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Factors affecting nest success of colonial nesting waterbirds in Southwest Louisiana

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FACTORS AFFECTING NEST SUCCESS OF COLONIAL NESTING WATERBIRDS IN SOUTHWEST LOUISIANA

A Thesis

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in

The School of Renewable Natural Resources

by
Karis Amanda Ritenour
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Abstract

As the coastline of Louisiana shifts with global climate change, subsidence, and accelerated sea level rise, important breeding islands for colonial nesting waterbirds are disappearing. In many recent studies flooding has been a leading cause of nest failure for a variety of species, especially those that nest on the ground. I examined the nest success of four species of colonial nesting waterbirds with various nesting strategies on Rabbit Island in southwestern Louisiana during 2017 and2018 by determining nest and fledging success. I monitored 855 nests, including 457 Brown Pelicans nests with an estimated hatch probability of 70%, 270 Forster's Terns with an estimated 12% hatch likelihood, 92 Tricolored Herons at a hatch success rate of 77%, and 36 Roseate Spoonbills with the highest hatch rate at 70%. My findings indicate that nest strategy and nest timing have a significant impact on survival rate, however the effect is mediated by conditions within a specific breeding season. The largest cause of nest failure was flooding for all species except Tricolored Herons, indicating that the island may currently be too low for small differences in elevation between nest sites to impact survival. Increasing island elevation could reduce the probability of nest failure due to overwash, but increased elevation may also lead to island abandonment or reduced nest success due to increased chance of island colonization by rank woody vegetation, mammalian predators, and/or fire ants.

Chapter 1.

Introduction

Habitat loss is a primary factor for species decline in many habitats globally. This is especially true in coastal wetlands and island habitats, threatened the world over by accelerated sea level rise due to global climate change (e.g., Deaton et al. 2017). Researchers often focus on modeling availability of current and future nesting habitat area (Sims et al. 2013) and analyzing the success of nesting sites by tracking the number of pairs within the area (Leburg et al. 1995, Raynor et al. 2013, Yeai et al. 2014, Selman et al. 2016). Less emphasis has thus far been put on the success of nesting waterbirds, not just their presence or absence. This metric is important to population growth, especially in Species of Concern, such as Brown Pelicans (*Pelecanus occidentalis*), reintroduced to Louisiana in the 1970s and removed from the Federal Endangered Species List in 2009 (USFWS 2009).

In Louisiana, many waterbirds nest on coastal islands, a habitat quickly disappearing due to erosion, subsidence, sea level rise, and frequent hurricanes (Visser et al. 2005). Selman et al. (2016) surveyed Brown Pelican nesting sites on islands in coastal Louisiana and found that the average island size decreased by 68.6% from 1998 to 2010, with one third of the islands they surveyed disappearing entirely. Island size and the size of Brown Pelican colonies were positively correlated, so carrying capacity decreased throughout the study (Selman et al. 2016). They predicted that Rabbit Island, the only inland island in the study, would be the most crucial habitat for Brown Pelicans going forward. This inland island was more stable than the barrier islands, primarily because it was protected from direct wave action in the Gulf of Mexico (Selman et al. 2016).

As islands disappear, subsidence and increased wave action increases overwashing – an event in which sea water floods at least part of the island. Often overwash occurs during storms or as a result of wave action and can completely destroy nests or colonies (Visser and Peterson 1994, Leburg et al. 1995). It can also cause prolonged flooding, especially on islands and marsh habitat. As a result, eggs or chicks can get wet and cold enough that they die, even if the nest stays intact. Owen and Pierce (2013) found that flooding was a main cause of nest failure for barrier island nesting Black Skimmers (*Rynchops niger*), with nest loss ranging from 8% in 2009 to 22% in 2010. Similarly, Brooks et al. (2014), also studying Black Skimmers on small islands, found that overwash was the most common cause of nest failure (approximately 33% over two years) and that the chance of nest survival decreased by 33% for each 10-cm gain in estimated tide height.

One solution to frequent overwash of nesting bird colonies is to use dredge spoil from a nearby channel to increase the elevation of nest sites on the island (Selman and Davis 2015). This is a costly and disruptive process, especially for islands that are remote and therefore difficult and expensive to access with dredging equipment. One estimate from an employee of the Louisiana Department of Wildlife and Fisheries for Rabbit Island was nearly $30 million just to get the dredge to the site, before any pumping took place (*pers. communication*). However, dredging costs tend to decrease as the volume of the material dredged increases (Turner and Streever 2002). Because of the high cost of the enterprise and the financial benefits of using more material, it may seem cost-effective to increase elevation drastically rather than conservatively. Birds can benefit from increased elevation; Fern et al. (2016) found that there was a correlation between nest success of Forster's Terns (*Sterna forsteri*) and elevation across several small island sites in the Gulf of Mexico. However, none of the islands in their study had an elevation higher than one meter.

While overwash and subsidence are dangerous to nesting waterbirds, increasing elevation too much can cause new habitat problems. Periodic flooding can minimize cover of woody, invasive, and overly thick vegetation, all of which can interfere with nesting. Leberg et al. (1995) found that the colonial nesting waterbirds that they studied only used dredge spoil islands for nesting in the first spring following their creation. They hypothesized that thick vegetation at ground level after the first growing season made the islands less suitable for nesting (Leberg et al. 1995).

Most woody trees and shrubs decrease nesting area for the majority of colonial nesting waterbirds; however, mangroves are one exception. Black mangroves (*Avicennia germinans*) have had a fairly limited range in Louisiana but they have been expanding northward into *Spartina alterniflora*-dominated saltmarsh as winter temperatures rise with climate change (Perry and Mendelssohn 2009). Walter et al. (2013) found that Brown Pelicans preferentially nested in mangroves and even marsh elder (*Iva frutescens*) when they were available on Raccoon and Wine Islands, both barrier islands in Louisiana. While mangroves reduce or eliminate nesting habitat for terns and other obligate ground-nesters, they could potentially improve nesting habitat for some colonial nesting waterbirds. However, habitat that facilitates growth of black mangrove is also a delicate balance. Guo et al. (2013) showed that mangroves did not do well in low-elevation marshes due to too frequent flooding, while in high-elevation salt marsh the soil moisture was too low to promote growth. Mangroves did best at an intermediate elevation, which Guo defined as the area of the marsh where *Batis maritima* was the dominant vegetation. Although they do not specify the exact elevation at which mangroves grew best, they do say that the difference between the low, intermediate, and high marsh can be as little as 2.5 cm (Guo et al. 2013). Marsh elder requires even higher elevation, high enough to avoid prolonged root flooding (Miller 2002).

Increasing elevation of dredge spoil islands has led to an increase in mammalian nest predators (Erwin et al. 2003, Visser et al. 2005). On barrier islands in both Virginia and Alaska, increases in woody habitat have been linked to expansion of mammalian predators (Erwin et al. 2001, Lantz et al. 2015). Mesopredators are devastating to ground and over-water nesting birds of many species. They are the leading cause of nest failure in many ground-nesting birds. In a study by Meckstroth and Miles (2005), 94 out of 102 artificial nests were depredated, most by striped skunks (*Mephitis mephitis*). One study showed that as raccoons (*Procyon lotor*) and foxes (*Vulpes vulpes*) expanded onto new barrier islands in Virginia sea bird nesting colonies decreased in size or disappeared entirely from those islands (Erwin et al. 2001). On an Australian Pelican (*Pelecanus conspicillatus*) breeding island in Australia introduced European foxes decreased both the nest success and the population of breeding birds on the island. Additionally, in drought years when pelicans were already stressed, foxes caused both larger numbers and a higher percentage of egg mortalities (Johnston 2016). In addition to direct effects on nest success, Fontaine and Martin (2006) demonstrated that parents of twelve species of nesting passerines invested more in their offspring when predation rates were lower. In areas with decreased predation, eggs were significantly larger, males fed incubating females more often, and both parents fed nestlings with greater frequency (Fontaine and Martin 2006).

Relatively frequent island flooding may also decrease the ability of invasive fire ants (*Solenopsis invicta*) to establish a foothold on colonial nesting islands. Fire ants have been documented to swarm and kill a variety of chicks in ground nests, as well as causing erratic behavior in incubating adults (Suarez et al. 2005). Even when they do not directly cause chick deaths, they can cause problems for developing chicks. Plentovich et al. (2009) observed eggs and chicks predated by ants, as well as chicks with mild to severe injuries from ant bites. They showed that those with more severe injuries grew significantly slower than those with mild or no injuries. DeFisher and Bronter (2013) found that Herring Gull chicks in high ant activity areas did not experience greater predation rates, but did exhibit lower growth rates, which can affect their survival in both the short and long-term. Multiple studies of terrestrial ant species in floodplain systems showed that flooding could be catastrophic to the population without available refugia for the survivors to migrate to and then recolonize from (Adis and Junk 2002, Ballinger et al 2007). It is possible that periodic complete overwash of these island sites may be the lynchpin to keeping invasive ant species at bay.

When multiple waterbird species nest within the same area they usually occupy different ecological niches. One of the most visible methods of niche differentiation is the difference in vertical stratification among species (Maxwell and Kale 1977). While Brown Pelicans are known to seek out and nest in woody vegetation at some sites, the number of nests on the ground and in grasses increases when there is no woody vegetation available (Walter et al. 2013). While Brown Pelicans build their nests up when they are on the ground, Forster's Terns tend to barely construct nests at all. They are commonly found on muskrat mounds and dead vegetation mats, either floating or on land (Bergman et al. 1970, Storey 1987). Tricolored Herons (*Egretta tricolor*) and Roseate Spoonbills (*Platalea ajaja*) may nest alongside Brown Pelicans and Forster's Terns but they build nesting platforms off the ground in vegetation (Strong et al. 1997, Lorenz et al. 2009). These differences in nesting strategy along with other factors such as elevation at the nest site can affect the likelihood of nest flooding, predation, and overwash.

The ideal elevation for a thriving population of colonial nesting waterbirds is a balance of trade-offs. Waterbirds are fairly long-lived group, with maximum lifespans recorded from fifteen years (Forster's Terns, Roseate Spoonbills) to over 40 years (Brown Pelicans) (Simons and O'Connor 2012, Lutmerding and Love 2015). It is not necessary for every pair to reproduce successfully every year to maintain and even increase their population levels. However, merely providing more island habitat, or even ensuring that a variety of colonial nesting waterbirds are present and/or nesting on an island is not enough to ensure that the population is sustainable. An island can appear to be a thriving colony over several years, but all eggs or chicks could fail to reach fledging age due either to regular flooding events or to high levels of predation, the two most common causes of death in previous studies of nesting success (Raynor et al. 2012, Owen and Pierce 2013).

I investigated nesting success of several species of colonial nesting waterbirds on an inland coastal marsh island in southwestern Louisiana that is subject to flooding events. Rabbit Island is the only Brown Pelican nesting island in southwestern Louisiana and, while it is sheltered from the wave action barrier islands are subjected to, it decreased in land area approximately 6.5% from 1998 to 2010, compared for around 68% for islands in Louisiana's coast during the same time period (Selman et al. 2016). Due to its relative isolation and shelter from the Gulf of Mexico, Rabbit Island was the site used for translocation of 182 oil-rehabilitated Brown Pelicans after the 2010 Deepwater Horizon Oil Spill so that they would not re-enter the oil (Selman et al. 2012). It is slated for dredge spoil restoration to increase the elevation and reduce land loss. Little quantitative data exists on actual nesting success but based on casual observations of previous overwash events, it is speculated that flood events are preventing nest success of several colonial waterbird species. Thus, the island was targeted for a restoration project designed to increase island elevation. Due to high rates of subsidence and relative sea level rise in the area (Visser et al 2005) and to the tremendous cost of dredge spoil restoration, increasing the island the maximum amount that would allow for successful colonial waterbird nesting without invasion by predators and fire ants would be advantageous.

The objectives of my study were to 1) determine hatch and chick success for several breeding waterbirds; 2) determine the effects of elevation on nest success of several waterbird species with a variety of nesting strategies; 3) compare predator presence on Rabbit Island to the surrounding dredge spoil islands, and 4) determine the frequency of overwash events based on long-term hydrologic records from the nearest tidal gauge.

I expected that elevation would drive nest success, especially for ground-nesting birds such as Forster's Terns and Brown Pelicans. I predicted that flooding and overwash would be the largest cause of nest failure, but that the species that nest on elevated platforms (i.e., Roseate Spoonbills and Tricolored Herons) would not be as impacted by it as the ground-nesting species. I expected the nearby dredge spoil islands to contain a greater number and diversity of mammals than Rabbit Island.

Methods

Study Area

My study site is Rabbit Island in Cameron Parish, Louisiana. It is located within Calcasieu Lake, sheltered from the Gulf of Mexico but still saline because the Calcasieu Ship Channel cuts from the Gulf northward through the middle of the lake allowing saltwater intrusion. The island is primarily tidal marsh habitat, the dominant plant species include *Spartina alterniflora, S. patens*, *Juncus roemerianus*, and *Distichlis spicata*. Island elevation ranges from about 0.3-0.5 m above mean sea level, including both ephemeral and permanent ponds used by foraging birds. Due to the unique marsh hydrology and permeable substrate on this island, flooding can occur and persist even without strong storm events. It is a breeding location for at least 20 species of waterbirds, including 1500 breeding pairs of Brown Pelicans as of 2011 (Selman et al. 2016) and 12 other Species of Conservation Concern designated by the Louisiana Wildlife Action Plan (Holcomb et al. 2015). There are no known records of mammalian predators, alligators, or invasive fire ants on this island within the last decade. I observed this island in the breeding season (February-June) in both 2017 and 2018.

Hydrology

To determine the effects of flooding on nests, I established two HOBO U20 Water Level Loggers in monitoring wells (WRAP 2000) at sites within highly populated nesting areas in the first breeding season and at least 3 m from the shore (2017). These were deployed in August 2017, outside of breeding season so as not to disturb nesting. Data were retrieved from the water level recorders 5 times throughout 2018, approximately every 2-3 months.

