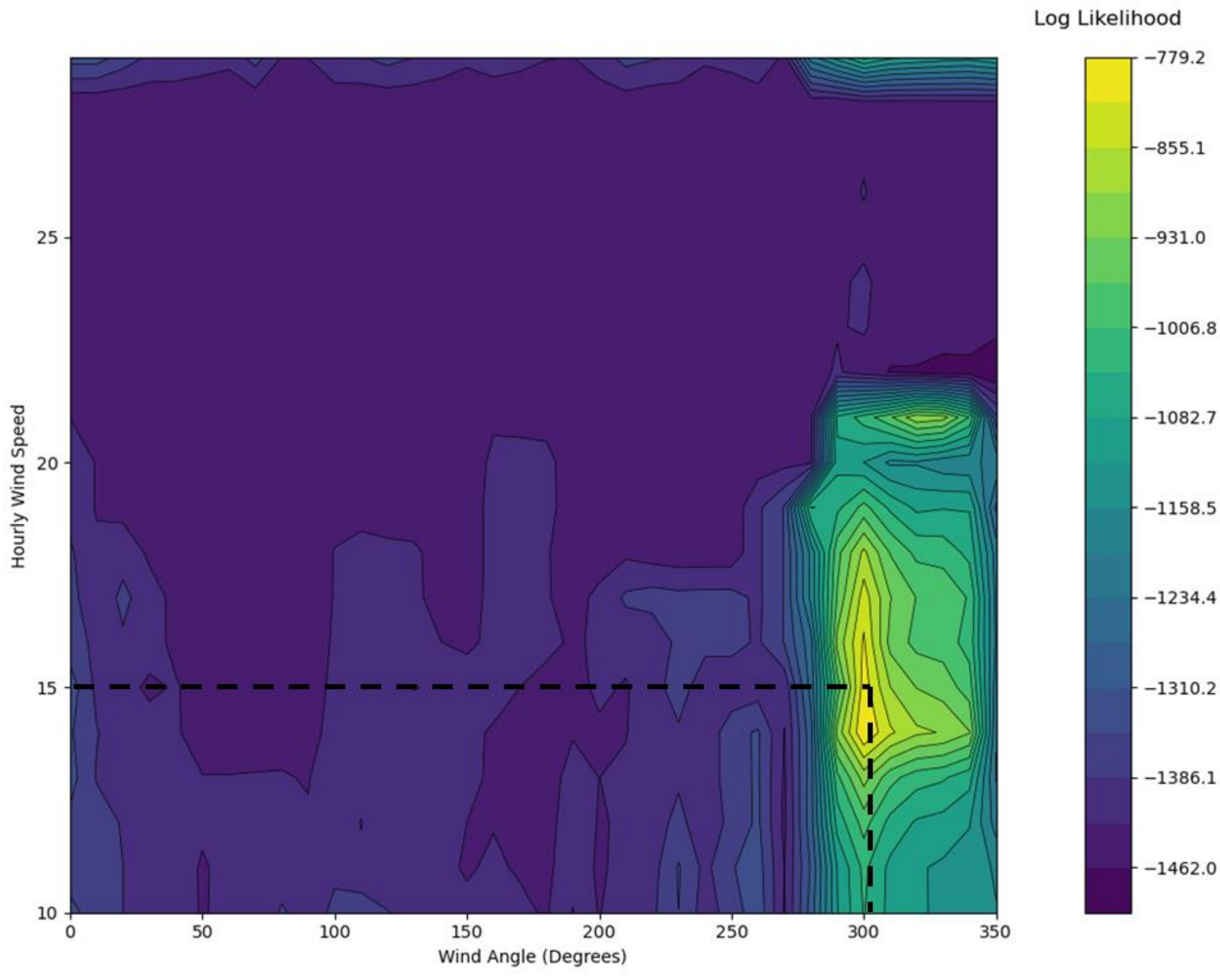


Figure 116. Likelihood Surface of ZIP Model Fit Using Different Wind Direction and Wind Speed Thresholds.

Figure 117 and Figure 118 show the predictions of the best fitting model ($\theta_{critical}$ = 300 degrees and $v_{critical}$ = 15 mph) relative to the actual pelican event data (daily number of downed pelicans). Figure 117 shows the predicted and observed pelican events for fall (September 1 to December 31), while Figure 118 shows the same information for spring events (January 1 to March 31) over the same period. In these figures, the solid red line illustrates the expected mortality as predicted by the best fitting ZIP model, while the black bars show the actual number of crashed pelicans (per calendar day) observed during the historical record. The thin red lines on the graph show the upper 95th percentile estimate of the best-fit model prediction assuming that pelican events are determined only by the structural components of the ZIP model (and do not include error terms associated with other factors not explicitly included in the model).

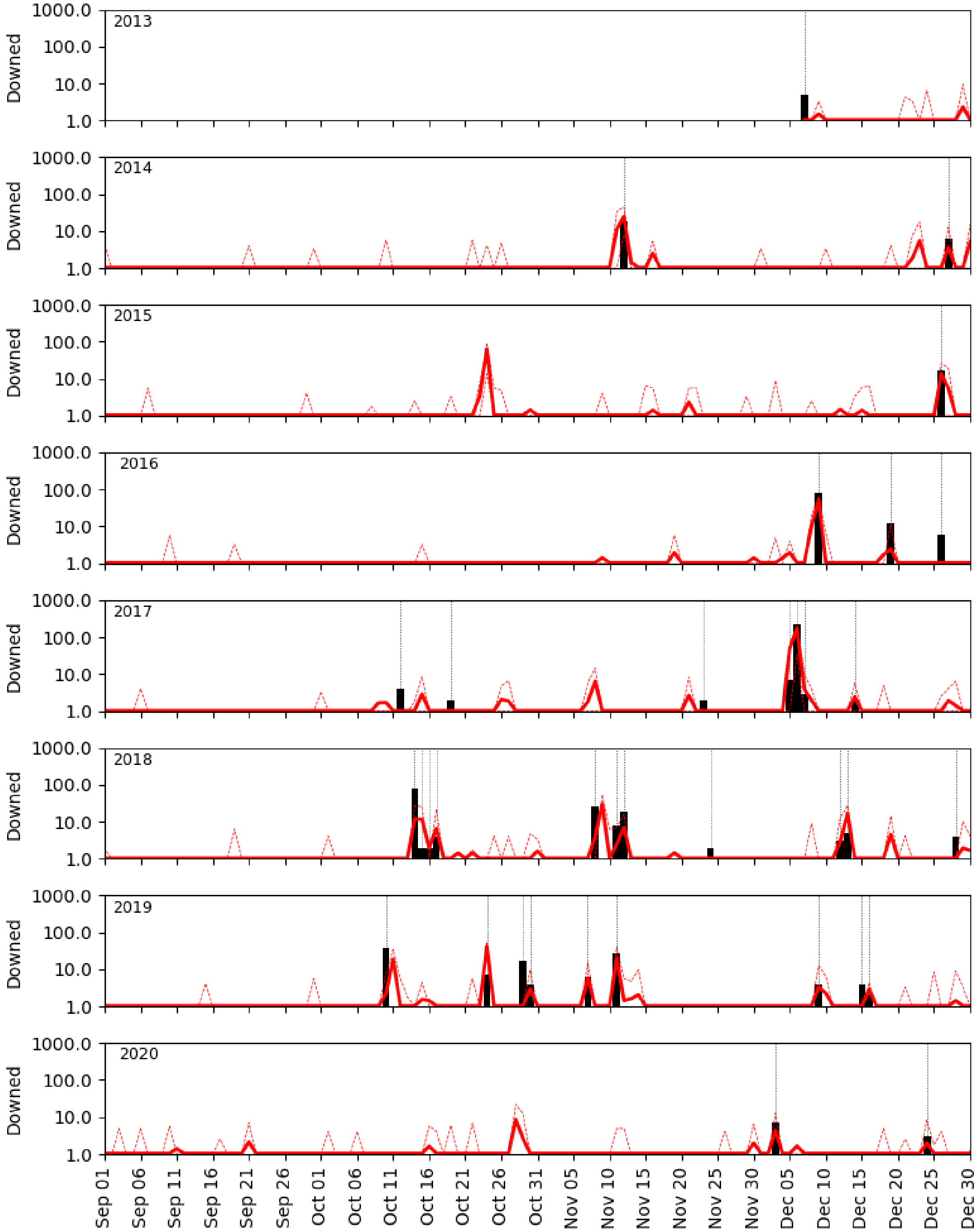


Figure 117. Observed and Predicted Fall Pelican Events (measured by crashed pelicans) between 2013 and 2021. The solid bars show observed numbers of crashed pelicans (per day). The solid red lines show predictions from the best fitting ZIP model. The dashed red line shows the upper 95th percentile predictions from the ZIP model.

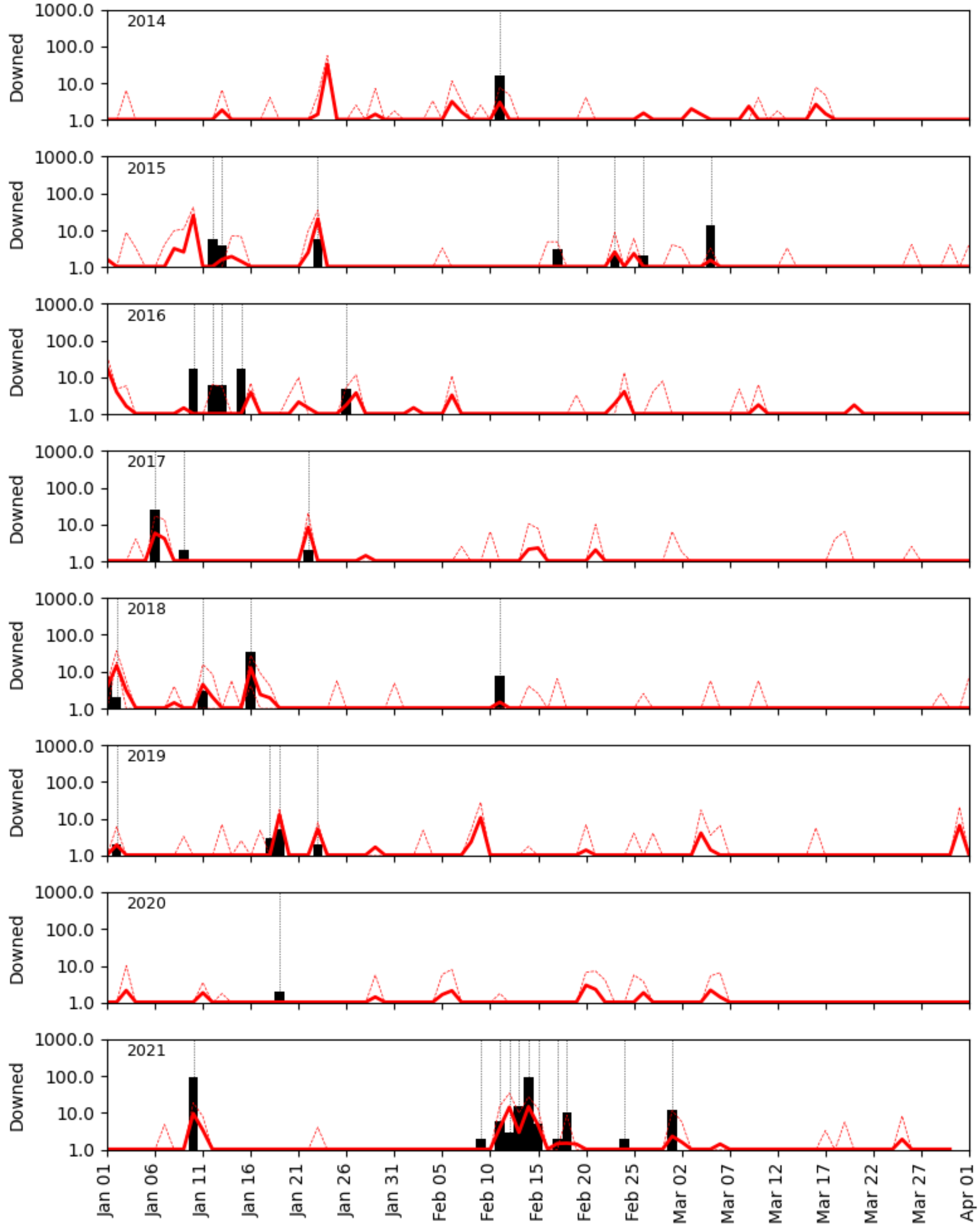


Figure 118. Observed and Predicted Spring Pelican Events (measured by crashed pelicans) between 2013 and 2021. The solid bars show observed numbers of crashed pelicans (per day). The solid red lines show predictions from the best fitting ZIP model. The dashed red line shows the upper 95th percentile predictions from the ZIP model.

Table 12 provides the full set of fitted parameters for the best fitting model. The best fitting log likelihood is −779.24, compared to a log likelihood of −1449.2 for a model that predicts the daily number of crashed pelicans using neither WRD nor WRV as independent variables. The McFadden pseudo R^2 value for the best-fit model is 46.2 percent—this value, which can be interpreted similar to the R^2 value of an ordinary least squares regression is derived from the ratio of the maximum likelihood and the null likelihood model.

Table 12. Best-Fit Parameters for the Wind-Mortality Model.

Parameter	Estimate	Standard Error	P Value
$\theta_{critical}$	300 (+/− 30 degrees)	na	na
$v_{critical}$	15 mph	na	na
β_1	4.757**	0.220	0.000
β_2	−5.158**	1.206	0.000
β_3	−0.143**	0.022	0.000
β_4	1.535**	0.100	0.000
β_5	4.515**	0.141	0.000
β_6	−0.026*	0.007	0.000

Overall, Figure 116 to Figure 118 and Table 12 show that the best-fit model provides reasonable predictions of both the timing and magnitude of pelican events (defined as the number of crashed pelicans per day). The analysis suggests that pelican events can be predicted by a simple model that assumes that daily risk is associated with (a) the proportion of time, on any given day, that winds are blowing between 275 and 335 degrees, and (b) the average wind speed defined by these critical thresholds (both velocity and direction).

The Influence of Other Environmental Variables

The wind threshold model described above formally demonstrates the role of strong northern winds (themselves the primary element associated with cold fronts) on the incidence of pelican events (crashed and killed pelicans) on SH 48. Using only wind-derived independent variables, the model predictions show good agreement with observed patterns of mortality defined by the timing and approximate magnitude of pelican events.

To complete the statistical analysis, the research team assessed whether other environmental factors (such as temperature, sea level, or precipitation) also drive pelican events. Given that the threshold wind model described above is already a good predictor of mortality events, the research team investigated the importance of other environmental factors by incrementally adding new variables to the existing model and then assessing goodness of fit. The research team use two measures of goodness of fit—the Akaike information criteria (AIC) and the root mean squared error (RMSE) of cross-validated model predictions. The environmental variables added to the model were:

- Daily minimum temperature in degrees Fahrenheit measured at the Brownsville NOAA weather station.
- Daily total precipitation (inches) measured at Brownsville NOAA station.
- Daily mean sea level (measured in feet above the sea level datum) recorded at Port Isabel Tidal Weather station.

The AIC enables the goodness of fit of models with different complexity (and therefore inherent ability to fit data) to be compared. Since models with an increased number of variables are inherently better able to fit data, the AIC penalizes the maximum likelihood of the model according to the number of parameters included in the model. The model with the smallest AIC is generally considered the most predictive (assuming overfitting has not occurred).

Another problem associated with increasing model parameters is overfitting—in which models provide a good fit to the data they were fit to but do not do a good job of predicting events on new, independent data sets. To evaluate overfitting, the research team used a cross-validation procedure in which the full pelican event data set is split into training and test subsets. A single cross-validation involved fitting each model to a training data set (and obtaining a goodness of fit statistic), and then evaluating the fitted model to an independent test data set. The RMSE was evaluated and compared for both training and test data. The research team used log transformed[26] counts of crashed pelicans to calculate the RMSE. The training and test subsets were chosen randomly (data were split according to a 75:25 ratio determined by a random number generator). The cross-validation procedure was repeated 100 times to determine the average difference between the RMSE obtained from training versus test data. The fundamental idea is that larger differences in RMSE between training and test data suggest a model that tends to overfit and therefore may not offer the most generalized predictions. In addition, the RMSE provides another indication of the goodness of fit of the model.

Table 13 shows the results of adding new weather and environmental variables to the previously described model based on wind thresholds alone (in Table 13 this is termed the base model). Based on AIC alone, the addition of new environmental variables appears to improve the goodness of fit (consequently, the predictive ability of the models). In particular, the AIC scores suggest that precipitation is an important factor in driving pelican events. However, the cross-validation results caution that the more complex models may be overfitting the data. In fact, based on the RMSE of both the training and test samples, the simple wind threshold model appears to offer the very best predictions despite its simplicity. Moreover, the small differences

[26] A constant of one was added for the $\log_e$ transformation.

in RMSE between the training and test data suggest a model that is likely to be very robust when presented with new data (capable of predicting new observations with little bias).

Table 13. Results of Adding Environmental Variables to Statistical Model.

Model Formulation	Number of Parameters	AIC	Pseudo R^2	Training RMSE	Test RMSE	RMSE Difference
Base Model (wind only)	8	1574.5	0.462	0.329	0.329	0.000
Base Model + Mean Sea Level	10	1848.7	0.4563	0.355	0.370	0.015
Base Model + Precipitation	10	1348.3	0.5417	0.348	0.362	0.015
Base Model + Minimum Temperature	10	1529.2	0.4823	0.354	0.358	0.004
Base Model + Precipitation + Minimum Temperature	12	1310.4	0.5588	0.416	0.417	0.001
Base Model + Precipitation + Mean Sea Level	12	1508.7	0.5586	0.414	0.415	0.001
Base Model + Minimum Temperature + Mean Sea Level	12	1774.6	0.4795	0.397	0.414	0.016
Base Model + Precipitation + Minimum Temperature + Mean Sea Level	14	1456.7	0.5752	0.414	0.432	0.018

DISCUSSION

This chapter presents the results of the research team's investigation into the interactions among pelican mortality and pelicans that crashed on SH 48 relative to local weather conditions. *Pelican event* describes days or periods during which inclement weather causes pelicans to crash on SH 48. For these analyses, the research team pooled pelican event data collected by TxDOT and the pelican conservation group prior to the current project (December 2013 through November 2017) with the more detailed records collected during the current project (December 2017 through January 2021). When possible, researchers recorded pelican event details, including the crash location, sex, age (adults or juveniles), and morphological characteristics of the individual pelicans.

A total of 263 pelicans were documented as killed on SH 48 in the four years prior to the start of this research project. During the 38 months of this research project, TTI researchers have recorded an additional 636 pelicans that crashed on SH 48, and of those, 198 pelicans were killed. The total for all pelican events includes a total of 899 crashed pelicans, killing 461 on SH 48 from December 2013 through January 2021.

The analysis found there to be no bias in age, sex, or morphological characteristics of pelicans that lead to pelicans crashing or being killed during pelican events.

Pelican mortality is shown to occur along the entire length of SH 48 between the Bahía Grande and San Martin Lake (Zapata Bridge). Pelican mortalities are concentrated in areas of SH 48 that border the water of the Bahía Grande and San Martin Lake, likely because of the tendency of pelicans to fly over waterways rather than over land to reach their roosting and loafing sites.

Qualitative analysis of weather and events highlights the change in conditions that occur during cold fronts. The key aspects of cold fronts are a change in wind direction to north or northwest, an increase in wind speed, and a drop in temperature. Although cold fronts tend to cause these shifts in weather (temperature, wind, often precipitation), it is the change in wind direction to a north wind and increased wind speed that are most directly related to pelican events. The presence of a strong south wind does not cause pelican events.

The review of severe and minor pelican events and the associated weather variables confirm previous observations that the most common factors influencing the severity of events are the change in wind direction to northwestern winds, especially when wind speeds are greater than 20 mph. These factors are most likely present during winter cold fronts since strong winds from this direction were rare in the summer data.

Pelican mortalities and crash landings also occur mostly during the afternoon and evening. The timing of cold fronts relative to the daily movement patterns of pelicans may influence the severity of mortality events.

The research team created a statistical model to simulate the timing and severity of future events. The model identified two key thresholds—direction and velocity based on hourly measurements from the NOAA weather stations—and confirms that wind-derived variables are a good predictor for the timing and magnitude of a pelican event based on WRD and velocity. Other environmental variables do not conclusively improve the performance of the models as predictors of pelican events.

CONCLUSIONS

- There appears to be no bias in age, sex, or morphological characteristics of pelicans that are downed or killed during pelican events.
- Pelican mortalities are concentrated in areas of SH 48 that border the water of the Bahía Grande and San Martin Lake, most likely because of the pelicans' tendency to fly over waterways rather than over land.
- The qualitative evaluation review of pelican events conducted in this study confirm that pelican events are primarily driven by wind direction and velocity, specifically north to northwest winds at higher speeds, especially when wind speeds are greater than 20 mph.

These factors are most likely present during winter cold fronts since strong winds from this direction were rare in the summer data.

- Statistical modeling confirms that wind-derived variables are a good predictor for the timing and magnitude of a pelican event based on WRD and velocity. Although precipitation is a contributing factor, a primarily wind-based model provides the most robust predictions. Statistical modeling based on wind speed and wind direction can potentially be used to predict pelican mortality events.

CHAPTER 8. PROJECT SUMMARY

This research project was motivated by pelican mortality that occurs on a section of the Brownsville-Port Isabel Highway (SH 48) in the Bahía Grande Wetland Complex (BGWC) near the southern Gulf Coast of Texas. Along this section of SH 48, cold fronts result in wind conditions that cause brown pelicans to crash-land on the roadway. Once on the roadway, pelicans have difficulty regaining flight, and many are hit by passing vehicles.

The periodic mortality of brown pelicans on this section of SH 48 has attracted concern from various state and federal agencies, including the Texas Department of Transportation (TxDOT), the United States Fish and Wildlife Service (USFWS), and Texas Parks and Wildlife Department (TPWD), as well as local conservationists and news channels. TxDOT's concern is focused on the fact that the agency is responsible for providing an efficient and safe transportation system for the traveling public, as well as reducing the negative environmental consequences of transportation. The pelican events (as they are termed throughout the report) present an environmental issue as well as a public safety risk to individuals who attempt to save downed pelicans from the roadway.

> Pelicans that crash on SH 48 may be subject to several outcomes: regain flight independently (and survive), be rescued by volunteers (and survive), or they may be hit by vehicles—usually fatally (mortalities).

Previous research on the SH 48 pelican problem has focused on understanding the interactions among pelican events, local weather conditions, and the roadway infrastructure of SH 48 to inform engineering-based solutions that have thus far been only partially successful. The goal of this research project is to investigate daily and seasonal movements of brown pelicans in the BGWC to inform the development of cost-effective engineering or ecological-based strategies to prevent or minimize pelican events on SH 48, and to provide information that will help TxDOT and other state agencies mitigate potential problems in other areas.

Understanding Brown Pelican Ecology

At the beginning of this project little was known about the ecology of brown pelicans in the study region. However, intuitively, pelican events on SH 48 occur because pelicans attempt to cross there. Therefore, the key research questions were: (1) how many pelicans cross and at what times of the day or year (i.e., daily and seasonal movements), (2) why do they cross (i.e., how brown pelicans are using the Bahía Grande habitat versus other areas of the landscape), and (3) what are the key environmental and pelican demographic variables that influence pelican events on SH 48?

Against this background, the TTI and TxDOT research team designed a series of field and modeling experiments to gather information about the daily and seasonal movements of brown pelicans in the BGWC and their broader Gulf Coast range.

Fine-Scale Daily and Seasonal Movements of Brown Pelicans

Between December 2017 and February 2019, 35 adult BGWC brown pelicans were captured at loafing sites in the lower Laguna Madre area—in the vicinity of Port Isabel, SH 48, and South Padre Island—and fitted with a global positioning system (GPS) transmitter. Given the cost of the GPS devices and the invasiveness of the devices, only a small sample of pelicans could be instrumented. However, each GPS-fitted pelican provided high resolution GPS data at 15- to 30-minute intervals, and at spatial accuracy of typically less than three feet (one meter). The GPS devices provided high-resolution data to determine the seasonal and daily movements of the BGWC brown pelican population, especially the location of overnight roost sites, loafing and feeding areas, major flight paths, and the use of habitats outside of the BGWC (including the seasonal range of pelicans that overwinter in the BGWC and breeding sites).

The GPS data collected revealed three key characteristics of daily and seasonal movements that help to explain crossings on SH 48. First, the Bahía Grande contains key brown pelican roost sites that explain the frequency of crossings. Second, the GPS data illustrate that nearly all movements into and out of the Bahía Grande occur via SH 48 crossings by pelicans using the Brownsville Ship Channel or other wetlands as movement corridors. As such, there were few observed movements of pelicans over the north or northeast end of the Bahía Grande into the Laguna Madre (the location of the most used roost site, and of foraging and loafing locations).

Finally, the GPS study indicates that the median time for entering or exiting roost sites is approximately sunset or sunrise respectively. As such, pelicans often begin their daily movements before sunrise, and after sunset. The fact that pelicans move after sunset has implications for mortality on SH 48. First, they are less visible to drivers after dark. Second, volunteers often cease rescue operations due to low visibility.

Migration and Survival of Brown Pelicans Using Mark-Resight Methods

Between November 2017 and February 2019, 310 brown pelicans in and adjacent to the BGWC study area were captured and banded with maroon leg bands displaying three white alphanumeric characters. Between November 2017 and March 2020, the research team undertook regular resight surveys with the purpose of identifying banded pelicans in the study area. These resight surveys were conducted at consistent locations for a fixed period of time. Data from the regular resight surveys were also supplemented with opportunistic resights made during other fieldwork and by data submitted to the U.S. Geological Survey Bird Banding Laboratory. Relative to the GPS study, this mark-resight study was less invasive, cheaper to undertake, and provided data from a larger sample of the pelicans in the BGWC population. Although the resulting mark-resight data are coarser in resolution than the GPS data, the larger sample sizes help infer key life history processes that are more representative of the entire BGWC population.

The research team modeled the mark-resight data using the Hidden Markov model (HMM). The HMM mark-resight analyses suggest that approximately 80 to 90 percent of the pelicans that overwinter in the BGWC study area undertake a seasonal migration to summer ranges. In contrast, all GPS tagged pelicans migrated from the BGWC in summer (although one pelican with a damaged GPS did remain). The analyses suggest that individual pelicans in the area begin to emigrate (out of the study area) during mid- to late- February, and pelicans continue to leave the area through March and early April. Pelicans begin to immigrate back to the area in mid-September and continue to return to the area as late as mid-November. Therefore, pelicans are most abundant in the BGWC during the winter months (November to March).

Modeling Brown Pelican Population Dynamics in the Bahía Grande Wetland Complex

Existing knowledge of the life history of brown pelicans, the GPS data, the marked-resight data, and the insights obtained from the HMM mark-resight analyses were integrated to develop a population dynamics model of Bahía Grande brown pelicans. The population dynamics model was used to integrate population processes (e.g., survival, reproduction, development, and migration) into a holistic view of the BGWC population. The model was then used to assess:

- The consistency of life-history processes measured during this study relative to information reported in the literature and relative to reasonable population growth rates.
- Which brown pelican life history processes are most important for maintaining a sustainable BGWC population?
- The influence of SH 48 mortality on the sustainability of the BGWC brown pelican population.

A sensitivity analysis of the modeled population growth showed that *adult survival* is the most important life-history process for maintaining a sustainable BGWC population. The population dynamics model also revealed important interactions between the size of the BGWC pelican population and the amount of extraneous mortality (assuming that traffic-induced mortality on SH 48 is independent of population size). It was found that modeled populations greater than 1,000 individuals are relatively unaffected by extraneous mortality of up to about 25 individuals per year and are not expected to decline unless mortality is greater than 75 individuals per year. Populations of greater than 2,000 individuals are expected to be buffered against external mortalities up to 50 individuals per year and are not at risk of decline if external mortality is less than approximately 175 individuals per year. This suggests that the traffic induced mortality currently occurring on SH 48 is unlikely to have major effects on the sustainability of the population. However, this does not diminish the importance of the issue as an environmental / wildlife welfare or public safety issue.

The population dynamics model also demonstrated that the survival rates estimated by the mark-resight are not consistent with a stable population in the BGWC. However, the survival rates reported from the literature review do result in population growth rates commensurate with independently reported population trends.

This finding led to further investigation of the causes of this inconsistency, and hypotheses that may be useful for understanding the BGWC population dynamics. Specifically, the research team hypothesize that in addition to providing permanent overwintering habitat to a portion of Gulf Coast pelicans, the region also provides temporary habitat for pelicans that may use the area as a temporary stop off as they migrate to more southern overwintering sites. Consequentially, it is likely that temporary or transient pelicans cause the more established BGWC overwintering population to increases greatly during the fall migration, and possibly again as individuals move through the region on their northbound migration to breeding sites.

Based on this idea, the research team have reanalyzed the mark-resight data after removing all records of pelicans that were captured during the winter months but were never resighted (thereby approximately eliminating transient individuals). Figure 119 shows the results of the new parameters obtained through this analysis. The figure shows the mean HMM estimates from this modified analysis (red dashed lines) versus the values reported in the original analysis in Chapter 3 (Figure 46). In this modified analysis, the 5-day survival rate is estimated as 0.9975, which translates to 0.999 per day or a mean longevity of approximately 3 years. This new value is consistent with the daily survival rates of 0.9995 and average longevity of approximately 5.5 years reported in the literature by Schreiber and Mock (1988). This new value is also consistent with the minimum survival values required for the population to grow, as evaluated using the population dynamics model. The other relevant life-history / migration parameters estimated using this rough analysis remain relatively unchanged (although, as might be expected the resight probability increases). The new analysis therefore supports the idea that transient individuals represent a significant portion of pelicans that use the BGWC as fall and winter habitat. This phenomenon also highlights the difficulty of working with brown pelican populations and suggests that valuable research could be undertaken to develop a better understanding of the migratory behavior of brown pelicans.

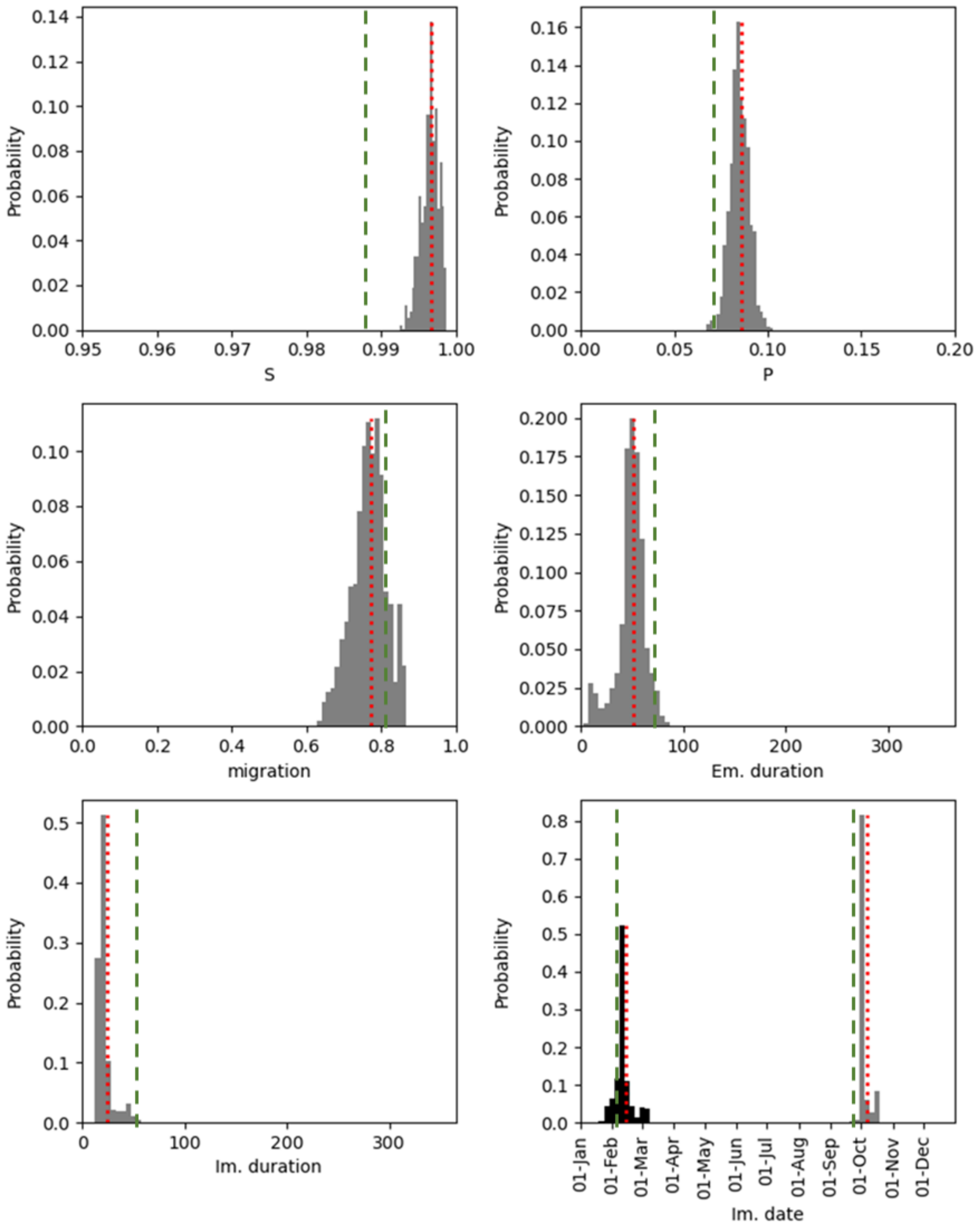


Figure 119. Mark Resight Parameters Estimated Using Field Data with Transient Individuals Excluded. The red dashed arrows show the new parameters estimated using the HMM models, while the green dashed lines show the original parameter estimates reported in Chapter 3.

Estimating Brown Pelican Population Abundance in the Bahía Grande Wetland Complex

Intuitively, the magnitude and frequency of pelican events on SH 48 is related to the size of the local population (although other factors will clearly play a role). The research team undertook regular abundance surveys alongside previously mentioned mark-resight surveys during which they collected information on the ratio of banded to unbanded pelicans. Models were then used to estimate population size. The research team used extensions of existing methods that account for an open population. Because new methods were used the research team used artificially generated data to check whether (in theory at least) they are able to satisfactorily estimate population size. The researchers also developed population estimates using field counts of the number of SH 48 crossings and surveys of their primary roost site.

The research team also undertook regular surveys of SH 48 crossings and counts at the most-used roost site and used them, along with estimates of roost site use obtained from the GPS study, to estimate abundance.

Using the abundance survey and estimation methods described above, the research team estimate that between 2,000 and 3,000 pelicans use the BGWC as a **permanent** overwintering location. According to the abundance estimation methods, pelican populations increase in August and reach approximately 3,000 by November. In summer, the population decreases to approximately 300–1000 pelicans. Although the research team checked that the methods used to estimate abundance are theoretically able to estimate abundance accurately (based on synthetic data), they acknowledge that estimates from field data may be biased by differences in the behavior of pelicans in the population. For example, it is possible that differences in the abundance estimates from different survey methods occur because the local population contains groups or subpopulations that use the landscape in different ways. The research team suggest that undertaking aerial counts over the entire study area may provide a more reliable method of estimating pelican abundance.

Pelican Events on SH 48

Analysis of Wind Station Data

The research team installed a project wind station (PWS) on SH 48 at the Carl Gayman Bridge to record local wind conditions. An analysis of the PWS data indicated that under typical weather conditions, wind in the BGWC blows from the southeast at a velocity between 5 to 20 mph perpendicular to the south edge of SH 48. During cold fronts, the wind direction on the bridge changes by 180 degrees and blows from the northwest. The switch in wind direction during cold fronts are typically accompanied by a 5- to 10-mph increase in wind speed (typical northwestern winds range between 10 to 25 mph). During northwestern winds, pelicans flying into the Bahía Grande (i.e., to roost sites) experience strong headwinds that cause crossing difficulties.

During northwestern winds, the PWS also indicates faster wind speeds measured at an altitude of 21 feet above the roadway versus 12 feet above the roadway. Because these wind speed differentials do not occur during southeastern winds, they are most likely caused by the topography on the northern side of SH 48. This topography includes the smooth water surface of the Bahía Grande, the berms separating the Bahía Grande from the elevated road (or bridge sections), and the northside and median concrete traffic barriers (CTBs) installed on the road. These field measured stratified wind profiles are consistent with the results of computation fluid dynamic models developed in previous studies. Pelicans flying into the Bahia Grande at low altitudes will therefore be affected by strong head winds and a stratified vertical column of airflow.

The research team also used simple regression models to relate hourly wind data collected at the PWS relative to local National Oceanic and Atmospheric Administration (NOAA) weather stations to assess the characteristics of wind conditions on SH 48 relative to the broader BGWC study area. The research team found that, at least at the scale of 1-hour measurements, wind conditions measured on the bridge can be accurately estimated using data from local NOAA weather stations. This suggested that the prevailing weather patterns on SH 48 (at the site of pelican mortality) are not considerably different from the broader BGWC study area. The ability to accurately model SH 48 wind speeds from the local NOAA stations allowed the research team to model past (i.e., those events recorded before the inception of this project and installation of the PWS) and future pelican mortality events on SH 48. To this end, the application of data from permanent NOAA stations may help to make in situ forecasts and traffic mitigation options, such as automatic warning signs, practically possible (discussed below).

Modeling Pelican Events on SH 48 Considering Weather Conditions

Between December 2013 and November 2017, TxDOT recorded 263 pelican mortalities on SH 48 following known pelican events. The data provided a record of pelican mortality events on SH 48 that preceded the current research study. Between October 2017 and January 2021, TTI field researchers monitored and recorded the number of crashed and killed pelicans on SH 48. During the 38 months of this research project, TTI researchers recorded 636 pelicans that crashed on SH 48, and of those, 198 pelicans were killed. An analysis of the data collected by TTI researchers found no effect of age, sex, or other morphological characteristics on downed pelicans. The researchers also found that pelican mortality occurs along the entire length of SH 48 where it borders the Bahia Grande, and also occurs at San Martin Lake (Zapata Bridge).

During all monitored pelican events, field researchers were stationed on SH 48, usually close to the Carl Gayman Bridge and channel. Researchers recorded details of the location, sex, and age (adults or juveniles) of pelicans. The TTI field researchers also checked the roadway for carcasses on days following cold fronts and whenever the researchers were present on SH 48 performing other field surveys (e.g., mark-resight, wind station monitoring).

A qualitative and quantitative analysis of weather and pelican mortality events found that pelican events are most parsimoniously explained by north to northwest winds of 15 mph or greater (as measured at NOAA stations). These winds only occur during cold fronts. In most cases, the strongest winds occur at the beginning of the cold front. The presence of a strong south wind does not cause pelican events. Furthermore, the research team found that the duration of abnormally high northern winds drives the severity of pelican events. Finally, the research team found that pelican mortalities and crash landings occur mostly during the afternoon and evening (corresponding to movements to and from overnight roosts). The timing of cold fronts relative to the daily movement patterns of pelicans may therefore influence the severity of mortality events.

The research team did not find any consistent evidence that other environmental factors drive pelican events. In previous studies, water level was considered a factor that contributed to pelican events. At the beginning of this project the researchers hypothesized that changes in water level may cause roost sites in the Laguna Madre to become temporarily unavailable thus causing more pelicans to use Bahia Grande roost sites. The data and models collected during this study provide no real support for this hypothesis. Similarly, it was hypothesized that cold fronts may affect the daily movement of pelicans. However, this hypothesis was not supported by an analysis of daily movement distances (from GPS data) on cold front versus non-cold front days.

Mitigation

The research undertaken during this project provide useful information for mitigating the current SH 48 pelican problem, other pelican crossing problems, or wildlife crossing problems in general. Mitigation options for the pelican problem can be grouped into several categories including:

- Planning or environmental impact assessments (i.e., pre-construction processes that aim to ensuring proposed transportation projects do not result in environmental issues),
- Infrastructure engineering solutions designed to change infrastructure in a way to minimize downed pelicans,
- Traffic engineering solutions – methods to reduce the conflicts among vehicles, downed pelicans, and pelican volunteers.
- Ecological interventions – methods that attempt to modify the ecology of pelicans and therefore either reduce or prevent SH 48 crossings.

Planning

The construction of the Brownsville Ship Channel effectively destroyed the historic ecological value of the BGWC by cutting off tidal water flow between the Laguna Madre and the BGWC. Restoration of the Bahía Grande began unofficially in 1983 and officially in 1999 when a channel between the Bahia Grande was recreated. TxDOT assisted the USFWS and its partners with the channel restoration project by widening and extending the Carl Gayman Bridge. At the same time, TxDOT constructed a new four-lane highway, and installed concrete traffic barriers to improve safety. The channel improvements restored tidal flow to the Bahía Grande and surrounding lagoons. These efforts have successfully restored the BGWC from a degraded, seasonal dryland/wetland system to a natural wetland system made up of interconnected hypersaline lagoons, including islands that provide important habitats for a variety of bird life. Although the restoration efforts have been hailed as an environmental and social success, the conflict that emerged between brown pelicans crossing SH 48 and restoration efforts was unforeseen by TxDOT, USFWS, and its partners.

> Improvements to SH 48 in 2007 included roadway widening and the modification (lengthening) of two bridges to span the two channels that hydrologically link the lagoons to the Brownsville Ship Channel (Bahía Grande Restoration Channel and the San Martin Lake Channel adjacent to the Zapata Memorial Boat Ramp). Most of the current SH 48 roadway is a four-lane, concrete barrier-divided highway with speed limits of 75 mph, peak traffic volumes of approximately 300 vehicles per hour, and an average daily volume of approximately 11,480 vehicles (2016 data accessed from the TxDOT STARS II system).

Given the recent recovery of Texas' brown pelican populations, the success of the Bahia Grande restoration, and the fact that wildlife crossing research is an emerging field, it is not surprising that the SH 48 problem was not identified in advance. However, this project does provide a useful case study for the unforeseen consequences of transportation planning and points to the benefits of planning and environmental linkages (PEL). As such it is possible that elements of this research may help guide PEL and roadway design for future projects that involve coastal roads, or roads that intersect ecologically sensitive areas. In cases where TxDOT is planning projects in environmentally sensitive areas, or actively working with conservation agencies to improve transportation, it may be prudent to enter into agreements to ensure commitment to develop effective mitigation options for transportation projects that have unintended environmental impacts and as such create conflicts between wildlife and transportation infrastructure. Such agreements would likely have the benefit of ensuring agencies work together to develop the most cost-effective solutions to wildlife crossing problems. Such agreements would also facilitate mitigation options that extend beyond the roadway (discussed in a later section) – in the case of the brown pelican problem it is possible that successful mitigation will only occur with the implementation of several different strategies and continual monitoring of the problem.

A multi-agency PEL approach to mitigating the pelican mortality should also consider future development surrounding SH 48. For example, during this project, transmission poles and lines were erected just outside of the TxDOT right of way. While it is not clear what impact (good or bad) the transmission poles will have on pelican crossings, they clearly represent a possible change to the existing system. One school of thought is that they could lead to more lower altitude crossings and therefore an increased risk of pelican events. Another school of thought is that they may cause pelicans to fly higher (on average) when crossing. In either case, multi-agency planning might have usefully identified risks to pelicans or even opportunities to mitigate the current pelican mortalities. For example, it might be possible that the transmission poles could be used to secure cables, rope or netting at a lower level as a method to force pelicans to fly at higher altitudes over the road. Clearly to do so would require support from the owners of the facilities. Similar multi-agency coordination efforts could benefit any new developments on SH 48 including additional Bahia Grande restoration plans.

On a similar note, the Bahia Grande is also used extensively by fishermen and wildlife watchers. This has led to the creation of unofficial parking and turn off areas close to the Carl Gayman bridge, and results in non-traveling public spending considerable amounts of time close to the road. Redevelopment of this area (such as the development that has occurred at the Zapata boat ramp near San Martin lake) could provide opportunities to incorporate pelican mitigation options such as reducing traffic speed, traffic calming, pelican warning signs, and modifications to road infrastructure such as safety barriers that can only take place if traffic speeds are reduced.

Infrastructure Engineering Solutions

TxDOT has implemented several engineering-based solutions to reduce pelican mortality. These include the addition of pelican poles and lights on the Carl Gayman and Zapata bridges, and most recently, between August 2019 and March 2020, replacement of the concrete traffic barrier on the north side of SH 48 with a railing design intended to improve wind conditions across the roadway.

The project monitored one year of pelican events that occurred following the modification of the concrete traffic barriers on SH 48. Given the stochasticity of pelican crossing events, a single year’s data is unlikely to provide conclusive results on the efficacy of this modification. Figure 120 shows the timing and magnitude of pelican events that occurred during and after modification of the barriers. In the figures, the solid bars indicate observed mortality, and the red lines show predictions from the statistical model described in Chapter 7. The figure suggests that the barrier modifications have not eliminated or even significantly reduced pelican events (although care must be taken interpreting less than two years of results when factors such as population size and timing of weather events are so inherently variable). However, there is conclusive evidence that the barrier replacement has affected pelican crossings. Figure 121 shows the number of pelicans that crash landed in eastbound and westbound lanes before and after the barrier replacement. Following the replacement of the barriers on SH 48 nearly all pelicans crash landed in the eastbound lane.

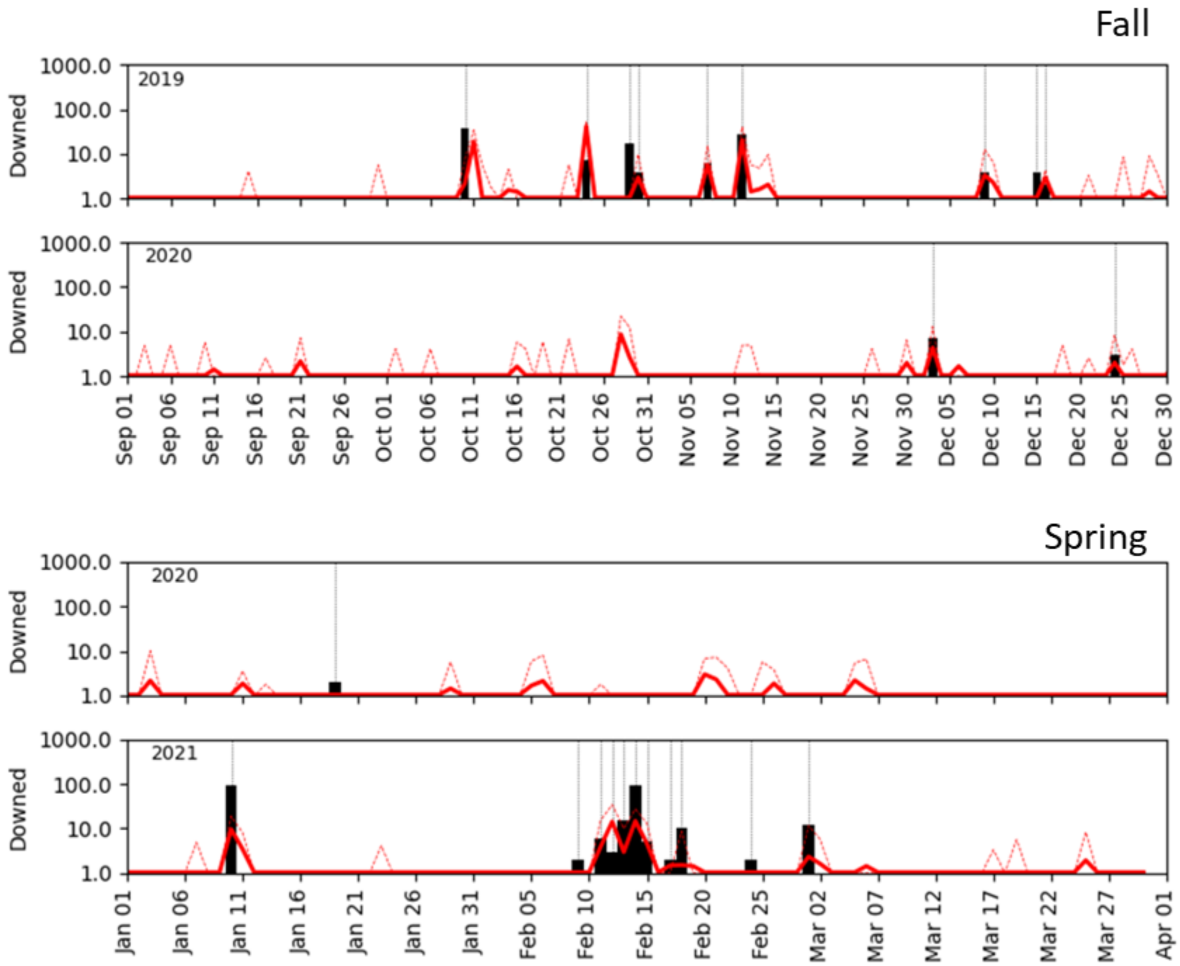


Figure 120. Summary of Pelican Events During and After Completion of Barrier Replacements on SH 48. The black bars show actual mortality, the red lines show mortality predicted by the statistical model described in Chapter 7.

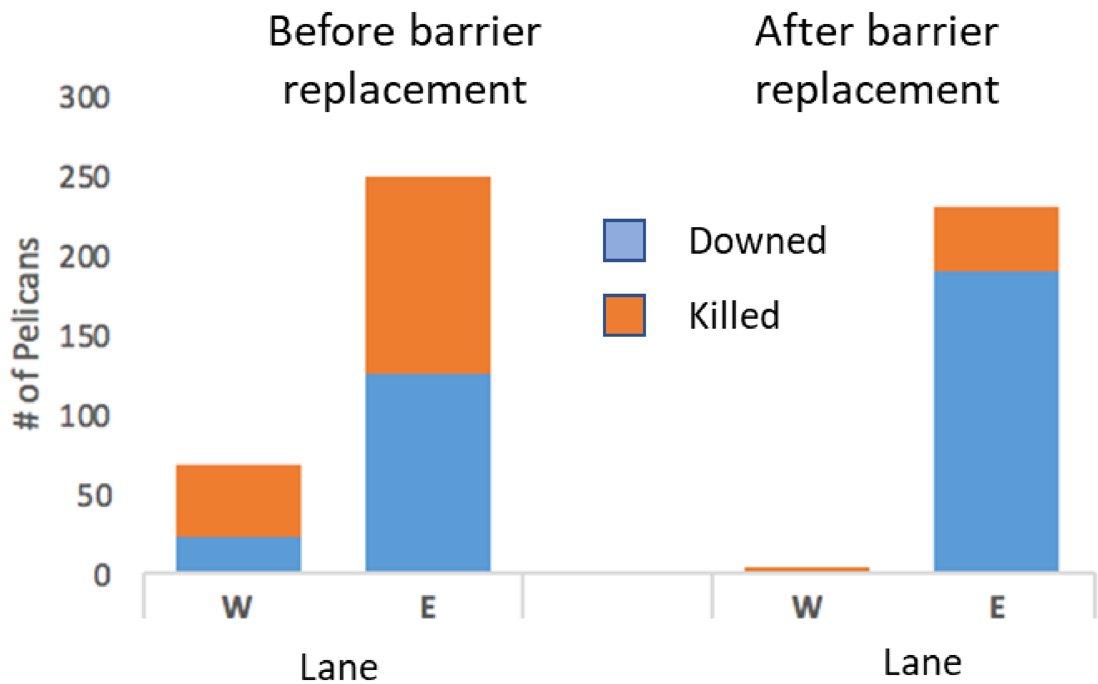


Figure 121. Location of Downed Pelicans by Lane Before and After Barrier Replacement on SH 48. All data collected since the beginning of the research project (i.e., historical data not included).

Given the complexity of wildlife crossing problems, the research team conclude that, in the absence of a comprehensive understanding of wildlife ecology, engineering-based solutions run the risk of being ineffective or worse, compounding environmental problems. The information presented in this report on the ecology of pelicans can therefore inform the evaluation of the feasibility and efficacy of other infrastructure mitigation options:

- **Installing flood lights**. The research team found that pelicans are active at night. This fact is supported by field observations that pelicans often cross SH 48 after light levels are too low for researchers to conduct accurate counts, and that dead pelicans were found on SH 48 the day after the arrival of cold fronts. Intuitively, pelicans landing on SH 48 after dark are likely to be at a greater risk of mortality because they are less visible to drivers. The installation of flood lights in the crossing zone may alleviate the risk of mortality by vehicles. Lights may also enhance visibility during low light conditions typical of cold fronts, thereby improving the safety of volunteers on the road. Lights may also provide visual cues that help pelicans navigate crossings after dark. However, the research team also acknowledge that lighting may also encourage volunteers to operate on the roadway for longer periods, and therefore increase human safety risk. Lighting may also have a deleterious effect on other species, or other activities in the area (such as fishing).

- **<u>Installing active warning signs</u>**. Permanent or semi-permanent roadside warnings could be installed to warn drivers of pelican events. The research team have demonstrated that NOAA wind stations can be used as a cost-effective, reliable source of wind data to predict pelican mortality events. This information can be used to implement a variety of dynamic traffic management scenarios (such as dynamic warning lights, community announcements or even road closures) on days when there is a high risk of a pelican mortality event.
- **<u>Netting or other barriers designed to encourage pelicans to cross SH 48 at higher altitudes.</u>** Data collected from the project weather station indicate that during northwestern winds, faster wind speeds were measured at an altitude of 21 feet above the roadway versus 12 feet above the roadway. These findings are corroborated by previous research on air flow over SH 48 (wind tunnel and CFD models). Infrastructure designed to encourage pelicans to fly higher over the bridge could therefore reduce the number of downed birds and help mitigate pelican mortality.

Traffic engineering

Intuitively, the risk of downed pelicans being hit by passing vehicles is a function of the number of birds failing to successfully cross SH 48 and the volume and speed of traffic on the roadway. Human safety risks are also a function of the presence of volunteers on the roadway and the volume and speed of traffic. The information presented in this report highlights that pelican events are to some extent forecastable because they coincide with cold fronts. As such it may be possible to develop formal plans to control traffic flow (volume and speed) during cold fronts. The research team acknowledge that these plans require considerable research because slowing traffic may also increase the risk of vehicle-to-vehicle crashes (caused by the differential in the speed of downstream versus upstream traffic). It is noted that throughout this project, the pelican volunteers organized Department of Public Safety (DPS) and state wildlife resources to help control traffic on SH 48, and this undoubtedly helped save pelicans and reduce human safety risk.

> TxDOT has attempted to modify the air flowing over SH 48SH 48 by replacing the concrete traffic barrier with a railing design. Although the modification did not reduce pelican mortality, it did result in consistent pattern of pelican's crash landing in the eastbound lane rather than the westbound lane. A potential short-term mitigation option is therefore to slow traffic and close the one lane during predicted pelican mortality events to allow volunteers to rescue downed pelicans in a safer

However, more formal and procedural systems could be implemented to help slow down traffic on SH 48 (again involving partnerships among state agencies). Figure 121 suggests that the recent barrier modification has resulted in pelicans consistently falling into the eastbound lane (whereas historically pelicans crash landed in both lanes). If this phenomenon continues, one potential solution would be to install a temporary contraflow system that diverts all SH 48 traffic to the west bound lane of SH 48 during forecasted events. A contraflow system would have the benefit of both providing an innate reason for drivers to slow speed and to allow pelican volunteers to work safely in the lanes into which most pelicans crash land.

While traffic engineering solutions may improve road safety, they are also likely to affect the mobility of the traveling public. Furthermore, unless the risk of pelican events is reduced, traffic engineering solutions will be required to be continually updated and monitored – representing a long-term cost to the public and TxDOT. Additionally, and as discussed previously, traffic engineering approaches designed to protect pelicans and volunteers must be balanced against the risks of causing other traffic incidents.

On the other hand, given the constraints of the SH 48 pelican problem, traffic engineering is arguably the most reliable and feasible way of reducing pelican mortality and improving human safety. The research team suggest that one way of offsetting the long-term inconvenience, safety risk, and cost of slowing traffic would be to incorporate traffic engineering solutions into a planning process for SH 48 that acknowledges future development on SH 48, and the inherent recreational value of the Bahia Grande (e.g., for fishermen and wildlife watchers). This may result in a reliable long-term solution that provides an intrinsic reason for vehicles to operate at lower speeds on this section of SH 48.

Ecological mitigation

The principal goal of this project is to understand the daily and seasonal movement of BGWC brown pelicans and relate these movements and other pertinent ecology to the issue of pelicans crossing SH 48. To this end, the research team have identified that islands in the Bahia Grande are commonly used for overnight roosts. Pelicans also use the Bahia Grande for loafing and feeding, but most of the movement in and out of the Bahia occurs because of pelicans seeking favored roost sites.

Intuitively then, the most permanent method of mitigating SH 48 mortality would be to reduce the number of pelicans crossing the highway by removing their primary motivation for using the Bahia Grande[27]. However, the Bahia Grande roost sites are in the Laguna Atascosa National Wildlife Refuge. Therefore, it is unlikely to be practical or palatable to intentionally affect the value of these islands to roosting pelicans. One reason for this is that the roost islands are important habitat for other overwintering birds. Another consideration is that pelicans are most likely choosing to use this habitat because it enhances their survival – so although manipulating

[27] The other most highly effective solution would be to eliminate all traffic on SH 48.

Bahia Grande roost sites might prevent SH 48 events, it might also impact the success of the population over the long-term.

