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Examination of Photographic Evidence of Disturbance on Interior Least Tern Breeding Behavior and Reproductive Success

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EXAMINATION OF PHOTOGRAPHIC EVIDENCE OF DISTURBANCE ON INTERIOR LEAST TERN BREEDING BEHAVIOR AND REPRODUCTIVE SUCCESS

By
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The evaluation committee hereby approves this thesis by Stephanie M. Nefas in partial fulfillment of the requirements for the degree of Master of Science.

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Abstract

The colonial ground nesting interior Least Tern (*Sternula antillarum athalassos*,) is an example of a species that requires frequent monitoring in order to estimate population size and determine long-term trends. Modifications in nesting habitat such as flooding, predation, and disturbances to colonies severely reduce reproductive success each year. I continued long-term monitoring efforts by identifying colonies and recording breeding activity along the Arkansas River. To improve the way that we understand factors that contribute to survival rates of nests and chicks, I examined survival at several colonies during the 2017 breeding season. Then to improve current monitoring techniques I tested the ability of time-lapse cameras to document instances of flooding, predation, and disturbances to nesting colonies. I successfully identified colonies that were successful or failed during the 2017 breeding season along with information about disturbances. I found that average survival of nests at 33% [0.15 SE] was poor and average survival of chicks at 56% [0.14 SE] was fair. I found that time-lapse cameras significantly improved our ability to document events at nesting locations. Most notably I was able to detect flooding, quantify avian predators within the colony, and accurately gauge levels of human disturbances to breeding birds from camera footage. Based on my findings, I would recommend focusing on improving nest success and continuing to use camera methods to document events at colonies.

Keywords: Least Tern; Chick; Nest; Survival; Camera; Time-lapse; Disturbance

Table of Contents

List of Tables

List of Figures

Introduction

It is critical, in the study of wildlife, to estimate the number of individuals in a population, birth rates, and death rates. Then it is necessary to reevaluate these population parameters since they are prone to change from year to year. The federally endangered interior Least Tern (*Sternula antillarum athalassos*, hereafter 'Least Tern') is an example of a species that requires frequent monitoring in order to estimate population size and long-term trends. The Least Tern's listing status is in part due to fluctuating reproductive success each year and nesting habitat conditions. For many Least Tern colonies, nesting habitat conditions influence reproductive success, predominately conditions such as flooding, predation, and human disturbance (Thompson et al. 1997). I monitored reproductive trends and nesting conditions in breeding colonies of Least Terns along the Arkansas River in order to quantify current conditions.

Nest and chick survival in Least Terns is a critical stage in reproductive efforts. Survival rates contribute to maintaining a population, return rates of breeding individuals too specific colonies, and even the success of the entire colony during the breeding season. In the study area on the Arkansas River, reproductive rates are variable with a history of at least some colonies completely failing each year. I monitored individual nests and chicks in order to determine nest and chick survival rates. Water levels were high and delayed breeding in many parts of the Arkansas River. This is a common occurrence; to prevent flooding throughout the watershed water levels are controlled. Rooftop colonies are constantly accessible but tend to be unproductive, so I included initiation date as a potential predictor of survival.

While monitoring survival of individuals, I also evaluated potential cause of death and failure at colonies. As Least Terns are a ground nesting avian species, they are susceptible to flooding, predation, and disturbances that occur at the nesting colony. Predation and disturbances can cause direct harm as nests and chicks are killed or indirect harm as adults expend energy to mob intruders and are unable to care for young. Interrupted care for eggs and chicks includes exposure to thermoregulatory stress and interruption of feeding rates.

I evaluated the suitability of using time-lapse cameras positioned to view the entire colony area to monitor and document flooding events, predator activity, frequency of human intrusions, and if frequent disturbances were inhibiting parental care. Some flooding that causes nest failure is likely due to a temporary increase in river height due to a local rain event not detected by regular survey methods. Known predators may visit Least Tern nesting locations regularly or on a single occasion and cause no nest failure or collapse of the entire colony. Human disturbance may act in a similar manor, evidence of human activity on sandbars during the Least Tern breeding season is also a concern, as it is a known cause of nest failure. Accurate disturbance rates in this area are unknown.

In the following chapters, I describe the results of monitoring during the 2017 breeding season. I evaluate population levels and reproductive trends by calculating survival of young during the breeding season during two age groups, nest and chick, at several locations. Then I evaluate disturbances at Least Tern nesting colonies and

potential relationships to reproductive success. I then evaluate my novel method of measuring disturbance with a time-lapse camera compared to standard survey methods.

Chapter 1: Least Tern breeding activity during the 2017 season on the Arkansas River and surrounding area

Introduction

Monitoring species is critical when reproductive rates vary greatly from year to year. For example, interior Least Tern (*Sternula antillarum athalassos*; hereafter Least Tern), reproductive success varies between no nests surviving to reported rates as high as 89% of nest hatching (Elliott et al. 2007). Least Terns in particular, like many species, have suffered declines due to habitat alteration in riparian ecosystems (Nilsson and Berggren 2000). Reductions in the overall nesting habitat and quality for Least Terns are a result of altered hydrological events that are responsible for maintaining available nesting habitat and habitat quality (Nilsson and Berggren 2000). Since habitat availability and reproductive rates can drastically vary each year, consistent monitoring over many years can track population levels and trends (Farnsworth et al. 2017). If habitat conditions and poor reproduction result in population declines, management interventions can then take place before it is too late or too costly.

Least Terns nest on riverine sandbars during the breeding season typically from May to August (Farnsworth et al. 2017). In unaltered river systems, nesting habitat consist of sparsely vegetated emergent sandbars on free-flowing natural braided river systems maintained by seasonal periods of high and low flows (Wohl et al. 2015). Over time, without some flooding, sandbars degrade by washing away or becoming vegetated. Periodic flooding then creates or restores sandbar habitat conditions. Thus, Least Terns are a disturbance-dependent species with a well-documented preference for nesting habitat shaped by hydrology (Mazzocchi and Forys 2005), with survival rates that are

influenced directly by the timing, duration, and height of flows (Dugger et al. 2002). Since Least Terns are colonial breeders, the concentration of adult activity near colonies make them obvious. Adults will flush away from nests and chicks when a threat is detected, mobbing predators that enter the colony (Thompson et al. 1997). Flooding maintains attributes of sandbar habitat that counter the colonies conspicuousness. Such as sparse vegetation, that provides visibility for adults, and bare sandbar substrate appropriate for camouflaging nests and chicks. Without natural flooding cycles maintaining the conditions of nesting habitat, predation can overwhelm nesting colonies. Least Tern nesting habitat has declined due to the construction of dams and changes in the timing, duration, and height of flows (Nilsson and Berggren 2000).

Since 2004, Arkansas Tech University has conducted yearly monitoring of Least Tern colonies on the Arkansas River within the McClellan-Kerr navigation system. Over the years, we have collected observations of flooding, nest predation, and human disturbances. Reasonable and prudent measures 2 and 3, monitoring then reducing predation and human disturbance, in the most recent Final Biological Opinion direct conservation actions of the U.S. Army Corps of Engineers in Oklahoma and Arkansas (USFWS 2016). Preventing disturbance, by predators and humans, is a priority as this causes nest failure and colony abandonment resulting in significantly lower reproductive output. Documenting evidence of flooding, predation, and disturbance while overall keeping track of survival and productivity can help guide management practices. I hypothesized that Least Tern reproduction during the 2017 breeding season would be consistent with previous year as habitat has not increased in this area. If habitat is stable, then reproduction should be consistent with previous years. In accordance with the 2016

Biological Opinion (USFWS 2016), I monitored Least Tern nesting colonies on the Arkansas River. Monitoring consisted of locating colonies, recording the timing of breeding activity, and determining the number of breeding adults. I then quantified productivity from estimations of nests, chicks, and fledglings in relation to the number of breeding adults at each colony. I recorded signs of flooding, predation, and human disturbances as events of interest to develop recommendations for management of nesting habitat.

Methods

Survey Area

Least Tern breeding activity was recorded and quantified along the Arkansas River from pool 12 down river to pool 2 within the McClellan-Kerr navigation system, between river miles 285 to 36 (hereafter RM). Each year we routinely check previously used nesting locations; frequently Least Terns will reuse colony locations. I discovered new colony locations by checking any suitable habitat for congregations of adults during the breeding season. I also conducted surveys on four rooftops in Clarksville, Conway, North Little Rock, and Little Rock identified in previous years as breeding colonies for Least Terns (Nupp and Ross 2015).

On river colonies, I conducted surveys between 14 June and 16 Aug 2017. Access required a boat on all river colonies. A small craft advisory on the Arkansas River, due to high releases, delayed surveys in 2017. When we detect the first adults at end of May, the initiation of nests can begin; therefore, nest initiation dates predate survey start dates. Rooftops were monitored from 6 June to 16 Aug., rooftop access was not affected by the

high releases; timing of surveys was dependent on permission and convenience of property operators.

Field Methods

I identified, by previous nesting history or by scanning from a boat to discover Least Tern activity, all suitable nesting habitat; defined as exposed sand or gravel that was sparsely vegetated. I considered a location a Least Tern colony by collecting observations of congregating Least Terns loafing on suitable nesting habitat associating in pairs and performing breeding behaviors, such as presenting a food item to a mate.

The numbers of observers varied from one to three, and each observer on the boat was equipped with binoculars. When approaching river colonies, I reduced our boat speed to avoid adult Least Terns flushing from the colony. Observers then counted all adults in the area, taking an average of all counts collected. Adult counts that were not complete before adults flushed were not included in colony estimates. Two to four surveyors systematically searched each active colony for nests. In order to locate all nests within a colony, surveyors searched by forming transect lines and walked across the sandbar, then recorded the number of nests, incubation stage, and number of eggs. I supplemented the transect nest searches with focal observations of incubating adults on the larger gravel bars to target search an area. In focal observations, I observed an adult potentially incubating in a known location and then I searched this area more intensely. Once a survey was complete, surveyors exited the sandbar by walking along the edges away from nests and chicks.

I performed all activities in this study under Arkansas Tech University Institutional Animal Care and Use Committee permit, USFWS Threatened and

Endangered Species permit number TE16616C-0, Arkansas State collection permit, and sub-permittee under master banding permit number 22520. In addition to restrictions outlined in our permits in order to limit disturbance to nesting Least Terns, when colonies were accessed for surveys I did not reenter the colony on that same day. Surveys did not take place when temperatures were above 32° C. Research activities within a colony were completed rapidly to minimalize disturbance in the colony. I spent no more than 20 minutes in any one part of the colony in order to reduce disturbances, usually. During surveys, I recorded an estimated number of chicks and the estimated age of each chick. Surveyors retreated if chicks congregated near an edge of the sandbar or appeared to be poised to attempt to swim away from the colony. If I could not approach an area with chicks due to disturbance concerns, I scanned the area with optics in order to estimate the number of chicks and of what age they were. This effectively prevented observers from causing harm to chicks by pushing them to swim away from the colony because of research activities.

I timed subsequent visits to a colony to capture the peak nesting period, and then scheduled the next survey to take place when I had estimated nests hatch dates. Typically, I conducted the next survey at least 18 days later to record the number of fledglings. During one of the visits either before nests were found or after the colony had been abandoned a surveyor used a Trimble™ GPS unit (Trimble Navigation, Ltd, Sunnyvale, CA) to delineate the area of the sandbar.

Data Analysis

I estimated initiation dates at each colony by comparing the floating position of an egg to the standardized floating chart for Least Terns. It is common for there to be

synchronization of initiation of nests in a colony, so many of the nests I observed were at the same incubation stage, which confirmed the initiation date. I utilized this method for each colony where I collected data for additional analysis of nest and chick survival (RM 184, 179.5, 179.2, 179, 170, 146.8, 130; see Chapter 2). For the remaining colonies, I estimated initiation dates by the earliest recorded survey to observe a completed clutch of three eggs. I used the estimated age of chicks to confirm the initiation date.

To estimate numbers of adults, nests, chicks, and fledglings, I considered the observed maximum count of each our best estimate. The recorded count of breeding pairs of Least Terns is the peak number of active nests for the breeding season. Breeding adults were then estimated by the peak number of active nests for the breeding season times two. I estimated fledglings per pair by considering the highest count of fledglings for a colony divided by the estimate of breeding pairs, our best estimate. Additional information from nest checks and chick banding was used, when available, to estimate maximum number of breeding adults, nests, chicks, and fledglings.