In order to measure the similarity between my water loggers and the nearby long-term water monitoring systems, I obtained the data from both the nearest NOAA station (CAPL1, located at 29.768 N 93.343 W) and the nearest CRMS station (CRMS0685-H01, located at 29.89 N 93.39 W). I ran a cross-correlation between one of my water loggers and the mean high high water level from the NOAA gauge as well as to the adjusted water level to marsh from the CRMS station using Program R, vers. 3.5.1 (base package; R Core Team 2019). I determined the critical water depth at which major overwash/flooding events occurred in 2017 and 2018 using both the NOAA and CRMS station. I then used past data from each station to determine the probability of this water level being exceeded for each day during the nesting season.

Nest Monitoring

Once nesting began, I systematically established 1-m wide transects within colonies, spaced at least 2m apart from each other. In the case of very small/compact colonies I marked every nest. New nests and transects were added opportunistically throughout the breeding season as the colonies expanded and new colonies formed. I counted new nesting efforts on old nests or nest platforms as renests, although it was impossible to know whether the new eggs were laid by the same parents as the original nest. Each nest was monitored on average between 6.1 and 7.4 days apart (Table 1), with variation depending on the weather, to limit researcher disturbance as much as possible. Observations ended when nests were no longer active.

Table 1. Distribution of observations throughout nesting seasons for each species by year.

2017	# of Observations	First Observation	Last Observation	# Days in Nesting Season	Average # of Days Between Observations
Brown Pelican	20	2/24/2017	6/25/2017	121	6.1
Forster's Tern	11	4/16/2017	6/25/2017	70	6.4
Roseate Spoonbill	9	4/27/2017	6/25/2017	59	6.6
Tricolored Heron	15	3/26/2017	6/25/2017	91	6.1
2018					
Brown Pelican	15	3/7/2018	6/26/2018	111	7.4
Forster's Tern	8	5/8/2018	6/26/2018	49	6.1
Roseate Spoonbill	8	4/18/2018	6/12/2018	55	6.9
Tricolored Heron	9	4/18/2018	6/21/2018	64	7.1

At each nest, I counted the number of eggs and/or chicks and made note of anything unusual, e.g. dead chicks in or around the nest, eggs or shell fragments outside the nest bowl. I also made note of any eggs pipping or in the process of hatching.

I analyzed both hatch success and chick success. Hatch success required a sighting of at least one chick at the nest. I recorded chick success instead of fledging success, because waterbird chicks leave the nest before they are capable of flight. Chick success is defined in this study as at least one chick surviving past the nestling stage as defined in the literature; Brown Pelicans, 28 to 35 days (Blus and Keahey, 1978); Tricolored Herons (Frederick et al. 1992) and Roseate Spoonbills (White 1982), 14 days. Forster's Tern chicks are more mobile and able to leave the nest within a couple of days after hatch however, chick success does not occur until 15 days (Cuthbert and Louis 1993). I thoroughly searched each Forster's Tern nest site for nearby chicks but unless they were large enough to hold a leg band it became impossible to link a chick to one specific nest.

In some nests, at least one chick hatched but reached the end of their nestling phase between observations. Unless these chicks were seen at the next observation date or definitive proof of nest failure was found, the fate of these nests was recorded as "unknown". In 2017, researchers observed multiple injuries to Brown Pelican chicks, usually inflicted by an adult on a chick, when large groups of mobile chicks fled as the researchers approached. To avoid this obvious detrimental disturbance in 2018, once the majority of chicks within Brown Pelican transects reached the end of their nestling phase and became large and mobile, researchers discontinued monitoring of that transect. I banded as many chicks as possible and monitored chicks with bands from outside the transect using binoculars. Chicks within those transects that had not reached the end of nestling phase were marked as unknown outcome.

Finally, failed nests fell into several categories. Whenever nests failed, I attempted to determine the cause of failure. "Overwashed" failed nests included any nest that was completely washed away, destroyed, or contained standing water. Also included in this category was any nest during or after a significant overwash or storm event in which all chicks were dead in or around the nest. I recorded nests as failed: abandoned if the nest was intact and either: 1) eggs were cold or showed signs of not having been turned for an extended period of time (e.g. eggs sunk into the nest, a distinctive line between the dirty side of the egg (down) and the clean side (up), and especially if the eggs were cold and damp) or 2) eggs or chicks present at last observation were not present and the nest was noticeably unkempt. If eggs remained in the nest more than one observation past their expected hatch date, or if a nest that previously contained eggs was found intact and well-kept but empty with no sign of eggshells or hatched chicks in the area, it was designated “failed: never hatched”. All nests that clearly failed without enough evidence to fit into any of the above categories, those that went missing completely, or those that contained dead chicks or broken eggs fell into the general “fail” category.

I measured the ground elevation at each nest site using a Trimble Geo 7 X GPS. The majority of elevation measurements were accurate within 3 cm; any nests that had elevations with accuracy estimates $\geq$ 5 cm were discarded. Additionally, I measured the height of each nest to the top of the construction with a meter stick, with the exception of Forster’s Terns because their nests were essentially flat. I visually estimated percent vegetation composition and aggregated it across each transect (Appendix A). Outside of breeding season in December 2018 I collected soil samples from several Brown Pelican and Forster’s Tern transects, as well as the dredge spoil island. Using classification by feel and loss on ignition methods recommended by Hoogsteen et al. (2015), I compared the soil composition as well as organic content (Appendix B).

Both hatch and chick success were calculated separately using the daily nest survival model (Dinsmore et al. 2002) to estimate daily survival rates and to fit 8 candidate models: a null model and all combinations of start date, elevation, and year. I determined parameter estimates for the best supported model for each species (PROGRAM MARK 9.0 packages RMark (Laake 2013) and MuMIn (Barton 2018), Program R, vers. 3.5.1 (R Core Team 2019)).

I used the age categories put forth by Walter et al. (2013) to look at the maximum age of chicks from each successful Brown Pelican nests. Chicks were categorized based on their age in weeks as follows: 1) 0 to 1.5, 2) 1.5 to 3, 3) 3 to 4.5, 4) 4.5 to 6, 5) 6 to 7.5, and 6) 7.5 to 9. I counted sightings of chicks in and around nests, as well as sightings of a few banded chicks once they left the nest each year.

Predator and Fire Ant Sampling

To determine the presence of mammalian predators, I set up track plates (Erwin et al. 2001, Raynor et al. 2012) at locations near former colonies on Rabbit Island after breeding season, as well as, on the nearest dredge spoil island, approximately 2,380 m away. This island, which supports no nesting waterbirds, is between 1.44 and 2.12 m in elevation, nearly ten times the average elevation of nest sites at Rabbit Island. It is covered in dense, woody vegetation, and showed some signs of mammalian habitation before track plates were deployed. Track plates consisted of smooth patches of sand mixed with mineral oil and were baited with cat food (Raynor et al. 2012, Erwin et al. 2001). I set up three plots at random points on each island for four observation nights. I checked every plot each morning for three mornings consecutively in August 2017, so as not to disturb or lure predators to active nests. All sign of animal use was documented and then raked clean. In addition, at least one site on each island was equipped with a field camera (Bushnell TrophyCam), and all areas were searched for sign or scat of mammalian predators before the sites were set up.

I also set traps for fire ants according to the methods laid out by Seymour (2007), using scintillation vials filled with hot dog. One vial was placed near an active transect during breeding season and left out for at least one hour. I repeated this experiment seven times in 2017.

Results

Hydrology

I compared the water level data from my wells with the water levels at the nearest NOAA station (CAPL1) and the nearest CRMS station (CRMS0685-H01) using cross-correlation. Although the CRMS station is 4.6 km away from the center of Rabbit Island and the NOAA station is 9.7 km away, both showed a lag of approximately +12 hours compared to the water level recorder on Rabbit Island. In a simple correlation, the Rabbit Island sensor and the CRMS station were more correlated (r=0.44) than Rabbit Island was with the NOAA station (r=0.25). I used the CRMS station for historical data and as a proxy for the Rabbit Island sensors when they failed.

In addition to failing to record the entire field season, the Rabbit Island sensor well data combined with the elevation data gathered at each nest indicated that the island should have been constantly flooded, which of course was not borne out during observations. I determined that there had been a mechanical error in the measurement or human error in the conversion measurements of the water level recorder data, and the data could not be used.

During breeding season in 2017, Rabbit Island experienced several storm events spread throughout the season that caused widespread overwash and generally wetter conditions, while 2018 was characterized by fewer and less severe storm and overwash events and drier overall conditions (Fig. 1). Almost all major flooding events causing failure of nests in both years occurred when hourly mean high-water depths recorded at the nearby CRMS station were approximately 0.4 m and were almost always associated with storms.

The exception was the overwash event on April 14, 2018. The highest water level recorded during this event was 0.32. On April 3, 2018 water levels reached 0.37 m without overwashing any nests, even though all nests destroyed in April 14 had already been initiated. The CRMS station is located within the marsh nearly 5 km northwest of Rabbit Island. The topography of Southwestern Louisiana, flat and low with low-lying marshes and several shipping channels hydrologically connecting multiple inland lakes, including Lake Calcasieu, particularly lends itself to wind-driven waves and changes in water level (Dietrich et al. 2010). It is possible that on April 3, 2018 strong winds - up to 25 knots - from the south (data recorded at NOAA CAPL1) could cause water to stack at the CRMS station but not on the Island, causing the water level to be higher at the CRMS station than it actually was on Rabbit Island. Similarly, much of the day on April 14, 2018 the wind was strongly from the north, which could cause water to be pushed out of the marsh, decreasing the water level at the CRMS station so that it does not compare accurately to Rabbit Island (Dietrich et al. 2010).

During the morning of April 14, 2018, there was an abrupt increase in windspeed and change in wind direction. Between 9:18 am and 10:36 am the wind direction suddenly shifted from S or SW to due N. During this time the wind gusts increased from 12.5 knots to 40.4 knots within 20 minutes. The speed quickly decreased but the direction stayed from the north for the rest of the day. This pattern of wind activity was markedly different from the pattern both on April 3, 2014 as well as other overwash days. It was the highest windspeed during the nesting season of 2018. In a wind-driven system, it is possible that this strong gust and abrupt directional change caused rogue wave action at Rabbit Island that would be strong enough to overwash nests but would not be picked up at the CRMS station a few kilometers away. Dietrich et al. (2010) demonstrated that wind speeds of 15 m s^{-1} or approximately 29 knots coming from the north pushed water out of Lake Calcasieu through its myriad hydrologic connections and decreased the water level within the lake. Throughout the rest of the study the flood threshold of 0.4 m is supported.

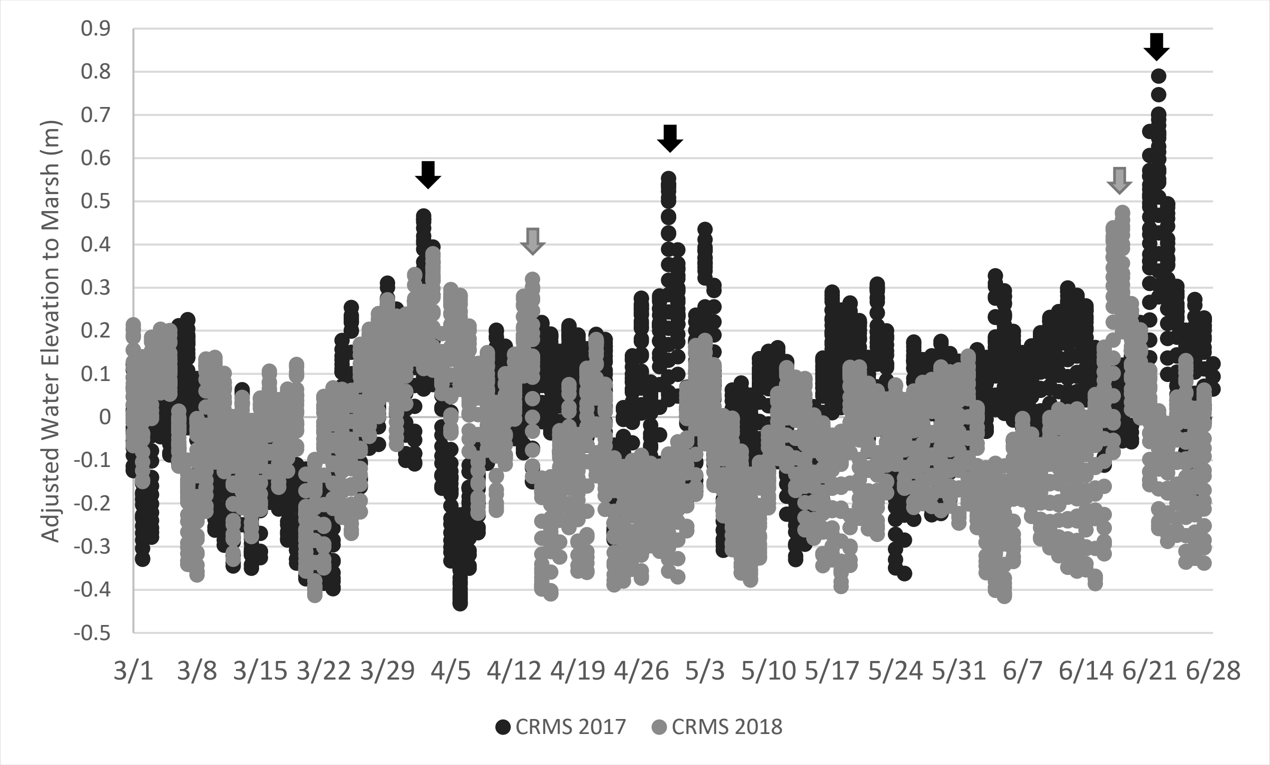


Figure 1. Water depth from CRMS0685-H01 throughout breeding seasons in 2017 and 2018. Black arrows indicate major flooding events in 2017, grey arrows indicate major flooding in 2018.

In 2017, major overwash/flood events occurred on April 2 (highest level 0.47 m), April 29 (max level 0.55), and June 22 (0.8 m). In 2018 one such event occurred on April 14 (0.32 m) and a second on June 18 (0.5 m). The highest water levels in each year occurred during the events in June. The highest water level recorded by the CRMS station in 2017 was 0.8 m during Tropical Storm Cindy (June 21-24). In 2018, there were no named storms during breeding season. The highest water level recorded at the CRMS station in 2018 was 0.5 m during the storm on June 18.