A more ecologically palatable option to reducing SH 48 crossings is to increase the availability of roost sites in the BGWC that would not require pelicans to cross SH 48. A significant finding of this project is that only a small number of sites are regularly used as roosts. The spoil islands located in the Laguna Madre north east of Laguna Vista are the most used roost site by far. However, there are many other islands in the Laguna Vista that are superficially like these spoil islands but are not extensively used as roost sites (at least according to the GPS data collected during this project). Similarly, several islands exist south of SH 48 that are also rarely used by pelicans. Understanding the reasons why pelicans use different roost islands is beyond the scope of this project. However, such research might provide realistic interventions useful for managing the SH 48 problem but could also benefit the management of pelicans across their entire Gulf Coast range.

REFERENCES

Bailey, A. M. (1920). The Brown Pelicans: A Series of Previously Unpublished Photographs of the Breeding Birds on the Louisiana Gulf Coast, with Notes on Their Haunts and Habits." *Natural History*, *20*, 197-201.

Bartholomew, G. A., and D. L. Goldstein. 1984. "The Energetics of Development in a Very Large Altricial Bird, the Brown Pelican." In Respiration and Metabolism of Embryonic Vertebrates, 347–57. Springer Netherlands. https://doi.org/10.1007/978-94-009-6536-2_25.

Bent, A. C. (1922). "Life histories of North American petrels and pelicans and their allies: Order Tubinares and order Steganopodes." *Bulletin of the United States National Museum*. i–xii, 1-343, 69 pls. https://doi.org/10.5479/si.03629236.121.i

BirdLife International (2018) Species factsheet: *Pelecanus occidentalis*. Downloaded from http://www.birdlife.org on 27/05/2018. Recommended citation for factsheets for more than one species: BirdLife International (2018) IUCN Red List for birds. Downloaded from http://www.birdlife.org on 27/05/2018.

Birt, A., Sharifi, F., Messhenas, S., Prozzi, J. (2018). "Evaluating the potential of alternative traffic barrier designs for reducing pelican mortality on Texas roads." Report prepared for the Texas Department of Transportation (IAC 0000015249), Texas A&M Transportation Institute Environment and Air Quality Division.

Blus, L., Cromartie, E., McNease, L., & Joanen, T. (1979). Brown pelican: population status, reproductive success, and organochlorine residues in Louisiana, 1971–1976. *Bulletin of Environmental Contamination and Toxicology*, *22*(1), 128-134.

Blus, L. J. (1982). DDE in Birds' Eggs: Comparison of Two Methods for Estimating Critical Levels. *The Wilson Bulletin*, 96(2), 268-276.

Blus, L. J., Joanen, T., Belisle, A. A., & Prouty, R. M. (1975). The brown pelican and certain environmental pollutants in Louisiana. *Bulletin of Environmental Contamination and Toxicology*, *13*(6), 646-655.

Blus, LJ, and JA Keahey. 1978. "Variation in Reproductivity with Age in the Brown Pelican." *The Auk*. http://www.jstor.org/stable/4085503.

Brandt, CA. 1984. "Age and Hunting Success in the Brown Pelican: Influences of Skill and Patch Choice on Foraging Efficiency." *Oecologia*. http://www.springerlink.com/index/n2262n47g3p44375.pdf.

Briggs, K. T., Tyler, W. B., Lewis, D. B., Kelly, P. R., and Croll, D. A. (1983). Brown Pelicans in Central and Northern California. *Journal of Field Ornithology*, 54(4), 353-466.

Franson, J. C., et a1. 2003. Lead fishing weights and other fishing tackle in selected waterbirds. *Waterbirds* ,26:345-352.

Fogarty, M. J., Nesbitt, S. A., and Gilbert, C. R. (1981). Diet of nestling brown pelicans in Florida. *Fla. Field Nat*. 9:38-40.

Graham, T. and P. Hudak. Potential hazards of wind energy for rare, threatened, and endangered birds and bats in Texas. *International Journal of Environmental Research* 5 (2011): 917-

Hainsworth, F. R. (1988). Induced Drag Savings from Ground Effect and Formation Flight in Brown Pelicans. *Journal of Experimental Biology*, 1988 135: 431-444.

Henny, CJ. 1972. An Analysis of the Population Dynamics of Selected Avian Species: With Special Reference to Changes during the Modern Pesticide Era. https://books.google.com/books?hl=en&lr=&id=1u0UAQAAIAAJ&oi=fnd&pg=PP12&dq=Henny+1972+Pelican&ots=9uRiIF3O5Y&sig=6bhrfjU4ZkZ0JDteqcPjLq69xPQ.

Holm, G. O., Hess, T. J., Justic, D., McNease, L., Linscombe, R. G., & Nesbitt, S. A. (2003). Population recovery of the eastern brown pelican following its extirpation in Louisiana. *The Wilson Bulletin*, *115*(4), 431-437. https://doi.org/10.1676/03-019

Johnston, Gregory R. 2018. The role of hatching asynchrony and sibling rivalry in pelican brood reduction. *Biological Journal of the Linnaean Society* 125: 441 - 451.

King, D. T., Goatcher, B. L., Fischer, J. W., Stanton, J., Lacour, J. M., Lemmons, S. C., & Wang, G. (2013). Home Ranges and Habitat Use of Brown Pelicans (*Pelecanus occidentalis*) in the Northern Gulf of Mexico. *Waterbirds, 36*(4), 494–500. http://doi.org/10.1675/063.036.0406

King, K. A., Blankinship, D. R., Payne, E., Krynitsky, A. J. and Hensler, G.L. (1985) Brown Pelican populations and pollutants in Texas 1975-1981. *Wilson Bulletin,* 97(2):201-214.

King, K. A., Flickenger, E. L., and Hildebrand, H. H. (1977). The decline of brown pelicans on the Louisiana and Texas Gulf Coast. *Southwest, Nat*. 21: 417-431.

Kushlan, James & Frohring, Paula. (1985). Decreases in the Brown Pelican Population in Southern Florida. *Colonial Waterbirds* 8(83) 10.2307/1521057.

Laist, D.W. 1997. Impacts of marine debris: entanglement of marine life in marine debris including a comprehensive list of species with entanglement and ingestion records. Chap. 10

In Marine Debris, J.M Coe and D.B Rogers (eds.). Springer Series on Environmental Management, 99–139: Springer New York

Lamb, Juliet. 2016. "Ecological Drivers of Brown Pelican Movement Patterns and Reproductive Success in the Gulf of Mexico." All Dissertations, May. https://tigerprints.clemson.edu/all_dissertations/1645.

Lamb, J. S., Satgé, Y. G., & Jodice, P. G. R. (2017). Influence of density-dependent competition on foraging and migratory behavior of a subtropical colonial seabird. *Ecology and Evolution*, *7*(16), 6469–6481. http://doi.org/10.1002/ece3.3216

Lamb, J. S., Newstead, D. J., Koczur, L. M., Ballard, B. M., Green, M. C., & Jodice, P. G. R. (2018). A bridge between oceans: overland migration of marine birds in a wind energy corridor. *Journal of Avian Biology*, *49*(2), 1–9. https://doi.org/10.1111/jav.01474

Lamb, J. S., Fiorello, C. V., Satgé, Y. G., Mills, K., Ziccardi, M., & Jodice, P. G. R. (2018b). Movement patterns of California brown pelicans (Pelecanus occidentalis californicus) following oiling and rehabilitation. *Marine Pollution Bulletin*, *131*(December 2017), 22–31. https://doi.org/10.1016/j.marpolbul.2018.03.043

Lowery, G. H., (1955). *Louisiana Birds*. Louisiana Wild Life and Fisheries Commission, Louisiana State University Press.

McEachron, L. W., G. C. Matlock, C. E. Bryan, P. Unger, T. J. Cody, and J. H. Martin. (1994). Winter mass mortality of animals in Texas bays. *Northeast Gulf Science* 13(2):121-138.

Minta, S., & Mangel, M. (1989). A simple population estimate based on simulation for capture-recapture and capture-resight data. Ecology, 70(6), 1738-1751.

Oberholser, H. C. (1938). *The Bird Life of Louisiana*. Department of Conservation, New Orleans, Louisiana. Bulletin 28:1-834.

McClintock, B. T., & White, G. C. (2012). From NOREMARK to MARK: software for estimating demographic parameters using mark–resight methodology. Journal of Ornithology,152(2), 641-650.

Owens, L. K., & James, R. W. (1991). Mitigation of traffic mortality of endangered Brown Pelicans on coastal bridges (No. 1312).

Pearson, T. G. (1919). *The Case of the Brown Pelican*. American Review of Reviews and the World's Work. (May). https://books.google.com/books?id=dw0pzQEACAAJ

Pearson, T. G. 1920. Exploring for new bird colonies. *Bird Lore* 23: 276-277.

Pearson, T. G. (1921). Notes on the Bird-Life of Southeastern Texas. *The Auk*, 38:513-523.

Ploger, Bonnie Jean. 1992. Proximate and ultimate causes of brood reduction in brown pelicans (Pelecanus occidentals). PhD Thesis, University of Florida.

Robinson, Orin J., and John J. Dindo. 2011. “Egg Success, Hatching Success, and Nest-Site Selection of Brown Pelicans, Gaillard Island, Alabama, USA.” *Wilson Journal of Ornithology* 123 (2): 386–90. https://doi.org/10.1676/10-125.1.

Sachs, E. B., and P. G. R Jodice. 2009. *Behavior of parent and nestling brown pelicans during early chick rearing*. Waterbirds 32:276-281

Schreiber, R. W. (1976). Growth and development of nestling Brown Pelicans. Bird-banding, 47(1), 19-39.

Schreiber, R. (1980) Nesting Chronology of the Eastern Brown Pelican. *The Auk*, 97(3):491-508.

Schreiber, Ralph W., and Patrick J. Mock. “Eastern Brown Pelicans: What Does 60 Years of Banding Tell Us? (El Pelícano Pardo Occidental: Que nos ha Enseñado 60 Años de Anillaje).” *Journal of Field Ornithology* (1988): 171-182.

Schreiber, Ralph W., and Robert W. Risebrough. (1972). “Studies of the Brown Pelican.” *The Wilson Bulletin*, 84:119-135.

Shields, M. 2014. Brown Pelican (*Pelecanus occidentalis*), The Birds of North America (P. G. Rodewald, Ed.). Ithaca: Cornell Lab of Ornithology; Retrieved from the Birds of North America Online, 13 April 2017.

Tavera et al. 2020. Oversummering juvenile and adult Semipalmated sandpipers in Perú gain enough survival to compensate for foregone breeding opportunity. *Movement Ecology* 8 (42).

Walter, S. T., Carloss, M. R., Hess, T. J., Athrey, G., & Leberg, P. L. (2013). Movement Patterns and Population Structure of the Brown Pelican. *The Condor*, *115*(4), 788–799. https://doi.org/10.1525/cond.2013.110195

Walter, S. T., Karubian, J. K., & Dindo, J. J. (2014). Factors influencing Brown Pelican (*Pelecanus occidentalis*) foraging movement patterns during the breeding season. *Canadian Journal of Zoology*, *92*(10), 885–891. https://doi.org/10.1139/cjz-2014-0051

Wilkinson, P. M., Nesbitt, S. A., and Parnell, J. F. (1994). Recent history and status of the Eastern Brown Pelican. *Wildl. Soc. Bull*. 22: 4200-430.

Williams Jr, Lovett E., and Ted Joanen. (1974) “Age of first nesting in the Brown Pelican.” *The Wilson Bulletin*, 279-280.

Williams, L.E., Jr., and L. Martin. 1968. Nesting status of the Brown Pelican in Florida in 1968. Quarterly Journal of the Florida Academy of Sciences 31:130–140.

Wright, S. K., Roby, D. D., and Anthony, R. G. 2007. Responses of California Brown Pelicans to disturbances at a large Oregon roost. i 30:479–487.

APPENDIX I. STAKEHOLDER WORKSHOP

INTRODUCTION

This memorandum provides an overview of the Stakeholder Meeting (Task 2) of RMC 0-6970 - Daily and Seasonal Movements of Brown Pelicans in the Bahia Grande Wetland Complex. The stakeholder meeting was hosted by TTI on 27 September 2018 from 13:00 to 16:30 at the Port Isabel Event Center. The purpose of the meeting was to engage other scientists and stakeholders in the area by presenting them information on the project goals, methods and preliminary results. The meeting was also designed to solicit feedback from the stakeholders on the approaches used in the project, and to identify key knowledge sources that may be useful for the remainder of the project. The meeting was attended by 27 stakeholders (including TxDOT and TTI staff), including biologists from Texas Parks and Wildlife, U.S. Fish and Wildlife Service, Coastal Bend Bays and Estuaries Program, and research professors and graduate students from UTRGV.

The RMC 0-6970 stakeholder meeting reported in this document followed an earlier meeting organized by TxDOT Pharr District (10am – 12pm). The earlier meeting discussed TxDOT's plans for managing the Pelican issue during the forthcoming fall and winter. The morning meeting was directed towards local stakeholders interested in Pelican mortality, including volunteers who rescue birds during events. TTI researchers presented research and were involved in discussions during the earlier meeting. The RMC 0-6970 stakeholder meeting was organized for the afternoon at the same venue. Its purpose was to engage local scientists and discuss the ecological drivers of Pelican mortality. This document reports on the proceedings and outcomes of the 0-6970 stakeholder meeting.

AGENDA AND ATTENDEES

Table 1 lists the workshop attendees and affiliations. Invitees were selected using knowledge of scientists working in the area. Each invitee was sent two emails, and most were personally contacted by telephone. The TTI research team planned for a group of 20-30 participants. In total, there were 27 participants on the day. This included 16 invited scientists, four TxDOT scientists (John Young, John Maresh, Robin Gelston, Edward Paradise), two Texas Parks and Wildlife Service scientists who serve as 0-6970 advisors (Willy Cupit and Liana Lerna), and four TTI scientists (Andrew Birt, Lianne Koczur, Jolanda Prozzi and Victoria Wilson).

The agenda was designed to both provide and gather information from the attendees. For this reason, TTI researchers (Birt and Koczur) developed three formal presentations which were interspersed with extended 'break out' sessions. The first formal presentation (by Andrew Birt) provided a high-level overview of the Pelican mortality problem and was designed to provide some context to attendees who were not familiar with Pelican mortality on SH 48. The second formal presentation (by Lianne Koczur) introduced the biology and ecology of Brown Pelicans, the goals of the 0-6970 project and preliminary tracking results. This presentation was designed to focus the attendees on Pelican ecology (rather than the Pelican-Road interactions). The third presentation focused on Pelican-roadway interactions, including the influence of wind conditions on the bridge, the design of the road, and the causes of mortality.

The breakout sessions were undertaken at the end of the second and third formal presentations. The first break out session focused on Pelican ecology. Two groups were formed, each moderated by two TTI researchers (Lianne Koczur and Jolanda Prozzi, and Andrew Birt and Victoria Wilson). The moderators asked a series of questions designed to promote extensive discussions among the group attendees. The second breakout session followed the presentation on Pelican-roadway interactions, and focused on potential mitigation solutions, and the value of the 0-6970 research outputs to the problem.

Table 14. List of Attendees for Stakeholder Meeting.

Name	Affiliation	Title
Stephanie Bilodeau	CBBEP	Waterbird Biologist
Dr. Karl Berg	UTRGV	Professor (ornithology, ecology)
Thomas deMaar	Gladys Porter Zoo	Senior Veterinarian
Liana Lerma	TPWD	Coastal Ecologist
Willy Cupit	TPWD	Coastal Ecologist
Tony Henehan	TPWD	Urban Biologist
Laura de la Garza	FWS Ecological Services	Fish and Wildlife Biologist
Ernesto Reyes	FWS Ecological Services	Fish and Wildlife Biologist
David Newstead	CBBEP	Director, Coastal Bird Program
Lindsay Brown	CBBEP	Waterbird Biologist
Shelby Bessette	UTRGV	Coastal Studies Lab Manager
Rory Eggleston	UTRGV	Graduate Student
Kevin Ryer	UTRGV	Graduate Student
Beau Hardegree	USFWS Corpus Christi	Fish and Wildlife Biologist
Dr. Richard Kline	UTRGV	Professor (marine science, applied ecology)
Bryan Winton	USFWS, Lower Rio Grande Valley NWR	Refuge Manager
Suzanne Walsh	TPWD	Transportation Conservation Coordinator
Chris Perez	USFWS	Fish and Wildlife Biologist

Edward Paradise	TxDOT	
John Young	TxDOT	
John Maresh	TxDOT	
Robin Gelston	TxDOT	
Homer Bazan Jr.	TxDOT	
Victoria Wilson	TTI	
Jolanda Prozzi	TTI	
Andrew Birt	TTI	
Lianne Koczur	TTI	

The following is a summary of the meeting's agenda. The remainder of this section describes each component of the agenda in more detail.

12:30 – 1:00 **Arrival**

1:00 – 1:15 **Presentation I – Welcome and Overview**

1:15 – 1:40 **Presentation II – Ecology of the Brown Pelican**

- Introduction
- Brown Pelican Ecology
- Tracking Studies
- Current Project
- Data from Winter 2017-2018

1:40 – 2:10 **Small Group Discussion I**

- Pelican movements in the Lower Laguna Madre / Bahia Grande Region.

2:10 – 2:35 **Presentation III – Mortality on SH 48**

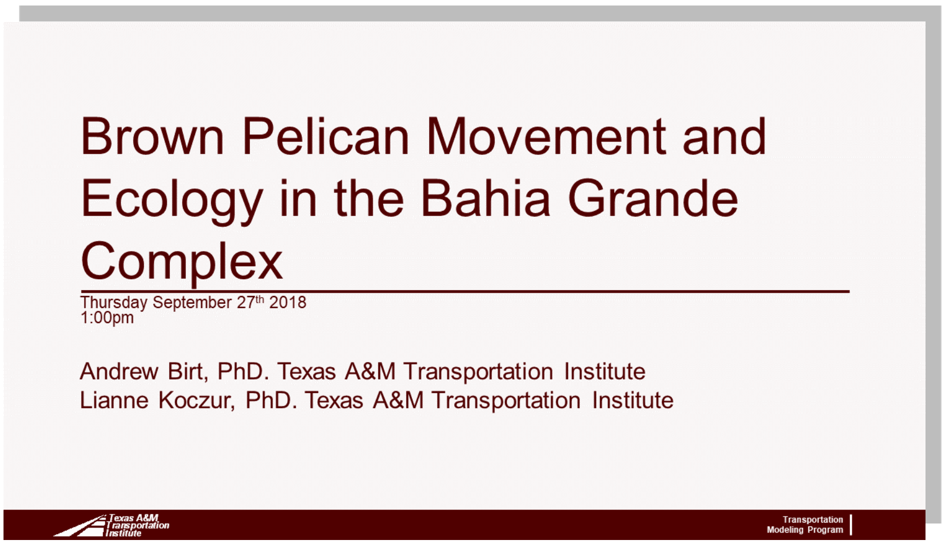
2:35 – 3:00 **Small Group Discussion II**

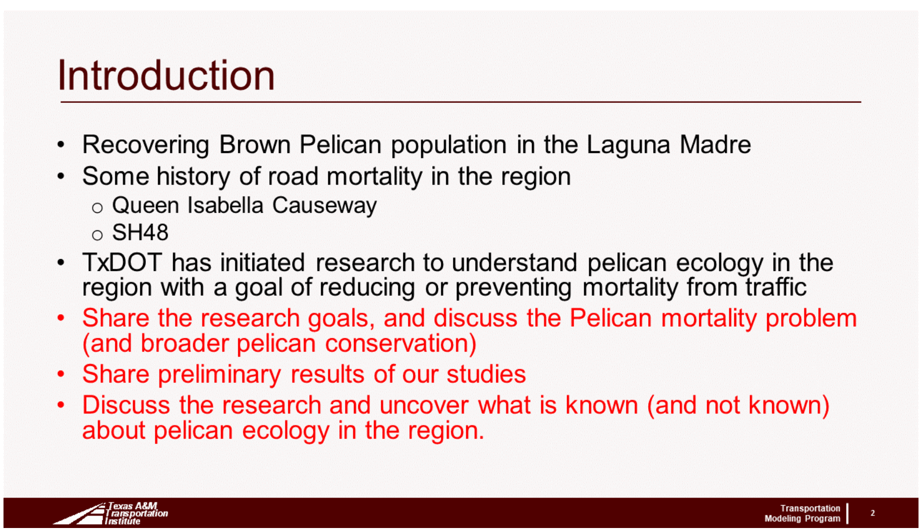
- Mitigating Mortality Events on SH 48

3:00 – 3:15 **Discussion/Wrap-up**

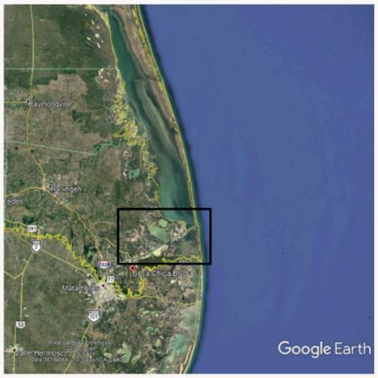
Presentation I - Introduction

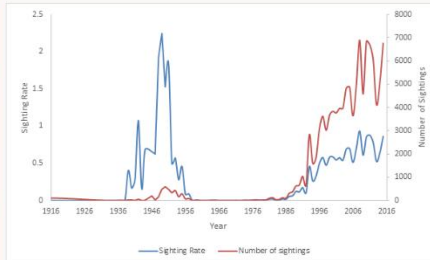
Andrew Birt began the meeting with an introduction to the project and background information on the mortality events on SH-48. This presentation began by outlining the recent increases in the Pelican population in the area and the history of vehicle-pelican collisions including the current situation on SH-48. The purpose of the meeting was introduced – i.e., to share research goals and preliminary results, and to tap into any knowledge or resources that may be useful for the project. The presentation highlighted the attention the Pelican mortality was receiving in the local press. To ensure the attendees understood the nature of the mortality, the attendees were shown a video of a Pelican struggling to fly across the road during a cold front. The presentation concluded with a description of TxDOT funded research, the agenda for the remainder of the meeting, and an advanced appreciation for all the attendees' time. Immediately following the introductory presentation, each workshop attendee introduced themselves to the group.





Study Area

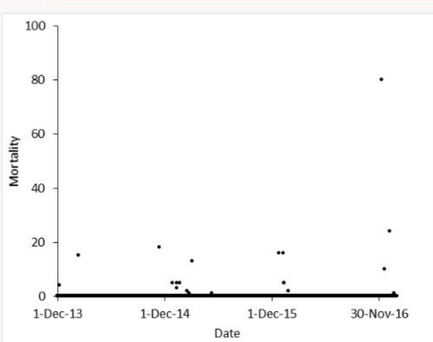




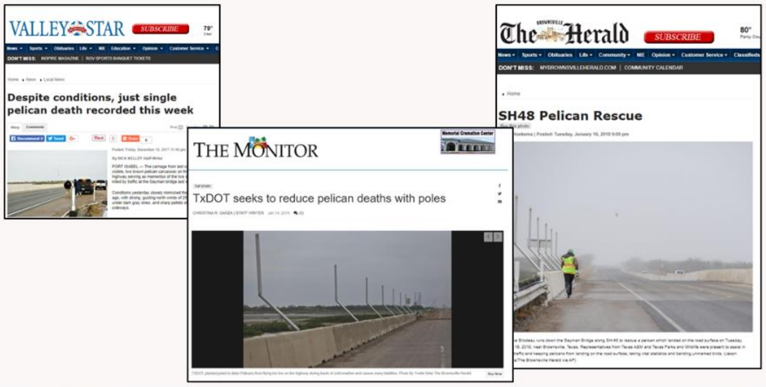
Audebon Christmas bird survey data

State Highway 48 and Queen Isabella Causeway

Pelican-Road Mortality



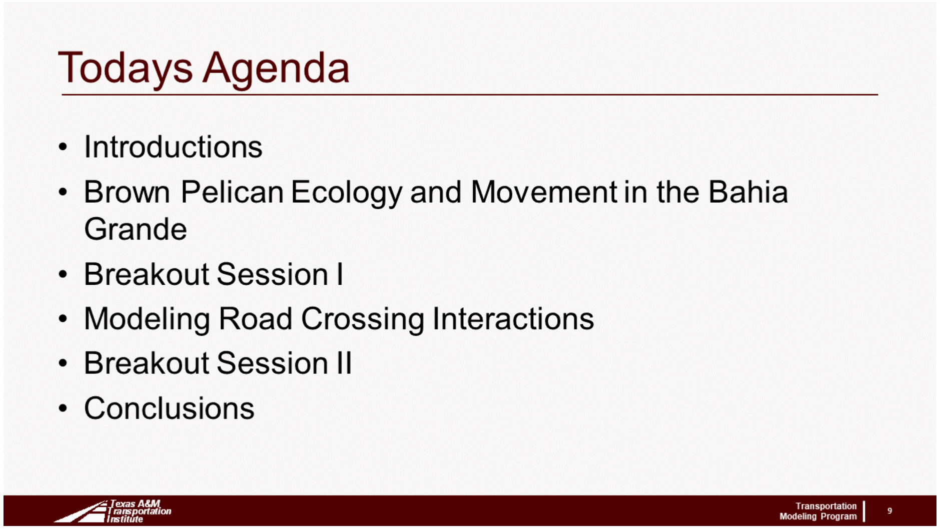
Local Attention



Pelican Crossing

Ongoing Research

- **Wind tunnel experiments** – how does the roadway design contribute to crossing difficulties?
- **Computational fluid dynamics modeling** - can we redesign the roadway (traffic barriers) to improve crossing conditions?
- **Movement and ecology of Pelicans** – Why, when and how frequently are they crossing the road?



Presentation II – Brown Pelican Ecology in the Bahia Grande

Lianne Koczur presented information on the general ecology of Brown Pelicans. The first half of the presentation covered the general biology of Pelicans, the history of the species' decline in the 1950s-1970s and the population increase following the banning of DDT. Lianne highlighted the importance of the Gulf of Mexico coast to the pelican population. The presentation introduced results from previous Brown Pelican tracking studies – making the points that only one of the four studies had marked individuals that were breeding in Texas; and although two studies documented partial migration, they did not get into specific detail on the movements or habitat use during the nonbreeding season. To conclude the ecological background, Lianne provided a brief history of the Bahia Grande, its restoration, and its effect on the Pelican population.

The second half of the presentation provided preliminary results from the 0-6970 Daily and Seasonal Movements study. This consisted of an overview of the methods and preliminary results for each aspect of the project (banding, citizen science, fixed-point observations, and deployment of transmitters). This portion of the presentation was intended to show the attendees the goals of the project and highlight some of the questions the project will begin to address. It was also intended to generate discussion among the attendees during the subsequent breakout sessions.

Daily and Seasonal Movements of Brown Pelicans

27 September 2018

Overview

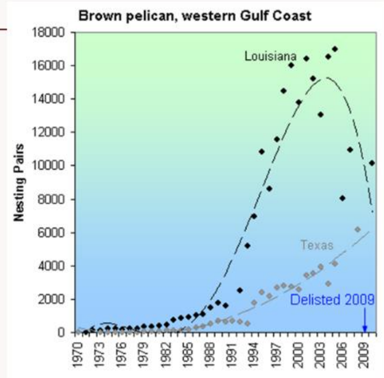
- Brown Pelican Ecology
- Tracking Studies
- Current Study
- Preliminary Results

Brown Pelican Ecology

- Nearshore seabird
- Long-lived, delayed sexual maturity
- Incubation: ~30 days
- Fledge: 11-12 weeks after hatch

Brown Pelican Ecology

- 1950s – 1970s population declined
  - Texas: 50 pairs left out of 10,000
- Listed as endangered in 1970
- DDT banned in 1972
- Pelican population steadily increasing since 1970s
- Delisted in 2009



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Brown Pelican Ecology

- Eastern subspecies
  - Entire range: ~120,000 individuals during 1999-2011
  - U.S.: ~70,000-88,000 breeding adults per year during 2007-2013
  - ~65% of the population occurring along the Gulf of Mexico coast

Brown Pelican Ecology

- Few tracking studies
- Croll et al. 1986
  - CA; 1 juvenile radio-tracked for 68.8 hours

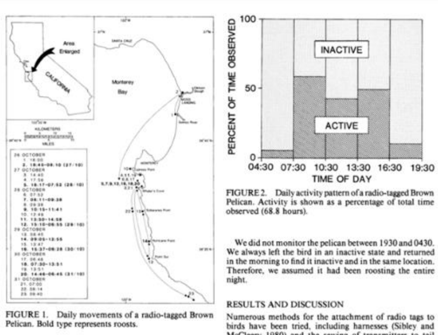


FIGURE 1. Daily movements of a radio-tagged Brown Pelican. Bold type represents roosts.

FIGURE 2. Daily activity pattern of a radio-tagged Brown Pelican. Activity is shown as a percentage of total time observed (68.8 hours).

We did not monitor the pelican between 1930 and 0430. We always left the bird in an inactive state and returned in the morning to find it inactive and in the same location. Therefore, we assumed it had been roosting the entire night.

RESULTS AND DISCUSSION

Numerous methods for the attachment of radio tags to birds have been tried, including harnesses (Sibley and McCleery 1980) and the sewing of transmitters to tail feathers (Dunstan 1973, Kenward 1978). We believe the

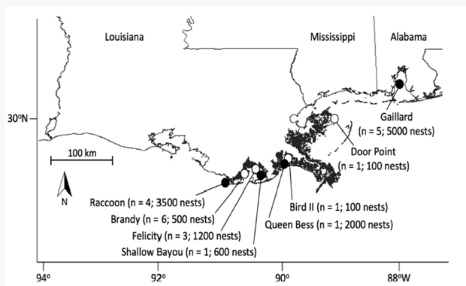
Brown Pelican Ecology

- King et al. 2013
  - o Breeding in LA
  - o 18 adults tracked for 2 years
    - ▪ 3 south Texas
    - ▪ 2 Yucatan

Figure 2. Locations of Brown Pelicans (n = 18) captured and fitted with satellite transmitters on Grand Isle, Louisiana, 31 August-2 September 2010. Locations were recorded from 31 August 2010-15 March 2012.

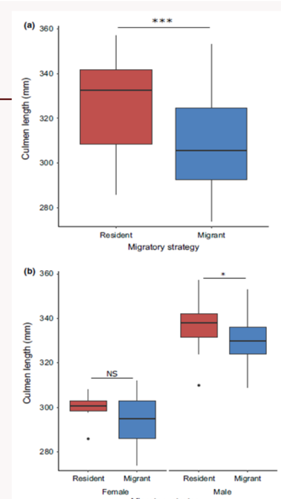
Brown Pelican Ecology

- Walter et al. 2014
  - o Breeding in AL and LA
  - o 32 adults
  - o Colony size and sex did not influence movement patterns
  - o Pelicans with lower body condition flew farther to forage after eggs hatched



Brown Pelican Ecology

- Lamb 2016; Lamb et al. 2017
  - o LA, TX
  - o 67 adults
  - o Partial migration
    - ▪ In Texas, pelicans from larger colony migrated greater distances
    - ▪ Smaller individuals more likely to migrate than larger
    - ▪ Females more likely to migrate than males

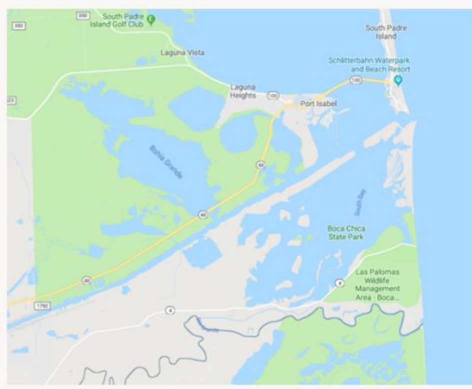


Brown Pelican Ecology

- Coastal south Texas is an important area for both breeding and wintering Brown Pelicans.
- Owens et al. (1990): 96% of the Texas population of pelicans wintered in the lower Laguna Madre.

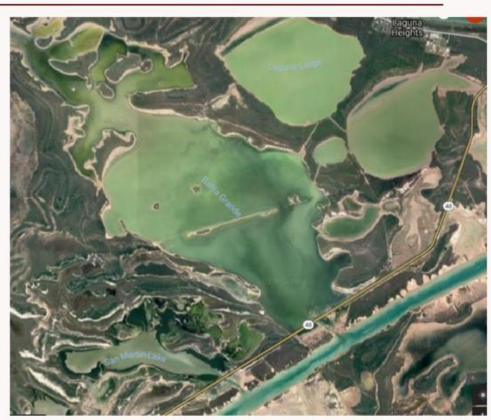
Bahia Grande

- 1936:
  - Construction of Brownsville ship channel and SH 48
  - Cut off water flow to BG
- 2000:
  - USFWS obtained BG
- 2005:
  - Channel constructed to restore water flow



Bahia Grande

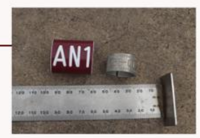
- Bahia Grande
  - Restoration was successful
  - High diversity and abundance of birds
  - ~1,000-3,000 pelicans roosting in winter



Cold Fronts

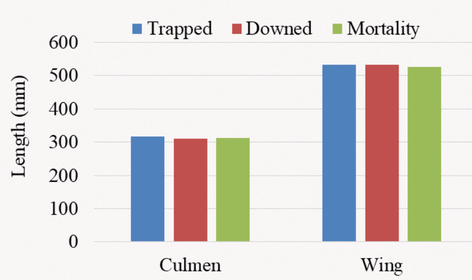
- Cold front conditions causing pelican mortality during winter
- TxDOT funded study in 2017
  - Daily and seasonal movements of Brown Pelicans
    - Banding
    - Citizen Science
    - Observations
    - Tracking

Banding and Morphometrics



Banding and Morphometrics

	Adult	Immature
Banded		
Female	26	14
Male	19	6
Unknown	9	1
Mortality		
Female	11	5
Male	5	2
Unknown	3	3

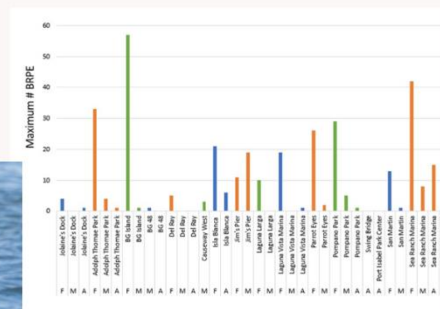


Banding and Morphometrics

- Trapped *(n = 49):*
  - 59% female, 41% male
  - $X^2 = 2.25$, $p = 0.13$
- Downed ($n = 23$):
  - 73% female, 27% male
  - $X^2 = 4.54$, $p = 0.03$
- Mortalities ($n = 29$):
  - 61% female, 29% male
  - $X^2 = 5.14$, $p = 0.02$

Citizen Science

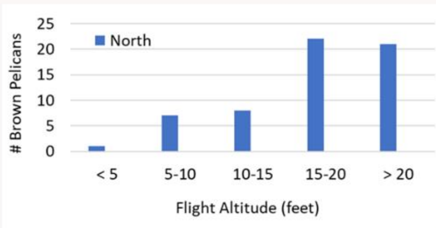
- Resights of banded birds
- Monthly survey
  - Roost count
- iNaturalist



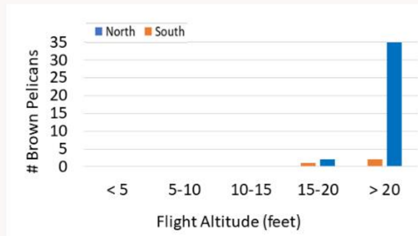
Observations

Observations

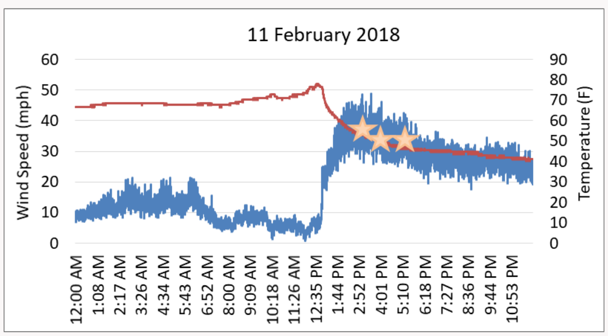
45ºF, 35 mph N wind



65ºF, 13 mph N wind



Observations

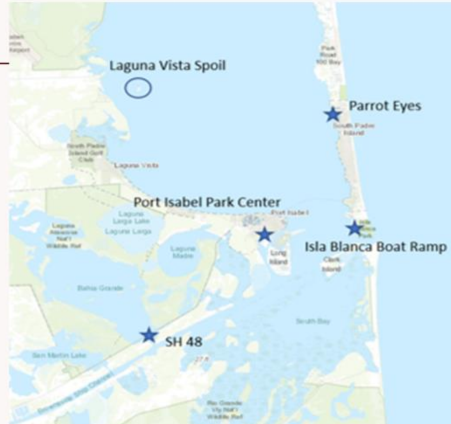


Tracking

- Milsar GSM transmitters
  - Locations every 15-60 minutes
  - Geofence capabilities
    - Locations every 3 seconds

Tracking

- Winter 2017-2018:
  - 4 pelicans tracked
  - 1 that used Bahia Grande

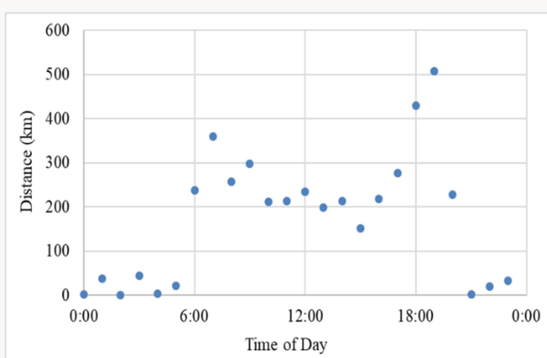


Tracking

ID	Sex	Avg. km/day	Min.	Max.
F7A	F	44.0	16.5	102.5
OB3	F	23.4	5.7	36.8
AA3	M	32.5	15.6	56.0
163	M	22.0	0.7	41.1

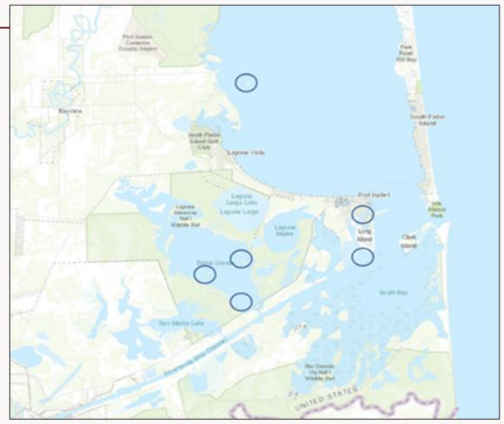
Tracking

- F7A
  - Daily distance
  - Cumulative distance



Tracking

- Roost Sites
- F7A



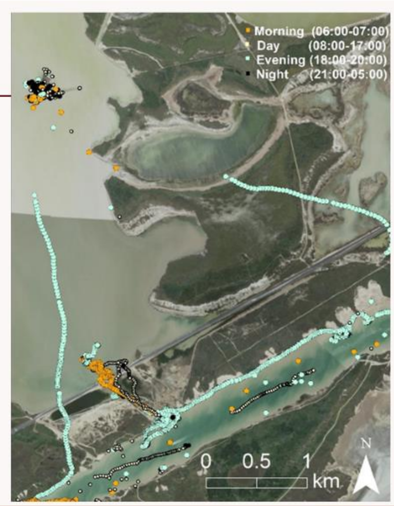
Tracking

- F7A
  - Roost site use in relation to daytime sites

	Distance to roost sites (km)	
	8am-3pm	4pm-5pm
Bahia	**1.9**	**2.5**
LV Spoil	15.1	14.5
Bahia	10.4	12.9
LV Spoil	**15.7**	**18.6**

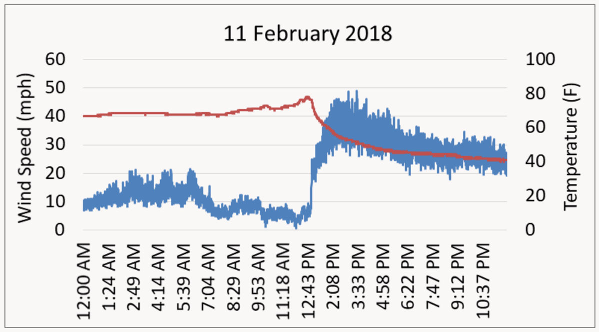
Tracking

- Road crossings



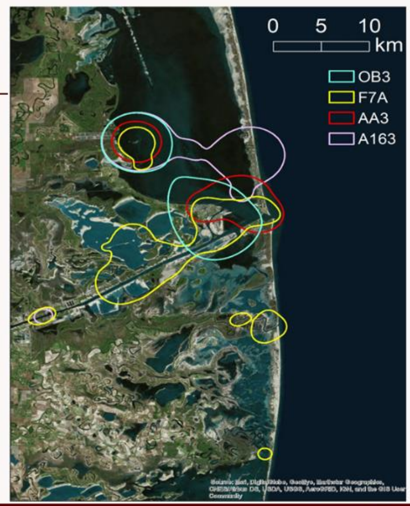
Tracking

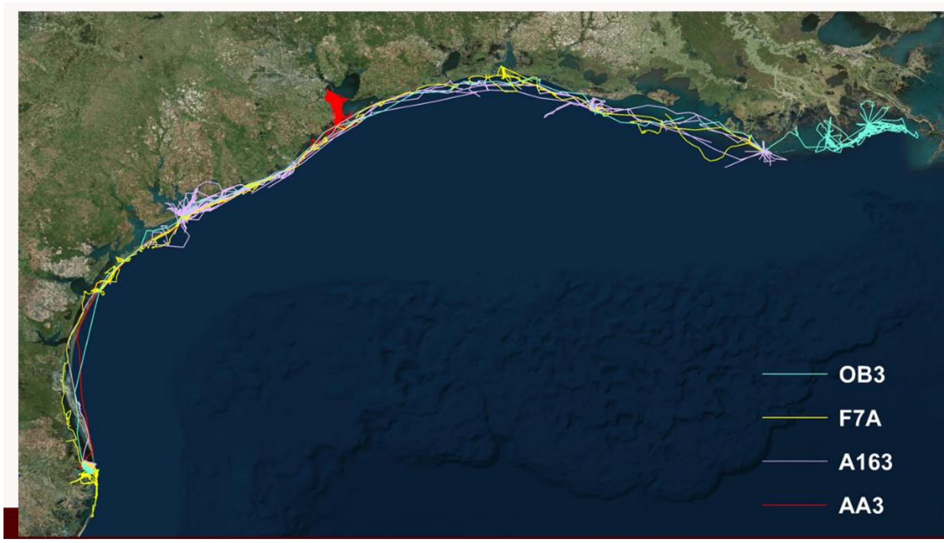
- AA3 & 163
- Remained out at daytime sites during cold front
- At roost by 4pm and 5pm



Tracking

- Home range
  - 95% kernel UD
  - AA3: 57 km^2
  - 163: 84 km^2
  - OB3: 97 km^2
  - F7A: 114 km^2





Breakout Session I – Discussion of Pelican Ecology

The first group discussion focused on the ecology and movements of pelicans in the region. The attendees formed two equal sized groups. One group was facilitated by Andrew Birt and Victoria Wilson (TTI); the other by Lianne Koczur and Jolanda Prozzi (TTI). The idea of the breakout sessions was to encourage the attendees to engage in free discussion about the ecology of Brown Pelicans in the region. To impart some structure, the moderators of each group were provided with a set of questions to prompt discussions (see box below):

Why are pelicans crossing SH 48?

- Why and under what conditions is the Bahia Grande a good place to roost?
  - We know that the use of the site is variable throughout the season. Any ideas?
  - Of the seven birds we have caught, only one has used the BG roost site. And then it returned to the spoil islands.
- Is there the same food supply in the Bahia Grande as Laguna Madre or elsewhere (San Martins Lake)
  - The birds seem very lazy – perhaps they like roost sites that they don't have to move far from to fish?
- Why do pelicans not access Bahia Grande via north end rather than south end (SH 48)?
  - Maybe they do, but we haven't much evidence?
- We wonder if the geography of the area predisposes crossing over SH 48 (e.g., is the ship channel used as a dispersal corridor?)
- What is the role of the Boca Chica wetlands for roosting? Are the islands isolated enough from predators? Does the hydrology of the Boca Chica mean safe roost sites are ephemeral?
- Does the Bahia Grande offer a more protected roost site during storms than the Laguna Madre?
- Are tides an influence?
- Does the Bahia Grande offer a closer roost site option during storms (especially for birds that are foraging south of the Laguna Madre?
- Are roost sites a limiting resource for these birds?

What are the most important variables that are influencing habitat use and movements of pelicans in this region?

- Wind (speed, direction)
  - Tides are largely wind-driven
  - Pelicans may expend less energy flying when there is a breeze
- Air temperature
  - Pelicans do not handle cold temperatures well
- Water – level, temperature, salinity
  - How does this influence prey distribution?
  - Pelicans can't plunge dive into very shallow water
- Fish cleaning stations
  - More important to some individuals than others?
- Roost Sites
  - Safety from predators
  - Disturbance from people
  - Proximity to foraging sites
  - Does vegetation on the island matter? They appear to use shoreline/mudflats on edges of islands.
  - Are there limited roost sites available in the lower Laguna Madre region?

Any ideas on data, complimentary research projects or volunteers to help?

Moderator sheet used in first breakout session.

Each breakout group were also provided with a number of handouts illustrating maps of the area and other information. A selection of this material is provided below:

Bahia Grande Dec 1996 (Pre-flooding)

Daily and Seasonal Movements of Brown Pelicans in the Bahía Grande Wetland Complex - Breakout I

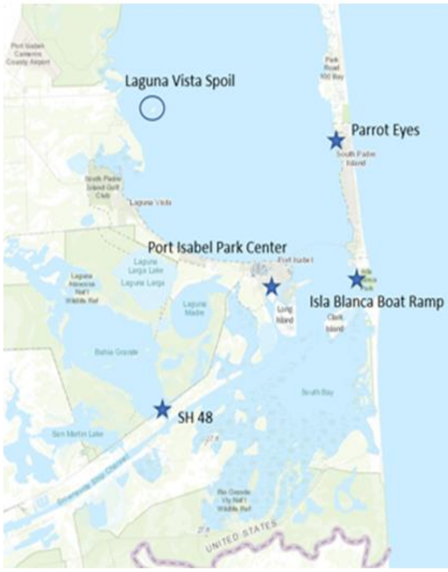
1

Bahia Grande Dec 2017 (Post-flooding)

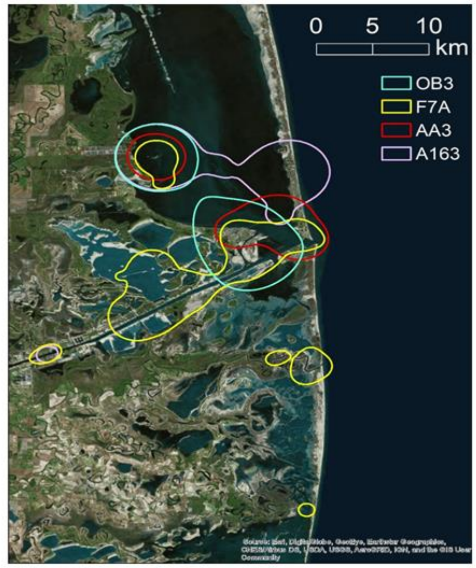
Daily and Seasonal Movements of Brown Pelicans in the Bahía Grande Wetland Complex - Breakout I

5

Pelican Capture Locations (GPS)



Pelican Estimated Home Ranges



Daily and Seasonal Movements of Brown
Pelicans in the Bahía Grande Wetland Complex
- Breakout I

7

Roost sites - Bahia

Daily and Seasonal Movements of Brown
Pelicans in the Bahía Grande Wetland Complex
- Breakout I

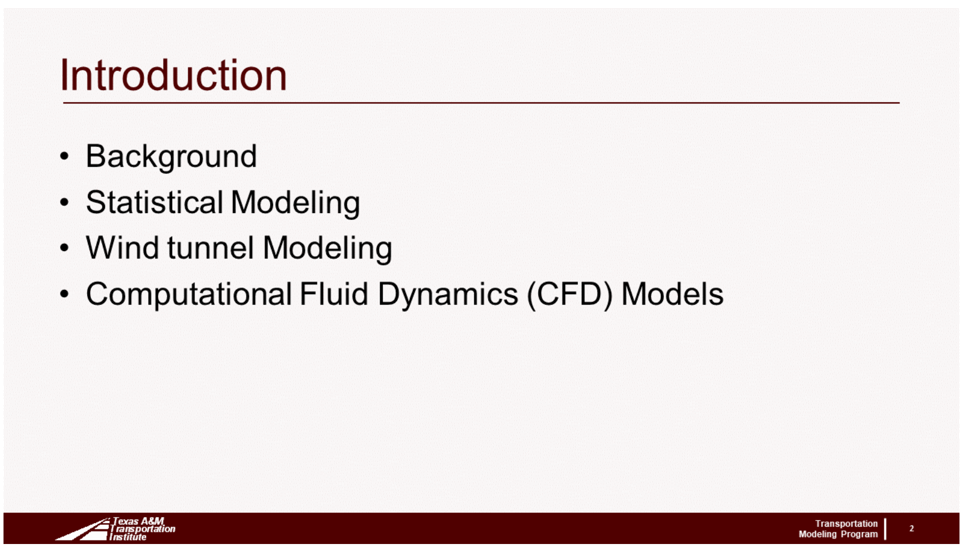
12

Examples of information (mostly maps and aerial imagery) provided for the first breakout session).

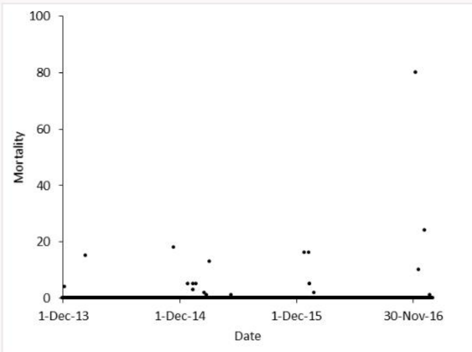
Presentation III

The third presentation focused on the reasons why the Pelican–vehicle interactions occur, and the value of the 0-6970 projects research findings for mitigating mortality. The presentation first defined the locations of mortality on SH 48, and the history of mortality events on the corridor. A statistical analysis of the mortality events was presented. The statistical model emphasized the role of strong winds and low temperatures, but also, that mortality does not always occur during cold fronts – suggesting that the movement of Pelicans over the bridge is temporally variable. This point was used to introduce the idea that information on the movement of Pelicans over the bridge (i.e. research from the 0-6970 project) is essential for providing a long-term solution to the problem.

The second half of the presentation introduced the results from wind tunnel and computational fluid dynamics (CFD) studies. The slides provided a movie of the airflow over the Carl Gayman Bridge, and a discussion of the features of the airflow that likely affect Pelican flight. They also demonstrated the results of a model of Pelican flight, and the idea that a bird flying into a 30-40mph wind gusts struggles to make headway. This point was reinforced by another video of Pelicans attempting to cross SH 48 during high winds, leading to some conclusions about the causes of Pelican mortality on the corridor. Finally, the attendees were shown slides demonstrating modeled airflow before and after replacing the concrete barriers with alternative railings. The importance of the 0-6970 study was reemphasized by noting that although the CFD helps us understand airflow across the bridge, we are still missing important information on the altitude at which birds cross the road (i.e., under different conditions) or models that can explicitly tell us how the airflow will affect the flight of the birds.

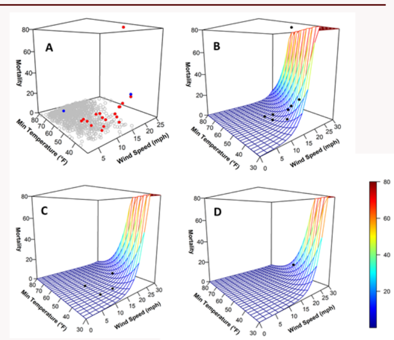


Mortality



Statistical Modeling

- Mortality statistically related to: temperature (low), wind speed (high), wind direction (perpendicular), and tide (high)
- But mortality does not occur *every* cold-front



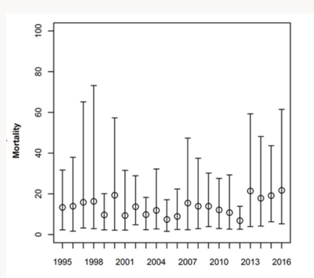
Panel A = actual data (red or blue dots show NP and SP winds respectively).
Panel B shows mortality for a NP wind and high tide.
Panel C shows mortality for a NP wind and low tide.
Panel D shows mortality for a SP wind and medium tide.

Statistical Modeling

Mortality depends on two independent events (probabilities):

1) Relatively rare weather events *and*
2) The number of pelicans flying over the bridge

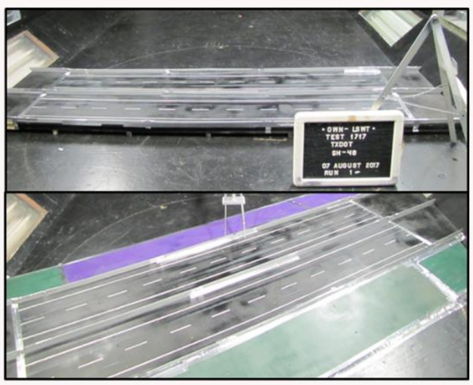
This represents the majority of the variation in the model predictions!



Predicted total annual mortality using statistical model. Variation between years is caused by variation in the weather! Variation within years is caused by 'crossing frequency'

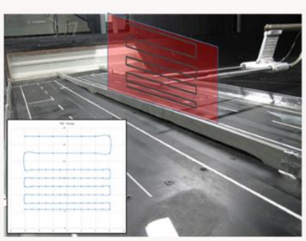
SH 48

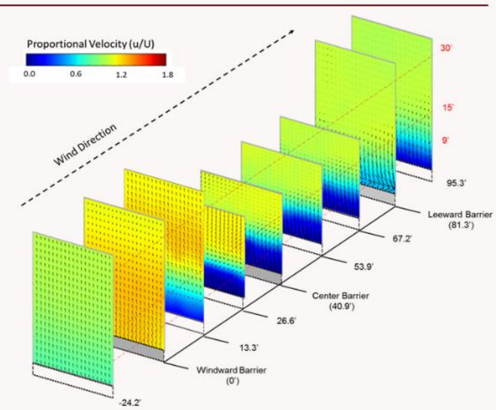
Wind Tunnel Modeling



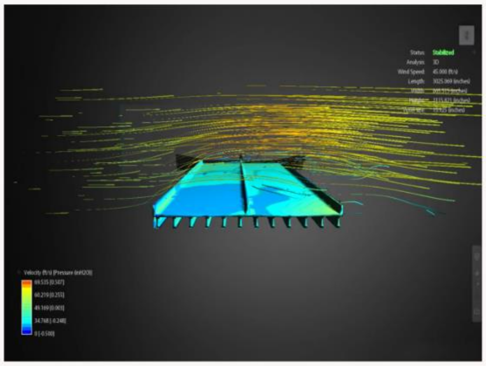
- Scale models built to represent bridge and causeway sections (approx. 1:37)
- Bridge could be raised up and down
- Wind tunnel @ 30 mph

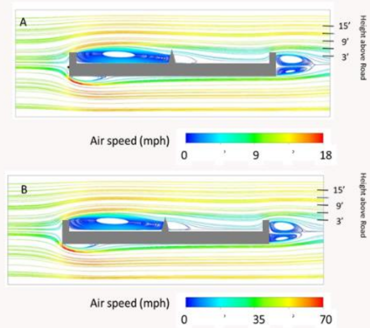
Wind Tunnel Results



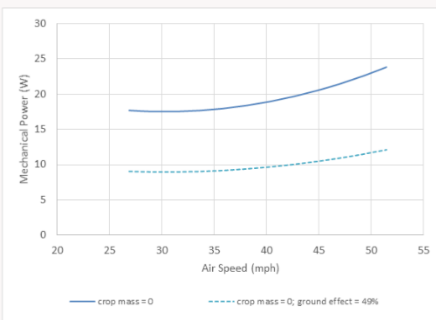


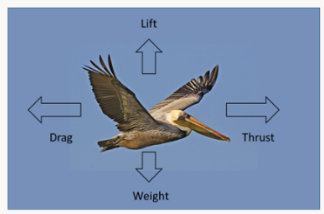
Computational Fluid Dynamics (CFD)





Flight Models



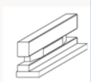
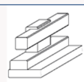
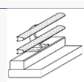


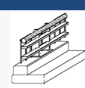
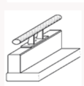
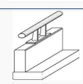
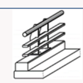
Videos

So why do pelicans 'crash' into the bridge

- The Bahia Grande important for roosting / feeding.
- Difficult to fly into 30-40 mph headwinds – under any circumstances.
- Over the westbound (leeward) lanes, birds fly into downdrafts.
- Slow ground speed – more time for 'bad' things to happen.
- Low flight over the road – more exposure to, and less time to adjust to bad air.