Results

Adult Counts

I estimated that 350 adults were present within the survey area across river and rooftop colonies (Table 1). The distribution of the population was among 13 river colonies that supported 246 terns and 4 rooftop colonies that had 104 terns (Table 2; Figure 1). Nest counts suggest that 422 breeding adults were active among the colonies (Table 1). The 13 river colonies supported 254 breeding adults and the 4 rooftop colonies supported 168 breeding adults (Table 2).

Initiation Dates

Initiation dates were 24 May 2017 for rooftop colonies and 3 June 2017 for the river colonies (Table 3). River sandbar nesting habitat was inaccessible throughout May and into mid-June due to high water releases. Colonies in relation to a lock and dam structure influenced sandbar exposure. For example, the river location with nests initiated on June 3rd was located just above a lock and dam. As water releases are high, water levels are actually lower directly above a dam in this system. The rapid release of water causes it to remain low behind the dam. Below a dam, water levels are still high as a large amount of water move through the system. I do not know when the exposure of nesting habitat happened because the river was unsafe for boats until after terns began nesting. Releases and therefore water height also declined upriver taking about two weeks to reach similar levels at the furthest down river colonies.

Nests

I estimated 211 nesting attempts in our survey area in 2017 (Table 4). Of these nests, 127 nests were produced on the 13 river colonies and 84 on the 4 rooftop colonies (Table 2).

Chicks

I estimated that this area produced at least 135 chicks (Table 4). The estimated number of chicks found on the 13 river colonies was 96 chicks with an additional 39 chicks on the 4 rooftop colonies (Table 2).

Fledglings

I estimated a maximum of 76 fledglings this year in our survey area (Table 4); 70 fledglings fledged from the 13 river colonies and 6 fledglings fledged from 4 rooftop

colonies (Table 2). I observed five fledglings at colonies that did not have any successful nesting attempts (RM 146.8 and 170). These colonies did not remain continuously exposed for a long enough period for reproduction to take place; recorded by camera. I observed fledglings late in the season and accompanied a group of adults that were likely migrating through the area. As I have some evidence that this study area did not produce these fledglings, I excluded them from our estimates.

In August after a large group of fledglings from a different river colony had dispersed from their natal colony I observed the peak fledgling counts at river colony RM 101. This colony produced only 16 chicks, at least 17 fledglings counted during August were likely from other colonies. A consideration in estimations of productivity is the common behavior of Least Tern fledglings to remain near colonies for up to 30 days and adults to form flocks late in the season before migrating (Bailey and Servello 2008). These fledglings were included in estimates as there is not enough evidence to disprove that this colony could have produced more chicks than were estimated by surveys.

Discussion

Within the entire survey area in 2017, high releases resulted in later initiation dates of nests and asynchrony of nesting activity among colonies. Asynchrony of nesting activity was apparent in the six-week time span between the initiation of the first colony and last colony of the season. Initiation dates for the river ranged from 3 June 2017 to 3 July 2017 an estimated 31-day span of time. While rooftop colonies ranged from 24 May 2017 to 5 July 2017 an estimated 42-day span of time. Mean initiation date for Least Terns on average is mid-May (Farnsworth et al. 2017). The 2017 breeding season on the Arkansas River then took place later in the season then what the average is for the

species. There was also a 10-day delay in the first initiation date between the rooftop colonies, that are independent of river releases, and the first river colony for the season. Observations of asynchrony between different colonies have not always been associated with an increased risk of predation; the overall size of the colony formed and the synchrony within the colony may instead be critical to whole colony's risks of predation (Hernández-Matias et al. 2003).

Changing water levels during colony formation and nest initiation likely influenced the asynchrony observed among colonies and the varying sizes of colonies between habitat types. The late season river sandbar nesting habitat availability may have influenced the number of Least Terns that joined river colonies. Then flooding during the colony formation period and nest initiation likely resulted in colony failure at river locations more prone to flooding (RM 184, 170, 146.8, 126, and 58). For example, the colony at RM 184 had nests initiation dates that ranged from 14 June 2017 to 15 July 2017 with early nesting attempts failing due to flooding. At RM 184, exposed nesting habitat when water releases declined in this area in mid-June also only attracted an estimated 12 adults. Other studies have also noted smaller colonies failing completely with one noting that all colonies with less than 10 nests failed (Brunton 1999).

Estimates that I collected, due to asynchrony of breeding behaviors among colonies, were over a long-time scale and I possibly double counted individuals. Double counting would have occurred as individuals attempted to nest on a colony but failed, then moved and initiate a second nest. The highest total observed adults in one colony could have included adults that were migrating if the survey occurred at the end of July or later. On 25 July 2017, I observed migrating mixed species flocks of shorebirds. Then on

28 July 2017, I observed mixed species flocks of terns. These observations indicated that migration in this area had started. The number of breeding adults is likely higher due to difficulties in surveying adults before they would flush from the colony. With shared incubating duties and foraging activities that would prevent all breeding individuals from being at a colony at one given time, I expect adult counts to be lower than breeding adult estimates.

Some colonies had evidence that predation contributed to colony failure. I observed adult and fledgling feather piles, an indication of predation on adults, at some failed colonies (RM 184, 179.2, 179). Other observations likely indicate predation as a cause of failure were observations of a Bald Eagle (*Haliaeetus leucocephalus*) predating nests at location 179 and an observation of a coyote at colony 36 during a survey. While colonial breeders like the Least Tern benefit from dilution, vigilance, or collective defense, exposed colonial nests are still prone to predation (Rolland et al. 1998).

Colonies at RM 179, 179.2, 179.5, 130, 101, and 36 had sufficient exposed sandbar nesting habitat during periods of high flows and were the only locations that produced chicks. For example, RM 179.5, was exposed early in the season and produced the greatest number of fledglings of all colonies monitored during the 2017 breeding season. Nesting habitat at this location was exposed early, potentially an attribute that can be manipulated to improve reproductive success. I did not observe any nest predation or evidence of adult predation. It is inherent that for a colony to be successful, nesting locations need a period of uninterrupted by flooding and for predation pressures to be less than reproduction in the colony. The colony at RM 179.5 was also in close proximity to two other failed colonies with signs of predation pressure. While they did not differ

noticeably in substrate and vegetation cover, I observed more adults at the RM 179.5 colony. This is in line with other observations that even closely related sub-colonies may have reduced predation pressures, when considered medium to large sized sub-colonies (Hernández-Matias et al. 2003).

The 2017 breeding season was unusual, with high releases resulted in later initiation dates. Nest and chick survival can be independent of changes in river flow rates, Least Terns can have varied nest initiation dates due to hydrologic patterns and still breed successfully (Bacon and Rotella 1998). Some characteristics of successful colonies, during 2017 in particular, can guide management practices for more robust nesting habitat in years of initial high water. Managing for larger colonies could be difficult as a single visit to a colony by some predators can result in complete failure of the colony. If managing for larger colonies reduces, the overall number of colonies, this could counter act the benefits of a larger colony. There is the need for further research to determine optimal colony numbers and sizes for the Arkansas River. On the other hand, some river locations due to their relationship to a dam, were exposed earlier creating additional nesting habitat in similar locations could provide much-needed habitat in years of high early season water. Previous work by Ross (2016), for this region, found that the downstream side of dams had the highest yearly measures of productivity for Least Terns. As my results for the 2017 breeding season agree with models developed by Ross (2016), focusing management efforts in these areas is likely to benefit Least Terns.

Chapter 2: Nest and chick survival of Least Terns on the Arkansas River during the 2017 breeding season

Introduction

Management of migratory avian species often focuses on preserving or improving breeding habitat. Reproductive success is directly related to habitat quality and in colonial breeding birds, where large congregations of individuals breed in close proximity to each other, trends of success or failure at a colony can describe surrounding habitat conditions (Zuria and Mellink 2005; Horn and Whitcombe 2015). In cases where environmental conditions are not favorable, including high predation pressure, breeding attempts may be abandoned all together. In studies such as Lescroel et al. (2009) of colonial breeding avian species, breeding adult's survival did not differ in years with more extreme environmental conditions while reproductive success did differ (Lescroel et al. 2009). Species that have relatively long-life spans have several breeding seasons to attempt to reproduce. It is then a strategy to abandon nests in one year, when threats are high, in order to survive to the next breeding season for the chance of improved conditions.

The Least Tern is a colonial nesting species that forms nesting colonies on emergent sandbars maintained by seasonal periods of high and low flows (Wohl et al. 2015). This defines Least Terns as a species that capitalizes on natural disturbance regimes (Brawn et al. 2001). Survival rates of nests and chicks are directly influenced by the timing, duration, and height of flows (Dugger et al. 2002). Least Terns will preferentially use continuously exposed sites during the nesting period (Smith and Renken 1991). While fluctuating water levels can cause colony failure, they also rely on

some degree of flooding to reshape nesting habitat to maintain open areas of sparse vegetation (Sidle et al. 1992). Open, sparsely vegetated, habitat is a critical feature of nesting habitat as colonial breeding birds combat predation pressure due to the conspicuous nature of this breeding strategy (Burger and Gochfeld 1990). Colony failure can also occur if predation rates are high, predators can directly depredate and indirectly cause nest abandonment in surrounding nests, as breeding adults abandon the colony this can inhibit the effectiveness of mobbing behaviors and depleting the benefits of dilution effects (Brunton 1997). Human disturbance to breeding colonies can act in a similar way either causing direct harm to nests and chicks or increasing predation risk (Stien and Ims 2016).

While Least Terns can display high site fidelity, they will respond to changing environmental conditions and nest failure by moving to another colony (Burger 1984). In one particular study by Tims et al. (2004), they found that new colonies were more successful than old colonies despite later initiation dates. New colonies in this instance were associated with being closer to foraging areas. Least Terns are also known to use rooftop-nesting locations that are near water sources (Forys and Borboen-Abrams 2006). Least Terns will shift to nesting habitat with different characteristics do to human activity and reductions in suitable habitat (Gochfeld 1983). Shifts of nesting habitat by Least Terns from natural nesting habitat to un-natural have coincided with poor reproductive success at natural sites in other breeding locations (Brooks et al. 2013). The formation of rooftop nesting colonies could be an indication of poor breeding conditions and limiting nesting habitat on river nesting habitat.

It is unknown if roof-top nesting locations are an ecological trap, high within habitat type variables and colony failures can make comparing habitat types difficult (Krogh and Schweitzer 1999). In other regions where Least Terns use roof tops to nest there are concerns that they are not a suitable alternative to natural ground nesting habitat as gravel and tar roofs become obsolete (Zambrano et al. 1997; Forys and Borboen-Abrams 2006). On the Arkansas River in years of high water, rooftops are the only nesting habitat available in the area. In a study by Catlin et al. (2011_a) when ground nesting, species can choose between natural and artificially created nesting habitat they increase their nesting success. Since Least Terns return to previously used or natal nesting habitat this may facilitate use of nesting habitat that is of poorer quality in years where river-nesting habitat is available. Least Terns use environmental characteristics to evaluate nesting habitat and choose a colony location (Sidle et al. 1992). Least Terns, in rooftop selection, cannot use these characteristics to evaluate a nesting location in years of delayed river nesting habitat availability due to early season high flows. Continuous use of rooftop colony locations may indicate that river nesting habitat availability later in the breeding season, due to high water, is encouraging Least Terns to utilize rooftop-nesting habitat. This effect may also be cumulative over the years, as larger colonies have higher probability of use in following years (Lombard et al. 2010). Nest and chick survival can be independent of changes in river flow rates, Least Terns can have varied nest initiation dates due to hydrologic patterns and still breed successfully (Bacon and Rotella 1998).

While estimates of Least Terns during the breeding season on the Arkansas River have been stable, I hypothesize that Least Tern nest survival on river colonies may be low

when compared to other locations. I predict that these colonies will have poor nesting success due to exposure to flooding, predation, and human disturbance. If river nesting conditions have poor nest survival then failed reproductive attempts are driving adults to attempt to breed elsewhere. Similarly, Least Tern chicks' survival on river sandbars may be low when compared to other locations. If nesting attempts are successful but chick survival is low, Least Terns are attempting to nest in unsuitable nesting habitat. With my objective to evaluate nesting habitat on river colonies, I evaluated nest and chick survival at colonies along the Arkansas River.

Methods

Study Area

In accordance with the 2016 Biological Opinion (USFWS 2016), a field crew of three technicians and I monitored Least Tern nesting colonies on the Arkansas River and populations nesting adjacent to this river in order to develop recommendations for management, creation, and preservation of nesting habitat on the Arkansas River. Monitoring consisted of locating colonies, recording the timing of breeding activity, and determining the number of breeding adults. I then quantified productivity from estimations of nests, chicks, and fledglings in relation to the number of breeding adults at each colony. I recorded signs of flooding, predation, and human disturbances as events of interest to develop recommendations for management of nesting habitat. I monitored Least Tern breeding activity along the Arkansas River from pool 2 to pool 12 within the McClellan-Kerr navigation system, between RM 36 to 285. In addition, this included four rooftops in Clarksville, Conway, North Little Rock, and Little Rock identified in previous years as breeding colonies for Least Terns (Nupp and Ross 2015).