Extrapolating that flooding events on Rabbit Island were associated with water levels of at least 0.4 m, I examined CRMS station hourly adjusted water level to marsh elevation data from the past 12 years. I grouped the hourly observations by day to identify the number of days in each breeding season where the water level exceeded 0.4 at least once (Fig. 2). There were no hourly observations of 0.4 m or greater from 2006 through 2011 or in 2013 or 2014. There were less than 10 days of flooding per year every year except for 2016. In 2016 there was a massive increase, from 2 days (2% of the breeding season) in 2015 to 16 (13% of the breeding season) in 2016. In 2017 there were 6 days on which overwash occurred (5% of the breeding season).

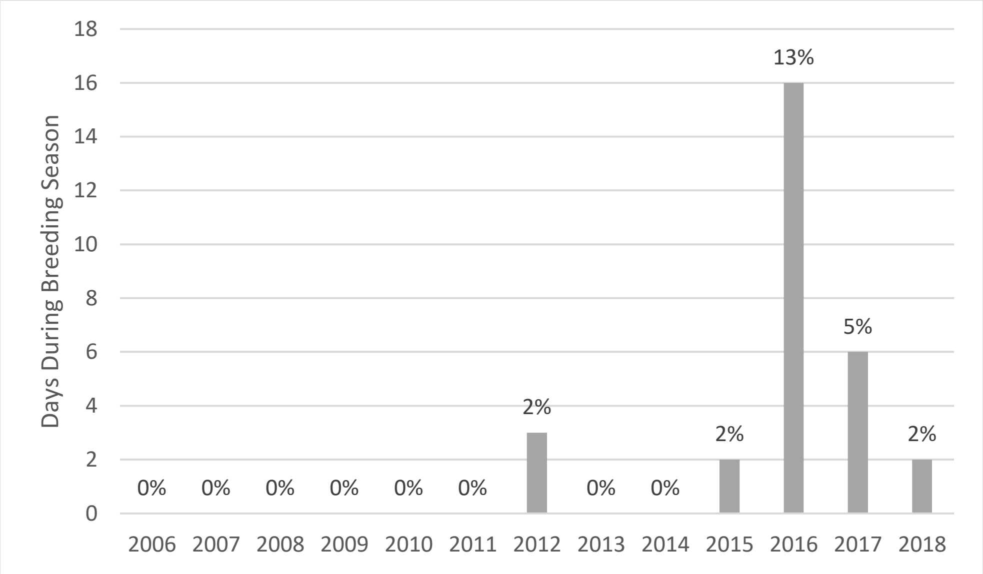


Figure 2. Number of days in the breeding season with at least one hourly water level recorded above 0.4 m. Labels indicate the percentage of overwash days during each year.

From 2006-2018, there were 271 hourly records of water level above 0.4 m during breeding season, 29 individual overwash events. Eleven (38%) overwash days occurred in April, followed by 7 (24%) in June. Five (17%) and 6 (21%) of flood days occurred in March and May, respectively (Fig. 3).

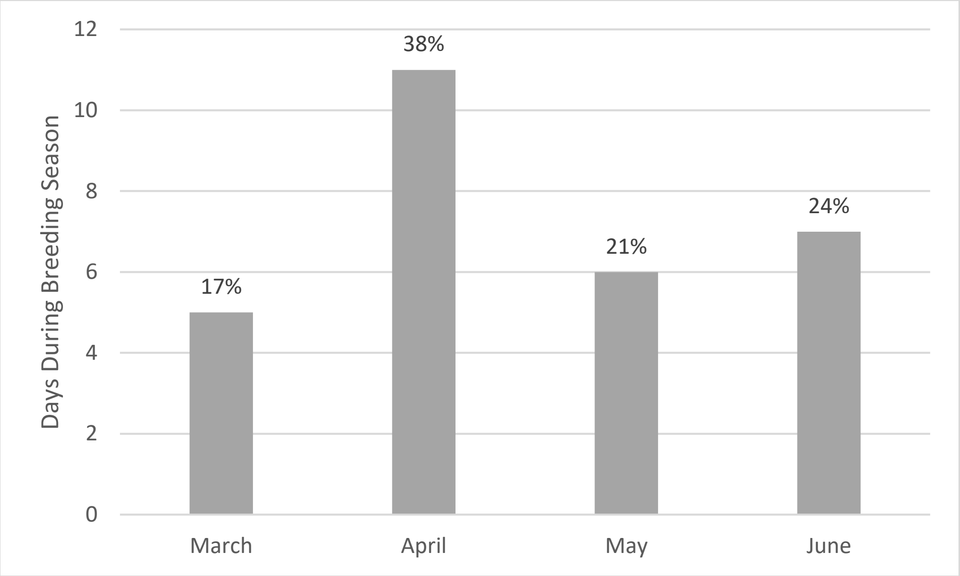


Figure 3. Number of daily observations above 0.4 m from CRMS station between 2006-2018 by month of the breeding season. Data labels indicate the percent of total overwash days across all years that occurred in each month.

Nest Timing

Brown Pelicans nested first in each season, with nests first sighted on February 24 in 2017 and March 7 in 2018 (Fig. 4). New pelican nests were initiated throughout the field season, some as late as May 7 in 2018 and May 25 in 2017. I first observed Tricolored Heron nests on March 26 in 2017 and April 18 in 2018. With the exception of three re-nests, I did not find any new heron nests after April 12 in 2017. Nest initiation after April 27 was rare in 2018. I only found 5 new nests in May. I first found Roseate Spoonbill nests on April 27 in 2017 and April 18 in 2018. In 2017 I continued to find new spoonbill nests until June 18, while in 2018 I found no new nests after April 27. The first Forster's Tern nests were found on April 16 in 2017, while they did not begin nesting until May 8 in 2018. They continued to initiate new nests until the large overwash events in June each year, after which the adult terns also disappeared from Rabbit Island.

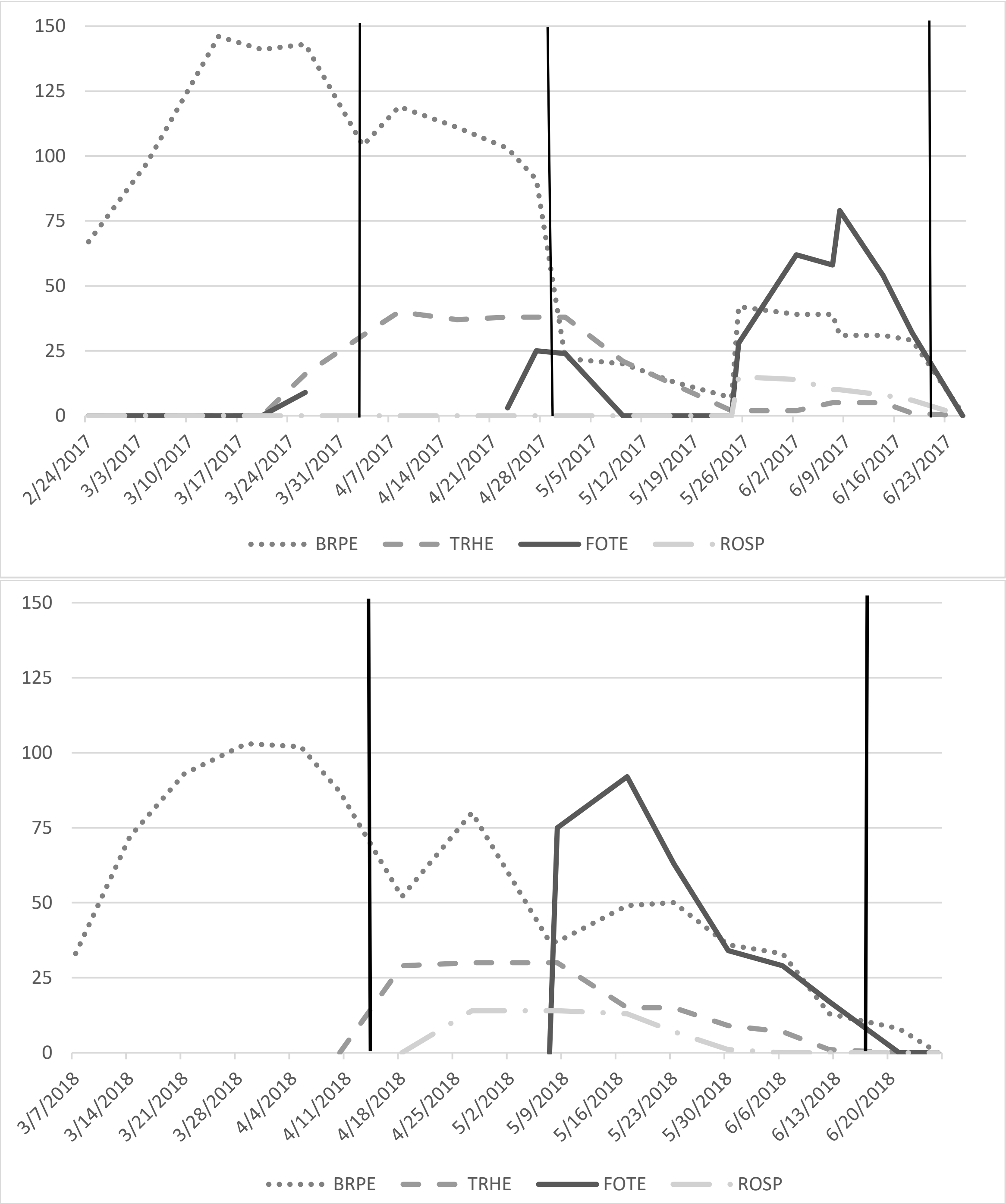


Figure 4. Number of active nests of each species by date in 2017 (top panel) and 2018 (bottom panel) at Rabbit Island in Louisiana. Solid vertical lines indicate major flooding events. BRPE = Brown Pelican, TRHE = Tricolored Heron, FOTE = Forster's Tern, ROSP = Roseate Spoonbill.

Summary Nesting Data

The number of nests of each species observed was approximately the same between 2017 and 2018 (Table 2). In 2017, out of 263 nests, Brown Pelicans laid 751 eggs, averaging 2.9 eggs per nest. Approximately 40% of nests successfully hatched at least one egg, averaging about 2.3 chick per nest. In 2018, Brown Pelicans laid 562 eggs distributed across 194 nests, averaging 2.9 eggs per nest again. Apparent hatch success was 43% in 2018 and pelicans averaged 2 chicks per nest.

Table 2. Summary data for each species by year. Nest and hatch success are apparent, standard deviations in parentheses. . BRPE = Brown Pelican, FOTE = Forster's Tern, ROSP = Roseate Spoonbill.

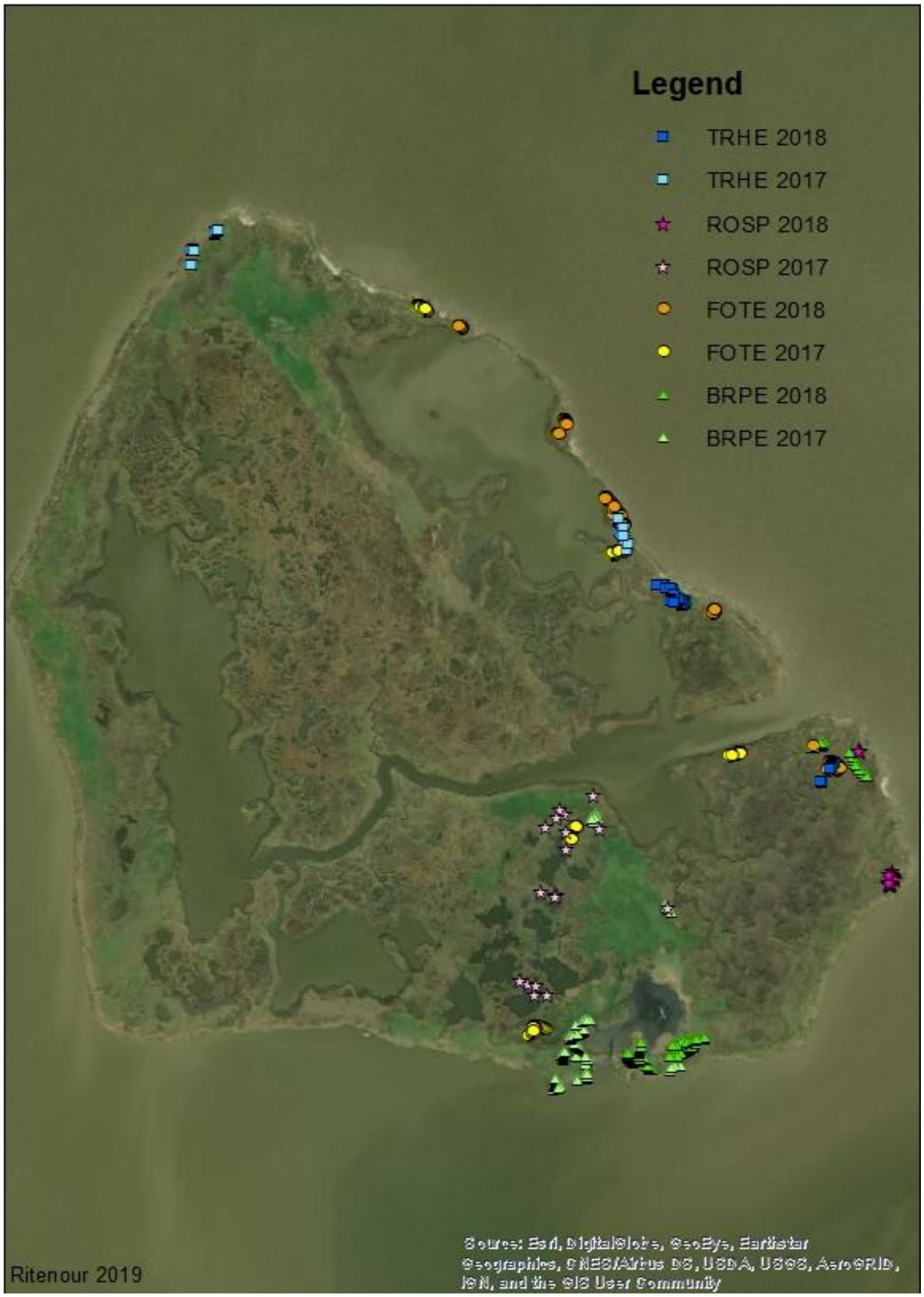
	# of nests	# of eggs	# of chicks	# of nests with eggs	# of nests with chicks	% Hatch Success	% Chick Success	Mean Eggs per nest	Mean Chicks per nest
2017									
BRPE	263	751	247	261	108	41%	16%	2.9 (0.45)	2.3 (1.25)
TRHE	46	151	106	46	37	80%	15%	3.3 (0.72)	2.9 (1.38)
FOTE	149	321	48	149	35	23%	0%	2.2 (0.74)	1.4 (0.72)
ROSP	22	40	28	21	13	62%	27%	1.9 (1.21)	2.2 (1.19)
2018									
BRPE	194	562	164	194	84	43%	12%	2.9 (0.38)	2.0 (1.09)
TRHE	46	140	67	46	31	67%	17%	3.0 (0.63)	2.2 (1.18)
FOTE	121	291	45	121	34	28%	2%	2.4 (0.7)	1.3 (0.68)
ROSP	14	55	44	14	14	100%	50%	3.9 (0.62)	3.1 (1.19)

I surveyed 46 Tricolored Heron nests in 2017 and 2018. In 2017 herons laid 151 eggs, averaging over 3.3 eggs per nest, 80% of which successfully hatched. Tricolored Herons in 2018 also averaged about 3 eggs per nest, 140 eggs in all. However, they only averaged 2.2 chicks per nest, at a hatch rate of 67%.