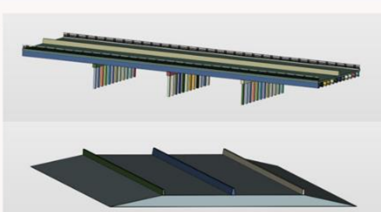
CFD Modeling of Alternate Barrier Designs

Railing Type I.D. and Classification	Figure	Height	Safety Rating
SSTR Concrete with multiple drain slots		36"	TL-4
T224 Concrete Traffic Railing		42"	TL-5
T66 Concrete Traffic Railing		32"	TL-3
T1F Metal and Concrete Traffic Railing		33"	TL-3

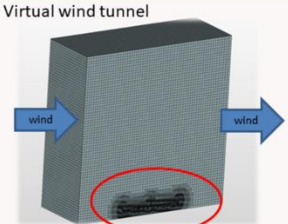
Railing Type I.D. and Classification	Figure	Height	Safety Rating
T1P Metal and Concrete Traffic Railing		36"	TL-3
T401 Metal and Concrete Traffic Railing		33"	TL-3
T402 Metal and Concrete Traffic Railing		42"	TL-3
T2P		44"	TL-4

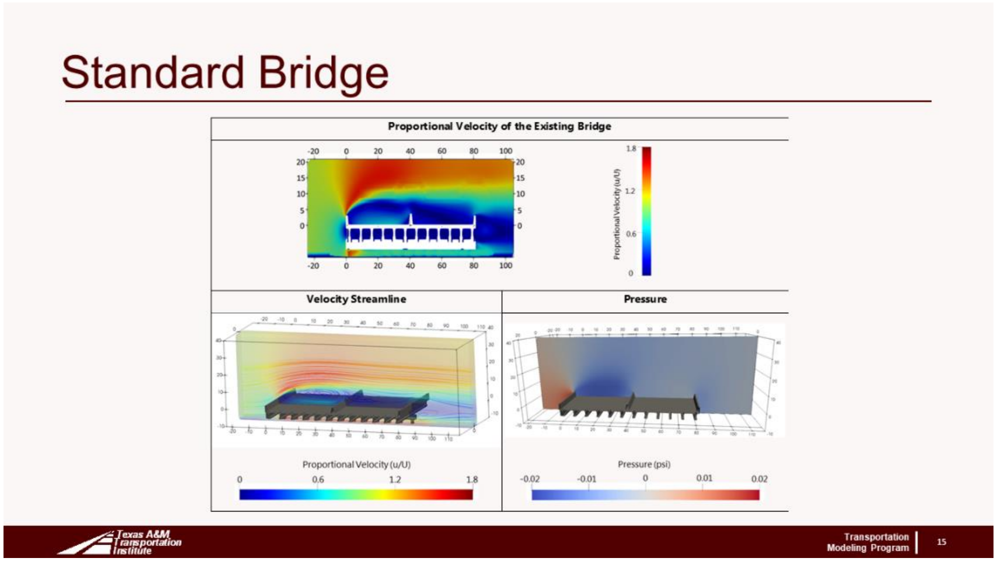
Test scenarios – Bridge and Causeway

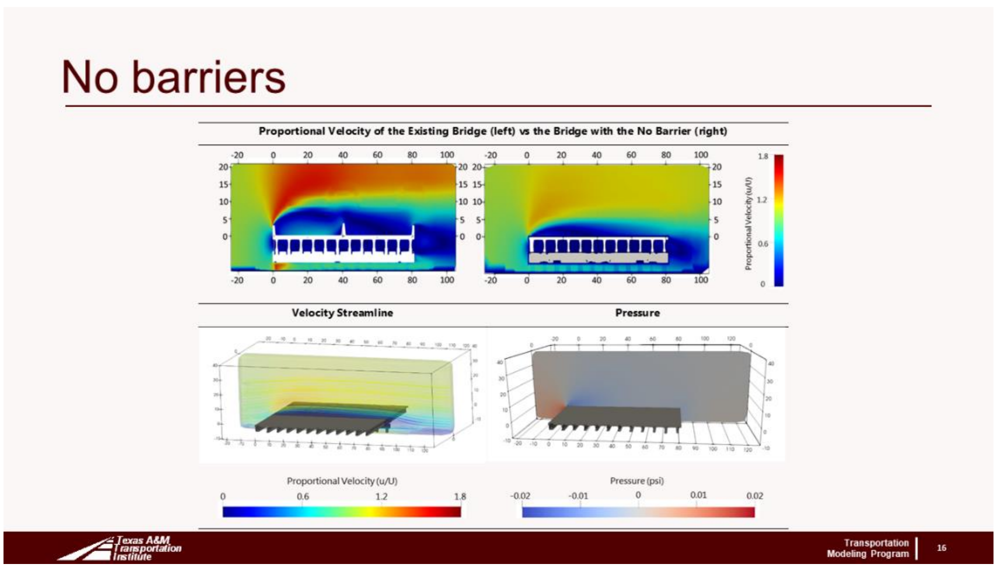
CAD Models

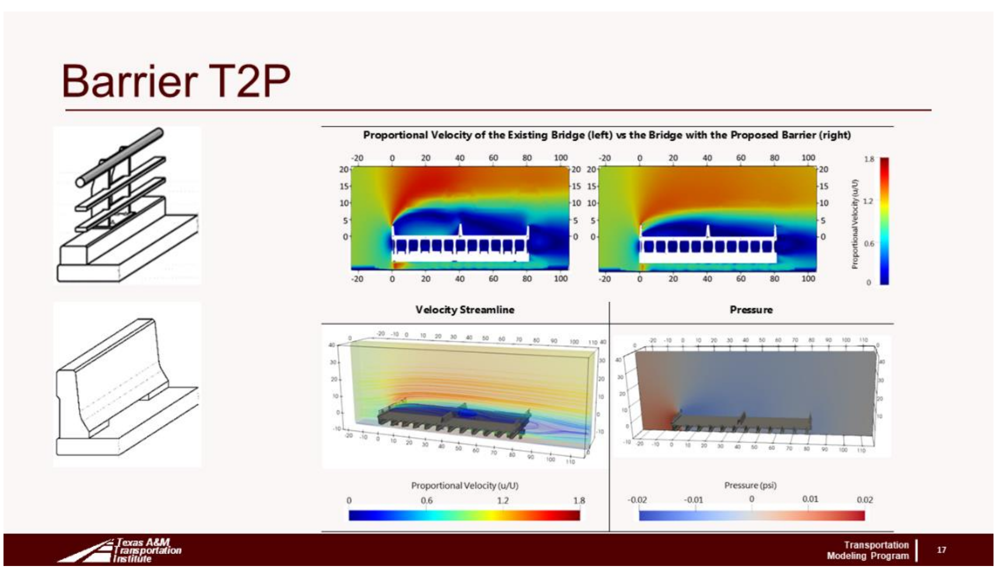


Virtual wind tunnel

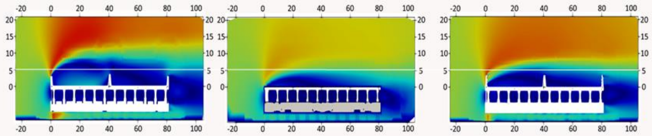



Standard Bridge
Proportional Velocity of the Existing Bridge
Proportional Velocity (u/U)
Velocity Streamline
Pressure
Proportional Velocity (u/U)
0 0.6 1.2 1.8
Pressure (psi)
-0.02 -0.01 0 0.01 0.02
Texas A&M Transportation Institute
Transportation Modeling Program
15


No barriers
Proportional Velocity of the Existing Bridge (left) vs the Bridge with the No Barrier (right)
Proportional Velocity (u/U)
Velocity Streamline
Pressure
Proportional Velocity (u/U)
0 0.6 1.2 1.8
Pressure (psi)
-0.02 -0.01 0 0.01 0.02
Texas A&M Transportation Institute
Transportation Modeling Program
16


Barrier T2P
Proportional Velocity of the Existing Bridge (left) vs the Bridge with the Proposed Barrier (right)
Proportional Velocity (u/U)
Velocity Streamline
Pressure
Proportional Velocity (u/U)
0 0.6 1.2 1.8
Pressure (psi)
-0.02 -0.01 0 0.01 0.02
Texas A&M Transportation Institute
Transportation Modeling Program
17

CFD Results



- Best barrier lowers the height of 'disturbed' air (over CTB) by approx. 3 feet (9' to 6')
- Best barrier significantly reduces zones of negative pressure behind windward and median barriers
- Similar results for causeway model
- Wind direction does not interfere with conclusions
- Median CTB does not have a big effect on the overall wind pattern

Conclusions

- Modifying the barriers does have an effect on air flow
  - but will it reduce mortality?
- CFD was a great tool for evaluating the potential of different barrier designs
  - Fast and inexpensive
  - Allows detailed models to be tested
- Vehicle – wildlife interactions are a real opportunity to unite engineering and ecology fields

OUTCOMES

The breakout sessions generated a great deal of discussion centered on Pelican ecology, and Pelican mortality on SH-48. The following sections describe some of the most important items mined from the workshop discussions. The TTI moderators have attempted to summarize each item using discussions from both break out groups. Many of the items were raised in both the first and second breakout sessions.

1) The phenomenon of Brown Pelicans experiencing difficulties crossing a road corridor has been observed elsewhere in Texas:

Immediately following the workshop, Beau Hargreaves (USFWS) sent a video to the research team showing Pelicans struggling to cross a road near the Packery Channel, Corpus Christi. The accompanying email is provided below:

> *All,*
>
> *Thanks for catching us up on all the research and initial findings. I wanted to pass this video along from Packery Channel back in 2006. This was caused by very strong southeast winds. As you can see, this bridge has the same type barricades. I would call this a rare event, although through the years since then, I have seen a few dead pelican on the bridge, but nothing like was happening on this particular day. I believe it would likely happen again if the same scenario with high winds, and large abundance of young pelicans trying to feed in the pass were to take place. Maybe your research will lead to better barricade designs for bridges crossing water bodies that are perpendicular to winds which can predictably be above 30 mph with some frequency.*
>
> *I am concerned that barricade modification alone will not solve the problem and that some visual barrier to cause the birds to fly higher will also be needed.*
>
> *I hope you are able to catch the rest of the pelicans you need for the study. I think your efforts so far have shown how important roost sites are for pelicans in the winter. I think construction of additional islands in the lower Laguna that could serve as rookeries as well as winter roost sites might be beneficial; however, this is a very expensive endeavor and one with many environmental issues.*
>
> *Thanks*

The panels below show three frames from the video, and the probable location of the incident. The nature of the crossings is very similar to the footage obtained from SH-48.

Three frames from a video of Brown Pelicans struggling to cross a road ner the Packery Channel, Corpus Christi. The video shows the birds beginning the crossing at a relatively high altitude (approx. 10 to 15 feet above the road), but then shows them gradually klose altitude until they land on the road surface.Note the outer concrete traffic barriers.

Location of the video footage above. Highway 361 across the Packery Channel, Corpus Christi.

2) Regional coastal bird surveys tend to concentrate on breeding birds. The importance of the Laguna Madre Brown Pelican roost sites was not widely appreciated:

The USFWS conduct regular breeding season surveys of birds along the coast. Fewer surveys exist for winter populations. Representatives from the USFWS were interested in the importance of the Laguna Madre roost sites for the overwintering Pelicans (also see the email in point 1).

3) The Bahia Grande roost sites were considered marginal habitat for the Brown Pelican:

The first question we asked each group in breakout session 1 was "why are Pelicans crossing SH-48?" The handouts provided maps of the roost islands in the Bahia Grande and the Laguna Madre. The groups began discussing that the Bahia Grande roost islands might provide good roost sites during storms or if the Laguna Madre roost sites were inundated by tides, but otherwise could be marginal roost sites for the Pelicans. Reasons included that the lagoons are hyper-saline; might be too shallow for plunge diving; or might not contain enough fish. The attendees noted that many birds roosting in the Laguna Madre appeared to forage close to the islands and were relatively immobile on many days. The participants also noted that the Bahia Grande sites may offer extra roost space for birds that stage in the region before migrating to Mexican wintering grounds. The participants noted that the use of the Bahia Grande roost areas may change in the future given the dynamics of the Pelican population and the Bahia Grande restoration.

4) The Laguna Madre roost sites (spoil islands) are gradually eroding:

USFWS personnel informed the group that they regularly survey coastal habitat and the Laguna Madre roost sites are eroding. Part of the agencies remit is to work with the US Army Corps of Engineers to manage and restore coastal habitat. The groups discussed the use of dredging materials from the Brownsville Ship Channel for restoring the islands, but that the problem was complex and involved considerable economic cost, environmental concerns, and interagency cooperation. The erosion was discussed in the context of the present and future availability of roost sites and the future dynamics of the Pelican population.

5) Fire Ant Colonies exist on many of the roost sites:

This issue was raised as a potential factor for the suitability of roost sites. It was reported that fire ant colonies exist on most of the islands and are regularly treated. The TTI research team will follow up on some research on the effects of Fire Ants on ground roosting birds.

6) The economic cost of building new roost sites (in the Laguna Madre is expensive, but roughly commensurate with the cost of replacing barriers:

An idea was raised that building new roost islands could be a more effective strategy than modifying road infrastructure. FHWA representatives suggested that this was possible but expensive (approximately $1 million per acre). The process also involves environmental surveys, for example ensuring that seagrass beds or other sensitive areas are not damaged. However, other attendees also suggested that although expensive, the cost was of the same order of magnitude as the replacement of traffic barriers. The most illuminating aspects of this discussion were: that there are agencies and people involved in managing these coastal areas; that nesting and roost sites are limited; and the management of such areas has the potential to affect multiple agencies (including TxDOT).

7) The attendees were impressed with the amount of research and effort TxDOT are employing to solve the problem:

There was a general agreement that the TxDOT funded research indicated the importance of the Pelican problem (and other environmental issues) to the agency, and that the research is well directed.

8) There was a general appreciation that no solution(s) will eliminate mortality. The goal should be to reduce (and document) the mass mortality associated with cold fronts:

Attendees agreed that eliminating all mortality on SH-48 was unlikely and unreasonable. All attendees agreed that the focus should be on eliminating mass mortality events. Several attendees also suggested that because the mortality is inherently stochastic (and driven by a dynamic Pelican population and variable weather), attempts should be made to track or model the effects of any implementation. In other words, it is important to demonstrate that any mitigation is truly successful (over the long term) and has been cost effective.

9) There was a general appreciation that the research dollars spend on this specific Brown Pelican problem could be usefully offset by publishing the research so that it can be used to address other Brown Pelican or other bird crossing problems –in Texas or elsewhere in the U.S.:

In line with point 7, attendees agreed that the research is of value to other DOTs that may experience bird-crossing problems.

10) Concern was expressed over the cost of replacing the concrete traffic barriers, and whether it would provide a definitive solution to the problem:

Some attendees expressed concern that the barrier replacement is expensive (see also the email in point 1). This opened up informed discussions concerning the novelty of this problem, and the need for research to identify possible solutions. The discussions also highlighted that all attendees clearly understood the trade-offs involved in natural resource management.

11) Some participants suggested that a useful research question would be to address why Pelicans aren't using the Bahia Grande roost sites more often:

Discussions over why the pelicans cross the road inevitably led to the importance of the Bahia Grande roost sites. However, in line with point 3), several attendees wondered why the mortality events do not occur during every cold front.

12) Injured Pelicans are taken to the Brownsville Zoo for treatment. But birds that cannot be fully rehabilitated (to the point that they can be returned to the wild) are euthanized:

A Brownsville Zoo veterinarian was present at the meeting and indicated that whenever possible, Pelicans bought in from the road would be treated and released back in the wild. However, if an assessment suggested that a Pelican could not be rehabilitated to the point where it could be released, it was euthanized. It seems these decisions are mostly based on moral issues of wild animal rehabilitation, additionally it would appear that Brownsville Zoo has no interest in maintaining Pelicans at the zoo for exhibit and is bound by laws that make this problematic. Most of the birds that were successfully rehabilitated were undamaged except for shock. Some discussion also occurred over the handling of birds during downed events.

13) Most attendees were surprised at the cost of implementing the Pelican poles and, to a lesser extent, replacing the outer barriers:

The existing Pelican poles were discussed in terms of both cost and effectiveness. Most attendees were surprised at the cost. There were some discussions that the Pelican poles had reduced mortality at San Martin Lake. Many attendees noted that the San Martin Bridge was naturally less of a risk because there are no roost sites in the lagoon.

14) Attendees acknowledged the influence of the Bahia Grande restoration as a contributing factor to the Pelican mortality. Many were aware of the future restoration efforts (deepening the Gayman channel) and the impact this may have on future Pelican mortality:

Most attendees were aware of the restoration of the Bahia Grande. Fewer were aware of TxDOT's involvement in the restoration which included interagency cooperation (with USFWS) over the design of the bridges during the reconstruction of the corridor. Most participants discussed the dynamics of the Bahia Grande restoration and the potential influence on future mortality. Over time, it is possible that mortality will increase as a result of more birds in the area, and changes in the salinity of the lagoon (leading to more food fish, and more hospitable roost sites). Local scientists (including professors at University of Texas Rio Grande Valley) are monitoring the environmental conditions and fauna in the lagoons. They will be happy to discuss data with the TTI research team.

15) Attendees suggested that traffic control may be an important partial solution to mitigating mortality. They suggested that the findings from the study may help to design and implement such strategies:

Attendees suggested that the data and information from the research may be useful for Intelligent Traffic System. More generally, there was considerable discussion on the speed limit and other traffic control structures. However, most attendees understood the balances TxDOT must make between mobility, safety and the environment.

16) Attendees suggested that the flight paths derived from the GPS tracking studies would be important information for understanding and mitigating mortality:

There were discussions over whether the crossing issue was caused by natural flight paths over water. Most attendees were aware of the improved efficiency of low flight over water (this was also noted in the presentations). All attendees agreed that the GPS tracking data would be important to understand these flight paths.

<u>17) Attendees suggested that more detailed and explicit models of Pelican flight through the wind patterns generated by the road would be essential for understanding and mitigating the mortality:</u>

Discussions surrounding the CFD and wind tunnel results focused on whether a 3-foot difference in the height of affected air will reduce mortality. It was generally agreed that explicit models of Pelican flight would be needed to assess this. Even then, the participants agreed that at some stage the only way to test the effect of modified barriers is by installing them and monitoring the results (see also point 8). As a whole, participants were aware of the risks and difficult decisions involved. Again, participants were impressed by the depth of TxDOTs research, and encouraged them share and communicate the Pelican problem, and the research and implementation it is undertaking to help solve it.

CONCLUSIONS

The TTI researchers consider the stakeholder meeting to have been a success, and a worthwhile endeavor. Specifically, the meeting drew together a broad range of stakeholders interested in the Pelican mortality problem. Many of the attendees traveled significant distances (e.g., from Corpus Christi) to attend the meeting. All attendees were prepared to spend considerable amounts of their time to discuss the issue, emphasizing cross agency interest in the problem. To this end, all attendees were thanked personally for attending (by email), and encouraged to share future thoughts, ideas and collaborations. The TTI team would like to reiterate its thanks to all attendees, and the TxDOT project team for helping to organize the meeting and providing knowledge useful for stimulating the discussions during the breakout sessions.

The workshop was designed to provide the background information attendees needed to make useful contributions during the breakout sessions. The goal of the TTI research team was to limit this information to short presentations, and to use the breakout sessions to promote informed discussions. These discussions were broad and provided a large amount of information to the TTI researchers and the project team members. In the introductions, the TTI researchers made a point to emphasize that TTI are an independent research agency, and that we were interested in openly discussing potential causes and solutions to the problem. During the workshop, TxDOT attendees and other project members discussed the problem freely with the other attendees, and there were no reported conflicts of interest or viewpoints. In general, the TTI research team suggest that the open discussion of the Pelican mortality problem helped to foster cooperation among all stakeholders.

A number of observations and discussions were of particular interest to the TTI researchers:

1) The fact that crossing difficulties have been observed elsewhere in Texas suggests that the research from 0-6970 is potentially transferable. The TTI researchers (and attendees) wonder whether Pelican mortality is occurring undetected at other locations or will occur

in the future. The TTI researchers conclude that the current project should provide methods and results that are potentially transferable to new locations.

2) The discussions on roost islands were particularly insightful. These discussions ranged from the agencies responsible for managing and monitoring these islands, the cost and difficulty of building new islands, and the value of the current Pelican research to other agencies. There was considerable agreement among attendees that the number and location of the roost sites likely plays a large role in understanding why Pelican mortality occurs on SH-48.
3) Overall, the participants were appreciative of TxDOT's research efforts, and the nature of the research. Most participants were scientists involved in environmental resource management and understood the difficulties and complexities of managing wildlife under resource limitations and other societal constraints. There was a general feeling that the key to this management is most likely to come from interagency collaboration, and research. Most participants also noted that research methods into wildlife-transportation interactions are still developing. Many problems (such as Brown Pelican mortality) involve specific species, and/or problems at specific locations. Research methods and implementation are not yet mature enough to provide general, universal and routine solutions. However, given the continuing need for transport, methods to research wildlife-vehicle interactions are likely to become increasingly important.

APPENDIX II. FIELD METHODS

This appendix describes the field methods for data collection in the daily and seasonal movements of Brown Pelican in the Bahia Grande Wetland Complex (BGWC) study. A major objective of the study is to determine the seasonal and daily movements of pelicans in the BGWC including the location of overnight roost sites, loafing and feeding areas, major flight paths, seasonal migrations, breeding sites, and the size of the local pelican population. This was accomplished through the use of a global positioning system (GPS) study and a mark-resight study using GPS-tagged pelicans and pelican banding. Field activities involved locating and capturing pelicans, collecting physiological and morphological data from captured pelicans, and equipping select pelicans with GPS equipment or leg bands. The field methods used for these activities are described below.

PERMITTING AND COORDINATION

Before conducting field activities, TTI obtained required state and federal permits and coordinated field activities with the Texas Department of Transportation (TxDOT) and the Texas Parks and Wildlife Department (TPWD). Permits included Federal Bird Banding Permits obtained from the U.S. Geological Survey (USGS) Patuxent Wildlife Research Center's Bird Banding Laboratory and Scientific Research Permits from the TPWD. All field activities were reviewed and approved by Texas A&M's Institutional Animal Care and Use Committee (IACUC). All field activities and reporting were conducted following the conditions of the state and federal permits.

PELICAN CAPTURE

Pelican capture is the first step for both the GPS study and the mark-resight study. Capture locations were identified using previously known pelican locations, through recommendations and coordination with local sources, and exploration by researchers throughout the study area. Pelicans were captured from known roosting or loafing sites at various publicly accessible locations around the BGWC and at locations where permission for access or entry was obtained. The study team also captured pelicans at opportunistic locations such as crashed-landed pelicans on SH 48. Many were captured at the locations used in the mark-resight surveys since these sites are frequently populated pelicans. These mark-resight locations are described later in this appendix.

Pelican capture was conducted by TTI researchers, local biologists from TPWD and the Coastal Bend Bays & Estuaries Program, Texas Master Naturalist, graduate students, and other volunteers trained to assist. The pelicans were captured using noose mats, noose lines, cast nets, or hand-captured when downed on SH 48. Juvenile and unhealthy pelicans were immediately released back into the wild. All capture, handling, and attachments (GPS units and leg bands) were approved by the IACUC. The average handling time for a pelican was 27 minutes.

Figure 122. Researcher Laying Out a Noose Mat for Pelican Capture.

PHYSIOLOGICAL AND MORPHOLOGICAL DATA COLLECTION

Upon capture, the TTI research team collected physiological and morphological data. The physiological data includes taking blood, fecal, and feather samples. The morphological data includes weighing the birds and measuring their wings, legs, and other body parts. Two blood samples were collected from the pelicans outfitted with the GPS (immediately after capture and before release) and one blood sample was collected from the pelicans outfitted with a band.

Physiological and morphological data were also collected from pelicans that were downed on SH 48—included pelican mortalities—when possible or practicable. For example, during cold fronts, the data was not collected when downed pelicans regained flight, were chased away by volunteers, or were rescued and taken to the opposite side of the road away from the researchers.

GPS FIELD METHODS

GPS field activities consist of locating and capturing pelicans and then attaching the GPS transmitters to the pelicans as securely and efficiently as possible. Once the transmitter is fitted to the pelican, it is released, and the transmitter begins tracking the pelican. The GPS data from the pelicans will be collected remotely via cellular network and direct radio communication. Following is a description of the GPS attachment considerations, attachment techniques, and the GPS unit.

GPS Transmitter Attachment

The TTI research team conducted extensive research on GPS transmitters and the possible adverse effects they might have on Brown Pelican behavior and flight before attaching to any wild pelicans for our study. Lamb et al. (2017) observed the effects of transmitter attachment on captive and wild Brown Pelicans and found increased preening and decreased resting behavior (less than two hours) directly after attachment in captive birds but found no behavioral changes for wild Brown Pelicans post-capture. Lamb et al. (2017) and Walter et al. (2014) examined nesting behavior following transmitter attachment and results from this research show that longer handling times could influence nest abandonment. To decrease the possibility of any adverse effects, Dr. Lamb emphasized the importance of minimizing handling time.

Transmitters were attached using a backpack-style harness. Teflon ribbons were used to make the straps for the attachment, and all knots were made above the ribbon so that there were no parts that would rub uncomfortably on their body (Figure 123). All harnesses and knots were glued to be secure and to make sure that no parts would slip, break, or possibly inhibit flight. Techniques were taught and practiced at the Dallas Zoo on captive pelicans with Dr. Juliet Lamb, who has used these attachment techniques on 90 brown pelicans. The GPS units are anticipated to fall off the pelicans after approximately 1-2 years.

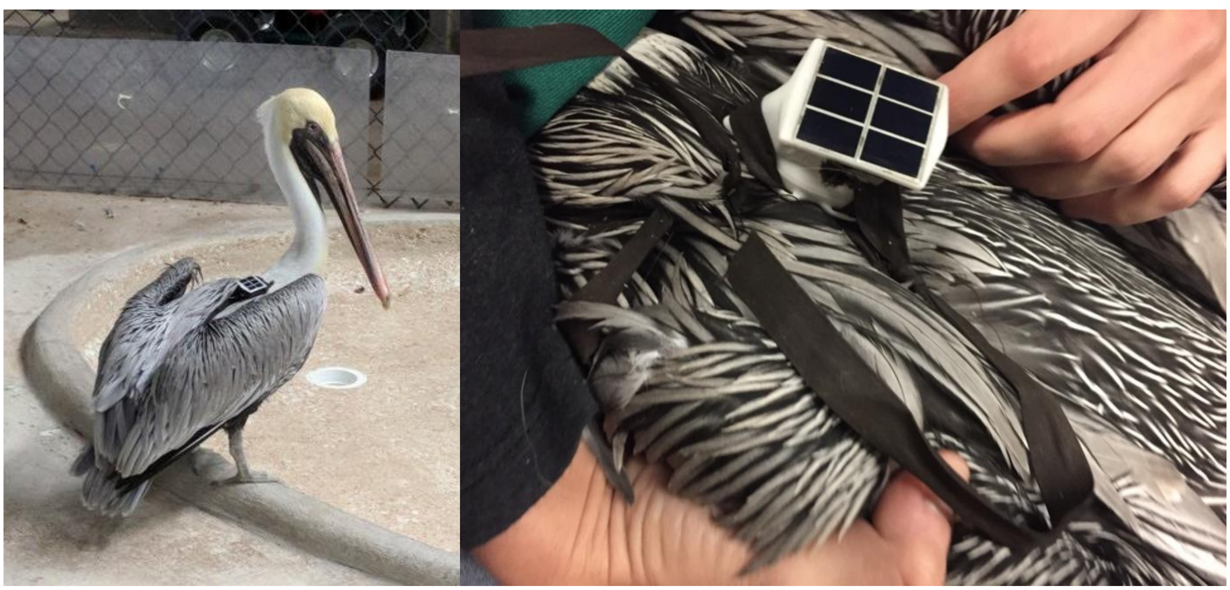


Figure 123. Backpack-Style Transmitter Harness Attached to a Captive Brown Pelican at Dallas Zoo for Practice. The right image shows the Teflon ribbon being tied into a backpack-style harness.

The TTI research team, along with trained biologists and volunteers, captured and attached GPS transmitters to 35 brown pelicans in the BGWC from December 2017 through February 2019 (Figure 124). All releases were conducted at the point of capture. All captures and GPS attachments were conducted following State and Federal permits using the techniques described above.

Figure 124. Image Showing a GPS-Tagged Pelican (center) within the BGWC.

Transmitter Specifications

The transmitters used are Milsar GSM Radio Tag-M9, which are capable of both cellular network (GSM) and direct radio communication. These GSM tags are much lighter than the standard satellite tags that have previously been used on Brown Pelicans and other birds. These tags weigh just 18.5g, around 0.09 percent of brown pelican body weight (2,000-5,000 grams) at the low end of pelican weight. This is much less than the recommended threshold of three percent of body weight for tag attachment. Furthermore, the manufacturer 3-D printed a brown pelican species–specific casing that will streamline the units for plunge diving and flight by molding them to the back of the pelican. The Tag-M9 has a solar panel to provide continual charging during long-term deployment. They come equipped with an accelerometer, temperature, and pressure sensors, and can record speed and location (latitude and longitude). It also provides “geofencing” technology so that researchers could set up zones around bridges and roads where a higher frequency of GPS points is desired to record fine-scale movement.

MARK-RESIGHT FIELD METHODS

Mark-resight experiments involve capturing a sample of a population and marking them in some way (for example with bands) so that individuals can be readily identified in the field. The marked individuals are then released, and surveys are undertaken to resight the marked individuals. The resulting resight data consists of a history of sightings (resights) associated with pelicans banded during the study. This section describes the field methods used in this study.

Banding Pelicans

Pelicans were captured for the mark-resight survey from December 2017 through February 2019. Pelicans were banded using federal leg bands and colored plastic bands following guidelines established by the USGS Bird Banding Laboratory. All releases were conducted at the point of capture. Figure 125 shows the field personnel banding a pelican and examples of the bands used in the study.

Figure 125. Banding Pelicans at Pampano Park (see Figure 126 and Figure 130 for location) and a View of the Colored Plastic Band and the Metal Federal Band.

Mark-Resight Survey Locations

Mark-resight surveys were performed at several locations that were regularly visited throughout the study period (February 2019 through January 2021). The surveys were focused on the area of the frequent pelican mortalities along SH 48 where the roadway is adjacent to the Bahia Grande near the Carl Gayman Bridge and Restoration Channel. Mark-resight surveys were also conducted at selected locations throughout the BGWC study area as shown in Figure 126.

Figure 126. Location of Each Study Site Used in Mark-Resight Surveys.

The SH 48 survey area and each of the survey locations in Figure 126 are described in detail in the *Mark-Resight Surveys on SH 48* and *Mark-Resight Survey Site Descriptions* sections of this appendix, respectively.

General Mark-Resight Survey Procedures

During each resight survey, the researcher recorded the location or station of the survey, survey date, the number of adult and juvenile pelicans, the numbers of banded and un-banded pelicans, the three-digit band code, and the number of pelicans that were present but whose legs could not be seen. Band codes were observed with binoculars or a spotting scope. Bands are most easily seen while the pelican is standing up, but the observer could also see if the pelican is banded by searching its legs while it is laying down. For pelicans farther away, researchers could usually determine that a flying bird is a brown pelican by its silhouette, color, flight patterns, and behavior. Figure 127 shows banded pelicans from the study, which have maroon bands with white digits. Brown pelicans from other studies (with different bands and digit colors) were be found in the study area as well.

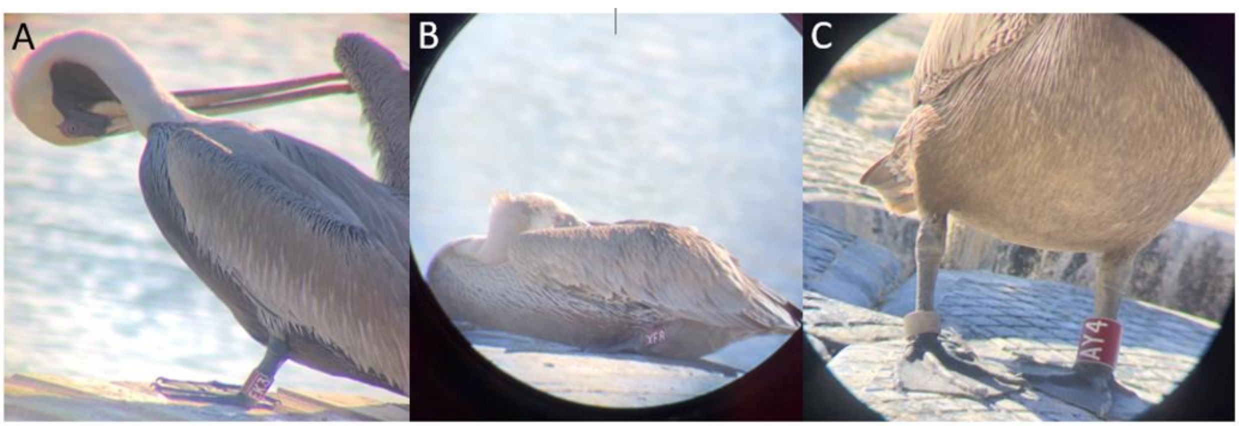


Figure 127. Band EK3 Is Visible on the Left Leg of an Adult Pelican (A). Band XE8 Is Visible on the Left Leg of a Sitting Pelican while Lifting Its Body (B). Band AY4 Is Visible on the Left Leg and a Federal Band Is Visible on the Right Leg of the Pelican (C).

Mark-Resight Surveys on SH 48

Mark-resight surveys on SH 48 were performed at specific locations (survey stations) in 15- or 30-minute intervals throughout the day from dawn to dusk. SH 48 along the Bahia Grande was divided into several sections to cover the entire area adjacent to the Bahia Grande. Early in the project, the survey sections of SH 48 were determined by four wooden poles that were erected as markers to create four survey stations (Figure 128). However, when transmission poles were constructed along SH 48, the wooden poles were removed, and the new transmission poles were used to indicate the limits of the new survey sections. The previous wooden poles and new transmission lines were used as guides for estimating flight heights. The field data was converted to ensure consistency among survey periods (pre- and post-transmission line installation).

Figure 128. Annotated Aerial Photograph of the Original SH 48 Resight Survey Stations along the Laguna Madre. Yellow markers indicate the location of the survey poles and their identification number. The green markers indicate the approximate field observers' position (survey station) used during the surveys. Transmission poles installed after the start of the field activities were used similarly in later surveys.

The SH 48 surveys were conducted as described in the previous section while recording additional information important to pelican crossings over SH 48 and pelican mortality. The researchers also recorded an estimate of how high the pelican flew above the roadway, flight direction, if they are flying over or below the top of old marker poles/new transmission lines, the section of SH 48 they are flying over, and the time. Figure 129 illustrates a section of SH 48 and a few of the variables that were recorded for each pelican crossing.

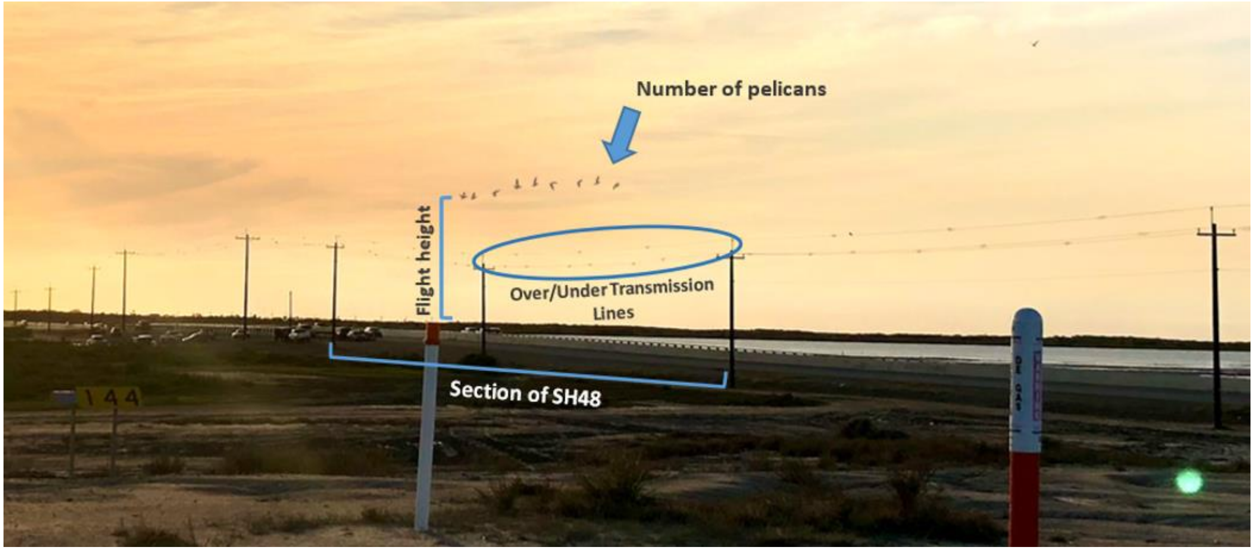


Figure 129. Image of Pelicans Crossing SH 48. Variables—such as flight height, the section of SH 48 crossed, if over or under transmission lines, and the number of pelicans—were recorded in each resight survey (view to the west).

Pelicans that were downed and pelicans that were hit by cars were recorded during the SH 48 surveys. During troubling cold fronts when volunteers group together to save downed pelicans, TTI researchers also recorded pelicans that were downed but chased off by volunteers or were caught and taken to the other side of the road.

Mark-Resight Survey Site Descriptions

The following section provides descriptions of the sites used for the mark-resight surveys not performed along SH 48. The locations for these sites are shown in Figure 123. The coordinate system (latitude and longitude) presented for the location of each site are in WGS_1984_World-Mercator in decimal degrees.

Pompano Park

Pompano Park (26.074853°, -97.215019°) is a public boat ramp area in "The Fingers" area of Port Isabel. The park also has a fish cleaning station that is often used by fishermen. Pelicans often congregate by the cleaning station when fish are being cleaned and scraps being thrown. It is surrounded mostly by residential properties, as well as a hotel and condo. Many of these properties have boat slips and the frequent fishing in the area is likely a reason for a large number of pelicans here year-round. There are also ample posts, piers, and roof ledges that pelicans loaf on (Figure 130). They are usually found on two roof ledges across from the park, as well as on the docks and posts.

Figure 130. Aerial Image of Pompano Park (A). Metal Roofs across from Pompano Park That Pelicans Loaf On (B-C). Docks at Pompano Park That Pelicans Loaf On (D).

Quik Stop

Quik Stop (26.072903°, -97.214150°) is a bait shop in Port Isabel by Highway 100. Shrimp and bait fisherman use their water access to dock their boats and clean and pack bait. Across from Quik Stop, there are several boat slips and a local business where fishing guides use a fish cleaning station. The fish cleaning station and frequent shrimp boats and bait boats are a large draw for the pelicans that loaf here. The pelicans are usually only present when fish and bait scraps are being thrown or if they see an active boat or fisherman that they associate with food. If these activities are not occurring, pelicans will fly to a different location. The pelicans can usually be seen on the metal roof of the marina across from Quik Stop or in the water waiting for scraps from fishermen (Figure 131).

Figure 131. Aerial image of Quik Stop (A). Image of Pelicans Congregating near Fish Cleaning Station in the Marina across from Quik Stop. Pelicans Also Loaf on the Roofs (B).

Jim's Pier

Jim's Pier (26.103547°, -97.169625°) is a long stretch of piers facing the Laguna Madre in South Padre Island. It has many boat slips and a boardwalk useful for observing pelicans. There are restaurants and a fishing store nearby, as well as a fish cleaning station on the pier. This pier consistently has a very large number of pelicans loafing here, as it has large stretches of deck and many posts without posts caps that prevent pelicans from sitting on them (Figure 132). Although there is a fish cleaning station, few fishing or cleaning activities take place at this location. Pelicans will loaf at this site without a food incentive and will likely stay all day if not disturbed.

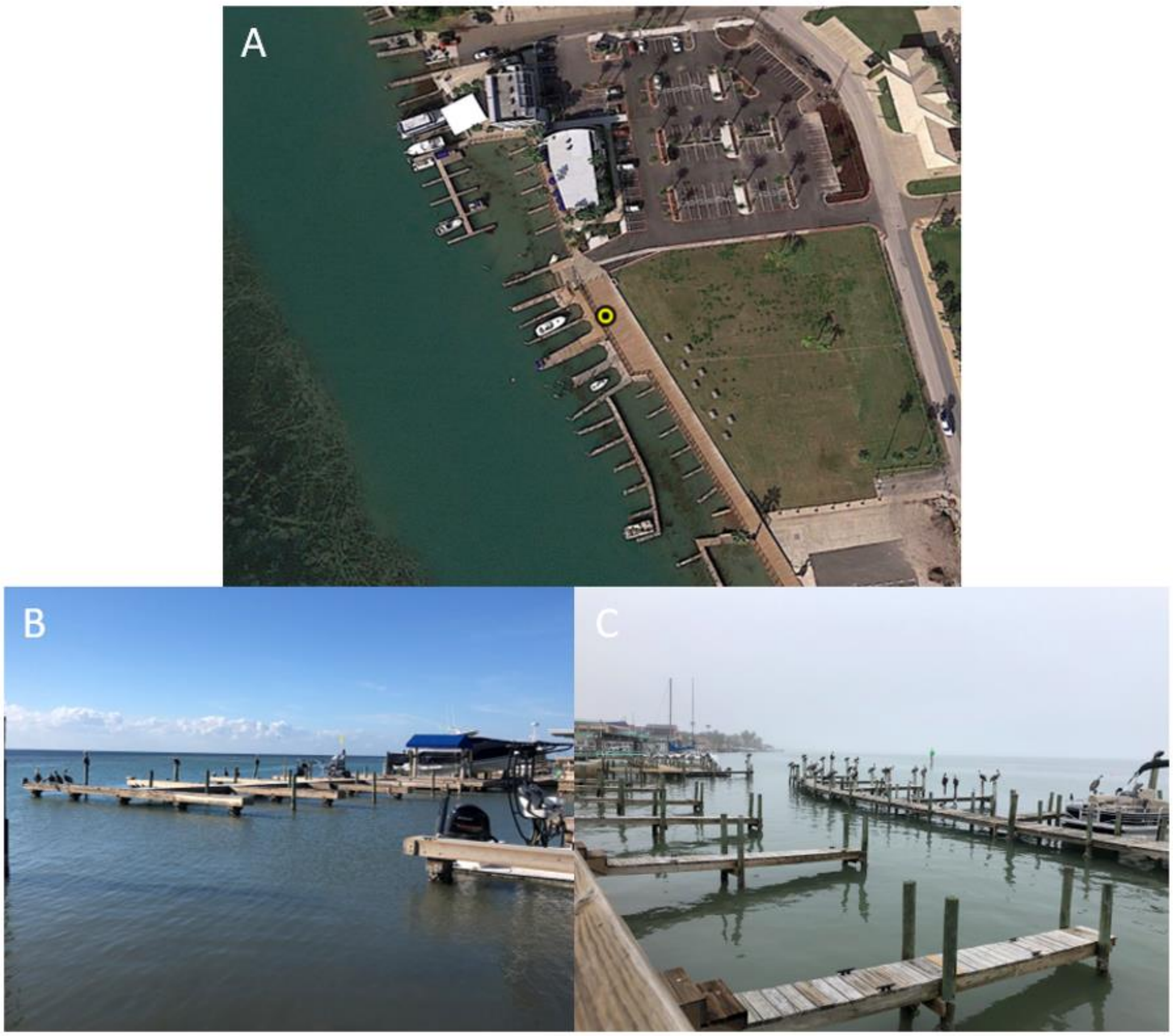


Figure 132. Aerial Image of Jim's Pier (A). Pelicans Loafing on Docks and Posts at Jim's Pier (B-C).

Sea Ranch

Sea Ranch (26.076397°, -97.164675°) is a restaurant located on the Sea Ranch Marina in South Padre Island. It is surrounded by many boat slips and several businesses that provide bay fishing services and wildlife tours. The fish being brought in and cleaned is likely a reason for the many pelicans loafing in this marina. The pelicans observed for this study were consistently observed on the boat slip decks and posts across from the restaurant (Figure 133). Here, the pelicans do not appear to be disturbed by the many boats that come through every day. The pelicans would sometimes fly away if fish were being cleaned at a nearby business but would usually come back to this loafing spot.

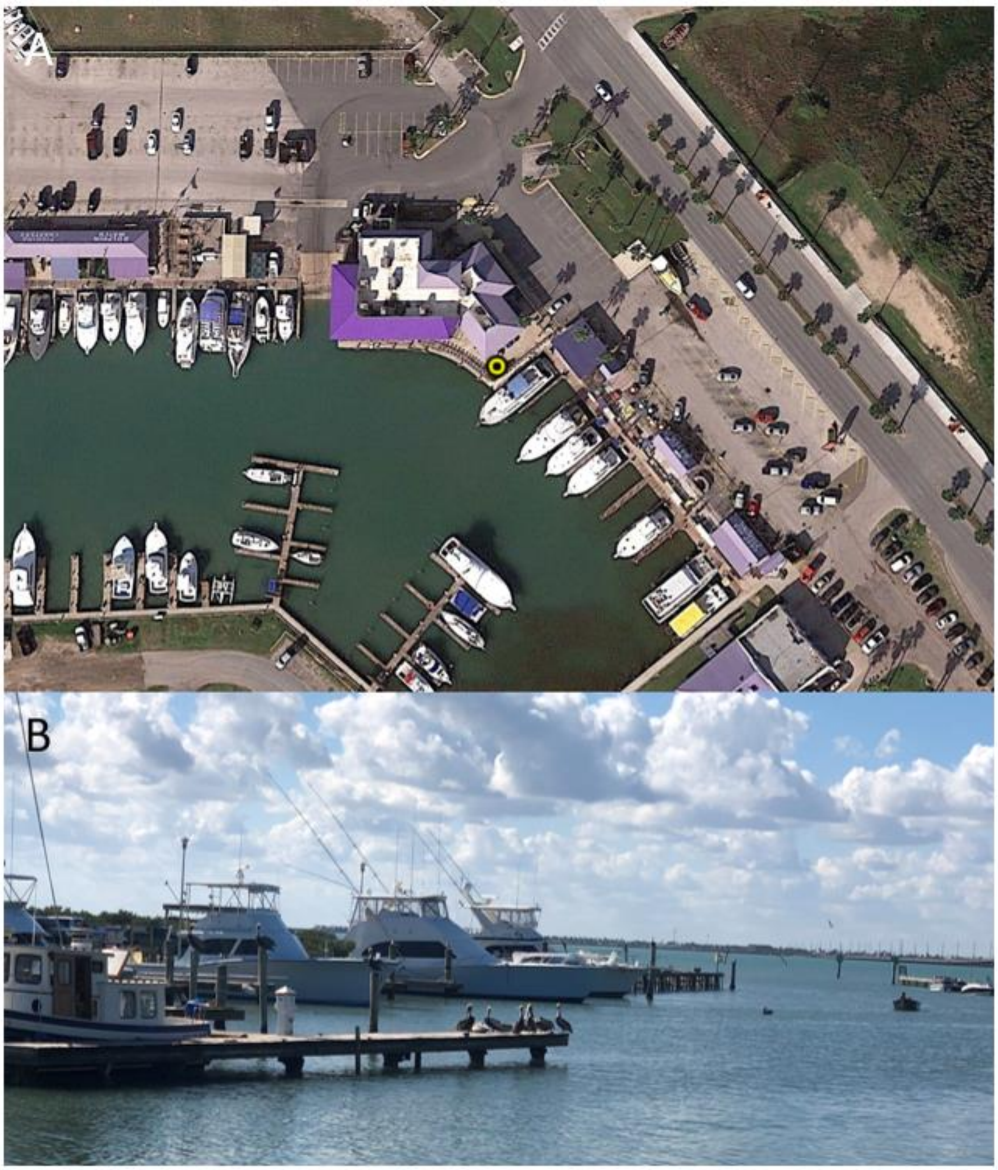


Figure 133. Aerial Image of Sea Ranch (A). Image of Pelicans Loafing on Docks and Posts at the Marina across from Sea Ranch Restaurant (B).

Parrot Eyes

Parrot Eyes (26.129117°, -97.171728°) is a restaurant located in South Padre Island with close access to the Laguna Madre. Several fishing charters rent out boat slips at Parrot Eyes and the fish cleaning station appears to be busy daily. This is a major attraction for the pelicans here, as most of them will fly or swim towards the cleaning station and wait for scraps. When fish cleaning is not occurring, pelicans will loaf on docks or the floating dock cubes that float around the property (Figure 134). Watersport rental activities based out of the restaurant (jet skis, paddle boarding, and kayaking) do not seem to affect pelican behavior substantially. When there are cold fronts, many pelicans will congregate in tight packs at the residential lawn and bulkheads across from Parrot Eyes.

Figure 134. Aerial Image of Parrot Eyes (A). Image of Pelicans Loafing across from Parrot Eyes Property on Bulkheads and Lawn (B). Pelicans Loafing on Different Floating Docks near Fishing Charter Boat Slips (C-D).

Isla Blanca Boat Ramp

Isla Blanca Boat Ramp (26.068789°, -97.162783°) is at the southernmost tip of Isla Blanca Park in South Padre Island and is situated near the Laguna Madre and the Brownsville Ship Channel. Fishermen use the fish cleaning station located on the boat ramp, which is an attraction for the nearby pelicans. Pelicans will loaf on the several wooden posts and signs in the water but most often be seen loafing or plunge-dive fishing in the water (Figure 135). Large numbers of pelicans in tight packs are observed during cold fronts loafing in shallow water on a nearby beach. Most pelicans do not stay at this site for long periods and are constantly moving between water and posts. The continuous passage of boats through this area might disturb the pelicans, which may be a reason for their constant movement.

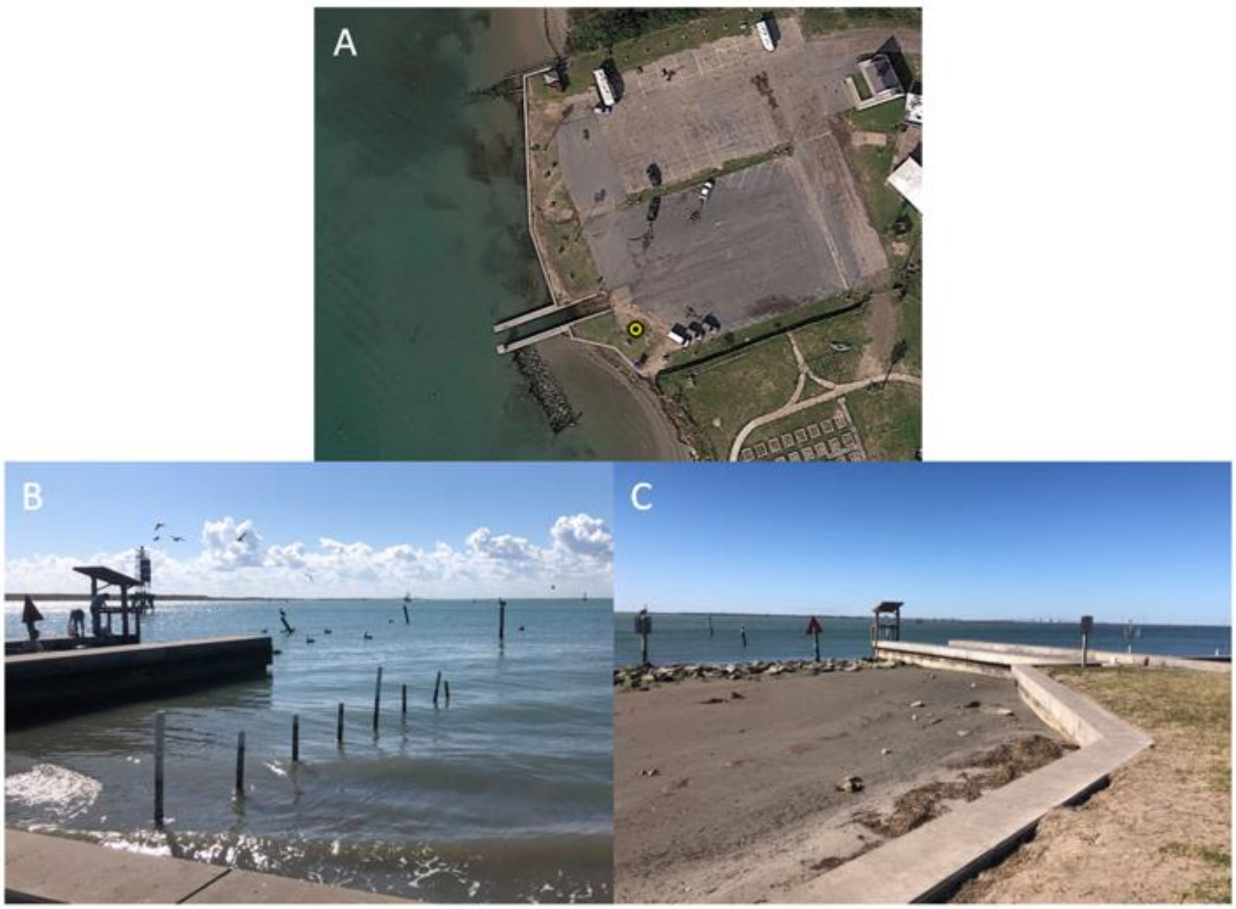


Figure 135. Aerial Image of Isla Blanca Boat Ramp (A). Image of Fish Cleaning Station at the Boat Ramp Where Pelicans Congregate in Water (B). Image of Posts and Signs That Pelicans Loaf On (C).

Dolphin Docks

Dolphin Docks (26.077756°, -97.205739°) is a local business in Port Isabel adjacent to the Queen Isabella Causeway providing boat excursions such as wildlife watching and bay fishing. This business has a cleaning station on the dock. When fish are being cleaned, pelicans congregate at the cleaning station or in nearby waters to wait for scraps. A large number of wooden posts and docks provide ample space for the many pelicans that loaf here throughout the day (Figure 136). The large boats docking and leaving several times a day does not appear to disturb the pelicans at this site.

Figure 136. Aerial Image of Dolphin Docks (A). Image of Pelicans Loafing on Docks and Posts (B).

Queen Isabella Inn

Queen Isabella Inn (26.077164°, -97.204317°) is a hotel located in Port Isabel facing the Laguna Madre. Near the boat ramp, there are many docks and several posts that the pelicans will use to loaf (Figure 137). This hotel does not currently use this site for fishing or boat rentals, so there is no food incentive for pelicans at this location. This site is extremely variable in the number of pelicans that use it, with some days having no pelicans and other days having tight congregations of them. As this site is very close to Dolphin Docks, this may be used by pelicans when they are disturbed there.

Figure 137. Aerial Image of Isabella Inn (A). Image of Pelicans Loafing on Boat Slip Docks and Posts (B).

Jaime Zapata Memorial Boat Ramp

Jaime J. Zapata Memorial Boat Ramp (26.001986°, -97.297931°) on Highway 48 provides boaters access to San Martin Lake to the north and the Brownsville Ship Channel to the south. Pelicans will often use this area for fishing in the shallow waters or to loaf on the nearby wooden posts that are scattered on both sides of the highway (Figure 138). Since the San Martin Lake, the Brownsville Ship Channel, and the nearby Bahia Grande are used as roosting sites, pelicans may be using this site to temporarily loaf, and do not seem to spend long amounts of time here.

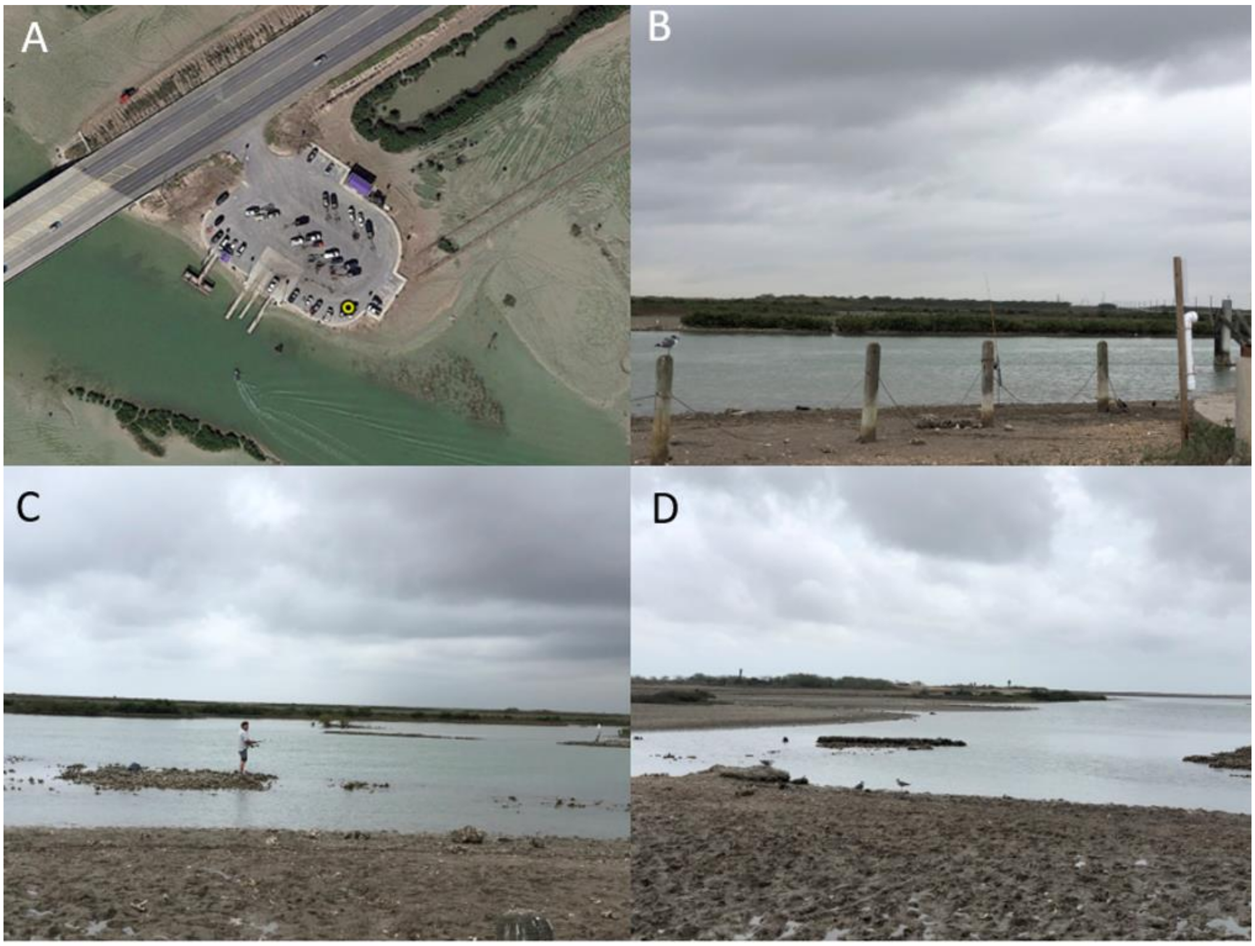


Figure 138. Aerial Image of Jaime Zapata Memorial Boat Ramp (A). Images of the Surrounding Water and Tidal Flats around Jaimie Zapata Memorial Boat Ramp Parking Lot Where Pelicans Will Loaf Nearby (B-D).