I conducted additional nest survival surveys and chick banding on a segment of the Arkansas River, between RM 126 to 240, within the state of Arkansas. I chose my study sites based on previous breeding efforts during the 2016 breeding season to monitor nest and chick survival. Suitable subsite locations had previous activity in 2016 and appropriate distance from Arkansas Tech University, where equipment was stored, to survey the location at least twice a week. Surveys included previously mentioned monitoring activities in addition to locating and marking individual nest, checking the status of known nest, capturing chicks to band with individual bands, and recapturing chicks.

Each colony is on The McClellan-Kerr Arkansas River Navigation System, which is composed of locks, dams, dikes, and a dredged channel that ultimately limits flooding and maintains a consistent navigable channel. The navigational channel facilitates the use of Arkansas River for commercial and recreational purposes that are potential causes of disturbances. Barge traffic and the public for recreation both use the channel. Multiple boat ramps, both public and private, along the river also provide access to each pool to the public for recreation. Adjacent shoreline uses consist of housing, agriculture, or forested non-developed land. There are several campgrounds, day use areas, and public parks situated along this section as well. The colony located at RM 130 was within the major metropolitan area of Little Rock AR, a concentration of human activities on the river, with upriver locations increasingly further away from this population center. Shoreline large natural areas with this stretch of the river include Pinnacle Mountain State Park, Galla Creek State Wildlife Management Area, and Holla Bend National

Wildlife Refuge. Managed for wildlife, these adjacent areas likely contribute to local wildlife abundance and potentially predator communities.

Field Methods

I identified sandbar habitat as potential sites of a Least Tern colony by searching for adult Least Terns. I evaluated nesting habitat, all un-vegetated and sparsely vegetated sand or gravel, by navigating a boat along the river then searching for Least Tern activity through optics. More specifically, I considered a flock of Least Terns loafing on suitable nesting habitat associating in pairs and performing breeding behaviors, such as presenting a food item to a mate, a colony. I chose seven Least Tern colonies, at RM 130, 146.8, 170, 179, 179.2 179.5, and 184, to monitor individual nest and chick survival from 16 June 2017 to 16 August 2017 in addition to colony monitoring efforts (see chapter 1).

All activities in this study were performed under Arkansas Tech University Institutional Animal Care and Use Committee permit, USFWS Threatened and Endangered Species permit number TE16616C-0, Arkansas State collection permit, and sub-permittee under master banding permit number 22520. In addition to restrictions outlined in our permits in order to limit disturbance to nesting Least Terns I did not reenter the colony on the same day that it was accessed for surveys. Surveys did not take place when temperatures were above 32° (C). I completed research activities within a colony quickly to minimalize interruptions in incubation and chick care due to our survey efforts. I spent no more than 20 minutes in any one part of the colony in order to reduce disturbances. Surveyors retreated if chicks congregated near an edge of the sandbar or stressed enough to attempt to swim away from the colony. If I did not approach an area with chicks due to disturbance concerns, I scanned the area with optics in order to

estimate the number of chicks and age them. This effectively prevented observers from causing harm to chicks. Once a survey was complete, surveyors exited the sandbar by walking along the edges away from nests and chicks.

I systematically searched each colony for nests weekly until I confirmed nesting activity. Two to four surveyors systematically searched the colony for nests. In order to locate all nests within a colony, surveyors searched by forming transect lines and walked across the sandbar recording nests, incubation stage, and number of eggs. I supplemented transect nest searches with focal observations of incubating adults on the larger gravel bars to target an area to search. When I located a nest, I floated the eggs to estimate the incubation stage. I calculated incubation stage by comparing the floating position of an egg it to the standardized floating chart for Least Terns. Then I recorded the location, I used a Trimble™ GPS unit (Trimble Navigation, Ltd, Sunnyvale, CA).

I estimated nest survival by checking the status and number of eggs biweekly (every three to four days) until all eggs were no longer present or viable. Evidence of nest outcome, included chicks in nest bowl, pipping fragment, brood scrapes, chick excrement, dropped fish, yolk, blood, broken egg fragments, animal tracks, weather, or no sign. Nest were assigned the fate of successful if ≥ one egg hatched, verified by a recently hatched chick being found in or near the nest cup during the hatching window (1-2 days). Nests were considered failed if eggs were missing well before the estimated hatch date, persisted beyond the estimated hatch date (seven or more days), or were found damaged. I also took note of colony wide events from camera data, for example I noted if the sandbar was flooded between visits that nests had failed due to flooding.

I attempted to capture and band chicks in bowl or young chicks away from nest bowls as they remained motionless when approached. I banded chicks with one U.S. Fish and Wildlife Service stainless steel bands and one colored Darvic plastic on each leg. Then I recorded weight and wing cord for each chick every time it was captured until fledging (ca. 18 days) in order to confirm age. I conducted efforts to recapture chicks during colony visits twice a week (every three to four days) when I check nests status and maintained cameras. Recapture efforts continued until all banded chicks were >18 days old or the colony was completely abandoned for two visits.

Data analysis

Breeding activity at each colony varied and I excluded some colonies from nest survival estimates due to not finding nests before flooding. I only observed adults at RM 146.8 performing breeding behaviors without nest or later any signs of chicks. Breeding behaviors in this context included creating scrapes, forming pairs, and performing mating behaviors. Eventually, abandonment at this colony was due to flooding. Incubation occurred on nests at RM 184 and 170, heavy rain caused flooding during colony initiation before nests were discovered (Table 5). Only terns that nested at colonies RM 179.5, 179.2, 179, and 130 are included in the nest and chick survival models as Least Terns incubated eggs and cared for young at these locations (Table 6).

Nest survival

I used the nest survival model available in program MARK (White and Burnham 1999) to estimate the daily survival (Φ) daily survival rate (hereafter DSR) of nests to evaluate nest survival and identify if initiation date influenced DSR (Dinsmore et al. 2002). I constructed a pair of *a priori* models, a base model and a model that included

initiation date as an individual covariate (Table 7). I also constructed a pair of *a priori* models, a base model and a model that included initiation date and colony as individual covariates (Table 8). I used the model with the most support to calculate the DSR. While I calculated nest success by raising the DSR to an exponent equal to the number of incubation days (21 days).

Chick survival

I used a Cormack-Jolly-Seber model in Program MARK (White and Burnham 1999) to estimate age-specific daily survival (Φ) and recapture rate (p) from hatch to fledge (18 days). I constructed a set of four models that included a constant survival and recapture rate model (Table 9). Goodness-of-fit was evaluated with Program RELEASE to estimate over-dispersion ($\hat{c}$) of the top model. I ranked models by the Akaike's Information Criterion adjusted for small sample sizes (AIC_c) to evaluate my results (Burnham and Anderson 2004). The model with the most support was then used to calculate the DSR while chick survival was calculated by raising the DSR to an exponent equal to the number of days untill chicks would have been able to fledge (18 days).

I also used a Cormack-Jolly-Seber model in Program Mark (White and Burnham 1999) to estimate age-specific daily survival (Φ) and recapture rate (p) from hatch to fledge (18 days) with estimated hatch date for chicks as a covariate. I constructed a set of six models that included a constant survival and recapture rate model with the hatch date covariate to test if this improved the models (Table 10). I then used the same methods with estimated hatch date for chicks and colony as covariates. I constructed a set of 11 models that included a constant survival and recapture rate model with the hatch date covariate to test if this improved the models (Table 11).

Results

Nest Survival

I recorded 102 Least Tern nests at 6 different colonies (Table 1). The fates of 26 nests were unknown and these nests were not included in the DSR calculations (Figure 2). Colonies varied in size from 2 to 48 nests. I estimated the initiation of the first nest of the season to be 3 June 2017, while I considered the latest active nest abandoned on 3 August 2017 (Figure 3). Daily nest survival was 0.95 ± 0.01, resulting in a predicted nest success of .33 ± 0.06. The model that incorporated initiation date as a nest specific covariate for nest survival was the top-ranking model in the set. In the set that included initiation date and colony, the model incorporating both was the top model (Table 8). Nest survival declined as initiation date was later in the season (Figure 4). Daily survival rate for nest varied between colonies, small sample sizes at some locations produced unrealistic calculations of errors (Figure 5). Survival estimates for nest from initiation to hatch (21 days) reflected similar restraints (Figure 6).

Chick Survival

I banded 103 Least Tern chicks with a mean age at banding of 3.44 days with ages ranging from 0-17 days (Table 6). Daily chick survival was 0.97 ± 0.01 resulting in a mean survival from hatch to fledge of 0.56 ± 0.14 throughout the study. The model with the most support of the set was the constant survival and constant recapture with a probability of 82% (Table 9). Including competing models with hatch date of chicks, resulted in this model performing slightly poorer (Table 10). In the set of models that included colony the top model was constant survival and recapture with covariates of colony (Table 11). When hatch date was included, there was a slight increase in survival

for later hatched chicks with more variability in the beginning and end of the season ($\beta = 0.09 \pm 0.1$; Figure 7). Daily survival estimates for individual colonies had more variance for less successful colonies with low sample sizes of chicks (Figure 8). Estimated survival from hatch to fledge (18 days) was similar with unreliable estimates for colonies with small sample sizes (Figure 9).

Discussion

Since incorporating a covariate of initiation date improved the nest survival model, it appears that timing is a factor in breeding efforts. Initiation date in similar species corresponds to reproductive success with older individuals arriving and initiating nests earlier in preferred areas (Becker 2015). Early season nesting habitat availability then could be a consideration for adult Least Terns when forming a colony and assessing habitat quality. In the chick survival models, the top-ranking model did not include chick hatch date. Exposure of the majority of river nesting habitat took place later in the nesting season, with hatch dates only beginning later in the season. This data set does not represent the full range of hatching dates that can take place in a normal breeding season. Breeding efforts that take place later in the season are without the opportunity to re-attempt. It may also be less likely that Least Terns will abandon late hatched chicks due to the greater investment and likelihood of success after successfully hatching a chick. In years where exposure of river-nesting habitat does not take place until later in the breeding season there may be some benefit to breeding earlier in the season that could be driving the use of rooftops in this area.

On the river colonies, there is likely an underestimation of nest loss due to predation because some nests had unknown outcomes. Instances of predation along with

successful hatches, wherein chicks leave the nest area, both do not leave an indication of nest fate. If other nests fail due to predation in the same colony, the number of failed nests due to predation is potentially underestimated. Many of the unknown nest fates are due to both estimated hatch date and a predation event taking place in the same period of time between visits. The cause and timing of chick mortality are unknown. Most notably, I recorded a Bald Eagle predating nests on the colony at RM 179. Abandonment of this colony followed this event, with the colony failing to produce any fledglings for the year. In a study by Brooks et al. (2013), they recorded observations of Black Vultures consuming Least Tern eggs. I observed Black Vultures at colonies but did not have a confirmed observation of nest predation. Recorded observations on the river colonies during daylight hours reveled known nest and chick predators visiting each colony. With my methods, I was unable to record predation during the night. Great Horned Owls are one example of known predators that only visit during the night (Brooks et al. 2013).

The river colonies were successful in 2017, when compared to other estimates of chick survival for this species. Other studies, for example, have reported a 0.43 survival rate of Least Terns chicks (Dugger et al. 2000). On the combined 13 river colonies, an estimate of 96 chicks hatched while at the four rooftop locations only an estimated 39 chicks hatched. Distance to foraging areas is possibly a factor in reproductive success at rooftop colonies, as a shorter distance to foraging areas is an attribute of successful colonies. Rooftop colonies are further away from foraging areas and chick access to water along with other habitats components that contribute to maintaining body temperature are not well understood (Forys and Borboen-Abrams 2006, Butcher et al. 2007). Since Least Terns are unable to move from one habitat type to another to raise

chicks, colonies have to meet both nest and chick rearing needs. Rooftop colonies meet the needs of nesting Least Terns, by having gravel substrate and sparse vegetation, but not chick rearing if foraging area, water, and temperature needs of chicks are not meet. River colonies naturally provide nesting habitat, access to foraging areas critical to chick growth, water, and cover.