Each year, Forster's Terns had the smallest average number of chicks, less than 1.5 chicks per nest. Though they laid 321 eggs across 149 nests in 2017 and 291 eggs across 121 nests in 2018, averaging 2.2 to 2.4 eggs per nest, less than 30% of those nests hatched chicks each year.

Roseate Spoonbills were the least common species of the four, resulting in only 22 nests in 2017 and 14 in 2018. In 2017, spoonbill nests were only loosely associated, not arranged in tight groups that enabled easy transects like the other species (Fig. 5). They were also the only species for which some nests that were found after hatch were included in the study. In 2017 only 11 of the 21 nests contained eggs during the observation period, the rest having already started the nestling phase. These nests did not contribute to the number of eggs per nest because there was no way to know how many eggs they had originally contained. Roseate Spoonbills laid 40 eggs in 2017, 1.9 per nest, on average. In 2018 with fewer total nests they laid 55 eggs, averaging nearly 4 eggs per nest. Their hatch rates were about 62% in 2017 and 100% in 2018, yielding 2.2 and 3.1 chicks per nest, respectively.

No species nested in the same location in 2018 as they did in 2017 (Fig. 5). At no time in either nesting season were any of this studies' focal species seen utilizing the west side of Rabbit Island. There appeared to be at least some Tricolored Heron and Roseate Spoonbill nests located in the central part of the island but it was not possible to survey those nests on foot or by motorized boat.



Ritenour 2019

Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

Figure 5. All nest points by species and year at Rabbit Island, Louisiana. All species nested in different areas in 2018 than they did in 2017. BRPE = Brown Pelican, TRHE = Tricolored Heron, FOTE = Forster's Tern, ROSP = Roseate Spoonbill.

All species nested at slightly higher elevations in 2018 than in 2017, though most within one standard deviation of their average elevation in 2017 (Fig. 6). In 2017, Forester's Terns nested at the lowest elevation (-20.3 cm), but in 2018, Forester's terns nested at the highest elevation (76 cm). However, it is worth noting that some of these nests were built on debris floating on the surface of the water. Elevation was taken at ground level below the water, and so some of these nests, as well as those located in particularly low areas on land, were actually below sea level. These below sea-level nests brought down the average elevation significantly in 2017. I did not observe any floating nests or nests located below sea level in 2018. Average nest height was 24.8 cm for Brown Pelicans, 31.7 cm for Roseate Spoonbills, and 43.9 cm for Tricolored Herons.

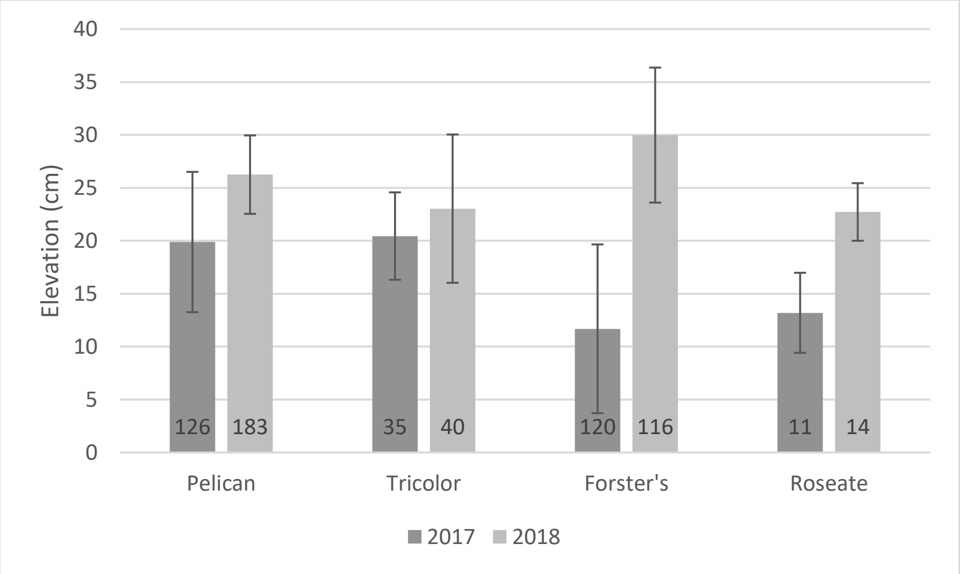


Figure 6. Average ground elevation at nest sites for each species by year. Error bars are standard deviation, labels are sample size (n).

Banded Pelican Sighting

Throughout the course of the 2017 field season I observed a Brown Pelican with a pink auxiliary color band with the alphanumeric code "C48" several times (Fig. 7). I reported these sightings to the Bird Banding Laboratory. This individual was one of the 182 oil-rehabilitated pelicans translocated to Rabbit Island after the 2010 Horizon oil spill (Selman et al. 2012). Although this bird's nest was not located on one of my transects, I did confirm several sightings of this bird actively nesting, including the below photo of the bird with at least one successfully hatched chick. This may be the first confirmation of a rehabilitated oiled pelican successfully nesting at least 7 years after being contaminated.

Figure 7. Photograph of Brown Pelican C48 with at least one egg and one live chick in its nest. Photo courtesy of Maggie MacPherson 2017.

Causes of Nest Failure

In both years, Brown Pelicans were impacted by overwash events early in the season that other species avoided by beginning their nesting later. In 2017, the overwash event on April 3 destroyed 21% of all the nests I observed in that year (n = 55). Another 37 nests (14%) were destroyed on April 30 (Fig. 8). The direct effects of the April 14 overwash event in 2018 was smaller, only 4% (n = 8) of total nests were destroyed, although an additional 32 nests (16%) were abandoned or otherwise failed before the next observation day (April 18).

However, the majority of Brown Pelican nests were complete or chicks were old enough to survive the largest overwash events in June of each year. In 2017, Tropical Storm Cindy (June 22) destroyed 31 nests (12%). Twenty-one Brown Pelican nests (11%) were lost in the overwash event on June 18, 2018.

Forster’s Terns were completely overwashed during the large flood events in June of each year. Only one colony had been initiated by the April 30 flood in 2017, but all 24 nests in that colony were destroyed. In addition to the large overwash events, specific colonies of Forster’s Terns nesting on washed up vegetation (rack) were sometimes flooded or overwashed by small local increases in water level that did not affect the island as a whole. Forster’s Terns failed due to overwash/flooding more than any other species (65%, 174 of 267 failed nests). After the large storms in June of each year all adult Forster’s Terns deserted Rabbit Island. For all other species, both adults and young of the year that were old enough to survive the storm, left the nest, or fledged stayed on the island and in the area. I never saw any fledged juvenile Forster’s Tern at Rabbit Island either year, suggesting that even the few nests that chicks managed to leave did not result in any new recruits.

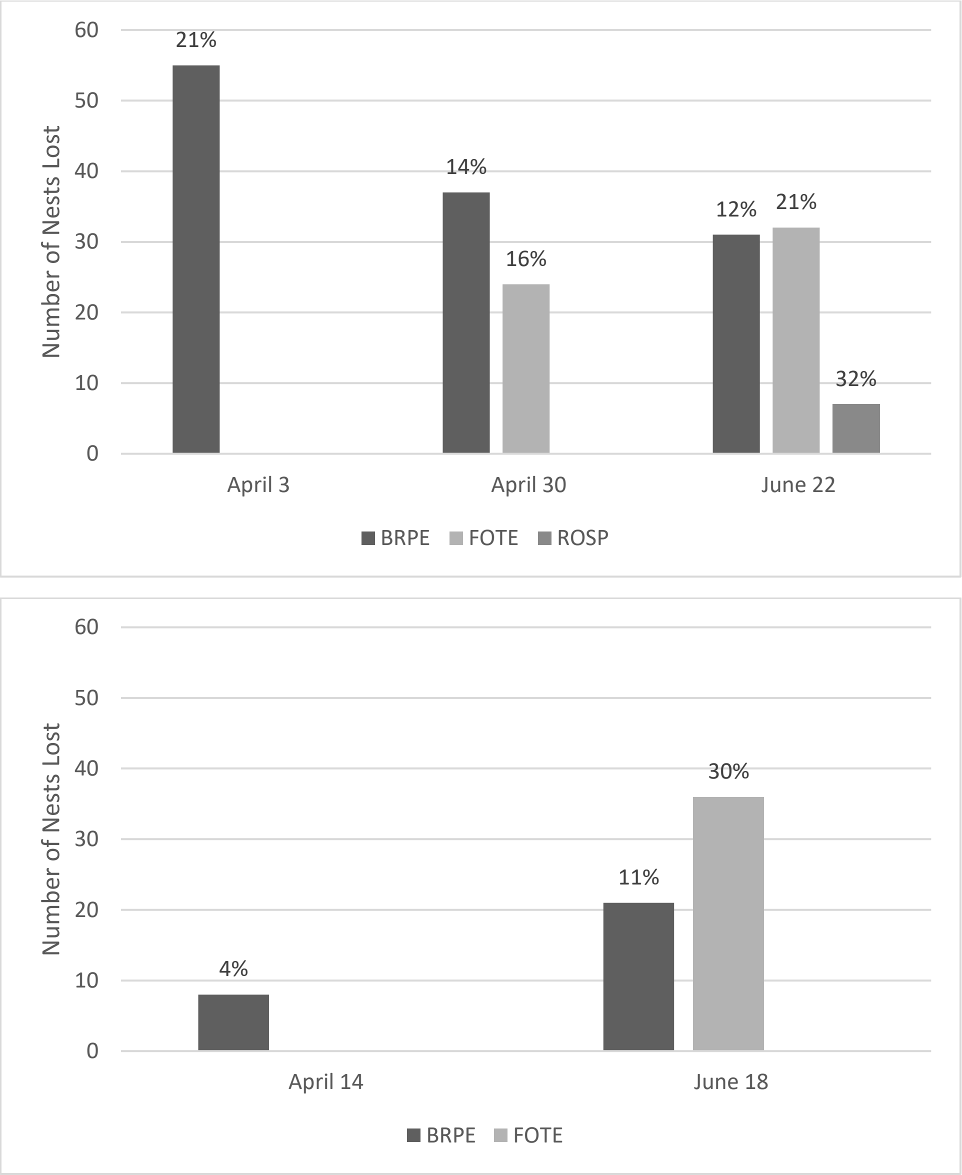


Figure 8. Number of nests of each species destroyed in each of the major flood events in 2017 (upper panel) and 2018 (lower panel) at Rabbit Island, Louisiana. Labels indicate the percent of total nests for each species destroyed. No Tricolored Heron nests were affected in either year, no Roseate Spoonbill nests in 2018. BRPE = Brown Pelican, FOTE = Forster's Tern, ROSP = Roseate Spoonbill.

Tricolored Herons were actively nesting during two of the three overwash events in 2017, but they were not impacted by the high water. In 2018, both Tricolored Herons and Roseate Spoonbills were able to begin and conclude nesting attempts after the first overwash event and before the second. Roseate Spoonbills lost 7 nests (32%) during Tropical Storm Cindy in 2017, though it is important to note that 5 out of the 7 were new nests that were located for the first time on June 18.

Brown Pelicans failed due to overwash second most at 44% of all failed nests (n = 154) (Fig. 9). Fifty-seven Brown Pelican nests (16%) failed to hatch by their expected hatch date. By comparison, 0 Forster's Tern, 8 Tricolored Heron (15%), and 6 Roseate Spoonbill nests (29%) failed to hatch. Only one out of 21 failed Roseate Spoonbill nests (5%) failed after chicks were found dead in the nest of unknown causes. Brown Pelican and Forster's Tern nests failed this way 1% of the time, 2 nests and 4 nests, respectively. Nests were abandoned or cause of failure could not be determined in 27% (n = 94) of failed Brown Pelican nests, 85% (n = 44) of Tricolored Heron, 34% (n = 90) of Forster's Tern, and 29% (n = 6) of Roseate Spoonbill nests. Additionally, 13% (n = 32) of Brown Pelican nests, all occurring simultaneously, were not visibly damaged by a flood event in April of 2018, but failed at the same time as several nests in the same area that were flooded or completely washed away. It seems likely that the flood event affected the failure of these nests in some way, so they were counted as "post overwash" failures. It is possible that subtle damage, damp, or cold from one of the overwash or severe weather events was the cause of failure in other unknown, abandoned, and even never hatched nests.