Pirate's Landing

Pirate's Landing (26.078955°, -97.206626°) is a restaurant and pier located in Port Isabel facing the Laguna Madre and is adjacent to the Queen Isabella Causeway. There is a long pier that is used for fishing as well as a dock for tour boat services. Pelicans can be seen loafing on posts surrounding the docks as well as the fish cleaning station that is often used by fishermen (Figure 139). Many pelicans can also be observed loafing on the bridge supports under the causeway.

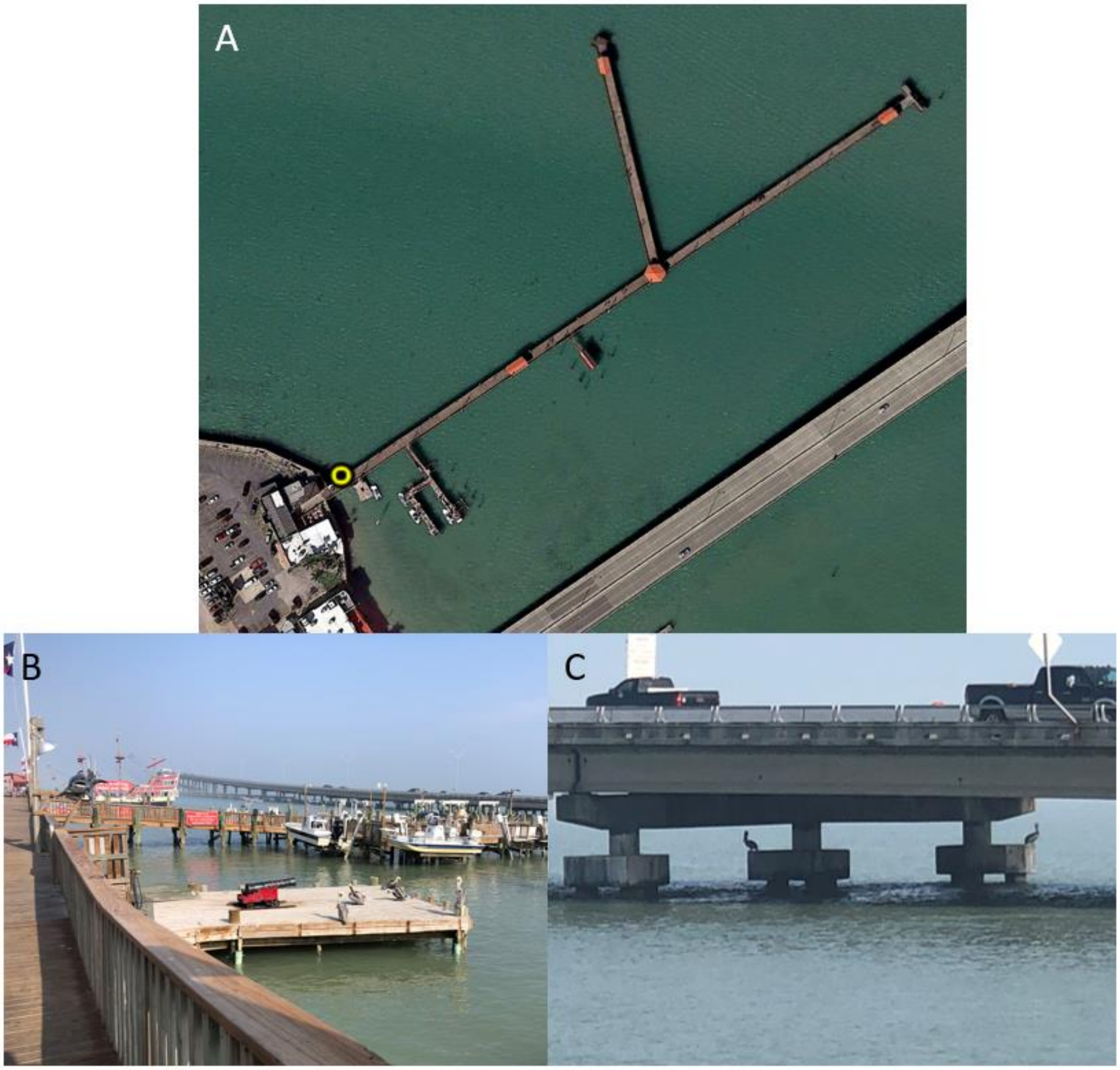


Figure 139. Aerial Image of Pirate's Landing (A). Image of Pelicans Loafing on Docks (B). Image of Pelicans Loafing on Causeway Supports (C).

Pier 19

Pier 19 (26.077840°, -97.170299°) is a restaurant located in South Padre Island on the Laguna Madre between the Queen Isabella Causeway and the Brownsville Ship Channel. The restaurant has a long pier with several boats that are used for fishing charters and other excursions. Pelicans can be seen loafing on docks and wooden posts (Figure 140). Pelicans often wait in the water for fishing excursions to bring scraps to nearby cleaning stations.

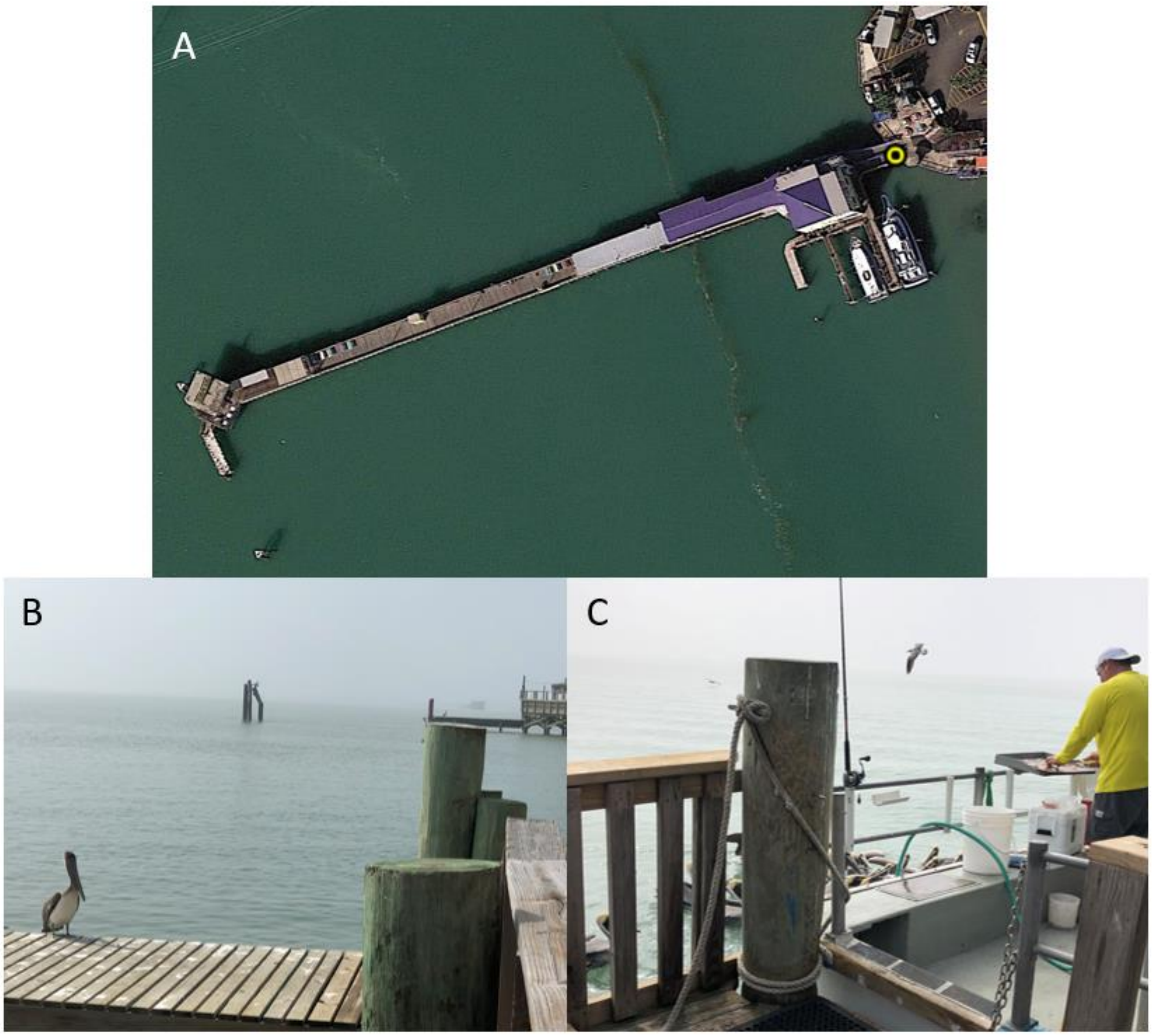


Figure 140. Aerial Image of Pier 19 (A). Image of Pelican Loafing on the Dock (B). Image of Pelicans Waiting in the Water for Scraps from Cleaning Station (C).

U.S. Coast Guard Station

The U.S. Coast Guard Station (26.072954°, -97.166168°) located in South Padre Island has a few coast guard vessels for law enforcement and search and rescue operations. There are a few concrete docks and supports that pelicans will loaf on (Figure 141). There is likely no food incentives from the Coast Guard station, so pelicans probably use this site since it is nearby other popular sites like the Sea Ranch, Pier 19, and the Isla Blanca Boat Ramp. This also appears to be a good location for plunge-dive fishing.

Figure 141. Aerial Image of U.S. Coast Guard Station and Surrounding Docks (A).

Swing Bridge

The Swing Bridge (26.071249°, -97.201878°) located in Port Isabel connects the City of Port Isabel to the Long Island and the residential Long Island Village (Figure 142). This channel connects the Laguna Madre and the Brownsville Ship Channel and has several small islands that pelicans loaf on. There are also several poles and other structures that pelicans will often be observed loafing on. This is also a site that pelicans could use between the many residential properties and businesses that they may receive fish scraps from.

Figure 142. Aerial Image of Port Isabel Swing Bridge (A). Image of Pelicans Loafing on the Island near Swing Bridge (B).

APPENDIX III. DAILY AND SEASONAL MOVEMENTS OF INDIVIDUAL GPS-TAGGED PELICANS

This appendix summarizes the individual daily and seasonal movements of each of the 35 pelicans that were tracked using global positioning system (GPS) devices. Specifically, this appendix describes the geographic range covered by each pelican during data collection, a brief description of the pelican's movements within the Bahia Grande Wetland Complex (BGWC) study region, a description of the migration patterns and characteristics for the individual pelican (for the pelicans that did migrate), and a description of the high site fidelity locations (i.e., pelican nesting sites) for the pelicans that nested. The data collected from each pelican are presented in separate sections identified by tag number in the chronological order in which the pelicans were tagged.

Each section begins with a map illustrating the full geographic range of the GPS observations for the individual pelican. The red dots in the geographic range maps show the location of each GPS data point collected for the pelican during the study. This is followed by the pelican's capture date, capture location, the number of days that GPS observations were collected (days active), and an indication of whether the pelican had migrated away from the BGWC study region. Each section includes a description of the pelican movements within the BGWC and presents a map showing the GPS observations within the study region.

For the 16 pelicans that migrated (Pelicans 163A, AA3A, F7A1A, 0B3A7, 523A, B6A3, 963A, A65A, 443A7, A45A, A05A, BCA6, A25A, A15A, BBA6C, and BAA6), an additional subsection is included describing seasonal migration. The subsection includes a figure showing the seasonal movements of the specific pelican through two or more of the 15 distinct coastal locations (zones) through the duration of the project. The coastal zones (Figure 143) run approximately south to north and were selected based on key habitat areas within the full geographic range of the pelicans. Reducing the GPS data into these zones simplifies each pelican's movements to allow for an easy comparison of the migration timing and destination relative to the other pelicans in the study. Refer to Chapter 2 of the report for additional detail.

Site fidelity was exhibited by four of the GPS-tracked pelicans (Pelicans 163A, 0B3A7, BCA6, and BAA6) suggesting nesting locations for breeding. For these four pelicans, the potential nesting locations are annotated on the geographic range map to show its generalized location, and on the seasonal-movement map to illustrate when the pelican was demonstrating site fidelity, followed by a brief discussion.

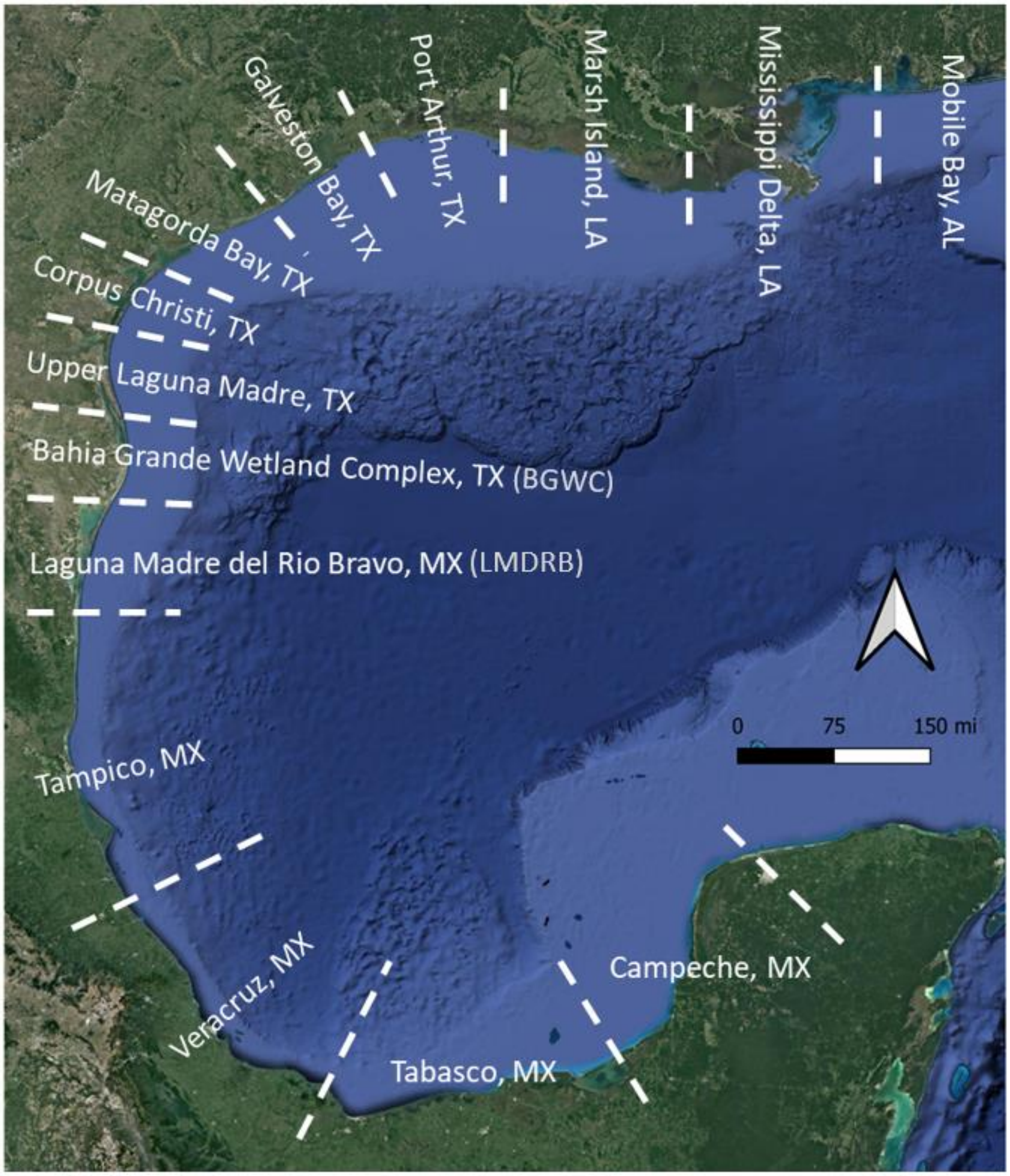


Figure 143. Map Showing the Coastal Zones Used to Define the Pelican Migration Patterns. The points represent selected habitats frequently used by pelicans as intermediate stops during their migration or as seasonal destinations. The lines between the points indicate the boundary between each coastal zone.

A full discussion of daily and seasonal pelican movement as a population and a description of the coastal zone map can be found in Chapter 2 of the report.

PELICAN F7A1

Date Caught:	December 18, 2017
Location Caught:	Pompano Park, Port Isabel, TX
Days Active:	18
Migration:	No

Pelican F7A1 was captured on December 18, 2017, at Pompano Park in Port Isabel and was active until January 14, 2018, providing 858 geo-locations. This individual was in the study for 18 days and did not leave the BGWC study region while it was tracked (Figure 144).

Figure 144. All GPS Observations of Pelican F7A1.

Movement in the BGWC Study Region

The main clusters of activity for this individual are on the Laguna Madre roost island, in and near Port Isabel, and smaller clusters near Laguna Vista and the southern point of South Padre Island. Roosting was almost exclusively on a spoil island in the Laguna Madre, although it also occasionally roosted on islands in the Port Isabel Channel. Daily movements were mainly from the roost island in Laguna Madre to these other listed areas for loafing.

PELICAN 163A

Date Caught:	January 10, 2018
Location Caught:	Parrot Eyes Marina, South Padre Island, TX
Days Active:	1,026+
Migration:	Yes

Pelican 163A was captured on January 10, 2018, at the Parrot Eyes Marina on South Padre Island and provided GPS data until January 2021 (Figure 145).

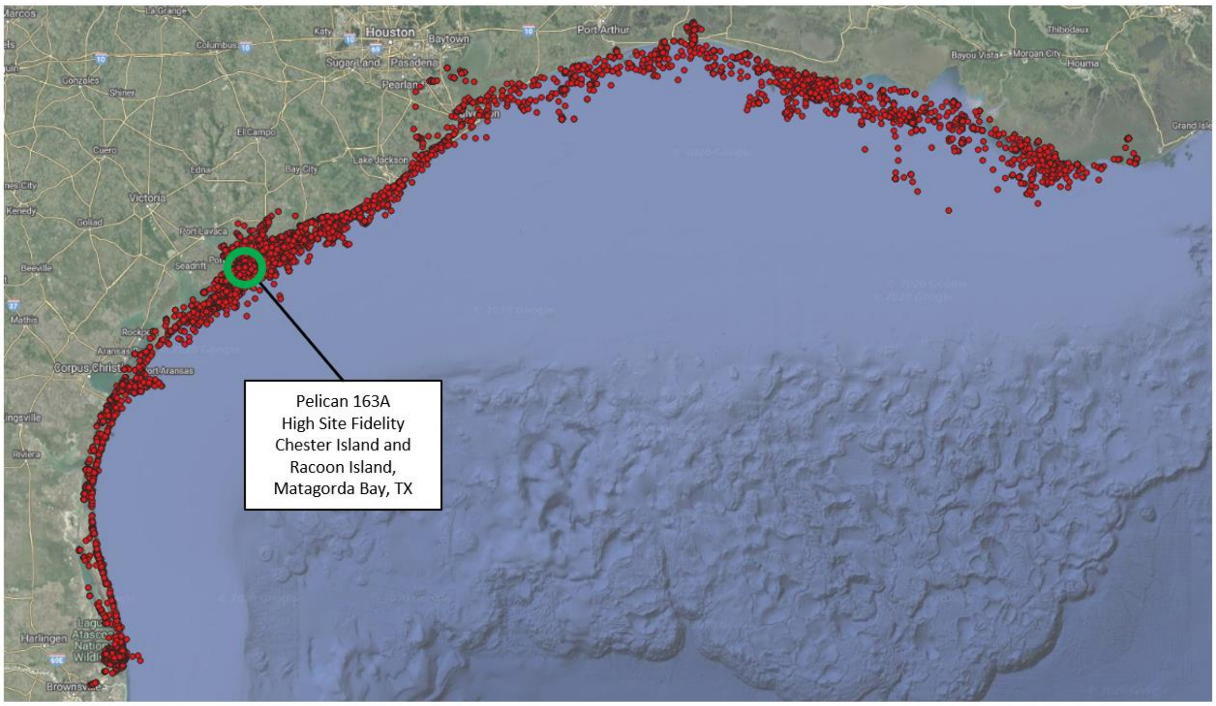


Figure 145. All GPS Observations of Pelican 163A. High Site Fidelity Was Exhibited in Matagorda Bay, Texas.

Movement in the BGWC Study Region

Within the BGWC study region, Pelican 163A mainly traveled between the main roost island in Laguna Madre and loafed mainly on the western coast of South Padre Island in a basin/inlet of multiple docks. This individual also loafed a few times in Port Isabel, Laguna Heights, Laguna Vista, Bahia Grande, and on shrimp fishing docks near the west end of the Brownsville Ship Channel (BSC). Pelican 163A spent a few nights roosting in Bahia Grande and a few nights roosting at the end of the BSC (Figure 146).

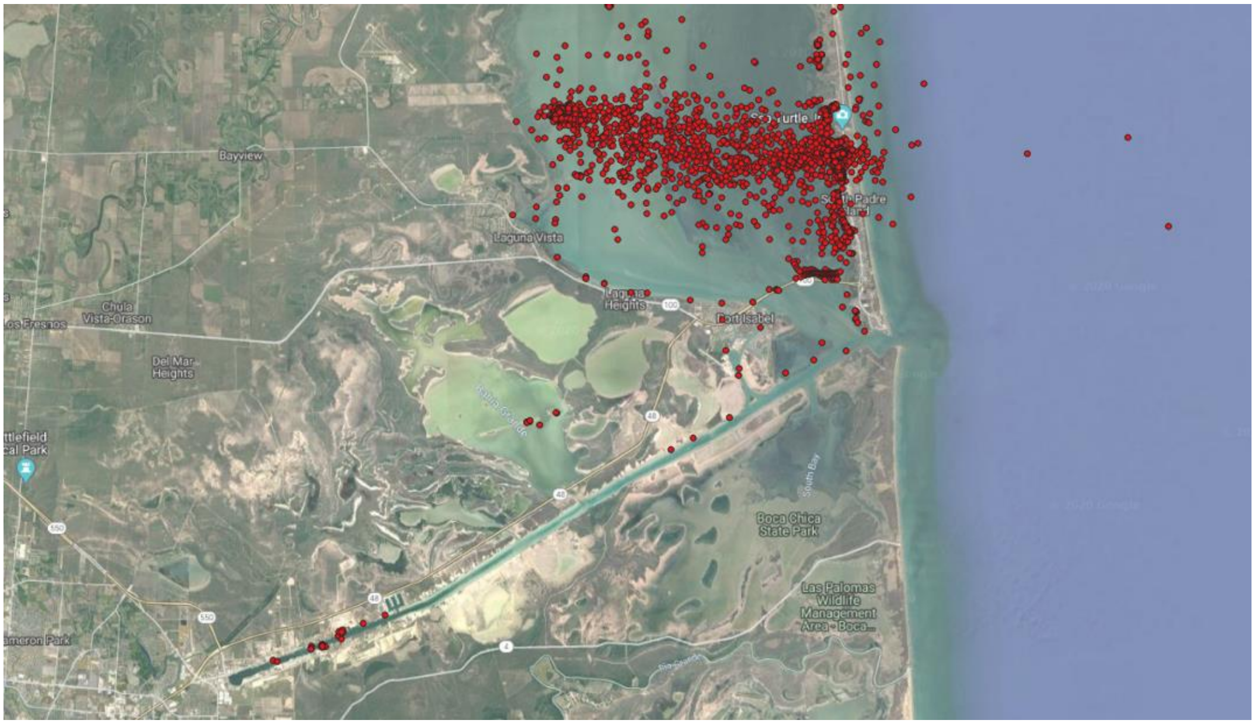


Figure 146. Pelican 163A Activity within the Bahia Grande Study Region.

Migration and Site Fidelity

Pelican 163A completed three years of annual seasonal migrations:

1. Its 2018 northbound migration was from March 17, 2018, to June 1, 2018, and the individual traveled non-continuously. The return migration was from August 26, 2018, to November 9, 2018, and travel was also noncontinuous.
2. Its 2019 northbound migration occurred from March 14, 2019, to August 15, 2019, with noncontinuous travel. The second southbound migration was from September 9, 2019, through September 16, 2019. On this southbound migration, the pelican stopped briefly to roost overnight before continuing south.
3. Its 2020 northbound migration began on March 11, 2020. The return migration (southbound) began in approximately September 2020. However, 163A made several stops along the coast before returning to the BGWC study region at the beginning of November 2020.

This individual's full range spanned from Caillou Bay off the southern coast of Louisiana to the BGWC study region in Texas. Figure 147 illustrates a generalized seasonal migration pattern for Pelican 163A relative to coastal zones. The red and gray lines correspond to the location (y-axis) and date (x-axis) of each migrating pelican tracked during the study. The red line represents the migration pattern of Pelican 163A. The gray lines show the seasonal movement of the other pelicans in the study for a relative comparison. Figure 143 provides an overview of the coastal zones.

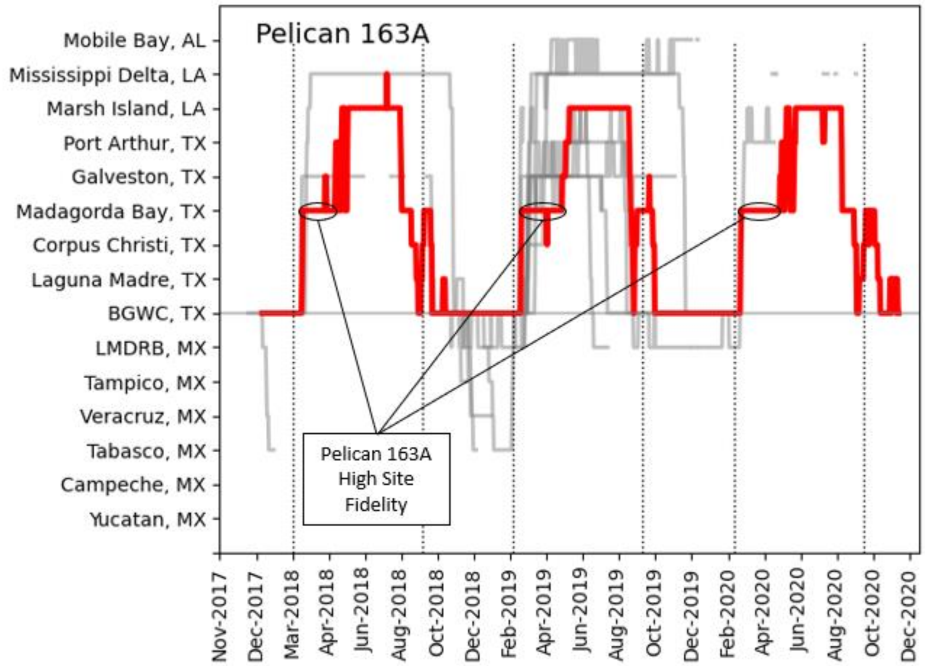


Figure 147. Seasonal Migration Pattern for Pelican 163A by Coastal Zone over Time. The y-axis represents each coastal zone (Figure 143). The horizontal line represents the BGWC study region. The vertical lines represent March 1st and September 1st of each year during the survey. The red line represents the migration pattern of Pelican 163A. The gray lines show the seasonal movement of the other pelicans in the study. High site fidelity (potential nesting sites) were exhibited within Matagorda Bay, Texas coastal zone. The circles indicate three general time ranges that high fidelity was observed.

Five of the six recorded migrations were noncontinuous, and the individual stopped extensively for weeks to months in several locations along the migration route. Major stops during this migration were Matagorda Island and Bays, especially Chester Island within the bay; Port Aransas; small islands near Rockefeller Wildlife Refuge and Pelican Island, LA; Racoon Island in Caillou Bay, LA; and Timbalier Island, LA.

During the 2018 breeding period, Pelican 163A showed high site fidelity and returned mostly continuously to roost on Chester Island within Matagorda Bay from March 20, 2018, to May 10, 2018; in a location near Pelican Island (town) from June 18, 2018, to July 1, 2018; and Racoon Island from July 4, 2018, through August 26, 2018 (Figure 147). This pelican likely nested on Chester Island and/or Racoon Island. Daily movements were also localized and a short distance from these islands. These are indicators that breeding likely occurred during this time frame.

Afterward, this individual migrated back to the BGWC study region with extensive stops at Chester Island in Matagorda Bay, TX from August 31, 2018, to September 13, 2018. The pelican then continued to Port Aransas and stopped for nine days before reaching the destination of Laguna Madre roost island the BGWC study region on September 22, 2018. Pelican 163A continuously traveled between Chester Island and the Bahia Grande region until mid-November, when it stopped moving between the two locations and only locally traveled within the Bahia Grande region. This limited activity between the Laguna Madre roost island and the western coast of South Padre Island continued through mid-March when this individual began its northbound migration.

Pelican 163A began its 2019 northbound migration on March 14, 2019. It reached Chester Island in Matagorda Bay, TX on March 16, 2019, and stayed through May 19, 2019, with high site fidelity. The individual then traveled semi-continuously to Racoon Island in Caillou Bay, LA. It arrived at Racoon Island on June 5, 2019 and stayed mostly continuously through September 9, 2019. The pelican likely nested on Chester Island and Racoon Island during the 2019 breeding season.

Migration back south was continuous with few short stops, unlike previous migrations. This individual began migration on September 9, 2019 and reached the BGWC study region and end of migration on September 16, 2019. After reaching the Bahia Grande region, the individual traveled between Chester Island and the study region through October 21, 2019. BGWC movement activity was similar across wintering seasons. The pelican traveled heavily between the dock basin on South Padre Island and the roosting island in Laguna Madre. However, this individual also moved between the BGWC study region and Chester Island in Matagorda Bay until mid-fall in both wintering seasons.

On March 11, 2019, Pelican 163A began its 2020 migration northbound. It reached Chester Island on March 12, 2020 and stopped there until May 9, 2020. The pelican then made travels up to Calcasieu Lake, reached May 19, 2020, and returned south to Chester Island (Matagorda Bay, TX) on May 21, 2020. On May 23, 2020, the pelican then traveled north again to islands off the coast of Pelican Island (Galveston, TX) and a few days later returned to the Chester Island region.

PELICAN A7A0

Date Caught: January 10, 2018
Location Caught: Pompano Park, Port Isabel, TX
Days Active: 19
Migration: Yes

Pelican A7A0 was captured on January 10, 2018 and stopped transmitting on January 29, 2018. This individual was in the study for 19 days. Major clusters of observations and areas of activity occurred in the Bahia Grande study region; El Mezquital, MX; Laguna Madre, MX; Rio Soto La Marina, MX; Laguna de Tamiahua, MX; Rio Tonala estuary, MX; Grassland Lagoon, MX; and interestingly, up small rivers inland off of the Coatzacoalcos River in Veracruz, MX (Figure 148).

Figure 148. All GPS Observations of Pelican A7A0.

Movement in the BGWC Study Region

This pelican did not exhibit much activity within the Bahia Grande study region. Roosting and other activities were concentrated in and around Port Isabel and occasionally near southern South Padre Island and in Laguna Madre (Figure 149). This individual only stayed in the study region for 1-2 days.

Figure 149. Pelican A7A0 Activity within the Bahia Grande Study Region.

PELICAN 0B3A

Date Caught:	January 14, 2018
Location Caught:	Jim’s Pier, South Padre Island, TX
Days Active:	30
Migration:	No

Pelican 0B3A was captured on January 14, 2018 and provided its last recording on February 13, 2018. 0B3A remained entirely within the BGWC study region for 30 days (Figure 150).

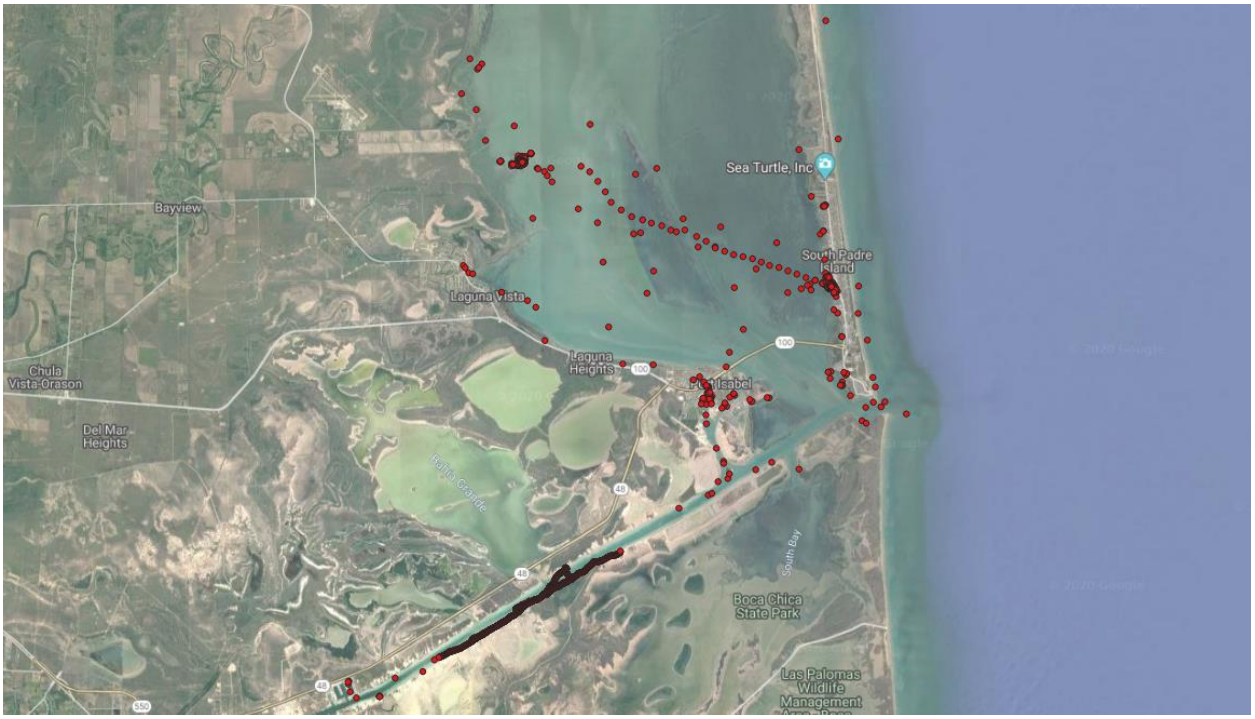


Figure 150. All GPS Observations of Pelican 0B3A.

Movement in the BGWC Study Region

This individual mainly traveled between South Padre Island, Port Isabel, and spoil islands in Laguna Madre. It also occasionally traveled down the BSC and along the coasts of South Padre Island. Pelican 0B3A roosted exclusively on a spoil island in the Laguna Madre. 0B3A loafed at docks, points, and structures near Port Isabel, and similar sites along the western coast of South Padre Island. Pelican 0B3A also spent a day at the Shrimp Basin and other areas of the BSC.

PELICAN AA3A

Date Caught:	January 31, 2018
Location Caught:	Isla Blanca Boat Ramp, South Padre Island, TX
Days Active:	330
Migration:	Yes

Pelican AA3A was captured on January 31, 2018, at Isla Blanca Boat Ramp at the southern end of South Padre Island. Expired on December 27, 2019 and provided 14,940 GPS data locations. This individual was in the study for 330 days. Major clusters of observations and areas of activity were in the Bahia Grande study region, Corpus Christi, and Galveston Bay (Figure 151).

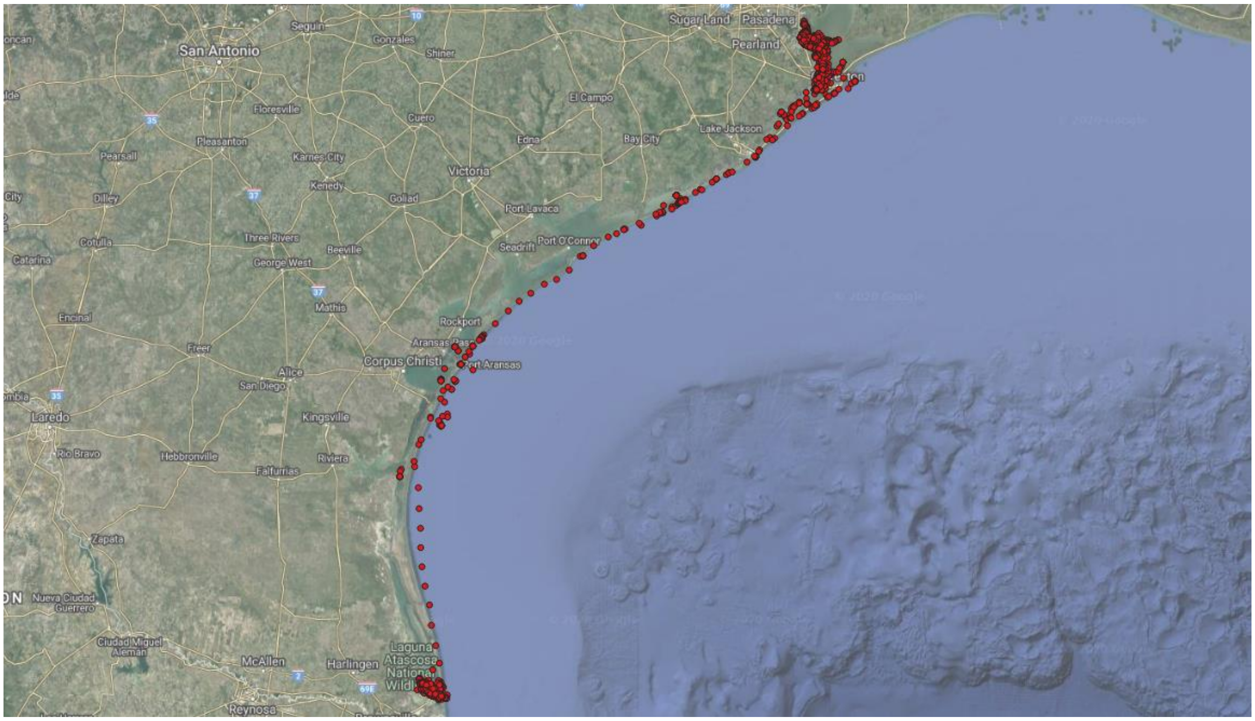


Figure 151. All GPS Observations of Pelican AA3A.

Movement in the BGWC Study Region

Within the Bahia Grande study region, this pelican mainly moved between Laguna Madre, the southern point of South Padre Island, Port Isabel, and Laguna Vista. Most of the daily movement was between the main roost island in Laguna Madre and southern South Padre Island. This individual crossed the Queen Isabella Causeway daily flying between foraging and roosting sites (Figure 152). This pelican almost exclusively roosted in Laguna Madre and very rarely roosted along the coast of South Padre Island and the opening of the BSC.

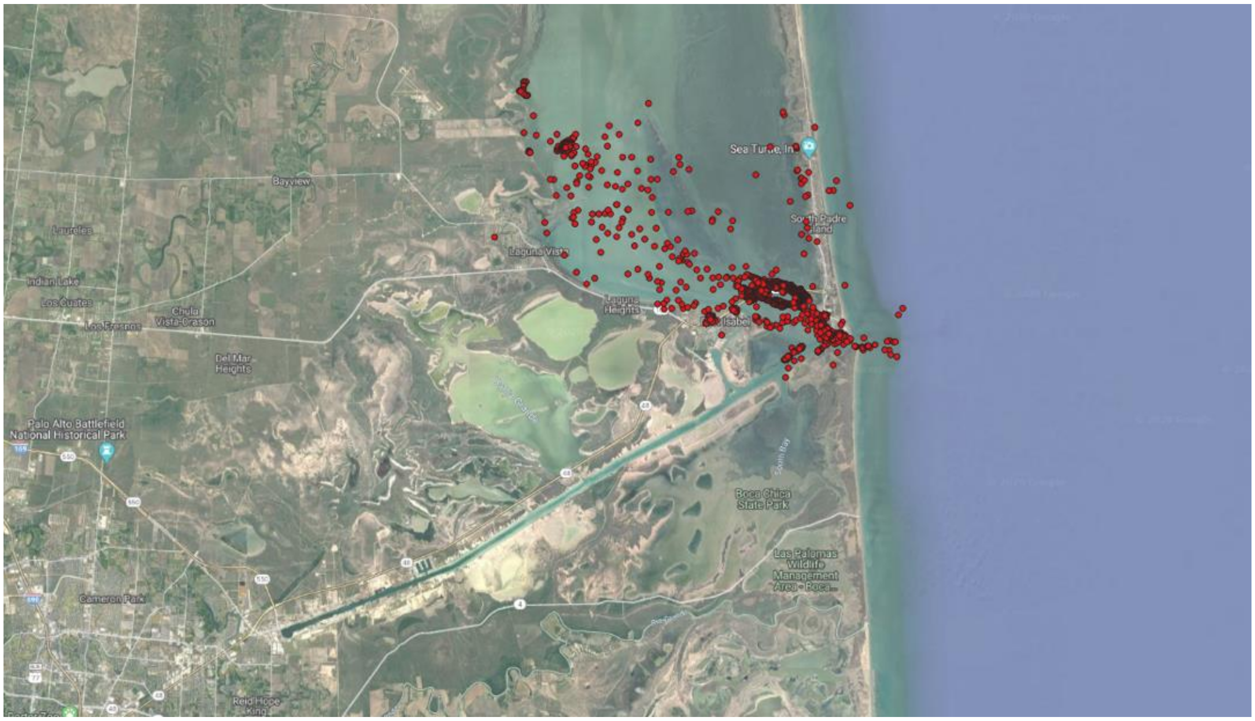


Figure 152. Pelican AA3A Activity within the Bahia Grande Study Region.

Migration

Figure 153 illustrates a generalized seasonal migration pattern for Pelican AA3A relative to coastal zones. Pelican AA3A began continuous migration north on March 16, 2018, only stopping for nights to rest, and reached Galveston bay on March 19, 2018. Within Galveston Bay, roosting occurred predominately on North Deer Island with high site fidelity from March 20, 2018, through June 26, 2018, but this individual also occasionally roosted on oil rigs and anthropogenic structures within the bay.

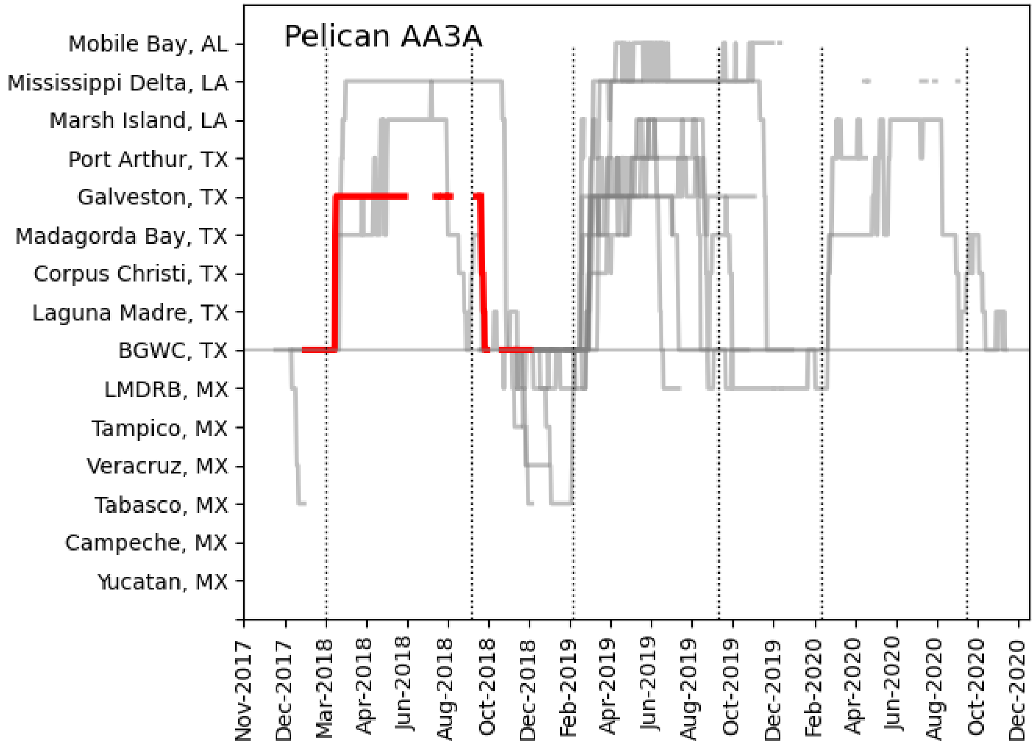


Figure 153. Seasonal Migration Pattern for Pelican AA3A by Coastal Zone over Time. The y-axis represents each coastal zone (Figure 143). The horizontal line represents the BGWC study region. The vertical lines represent March 1st and September 1st of each year during the survey. The red line represents Pelican AA3A. The gray lines show the seasonal movement of the other pelicans in the study.

This individual began migration south on October 17, 2019 and traveled continuously until reaching the BGWC study region on October 22, 2019. Movement patterns were like those from the previous winter, mostly concentrated between the roost island in Laguna Madre and the southern point of South Padre Island.

PELICAN F7A1A

Date Caught:	February 12, 2018
Location Caught:	SH 48
Days Active:	71
Migration:	Yes

Pelican F7A1A was captured on February 12, 2018 and stopped transmitting on April 24, 2018. This individual was in the study for 71 days. Major clusters of observations and areas of activity were in the Bahia Grande study region; Playa Bagdad, MX; in Laguna Madre near Port Mansfield, TX; Corpus Christi Bay; Port Aransas; and Calcasieu Lake, LA (Figure 154). However, observations occurred along the coast from Playa Bagdad, MX to Caillou Bay, LA, indicating that this pelican migrated slowly with multiple stops.

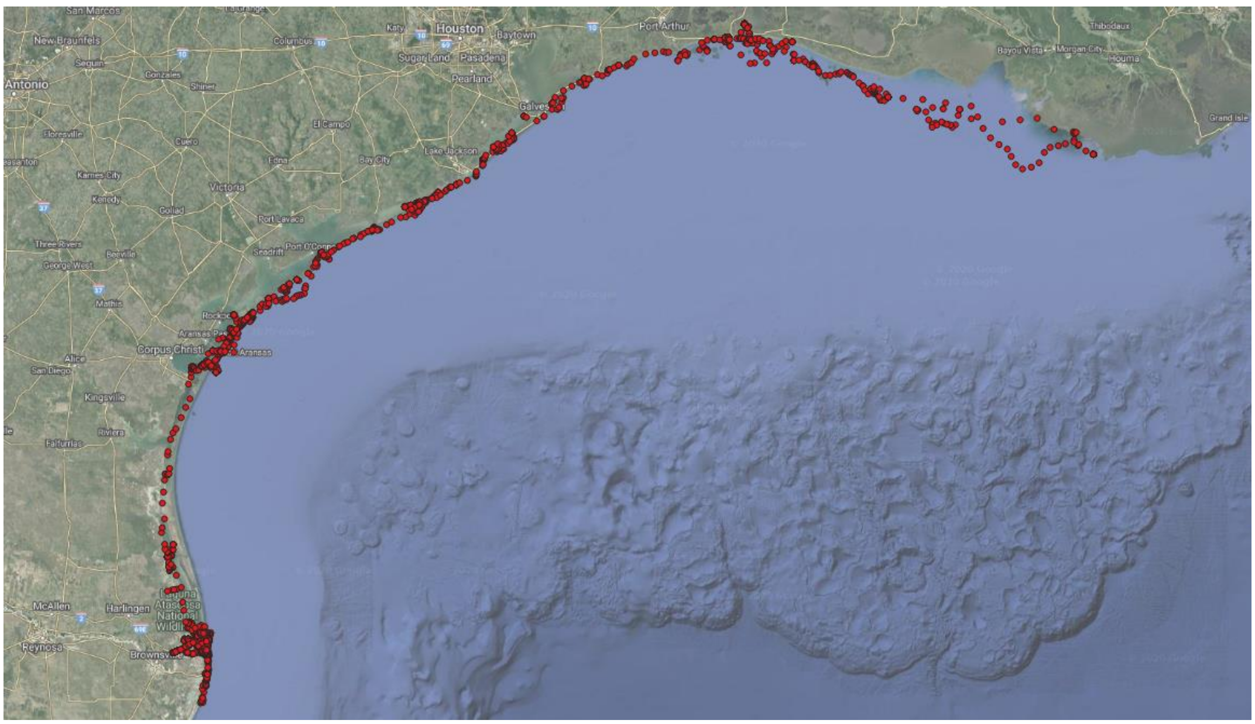


Figure 154. All GPS Observations of Pelican F7A1A

Movement in the BGWC Study Region

Within the Bahia Grande study region, Pelican F7A1A traveled between the roost island in Laguna Madre, Bahia Grande islands, Port Isabel Channel islands, and Port Isabel Side Channel islands and docks, on the Padre Island-Brownsville Ship Channel (PI-BSC) island[28]; located where the east side of the Laguna Madre meets the north side of the BSC), and along the southern tip of South Padre Island, as well as down the coast to Playa Bagdad (Figure 155). This

[28] The Padre Island-Brownsville Ship Channel island is located southeast of Port Isabel where the east side of the Laguna Madre meets the north side of the BSC.

individual also traveled a short distance inland of the Rio Grande. Pelican F7A1A foraged in the Brownsville Ship Channel and loafed and roosted on the easternmost and westernmost islands in the Bahia Grande. It also used sites in Port Isabel and South Padre Island for foraging and roosted on Laguna Vista spoil island (located in the Laguna Madre about one mile northeast of Laguna Vista). The individual flew from south to north over SH 48. During winter, before departure for the breeding grounds, the pelican moved an average of 44.0 km/day (range: 16.5-102.5 km/day).

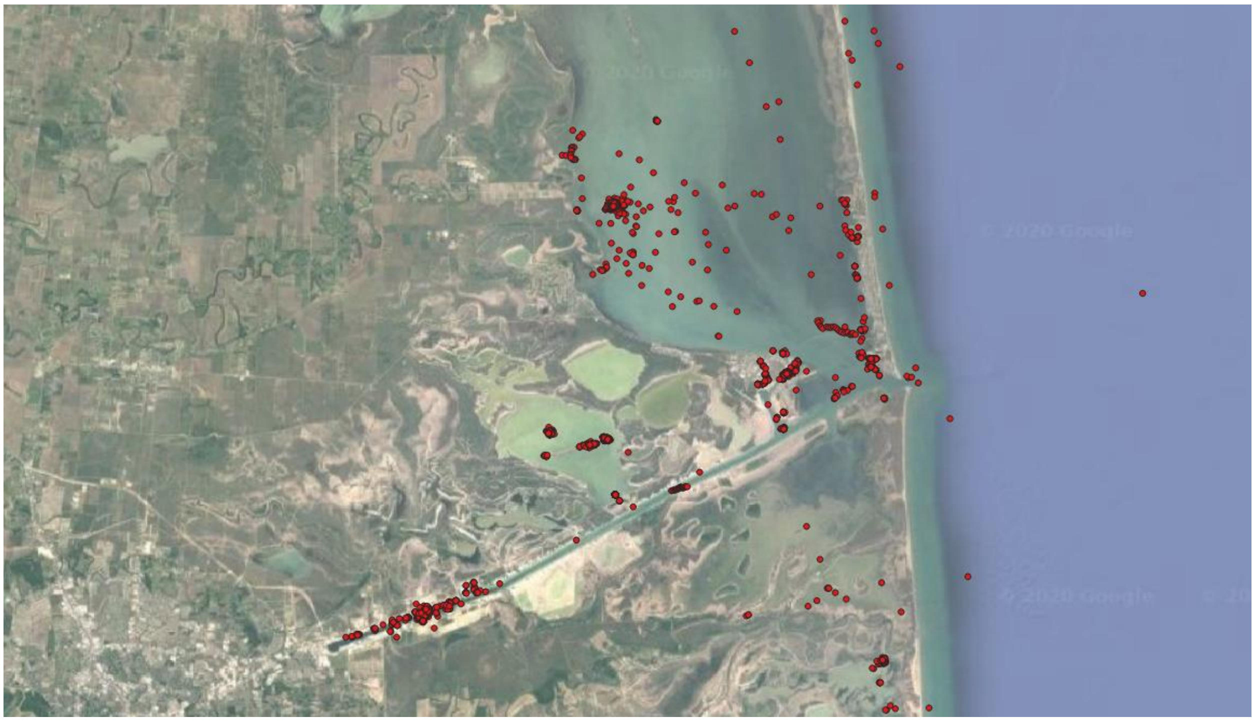


Figure 155. Pelican F7A1A Activity within the Bahia Grande Study Region.

Migration

Observations occurred along the coast from Playa Bagdad, MX to Caillou Bay, LA, indicating that this pelican migrated slowly with multiple stops. Figure 156 illustrates a generalized seasonal migration pattern for Pelican F7A1A relative to coastal zones.

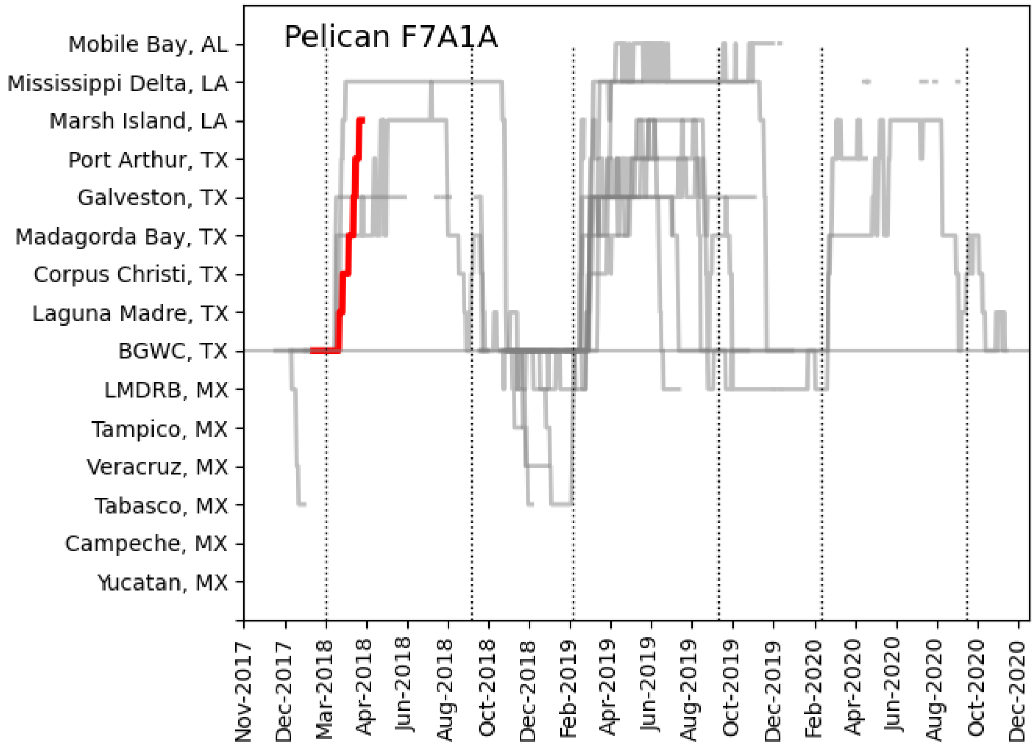


Figure 156. Seasonal Migration Pattern for Pelican F7A1A by Coastal Zone over Time. The y-axis represents each coastal zone (Figure 143). The horizontal line represents the BGWC study region. The vertical lines represent March 1st and September 1st of each year during the survey. The red line represents Pelican F7A1A. The gray lines show the seasonal movement of the other pelicans in the study.

Pelican F7A1A began migrating north on March 22, 2018, to the coast of Louisiana near Calcasieu Lake. This individual stopped multiple times for several days on its migration north and had relatively shorter migration distances (see Appendix II). During the entire time, the pelican has been tracked it has traveled approximately 4,200 km and most of the movement occurred during diurnal hours. The transmitter has not made a connection since June 12, 2018.