The Arkansas River system could potentially have poor nesting habitat attracting breeding adults. The opportunity to nest independently of water levels exists on nearby rooftops, with nesting habitat that is available earlier in the season but can have poor nesting conditions. Fledgling rates were much higher on river colonies compared to rooftop colonies, 72 fledged on river sandbars and 6 at rooftops. Older and more experienced breeders tend to arrive earlier and initiate nests first in tern breeding colonies, rooftop availability then could disproportionately affect experienced Least Terns (Meehan and Nisbet 2002). This can draw in terns with higher parental quality to lower quality nesting habitat, potentially effecting overall productivity. I surveyed a disproportionate number of adults, 40% of all breeding adults, on the 4 rooftop locations while the 13 river colonies supported only 60% of all breeding adults.

Colonies that are formed later in the season may have difficulties recruiting adults into the colony. Least Terns have a preference of joining colonies where there is a mix of paired and unpaired adults (Burger 1988). Therefore, smaller colonies may form as a few individuals form pairs and begin to nest not joined by more breeding adults. River colonies had a number of small sized colonies with less than 20 breeding pairs. Coupled with the fact that smaller colonies are more likely to fail, later nesting attempts that fail to recruit enough adults into the colony would tend to fail. This would also explain why

hatch date did not appear to be a strong predictor of chick survival. If the colony was successful in recruiting enough individuals to incubate, they were also likely to rear chicks. Our observations suggest that rooftop colonies open to colony formation before water recedes from sandbars could reduce the number of adults available to form colonies on the river during the 2017 breeding season.

When river colonies are responsible for nearly all fledglings produced (72 out of 78), having adults attracted to rooftops negatively affects overall reproduction. Previous work by Ross (2016), for this region, found that the upstream side of dams had the highest yearly measures of productivity for Least Terns. My results for the 2017 breeding season agree with models developed by Ross (2016), with the most productive river colony in a similar location, benefiting from earlier exposure. Options are limited to nesting habitat available shortly after arrival early in the season, when choosing to return to a colony or attempting to move. If faced with the option to nest on rooftops without alternatives, this inhibits the ability to choose nesting habitat or move to a new colony. Least Terns then may not have the flexibility to leave previously unsuccessful rooftops if early season habitat availability limitations persist. Interior Least Terns in particular may be more adapted to changing river conditions as adults in one study by Renken and Smith (1995) displayed low site fidelity of 50% (Renken and Smith 1995). The frequency of years with early season high water would inhibit movement from failing colonies, as Least Terns can only respond to failed breeding attempts a year later during the next breeding season.

Further research on the survival of chicks on rooftop colonies in addition to river colonies may provide more insights into the complexities of this particular system.

Movement of adults between colonies and timing of nest initiations each year may need to be investigated more intensely to fully explore and answer population sink questions.

Chapter 3: Time-lapse camera evidence of flooding, predation, and disturbance on breeding Least Tern colonies on river sandbars

Introduction

With modern cameras of relatively small size powered by household batteries, there are more opportunities to utilize cameras to gather data about colonial nesting avian species without observers having to be present. Many other studies have used camera techniques to document nest success (Flemming et al. 2016; Liebezeit and George 2003). In particular, other studies have recorded the application in the monitoring of isolated sea bird colonies with time-lapse setting (Flemming et al. 2016). In another study, video cameras recorded disturbances to colonies (Devney and Congdon 2009). Video monitoring, in other instances was considered as a management tool to decrease human disturbance at nest colonies (Forys et al. 2016).

Interior Least Terns nest on riverine sandbars during the breeding season from May to August. Breeding success of Least Terns is threatened by three main factors, flooding, predation, and disturbance. The drastically altered riverine habitats, as anthropomorphic structures control the flow of water, now commonly flood during nesting season. While fluctuating water levels can cause colony failure, they also rely on some degree of flooding to reshape nesting habitat to maintain open areas of sparse vegetation (Sidle et al. 1992). Nesting habitat must facilitate Least Tern's ability to detect predators and mob them. Flushing off nests or away from chicks while threats are at a distance combined with cryptic coloration of chicks, are important survival strategies. This strategy may be harmful if high rates of disturbance drive adult Least Terns away

-from parental duties and/or disrupt reproductive efforts. As Least Terns respond to many species including humans by flushing off nests and mobbing, disruption in nest and chick care can result in lower reproductive output. Disruption exposes nests and chicks to thermoregulatory stress along with interruptions in feeding rates (Beale and Monaghan 2004).

Disturbances that occur at the beginning of the breeding season during colony establishment could disrupt colony formation and mating behaviors. Tern colonies perform better when nesting is synchronized (Minias et al. 2015). Behaviors of Least Terns also favor synchronization as Burger (1988) found Least Terns were attracted to large groups that appeared to have unmated birds, as this would facilitate synchronized nesting behavior. Distribution and amount of human disturbance across a landscape can dictate nesting density in ground nesting species citation (Lowe et al. 2014). Lowe et al. (2014) found influences of nest location selection for European Nightjar (*Caprimulgus europaeus*) by human disturbance, when disturbance doubled there was no effect on reproduction but density still significantly decreased. In Woodlarks *(Lullula arborea)* a ground nesting passerine, nesting pairs did not colonize suitable habitat with rates of eight disturbance events per hour (Mallord et al. 2007).

Disturbance indirectly affects nest success by causing nests to become more prone to predation, addling, or abandonment (Ronconi and Hipfner 2009). The perceived threat of human activity often elicits the same response from ground-nesting birds, as they would display toward a predator, in Least Terns this includes flushing from a distance and mobbing behavior of the potential predator. Human disturbance nearly always has some degree of negative effect on nesting colonial water birds (Carney and Sydeman

1999). Terns flush and circle above the colony during close or high-speed watercraft approaches indicating that terns display a similar response to boats as to predators (Burger 1988). Disturbance interrupts chick and fledgling care, potentially exposing young to deadly heat or starvation if the adult is away from the nest for too long. Disturbance by boats has caused egg and chick loss in other sea bird species with young fleeing from the colony before fledging and predators taking advantage of the absence of adults (Rojek et al. 2007).

In cases where a perceived threat could endanger an adult bird's life, breeding attempts may be abandoned all together. Adult Least Terns have relatively long-life spans and may have several breeding seasons to attempt to reproduce; therefore, Least Terns may abandon nests in one year when threats are particularly high in order to survive to the next breeding season when conditions have improved. Colonial breeders will completely abandon a colony if many adults cease breeding due to disturbance (Carney and Sydeman 1999). In other words, there is a density dependent tipping point of nest abandonment where other adults in the colony base breeding efforts on the success of other individuals in the colony.

The McClellan-Kerr Arkansas River Navigation System is composed of structures such as locks, dams, dikes, and a dredged channel that ultimately limit flooding and maintain a consistent navigable channel. Barge traffic, and the public for recreation, use the navigational channel. Nesting habitat and loafing areas on the Arkansas River appear to be limited and spaced apart along the river. Previously, disturbance was assessed indirectly on the Arkansas River through documenting clear evidence of human activity or predation that caused nest or colony failure. One such instance included adult Least

Terns found dead from gunshot (Nupp and Ross 2014). Less direct human disturbance may be more common than we currently know. Surveys of Least Tern nesting locations have reported human disturbances accounted for high rates of failure, as much as over half of failed colonies (Burger 1984). Least Tern breeding takes place during periods of high rates of human activity such as the 4^{th} of July holiday when many people celebrate by visiting sandbars and in some cases even setting off fireworks on or near sandbar nesting locations. Incidences the use of fireworks in proximity to Least Tern colonies has resulted in complete abandonment of colonies in some years (Nupp and Ross 2014). Although signs are placed at some highly vulnerable nesting colonies to educate the public on the biological and legal consequences of human activity at colonies, human disturbance has still been a problem.

I hypothesize that the undocumented types of disturbance events may be causing significant disruptions to Least Tern reproduction. I predict that disturbances recorded with time-lapse camera methods will be frequent and influence reproduction. If disturbances, that are undocumented by current survey methods, are common, then Least Terns are likely suffering the negative affect of frequent disturbance. I hypothesize that Least Tern nesting habitat on the Arkansas River may be negatively affected by high rates of disturbances causing them to attempt to nest on rooftops. I predict high rates of human disturbances on river colonies that are likely not found on rooftops. If river nesting locations with high disturbances are unproductive then disturbances could be causing the use of rooftops as nesting habitat. During the 2017 Least Tern breeding season on the Arkansas River, my objective was to evaluate the efficiency of using small modern time-lapse cameras to monitor disturbances to Least Tern breeding with cameras,

an alternative to more expensive observer-based observations. Camera methods have the potential to allow sampling during the entire Least Tern breeding cycle, record human disturbance accurately without detection, and evaluate impacts of disturbances to reproductive success along with standard monitoring practices. The use of time-lapse cameras can potentially improve upon current monitoring practices and accurately describe conditions at colonies if records add to the body of data that is collected during monitoring. It was also my objective to evaluate breeding success on river sandbar colonies while monitoring disturbances that took place, in order to quantify human disturbance to river colonies.

Methods

Study Area

In accordance with the 2016 Biological Opinion (USFWS 2016), I monitored Least Tern nesting colonies on the Arkansas River and related populations nesting adjacent to the river in order to develop recommendations for management, creation, and preservation of nesting habitat on the Arkansas River. Monitoring consisted of locating colonies, recording the timing of breeding activity, and determining the number of breeding adults. I then quantified productivity from estimations of nests, chicks, and fledglings in relation to the number of breeding adults at each colony. I recorded signs of flooding, predation, and human disturbances as events of interest to develop recommendations for management of nesting habitat. I monitored Least Terns breeding activity along the Arkansas River from pool 2 upriver to pool 12 within the McClellan-Kerr navigation system, between RM 36 to 285. In addition, I monitored four rooftops in

Clarksville, Conway, North Little Rock, and Little Rock identified in previous years as breeding colonies for Least Terns (Nupp and Ross 2015).

I conducted my research on using time-lapse cameras to monitor colonies on a segment of the Arkansas River within the state of Arkansas. I chose seven Least Tern colonies, RM 130, 146.8, 170, 179, 179.2 179.5, and 184, to monitor flooding, predation, and disturbances caused by intrusions of other species in Least Tern colonies from June 16, 2017 to August 16, 2017. This research was conducted in addition to colony and individual monitoring efforts being conducted at these locations (see chapter 1 and 2). Each colony is on the McClellan-Kerr Arkansas River Navigation System, which is composed of locks, dams, dikes, and a dredged channel. These structures ultimately limit flooding and maintain a consistent navigable channel. The navigational channel facilitates the use of Arkansas River for commercial and recreational purposes. Use of the river for barge traffic and the public for recreation are potential indications that disturbances are influencing Least Tern colonies. Multiple boat ramps, both public and private, along the river also provide access to each pool for public recreation. Adjacent shoreline is used for housing, agriculture, or is forested non-developed land. There are several campgrounds, day use areas, and public parks situated along this section as well. The colony located at RM 130 was within the major metropolitan area of Little Rock AR, a concentration of human activities on the river, with upriver locations increasingly further away from this population center. Shoreline with large natural areas along this stretch of the river includes Pinnacle Mountain State Park, Galla Creek State Wildlife Management Area, and Holla Bend National Wildlife Refuge. These semi-natural areas

managed for wildlife are likely to contribute to local wildlife abundance and potentially have increased predator communities.

Field Methods

During the 2017 breeding season, I identified colonies of Least Terns as part of efforts to record population levels and reproduction (see Chapter 1). From June 16, 2017 to August 16, 2017, I identified a total of seven colonies at RM 184, 179.5, 179.2, 179, 170, 146.8, and 130 that occurred within the study area. Colonies were located during survey efforts by searching for the presence of adult Least Terns on nesting habitat. I evaluated nesting habitat, all un-vegetated and sparsely vegetated sand or gravel, by navigating a boat along the river then searching for Least Tern activity through optics. More specifically, I considered a flock of Least Terns loafing on suitable nesting habitat associating in pairs and performing breeding behaviors, such as presenting a food item to a mate, a colony.

All activities in this study were performed under Arkansas Tech University Institutional Animal Care and Use Committee permit, USFWS Threatened and Endangered Species permit number TE16616C-0, Arkansas State collection permit, and sub-permittee under master banding permit number 22520. In addition to restrictions outlined in our permits in order to limit disturbance to nesting Least Terns, I did not reenter the colony on the same day that it was accessed for surveys. Surveys did not take place when temperatures were above 32° C. Research activities within a colony were completed rapidly to minimalize disturbance in the colony. I spent no more than 20 minutes in any one part of the colony in order to reduce disturbances, usually. During surveys, I recorded an estimated number and age of each chick. Surveyors retreated if

chicks congregated near an edge of the sandbar or appeared to be stressed enough to attempt to swim away from the colony. If I could not approach an area with chicks due to disturbance concerns, I scanned the area with optics in order to estimate the number of chicks and of what age they were. This effectively prevented observers from causing harm to chicks by pushing them to swim away from the colony because of research activities.