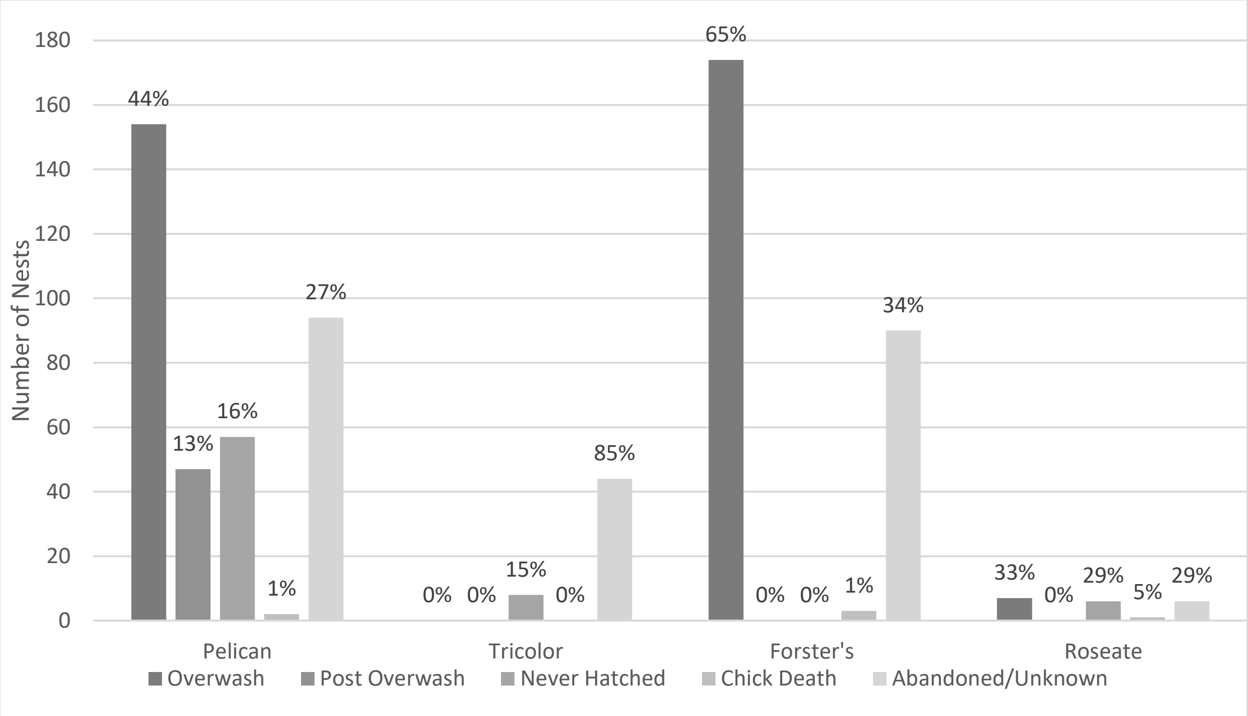


Figure 9. Number of failed nests that resulted from each of five cause categories for each species in 2017 and 2018 at Rabbit Island, Louisiana. Labels indicate the percentage of all failed nests of that species by cause. These results do not include one Roseate Spoonbill nest that was suspected to have failed due to avian predation.

Hatch Success

To perform statistical analysis and model selection, I censored all nests lacking elevation measurements, including many that were destroyed in early overwash events in 2017. Elevation was not included as an explanatory variable in the most supported models for any species (Table 3). Likelihood of survival to hatch, calculated for each species depending on estimated daily survival rate (DSR) and their average incubation period, was 70% for Brown Pelicans (DSR = 0.989, incubation = 31 days) and Roseate Spoonbills (DSR = 0.984, incubation = 22), 77% for Tricolored Herons (DSR = 0.989, incubation = 23 days), 12% for Forster’s Terns (DSR = 0.914, incubation = 24).

Table 3. Model selection results for regression models evaluating the relationship of hatch success to year, elevation, and date the nest was found. Models are ranked based on Akaike's Information Criterion (AIC) adjusted for model weights (w_i). K is the number of parameters in each model.

Species	Model	AICc	ΔAIC	w_i	K	Deviance
Brown Pelican	FirstFound*Year	860.025	0.000	0.977	3	848.01
	FirstFound*Year*Elevation	867.562	7.538	0.023	4	843.52
	Elevation	896.238	36.213	0.000	1	892.24
	Constant	896.910	36.885	0.000	1	894.91
	Year	898.710	38.686	0.000	2	894.71
	FirstFound	899.370	39.345	0.000	1	893.37
	Year*Elevation	899.911	39.886	0.000	2	891.91
	FirstFound*Elevation	900.433	40.408	0.000	2	888.42
Tricolored Heron	FirstFound	123.705	0.000	0.269	1	117.69
	Year*Elevation	123.967	0.262	0.236	3	115.94
	Elevation	124.594	0.889	0.172	1	120.59
	Constant	125.051	1.346	0.137	1	123.05
	Year	126.039	2.334	0.084	2	122.03
	FirstFound*Elevation	127.295	3.590	0.045	2	115.24
	FirstFound*Year*Elevation	127.408	3.703	0.042	4	103.21
	FirstFound*Year	129.504	5.799	0.015	3	117.45
Forster's Tern	FirstFound*Year	655.445	0.000	0.933	3	643.42
	FirstFound*Year*Elevation	661.414	5.969	0.047	4	637.31
	FirstFound	663.321	7.877	0.018	1	657.31
	FirstFound*Elevation	668.448	13.003	0.001	2	656.42
	Year*Elevation	678.185	22.740	0.000	3	670.17
	Year	680.573	25.128	0.000	1	676.57
	Elevation	685.783	30.338	0.000	1	681.78
	Constant	694.436	38.991	0.000	1	692.43
Roseate Spoonbill	FirstFound	34.449	0.000	0.688	1	28.38
	FirstFound*Year	37.010	2.561	0.191	3	24.77
	FirstFound*Elevation	39.525	5.076	0.054	3	27.29
	Elevation	40.331	5.882	0.036	1	36.30
	Year	41.257	6.808	0.023	1	37.22
	Year*Elevation	43.858	9.409	0.006	3	35.75
	Constant	48.742	14.293	0.001	1	46.73
	FirstFound*Year*Elevation	49.053	14.605	0.000	4	24.16

The daily survival rate of Brown Pelicans until hatch (DSR = 0.989) was a function of the date the nest was found and the year. This model was extremely well supported with a weight of 0.98, meaning that there is only a 2% chance that another variable would improve the model. The later in the season Brown Pelicans nested, the less likely they were to survive (β = -93.73, SE = 0.00) and this trend was much stronger in 2017 than in 2018 (β = -1.3, SE = 0.00) (Fig. 10). Forster's Terns daily survival rate (DSR = 0.914) was also best described by the date the nest was found and year (w_i=0.933). However, for Forster's Terns, nesting later improved their chances (β = 23.34, SE = 0.00) and this effect was larger in 2018 than in 2017 (β = 2.66, SE = 0.00). Both Tricolored Herons and Roseate Spoonbills (DSR = 0.989 and 0.984, respectively) were best supported by the date found alone, though neither model was as robust (w_i = 0.269 for Tricolored Herons and 0.688 for Roseate Spoonbills), suggesting that there are other factors not considered in this study that affect nest success in these species. Tricolored Herons benefited from nesting earlier (β = -0.14, SE = 0.1), while Roseate Spoonbills did better when they nested later (β = 0.165, SE = 0.17).

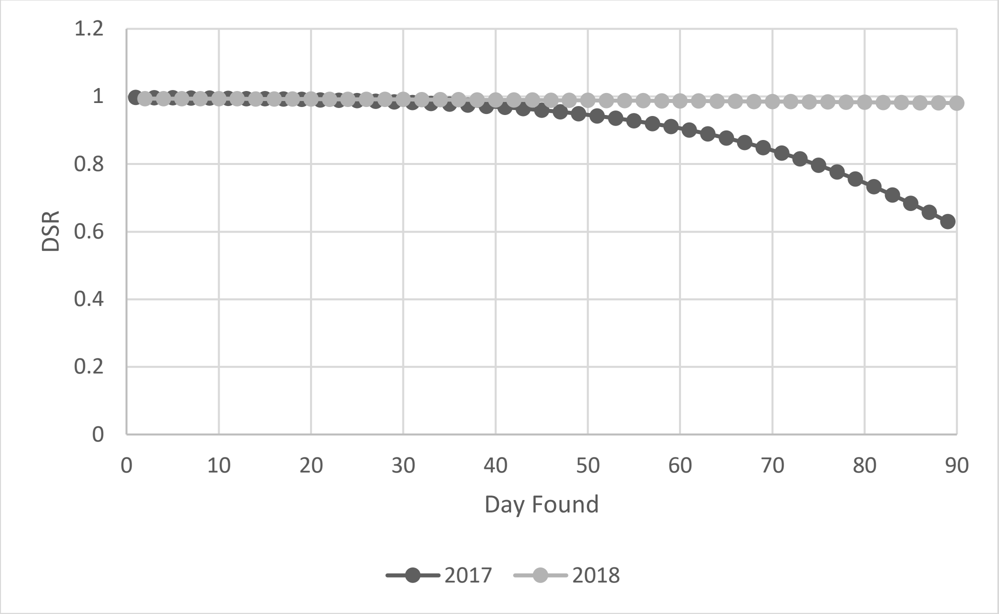
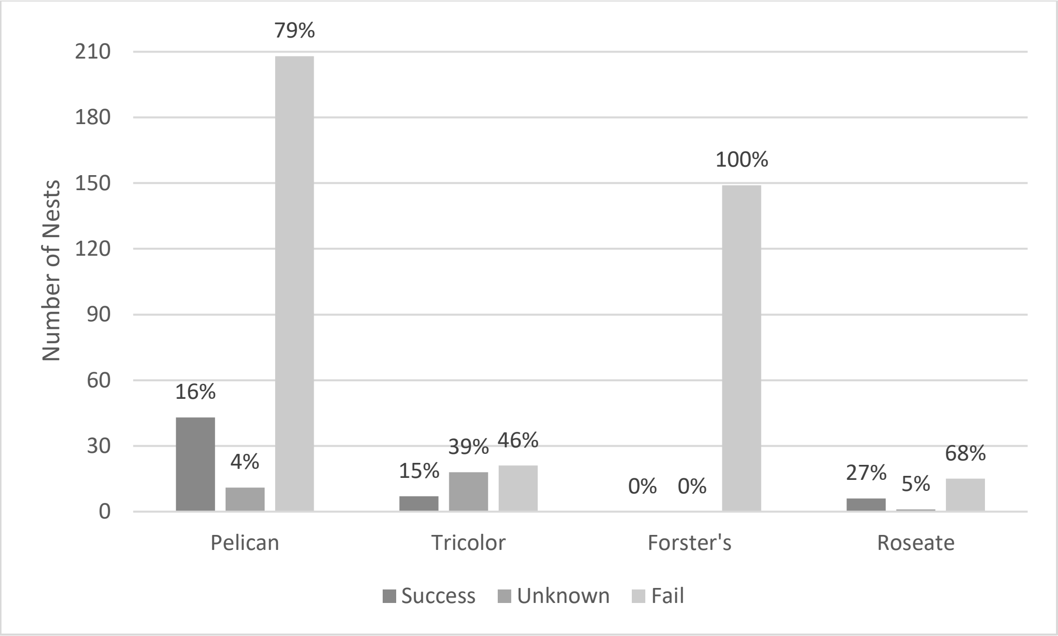


Figure 10. Daily survival rate predictions until hatch for Brown Pelicans by day the nest was found (0 = Febuary 24) and year.

Chick Success

I modeled chick success, the likelihood that at least one egg would survive through hatch and the chick would successfully leave the nest at the end of the nestling phase, separately from hatch success. I was able to determine whether or not every nest hatched, however it was more difficult to parse whether or not chicks were successful. Almost all species had at least a few unknown outcome nests, with the greatest percentage in Tricolored Heron (Fig. 11). In order to run nest survival models with a binomial outcome I removed all unknown nests.



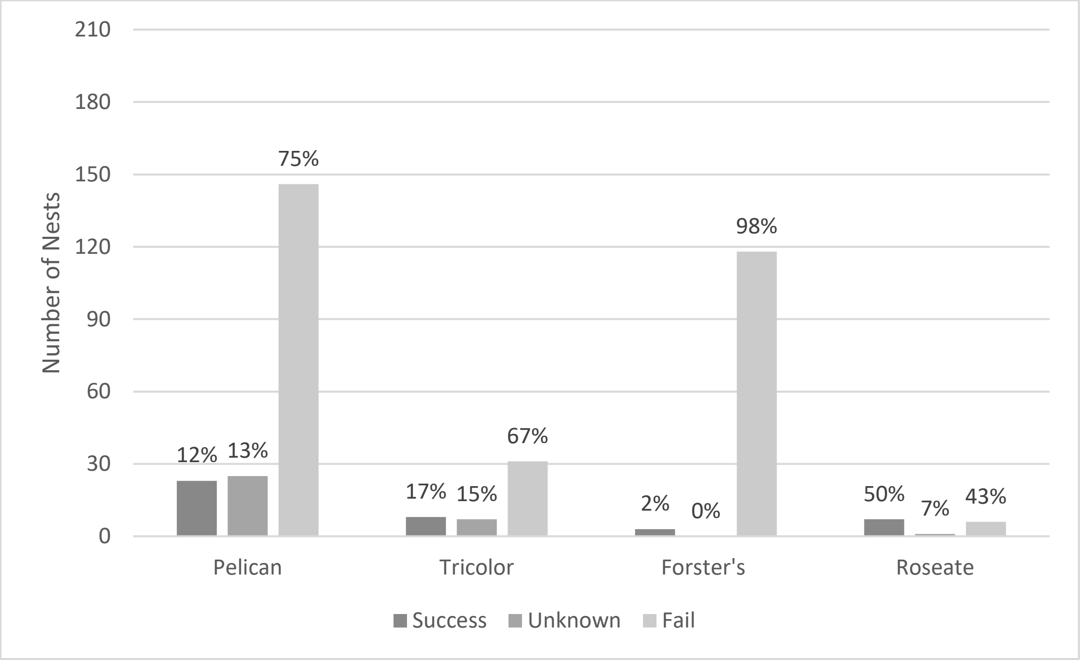


Figure 11. Number of nests of each chick outcome for each species at Rabbit Island 2017 (upper panel) and 2018 (lower panel). Labels indicate percentage of total nests for each species.