PELICAN 0B3A7

Date Caught:	February 22, 2018
Location Caught:	Port Isabel Park Center, Port Isabel, TX
Days Active:	339
Migration:	Yes

Pelican 0B3A7 was captured on February 22, 2018, and remained active until January 27, 2019, (providing 21421 locations). Pelican 0B3A7 was monitored for 339 days in total. This included a seasonal migration from the BGWC study region to its summer habitat in the Mississippi Delta. This individual's range spanned from the Chandeleur Sound off the eastern coast of Louisiana to El Mezquital, MX, a small town on the coast of Laguna Madre y Delta del Rio Bravo, MX (Figure 157).

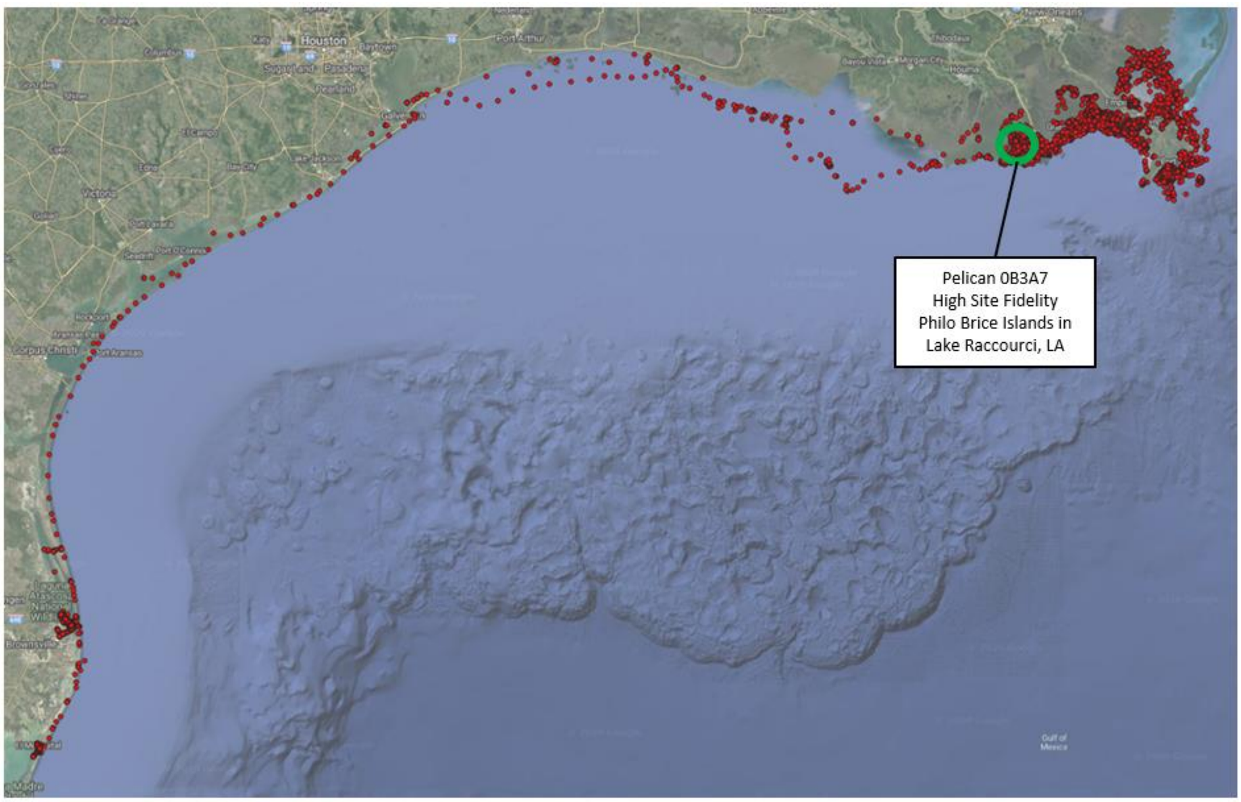


Figure 157. All GPS Observations of Pelican 0B3A7.

Movement in the BGWC Study Region

Within the Bahia Grande study region, Pelican 0B3A7 mainly traveled between the main roost island in Laguna Madre and Port Isabel islands and docks (Figure 158). 0B3A7 also loafed on the western coast and southern tip of South Padre Island, the Bahia Grande, as well as loafing and moving along the Brownsville Ship Channel.

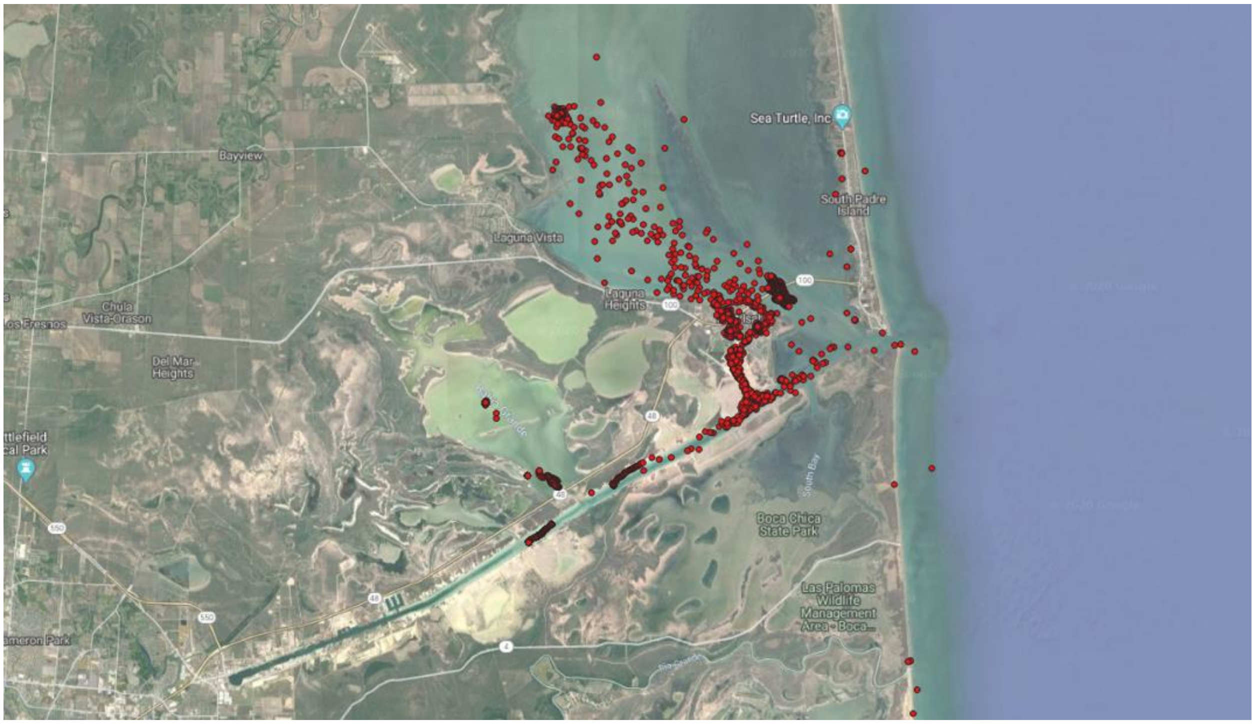


Figure 158. BGWC GPS Observations of Pelican 0B3A7.

Migration and Site Fidelity

Pelican 0B3A7 completed a northbound migration from March 23, 2018, through April 1, 2018, and a southbound migration from November 16, 2018, through November 23, 2018. Figure 159 illustrates a generalized seasonal migration pattern for Pelican 0B3A7 relative to coastal zones.

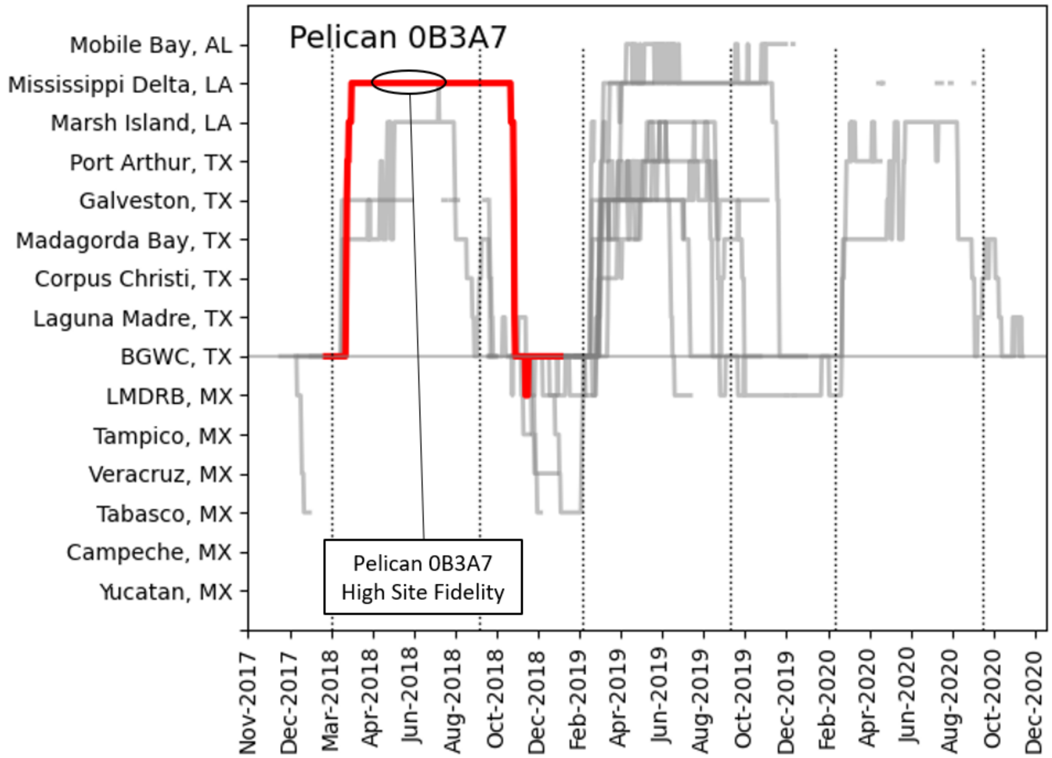


Figure 159. Seasonal Migration Pattern for Pelican 0B3A7 by Coastal Zone over Time. The y-axis represents each coastal zone (Figure 143). The horizontal line represents the BGWC study region. The vertical lines represent March 1st and September 1st of each year during the survey. The red line represents Pelican 0B3A7. The gray lines show the seasonal movement of the other pelicans in the study. High site fidelity (potential nesting site) was exhibited within the Mississippi Delta, Louisiana coastal zone. The circle indicates the general time range that high fidelity was observed.

This individual reached the end of northbound migration on the coast of Mississippi Delta, where it remained through the breeding season. Pelican 0B3A7 appears to have bred from April 1, 2018, through June 25, 2018, as there was high site fidelity and it returned almost continuously to the same island within the Philo Brice Islands in Lake Raccourci, LA. Throughout this period, daily movements occurred within a short distance of this island. After breeding, Pelican 0B3A7 began moving from island to island within the peninsula region, including islands near Port Fourchon and Little Lake, Grand Isle State Park, and the Breton Islands. Pelican 0B3A7 also roosted on the Brenton Islands within the Chandeleur Sound with high site fidelity, but roosting was not continuous.

Pelican 0B3A7 migrated back to the BGWC study region and arrived November 23, 2018, after which its movements involved daily round trips from a roost island in the Laguna Madre to docks in the Port Isabel area. However, on December 8, 2018, Pelican 0B3A7 undertook a southward excursion to El Mezquital, MX, and spent four days in the area before returning to the BGWC.

PELICAN F038

Date Caught:	October 15, 2018
Location Caught:	SH 48
Days Active:	1
Migration:	No

Pelican F038 was captured on October 15, 2018 and stopped transmitting GPS locations on October 16, 2018 (Figure 160).

Figure 160. All GPS Observations of Pelican F038.

Movement in the BGWC Study Region

This individual was in the study for one day and did not leave the Bahia Grande. The pelican was exclusively in the Bahia Grande spending almost all the time on the Bahia Grande spoil islands.

PELICAN 1639

Date Caught:	October 16, 2018
Location Caught:	SH 48
Days Active:	10
Migration:	No

Pelican 1639 was captured on October 16, 2018 and stopped transmitting GPS points on October 26, 2018. This individual was in the study for 10 days and moved within the BGWC study region as well as near the estuary at the junction of the Rio Grande and Gulf Coast of Mexico (Figure 161).

Figure 161. All GPS Observations of Pelican 1639.

Movement in the BGWC Study Region

This individual primarily spent time on Bahia Grande islands, within the Las Palomas Wildlife Management Area, and along the Rio Grande and its coastal estuary. The Bahia Grande islands were the main roost site. Two roost nights were spent on islands near Chuviscar River, MX off the Rio Grande, and one night was spent in the Las Palomas Wildlife Management Area.

PELICAN 2539

Date Caught: October 18, 2018
Location Caught: SH 48
Days Active: 2
Migration: No

Pelican 2539 was captured on October 18, 2018 and stopped transmitting GPS locations on October 20, 2018. This individual was in the study for two days (Figure 162).

Figure 162. All GPS Observations of Pelican 2539.

Movement in the BGWC Study Region

Pelican 2539 traveled between the BGWC study region and the Rio Grande estuary region. It roosted on an island in the Bahia Grande, as well as on the shore of the channel into the Bahia Grande and crossed SH 48.

PELICAN 6E3A

Date Caught:	November 13, 2018
Location Caught:	SH 48
Days Active:	82
Migration:	Yes

Pelican 6E3A was captured on November 13, 2018 and stopped transmitting on February 3, 2019. This individual was in the study for 82 days and provided 6,089 locations. Major clusters of GPS locations occurred in the Bahia Grande study region; along the Rio Grande; the Chuviscar River off the Rio Grande, MX; just south of the Rio Grande in the Mar Negro Wetlands, MX; Playa Bagdad, MX; El Mezquital, MX; and Laguna Madre, MX (Figure 163). This individual did not travel north of the Bahia Grande study region.

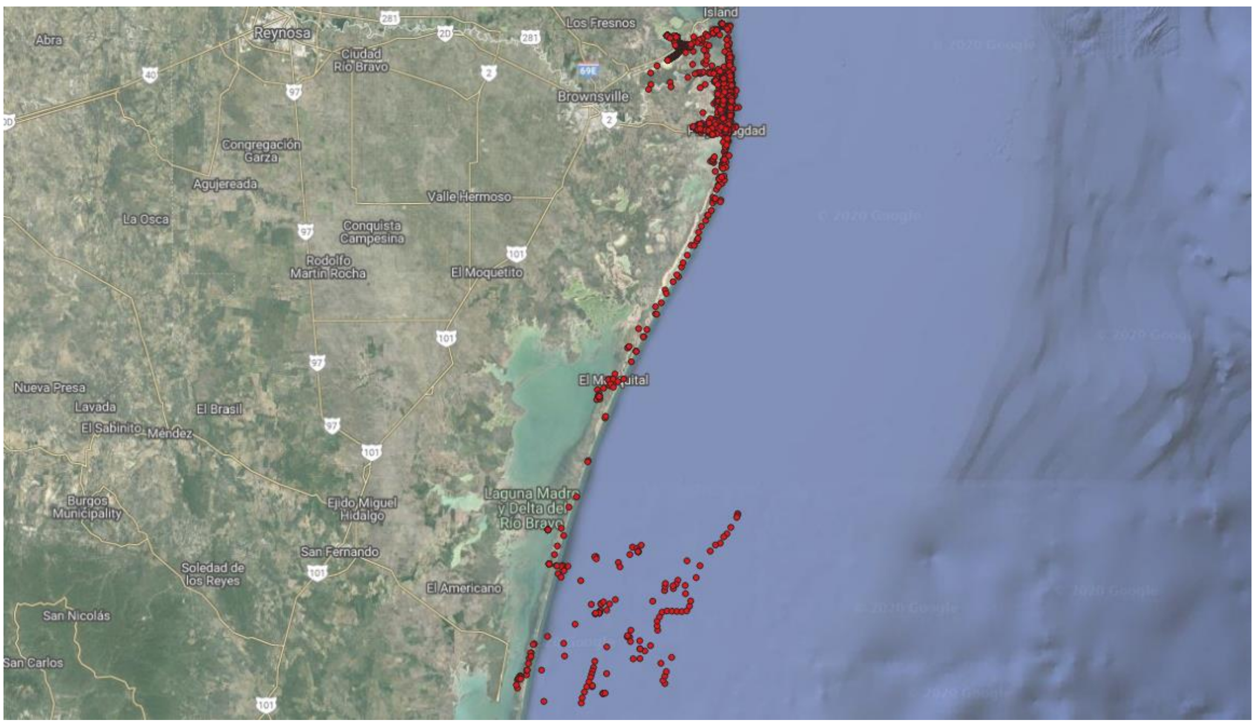


Figure 163. All GPS Observations of Pelican 6E3A.

Movement in the BGWC Study Region

Within the Bahia Grande study region, this pelican's movement was mostly limited to Bahia Grande and the Brownsville Ship Channel. The GPS data suggest that this pelican crossed SH 48 at multiple points. The only roost site used in the study region was on the Bahia Grande islands (Figure 164).

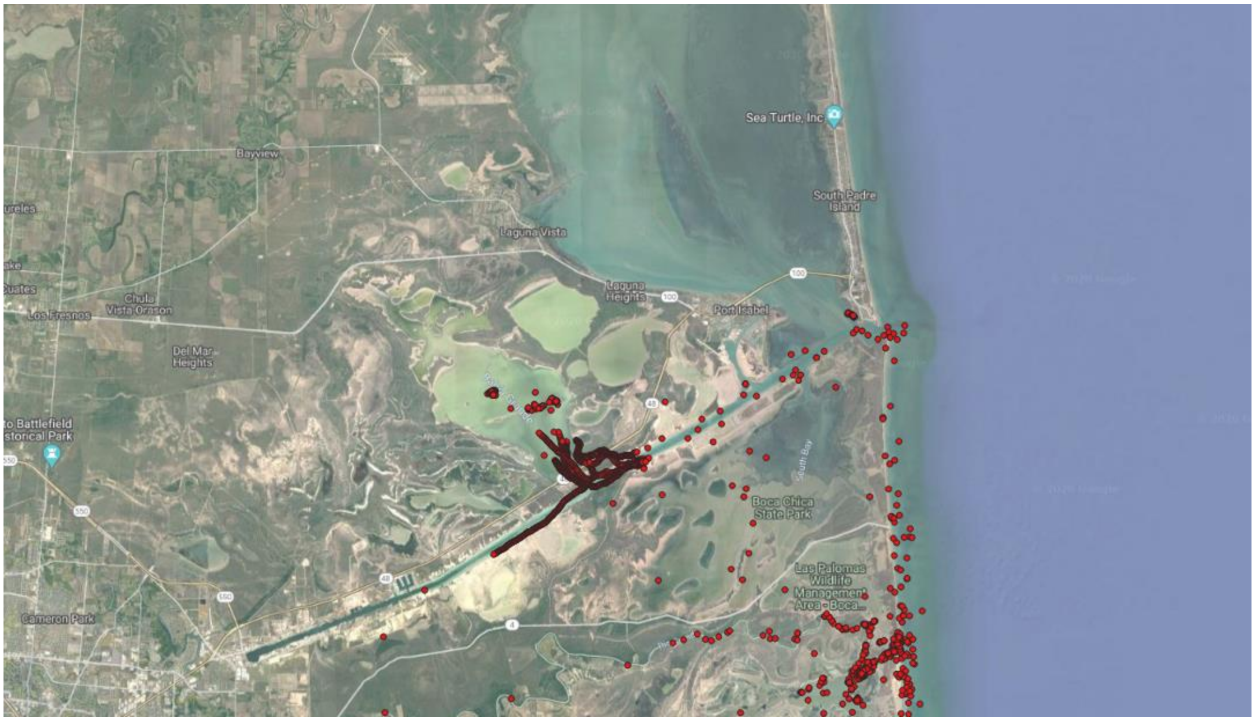


Figure 164. Pelican 6E3A Activity within the Bahia Grande Study Region.

Pelican 6E3A moved long daily distances, often 100 km or more between the Bahia Grande roost island, the Rio Grande estuary region, and the Mar Negro Wetlands, MX, sometimes returning within the same day (see Appendix II). This pelican roosted in the Bahia Grande island (25 percent of the time), the Chuviscar River and Mar Negro region (70 percent of the time), and Laguna Madre wetlands (5 percent of the time). It also made a trip up the Rio Grande and traveled to other non-coastal (inland) bodies of water more than other pelicans in this study (Figure 165).

Figure 165. Pelican 6E3A Activity along the Rio Grande and Upper Laguna Madre, MX.

PELICAN 62A3

Date Caught: November 19, 2018
Location Caught: Isla Blanca Boat Ramp, South Padre Island, TX
Days Active: 15
Migration: No

Pelican 62A3 was captured on November 19, 2018 and stopped transmitting on December 4, 2018. This individual was in the study for 15 days and did not leave the BGWC study region (Figure 166).

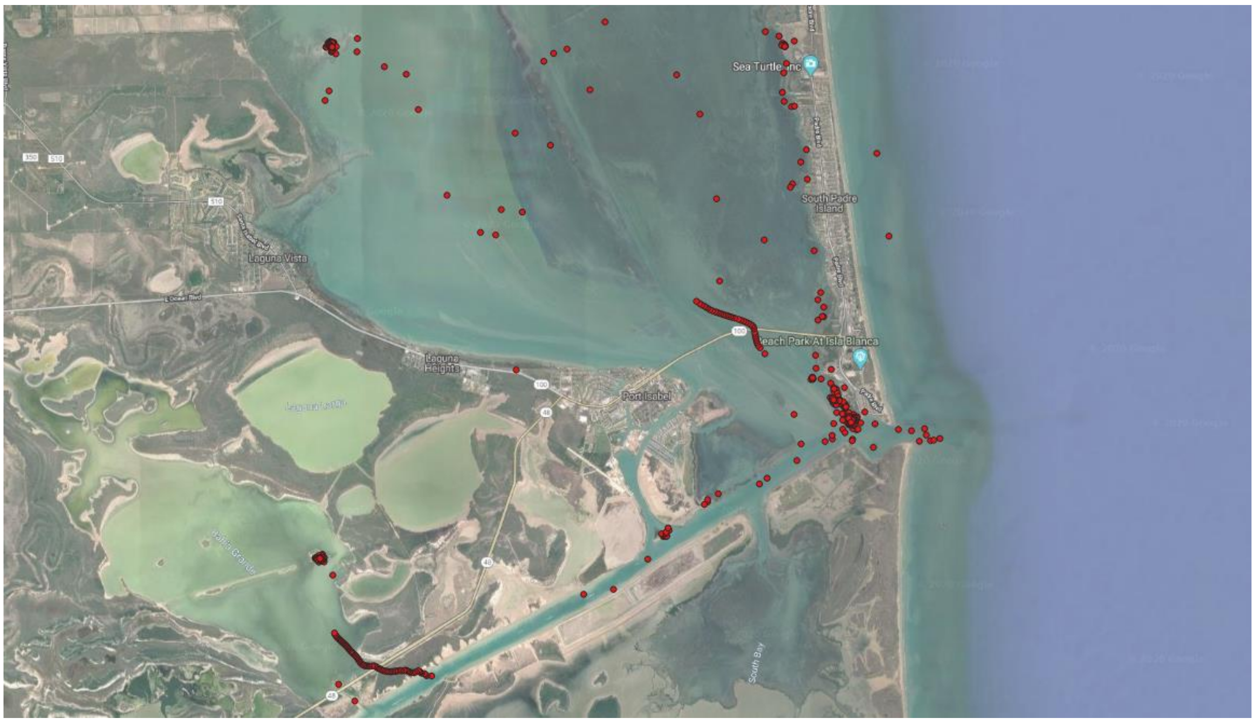


Figure 166. All GPS Observations of Pelican 62A3.

Movement in the BGWC Study Region

This individual mainly traveled between protected islands in Laguna Madre, the western coast and southern point of South Padre Island, and Bahia Grande islands. There is evidence that this pelican crossed SH 48 and Queen Isabella Causeway. It also traveled down the BSC and along the coasts of South Padre Island and loafed on islands in the BSC close to Port Isabel. Roosting occurred on the Bahia Grande islands (approximately 40 percent of the time), beaches on the western coast of South Padre Island (approximately 10 percent of the time), and the Laguna Madre islands (50 percent of the time). This pelican loafed at common sites including along docks, points, and structures along the western coast of South Padre Island, Laguna Madre, Bahia Grande, and the southern point of South Padre Island.

PELICAN 34A1

Date Caught:	November 22, 2018
Location Caught:	Port Isabel
Days Active:	19
Migration:	No

Pelican 34A1 was captured on November 22, 2018 and stopped transmitting on December 11, 2018. This individual was in the study for 19 days and did not leave the BGWC study region in the duration it was tracked (Figure 167).

Figure 167. All GPS Observations of Pelican 34A1.

Movement in the BGWC Study Region

Pelican 34A1 mainly traveled between the Laguna Madre roost island, Port Isabel, Laguna Vista, and loafed briefly on the western coast of South Padre Island. This pelican roosted exclusively on the Laguna Madre main island.

PELICAN 523A

Date Caught:	November 23, 2018
Location Caught:	Port Isabel Park Center, Port Isabel, TX
Days Active:	114
Migration:	Yes

Pelican 523A was captured on November 23, 2018 and stopped transmitting on March 17, 2019. This individual was in the study for 114 days. Major clusters of observations and areas of activity were in the Bahia Grande study region; El Mezquital, MX; and on oil rigs off the coast of Rockefeller Wildlife Refuge, LA (Figure 168).

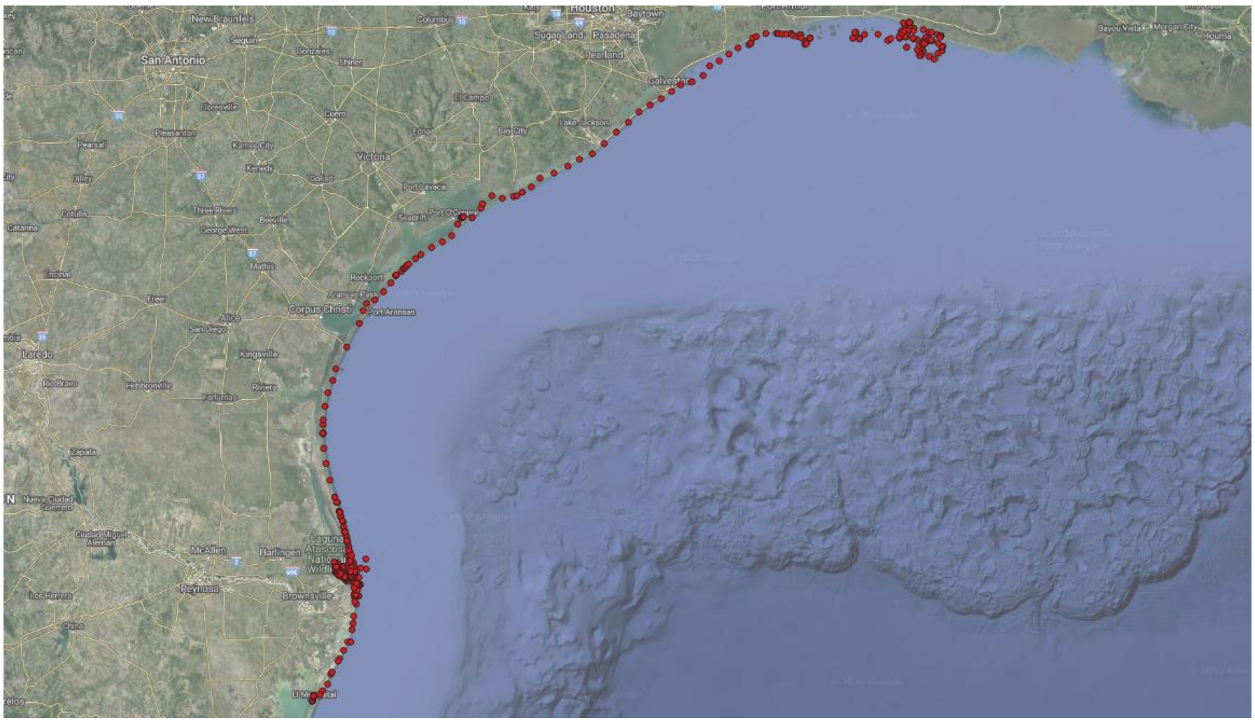


Figure 168. All GPS Observations of Pelican 523A.

Movement in the BGWC Study Region

Within the Bahia Grande study region, Pelican 523A traveled between the main roost island in Laguna Madre, Port Isabel Channel islands, and Port Isabel Side Channel islands and docks, and made occasional trips to the southeastern coast of South Padre Island and out further off the eastern coast (Figure 169). This pelican also traveled south to El Mezquital on January 23, 2019, and back to the BGWC study region on the following day. It made another short trip on February 21, 2019, and March 2, 2019, up the eastern coast of South Padre Island and back again on the same day each time.

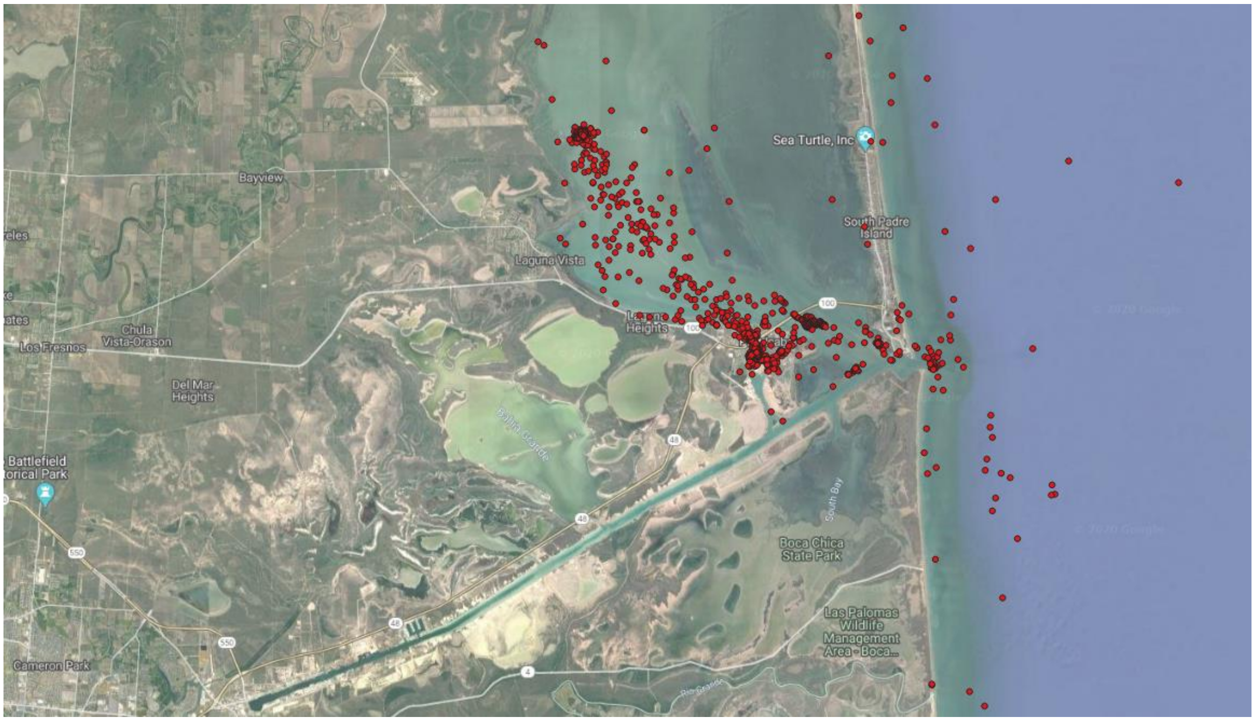


Figure 169. Pelican 523A Activity within the Bahia Grande Study Region.

Migration

Figure 170 illustrates a generalized seasonal migration pattern for Pelican 523A relative to coastal zones. The red and gray lines correspond to the location (y-axis) and date (x-axis) of each migrating pelican tracked during the study. The red line represents the migration pattern of Pelican 523A. The gray lines show the seasonal movement of the other pelicans in the study for a relative comparison. Figure 143 provides an overview of the coastal zones.

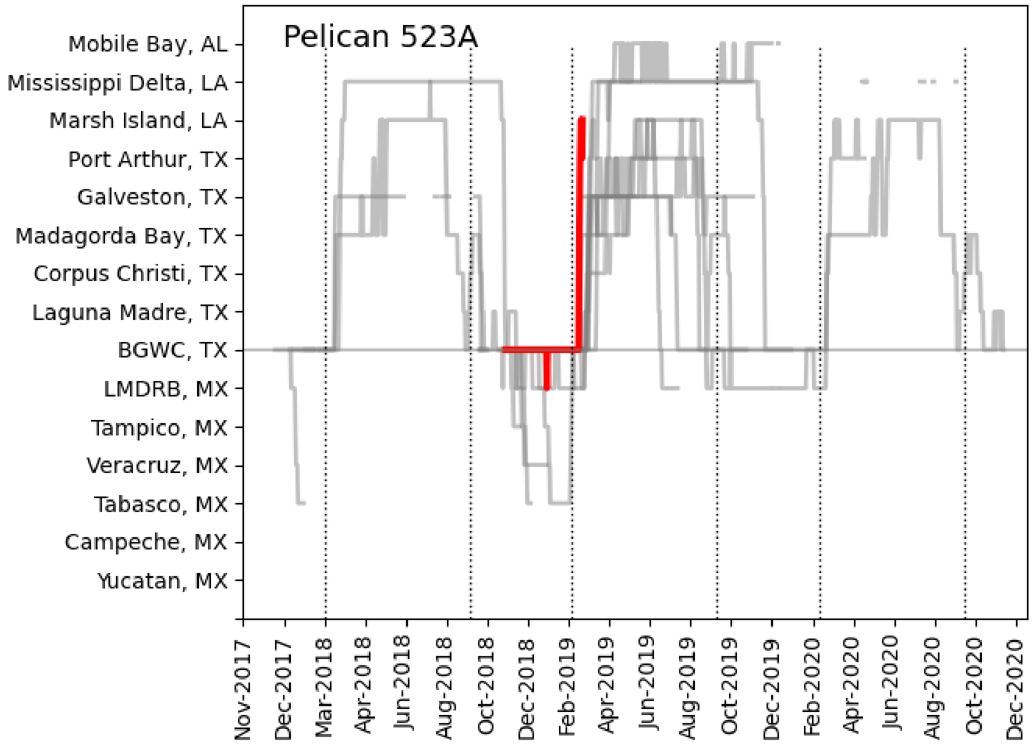


Figure 170. Seasonal Migration Pattern for Pelican 523A by Coastal Zone over Time. The y-axis represents each coastal zone (Figure 143). The horizontal line represents the BGWC study region. The vertical lines represent March 1st and September 1st of each year during the survey. The red line represents Pelican 523A. The gray lines show the seasonal movement of the other pelicans in the study.

Pelican 523A began a northbound migration on March 12, 2019, and the GPS tracking ended during this migration. Data collected during the migration suggested that its movements north were continuous and did not stop for more than a night to rest.

PELICAN 85A3

Date Caught:	November 24, 2018
Location Caught:	Sea Ranch Marina, South Padre Island, TX
Days Active:	36
Migration:	No

Pelican 85A3 was captured on November 24, 2018 and stopped transmitting on December 30, 2018. This individual was in the study for 36 days and did not leave the BGWC study region for the duration it was tracked (Figure 171).

Figure 171. All GPS Observations of Pelican 85A3.

Movement in the BGWC Study Region

This individual mainly traveled between Port Isabel and the BSC adjacent to Port Isabel, protected islands in Laguna Madre, and the southern point of South Padre Island. Travel around and over the Queen Isabella Causeway was also observed. Roosting was split equally among the Laguna Madre island, the southern point of South Padre Island, and the islands and docks in the Port Isabel Channel.

PELICAN B6A3

Date Caught:	November 25, 2018
Location Caught:	Jim’s Pier, South Padre Island, TX
Days Active:	59
Migration:	Yes

Pelican B6A3 was captured on November 25, 2018 and stopped transmitting on January 23, 2019. This individual was in the study for 59 days. Larger clusters of observations and areas of activity were in the Bahia Grande study region; Port Mansfield in Laguna Madre, TX; El Mezquital, MX; and near Heroica down to Boca del Rio, Veracruz, MX (Figure 172).

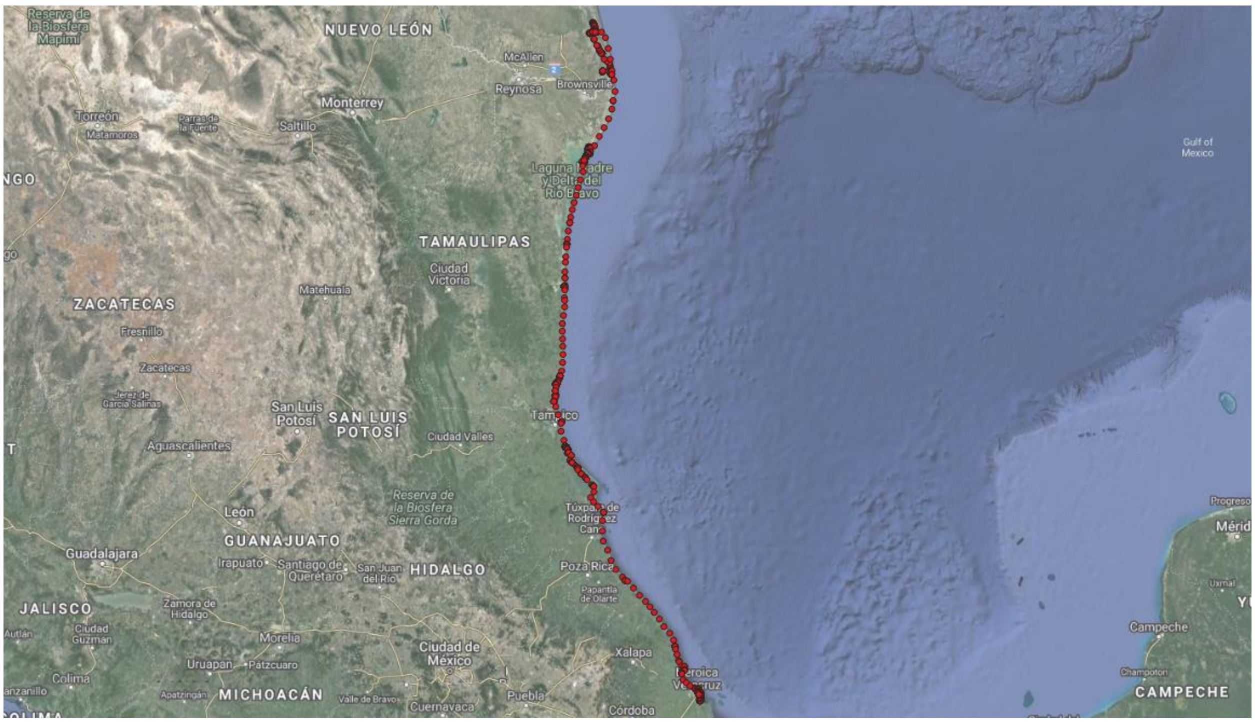


Figure 172. All GPS Observations of Pelican B6A3.

Movement in the BGWC Study Region

Within the Bahia Grande study region, most activities were concentrated in and around the roosting island in Laguna Madre, and occasionally near the eastern coast of South Padre Island (Figure 173). This individual only stayed in the study region for two nights and roosted exclusively on the spoil island in the Laguna Madre.

Figure 173. Pelican B6A3 Activity within the Bahia Grande Study Region.

Migration

Figure 174 illustrates a generalized seasonal migration pattern for Pelican B6A3 relative to coastal zones. Pelican B6A3 began a migration south on December 9, 2018. It reached its destination of Veracruz, MX on December 12, 2018, where it stayed until the GPS tracking expired.

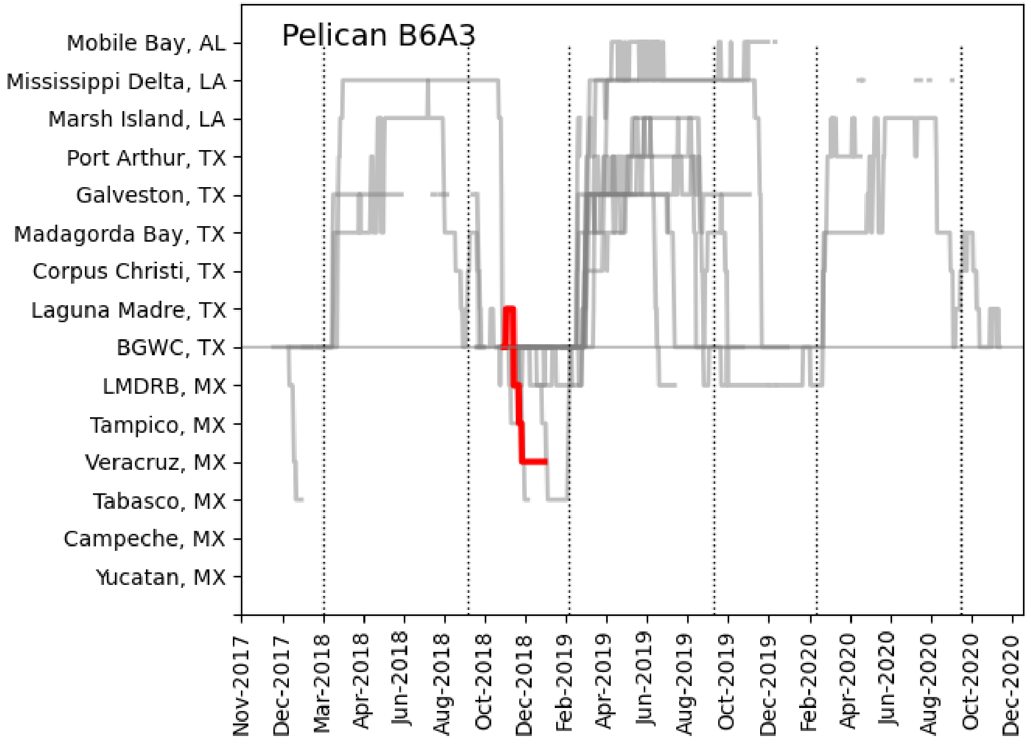


Figure 174. Seasonal Migration Pattern for Pelican B6A3 by Coastal Zone over Time. The y-axis represents each coastal zone (Figure 143). The horizontal line represents the BGWC study region. The vertical lines represent March 1st and September 1st of each year during the survey. The red line represents Pelican B6A3. The gray lines show the seasonal movement of the other pelicans in the study.

PELICAN 963A

Date Caught: November 30, 2018
Location Caught: Sea Ranch Marina, South Padre Island, TX
Days Active: 14
Migration: No

Pelican 963A was captured on November 30, 2018 and stopped transmitting GPS locations on December 14, 2018. This individual was in the study for 14 days. Most observations were in Mexico, with a cluster in Rio Soto La Marina wetlands and a larger cluster in Laguna de Tamiahua wetlands near Tampico (Figure 175).

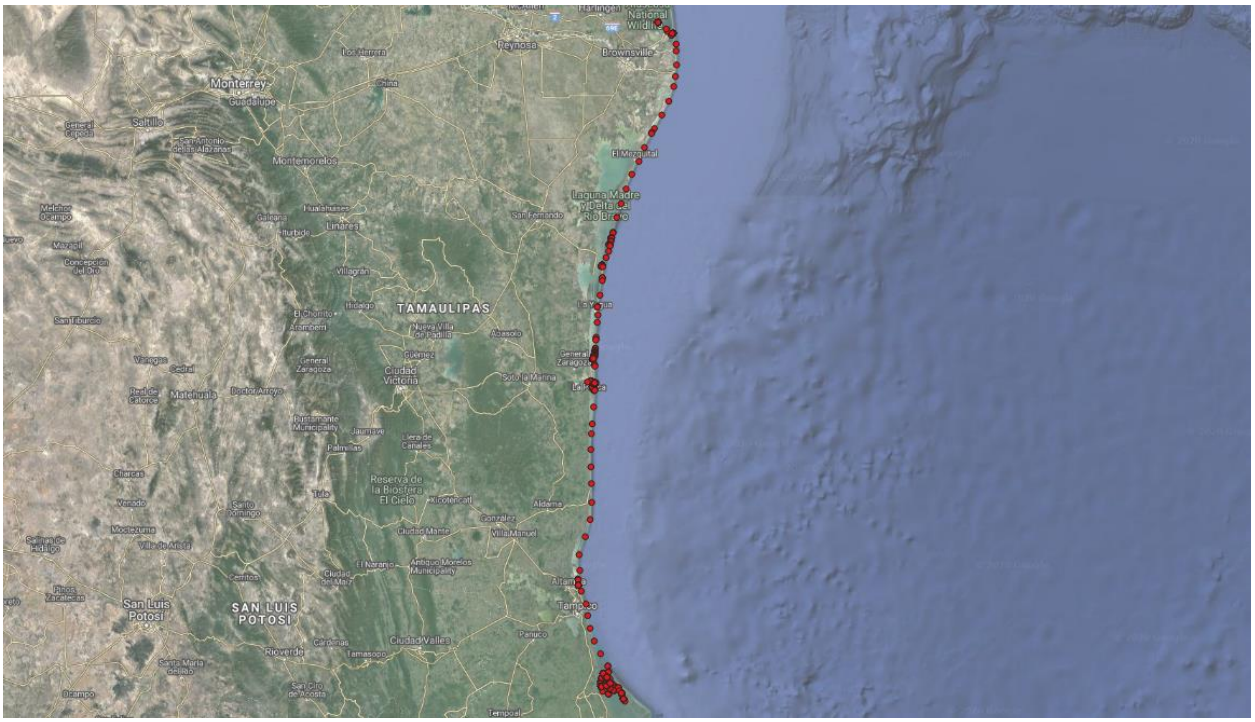


Figure 175. All GPS Observations of Pelican 963A.

Movement in the BGWC Study Region

Pelican 963A remained general vicinity of Bahia Madre roost island, Port Isabel, and South Padre Island in the BGWC study region for less than two days before migrating south on the morning of December 2, 2019.

Migration

Figure 176 illustrates a generalized seasonal migration pattern for Pelican 963A relative to coastal zones. This individual only roosted two nights in Laguna Madre before traveling continuously south along the coast to Laguna de Tamiahua near Tampico, MX, stopping briefly in Rio Soto La Marina wetlands.

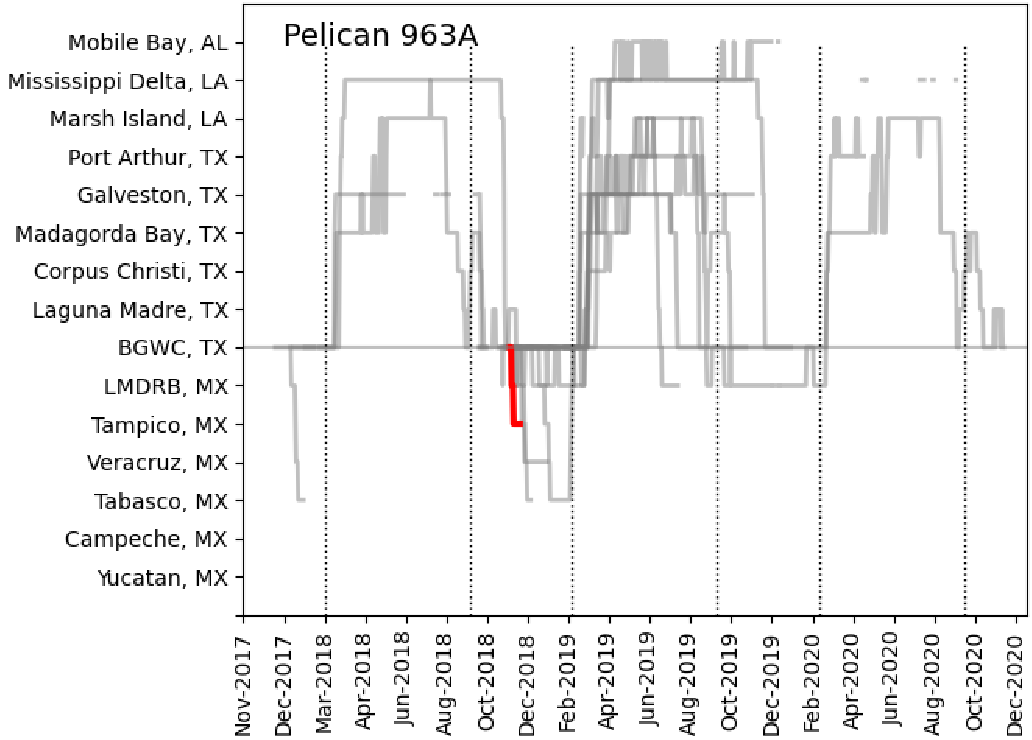


Figure 176. Seasonal Migration Pattern for Pelican 963A by Coastal Zone over Time. The y-axis represents each coastal zone (Figure 143). The horizontal line represents the BGWC study region. The vertical lines represent March 1st and September 1st of each year during the survey. The red line represents Pelican 963A. The gray lines show the seasonal movement of the other pelicans in the study.

PELICAN 443A

Date Caught:	November 30, 2018
Location Caught:	Parrot Eyes, South Padre Island, TX
Days Active:	6
Migration:	No

Pelican 443A was captured on November 30, 2018 and stopped transmitting on December 6, 2018. This individual was in the study for 6 days and did not leave the BGWC study region for the duration it was tracked (Figure 177).

Figure 177. All GPS Observations of Pelican 443A.

Movement in the BGWC Study Region

Pelican 443A's main GPS clusters occurred on the spoil island in Laguna Madre and on the southern point of South Padre Island. There were a few loafing observations in Port Isabel and the docks on the western coast of South Padre Island. Roosting was split approximately equally between the island in Laguna Madre and the southern point of South Padre Island.

PELICAN 3939

Date Caught:	December 5, 2018
Location Caught:	South Shore Bait Shop, Port Isabel, TX
Days Active:	7
Migration:	No

Pelican 3939 was captured on December 5, 2018 and stopped transmitting on December 12, 2018. This pelican was in the study for 7 days and did not leave the BGWC study region during this time (Figure 178).

Figure 178. All GPS Observations of Pelican 3939.

Movement in the BGWC Study Region

Almost all GPS observations occurred on a small island near the swing bridge in Port Isabel and docks nearby. All roosting observations were on the small island in the Port Isabel Channel (located approximately 500 feet southwest of the South Garcia Street swing bridge), and loafing occurred on this island and docks nearby.

PELICAN 383A

Date Caught:	December 6, 2018
Location Caught:	Shrimp Basin, Brownsville, TX
Days Active:	55
Migration:	No

Pelican 383A was captured on December 6, 2018 and stopped transmitting on January 30, 2019. This pelican was in the study for 55 days and mostly stayed within the study region (Figure 179).

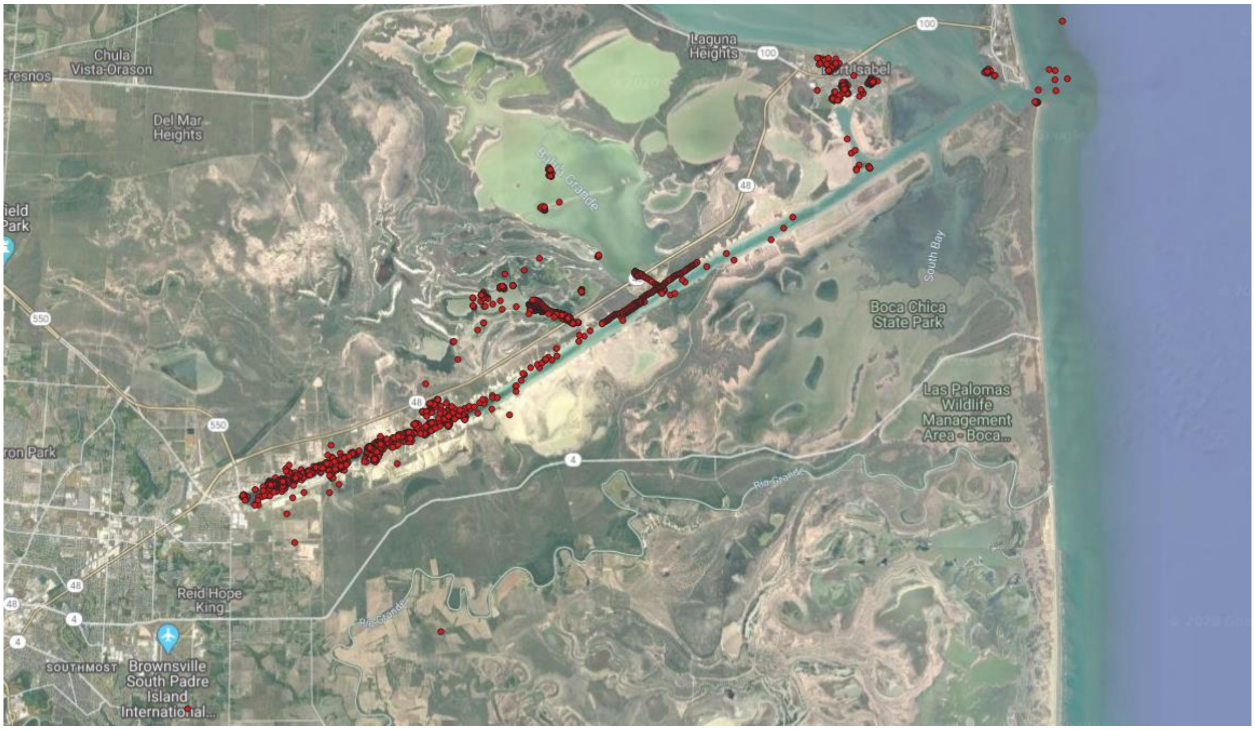


Figure 179. All GPS Observations of Pelican 383A.

Movement in the BGWC Study Region

This individual mainly traveled along the BSC, the San Martin Lake islands, the Bahia Grande islands, in and around Port Isabel, and the southern point of South Padre Island. There are GPS observations of this individual flying over SH 48 to cross between the BSC and Bahia Grande, as well as between the BSC and San Martin Lake. This is the only pelican in the tracking study that used the San Martin Lake and flew across this section of SH 48.

Pelican 383A mainly traveled along the BSC to docks on the BSC, the Shrimp Basin, and Port Isabel. Approximately 80 percent of nights, this pelican roosted along docks near the end of the BSC, and approximately 20 percent of nights were spent roosting on islands in the Port Isabel Channel. Roosting in the Bahia Grande occurred only a few times during the tracked period.

PELICAN 75A3

Date Caught:	December 10, 2018
Location Caught:	South Shore Bait Shop, Port Isabel, TX
Days Active:	51
Migration:	No

Pelican 75A3 was captured on December 10, 2018 and stopped transmitting on January 30, 2019. This individual was in the study for 51 days and did not leave the BGWC study region for the duration it was tracked (Figure 180).

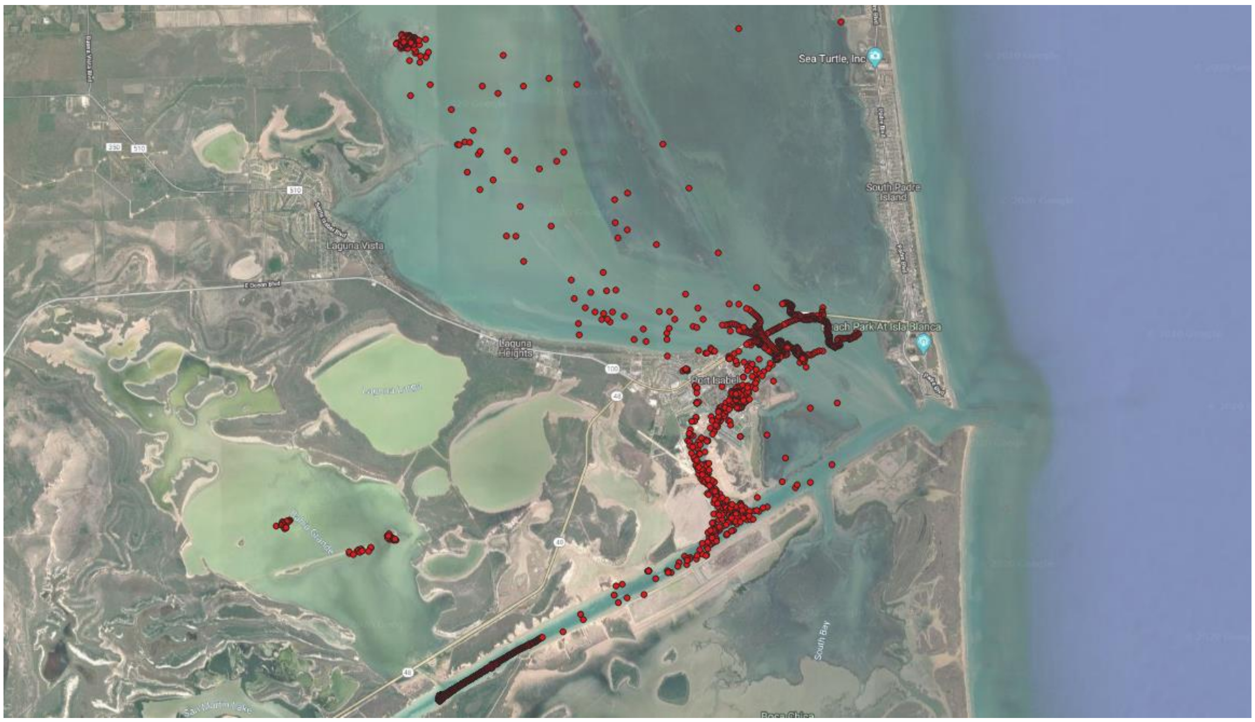


Figure 180. All GPS Observations of Pelican 75A3.