I systematically searched each colony for nests weekly until I confirmed nesting activity. Two to four surveyors systematically searched the colony for nests. In order to locate all nests within a colony, surveyors searched by forming transect lines and walked across the sandbar recording nests, incubation stage, and number of eggs. I supplemented transect nest searches with focal observations of incubating adults on the larger gravel bars to target an area to search. When I located a nest, I floated the eggs to estimate the incubation stage. I calculated incubation stage by comparing the floating position of an egg it to the standardized floating chart for Least Terns. Then I recorded the location, I used a Trimble™ GPS unit (Trimble Navigation, Ltd, Sunnyvale, CA).

I estimated nest survival by checking the status and number of eggs biweekly (every three to four days) until all eggs were no longer present or viable. Evidence to discern the fate of nests included chicks in nest bowl, pipping fragment, brood scrapes, chick excrement, dropped fish, yolk, blood, broken egg fragments, animal tracks, weather, or no sign. Nests were assigned the fate of successful if ≥ one egg hatched, verified by a recently hatched chick being found in or near the nest cup during the hatching window. Nests were considered failed if eggs were missing well before the estimated hatch date, persisted beyond the estimated hatch date (seven or more days), or

were found damaged. I recorded colony wide events from camera data, for example, I recorded if the sandbar was flooded between visits that nests had failed due to flooding.

I attempted to capture and band chicks in bowl or young chicks away from nest bowls as they remained motionless when approached. I banded chicks with one U.S. Fish and Wildlife Service stainless steel bands and one colored Darvic plastic on each leg. Then I recorded weight and wing cord for each chick every time it was captured until fledging (ca. 18 days) in order to confirm age. I conducted efforts to recapture chicks during colony visits twice a week (every three to four days) as I checked nests status and I maintained cameras. Recapture efforts continued until all banded chicks were >18 days old or the colony was completely abandoned for two visits. During survey activities, as I systematically searched nesting habitat, I recorded each occurrence of any sign of disturbance or visitation of a predator. I estimated the number of individuals and identified species.

Camera Setup

I used Bruno TLC200 cameras, each housed in a weatherproof case with 16 GB memory cards. Cameras were set to take time-lapse photos every five seconds, the cameras used a light sensing setting to take photos only during daylight hours. Software on the camera compiled time stamped photos into an .avi video file. I mounted each camera between two educational signs, aimed at informing the public to refrain from entering the colony, with a hole cut out for the camera on the side facing inward towards the colony. Cameras were then not visible to people outside the colony. On average, memory cards needed to be replaced every four to five days, and batteries needed to be replaced every three weeks with the setting described. Colonies had one to three cameras

installed based on colony size and amount of vegetation. After the first camera was set up, I reviewed the footage to address blind spots and evaluate the quality of recording for identifying distances within the colony. Additional, I installed cameras to allow the entire nesting area to in view of the cameras. Once cameras were installed they were serviced (battery and memory replacement) when I conducted surveys, conducted nest checks, or captured chicks. I only installed cameras and signs in areas away from nests if nests were already in place at the colony. To minimalize disturbance, I did not move cameras and signs until the Least Terns were gone.

Each video was reviewed after the breeding season by having an observer watch the footage and enter data into a Microsoft Access (2010© version 14.0.7194.5000), a Windows-based database management system. I viewed videos with VLC media player (version 2.2.4; VideoLAN, Paris, France). Each time any species other than a Least Tern entered the colony I recorded the duration, species, and number of individuals. Duration was determined by noting the time each subject entered the camera view of colony (day: hour: minute) and subject leaving camera view of colony (day: hour: minute)). Camera observations were excluded when they were not properly set or when severe weather events rendered footage unusable. It is unlikely that I missed significant amounts of activity at these times (Table 12). When cameras were not set correctly, at least one camera remained operational at each location and only inhibited identification of disturbance to species. Severe weather events included morning fog for 10 to 30 min; high winds associated with rainstorms that shook cameras usually only lasting 30 to 60 min, and heavy rain obscuring lenses when blown towards the camera for one to two hours. Common species known to be a threat to adult Least Terns, chicks, or eggs were

combined into three groups for further analysis (Table 12); American Crow (*Corvus brachyrhynchos*, hereafter crow), Great Blue heron (*Ardea herodias*, hereafter GBH), and raptor (Table 13). Raptor included Bald Eagles, juvenile Bald Eagles, Black Vultures (*Coragyps atratus*), and raptors that could not be identified to species. Based on existing Least Tern literature each of these species groups are known predators, I directly observed Bald Eagles and crows preying on nests (Hernandez-Matias et al 2003; Thompson et al. 1997; Farnsworth et al. 2017). I recorded human disturbance in the categories of human and as dog when there was additionally a dog present.

Data Analysis

Camera Observation and Survey Observations

In order to quantify the differences in ability to record disturbances between the survey crew and the cameras I conducted a paired t-test. I considered the estimated number of disturbances between visits to a colony by surveys and cameras a paired sample. I considered the difference statically significant at the alpha 0.05 level.

Camera Functions

I used observations via camera data of colony wide events to evaluate conditions at each Least Tern colony. Colony events included flooding, predation of multiple nests, and disturbances that occurred directly before colony abandonment. I evaluated breeding activity at each colony given observations during surveys.

Disturbance

I conducted a t-test between colonies that had fledged at least one chick (n=3) and colonies that had not fledged chicks (n=4) for average daily disturbances of all disturbances, crows, GBH, and raptors. In order to identify seasonal patterns and trends

in disturbances I produced a general additive model of disturbances rates per day for day of the breeding season.

Results

Camera Observation and Survey Observations

I recorded more observations of disturbance with cameras than were observed in physical surveys (mean diff = 30.19231 ± 7.11, $t = 8.43$, $P < 0.001$). In particular, cameras recorded more disturbances by crows, Great Blue Herons, raptors, and humans (Table 14; Figure 10). There was no difference in recorded observations of dog activity with either physical surveys or camera methods (mean diff = 0.06 ± 0.11, $t = 1.06$, $P = 0.29$; Table 15; Figure 11)

Camera Functions

Flooding

During three instances cameras captured daytime flooding events, (RM 146.8, 170, and 184), and in two cases clearly submerged areas with nests (RM 170, and 184). Evidence of flooding was not apparent from physical surveys of these sites and eggs remained in nest bowls after being submerged. Although I observed only breeding behavior at RM 146.8 (including creating scrapes, forming pairs, and performing mating behaviors), and no colony formation occurred at this location, the cameras recorded flooding at this colony which probably caused terns to abandon this colony. I observed incubation of nests at RM 184 and 170, heavy rain and flooding occurred shortly after colony initiation and the beginning of incubation. Only terns that nested at colonies 179.5, 179.2, 179, and 130 incubated eggs and cared for young. Of these colonies only 179.5, 179.2, and 130 produced fledglings (Table 16; Figure 12).

Predation

I positioned cameras to view the entire colony and not individual nests; I was able to identify some predation events from my knowledge of nest locations (Table 17). On one occasion, a Bald Eagle depredated several nests at RM 179, adult Least Terns mobbed this individual driving it away, and then I did not record another observation of a Bald Eagle at this location. At RM 170, I attributed egg loss of some nests to crows after reviewing camera footage. I observed a flock of crows at the location of recorded nests in a previous survey. Although this observation explains the disappearance of the nests and identifies crows as the potential nest predator, these nests were abandoned and adults did not actively them (RM 170).

Disturbances

I identified 2,106 instances of intrusions into breeding colonies by wildlife species or humans from time-lapse cameras (Table 18). Camera footage revealed visitation at colonies by Bald Eagles, Black Vultures, Boats, Canada Geese (*Branta Canadensis*), Cattle Egrets (*Bubulcus ibis*), Cormorants, crows, White-tailed Deer (*Odocoileus virginianus*), Dogs, doves, Great Blue Herons, Great Egrets (*Ardea alba*), Human, Rock Dove (*Columba livia*), snake, and Snowy Egret (*Egretta thula*). Group size ranged from 1 to 86 individuals and duration lasted from 1 to 384 min on any single occasion (Table 17). Observations of visitations varied from 1 to 502 minutes per day while occurrences were as high as 20 instances during a single day (Table 17). The maximum number of individuals observed at a location was a flock of 86 Pigeons and a flock of 86 Canada geese. Neither Pigeons nor Canada Geese are considered predators of Least Terns; the largest group of predators observed was a flock of 80 crows.

I chose to examine the impact of predator disturbances on Least Tern colonies by focusing on three groups of potential predators crows, Great Blue Heron, and raptors (Bald Eagles, vultures, and birds of prey not identified to species). Previous studies have identified these species as predators of Least Tern adults, chicks, or eggs (Stien and Ims 2016; Brunton 1997) (Table 14, Figure 12). I observed signs of human and dog disturbances at one colony with both camera and physical surveys (RM 130).

Analysis of Disturbance

Between colonies that produced fledglings and those that failed the minutes of disturbance per day by all predators did not differ (Table 19). A general additive model displayed what appeared to be early season and later season differences in disturbances with the model accounting for only 20.8% of the variation observed ($r^2 = 0.15$; Figure 13). This pattern was driven by activity on only one colony and once it was excluded there appeared to be no pattern of disturbances over the season and the model only accounted for 13.6% of the variation ($r^2 = 0.11$; Figure 14). Seasonal patterns of survival for nest and chicks were observed, and then could be related to other habitat factors (Figure 4, Figure 7)

Discussion

Time-lapse cameras produced vastly greater estimates of disturbance than physical surveys revealing the bias of relying on observations of disturbances from only physical surveys. The period of time the camera recorded and the period in which surveys estimated signs of disturbances were equal. Time spent on the colonies searching for signs of disturbances by surveyors was about one to two hours. The time it took to review footage taken between visits was similar, about one to two hours. The presence of crows

was only occasionally noted during physical surveys while the abundance of avian predators, such as corvid, can strongly correlate with nest predation rates (Luginbuhl et al. 2001). In general, observations during physical surveys appeared to underestimate avian predator activity level at Least Tern nesting colonies. Physical surveys tended to produce an accurate estimate of dog and human activity. This may lead to the perception that anthropogenic disturbances have a greater impact on colony conditions. Previous research has shown that human disturbance on nesting colonial water birds causes significant negative effects and management can be costly and complicated (Carney and Sydeman 1999). Restrictions and fines are unpopular with the public. Accurate estimates of the amount of human disturbance are necessary for making sound management decisions. Some ground nesting species such as Black Oystercatchers can be resilient to low levels of human disturbance (Morse et al. 2006). The exact disturbance rate that begin to have negative effects on Least Terns is not known and given listed status it would be difficult to test directly. A study conducted by Tarr et al. (2010) found that by experimentally conducting vehicle disturbance, at a rate of 1 pass for no longer than 1 min every 10 min for four hours, significantly reduced shorebird numbers along beach habitat. I observed higher disturbance rates at nesting Least Tern colonies with our methods and could expect a similar response to disturbances.

Our results testing camera observations against physical surveys numerically showed very large differences in recorded amounts of disturbances (Fig. 3). The ability to monitor sandbar habitat and evaluate how much disturbance-causing species utilize nesting habitat gave us a glimpse of true disturbance and predation pressures. Camera monitoring increased our ability to detect flooding at a colony. Harvey (2001) described

flooding from a rain event, on other river nesting Least Tern colonies, where rainfall could cause sheet flooding. Events such as sheet flooding from rain may be difficult to detect and cause colony failure. Large scale flooding is often recorded with an increase of flow or releases for a period of a few days while a rise in water levels for a few hours during a hard rain can go unnoticed.

The camera set up that I used can also feasibly be incorporated into current practices. The effort of incorporating cameras into surveys is also low, for the amount of information they can provide. For example, cameras, and equipment used to operate them, cost about $200. Serviced every two weeks, the cameras can be used in the same time frame in which monitoring survey visits usually take place. Then the amount of time required to collect similar data would take an observer 12 hours per day. While reviewing camera footage took about 20 to 30 minutes per sampled day. Depending on specific observations of interest, developed software to automatically review and record video images would reduce time required to review video.