Likelihood of survival past the nestling stage was much lower for all species, calculated with the entire nest age, from initiation until at least one chick leaves: 28% for Brown Pelicans (DSR = 0.980, nesting = 62 days), 32% for Tricolored Herons (DSR = 0.97, nesting = 37 days), Roseate Spoonbills at 27% (DSR = 0.834, nesting = 39 days), and Forster's Terns had 0% likelihood to survive to leave the nest (DSR = 0.834, nesting = 39 days). All species except Tricolored Herons had the same strongest model for chick success as they did for hatch success. Tricolored Herons' daily survival rate throughout the nestling phase (0.97), was actually best described by the constant model, without any of the variables we examined. This model, again, was not well-supported (w_i = 0.405), so it is likely there are other variables affecting success in this species.

Date found was a better predictor of daily survival rate throughout the nesting season (DSR = 0.964) for Roseate Spoonbills (w_i =0.888) than it was for only the incubation period (Table 4). Once again, nesting later increased the daily survival rate (β = 0.283, SE = 0.133). While date found and year was still the strongest model for daily survival of Forster's Terns (0.834), it is not as strong as the same model for hatch success (w_i = 0.852), with a 15% chance that other factors are involved. Daily survival rate increased with later nest initiation dates for terns (β = 46.59, SE = 0.00) and were higher in 2018 than 2017 (β = 6.52, SE = 0.00). Daily survival rate of Brown Pelicans throughout the nestling phase was almost as high as it was for incubation only (DSR = 0.981). DSR decreased for Brown Pelicans the later they nested (β = -49.83, SE = 0.02) and was lower in 2017 (β = -1.07, SE = 0.00), although DSR decreased later in the season and both years followed the pattern more strongly than during only the incubation period (Fig. 12). This model was very strongly supported, as well (w_i = 0.984).

Table 4. Model selection results for regression models evaluating the relationship of chick success to year, elevation, and date the nest was found. Models are ranked based on Akaike's Information Criterion (AIC) adjusted for model weights (w_i). K is the number of parameters in each model.

Species	Model	AICc	ΔAIC	w_i	K	Deviance
Brown Pelican	FirstFound*Year	1163.852	0.000	0.984	3	1151.84
	FirstFound*Year*Elevation	1172.075	8.222	0.016	4	1148.04
	FirstFound*Elevation	1194.102	30.250	0.000	2	1182.09
	Year*Elevation	1195.384	31.531	0.000	3	1187.38
	FirstFound	1195.832	31.979	0.000	1	1189.83
	Elevation	1199.248	35.395	0.000	1	1195.25
	Constant	1200.917	37.064	0.000	1	1198.92
	Year	1202.438	38.585	0.000	2	1198.44
Tricolored Heron	Constant	198.592	0.000	0.405	1	196.59
	Elevation	200.186	1.594	0.183	1	196.18
	FirstFound	200.219	1.626	0.180	1	194.20
	Year	200.571	1.979	0.151	2	196.56
	FirstFound*Elevation	203.289	4.697	0.039	2	191.22
	Year*Elevation	203.971	5.378	0.028	3	195.94
	FirstFound*Year	205.146	6.554	0.015	3	193.08
	FirstFound*Year*Elevation	214.542	15.950	0.000	4	190.29
Forster's Tern	FirstFound*Year	777.556	0.000	0.852	3	765.53
	FirstFound	781.628	4.072	0.111	1	775.62
	FirstFound*Elevation	784.346	6.790	0.029	2	772.32
	FirstFound*Year*Elevation	786.762	9.206	0.009	4	762.65
	Year	799.341	21.785	0.000	2	795.34
	Year*Elevation	800.474	22.918	0.000	3	792.46
	Elevation	809.779	32.223	0.000	1	805.78
	Constant	822.650	45.094	0.000	1	820.65
Roseate Spoonbill	FirstFound	80.352	0.000	0.888	1	74.31
	FirstFound*Year	85.868	5.516	0.056	3	73.73
	FirstFound*Elevation	85.998	5.646	0.053	2	73.86
	Year	93.184	12.832	0.001	2	89.16
	Elevation	95.506	15.154	0.000	1	91.49
	Year*Elevation	97.154	16.802	0.000	3	89.09
	Constant	97.578	17.226	0.000	1	95.57
	FirstFound*Year*Elevation	97.874	17.521	0.000	4	73.36

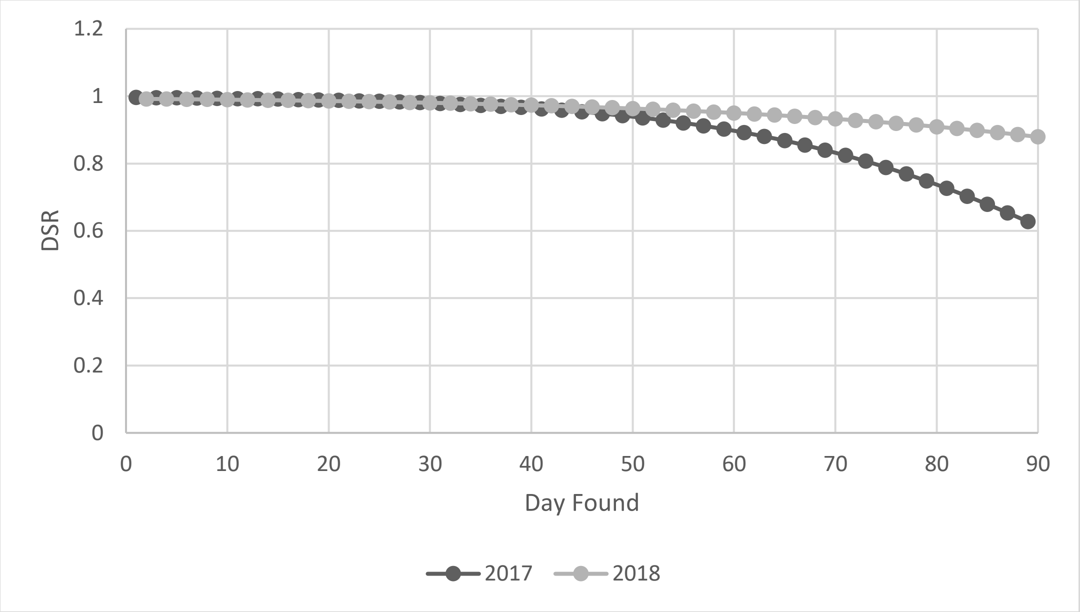


Figure 12. Daily survival rate predictions throughout nesting phase for Brown Pelicans by day the nest was found (0 = Febuary 24) and year.

Elevation was not a primary driving factor in the survival rate of any species. That may be because Rabbit Island has fairly homogenous topography. Mean nest elevation for each species, regardless of status (chick success, unknown outcome, or failed nest), were all within one standard deviation of each other (Fig. 13).

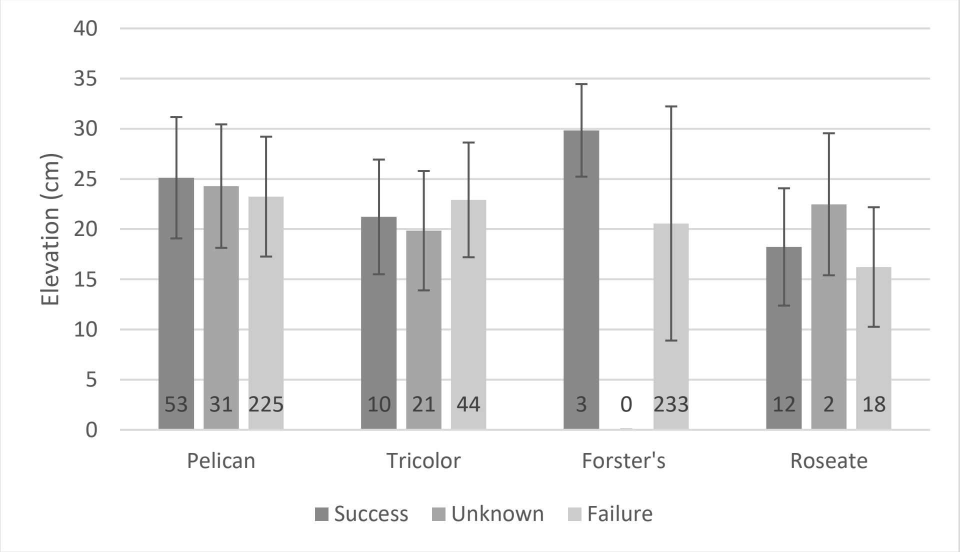


Figure 13. Average elevation of each species by chick outcome. Error bars are standard deviation; labels are sample size (n).

I found that most nests lost chicks between 1.5 and 3 weeks in both years (Fig. 14). Chicks were not considered successful until they reached Category 3: 3 to 4.5 weeks. In 2017 29 Brown Pelican nests had at least one chick reach Category 3. With an average of 1.16 chicks per nest (Table 2), I estimate that 33.6 chicks were actually recruited by this metric. In 2018 only 17 Brown Pelican nests reached at least Category 3. The average number of chicks per nest was less in 2018 as well, only 0.99. By this calculation 14.8 chicks were recruited in 2018, for a total of 48.4 during this study out of 309 total nests. The distribution of age categories was significantly different between 2017 and 2018 ($\chi^2 = 30.73$, $P < 0.0001$).

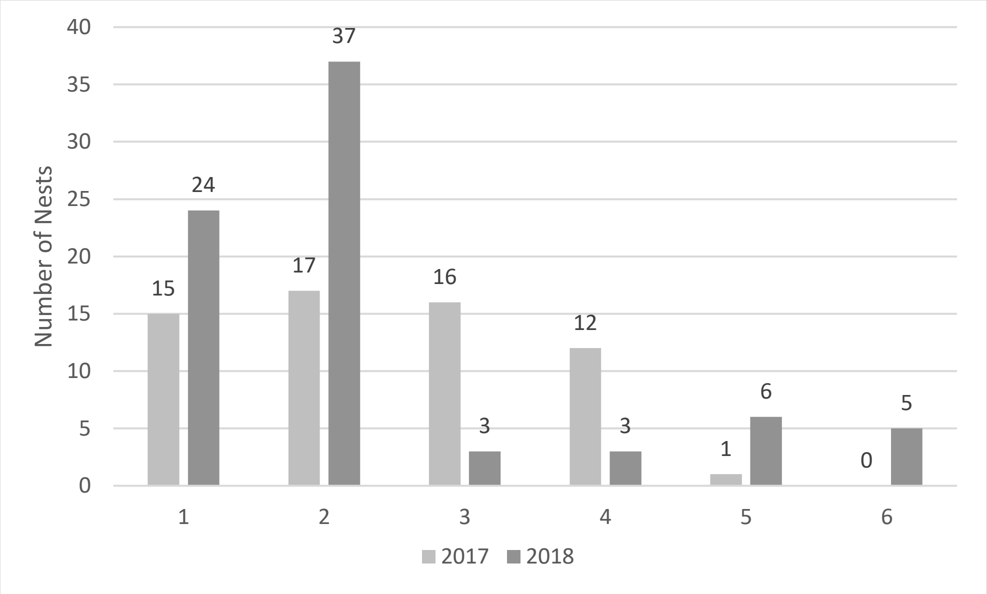


Figure 14. Age category reached by the oldest/largest chick from each Brown Pelican nest as defined by Walter et al. (2013). (1) 0 to 1.5, 2) 1.5 to 3, 3) 3 to 4.5, 4) 4.5 to 6, 5) 6 to 7.5, and 6) 7.5 to 9).

Predator and Fire Ant Presence

Evidence of mammalian predation was never recorded at a nest on Rabbit Island. Tracks of mammalian predators were never found on Rabbit Island, though there were frequently bird tracks present on the track plates. Though some field cameras trained on individual nests failed, one was washed over in the flood on April 3, and one randomly placed camera was trained on a nest that had already abandoned, one camera covering multiple Brown Pelican nests captured photos every 7 minutes and when the motion sensor was triggered every night from March 26-28, 2017. No mammals or predators of any kind were visible in any of these 1700 pictures. The only definitive mammalian sign ever seen throughout the entire research period were from muskrats (*Ondatra zibethicus*). In addition, no fire ants were ever detected at the lures. Researchers investigated any and all potential mammal tracks or sign of any kind and opportunistically examined dead birds during regular monitoring duties. Corpses routinely remained in place for several weeks without being moved and with no visible sign of mammalian bite or claw marks or fire and activity.

Originally, I set traps for fire ants according to the methods laid out by Seymour (2007), but no ants were ever collected across seven trials. To test the viability of this method I placed a test vial off-site within a foot of an active fire ant mound and still collected no ants. However, the cat food lure attracted fire ants at every site on every day on the dredge spoil island, while no fire ants were ever seen on Rabbit Island, either during predator sampling on cat food lures or at any other time during the study period. Throughout both nesting seasons there were many anecdotal sightings of bird corpses, none of which ever showed any sign of mammalian scavenging or decomposition by fire ants.

By contrast, the nearby dredge spoil island, 1.5 to 2 m higher than Rabbit Island, showed tracks from feral hogs (*Sus scrofa*), a relatively large unidentified canid, and an unidentified rodent, most likely the marsh rice rat (*Oryzomys palustris*). Only the rodent prints were observed on the track plates. I encountered the hog and canine tracks in mud near predator trap sites. Trail cameras on this island, also malfunctioned and no photographs were taken of any mammal.

Discussion

The results of this study indicate that nest timing, nesting strategy, and conditions in a particular year can all have effects on nest success of colonial nesting waterbirds on coastal islands. Species nesting above ground level such as Tricolored Herons and Roseate Spoonbills are less susceptible to overwash than those that nest on the ground. Walter et al. (2013) found that nest height was a significant factor in nest success for Brown Pelicans on nearby Wine and Raccoon Islands, where they nested both in woody vegetation and on the ground. Birds that nested higher above the substrate were more successful. Year was another highly influential factor in nest success, possibly due to large overwash events, erosion, and shoreline retreat which destroyed 20% of nests on Wine Island in 2009 and 15% in 2010 (Walter et a. 2013).