Movement in the BGWC Study Region

This individual mainly traveled between Port Isabel and the Port Isabel Channel and Port Isabel Side Channel, protected islands in Laguna Madre, an island in the BSC adjacent to Port Isabel, the Bahia Grande, and the Brownsville Ship Channel.

PELICAN A65A

Date Caught:	December 12, 2018
Location Caught:	Isla Blanca Boat Ramp, South Padre Island, TX
Days Active:	27
Migration:	Yes

Pelican A65A was captured on December 12, 2018 and stopped transmitting on January 8, 2019. This individual was in the study for 27 days. Major clusters of observations and areas of activity were in the Bahia Grande study region; El Mezquital, MX; Laguna Madre, MX; and smaller clusters in Laguna de Tamiahua, MX; Grassland Lagoon, MX; and near Laguna de Terminos in Campeche, MX (Figure 181). This individual began a continuous southbound movement on December 17, 2018, traveling until it stopped transmitting GPS locations close to the city of Ciudad del Carmen, MX.

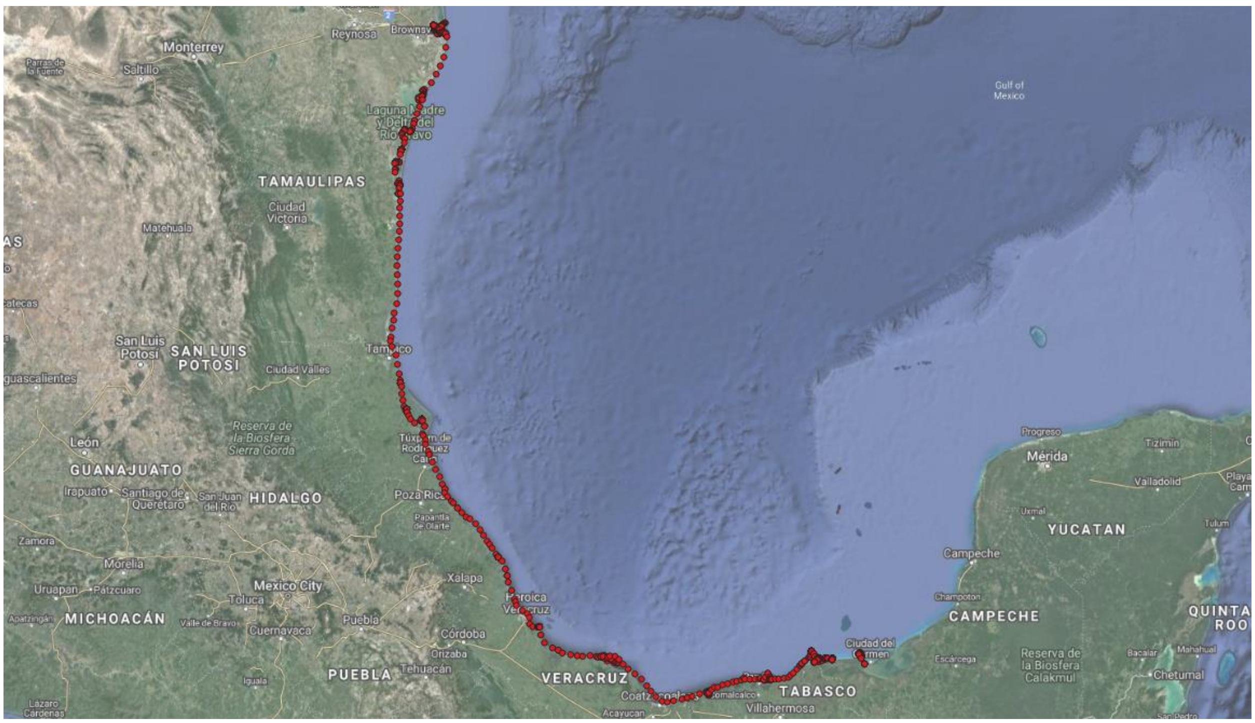


Figure 181. All GPS Observations of Pelican A65A.

Movement in the BGWC Study Region

Within the Bahia Grande study region, roosting and most activities were concentrated in and around Bahia Grande. This individual crossed SH 48 multiple times, and movement was mainly between in the Bahia Grande, BSC, and the Rio Grande (Figure 182). This pelican also made an excursion up the Rio Grande.

Figure 182. Pelican A65A Activity within the Bahia Grande Study Region.

Migration

Figure 183 illustrates a generalized seasonal migration pattern for Pelican A65A relative to coastal zones. Pelican A65A began a southern migration on December 17, 2018 and ended in Tabasco, MX on December 29, 2018. The pelican stayed in an area about 40 miles west of Ciudad del Carmen, MX for two days when the GPS tracking ended.

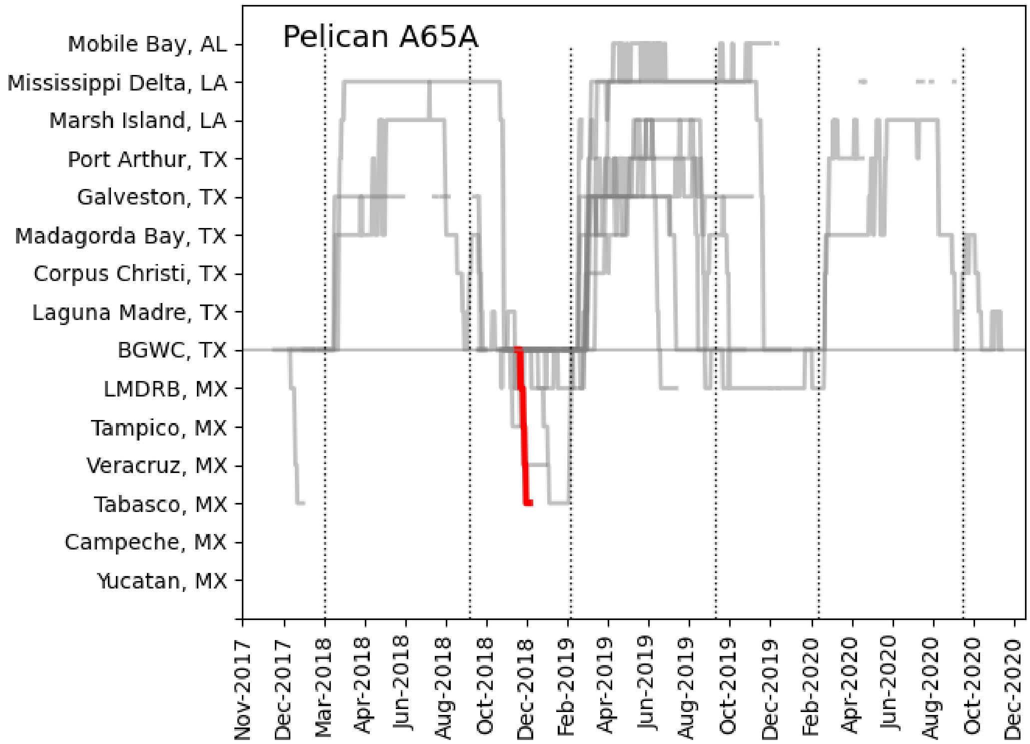


Figure 183. Seasonal Migration Pattern for Pelican A65A by Coastal Zone over Time. The y-axis represents each coastal zone (Figure 143). The horizontal line represents the BGWC study region. The vertical lines represent March 1st and September 1st of each year during the survey. The red line represents Pelican A65A. The gray lines show the seasonal movement of the other pelicans in the study.

PELICAN 443A7

Date Caught:	December 12, 2018
Location Caught:	Pompano Park, Port Isabel, TX
Days Active:	511
Migration:	Yes

Pelican 443A7 was captured on December 12, 2018 and stopped transmitting on May 6, 2020. This individual remained in the study for 511 days. Major clusters of observations and areas of activity were in the BGWC study region, and along the coast of the Mississippi Delta, especially throughout the Chandeleur Sound islands in the Brenton National Wildlife Refuge, LA (Figure 184).

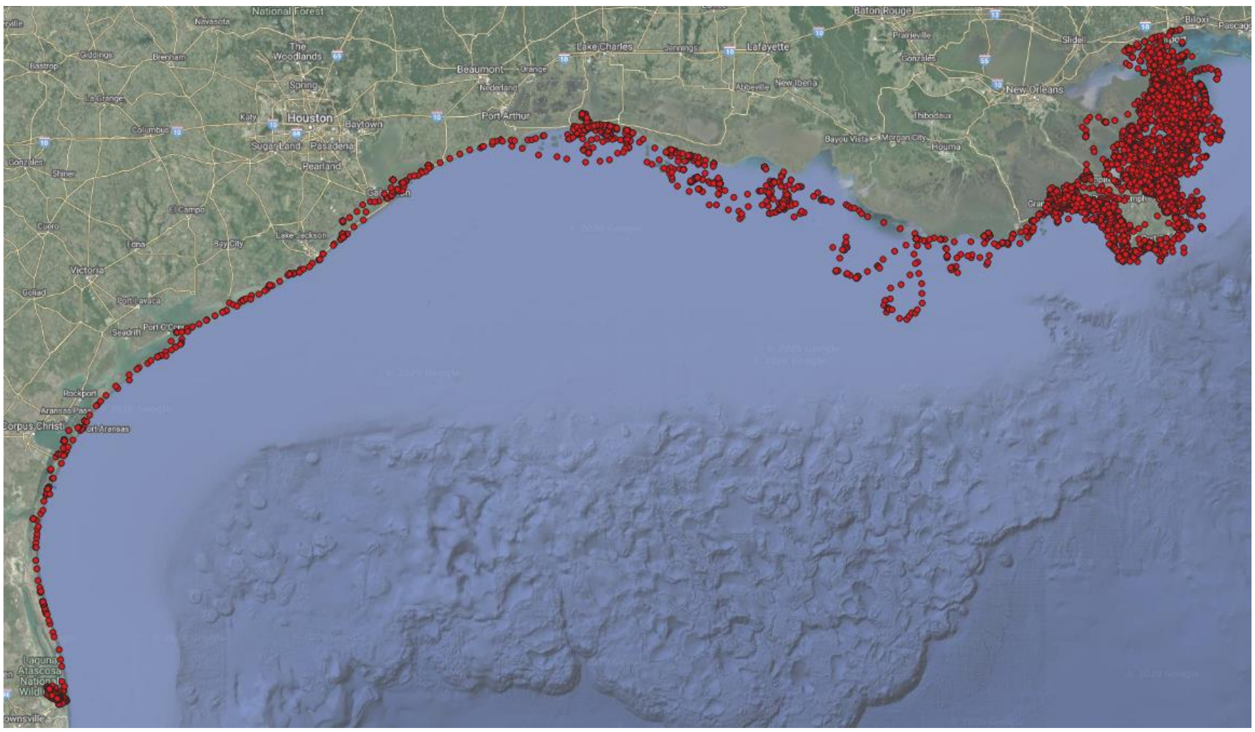


Figure 184. All GPS Observations of Pelican 443A7.

Movement in the BGWC Study Region

Within the Bahia Grande study region, Pelican 443A7 traveled between the main roost island in Laguna Madre; Port Isabel Channel and Port Isabel Side Channel islands and docks; along and across the Queen Isabella Causeway; and at multiple points off Port Isabel, such as the Port Isabel Fishing Pier, Pelican Point Marina, and Dolphin Docks (Figure 185). Movement was mainly between the Laguna Madre roost island and Port Isabel areas, and movement to other locations were occasional. This individual did not travel farther than the PI-BSC island into the BSC or Bahia Grande. Roosting occurred exclusively on the main Laguna Madre spoil island.

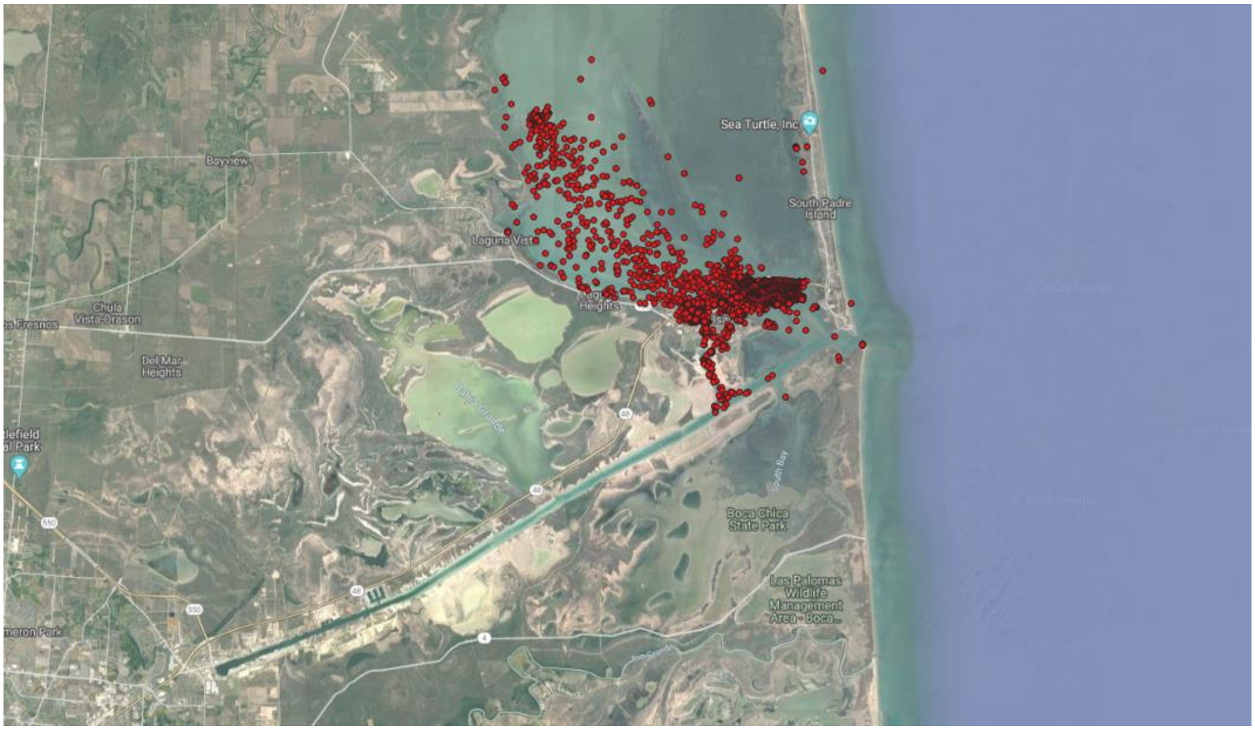


Figure 185. Pelican 443A7 Activity within the Bahia Grande Study Region.

Migration

Figure 186 illustrates a generalized seasonal migration pattern for Pelican 443A7 relative to coastal zones. Pelican 443A7 completed a northbound migration from March 23, 2019, through April 10, 2019, with stops along the Louisiana coast and a southbound continuous migration from December 7, 2019, through December 11, 2019, only stopping at night to rest (see Appendix II). This individual's range spanned from the BGWC study region to Mississippi City, Mississippi.

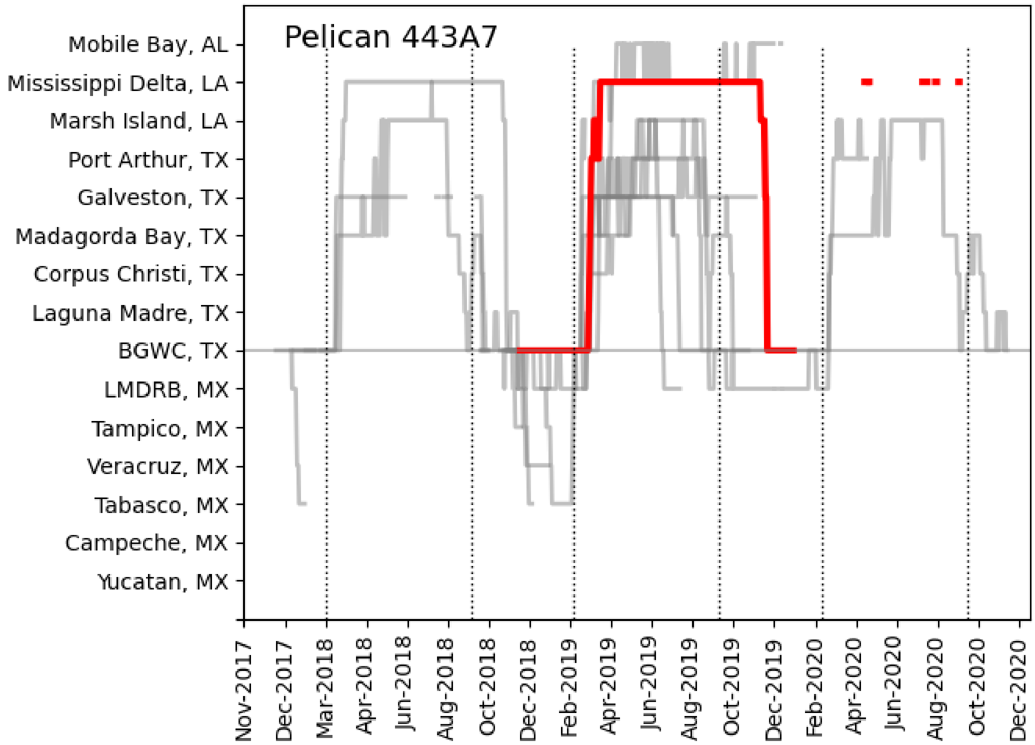


Figure 186. Seasonal Migration Pattern for Pelican 443A7 by Coastal Zone over Time. The y-axis represents each coastal zone (Figure 143). The horizontal line represents the BGWC study region. The vertical lines represent March 1st and September 1st of each year during the survey. The red line represents Pelican 443A7. The gray lines show the seasonal movement of the other pelicans in the study.

This individual inhabited multiple islands during the breeding season, especially those bordering the Mississippi Delta. Islands with higher site fidelity were Queen Bess Island, LA, and the Breton Islands in the Breton National Wildlife Refuge, LA. However, pelican 443A7 did not roost continuously on any of these islands for more than a week. It appears that this individual did not breed as it moved frequently from island to island in this region.

PELICAN A45A

Date Caught:	December 18, 2018
Location Caught:	Isla Blanca Boat Ramp, South Padre Island, TX
Days Active:	378
Migration:	Yes

Pelican A45A was captured on December 18, 2018 and stopped transmitting on December 31, 2019. This individual was in the study for 378 days. Major clusters of observations and areas of activity were in the Bahia Grande study region; El Mezquital, MX; Copano Bay (Aransas Bay) and Corpus Christi, TX; and along the coast of the Mississippi Delta and coastal Alabama, including the Chandeleur Sound, LA (Mississippi Delta) and Mobile Bay, AL (Figure 187). Of all individuals tracked during the study, this individual occupied the most northern summer habitat (as far north as Choctawhatchee Bay, FL).

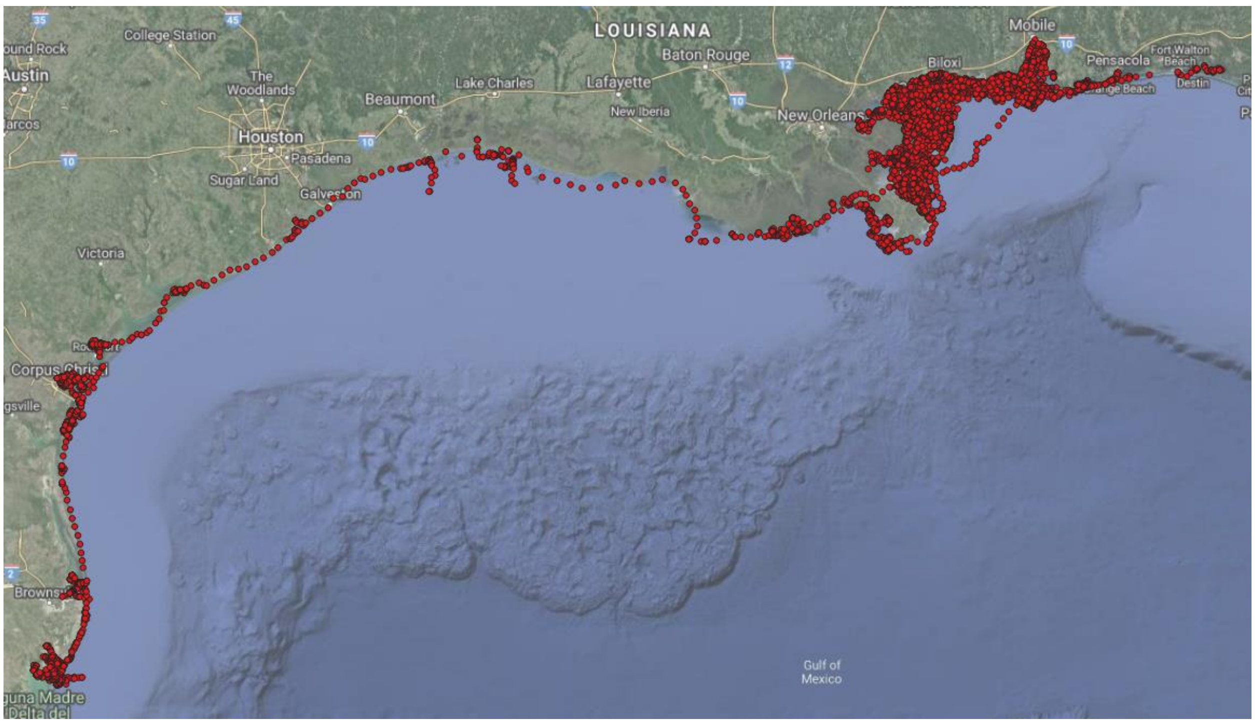


Figure 187. All GPS Observations of Pelican A45A.

Movement in the BGWC Study Region

Within the Bahia Grande study region, Pelican A45A traveled between the main roost island in Laguna Madre, Port Isabel Channel and Port Isabel Side Channel islands and docks, on the PI-BSC island, the southern point of South Padre Island, along the Queen Isabella Causeway, in Laguna Vista, and along the BSC (Figure 188). Roosting occurred mainly on an island in the Port Isabel Channel approximately 75 percent of the time, and on the main spoil island in Laguna Madre the other 25 percent of the time. Loafing mainly occurred along the BSC and Port Isabel.

This individual also undertook two, 2-day trips between the Bahia Grande region and El Mezquital, MX.

Figure 188. Pelican A45A Activity within the Bahia Grande Study Region.

Migration

Figure 189 illustrates a generalized seasonal migration pattern for Pelican A45A relative to the coastal zones. This individual began a northbound migration on March 21, 2019, towards Corpus Christi, TX, and stayed in the area for a month before continuing north. On April 20, 2019, this pelican began migration north to Gaillard Island in Mobile Bay, AL, and stopped briefly in between Port Arthur, TX, and Calcasieu Lake, LA.

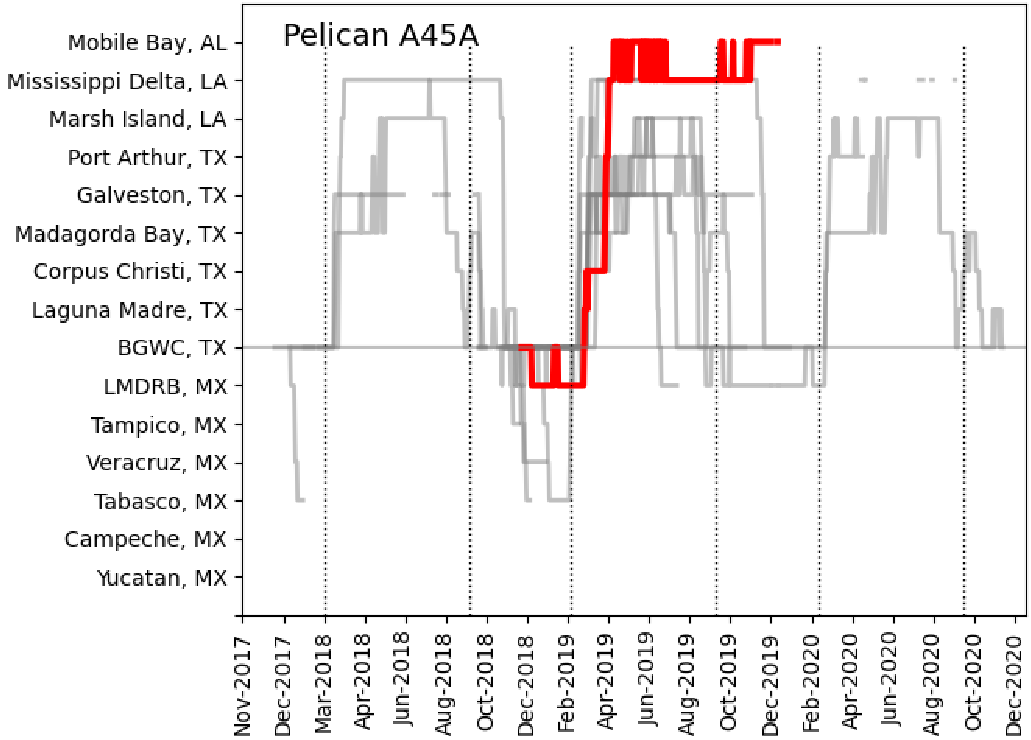


Figure 189. Seasonal Migration Pattern for Pelican A45A by Coastal Zone over Time. The y-axis represents each coastal zone (Figure 143). The horizontal line represents the BGWC study region. The vertical lines represent March 1st and September 1st of each year during the survey. The red line represents Pelican A45A. The gray lines show the seasonal movement of the other pelicans in the study.

Once it reached its destination of Gaillard Island on May 3, 2019, the pelican began daily movements from this roost island along the coastal islands in Mobile Bay and the Chandeleur Sound regions. This individual had high site fidelity on Gaillard Island until July 21, 2019, when it began short-term stays on multiple islands along the Brenton Islands, Chandeleur Sound, and the southern point of the Louisiana peninsula. This pelican also traveled further northbound as far as Choctawhatchee Bay, FL during day trips from the Orange Beach area.

PELICAN A95A

Date Caught:	December 18, 2018
Location Caught:	Shrimp Basin, Brownsville, TX
Days Active:	77
Migration:	Yes

Pelican A95A was captured on December 18, 2018 and stopped transmitting on March 5, 2019. This individual was in the study for 77 days (Figure 190).

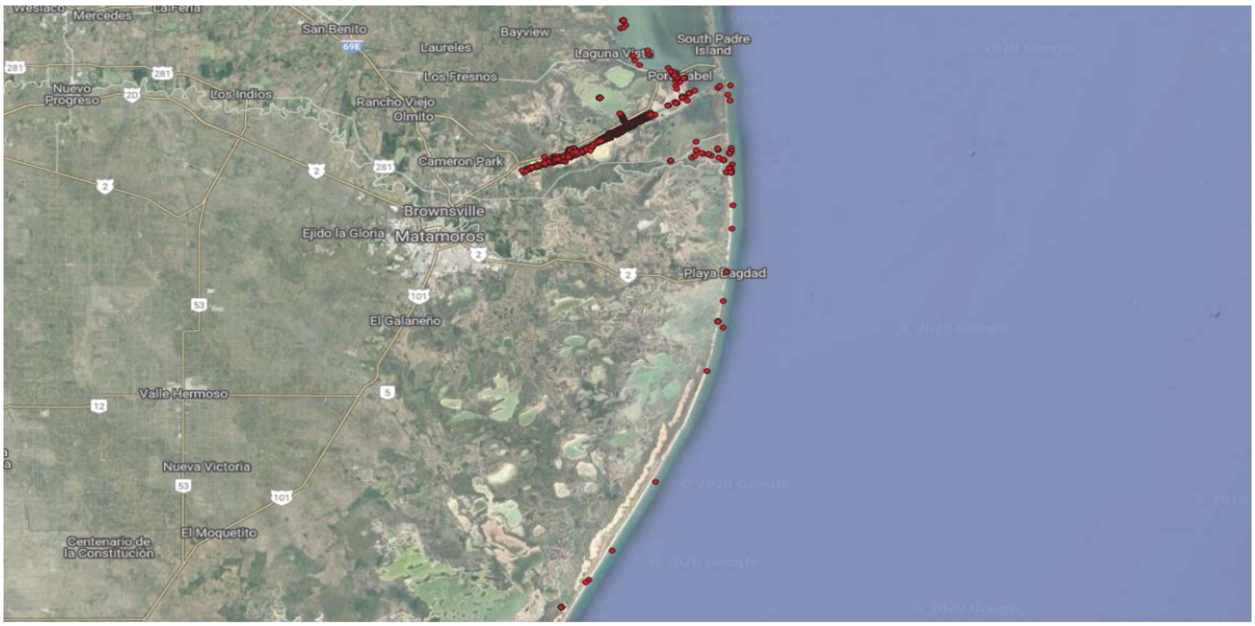


Figure 190. All GPS Observations of Pelican A95A.

Movement in the BGWC Study Region

Pelican A95A spent most of its time roosting and loafing along the BSC and traveled between the Laguna Madre, Port Isabel, and the BSC, occasionally roosting at the Bahia Grande roost site. The pelican also crossed SH 48 between the Bahia Grande and the BSC (Figure 190). Roosting occurred primarily on docks in the BSC near the Shrimp Basin, but also occasionally on islands in the Laguna Madre, the Bahia Grande, the PI-BSC island, and in the Port Isabel Channel.

The individual also traveled through the Las Palomas Wildlife Management Area near the Rio Grande estuary as well as making a short trip to El Mezquital, MX, and back to the BGWC study region. Although Pelican A95A left the BGWC coastal zone, this was not considered a migration. The timing (i.e., moving south in February when most pelican movement is to the north) and a relatively short travel distance moving south may simply suggest that this pelican has a wider home range than the study region or that data collection stopped before migration began.

PELICAN BBA6

Date Caught:	December 27, 2018
Location Caught:	Shrimp Basin, Brownsville, TX
Days Active:	19
Migration:	No

Pelican BBA6 was captured on December 27, 2018 and stopped transmitting on January 15, 2019. This individual was in the study for 19 days. Observations of this individual were entirely within the BSC in the Bahia Grande study region (Figure 191).

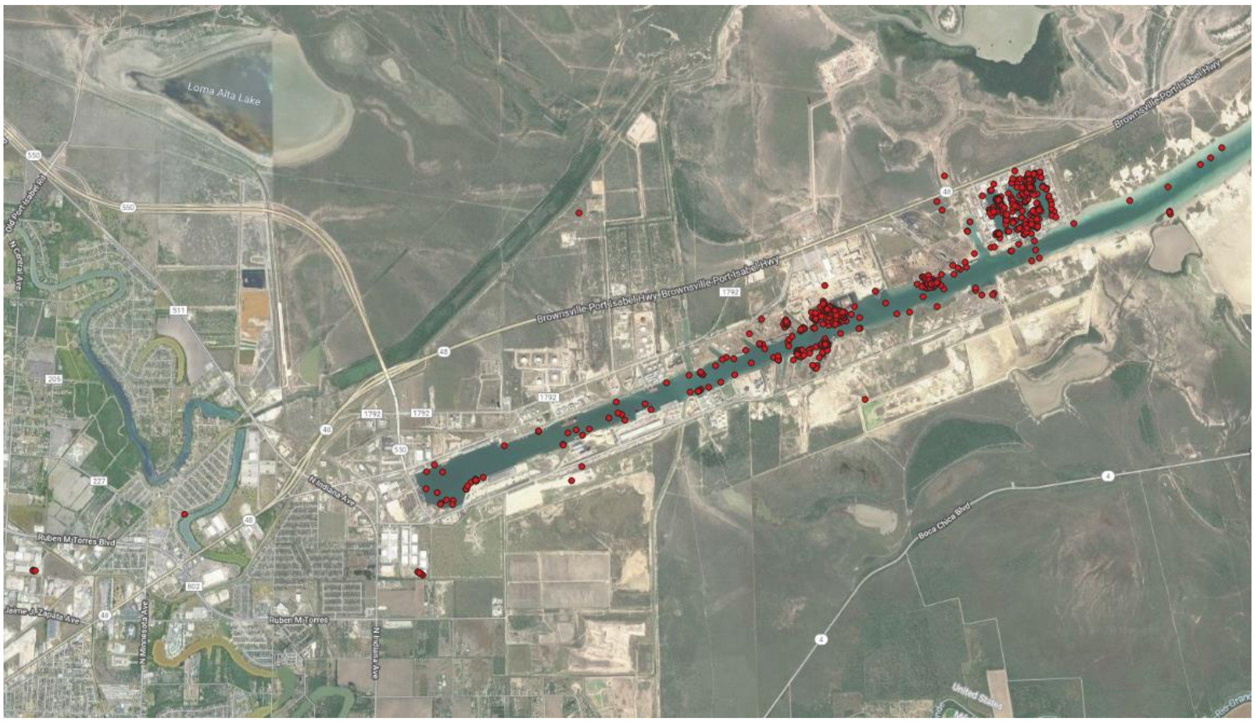


Figure 191. All GPS Observations of Pelican BBA6.

Movement in the BGWC Study Region

The largest cluster of observations was in the Shrimp Basin and along docks close to Bay Bridge in the BSC (Figure 191). This pelican loafed with high fidelity in the Shrimp Basin but rarely roosted there. Approximately 70 percent of the time, this individual roosted on a dock in the BSC.

PELICAN A05A

Date Caught:	January 1, 2019
Location Caught:	Jim's Pier, South Padre Island, TX
Days Active:	215
Migration:	Yes

High-density GPS observations and areas of activity were in the Bahia Grande study region; Playa Bagdad, MX; El Mezquital, MX; Tampico, MX; Laguna de Tamiahua, MX; and Grassland Lagoon in Tabasco, MX in the Agua Dulce, MX region; Matagorda Bay, TX; densely within Galveston Bay; near Calcasieu Lake; and along the coast of Louisiana near Pelican Island (town) and Marsh Island, LA (Figure 192).

Figure 192. All GPS Observations of Pelican A05A.

Movement in the BGWC Study Region

Within the Bahia Grande study region, Pelican A05A traveled between the main roost island in Laguna Madre, Port Isabel, the southern point and lower end of both coasts of South Padre Island (Figure 193). The pelican also traveled along and over the Queen Isabella causeway and along South Padre Island coasts. It roosted mostly within the Laguna Madre and once in the Bahia Grande islands.

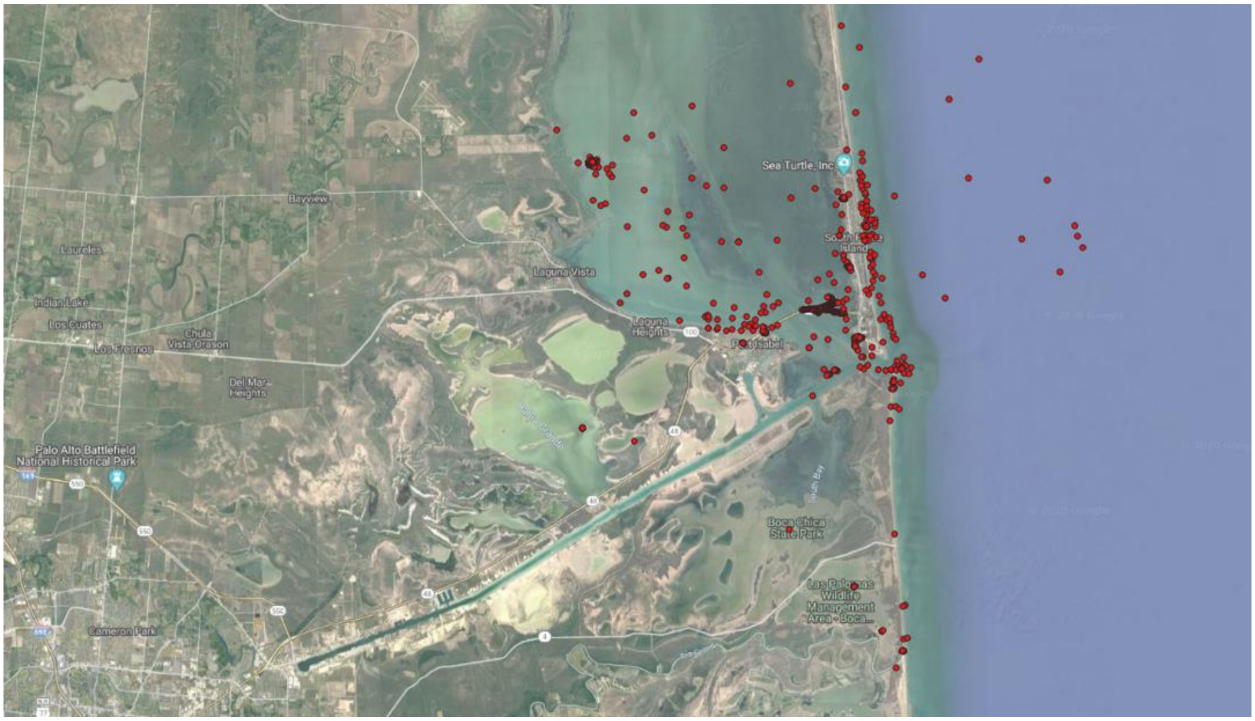


Figure 193. Pelican A05A Activity within the Bahia Grande Study Region.

Migration

Figure 194 illustrates a generalized seasonal migration pattern for Pelican A05A relative to coastal zones. This individual began a southward migration to the Lagunas de Tamiahua region on January 20, 2019, where it stayed for several days before resuming southbound travel. It reached its destination of the Grassland Lagoon in the Agua Dulce, MX region on January 29, 2019. This individual roosted in and traveled between islands in the Grassland Lagoon and Rio Tonala.

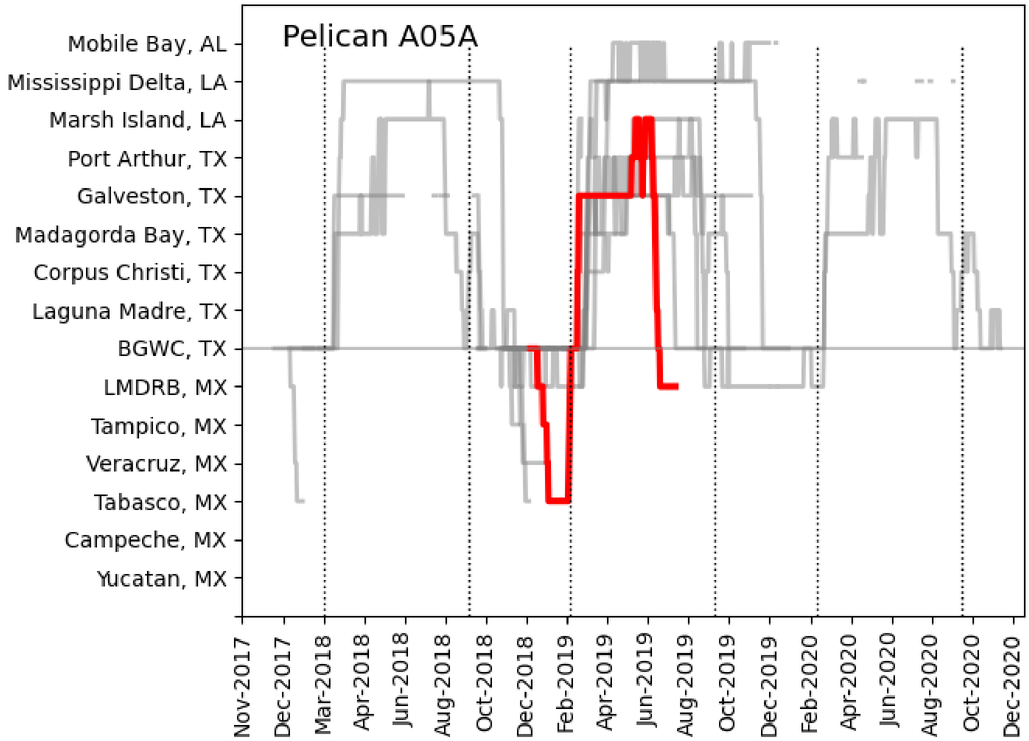


Figure 194. Seasonal Migration Pattern for Pelican A05A by Coastal Zone over Time. The y-axis represents each coastal zone (Figure 143). The horizontal line represents the BGWC study region. The vertical lines represent March 1st and September 1st of each year during the survey. The red line represents Pelican A05A. The gray lines show the seasonal movement of the other pelicans in the study.

Long-distance travel north back to the study region began on February 27, 2019. The pelican arrived back in the study region on March 4, 2019. Within the Bahia Grande study region, the pelican moved between the Laguna Madre, Port Isabel, and South Padre Island until it resumed travel north on March 12, 2019. Pelican A05A reached Galveston bay on March 15, 2019, where it roosted on protected islands and docks in the bay. This individual continued north to the Calcasieu Lake region up to Marsh Island on May 21, 2019 and traveled back and forth between this area and Galveston Bay every few days.

Long-distance travel south back to the BGWC study region began July 3, 2019, through July 9, 2019, and travel was continuous, only stopping overnight to rest. This pelican again traveled south on July 12, 2019, back down to El Mezquital, MX, and Laguna Madre, MX until tracking of this pelican stopped. Notably, this individual did not spend much time in the study region and was one of the farthest migrations south.

PELICAN A35A

Date Caught:	January 4, 2019
Location Caught:	Shrimp Basin, Brownsville, TX
Days Active:	21
Migration:	No

Pelican A35A was captured on January 4, 2019 and stopped tracking on January 25, 2019. This individual was in the study for 21 days and did not leave the BGWC study region in the duration it was tracked (Figure 195).

Figure 195. All GPS Observations of Pelican A35A.

Movement in the BGWC Study Region

This individual mainly traveled between the Bahia Grande, the Shrimp Basin in the BSC, and occasionally in and near Port Isabel (see Appendix II). Crossings of SH 48 were recorded on multiple occasions. The largest cluster of observations was in the Shrimp Basin, though roosting mainly occurred in the Bahia Grande. This individual made near-daily trips to loaf in the Shrimp Basin from the Bahia Grande loafing site and rarely roosted in Port Isabel and along docks in the BSC.

PELICAN BCA6

Date Caught:	January 28, 2019
Location Caught:	Sea Ranch Marina, South Padre Island, TX
Days Active:	463
Migration:	Yes

Pelican BCA6 was captured on January 28, 2019 and stopped transmitting on May 5, 2020. This individual was in the study for 463 days. Major clusters of observations and areas of activity were in the Bahia Grande study region; near El Mezquital, MX; Arroyo City, TX; and along the coast from Galveston Bay to Calcasieu Lake (Figure 196). There were also continuous observations and clustering from the Playa Bagdad region to Arroyo City along South Padre Island through the study region.

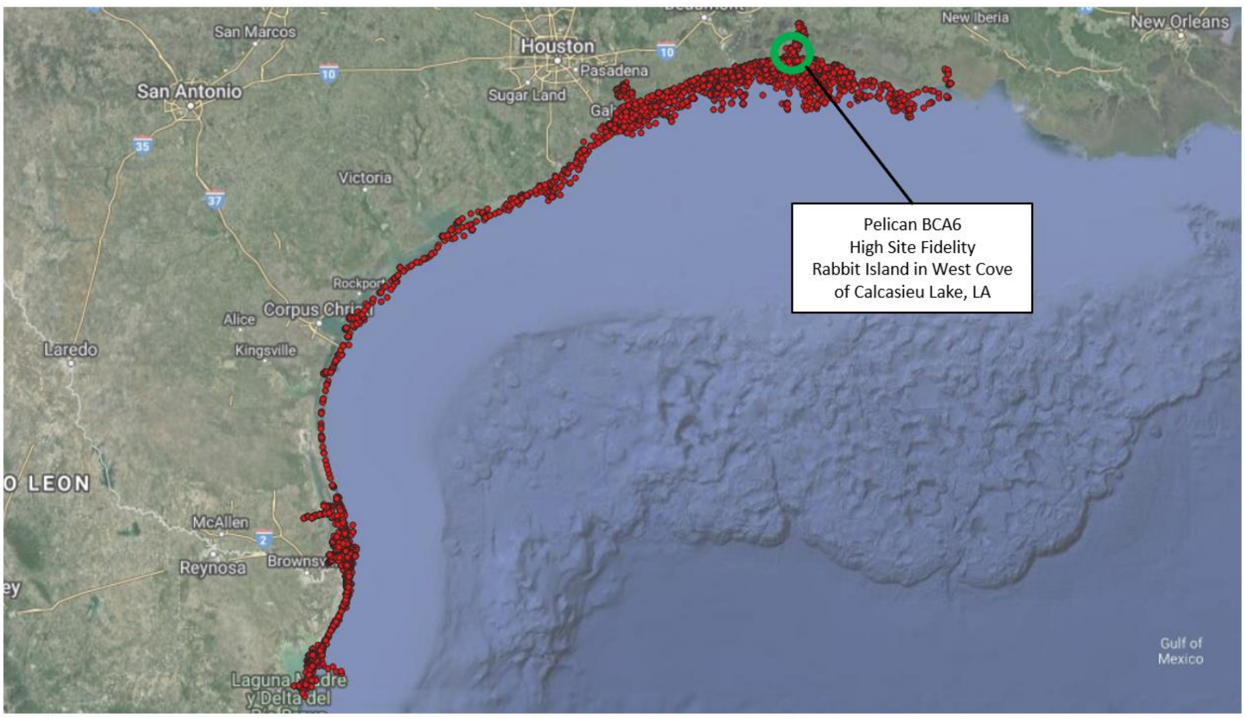


Figure 196. All GPS Observations of Pelican BCA6.

Movement in the BGWC Study Region

Within the study region, there was a large cluster on the southern point of South Padre Island, in the BSC, the Bahia Grande, and a smaller cluster on the Laguna Madre islands. This individual appears to have crossed SH 48 at multiple points, including over the Carl Gayman bridge, as well as the Queen Isabella Causeway. This pelican also traveled down the BSC, but not as far as the Shrimp Basin (Figure 197). In the study region, roosting was mainly split evenly between the Bahia Grande, Laguna Madre island, and the southern point of South Padre Island. This individual did not display high fidelity to any one site. During the 2019 wintering season, most movement, roosting, and loafing were between the Laguna Madre, southern South Padre Island, and the Bahia Grande.

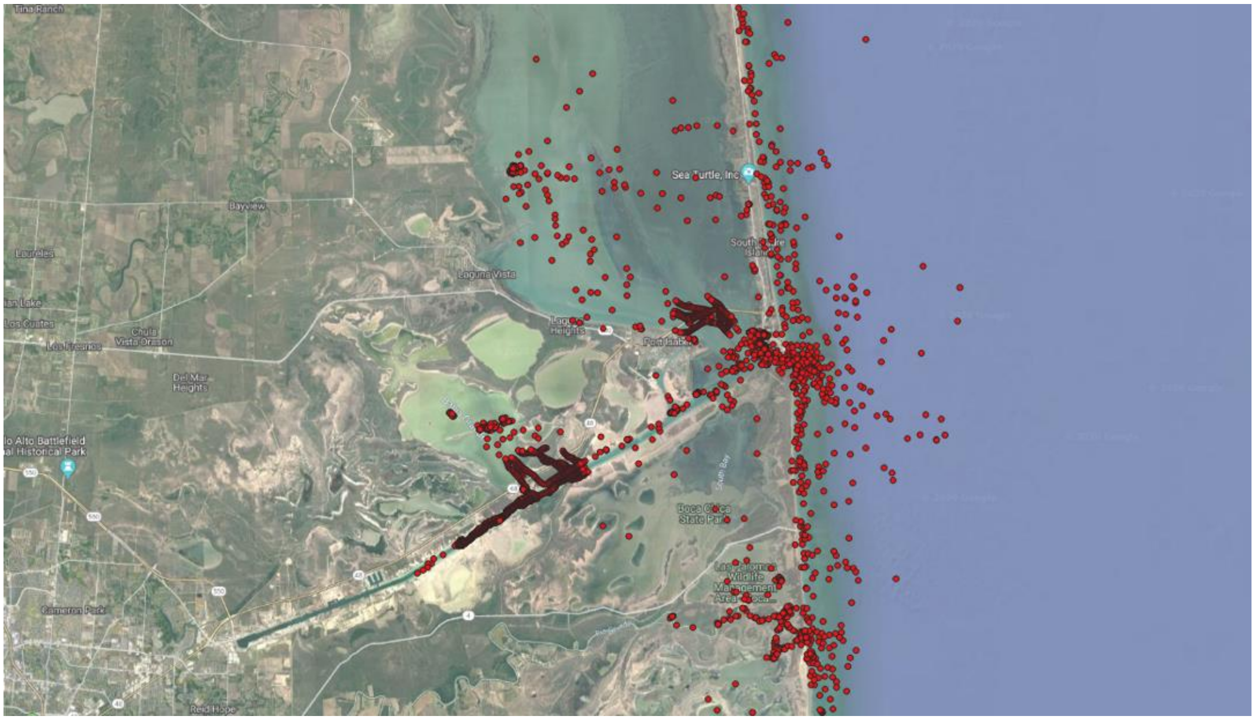


Figure 197. Pelican BCA6 Activity within the Bahia Grande Study Region.

Migration and Site Fidelity

Figure 198 illustrates a generalized seasonal migration pattern for Pelican BCA6 relative to coastal zones. Migration north began on March 25, 2019, and was continuous to Galveston Bay, TX. This pelican mainly roosted on North Deer Island and traveled around the region from this island. On May 24, 2019, the pelican traveled north to Calcasieu Lake, where it roosted on Rabbit Island beginning on May 31, 2019, and occasionally roosted on nearby oil rigs and anthropogenic structures off the coast. This pelican displayed high site fidelity through August 24, 2019, when it began migration south. It is likely that this pelican bred and nested on Rabbit Island.

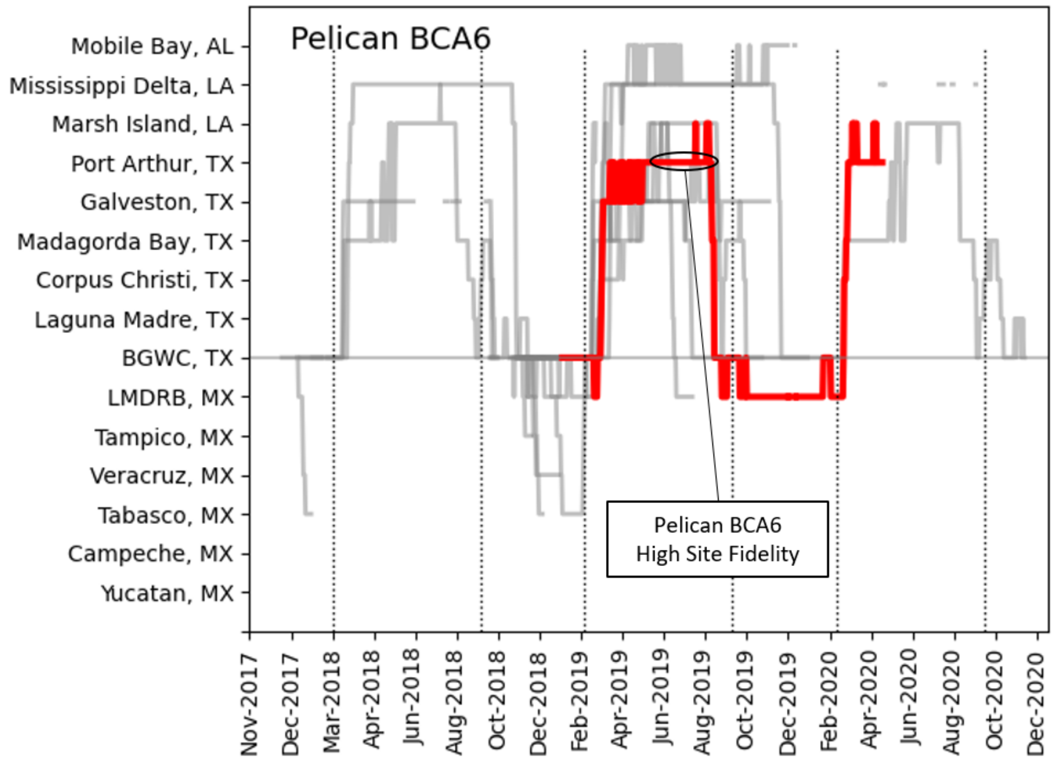


Figure 198. Seasonal Migration Pattern for Pelican BCA6 by Coastal Zone over Time. The y-axis represents each coastal zone (Figure 143). The horizontal line represents the BGWC study region. The vertical lines represent March 1st and September 1st of each year during the survey. The red line represents Pelican BCA6. High site fidelity (potential nesting site) was exhibited within the Port Arthur, Texas coastal zone. The circle indicates the general time range that high fidelity was observed.

After a continuous migration south, pelican BCA6 reached the BGWC study region where it primarily roosted on islands in Bahia Grande and traveled south into Mexico, as far as El Mezquital, MX regularly. Local movement patterns differed from the previous wintering season in that this pelican used the Bahia Grande roost islands as often or more than the Laguna Madre islands, whereas the previous season, it did not travel to the Bahia Grande (see Appendix II).

Pelican BCA6 began its 2020 continuous breeding migration north on March 10, 2020, and reached the destination of Rabbit Island, LA on March 20, 2020, and had high site fidelity until tracking expired.

PELICAN A25A

Date Caught:	January 30, 2019
Location Caught:	Jim's Pier, South Padre Island, TX
Days Active:	287
Migration:	Yes

Pelican A25A was captured on January 30, 2019 and stopped transmitting on November 13, 2019. This individual was in the study for 287 days. Major clusters of observations and areas of activity were in the Bahia Grande study region; the Rio Grande estuary region; Playa Bagdad, MX; Matagorda Bay, TX; and densely within the Galveston Bay region (Figure 199).

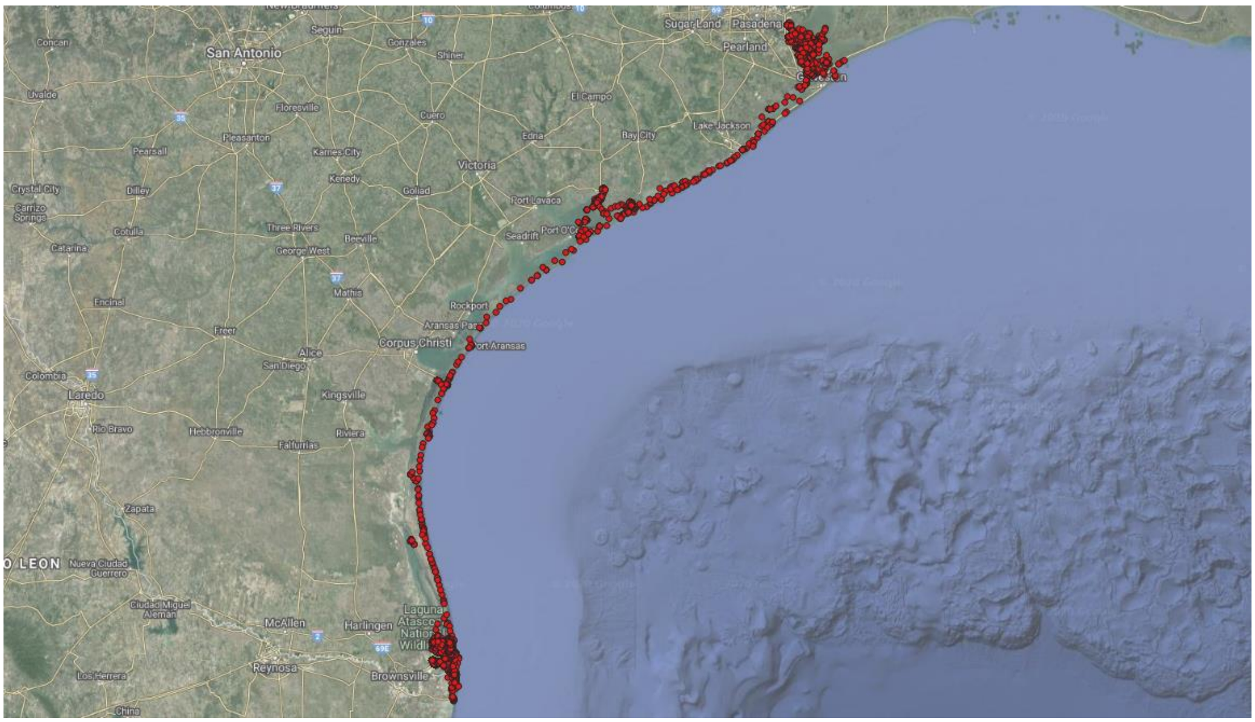


Figure 199. All GPS Observations of Pelican A25A.

Movement in the BGWC Study Region

Within the Bahia Grande region, the pelican's movement was largely between the Laguna Madre spoil island and the western coast of South Padre Island, as well as in Port Isabel and surrounding Port Isabel Channel and Port Isabel Side Channel, and the PI-BSC island. This individual also traveled along the BSC and crossed SH 48 into the Bahia Grande (Figure 200).