Observations of colony-wide events from videos recorded at colonies contributed to a better understanding of why and how Least Tern colonies were successful. Colony RM 179.5 produced 30 fledglings and camera monitoring indicated that it was also free of flooding, observations of predation, and human-related disturbance. At RM 179.5 had an average of 88 minutes total daily disturbances per day, the same as the RM 179 colony that was similar in the number of nesting adults but failed to produce fledglings. The colony at 179.5 with the most success however had the fewest number of days of disturbances.

My conclusion conflicts with findings of Kruse et al. (2001) who reported more observations by surveys and observers than time-laps photos. I believe this incongruity was due in part to the improvements in camera function from earlier attempts and in this particular case I used a 5 sec time-lapse interval while Kruse et al. (2001) used 15 sec and only collected camera data for 7 days. While game cameras are more commonly used for outdoor performance capabilities the Bruno cameras performed well in the elements with no failures do to electronics. Limitations in memory card space, battery, and positioning were the only causes of failure. The cameras I used had limited ability to detect disturbances and predation at night. Some known nocturnal predators have significant impacts on Least Tern colonies. For example, Catlin et al. (2011_b) found that removal of Great-Horned Owls increased chick survival in ground nesting piping plovers. Physical surveys did not assign any nest failures directly to nocturnal predators or observe any signs of mammalian presence on Least Tern colonies. I was not able to identify the fates of all nests or causes of predation. As physical surveys missed activity during the day it is likely they could have missed nocturnal predators and mammalian predators.

Monitoring along with reducing predation and human disturbance have been listed as reasonable and prudent measures 2 and 3 in the most recent Final Biological Opinion directing conservation actions of the U.S. Army Corps of Engineers in Oklahoma and Arkansas (USFWS 2016). Preventing disturbance (by predators and humans) is a priority because of known effects of causing nest failure and colony abandonment, possibly resulting in significantly lower reproductive output. Evaluating the rate that known predators and other species disturb Least Tern colonies could be a useful management tool to increase survival and reproductive output.

Other studies found that adopting different management strategies to reduce predator activity to be very effective on the Atlantic Coast, with nest success for an unmanaged area at 6% and 59% for a managed area (Spear et al. 2007). Management actions often focus on a particular predator or predator group. For example, fences have been successful in limiting terrestrial predators (Rimmer and Deblinger 1992). Electric fences to keep mammalian predators out of nesting colonies will likely not be effective against avian predators. Camera monitoring techniques that I used in this study, can inform managers of what locations will benefit the most from particular management strategies. Other management strategies may include directing nest site selection. In Marcus et al. (2007), directing nesting with management was an effective method to avoid conflict with human activities. Methods described in this study, could also be used to detour nesting at locations that are acting as populations sinks conversely encouraging use of more productive nesting habitat. Sufficient information would need to be collect with methods, such as camera monitoring, to be certain that habitat is not suitable for reproduction. In conclusion, information collected by camera methods that I explored, about predator communities and disturbance rates at colonies, can guide management practices.

Conclusions

Monitoring species yearly is critical when reproductive rates vary greatly from year to year. The Least Tern, the focus of this research, in poor years can have zero reproductive success while in good years it can be substantial. For the 2017 breeding season the type of habitat, timing of nesting habitat availability, and predation appeared to play a critical role in reproductive productivity. Since habitat availability and reproductive rates can drastically vary each year consistent, monitoring over many years is necessary to track population levels. If habitat conditions and poor reproduction result in declines, management interventions can then take place before it is too late or too costly.

Within the segment of the Arkansas River where breeding activity was monitored in 2017, high releases resulted in later initiation dates of most nests and asynchrony of nesting activity among colonies. Asynchrony of nesting activity was apparent in the 6-week time span between the initiation of the first colony and last colony of the season. Asynchrony, in particular in this system, among colonies and the timing of migration need to be accounted for or considered to produce a more accurate estimation of adults and reproductive efforts. There was also a 10-day delay in the first initiation date between the rooftop colonies and the first river colony for the season. Between rooftop colonies and river colonies, this delay was likely due to rooftops not being influenced by the 2017 high river releases.

Understanding the factors that drive reproductive success within a population, can guide management practices. A predicted nest success of .33 ± 0.06 and a mean survival from hatch to fledge of 0.56 ± 0.14 throughout the study indicates that management should focus on nest success. In years such as 2017 where river colonies were more

successful, responsible for nearly all the fledglings produced (70 out of 76), having adults attracted to rooftops negatively effects overall reproductive efforts in this area. Further research on the survival of rooftop colonies in addition to river colonies may provide more insights into the complexities of this particular system. Movement of adults between colonies and timing of nest initiations each year may need to be monitored more intensely to fully explore and answer population sink questions. If long-term trends continue, management intervention could be necessary to either provide available nesting habitat early in the breeding season or prevent Least Terns from utilizing rooftops.

With modern cameras of relatively small size that can be powered by small batteries, there are more opportunities to utilize cameras to gather data about colonial nesting avian species when observers are not present. Cameras greatly increased our ability to detect if flooding had taken place in situations where nests remained intact and Least Tern activity persisted after flooding. The vast differences in the estimated instances and amount of disturbances between survey observations and camera footage reveal the dangers of relying on observations of conditions during surveys. With human disturbances concentrated at one colony, management officials can use this information to target any educational efforts to the exact location that is experiencing this problem. Camera monitoring techniques that I used in this study, can inform managers of what locations will benefit the most from any particular management strategy such as focusing on methods to reduce avian or mammalian predators. Methods described in this study, could detour nesting at locations that are acting as populations sinks conversely encouraging use of more productive nesting habitat. Sufficient information would need to be collect with methods, such as camera monitoring, to be certain. In conclusion,

information about predator communities and disturbance rates at colonies can guide management practices.

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Tables

Table 1. Estimates of adult Least Tern numbers for all colonies in the survey area during the 2017 breeding season on the Arkansas River, based off the highest number observed on any single survey attempt for the season. Estimated breeding adult counts by multiplying, by two, the greatest number of active nests. Breeding adult counts were not conducted for the Hanes and Snap on location due to difficulties accessing colonies during nesting. Locations are given in river miles.

Location	Initiation	Surveys		Adults	
			Incubating	Counts	Breeding
275	15 Jun.	6	4	28	34
240	-	2	0	0	0
184	15 Jun.	19	7	10	12
179.5	5 Jun.	20	16	38	86
179.2	3 Jun.	18	2	8	10
179	4 Jun.	20	3	26	54
170	3 Jul.	14	2	26	4
146.8	-	13	6	26	0
130	13 Jun.	16	0	10	4
126	-	2	0	5	0
101	25 Jun.	4	2	41	34
58	28 Jun.	4	4	14	16
36	-	2	4	14	0
Belk	29 May	5	2	31	84
Hanes	-	4	0	22	-
LRAFB	24 May	5	8	33	84
Snap on	-	3	2	18	-
Totals				350	422

Table 2. Least Tern colony estimates on river sandbars and rooftop location estimates for the 2017 breeding season on the Arkansas River. Estimated breeding adult counts by multiplying, by two, the greatest number of active nests. The number of nests represents the greatest number of nests observed active at one time in order to not include renests.

Location	Adults			Young		
	Incubating	Counts	Breeding	Nests	Chicks	Fledge
River (13 colonies)	50	246	254	127	96	72
Roof Top (4 colonies)	12	104	168	84	39	6
Totals	62	350	422	211	135	78

Table 3. Distribution of active Least Tern colonies and range of initiation dates for the 2017 breeding season on the Arkansas River.

Location	Initiation Date		Colonies
	Earliest	Latest	
River	3 Jun.	3 Jul.	10
Roof Top	24 May	29 May	4
Totals			14

Table 4. Estimates of reproductive success for all colonies in the survey area during the 2017 breeding season, based off the highest number observed on any single survey attempt for the season. The number of nests represents the greatest number of nests observed active at one time to not include renests. Locations are listed in river miles.

Location	Initiation	Surveys	Young			Fledges per Breeding Adult
			Chicks	Nests	Fledges	
275	15 Jun.	6	21	17	5	0.15
240	-	2	0	0	0	0
184	15 Jun.	19	0	6	0	0
179.5	5 Jun.	20	36	43	30	0.35
179.2	3 Jun.	18	5	5	1	0.1
179	4 Jun.	20	12	27	0	0
170	3 Jul.	14	0	2	3*	-
146.8	-	13	0	0	2*	-
130	13 Jun.	16	2	2	2	0.5
126	-	2	0	0	0	0
101	25 Jun.	4	16	17	33	0.97
58	28 Jun.	4	4	8	1	0.06
36	-	2	0	0	0	0
Belk	29 May	5	7	42	2	0.02
Hanes	-	4	8	0	0	-
LRAFB	24 May	5	18	42	4	0.05
Snap on	-	3	6	0	0	-
Totals			135	211	78	0.18

* No chicks or successful nests found, fledglings spotted with an influx of adults when, likely migrating birds from unknown location.

Table 5. Least Tern nest fates by study colony for nests observed on the Arkansas River during the 2017 breeding season. The number of nests represents the number of nests that were found at each colony during the breeding season. Locations are listed in river miles.

Location	Nests	Successful	Failed	Flooding	Unknown
130	4	2	2	0	0
170	2	0	2	2	0
179	31	7	13	0	11
179.2	8	4	0	0	4
179.5	48	18	20	0	11
184	10	0	10	10	0
Total	103	31	47	12	26

Table 6. Summary of Least Tern chick banding and recapture efforts by study colony on the Arkansas River during the 2017 breeding season. Locations are listed in river miles.

Location	Banding		Total	
	Individuals	Age	Captures	Recaptures
130	3	1-5	7	4
179	19	1-8	23	4
179.2	11	1-17	16	5
179.5	70	1-16	162	92
Total	103	1-16	208	105

Table 7. Model ranking of survival (Φ) and initiation date for Least Tern nests on the Arkansas River during the 2017 breeding season.

Model[a]	ΔAIC_c	w_i	Likelihood	k[b]	Deviance
Φ(.) + ID	0.00	0.941	1.00	2	222.30
Φ(.)	5.56	0.059	0.06	1	229.87

a. Variables used in the models: (.) constant and (ID) Initiation Date.
b. Number of parameters in the model.

Table 8. Model ranking of survival (Φ), initiation date, and colony for Least Tern nests on the Arkansas River during the 2017 breeding season.

Model[a]	ΔAIC_c	w_i	Likelihood	k[b]	Deviance
Φ(.) + ID + C	0.000	0.501	1.00	5	216.02
Φ(.) + ID	0.217	0.450	0.90	2	222.30
Φ(.)	5.773	0.028	0.06	1	229.87
Φ(.) + C	6.332	0.021	0.042	4	224.38

a. Variables used in the models: (.) constant, (ID) Initiation Date, and (C) Colony.
b. Number of parameters in the model.

Table 9. Model ranking of Cormack-Jolly-Seber models of survival (Φ) and recapture rate (p) for pre-fledged Least Tern chicks on the Arkansas River, 2017.

Model[a]	ΔAIC_c	w_i	Likelihood	k[b]	Deviance
Φ(.) p(.)	0.00	0.82	1.00	2	122.74
Φ(.) p(t)	3.02	0.18	0.22	21	82.83
Φ(t) p(.)	22.91	0.00	0.00	21	102.71
Φ(t) p(t)	47.48	0.00	0.00	39	77.60

a. Variables used in the models: (.) constant (t) varied by time.
b. Number of parameters in the model.

Table 10. Model ranking of Cormack-Jolly-Seber models of survival (Φ) and recapture rate (p) for pre-fledged Least Tern chicks on the Arkansas River, 2017.

Model[a]	ΔAIC_c	w_i	Likelihood	k[b]	Deviance
Φ(.) p(.)	0	0.69	1	2	544.91
Φ(.) H p(.) H	2.97	0.16	0.23	4	543.74
Φ(.) p(t)	3.02	0.15	0.22	21	504.99
Φ(t) p(.)	22.91	0	0	21	524.88
Φ(.) p(.) H	26.72	0	0	3	569.57
Φ(t) p(t)	47.48	0	0	39	499.77

a. Variables used in the models: (.) constant (t) varied by time and (H) hatch date.
b. Number of parameters in the model.

Table 11. Model ranking of Cormack-Jolly-Seber models of survival (Φ) and recapture rate (p) for pre-fledged Least Tern chicks on the Arkansas River, 2017.