Flooding was the most common reason for nest failure in all species except Tricolored Herons. This is consistent with the findings of McNease et al. (1992). Flooding, particularly associated with storms, was the biggest threat to nesting Brown Pelicans throughout their 19-year study, especially those that nested on the ground. Reportedly, one flood caused the loss of at least 400 nestlings and many more eggs (McNease et al. 1992). In both years of this study, overwash and flooding events almost always occurred when the water level was above 0.4 m according to nearby gauges. On one occasion, April 3, 2018, an overwash event occurred without water levels at either the nearby NOAA or CRMS station reaching 0.4 m. However, this event was accompanied by strong winds and a swift change in wind direction. Although more measurements are required to know for certain, this event may have been a meteotsunami, a wave caused by localized atmospheric and barometric perturbations (Sheremet et al. 2016). At least one such event has been documented on the Atchafalaya Shelf, where Rabbit Island is located, and researchers suspect this was not an isolated incident based on the hydrology in the area (Sheremet et al. 2016). Within the scope of this study it appears that data supports a flood threshold of 0.4 m outside of such meteorological events. Occasional overwash events are unlikely to have any serious effect on even local recruitment, since waterbird species are long-lived and have many opportunities to nest and raise young. However, more comprehensive demographic data for each species is necessary to accurately model the degree and frequency of flooding that could decrease productivity below the level needed to sustain the population.

Despite the prevalence of flooding and evidence of a flood threshold once water levels reached 0.4 m compared to the marsh, elevation was not a significant factor in determining daily survival rate for any species. This may be because Rabbit Island is so low-lying and topographically homogenous that birds cannot nest high enough for elevation to have an impact. If birds are not able to nest above the flood line, then nesting early or late enough to avoid the most common and usually largest overwash events in April and June may be their best strategy for survival. Unfortunately, though nest timing can mitigate the effects of flooding, strategies that increase success one year may be detrimental the next as evidenced by the variability in timing of overwash events over the last 13 years.

Though difficult to measure, my study also suggests that flooding may impact ground nests in subtler ways. While flooding and overwash are often associated with of nest bowls washing away entirely or several centimeters of standing water in the nest, it is likely that nests that remain intact can also fail due to nest material becoming damp and change the temperature and the humidity of the nest, altering the ability of the parents to thermoregulate the eggs effectively. I found evidence in abandoned nests that the eggs may have been wet on their undersides, although whether that occurred before or after abandonment is difficult to say. In fact, nearly as many Brown Pelican nests failed due either to suspected post-overwash effects and abandonment as failed due to direct flooding (n = 141 and 154, respectively). Other studies have shown nest abandonment may not require damage to the nest at all, merely environmental cues that may indicate a high risk of overwash. In 2010 all 52 nests on Wine Island were abandoned before eggs could hatch, apparently due to the decrease in suitable habitat (Walter et al. 2013). However, there are alternative explanations for the large number of abandoned nests. Anderson et al. (1982) linked large-scale nest abandonments of Brown Pelicans in Southern California to food stress due to a lack of pelagic fish in the area. More study is required to rule out other environmental factors.

Forster's Terns were by far the least successful of all the species in this study. While I banded terns from 3 nests past their nestling stage in 2018, none of the chicks were fledged at that time. In both 2017 and 2018, Forster's Terns did not renest on Rabbit Island after the overwash events in June, and nearly all adult terns left the area. Based on the timing of the overwash events and the fact that I never identified any fledgling terns in either year, I believe that no recruitment took place from the Forster's Terns on Rabbit Island. This is reflected in the nest survival estimates in which Forster's had a 12% chance of surviving to hatch but a 0% chance of leaving the nest. A previous study in Minnesota showed that Forster's Terns also had fairly low hatch and success rates there. Hatch rates ranged from 0 to 33% while fledge rates were 0 to 17% between two breeding seasons (Cuthbert and Louis 1993).

Forster's Terns nest preferentially on dry dead vegetation (Bergman et al. 1970). Due to the low elevation and frequent overwash of Rabbit Island, the majority of this vegetation is deposited in areas that are repeatedly overwashed. Ideally on higher elevation islands nesting substrate for Forster's Terns would consist of vegetation washed up further inland during tropical storms or hurricanes in the late summer or early fall, or periodic meteotsunamis throughout the year. If overwash were less frequent and less intense this rack vegetation from extreme weather would persist until the next nesting season but little to no rack would accumulate in the lowest areas of the island. Then Forster's Terns would be able to nest on their preferred substrate without guaranteeing their eventual overwash. As more coastal islands lose elevation, loss of safe substrate could cause a population decrease in Forster's Terns.

However, Forster's Terns face more than just flooding on Rabbit Island. Unlike Brown Pelicans, Tricolored Herons, and Roseate Spoonbills, Forster's Tern chicks were rarely seen more than once and empty nests with no sign of whether or not an egg hatched was fairly common. This could be because they become mobile and leave the nest earlier than the rest of the species, but even when I thoroughly searched the entire transect area, I rarely found older chicks hiding nearby. This reflects the 1993 study by Cuthbert and Louis, in which "disappearance" was the most common cause of nest failure, both before eggs hatched (61%) and after chicks had been confirmed (67%). Another 13% of eggs were abandoned (Cuthbert and Louis, 1993).

Late nesting not only makes Forster's Terns more susceptible to storms late in the season, but they begin nesting around the same time as Laughing Gulls on Rabbit Island (anecdotal observation). While I was unable to document any instances of avian predation on Rabbit Island, Laughing Gulls are notorious nest predators and I did find some evidence of avian predation at Marsh Island (Chapter 2). O'Connell and Beck (2003) found that gull predation on tern and skimmer nests in Virginia accounted for more nest mortalities than tidal flooding, the second most common cause of failure. Additionally, they suggested that large populations of gulls may also force terns and skimmers into nesting areas where they are more susceptible to flooding (O'Connell and Beck 2003). Forster's Tern eggs and chicks on Rabbit Island may be facing much higher levels of predation and competition than the other species due to their small relative size, as well as an increase in avian predation during Laughing Gull nesting, in order to provide food for their young. More information is needed to determine the impact of avian predation on nest failure in Forster’s Terns.

Frederick and Collopy (1989) determined that Tricolored Herons had a 46-66% probability of nest success using the Mayfield method compared to an estimated 32% in this study. My probability may be artificially low, due to the number of unknown outcome nests. The likelihood of hatch success was much higher, approximately 77%. Interestingly, they also found that the largest cause of nest failure by far in Tricolored Herons was nest abandonment. This was not associated with overwash or flooding events but was correlated with heavy rain (Frederick and Collopy 1989). Roseate Spoonbills in Texas had a slightly higher rate of hatch success to those at Rabbit Island (70%). White et al. (1982) recorded 79 to 97% success rates among their nests over three years.

There was no sign of any mammal on Rabbit Island except for muskrats. In earlier studies of nest success within southwestern Louisiana, muskrats were present in the study area but were not considered nest predators (Gabrey et al. 2002). Both old and active muskrat mounds provide nesting sites for Forster’s Terns, suggesting that the presence of muskrats may even be beneficial for nesting waterbirds (Bergman et al. 1970, Gabrey et al. 2002). The presence of large mammalian predators and fire ants on the nearby dredge spoil island is concerning in the context of future restoration of Rabbit Island. Walter et al. (2013) suggested that some nest failures during that study were due to imported red fire and as well as raccoon predation. The addition of nest predators on such a small island could be much more detrimental to nesting birds than occasional flooding (Erwin et al. 2001).

Management Implications

Restoration measures are needed to counteract subsidence and erosion on Rabbit Island. However, raising the elevation more than 1 m would substantially increase the probability of invasion by woody plants and mammalian predators, as evidenced by the dense woody vegetation, mammalian predators, and invasive red fire ants prevalent on the dredge spoil island just 2.4 km away and only 1.44 m in elevation. Additionally, while increasing the elevation may increase the flood threshold, uncertainty regarding frequency and magnitude of flood events and colonial nesting waterbird demographics limit our ability to make strong predictions. Overwash events only occurred in 5 of the past 13 years, according to past CRMS station data. Water levels above the flood threshold have occurred every year since 2015, and while sea level is increasing (Visser et al. 2005, Deaton et al. 2017), and storms are becoming more frequent and intense (Day et al. 2008), it is not yet clear whether more frequent high water events in Lake Calcasieu are the new normal.

Furthermore, not all invasion by woody vegetation would decrease habitat for all species. Forster's Terns are obligate ground or overwater nesters, but Roseate Spoonbills and Tricolored Herons build nests above the ground even in grassy vegetation and are known to nest in woody vegetation elsewhere (Maxwell and Kale 1977, White et al. 1982, Cuthbert and Louis 1993). Another study showed that Brown Pelicans have higher nest success when nesting in taller vegetation, specifically black mangrove and marsh elder (Walter et al. 2013). This also points towards caution in increasing island elevation, as mangroves do best in intermediate marsh, which cannot be maintained if the elevation is raised too high (Guo et al. 2013). However, the islands in Walter and colleagues' (2013) study that supported mangroves and therefore must have been fairly low in elevation were home to both fire ants and mammalian predators. The spread of vegetation and predators from one island to another is difficult to predict. In a study of barrier islands in Virginia, 6% of 51 radio-collared raccoons moved overwater from one island to another (Dueser et al. 2013). Expansion in mammalian predators throughout barrier islands in Virginia have corresponded with an overall decrease in population of several species as well as a decrease in colony size (Erwin et al. 2003).

Rabbit Island is a unique case-study due to its lack of predators and relatively slow subsidence compared to most coastal islands. This allowed me to isolate flood risk as a factor affecting nest success in colonial nesting species with a variety of nesting strategies. On low-elevation coastal nesting islands, increasing elevation slightly to increase the flood threshold and decrease the number of overwash events may substantially increase nest survival. However, the effects this could have on other factors and therefore on the ecosystem as a whole are still largely unknown and unpredictable. More research is needed, particularly monitoring after restoration occurs, in order to determine the most successful methods for restoring coastal islands for nesting waterbirds.

The average land loss rate of barrier islands in coastal Louisiana is over 10 times that of Rabbit Island, primarily due to wave action within the Gulf of Mexico (Selman et al. 2016). Selman and colleagues (2016) concluded that Rabbit Island in particular and restoration efforts such as the recent stabilization of Queen Bess in southeastern Louisiana will be important for the future of nesting waterbirds. I submit that it also may be important to establish, and not just restore, islands like Rabbit Island that are more protected from waves than barrier islands. I suggest this because it may be more cost-effective to create new inland islands that will not erode as quickly than it is to slow erosion of existing barrier islands in the open Gulf.

Chapter 2.

Methods

Study Area

My secondary site consisted of four small islands that were restored in 2015 located within Bayou Platte in Marsh Island NWR, between Vermilion Bay and the Gulf of Mexico (Fig. 1). The substrate is mostly rock and the islands are treated with herbicide to give a more favorable nesting habitat for birds that prefer bare ground. These islands are primarily managed for Forster's Terns, Gull-billed Terns (*Gelochelidon nilotica*) and Black Skimmers. Two of the four small island sites support invasive fire ants. No mammals live on the islands but these islands are in shallow water close to a larger continuous marsh, and so it is possible that mammals will cross to feed on eggs and chicks during nesting season. Additionally, alligators are prevalent in this area (personal observation).

Figure 1. Map of Coastal Louisiana, USA with inset of Bayou Platte within Marsh Island. Breeding island sites circled in orange.

I visited the Marsh Island sites every 2 to 3 weeks beginning in March each year. Once Forster’s Terns began nesting on these islands, I followed the same protocol for nest monitoring as in Chapter 1, however site visits were conducted approximately bimonthly due to the distance and relative difficulty of travel to these sites. These islands and the Forster’s Tern colonies on each were relatively small, so I marked every nest I found on all four islands within Bayou Platte.

I took elevation points at each nest and in transects across each island using a Trimble 7X, however these islands were located too far away from the nearest base station and the points were too inaccurate to use. I used the nearest CRMS station (CRMS0529-H01, 29.60 N 91.92 W) to examine past water level data. Because I could not get an accurate elevation reading on the islands, the water level data logger I installed was also unusable.

I deployed field cameras (Bushnell TrophyCam) at colonies on the two largest islands (Henrietta Island and the Big Island) 4 times during both field seasons for periods of 10-14 days, positioned so as to encompass several tern nests at once. During nest searches researchers monitored the islands for signs of predator presence. Alligator sightings were recorded at each site visit. A separate field camera was deployed at the entrance of a hole that appeared to be a mammalian den during the 2018 nest season.

Results and Discussion

In 2017, I recorded Forster’s Tern nests on three islands within Bayou Platte. In 2018, there were Forster’s Terns nesting on the same three islands and an additional small island west of the Big Island, where I did not find any nests the year before. I observed 350 nests, producing 685 eggs over both years (Table 1). Only one chick was confirmed to have successfully hatched.

I observed more than one chick near my transects, however, due to the flat nesting substrate unobstructed by vegetation, it was nearly impossible to determine which nest chicks came from. While there were other chicks that attained hatch success, I believe that chick success was essentially zero across all islands both years.

Table 1. Number of nests and eggs at four island sites within Bayou Platte in two field seasons.

2017	# Nests	# Eggs	# Chicks
Henrietta	24	40	0
Crescent	38	73	0
Big Island	77	121	0
West Island	0	0	0
2018			
Henrietta	130	302	1
Crescent	13	21	0
Big Island	53	98	0
West Island	15	30	0

The breeding season on Marsh island was later and shorter than on Rabbit Island (Chapter 1). The earliest nest was found in 2017 on May 11 and all nests were destroyed by June 9. In 2018, I didn't see any nests until June 6, and there was no nesting activity as of August 1. Therefore, I defined the breeding season for Marsh Island as May 1 – July 31.

The water level data from the nearest CRMS station over the past 10 years shows a general pattern of somewhat stable water levels throughout the breeding season, generally between 0-0.4 m (Fig. 2). It is clear from Figure 2 that 2017 (denoted by white dots with a black outline) and 2018 (black dots) were anomalous years. Water levels up to 0.96 were recorded on June 22, 2017 during Tropical Storm Sandy. This event was by far the highest water level recorded in the past 10 years. In 2018, water levels were persistently low throughout the whole season.