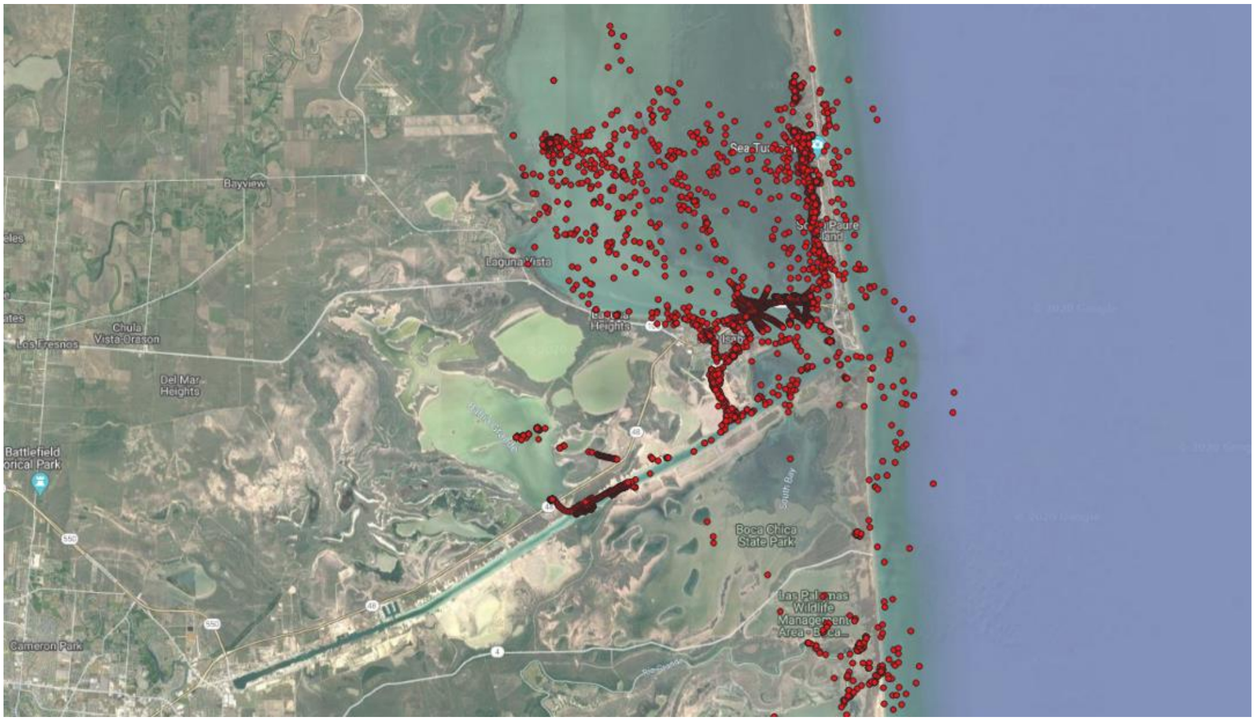


Figure 200. Pelican A25A Activity within the Bahia Grande Study Region.

Migration

Figure 201 illustrates a generalized seasonal migration pattern for Pelican A25A relative to coastal zones. Pelican A25A started a continuous north migration on April 6, 2019 and ended at Galveston Bay on April 9, 2019. In Galveston Bay, this pelican stayed locally within islands, docks, and points in the bay, especially near Moses Lake and North Deer Island.

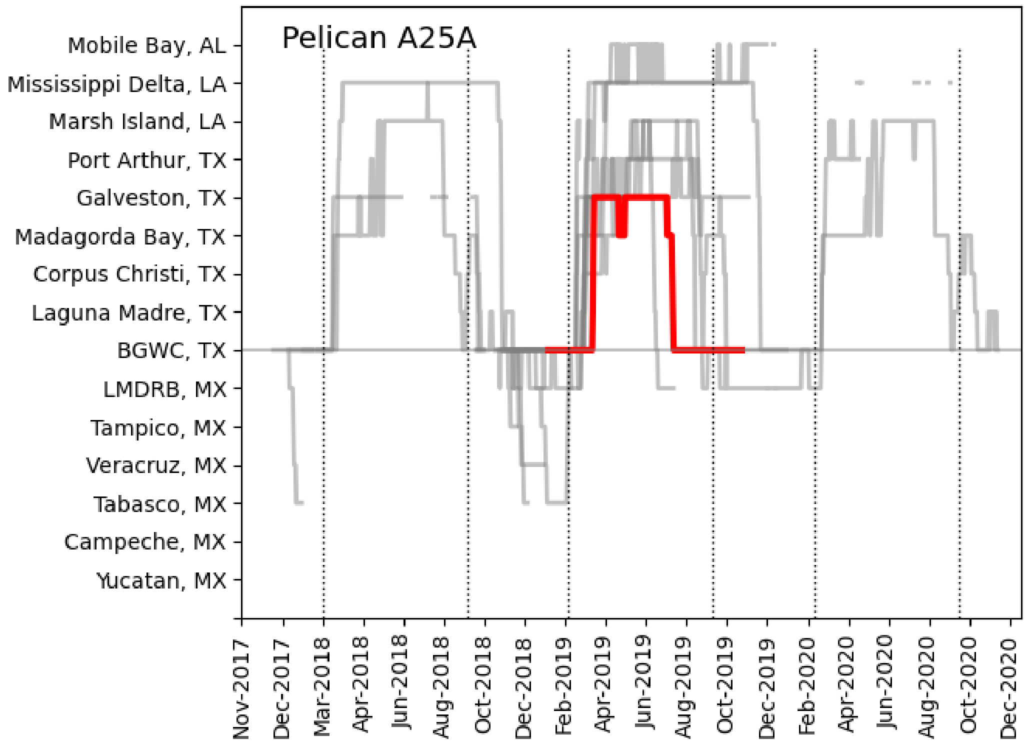


Figure 201. Seasonal Migration Pattern for Pelican A25A by Coastal Zone over Time. The y-axis represents each coastal zone (Figure 143). The horizontal line represents the BGWC study region. The vertical lines represent March 1st and September 1st of each year during the survey. The red line represents Pelican A25A. The gray lines show the seasonal movement of the other pelicans in the study.

On May 15, 2019, Pelican A25A began the movement south to Matagorda Bay and stayed there until August 2, 2019, before continuing south to the study region. This pelican reached the BGWC study region on August 4, 2019. There, it mostly roosted on the Laguna Madre island and returned to similar regional movement patterns, but occasionally made larger day trips to Playa Bagdad, MX. In the Bahia Grande study region, 90 percent of roosting observations were on the Laguna Madre island, 5-10 percent of roosting was on Bahia Grande islands, and 5-10 percent of roosting was in and near Port Isabel. This individual traveled to Playa Bagdad but did not appear to have roosted south of the study region.

PELICAN BDA6

Date Caught:	January 30, 2019
Location Caught:	Jim's Pier, South Padre Island, TX
Days Active:	31
Migration:	No

Pelican BDA6 was captured on January 30, 2019 and stopped transmitting on March 2, 2019. This individual was in the study for 31 days and did not leave the BGWC study region while it was tracked (Figure 202).

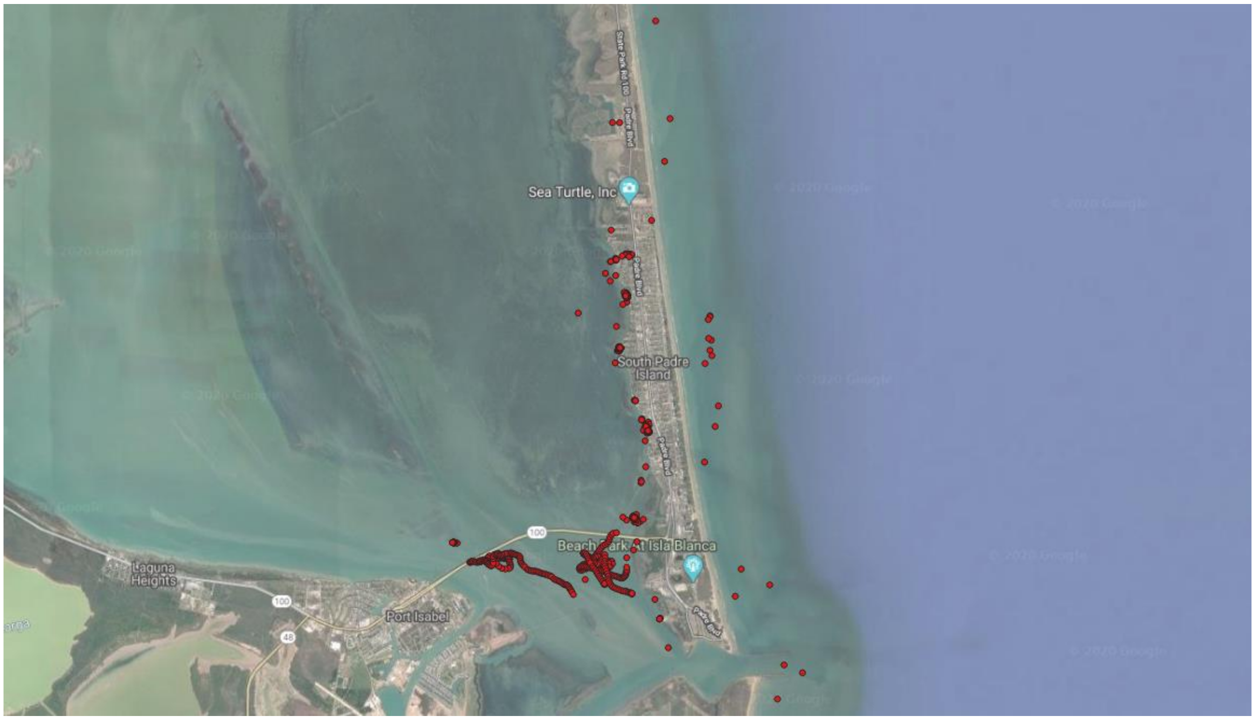


Figure 202. All GPS Observations of Pelican BDA6.

Movement in the BGWC Study Region

The main clusters of observations and activity are near the Queen Isabel Causeway where the pelican passed through the geofence[29] while crossing or flying near the bridge. The individual also traveled along the western and eastern coast of South Padre Island.

[29] A geofence area was set up to collect high frequency GPS-location data in the vicinity of Queen Isabella Causeway.

PELICAN A15A

Date Caught:	February 18, 2019
Location Caught:	Del Rey Boat Ramp, Arroyo City, TX
Days Active:	134
Migration:	Yes

Pelican A15A was captured on February 18, 2019 and stopped transmitting on July 2, 2019. This individual was in the study for 134 days. Major clusters of observations and areas of activity were in the Padre Island National Seashore; Galveston Bay; and the Calcasieu Lake region towards the town of Pelican Island (Figure 203).

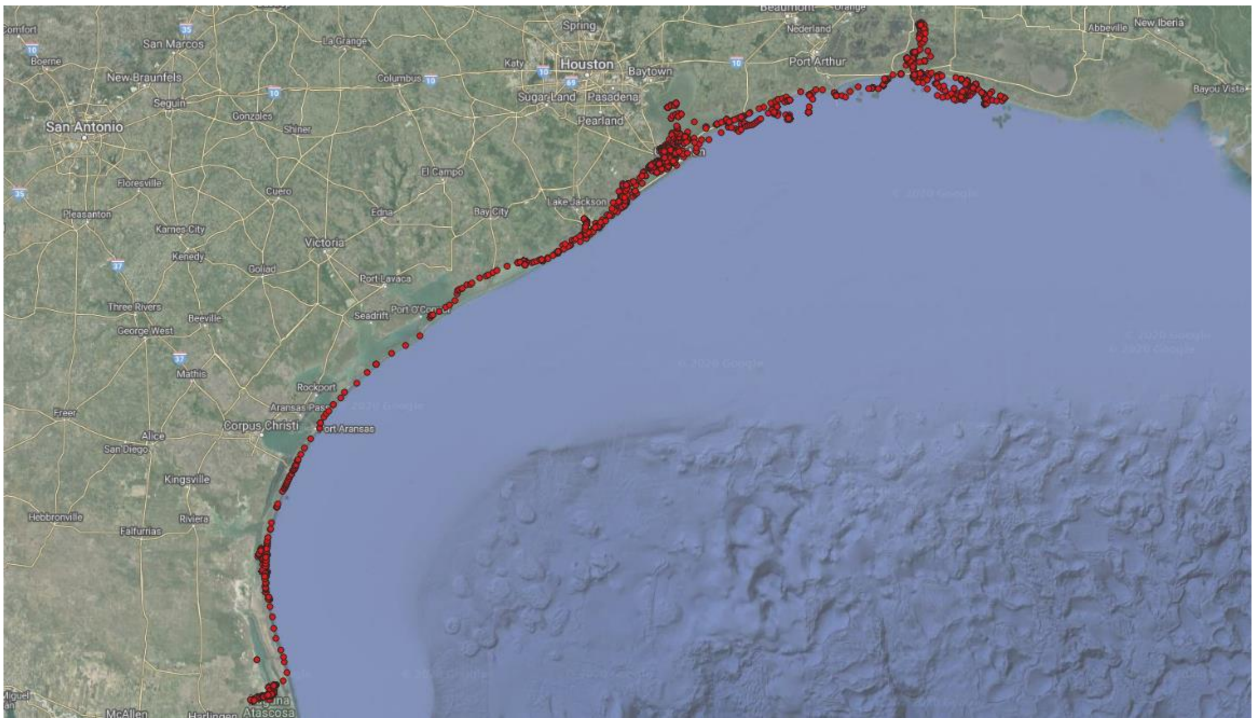


Figure 203. All GPS Observations of Pelican A15A.

Movement in the BGWC Study Region

The furthest south this individual was observed was near Arroyo City and along the Arroyo Colorado inland. It traveled between the protected roost site between South Padre Island and Arroyo City and regularly down the Arroyo Colorado.

Migration

Figure 204 illustrates a generalized seasonal migration pattern for Pelican A15A relative to coastal zones. This pelican began migrating north from the Arroyo City region on March 21, 2019, up to Galveston Bay, which it reached on March 27, 2019, and stopped along Padre Island and Matagorda Bay along the way. On June 9, 2019, through June 19, 2019, this individual continued up the coast to Calcasieu Lake. As this individual did not roost within the Bahia Grande study region, most roosting observations were in Galveston Bay and Calcasieu Lake.

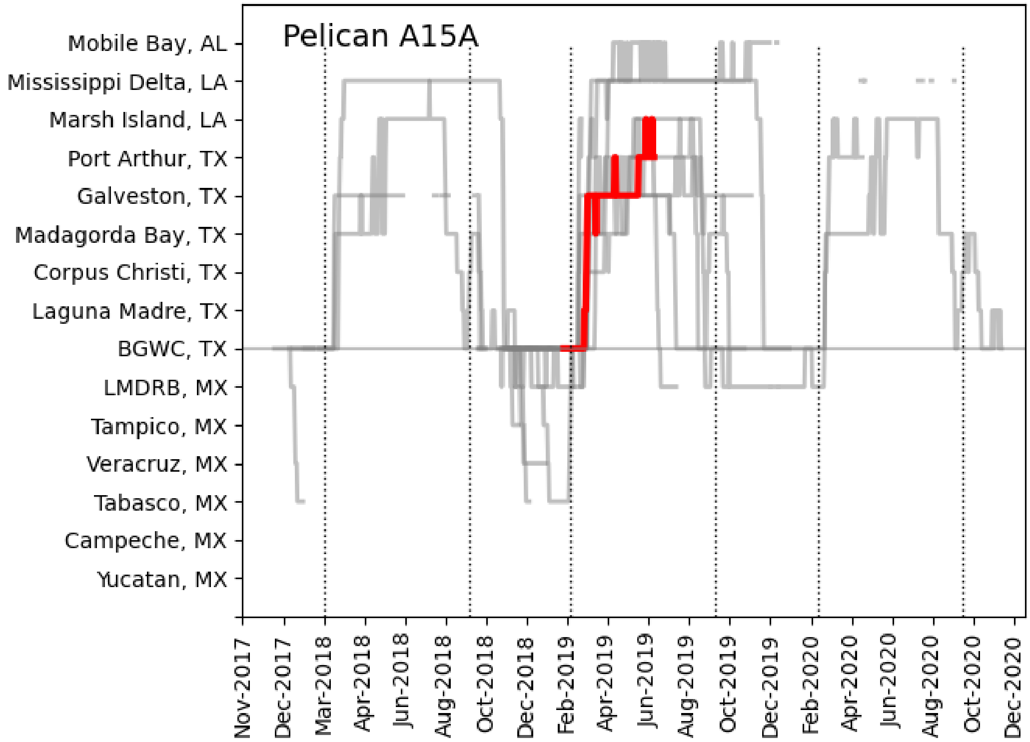


Figure 204. Seasonal Migration Pattern for Pelican A15A by Coastal Zone over Time. The y-axis represents each coastal zone (Figure 143). The horizontal line represents the BGWC study region. The vertical lines represent March 1st and September 1st of each year during the survey. The red line represents Pelican A15A. The gray lines show the seasonal movement of the other pelicans in the study.

PELICAN B8A6

Date Caught:	February 19, 2019
Location Caught:	Pompano Park, Port Isabel, TX
Days Active:	24
Migration:	No

Pelican B8A6 was captured on February 19, 2019 and stopped transmitting on March 15, 2019. This individual was in the study for 24 days and did not leave the BGWC study region in the duration it was tracked (Figure 205).

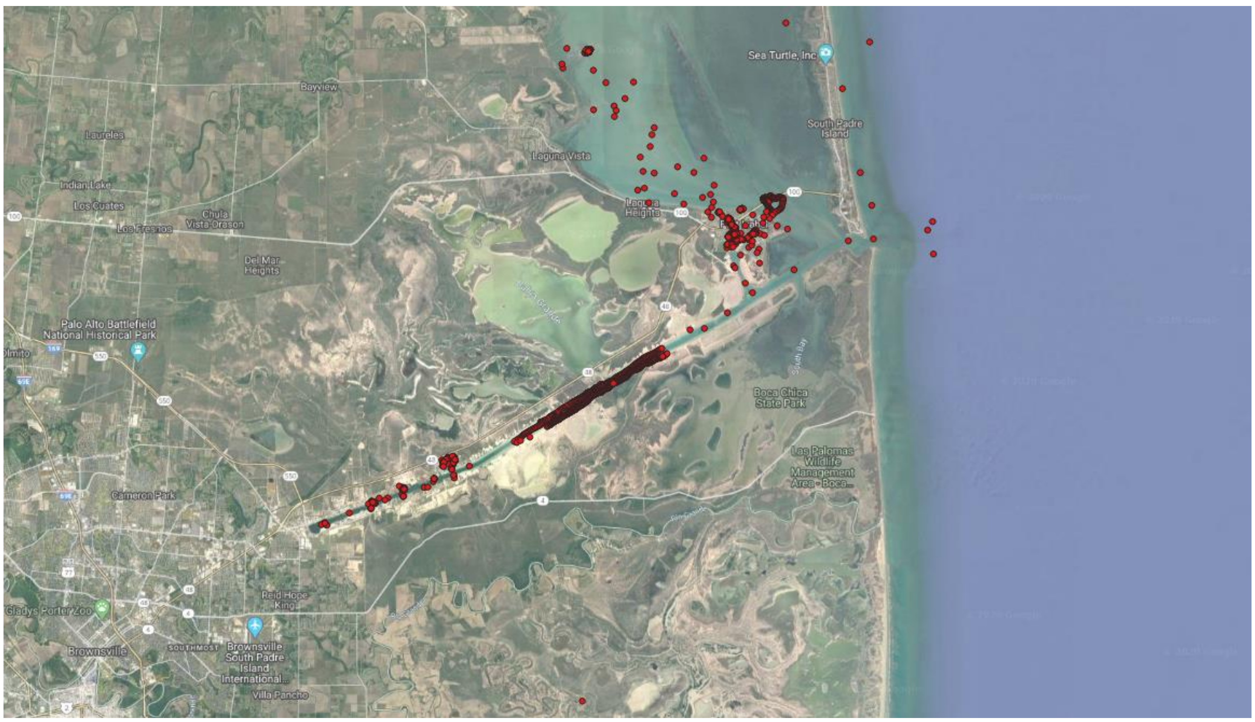


Figure 205. All GPS Observations of Pelican B8A6.

Movement in the BGWC Study Region

This individual mainly traveled between the Laguna Madre, Port Isabel, Port Isabel Channel, Port Isabel Side Channel, and the BSC Shrimp Basin (see Appendix II). It used the BSC to travel in between Port Isabel roosting sites and the Shrimp Basin, and it traveled the length of the BSC to loaf on docks near the end. Pelican B8A6 also crossed the Queen Isabella Causeway within the geofenced area.

This individual mostly roosted on the coast of the Port Isabel Channel approximately 60 percent of the time, and in Laguna Madre 30 percent of the time. Very occasionally, this pelican roosted on docks near the end of the BSC.

PELICAN BBA6C

Date Caught:	February 19, 2019
Location Caught:	Pompano Park, Port Isabel, TX
Days Active:	274
Migration:	Yes

Pelican BBA6C was captured on February 19, 2019 and stopped transmitting on November 20, 2019. This individual was in the study for 274 days. The pelican traveled from Matagorda Bay to the Port Arthur region, with the densest cluster of observations and activity in West Bay of the Galveston region (Figure 206).

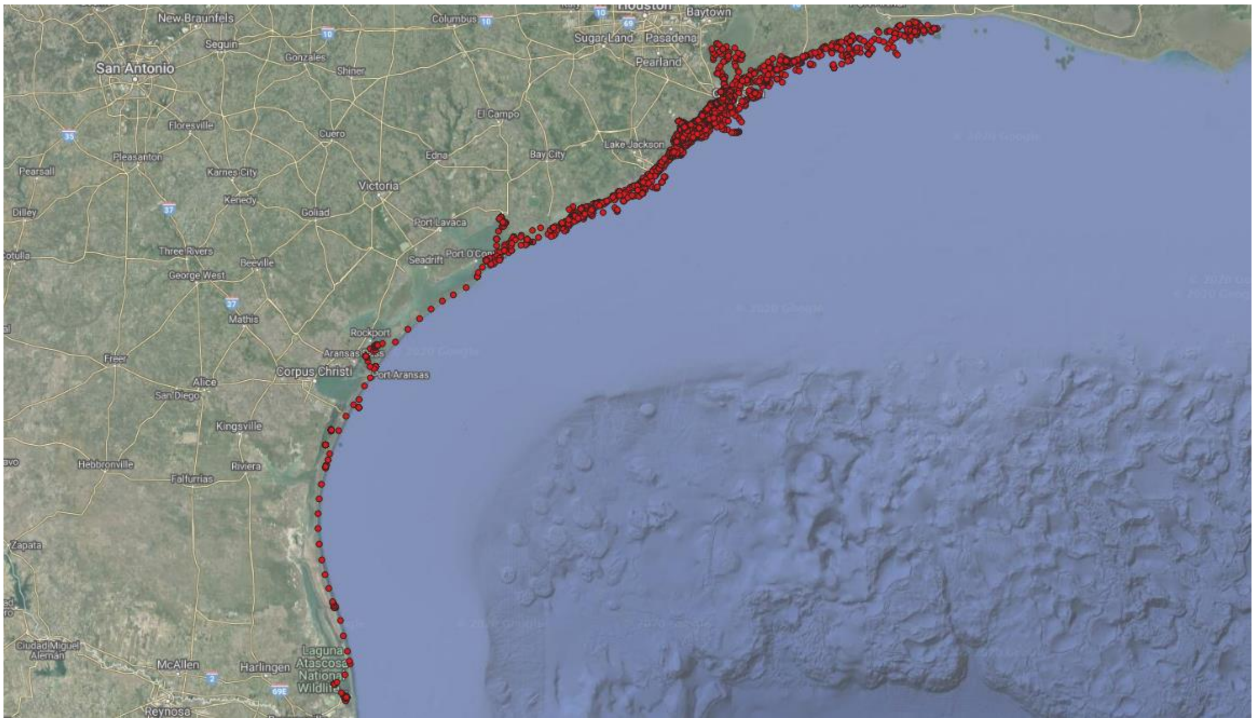


Figure 206. All GPS Observations of Pelican BBA6C.

Movement in the BGWC Study Region

Within the BGWC study region, most observations occurred in Port Isabel (Figure 207). Almost all roosting observations were on the island in the Port Isabel Channel and this pelican displayed high roost site fidelity.

Figure 207. Pelican BBA6C Activity within the Bahia Grande Study Region.

Migration

Figure 208 illustrates a generalized seasonal migration pattern for Pelican BBA6C relative to coastal zones. Pelican BBA6C began a continuous migration beginning March 25, 2019, to the West Bay Galveston region. It reached the West Bay Galveston region on March 30, 2019 and traveled widely within the Galveston region. It exhibited high roosting site fidelity to several small islands in West Bay, including North Deer Island and other smaller islands. However, the pelican moved between these few islands regularly and made several long-distance trips up and down the coast for a few days each, so it is unlikely that it was nesting or breeding (see Appendix II).

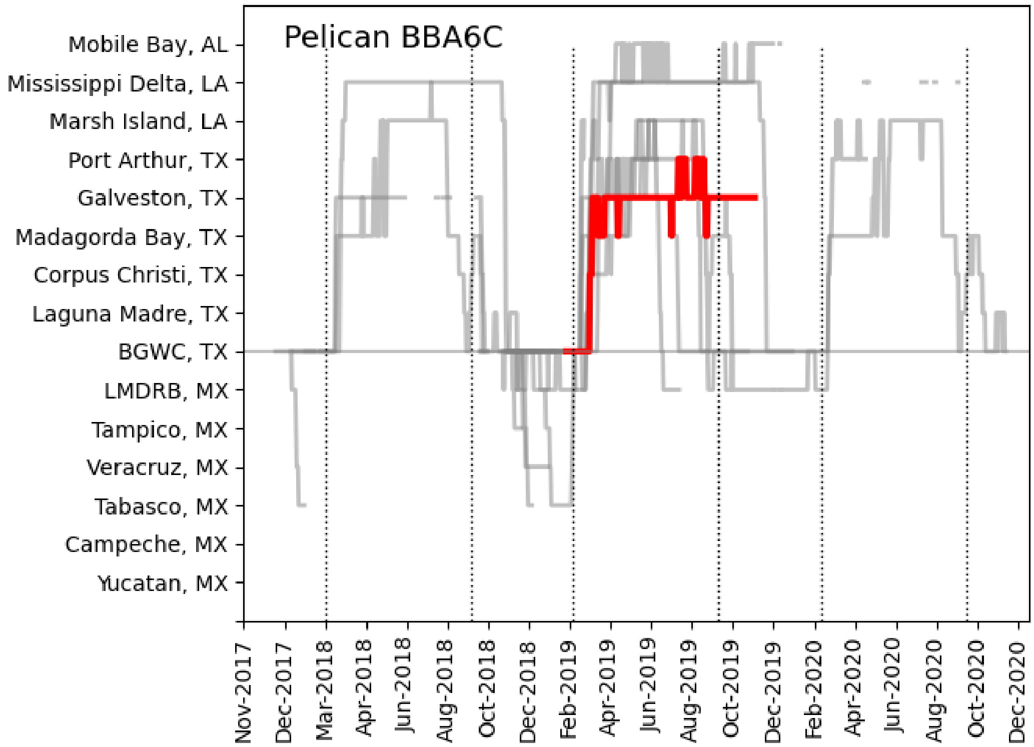


Figure 208. Seasonal Migration Pattern for Pelican BBA6C by Coastal Zone over Time. The y-axis represents each coastal zone (Figure 143). The horizontal line represents the BGWC study region. The vertical lines represent March 1st and September 1st of each year during the survey. The red line represents Pelican BBA6C. The gray lines show the seasonal movement of the other pelicans in the study.

PELICAN BAA6

Date Caught:	February 21, 2019
Location Caught:	Del Rey Boat Ramp, Arroyo City, TX
Days Active:	104
Migration:	Yes

Pelican BAA6 was captured on February 21, 2019 and stopped transmitting on June 5, 2019. This individual was in the study for 104 days. Most observations were north of the study region along the Arroyo Colorado and nearby islands in the Laguna Madre, with the largest cluster in the Port Fourchon region of Louisiana (Figure 209).

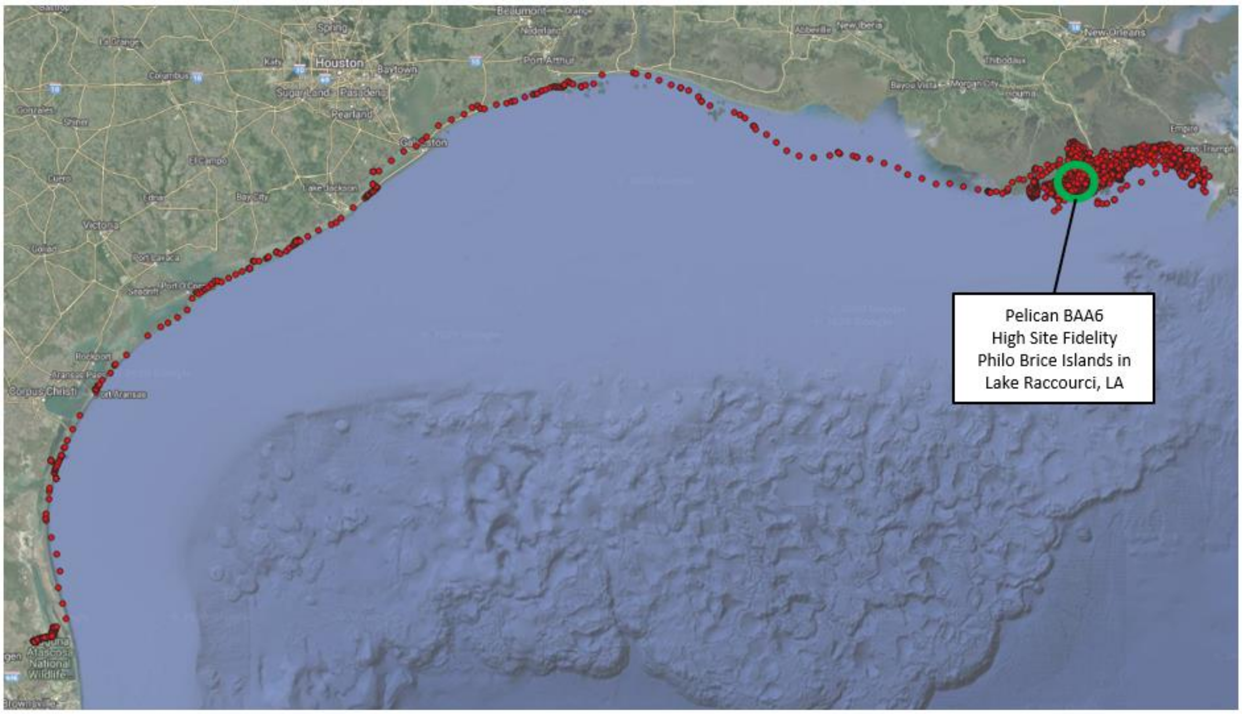


Figure 209. All GPS Observations of Pelican BAA6.

Movement in the BGWC Study Region

After being tagged, Pelican BAA6 remained in the study region for approximately 31 days. Before migration north, this individual traveled down and back the Arroyo Colorado daily from a possible roost site located in the center of the Laguna Madre west of the Arroyo Colorado delta.

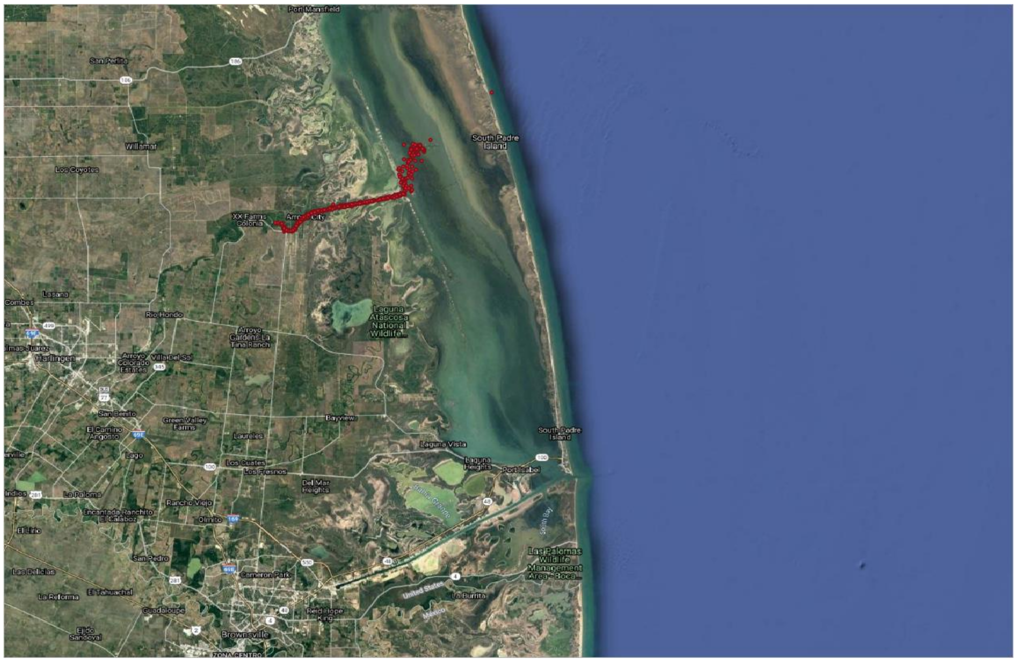


Figure 210. Pelican BAA6 Activity within the Bahia Grande Study Region.

Migration and Site Fidelity

Figure 211 illustrates a generalized seasonal migration pattern for Pelican BAA6 relative to coastal zones. Beginning March 24, 2019, this pelican migrated mostly continuously north to Louisiana, which it reached on March 31, 2019, and spent the bulk of the tracked time in the Port Fourchon and southern Louisiana peninsula regions. There was high site fidelity on the roost island of Philo Brice Islands near Port Fourchon from early April through the expiration of tracking (see Appendix II). It is likely this pelican nested and bred on the Philo Brice Islands.

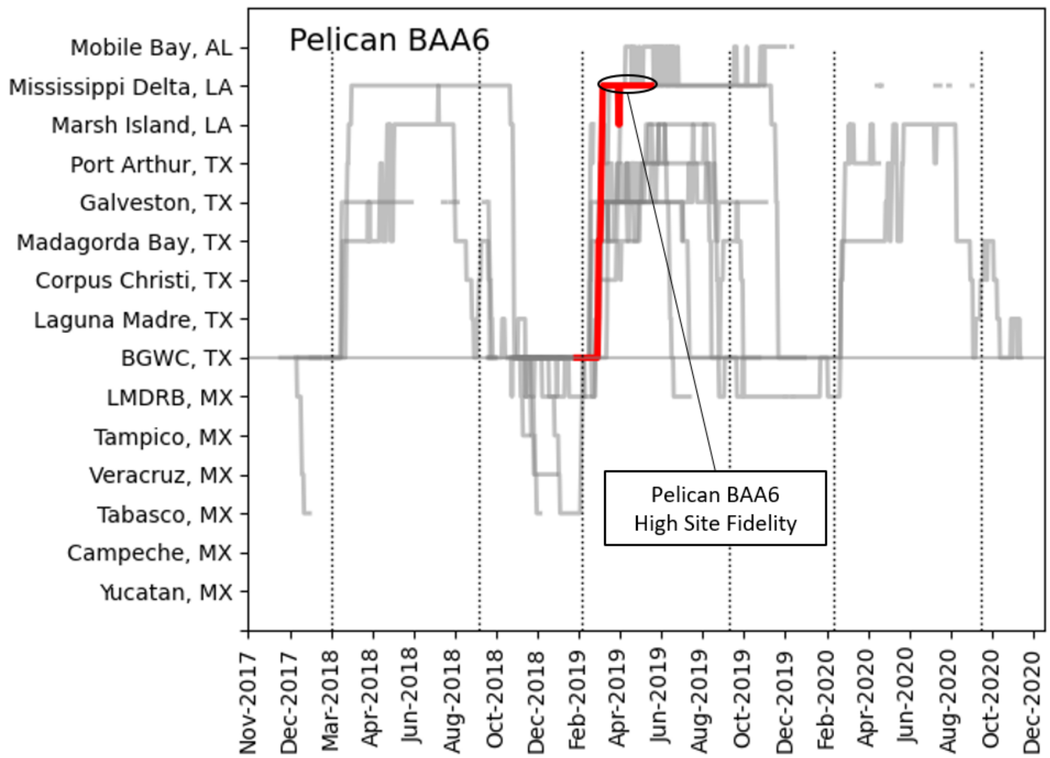


Figure 211. Seasonal Migration Pattern for Pelican BAA6 by Coastal Zone over Time. The y-axis represents each coastal zone (Figure 143). The horizontal line represents the BGWC study region. The vertical lines represent March 1st and September 1st of each year during the survey. The red line represents Pelican BAA6. The gray lines show the seasonal movement of the other pelicans in the study. High site fidelity (potential nesting site) was exhibited within the Mississippi Delta, Louisiana coastal zone. The circle indicates the general time range that high fidelity was observed.

APPENDIX IV. GENERATING SIMULATED MARK-RESIGHT DATA

The researchers used the following basic procedure to generate simulated mark resight data for a virtual population of birds:

1. Parameters are defined to represent the processes of Survival (S), resight probability (P), and migration (M). Variables are also defined to represent the duration of the virtual study (T = number of survey intervals) and the size of the banded population (N = number of banded birds).

Steps 2 to 7 are repeated for N simulated birds:

2. Two empty vectors of integers were created to store data for each of the T survey periods throughout the simulated mark-resight experiment. The first array is initialized to store the actual state of the bird at each simulated survey period ST = [$ST_{t=0}$, $ST_{t=1}$,…$ST_{t=T}$]. The integer values for ST represent one of three possible states (0 = dead, 1 = Alive and within the study area, 2 = Alive and outside study area) The second array is initialized to store whether a simulated bird was resighted during a survey period O = [$O_{t=0}$, $O_{t=1}$,…$O_{t=T}$].

3. At time t=0, the state of the bird is set to 1 (indicating that it was caught in the study region, and by definition, alive).

4. The state of the bird at time t+1 is calculated using the state at time t and the values of parameters S to determine survival and M migration. First, a random number was drawn from a uniform distribution with the interval (0,1). If this value is greater than the parameter value S, the ST_{t+1} is set to the value 0 (i.e., dead) at this point the simulation for the bird stops. If the bird survives, a second random number is drawn and compared against the migration parameter M to determine whether the bird switches state or remains in the same state (i.e., if ST_t is 1, the state at ST_{t+1} is 2 and vice versa).

5. The probability of observing a bird at O_t was determined by both ST_t and the parameter P. For example, to simulate a situation where birds can only be observed within the study region:

   If Uniform (0,1) < P and STt equals 1, Ot is set to 1 (indicating a resight)

   Otherwise, O_t is set to 0 (indicating no resight).

6. Steps 3 and 4 were repeated for each simulated observation/survey period (or until the bird is simulated to be in the dead state).

7. The ST and O arrays were saved to text files. The O array represents the resight history of a simulated bird. The ST array represents the true state of the bird.

The pseudocode above was adjusted slightly to accommodate slightly different model processes and to constrain migration to certain dates and certain individuals.

Table 15 shows the parameterization of the simulation model used to test the statistical models outlined in the mark-resight analysis chapter. In this form of the simulation model, additional state variables were introduced (probabilistically) to indicate whether an individual was a migratory or non-migratory individual and to determine emigration and immigration dates. Each of these quantities was set probabilistically when each bird was initialized. The migration arguments in step 4 were changed to model a case where the bird changes state (ST) from the study area to the non-study area corresponding to its predetermined emigration/immigration dates.

The simulation model was also extended to enable virtual banded birds to be introduced to the population over a period rather than all on the same day (as was the case in the field mark-resight data). And in practice, details were added to the pseudocode to help post analyze the simulated mark-resight data (e.g., adding dates to sample periods and unique IDs to birds).

Table 15. Description of Parameters Used to Simulate Mark-Resight Data.

Parameter	Symbol	Description
Survival probability	S	Probability of surviving a survey period.
Resight probability	P	Probability of resighting a simulated bird during a survey period.
Migration probability	M	Proportion of migrating individuals.
Date of emigration	E_{date}	Date at which individuals in the population begin to emigrate from the study region.
Date of immigration	I_{date}	Date at which individuals in the population begin to immigrate from the study region.
Duration of emigration	$E_{duration}$	Duration of the population level emigration process.
Duration of immigration	$I_{duration}$	Duration of the population level immigration process.

APPENDIX V. ASSESSING THE ACCURACY OF ABUNDANCE ESTIMATORS

Testing statistical estimation methods on simulated data sets is a useful way of assessing their accuracy and validity. This section discusses how the researchers assessed the accuracy of population abundance estimators using simulated population data and the MM population model described in the previous section. This model uses parameters for the birth, death, development, and fecundity rates of brown pelicans to simulate temporal population dynamics. The model also simulates migration, including the magnitude (proportion of pelicans migrating) and timing of an annual migration from overwintering sites (i.e., the BGWC) to summer breeding grounds. Table 16 summarizes the parameters used to simulate population and resight survey data used to test the validity of the population estimation methods.

Table 16. Parameters Used to Generate Virtual Population and Resight-Abundance Data.

Parameter	Value	Notes
Initial pelican population size	3,000 birds	The population model was parameterized to simulate a relatively stable population of 3,000 pelicans.
Proportion of migrating pelicans	0.8	80 percent of pelicans simulated to emigrate from and return to the study area each year. Average migration date set to March 1 and October 31.
Initial banding period	300 days	Simulates 300 banded pelicans.
Bands per day	1	
Total sightings per location	Approximately 40	Approximately 40 total sightings per survey location.
Number of surveyed locations per sample date	5	Five separate survey locations simulated per sample date.
Number of surveys (number of days between surveys)	5	Surveys every three days.
Survey period	One year	Resulting in 365 (365/ 5 * 5) individual surveys over a year.

The pelican population and mark-resight simulation models were run using life history parameters outlined in Chapter 4 and an initial population size (N_{total}) of 3,000 pelicans. Life history parameters were chosen that lead to an approximately long-term stable population. The simulations were run based on seasonal migration, with 80 percent of the population emigrating to summer breeding grounds in March, followed by the same individuals (subject to survival) returning to the core study area in October.

Figure 212 shows the number of total and banded resighted birds simulated by the population model. This figure is analogous to Figure 70, which shows the same information derived from field data (rather than the simulated data shown here). Figure 213 shows the proportion of banded to total birds from the simulation. These data are analogous to the field data shown in Figure 71. The fundamental patterns of the simulated data match those of the field-collected data (and vice versa). Notably, the proportion of banded birds remains roughly constant throughout the surveys. However, the field data exhibit considerably more variability than the simulated data. Figure 214 shows the sighting frequencies from the population/abundance survey simulation. This figure is an analog of Figure 72, which displays the same information for the field-collected (real-world) data.

Figure 215 shows the accuracy of the Lincoln-Peterson method for estimating the simulated population size. In this figure, the red lines show the simulated population (the value of which is known and indisputable because it is a product of the simulation). In the lower graph, each dot represents the population estimated at each survey period. In the upper graph, the black dots show the population estimated for each month after averaging the estimates for each survey period to monthly values.

Figure 216 shows the accuracy of the modified MM method for estimating the simulated population size. The graph shows the true (known) population size (red line) relative to the estimated temporal population size (black line). The graph also shows approximate 95 percent confidence intervals for this estimate.

Figure 215 and Figure 216 show a good agreement between the known (simulated) population size and the estimates provided by the Lincoln-Peterson and the modified MM methods, respectively.

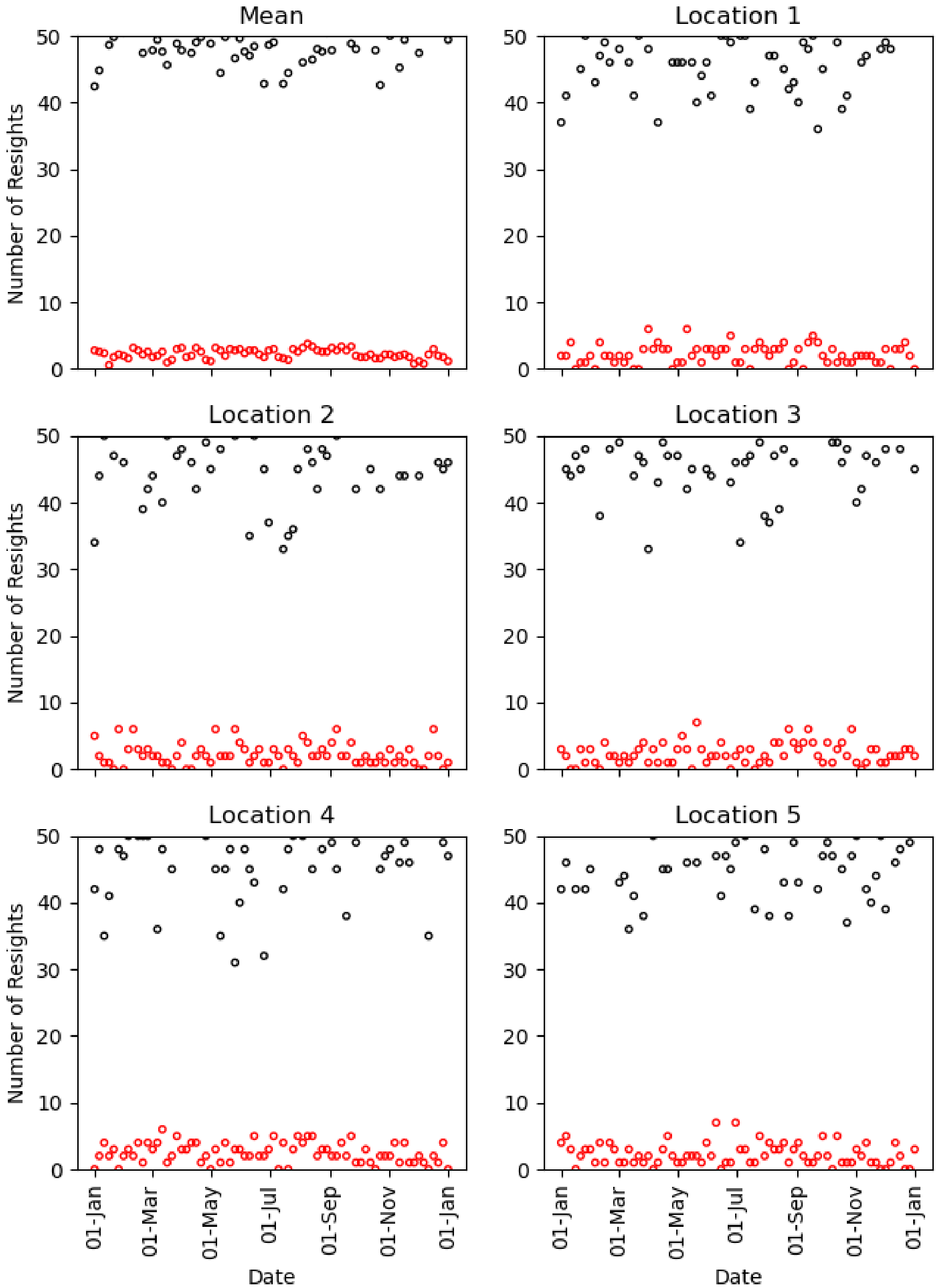


Figure 212. Number of Total (black circles) and Banded (red circles) Resighted Pelicans Simulated Using the Pelican Population Model with Migration. The top left graph shows the mean for all locations. The remaining graphs show the numbers simulated at each of five simulated survey locations.

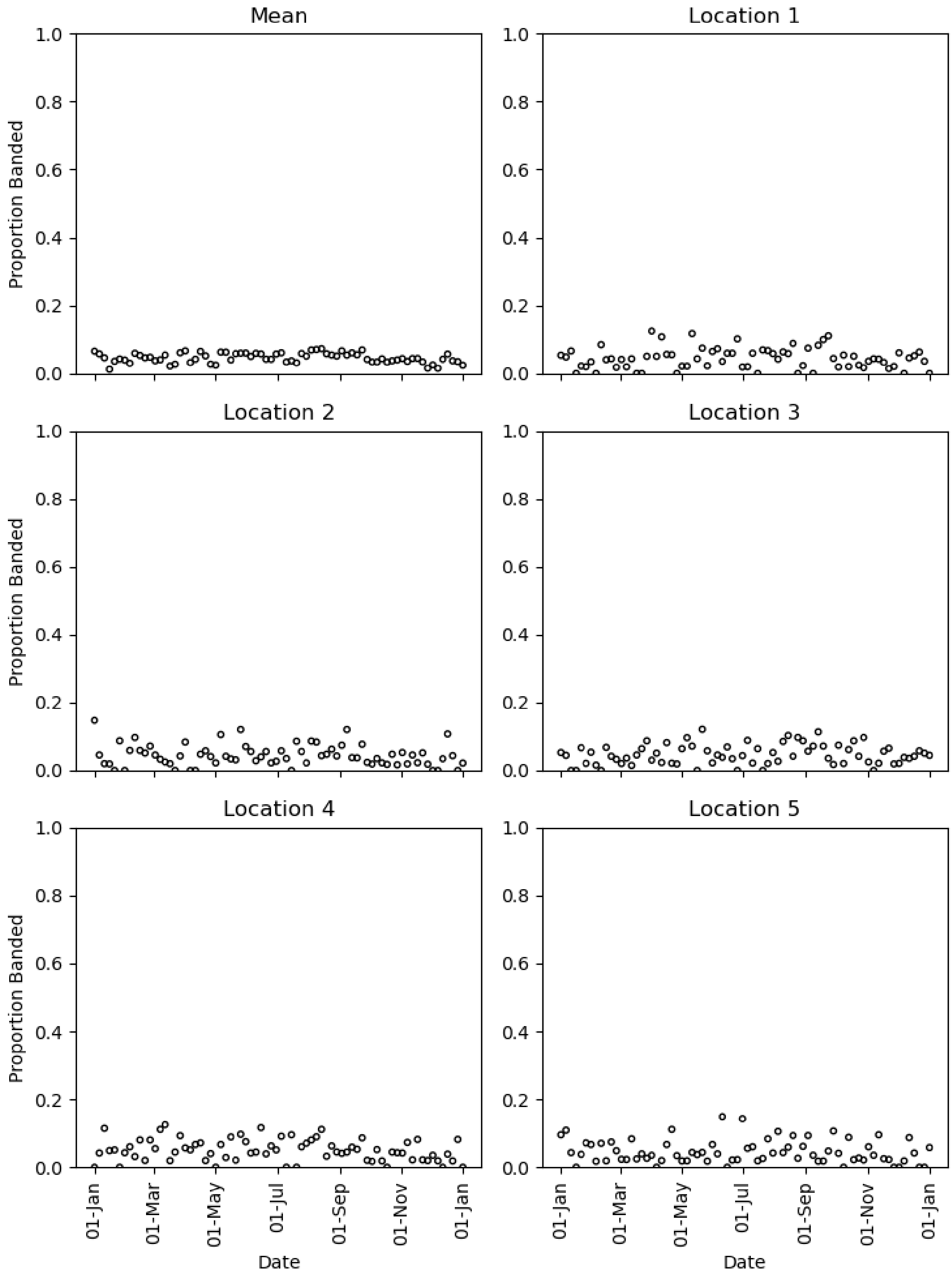


Figure 213. Proportion of Banded to Total Resighted Pelicans Simulated Using the Pelican Population Model with Migration. The top left graph shows the mean for all locations. The remaining graphs show the numbers simulated at each of five simulated survey locations.

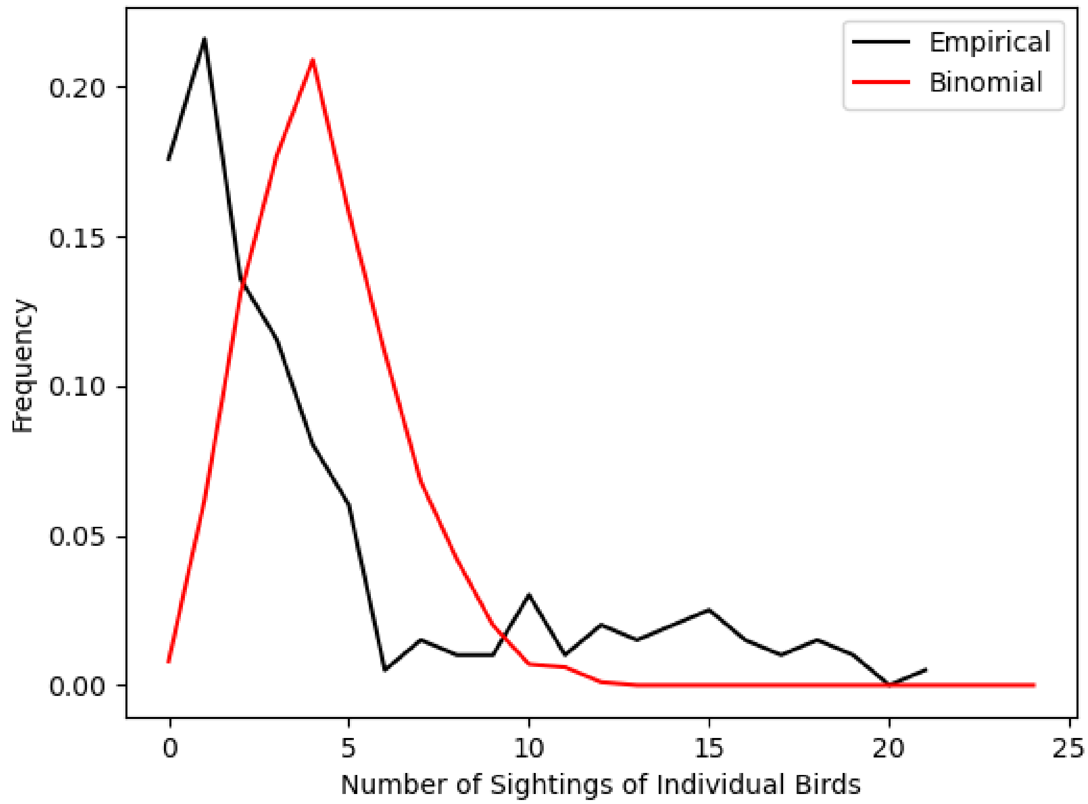


Figure 214. Sighting Frequencies of Banded Birds Simulated Using the Population Model. The black line shows the sighting frequencies derived from the simulated data. The red line shows sighting frequencies assuming all banded birds are sighted with equal probability (i.e., a binomial distribution).

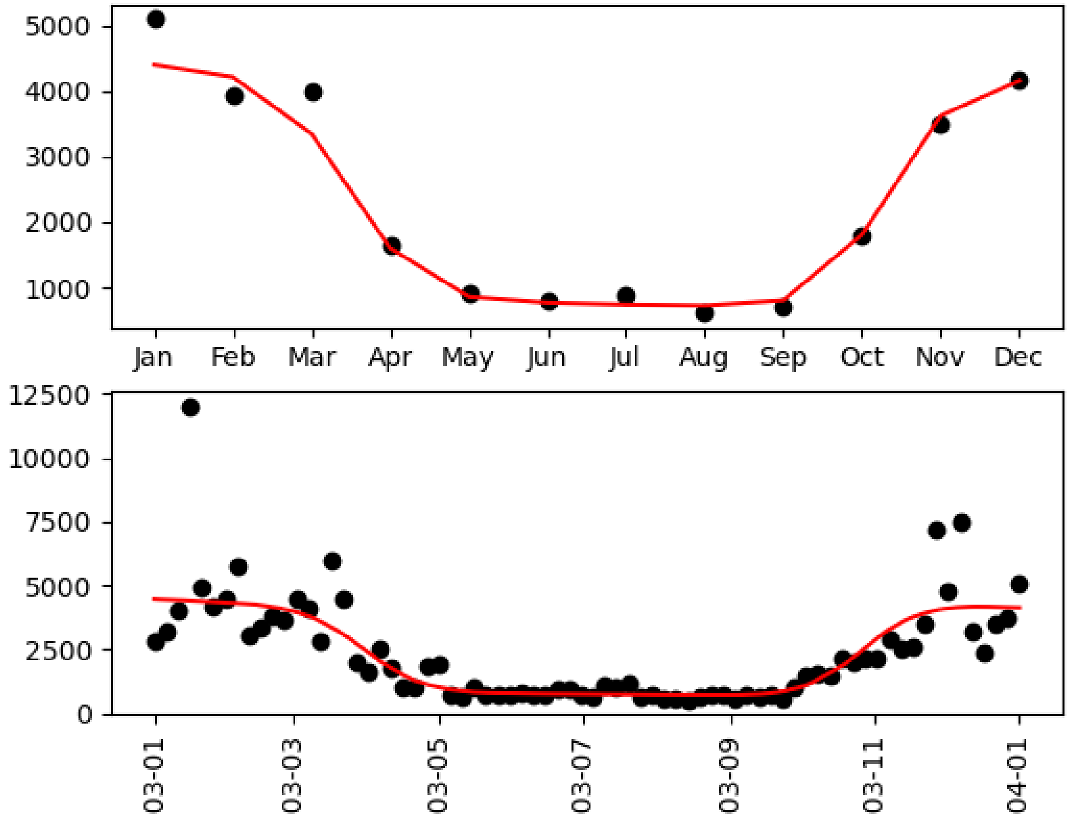


Figure 215. Lincoln-Peterson-Based Estimate of the Simulated Population Size. The black dots show the estimated population size. The red lines show actual (simulated) population size. The top graph shows the average monthly estimates. The bottom graph shows estimates for each virtual sample survey.