Model[a]	ΔAIC_c	w_i	Likelihood	k[b]	Deviance
Φ(.) C p(.) C	0	0.54	1	8	511.62
Φ(.) H + C p(.) C	1.95	0.20	0.38	9	511.39
Φ(.) C p(.) H + C	2.03	0.19	0.36	9	511.47
Φ(.) H + C p(.) H + C	4.11	0.069	0.13	10	511.34
Φ(.) H p(.)	19.56	0	0	2	543.85
Φ(.) p(.)	20.62	0	0	2	544.91
Φ(.) H p(.) H	21.51	0	0	3	543.74
Φ(.) p(t)	23.64	0	0	21	504.99
Φ(t) p(.)	43.53	0	0	21	524.88
Φ(.) p(.) H	47.34	0	0	3	569.57
Φ(t) p(t)	68.10	0	0	39	499.77

a. Variables used in the models: (.) constant (t) varied by time, (H) for hatch date, (C) for colony.
b. Number of parameters in the model.

Table 12. Summary of camera set up and performance during the 2017 Least Tern breeding season on the Arkansas River.

Location	Deployment	Collection	Total Min	Recorded Time	% Time captured
130	6/19/2017	8/10/2017	75,332	71,044	0.94
146.8	7/1/2017	8/11/2017	58,677	58,414	0.99
170 D[a]	6/24/2017	8/10/2017	67,657	62,752	0.93
170 U[b]	7/2/2017	8/10/2017	55,886	39,969	0.72
179 D	6/25/2017	8/10/2017	66,356	56,252	0.85
179 M[c]	6/16/2017	8/10/2017	79,348	76,424	0.96
179 U	7/1/2017	8/10/2017	57,913	54,966	0.95
179.2 D	6/29/2017	8/10/2017	60,450	58,028	0.96
179.5 D	6/21/2017	8/10/2017	71,978	67,721	0.94
179.5 U	6/25/2017	8/10/2017	66,289	63,573	0.96
184 D	6/21/2017	8/10/2017	71,963	70,755	0.98
184 U	6/29/2017	8/9/2017	59,292	54,084	0.91

a. D down river end of colony
b. U up river end of colony
c. M mid colony

Table 13. Total occurrences, group sizes, and amount of disturbances in minutes on daily bases of combined seven colonies captured by camera methods during the 2017 Least Tern breeding season on the Arkansas River.

Species	Occurrences		Group		Disturbance	
	max	avg	max	avg	max	avg
Crow	16	3.54	80	12.31	409	55.28
GBH	18	2.79	20	3.43	434	69.89
Raptor	4	1.53	14	2.43	227	42.49
All[a]	20	4.6	87	10.85	502	95.95

a. All includes all species identified and observed at colony.

Table 14. Disturbances occurring at each given Least Tern colony of the three identified predator groups during the 2017 breeding season on the Arkansas River. Location are given in river miles.

Location	Activity[a]	Crow	GBH	Raptor	Total
130	Fledgling	135	109	12	256
146.8	Colony	18	93	13	124
170	Nests	4	97	13	114
179	Chicks	211	21	14	246
179.2	Fledgling	38	18	0	56
179.5	Successful	55	137	20	212
184	Nests	169	66	41	276
Total	-	630	541	113	1284

a. Furthest recorded progress in reproductive success, fledging indicates at least one chick fledged, successful indicates greater than 0.50 fledgling per breeding pair were produced.

Table 15. Paired T-Test results of camera estimates and survey estimates of occurrences of activity considered to be a disturbance to nesting Least Terns at river colony locations during the 2017 breeding season on the Arkansas River. Great Blue Heron is abriveated as GBH.

Disturbance	Mean Observations			P
	Camera	Survey	Difference	
Crow	21.46	0.18	21.28 ± 6.58	<0.001
GBH	6.202	0.37	5.84 ± 1.62	<0.001
Raptor	1.731	0.16	1.57 ± 0.71	<0.001
Human	1.635	0.18	1.45 ± 0.75	<0.001
Dog	0.125	0.067	0.06 ± 0.11	0.291

Table 16. Colony wide disturbance events that occurred on Least Tern nesting colonies during the 2017 breeding season on the Arkansas river, indicated with black if the disturbance occurred at the specific location. Locations are in river miles.

Location	Activity[a]	Flooding	Nest Predation	Feather Pile[b]	Human[c]	Dog[d]
130	Fledgling		■		■	■
146.8	Colony	■				
170	Nests	■	■			
179	Chicks		■	■		
179.2	Fledgling			■		
179.5	Successful					
184	Nests	■		■		

a. Furthest recorded progress in reproductive success, fledging indicates at least one chick fledged, successful indicates greater than 0.50 fledgling per breeding pair were produced.
b. Pile of feathers indicating predation of adult Least Tern or fledgling indicating predation pressures observed during surveys.
c. Human disturbance at least once when occupied by Least Terns
d. Dog disturbance at least once when occupied by Least Terns

Table 17. Recorded intrusions in Least Tern colonies by all species observed during the 2017 breeding season on the Arkansas River. Locations are in river miles.

Location	Individuals			Disturbance (min)			n
	max	mean	median	max	mean	median	
All	86	5.71	2	384	24.55	11	2106
130	86	8.51	2	384	27.16	12	746
146.8	40	5.68	1	320	31.32	15.5	212
170	30	2.65	1	259	37.02	21.5	132
179	33	3.17	2	201	15.53	8	308
179.2	65	5.21	2	181	19.17	6	86
179.5	38	3.82	1	351	21.14	10	281
184	64	4.73	2	267	22.16	10	341

Table 18. Daily totals of recorded intrusions in Least Tern colonies by all species observed with cameras, n = number of days with disturbances during the 2017 breeding season on the Arkansas River.

Colony	Occurrences			Individuals			Disturbance (min)			n	sampled
	max	mean	median	max	mean	median	max	mean	median		
All	20	4.61	4	87	10.85	7	502	95.95	62	281	330
130	15	5.54	5	87	15.92	8.5	391	115.15	86	48	52
146.8	9	3.29	2	13	4.39	4	270	83.26	62.5	38	40
170	13	3	2	14	3.92	3	502	120.71	81.5	38	43
179	17	5.72	5	81	14.6	9	421	88.07	51	43	55
179.2	5	2.07	2	36	7.81	6	126	28.85	20	27	42
179.5	20	5.44	4	53	12.26	8	423	88.18	54	39	50
184	12	5.75	5	35	13.6	12.5	453	118.33	90	48	48

Table 19. T-test results between Least Tern colonies during the 2017 breeding season on the Arkansas River that fledged at least one chick and colonies that failed to produce fledglings for all disturbances, crow, GBH, and raptor disturbances in minutes. Great Blue Heron is abbreviated as GBH.

	Mean Fledged	Mean Failed	P-Value
All	58.52	90.27	0.320
Crow	26.41	30.62	0.844
GBH	30.35	52.16	0.425
Raptor	5.28	12.83	0.387

Figures

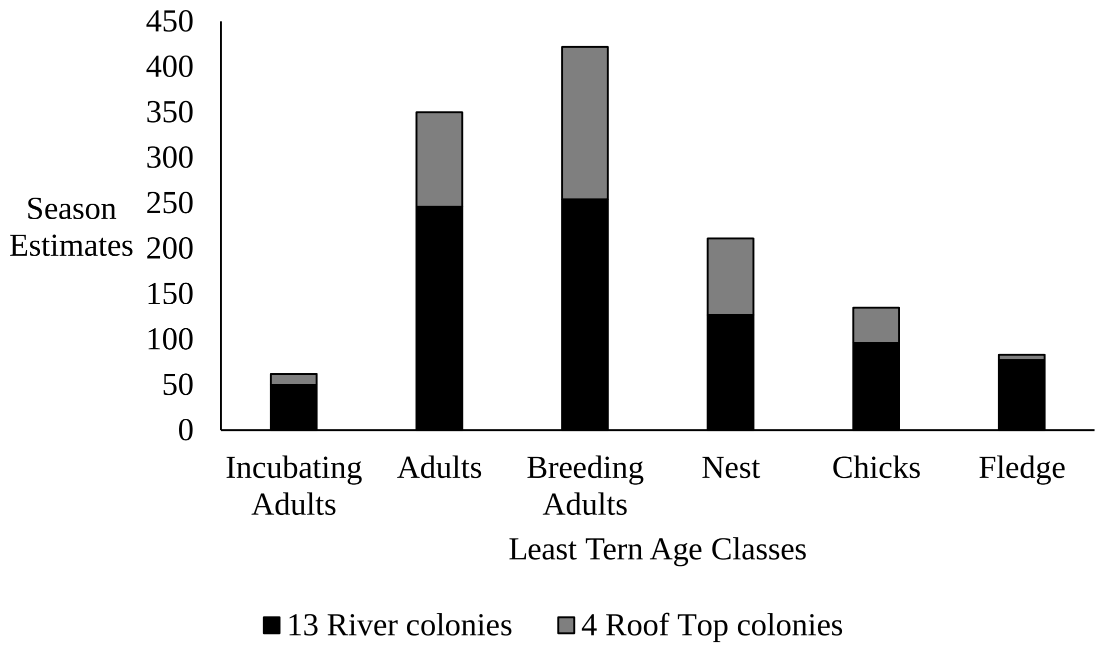


Figure 1. Least Tern colonies, river sandbars and rooftop location, estimates for the 2017 breeding season on the Arkansas river.

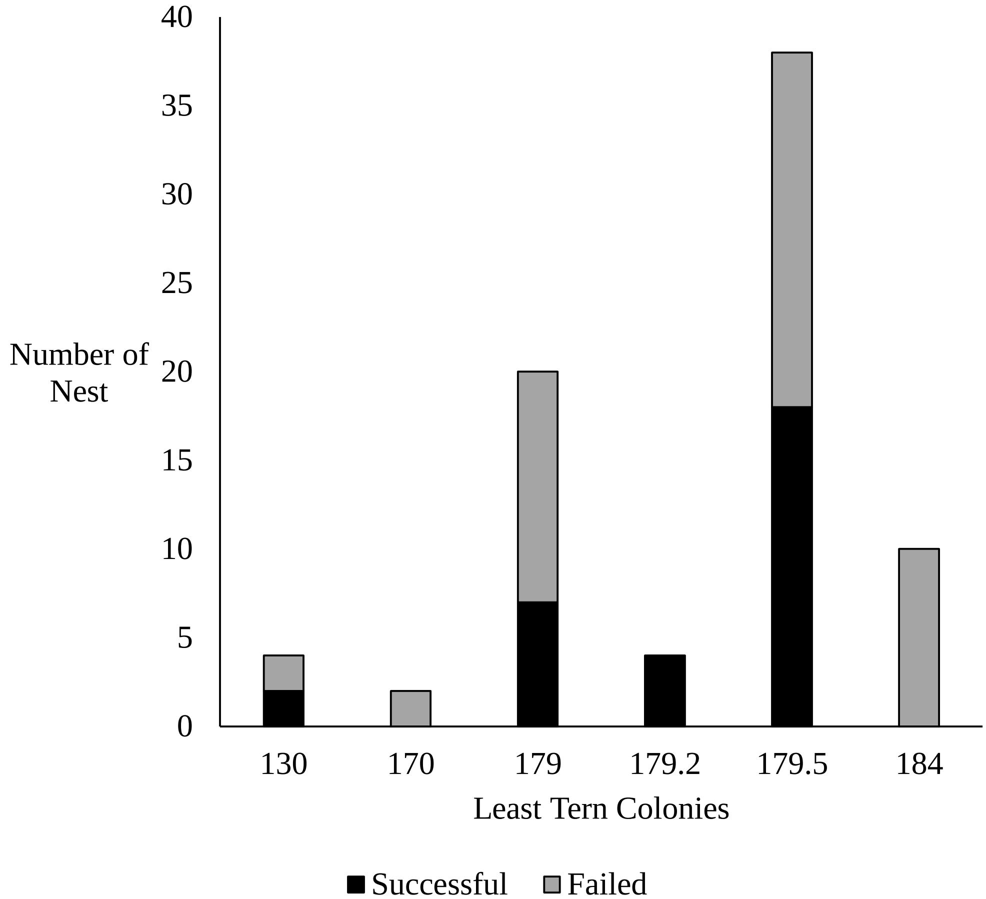


Figure 2. Fates of nests on river Least Tern colonies in the study area during the 2017 breeding season on the Arkansas River. Locations of Least Tern colonies are in river miles.