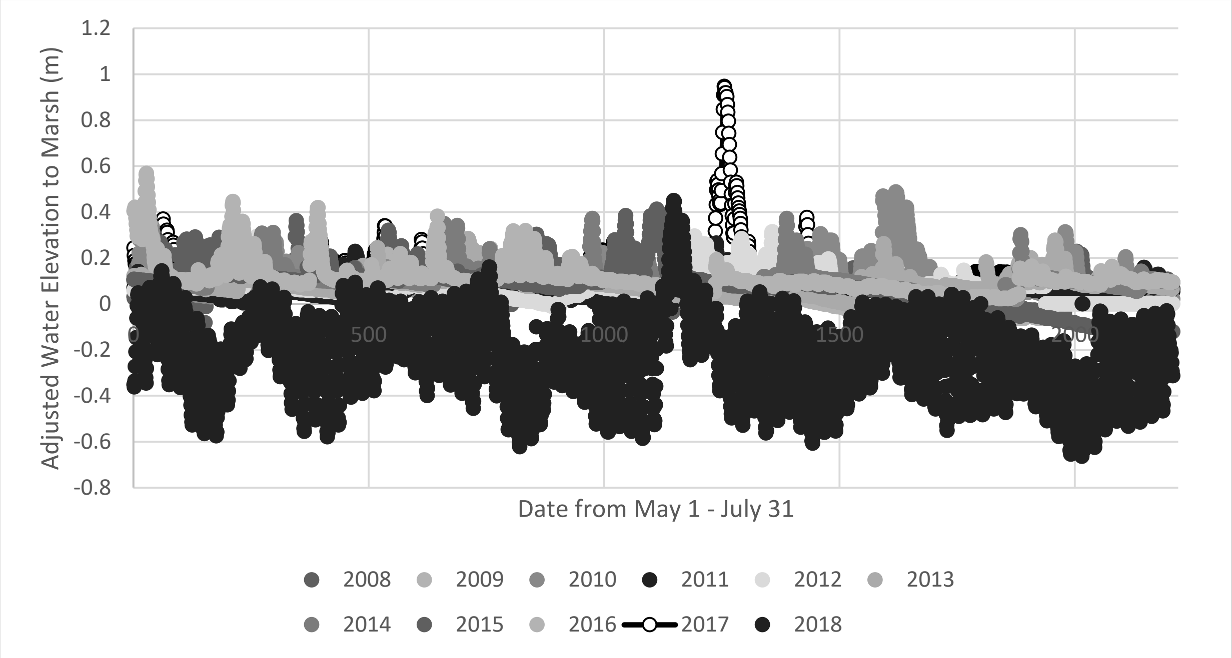


Figure 2. Water level data from nearest CRMS station 0529-H01 during breeding season from 2008 through 2018.

While there was one extreme event in 2017, the mean water level was only slightly higher than all other years. The mean water level in 2018 was the only negative mean and was the only mean more than one standard deviation away from all other years (Fig. 3). It is possible that these water levels were a mechanical error rather than such a drastic change from all other previous seasons. However, Nyman et al. (2009) showed that water levels in marshes at Marsh Island and nearby experienced lower mean daily low water levels than marshes surrounding Calcasieu Lake and attributed the difference to the greater connectivity between the Gulf of Mexico and Atchafalaya Bay than between the Gulf of Mexico and Calcasieu Lake. Although the water was shallow in 2018, I was able to get the boat to each island on every visit, which indicates that the water level was not below 0 m for the majority of the season. Whether or not the CRMS information was accurate, it is impossible to draw conclusions about flood thresholds or probabilities based solely on these two years.

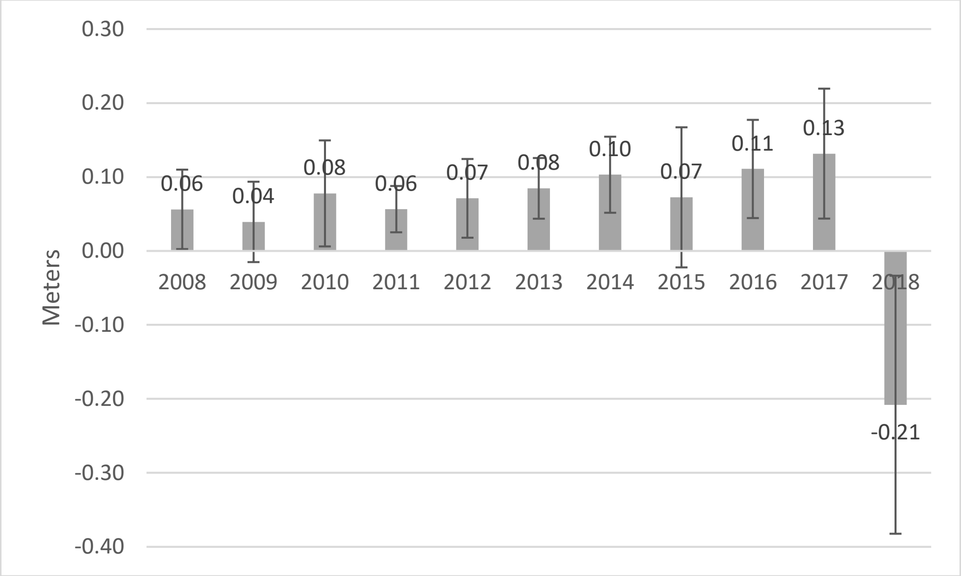


Figure 3. Mean water level during breeding season (May 1 – July 31) for the past 10 years. Error bars are standard deviation.

Across all islands in both 2017 and 2018, Forster's Terns nested exclusively on washed up dead vegetation (rack) from previous overwash events. Since water levels were low in 2018, and 3 monitoring visits to Marsh Island before breeding began revealed no rack or dead vegetation on any of the islands. In fact, Forster's Terns did not begin to nest in 2018 until June 6, the first time I observed rack lines on each of the islands. When I returned to Henrietta Island six days later on June 12, an overwash event had destroyed all previous nests and deposited rack at least 7 m inland from the previous rack line. Forster's Terns had already colonized and built nests on this new dead vegetation. To allow Forster's Terns to nest earlier and in an area less prone to overwash, I join Leburg et al. (1995) in recommending managers deposit dead vegetation well above the rack line.

In 2017, there were four nests with definitive signs of avian predation by the way the shells were broken. I assume that other nests were also depredated. These islands hosted Laughing Gulls as well as terns and Black Skimmers. The same storm, Tropical Storm Cindy, that destroyed all remaining nests on Rabbit Island in June (Chapter 1) completely overwashed these low-lying islands. Like Rabbit Island, after that storm no adult or juveniles were seen on any of the island sites.

The island of Henrietta was overwashed three times and re-colonized twice in 2018. The first attempt consisted of 47 nests in which 101 eggs were laid. That colony was present from June 6-12. The second attempt lasted from June 12-26 and contained 44 nests and 111 eggs. Finally, from June 26-July 13, 39 nests contained 90 eggs. One chick successfully hatched during the third attempt. On July 13, all nests on Henrietta Island were either empty or gone. There were approximately 10 adult Forster's Terns present and aggressive both on July 13 and at my final visit on August 1. Despite searching, I did not find any chicks, although the adults' behavior was consistent with nest or chick defense.

I saw what may have been a single fledged Forster's Tern on West Island on July 13, but there were no adults, chicks, or intact eggs present at any other island site. However, the majority of nests at all sites were still present and intact, indicating that no overwash event or large predator was responsible. I suspect the majority of the nest failures in 2018 were caused by avian predation, although there was little proof and no way to determine the species depredating Forster's Tern nests.

Cameras at various colonies on Henrietta and the Big Island never captured mammals or other large predators near nests in either nesting season. Multiple alligators were present during every site visit, and I once witnessed an alligator predate a Gull-billed Tern chick in the water, but there was never any sign that alligators depredated nests. During the 2018 nest season I captured photographs of at least one nutria (*Myocastor coypus*) on Henrietta Island. While nutria have been documented raiding bird nests (Windhoffer and Pierce, *unpublished data* quoted by Baurick 2018), the nutria never appeared on nest cameras located near its burrow and there was no sign of mammalian predation at any nest.

While our cameras failed to capture any actual depredation, they did show some potential nest predators, all avian. In 2017, cameras on the Big Island caught large numbers of White Ibis (*Eudocimus albus*) flying in and landing on top of Forster's Tern colonies during the night. Additionally, in 2018 large numbers of Gull-billed Terns appeared just behind nesting Forster's Terns. Within a few minutes several Forster's Terns flushed off their nests and returned, however the eggs that were previously visible were not seen again after that flushing photo. Both White Ibis and Gull-billed Terns are carnivorous and feed primarily on invertebrates and small amphibians, reptiles, crustaceans, and fish (Kushlan 1979, Erwin et al. 1998). It seems plausible that either of these species may opportunistically depredate nests, however I did not capture that behavior.

Interestingly, while all adult Forster's Terns and any eggs or chicks on the Big Island, Crescent Island, and West Island disappeared on July 13, 2018, Black Skimmers and their nests and eggs were still present. There were active skimmer nests within as little as 0.5 m from empty Forster's Tern nests, some containing traces of shell and yolk. However, Black Skimmers' unique bill morphology and nearly exclusive diet of fish make it extremely unlikely that they were responsible for depredation of any other avian species (Favero et al. 2001). In preliminary visits to the sites before breeding began in 2017, multiple owl pellets were observed on the Big Island and Henrietta. I did not see owls, owl pellets, or field camera photos of owls during either nesting season, but birds of prey are another candidate for possible nest predator. More intensive sampling and video surveillance instead of field cameras are needed to determine the fate of these nests.

Appendix A. Rabbit Island Vegetation Data for Chapter 1

Table A1. Approximate percent composition of vegetation for each transect. BRPE = Brown Pelican, TRHE = Tricolored Heron, FOTE = Forster's Tern, ROSP = Roseate Spoonbill.

Year	Species	Transect	*S. alterniflora*	*S. patens*	*D. spicata*	*J. roemerianus*
2017	BRPE	A	0	0	100	0
2017	BRPE	B	0	0	100	0
2017	BRPE	C	50	0	50	0
2017	BRPE	D	50	0	50	0
2017	BRPE	E	70	30	0	0
2017	BRPE	F	85	15	0	0
2017	BRPE	G	60	40	0	0
2017	BRPE	S	75	25	0	0
2017	BRPE	T	100	0	0	0
2017	TRHE	East	80	0	20	0
2017	TRHE	North	50	30	20	0
2017	FOTE	Bayou	50	0	20	30
2017	FOTE	Sammy	75	25	0	0
2017	FOTE	NE	50	30	20	0
2017	FOTE	MM[a]	N/A	N/A	N/A	N/A
2017	FOTE	BS[b]	0	0	0	100
2017	FOTE	P[b]	100	0	0	0
2017	ROSP	51-69	80	20	0	0
2017	ROSP	100-104	100	0	0	0
2018	BRPE	H	100	0	0	0
2018	BRPE	I	100	0	0	0
2018	BRPE	J	100	0	0	0
2018	BRPE	K	100	0	0	0
2018	BRPE	L	100	0	0	0
2018	BRPE	M	100	0	0	0
2018	BRPE	N	90	0	10	0
2018	TRHE	A	75	0	0	25
2018	TRHE	B	20	80	0	0
2018	FOTE	A	20	80	0	0
2018	FOTE	B	50	35	15	0
2018	FOTE	C[c]	80	0	20	0
2018	FOTE	D	90	10	0	0
2018	FOTE	E	40	40	20	0
2018	ROSP	ROSP	100	0	0	0

[a] Transect on abandoned muskrat mound, no live vegetation

[b] Nests in this transect primarily floating on water, emergent vegetation around nests listed

[c] Some nests in this transect directly on shell hash

Table A2. Average percent composition of vegetation for each species

	S. alterniflora	S. patens	D. spicata	J. roemerianus
BRPE	73.75	6.88	19.38	0
TRHE	56.25	27.5	10	6.25
FOTE	55.5	22	9.5	13
ROSP	93.33	6.67	0	0

Appendix B. Rabbit Island Soil Characteristics Data for Chapter 1

Table B. Soil classification, water content, and organic matter content averaged across two subsamples from each site. Two subsamples from each location were dried at 60℃ for three days[a], weighed to determine water content, then ground and burned at 550℃ for 3 hours and weighed again to determine organic matter content (Hoogsteen et al. 2015). Standard deviations for each mean are in parentheses.

Sample Site	Classification	Mean % Water	Mean % Organic Matter
Dredge Island	Clay	15.76 (0.1)	6.06 (0.1)
West[b]	Silty clay loam	55.37 (5.33)	17.06 (2.62)
BRPE A	Silty clay loam	36.19 (7.63)	7.07 (3.17)
BRPE M	Silty clay loam	51.84 (0.04)	14.78 (0.52)
FOTE A	Silty clay loam	49.08 (0.32)	14.62 (0.94)
BRPE G	Silty clay loam	58.75 (7.23)	18.3 (3.9)
BRPE C/D	Silty clay loam	54.1 (2.41)	22.37 (10.49)
BRPE H/I	Silty clay loam	59.17 (0.53)	9.80 (12.06)

[a] Samples were kept at room temperature for several weeks prior to drying, potentially skewing both water and organic matter content. However, all samples were handled in the same way so data may be used comparatively.

[b] Soil collected from a point chosen unsystematically on the west side of Rabbit Island where no birds nested in either year (Ch. 1, Fig. 5).

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Vita

Karis Amanda Ritenour grew up in Bloomington, Minnesota and graduated Magna cum Laude from Beloit College (Beloit, Wisconsin) in 2011 with a degree in Ecology, Evolution, and Behavioral Biology. After an internship with USGS tracking and handling desert tortoises in the Mojave Desert and a couple of years in the domesticated world caring for dogs and horses, the International Crane Foundation in Baraboo, Wisconsin took Karis under their wing. She worked several jobs over the course of two years: costume-rearing Whooping Crane chicks for release, tracking and monitoring cranes in Wisconsin, on migration across four states, and at the wintering grounds of the wild flock in south Texas. Hooked on birds, in 2016 she took a job as an assistant to a PhD student studying predator-prey dynamics with Bachman's Sparrows at Tall Timbers Research Station, handling not only sparrows but snakes and rodents as well. A fascination with the dynamics of nest survival took hold and she continued on to Louisiana State University in January 2017. Upon completion of her master's degree, she will seek to continue ecological field research to aid in conservation.