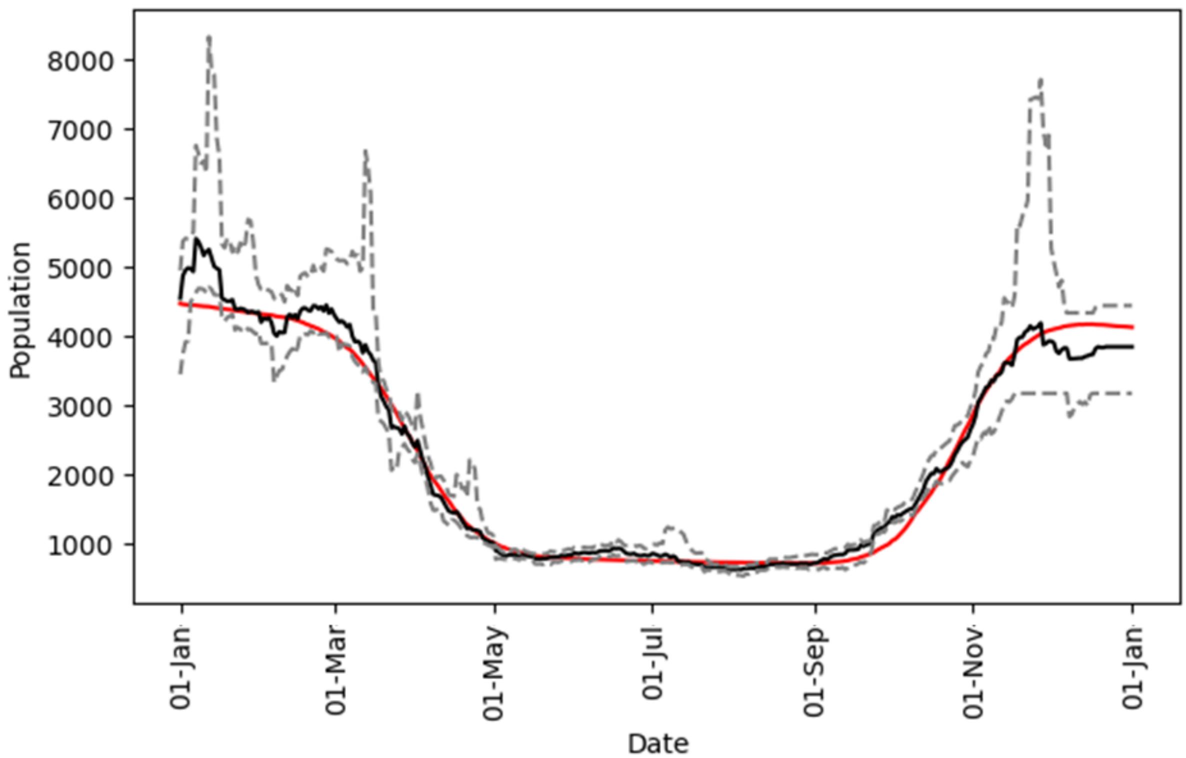


Figure 216. Time-Varying Estimates of a Simulated Population Using Modified MM Estimators with a Binomial Resight Frequency Distribution. The solid black line shows the estimated mean population size. The dashed gray lines show the estimated 95 percent confidence intervals. The red line shows the actual (known) time-varying population size.

APPENDIX VI. MODELING VEHICLE AND PELICAN INTERACTIONS

Understanding the interaction between vehicle traffic and pelicans is vital for the study of pelican mortality on SH 48. Strong north winds passing over the Carl Gayman Bridge create conditions that can cause northbound, low-flying pelicans passing over the bridge to suddenly crash onto the roadway. For as long as they remain on the roadway, downed pelicans are vulnerable to mortality and injury from passing motorists.

In this appendix, the TTI researchers develop simple models that can be used to estimate the likelihood of downed birds being hit by passing vehicles. Intuitively, several interacting factors determine risk of downed pelicans being hit by passing vehicles – these include the volume of traffic on the roadway, vehicle speed, and the ability of drivers to see pelicans at a distance that will enable them to react to the presence of the downed pelican, and then safely stop in time to avoid hitting the pelican.

To understand this, the TTI researchers developed models to evaluate vehicle-pelican collisions through explicit traffic simulations and through simpler mathematical models.

In the following sections, the research team outline a conceptual model of vehicle-pelican interactions based on traffic volume, vehicle speed, driver reaction time and physical stopping time and distance. The research team then implement this conceptual model using a traffic micro-simulation model that explicitly simulates the interactions among the relevant components of the conceptual model. In the final experimental section of this appendix, the research team reformulate the complex simulation model into a mathematical model. The mathematical model provides computational efficiencies and leads to a simpler analysis. The appendix concludes with a discussion of the implications of the model in the context of pelican mortality.

CONCEPTUAL MODEL OF VEHICLE-PELICAN INTERACTIONS

Figure 217 shows a conceptual view of the interaction between a driver (vehicle) and a pelican that crash lands on the road. The first component of the model is the distance between the pelican and the nearest upstream vehicle. This variable is driven by the volume/density of traffic on the road —which can be simulated for various traffic scenarios using SUMO—and the random timing and location of the downed pelican. The second component is the distance required for the driver to see the pelican and recognize it as an obstacle (detection or sight distance). The third component of the model is the driver reaction time—the time (or distance) it takes a driver to initiate an avoidance behavior such as deceleration. The fourth component of the model is the braking distance, which is driven by the ability of the vehicle to decelerate (given the state of the vehicle, road conditions, etc.).

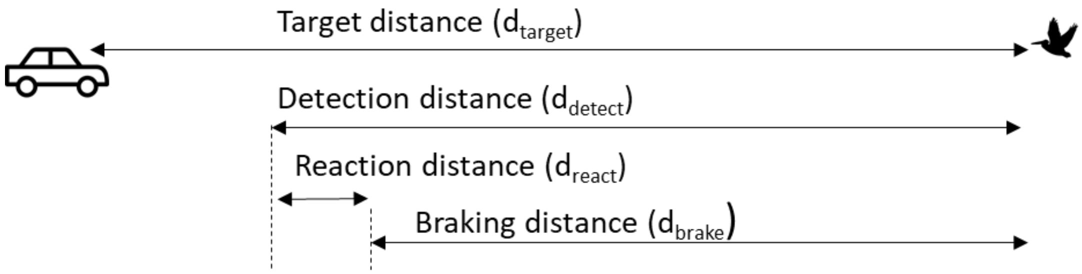


Figure 217. Model of the Interaction between a Vehicle and a Pelican on the Road.

Table 17 summarizes each component of the model and suggests factors that affect each. Note that this model is an extension of the standard stopping site distance model recommended by the American Association of State Highway and Transportation Officials (AASHTO). The model proposed by the TTI researchers for pelicans (and other wildlife) includes an explicit detection/sight distance component, whereas the AASHTO model assumes an object with a vertical height greater than two feet will have a detection distance greater than reasonable reaction time and brake distances. The AASHTO model is designed to be used differently than the extended model developed by the research team. The AASHTO model provides guidance for the minimum sight distance required along a roadway to enable a vehicle traveling at or near a design speed to stop before reaching a fixed object in its path. In contrast, the researchers extended model is intended to break down the elements of driver avoidance in the context of a pelican landing randomly on the road in front of oncoming vehicles. For completeness, AASHTO's recommended stopping sight distances are shown in Table 18.

Table 17. Factors Affecting the Stopping Distance of Drivers Reacting to Pelicans on the Road.

Model component	Contributing factors
Target distance	Traffic patterns, especially the size of gaps between vehicles.
Detection distance	Size and color of pelicans. Light conditions caused by weather and/or time of day. Eyesight of driver. Headlight efficacy (including low- or high-beam use).
Reaction distance	Driver attentiveness, experience, and physical health.
Braking distance	Speed of vehicle. Type of vehicle. Condition of vehicle. Road conditions (traction).

Table 18. AASHTO Recommended Stopping Sight Distances.

Metric					US Customary				
Design speed (km/h)	Brake reaction distance (m)	Braking distance on level (m)	Stopping sight distance Calculated (m)	Stopping sight distance Design (m)	Design speed (mph)	Brake reaction distance (ft)	Braking distance on level (ft)	Stopping sight distance Calculated (ft)	Stopping sight distance Design (ft)
20	13.9	4.6	18.5	20	15	55.1	21.6	76.7	80
30	20.9	10.3	31.2	35	20	73.5	38.4	111.9	115
40	27.8	18.4	46.2	50	25	91.9	60.0	151.9	155
50	34.8	28.7	63.5	65	30	110.3	86.4	196.7	200
60	41.7	41.3	83.0	85	35	128.6	117.6	246.2	250
70	48.7	56.2	104.9	105	40	147.0	153.6	300.6	305
80	55.6	73.4	129.0	130	45	165.4	194.4	359.8	360
90	62.6	92.9	155.5	160	50	183.8	240.0	423.8	425
100	69.5	114.7	184.2	185	55	202.1	290.3	492.4	495
110	76.5	138.8	215.3	220	60	220.5	345.5	566.0	570
120	83.4	165.2	248.6	250	65	238.9	405.5	644.4	645
130	90.4	193.8	284.2	285	70	257.3	470.3	727.6	730
					75	275.6	539.9	815.5	820
					80	294.0	614.3	908.3	910

Note: Brake reaction distance predicated on a time of 2.5 s; deceleration rate of 3.4 m/s^2 [11.2 ft/s^2] used to determine calculated sight distance.

TRAFFIC SIMULATION MODELING

The foundation of the research team's traffic simulation model is an open-source traffic microsimulation model called Simulation of Urban Mobility (SUMO). SUMO is designed to simulate traffic and traffic-routing behaviors for a range of applications including air quality and emissions analysis, automated and connected vehicle research, and travel behavior. SUMO contains inbuilt (off-the-shelf) functions and behaviors useful for modeling these transportation issues, but to the knowledge of the research team, the simulations have never been used to model vehicle-wildlife interactions.

To overcome the lack of inbuilt support for modeling vehicle-wildlife interactions, the research team developed algorithms (written in Python) to interact with the SUMO model and execute sub-models useful for this research. The approach is to use the sophisticated car-following and car-overtaking behavior of SUMO to predict vehicle behavior (speed, volume, density) on SH 48. Custom algorithms then translate these properties of the local traffic into metrics useful for understanding vehicle-wildlife collisions.

Figure 218 shows annotated screenshots from SUMO with a simple roadway network developed to represent SH 48. SUMO keeps track and iterates individual vehicles on the network using rules that describe how each vehicle interacts with the roadway network (e.g., junctions, road geometry, and speed limits) and with other vehicles (e.g., car following, overtaking, or yielding at junctions). The network shown in Figure 218 represents the modeling-relevant details of the SH 48 case-study such as the number of lanes, speed limits, geometry, junctions[30]. The simulation also requires traffic to be generated on the modeled roadway network. Each vehicle in

[30] Although the background polygons that delineate the Bahia Grande, ship channel and Gayman channel are superficial to the simulations, they have been included to provide context and scale.

the model can be generated with a set of parameters that affect how it behaves on the network. For example, an aggressive driver can be simulated by setting behaviors that cause the driver to drive at fractionally higher speeds, with relatively high acceleration and deceleration rates, or that follow closer to other vehicles. The models that drive these vehicle behaviors are well established and widely used, such that default and customized parameter sets are available and tractable. The parameters of each vehicle are set when the vehicle is generated on the network but can also be dynamically modified (by the researchers) during the simulation. For example, to simulate the effect of a warning sign on traffic activity, an algorithm can be developed that shows a specified percentage of randomly selected vehicles on a specified section of the roadway network that will slow in response to the warning sign, while others do not.

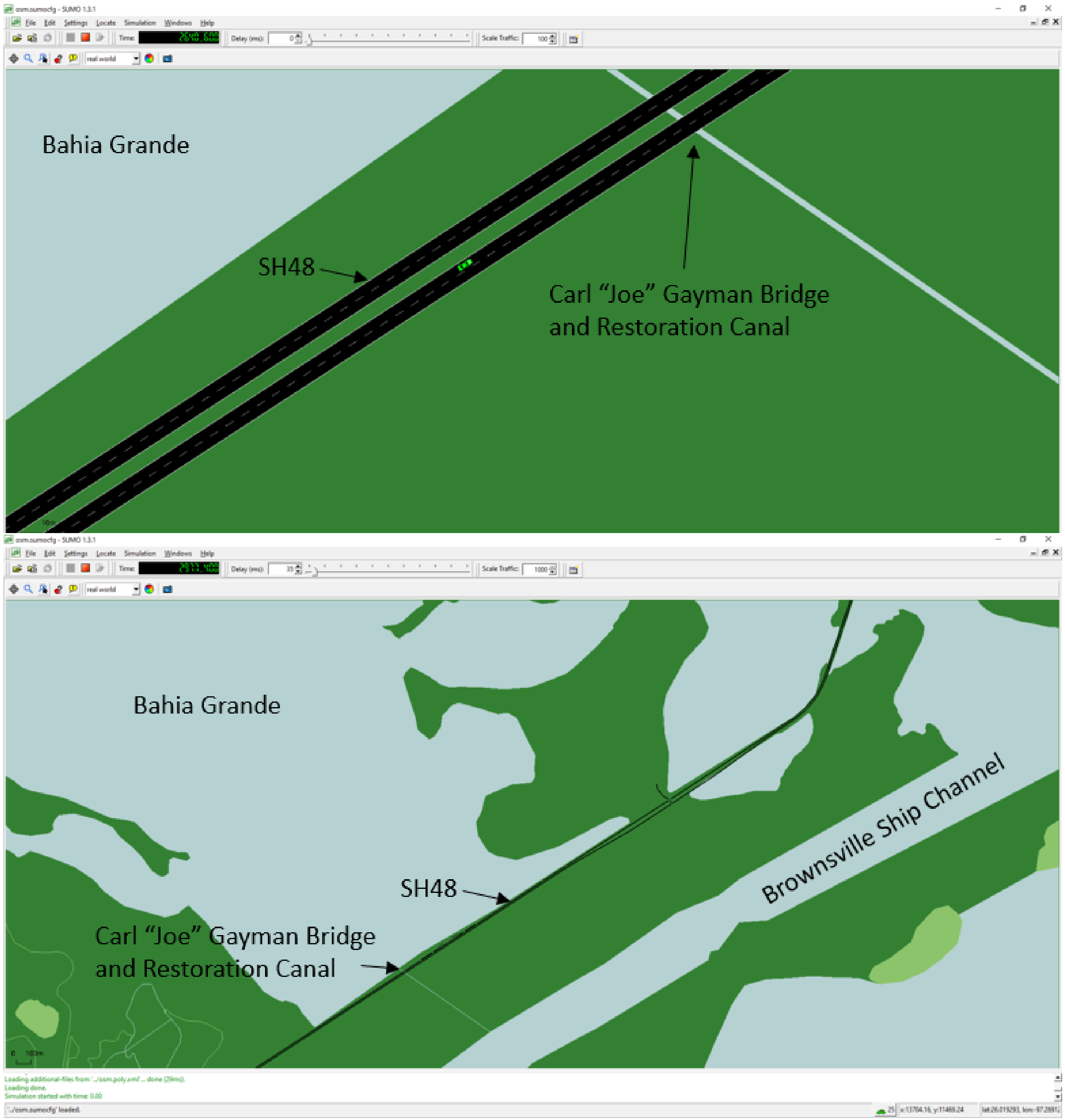


Figure 218. Annotated Screenshots from Simulation of Urban Mobility (SUMO) Software Used in the Vehicle-Pelican Interaction Model.

Simulation Modeling Approach

The research team's approach to modeling and exploring the interactions between downed pelicans and traffic are as follows:

Step 1 Design/construct a simulation scenario and simulate traffic/vehicle activity using SUMO.

Step 2 Randomly generate the time and position of 'downed' pelicans in the simulation. Collect information on the vehicles upstream of the 'downed' pelican (e.g., the distance of nearest vehicles to the pelican, vehicle speed, and the lane the vehicle is traveling on).

Step 3 Use the information from Step 2 to simulate the stopping behavior of the driver/vehicle (using custom algorithms developed independently of SUMO).

To illustrate these steps and explore the interaction among variables in the model, the researchers simulated the effect of average vehicle speed and traffic volume on vehicle-pelican collisions. SUMO was used to simulate vehicle speeds between 30 and 80 mph over the modeled network. Each speed scenario was run with traffic volumes of 100 and 500 vehicles per hour. During each simulation, the researchers simulated multiple downed pelicans (single pelicans falling on the road at random location and time) and for each of these events, extracted key vehicle information from the simulation (e.g., vehicle speed, location relative to the downed pelican). Each simulated downed pelican incident (for each speed and volume scenario) was stored in a database.

Figure 219 and Figure 220 show probability histograms of the distance between simulated downed pelicans and closest upstream vehicle (A), and the speed of the closest upstream vehicle for each simulated pelican incident at the time the pelican enters the road (B). Figure 219 shows data extracted from a simulation using a vehicle volume of 500 vehicles per hour and a speed limit of 70 mph. Figure 220 shows data extracted from a simulation using a vehicle volume of 500 vehicles per hour and a speed limit of 30 mph.

The distance histograms (graphs A in Figure 219 and Figure 220) also provide AASHTO's calculated stopping sight distance for the modeled speed. In the histograms, the vertical bars in graph A can be interpreted as the modeled proportion of vehicles that can be expected to stop in time to avoid hitting a downed pelican (assuming the AASHTO stopping distances). Vehicles (probabilities) to the right of this dashed line will be expected to stop before reaching the downed pelican, while those to the left will require greater rates of deceleration than recommended by AASHTO to stop in time for a pelican in the road.[31]

[31] AASHTO calculates stopping sight distance using a deceleration rate of 3.4 meters per second squared (m/s^2) or 11.2 feet per second squared (ft/s^2).

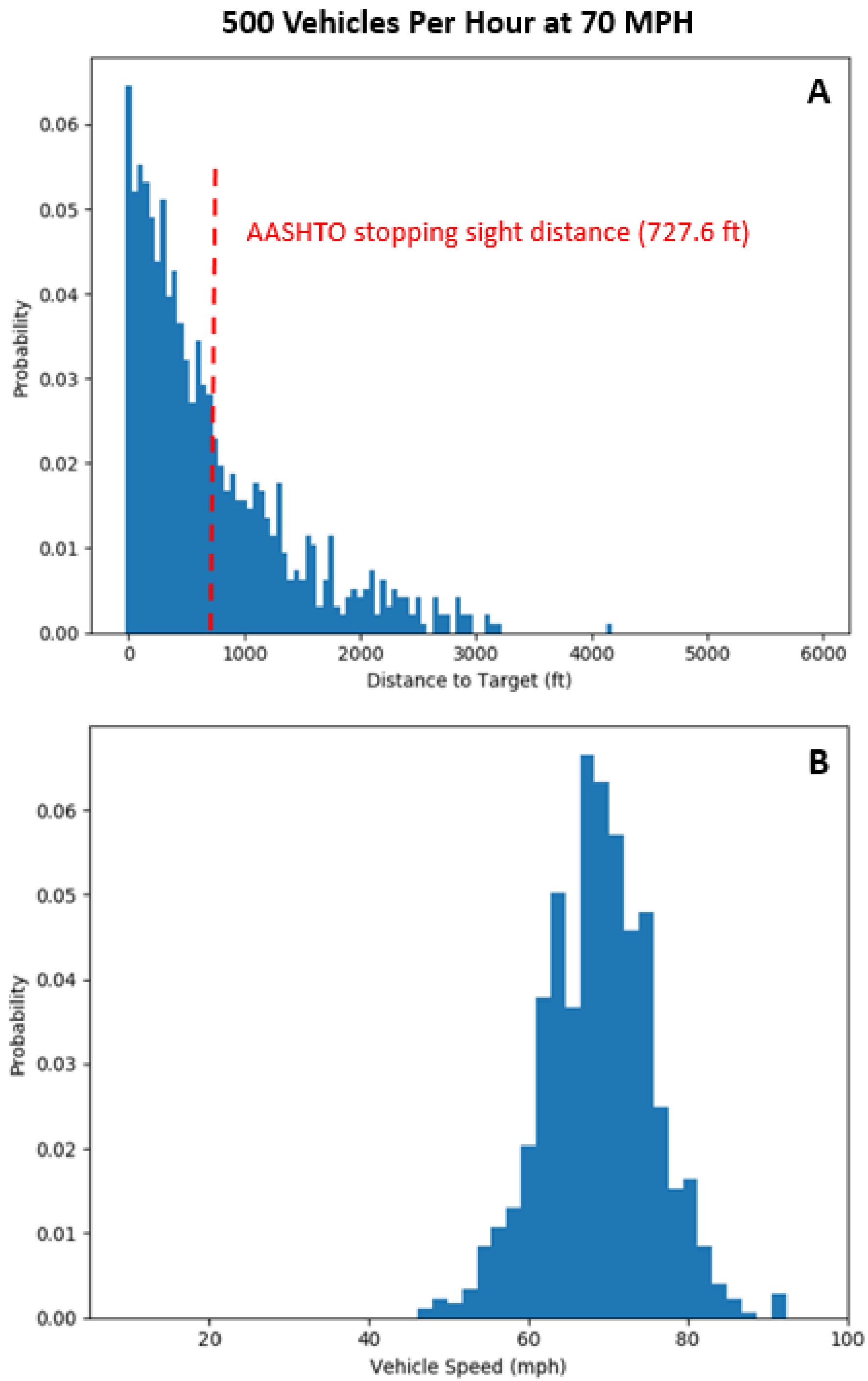


Figure 219. Probability Distributions of Distance to Target (A) and Speed (B) Derived from SUMO Simulation of 70 mph and 500 vehicles per hour Scenarios. In graph A, the AASHTO recommended stopping sight distance (727.6 ft) is shown.

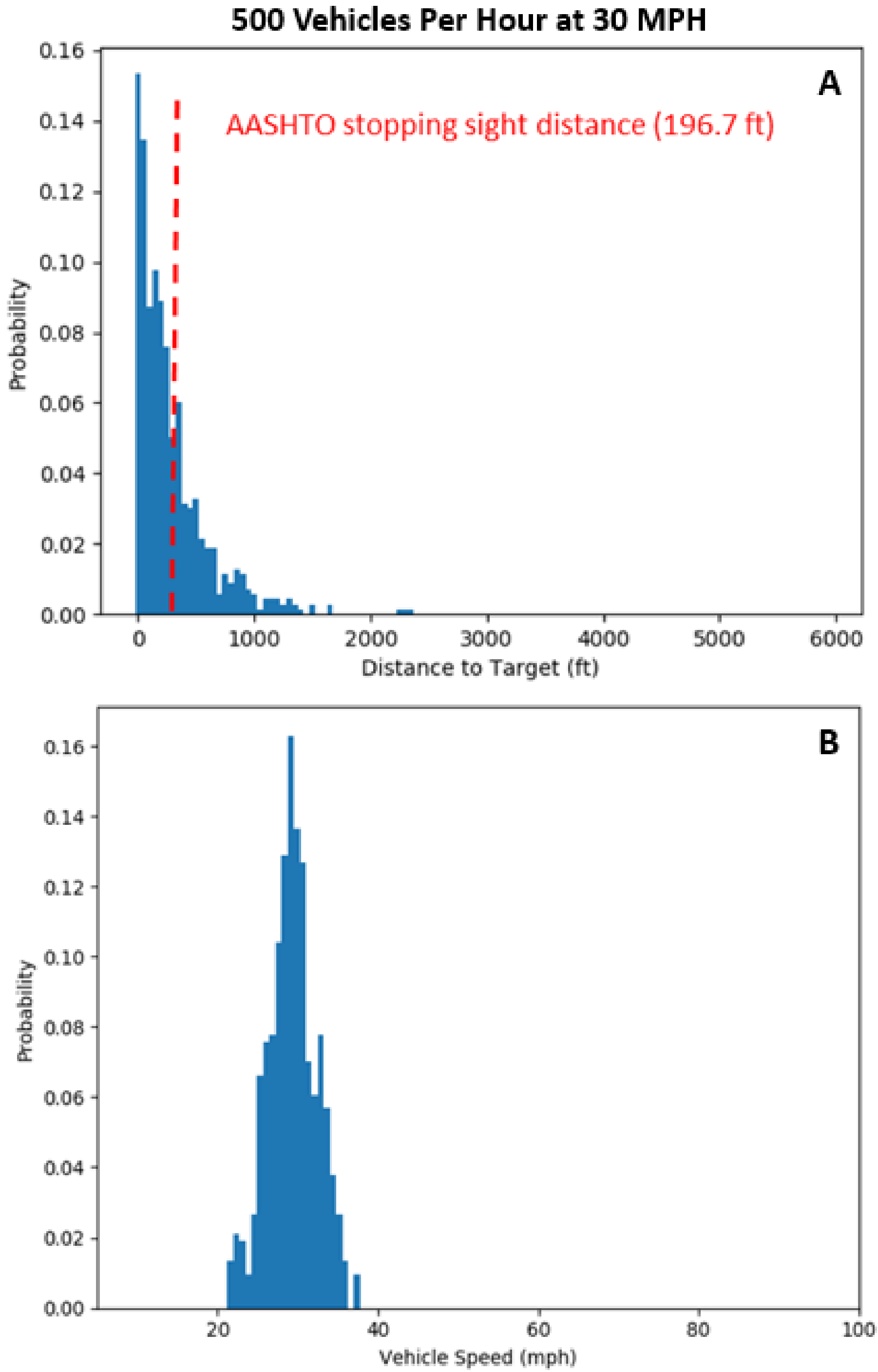


Figure 220. Probability distributions of distance to target (A) and speed (B) derived from SUMO simulation of 30 mph and 500 vehicles per hour scenarios. In graph A, the AASHTO recommended stopping sight distance (196.7 ft) is shown.

Incorporating Speed, Sight Detection Distance, and Deceleration

The calculated AASHTO stopping sight distance and the distribution of vehicle to pelican distances illustrate the logic behind determining whether a vehicle will be able to stop in time for a downed pelican. In practice, however, the maximum deceleration rate to stop a vehicle is likely to vary among drivers and vehicles, and for different road conditions. To address this, the analysis can be modified by incorporating an extended stopping sight distance in the model described in Figure 217

Figure 221 and Figure 222 reframe the problem by displaying probability-density functions describing the minimum deceleration required to stop SUMO-simulated vehicles from colliding with pelicans. The graphs present results for traffic volumes of 100 and 500 vehicles per hour and speeds between 30 and 80 mph (at 10-mile per hour increments). The two graphs show deceleration rates required to stop a vehicle assuming two different detection/sight distances. Figure 219 illustrates the required deceleration for a detection/sight distance of 300 meters (984 feet), while Figure 220 illustrates the required deceleration for a detection/sight distance of 100 meters (328 feet). The results in both figures are derived using a driver reaction time of 1.5 seconds. The red line on each graph shows the proportion of simulated vehicles that will avoid pelicans (assuming the drivers are capable of or prepared to decelerate up to 5 m/s^2 [16.4 ft/s^2])[32].

Figure 223 summarizes the proportion of vehicles able to stop in time for a downed pelican assuming different traffic volumes, average speeds, and a deceleration rate of 5 m/s^2. Note that in all graphs, the cumulative probabilities do not reach a value of one because a certain number of pelicans are predicted to crash onto the road within a distance less than the reaction distance.

[32] The maximum deceleration that can occur on a dry road with effective antilock brakes is approximately 9 m/s^2, while a 4.6 m/s^2 is often used as the maximum deceleration that enables a typical driver to maintain full control of the vehicle.

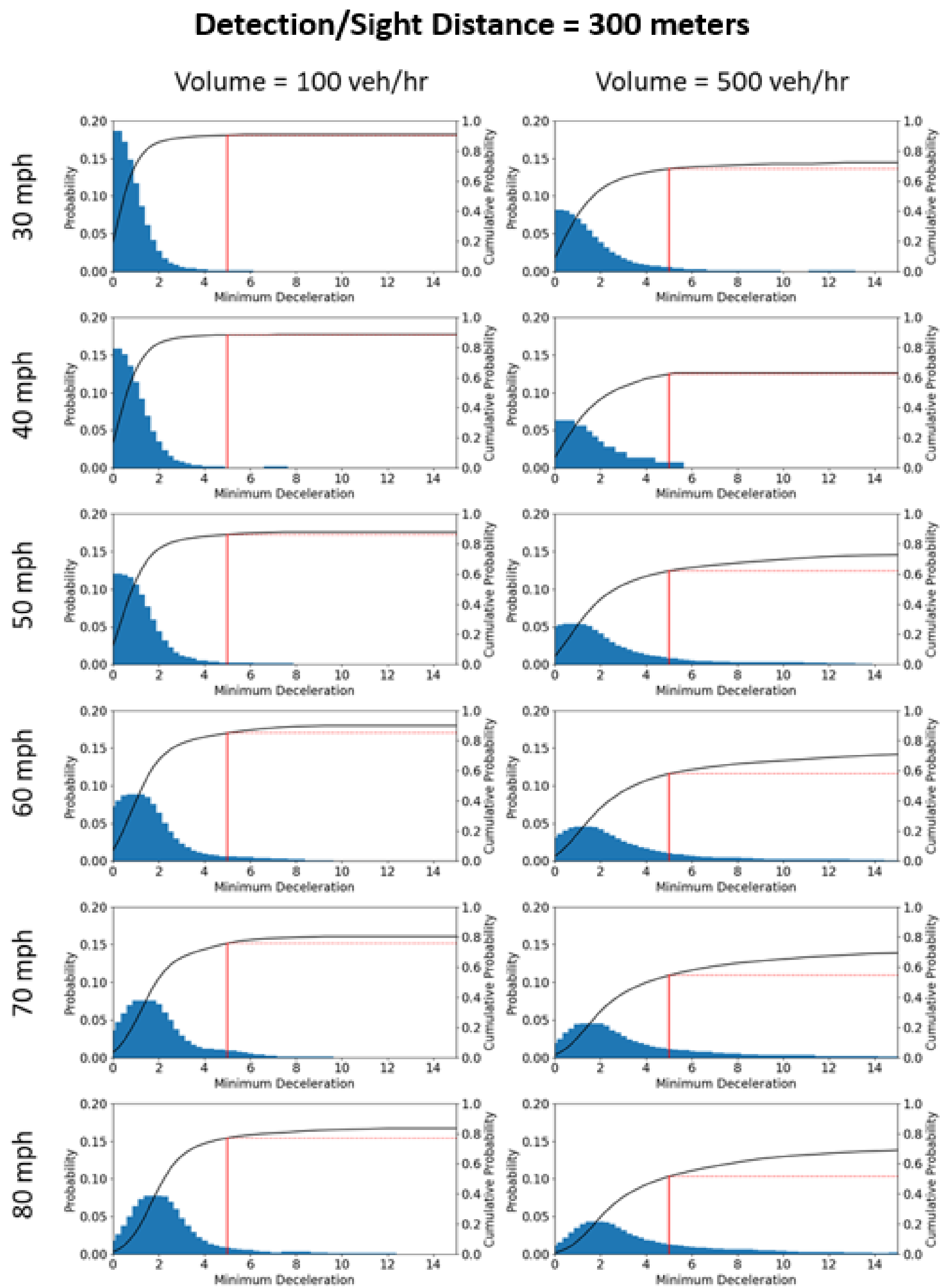


Figure 221. Plots Illustrating Probability-Density Functions (bars plotted on the left y-axis) and Cumulative Probability (black line plotted on the right y-axis) of Minimum Deceleration (in m/s2) Required to Stop Vehicles before They Reach a Downed Pelican (assuming a detection distance of 300 meters). Each plot shows the deceleration required for a different speed and volume. The red lines illustrate the probability or proportion of vehicles (read off the second y-axis) able to stop for a downed pelican assuming a 'safe' deceleration rate of 5 m/s^2 (16.4 ft/s^2). The cumulative probabilities do not reach a value of one because some pelicans enter the roadway at a distance less than the reaction time distance.

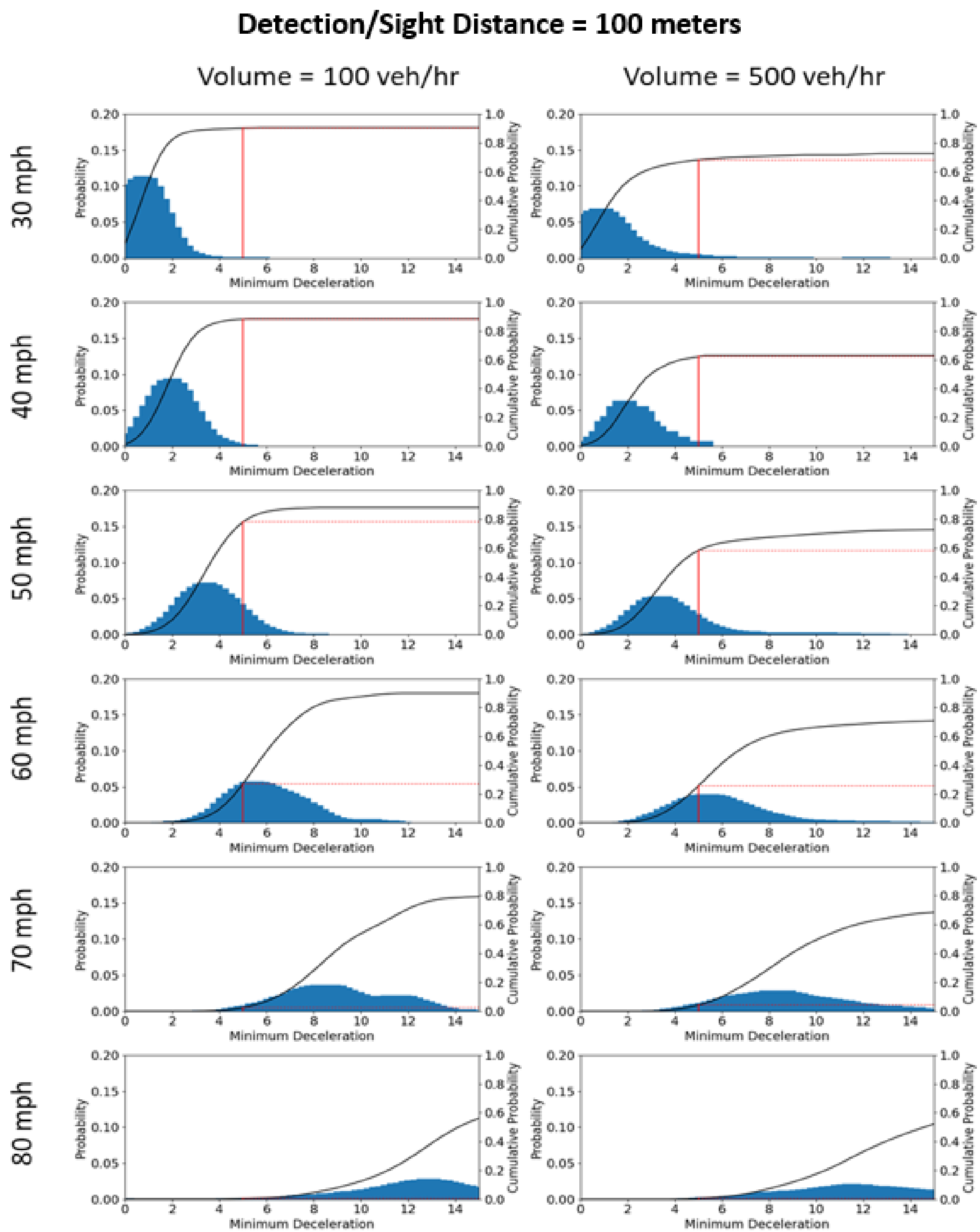


Figure 222. Plots illustrating probability-density functions (bars plotted on the left y-axis) and cumulative probability (black line plotted on the right y-axis) of minimum deceleration required to stop vehicles before they reach a downed pelican (assuming a detection/sight distance of 100 meters). Each plot shows the deceleration required for a different speed and volume. The red lines illustrate the probability or proportion of vehicles (read off the second y-axis) able to stop for a downed pelican assuming a 'safe' deceleration rate of 5 m/s² (16.4 ft/s²). The cumulative probabilities do not reach a value of one because some pelicans enter the roadway at a distance less than the reaction time distance.

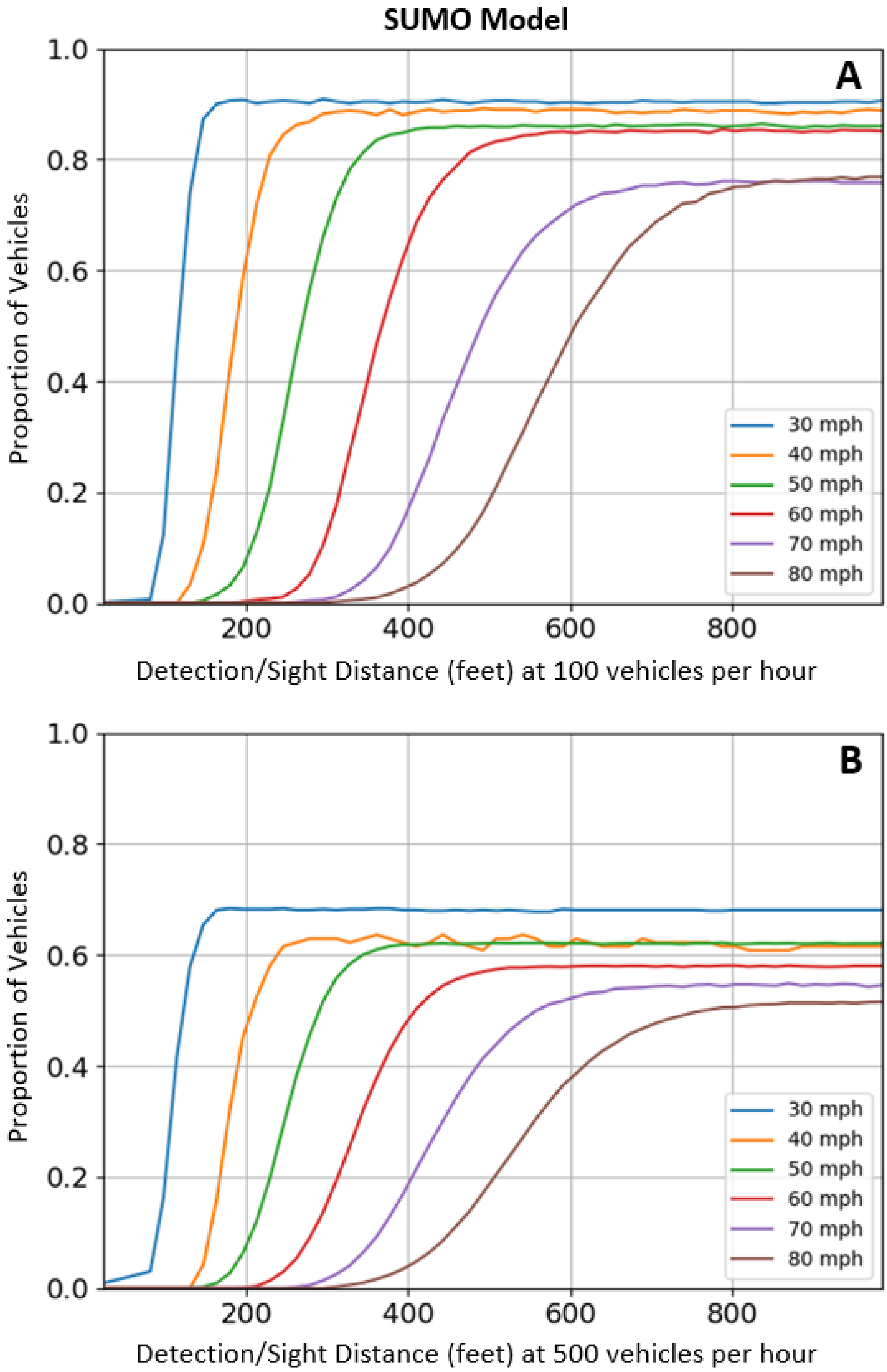


Figure 223. Proportion of SUMO-Simulated Vehicles Able to Stop in Time for a Downed Pelican for Traffic Volumes of 100 (A) and 500 (B) vehicles per hour, Speeds between 30 and 80 mph, and Detection/Sight Distances of between zero and 1,000 feet. All simulations assumed a reaction time of 1.5 seconds and a maximum rate of deceleration of 5 m/s^2 (16.4 ft/s^2).

Figure 221, Figure 222, and Figure 223 illustrate several important features of the vehicle-pelican collision model.

- Detection/sight distance is an important variable in the model and has a large effect on the probability of vehicles stopping in time for a downed pelican. This is important because mortality weather events (conditions that cause pelicans to land on the roadway) often occur in weather conditions with low visibility, potentially decreasing sight/detection distance. It is also known that pelicans remain active (and therefore attempt to cross the road) after sunset.
- Although it is unlikely that major changes in speed limit can be implemented on SH 48, the model and simulations illustrate important relationships between vehicle speed, detection/sight distance, and the ability of vehicles to stop for a downed pelican. One important practical insight is that the proportion of vehicles able to stop in time for a pelican does not increase linearly with speed. For example, Figure 223 shows that for a volume of 500 vehicles per hour and a detection/sight distance of 200 feet, only 10 percent of vehicles traveling at a 50-mph speed limit can be expected to stop in time for a downed pelican. In contrast, 50 percent of vehicles traveling at a 40-mph speed limit, and 70 percent of vehicles traveling at a 30-mph speed limit will be able to stop. The model is therefore potentially useful for assessing a change in speed limit (i.e., cautionary speed limit) that will have the largest effect on pelican mortality.
- Traffic volume has a large effect on the probability of vehicle-pelican collisions simply because the average gaps between vehicles are smaller at higher traffic volumes.

The model and simulations previously described focus on the distance between a downed pelican and the nearest upstream vehicle, and the ability (probability) of that vehicle to stop in time. The simulation model could be extended to estimate the likelihood of other safety-related variables. For example:

- The likelihood of rear-end collisions can be modeled using the distance between a lead vehicle (immediately upstream of a downed pelican) and its following vehicle. It is hypothesized that differentials in speed between vehicles may be especially problematic on sections of road with advisory speed limits (where some drivers slow down, and others do not).
- The likelihood of adjacent vehicle collisions. On a four-lane highway, there is a probability of vehicles occurring in two lanes simultaneously, increasing the risk of vehicle collisions and pelican mortalities.
- More explicit wildlife avoidance driving behavior could be included in the model. Examples include drivers being able to decelerate and swerve to avoid pelicans.

MATHEMATICAL MODELS OF VEHICLE AND PELICAN COLLISIONS

The traffic simulation modeling approach previously described provides a useful tool for simulating the interactions between pelicans and vehicles. The car-following and overtaking models in SUMO are useful for simulating specific road management scenarios, where detailed and realistic traffic behavior is important. However, simple mathematical and probability models can also be used to understand the causes and effects of vehicle-pelican collisions (and vehicle-wildlife collisions in general). In contrast to complex simulation models such as the SUMO model, mathematical models are faster to implement (simulate) and present a highly tractable and transparent description of processes and predictions. This section introduces a simple probabilistic model of vehicle-pelican interactions to complement the more complex SUMO-based simulation approach.

Calculating Distance between Vehicles

The Poisson distribution can be used to represent the number of vehicles on a single (unidirectional) lane passing a specified point in a specified period of time, given the average number of vehicles traversing the road (i.e., volume measured in vehicles per hour, or another time period)[33]:

$$P(X = k) = \frac{\lambda^k e^{-\lambda}}{k!} \qquad \text{Equation 1}$$

Where P(X=k) is the probability of X events per time period (i.e., number of vehicles) and λ is the average rate of vehicles per time period. Figure 224 shows Poisson probability mass functions describing the probability of a number vehicles passing a point in10 seconds (Δt) for lane volumes (I) of 100, 500, and 1,000 vehicles per hour.

[33] The Poisson distribution assumes a fixed rate of vehicles per time period, and that events are independent between time periods.

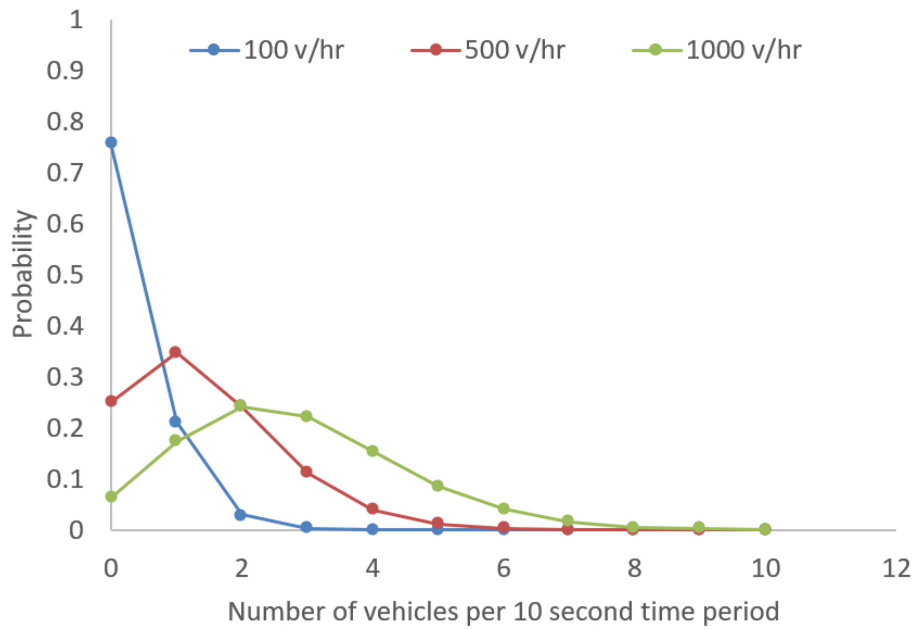


Figure 224. Poisson Distributions Describing the Probability of the Number of Vehicles Passing a Point in 10-seconds for Lane Volumes of 100, 500, and 1,000 vehicles per hour.

For these curves, the Poisson rate λ is calculated by multiplying the volume in vehicles per hour by the time interval Δt ((in seconds) as a fraction of the number of seconds in an hour, i.e.:

$$\lambda = I * \frac{\Delta t}{3600} \qquad \text{Equation 2}$$

Time gaps between vehicles are described by an exponential distribution. Specifically, the probability of observing a time gap between vehicles greater than x time periods (Δt) is given by:

$$P(X \leq x) = e^{-\lambda x} \qquad \text{Equation 3}$$

Time gaps can be converted to distance by multiplying by the average speed of traffic (in meters or feet per second) on the lane. Alternatively, the λ parameter can be transformed to provide a distribution of distances (in meters or feet) between vehicles on the road.

$$\lambda_{distance} = \frac{\lambda_{time}}{v * \Delta t} \qquad \text{Equation 4}$$

Equation 1 approximates the gaps between successive vehicles on a single-lane road. Because Poisson rates are additive, the theory extends to a multiple-lane road with traffic moving in a single direction. In other words, the distribution of gaps between vehicles for a two-lane, unidirectional highway with a total volume of *x* vehicles per hour is the same as the gaps between vehicles on a single lane with the same total volume (assuming vehicles are Poisson distributed and moving freely).

Distances between Downed Pelicans and Nearest Upstream Vehicles

An interesting property of the Poisson and exponential distributions is that—assuming pelicans land on the road randomly through space and time—the distribution of gaps between a downed pelican and the nearest upstream vehicle follows the same distribution as the distance between vehicles (i.e., Equation 3). Figure 225 shows probability densities for the vehicle to pelican distances (in feet) predicted by Equation 3 and Equation 4. Note the similarity of these distributions to Figure 219 (A) and Figure 220 (A) which show the same metric estimated using the more complex SUMO model.

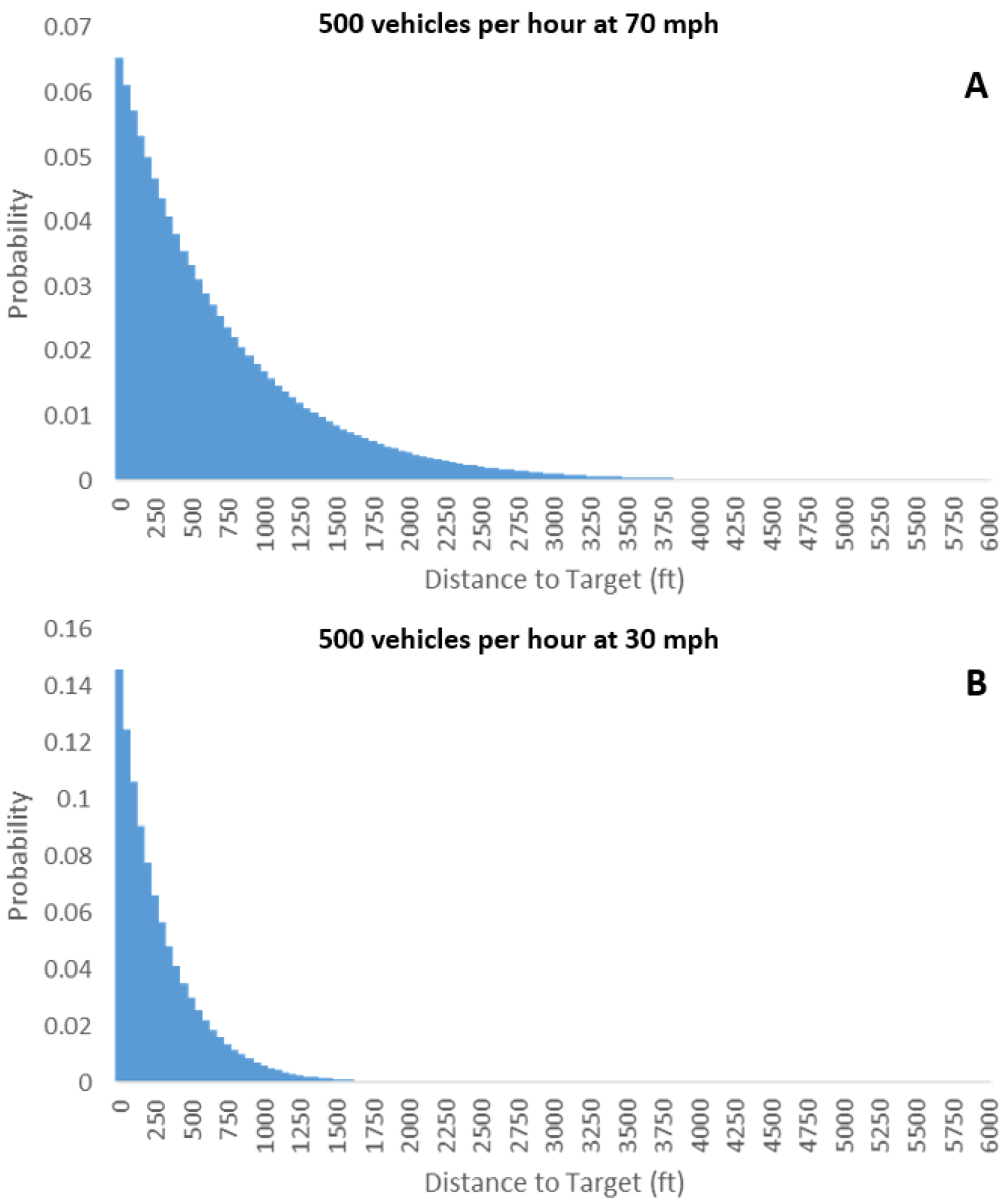


Figure 225. Theoretical Probability Distances to Target for Lane Volumes of 500 vehicles per hour and Speeds of 70 mph (A) and 30 mph (B).

Figure 226 summarizes the relationship between detection/sight distances, traffic volumes, and traffic speeds using the theoretical model. The results assume a maximum deceleration rate of 5 m/s^2 (16.4 ft/s^2), a fixed reaction time of 1.5 seconds, and vehicle speeds normally distributed around the speed limit of the roadway with a coefficient of variation of 5 percent. Figure 226 is analogous to the SUMO-derived results presented in Figure 223, but with probabilities/proportions estimated using the simple mathematical model rather than the more complex SUMO-based simulation. The results presented in both figures are strikingly similar. The small differences between results arise because of the computational requirements of the SUMO simulation (versus the theoretical formulas) which practically limit the number of simulation replicates. The SUMO model also incorporates extra 'realism' in traffic patterns generated by explicit car-following and overtaking models.

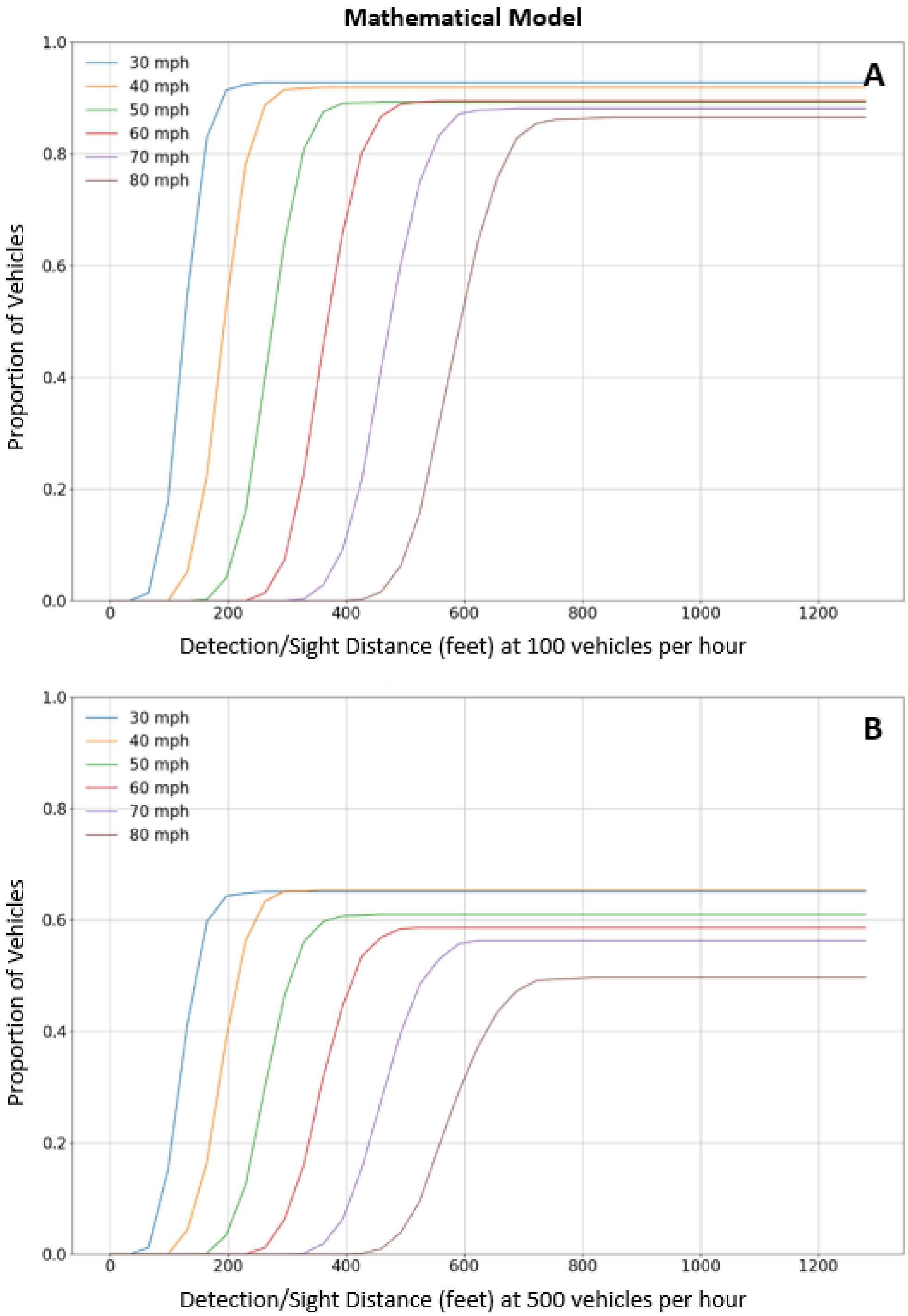


Figure 226. Proportion of Vehicles Able to Stop for a Downed Pelican for 100 vehicles per hour (A) and 500 vehicles per hour (B) Traffic Volumes. In each graph, each colored line shows the proportion of vehicles able to stop assuming an average speed of traffic (30 to 80 mph) and detection/sight distances between zero and 1,200 feet. The probability of successfully stopping does not reach one because (within the assumptions of the model) some pelicans will crash so close to an approaching vehicle that stopping is impossible at any rate of deceleration.

SUMMARY OF VEHICLE AND WILDLIFE CROSSING MODELING

The SUMO-based simulation model and the simpler mathematical model provide two different ways to implement a vehicle-wildlife collision model that incorporates detection/sight distance, reaction distance, and driver avoidance. Both models complement each other. The mathematical model is useful for breaking down the wildlife crossing problem into logically consistent components and can be implemented with minimum computing power. The SUMO model can incorporate more explicit behaviors of both vehicles (and drivers) and wildlife but is computationally expensive to implement.

The two implementations of the models give very similar results, confirming the logical integrity of both. Additionally, both models illuminate the importance of several intuitive variables that can be measured or extracted from the literature to fully parameterize the model and to explore traffic mitigation scenarios. Examples include the relationship between pelican size and luminosity and these effects on detection distance; typical effects of warning signs on speed differentials of vehicles before and after the sign; typical deceleration rates for crash incidents.

The challenge with both models is to incorporate enough detail that they can represent the most pertinent processes that result in vehicle-pelican collisions, but that they also remain simple, tractable, and capable of yielding analyses that provide useful insight into the problem.