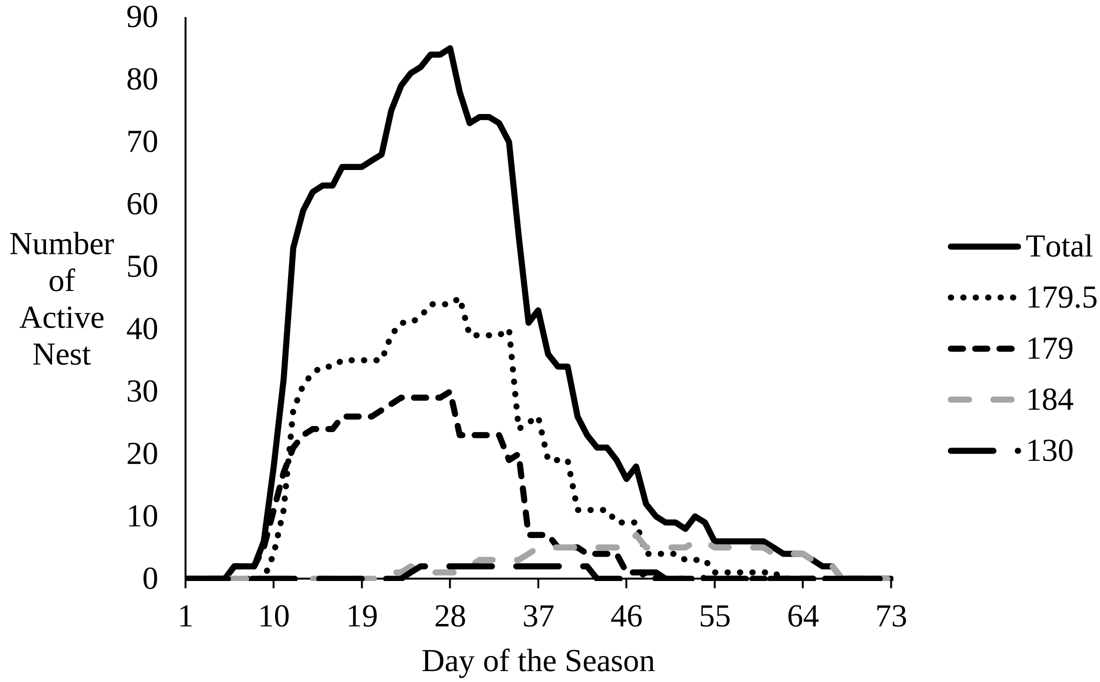


Figure 3. The number of active Least Tern nests on each day of the season at study colonies that produced nest on the Arkansas River during the 2017 breeding season. Season day one is the first initiated nest of the year.

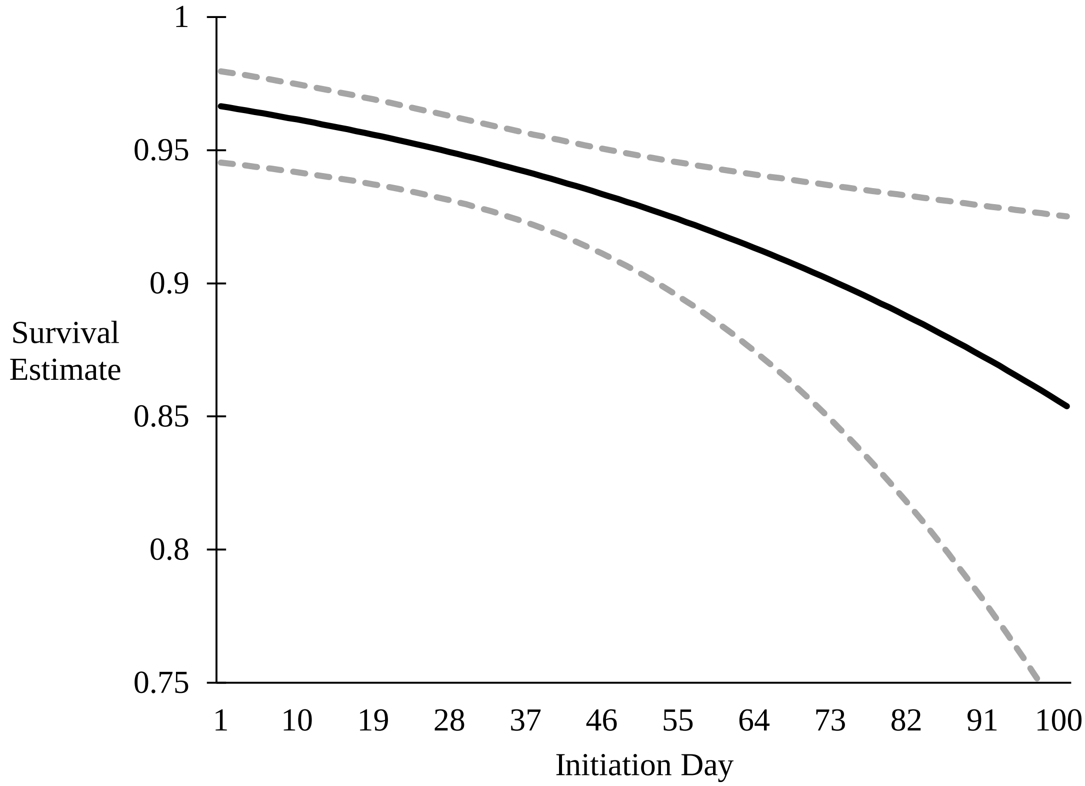


Figure 4. Daily survival probability estimates of Least Tern nests when initiation date incorporated into calculations for the 2017 breeding season on the Arkansas River with 95% confidence intervals. Initiation day one is the first initiated nest of the year.

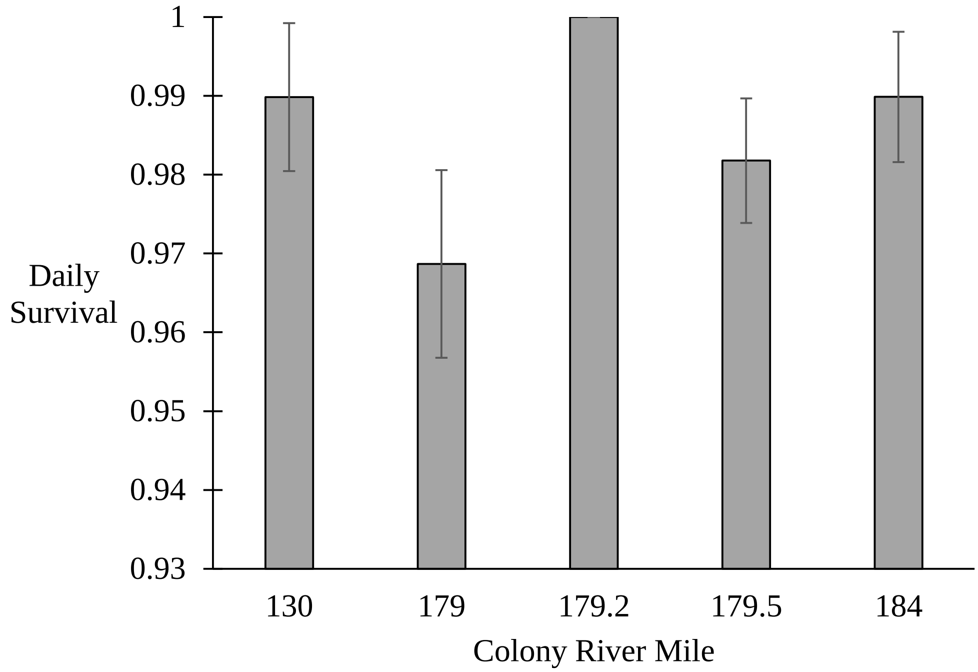


Figure 5. Daily survival probability estimates of Least Tern nests when colony was incorporated into calculations for the 2017 breeding season on the Arkansas River with standard error bars.

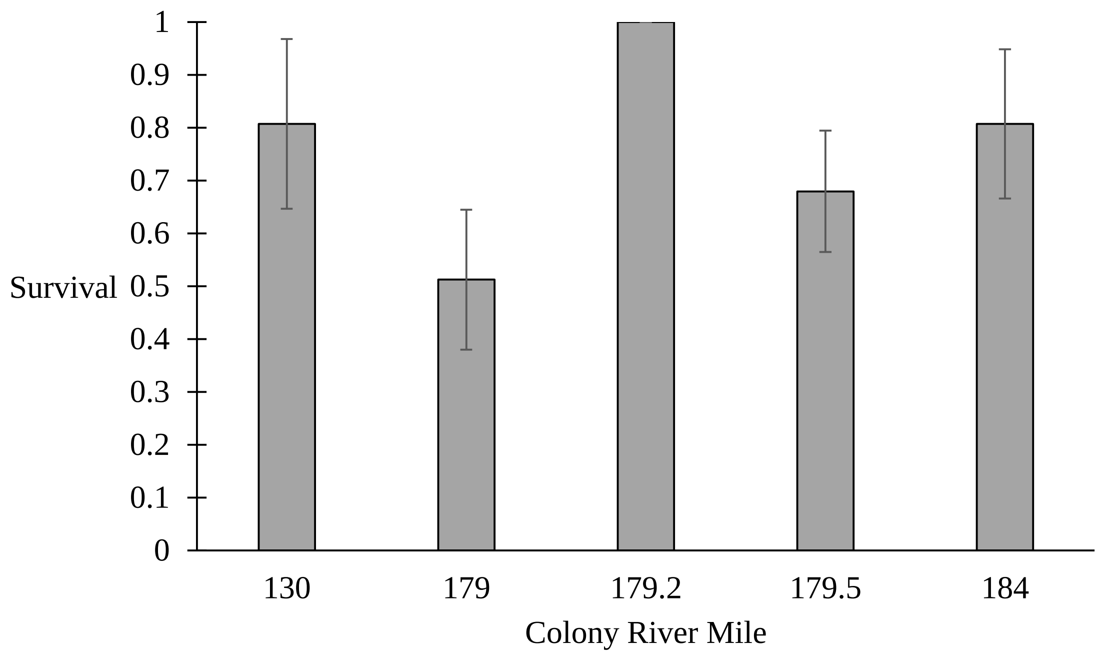


Figure 6. Survival estimates of Least Tern nests, from initiation to hatch (21 d), when colony was incorporated into calculations for the 2017 breeding season on the Arkansas River with standard error bars.

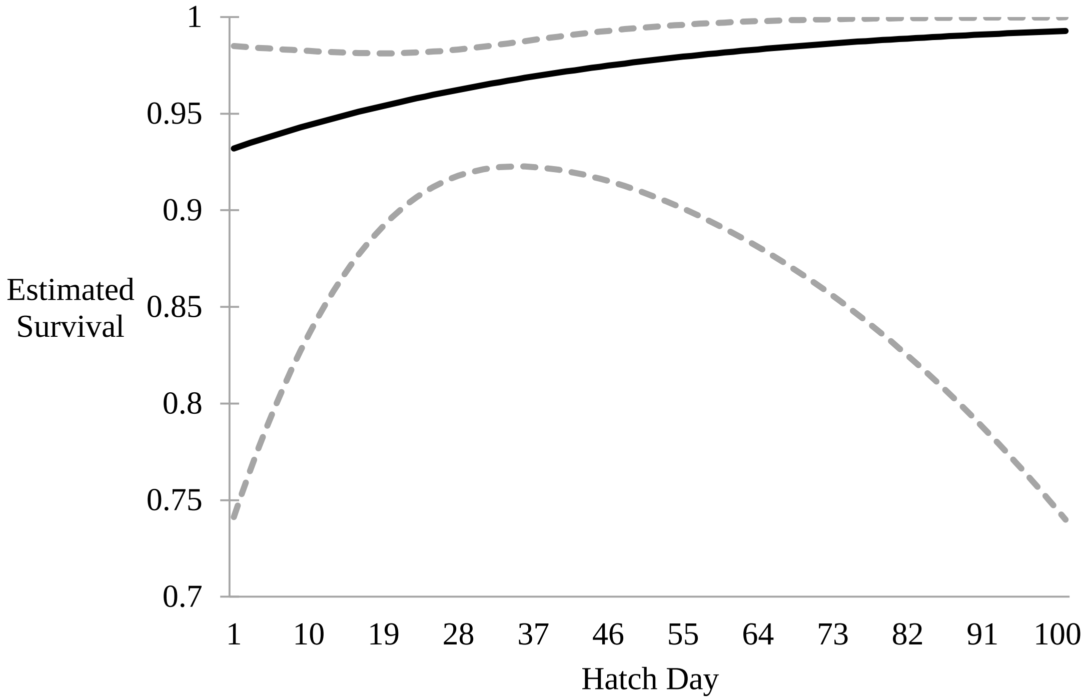


Figure 7. Daily survival estimates for Least Tern chicks when the hatch day was incorporated into the model for the 2017 breeding season on the Arkansas River with 95% confidence intervals. Hatch date is in day of the season starting at one with the first initiation of a nest.

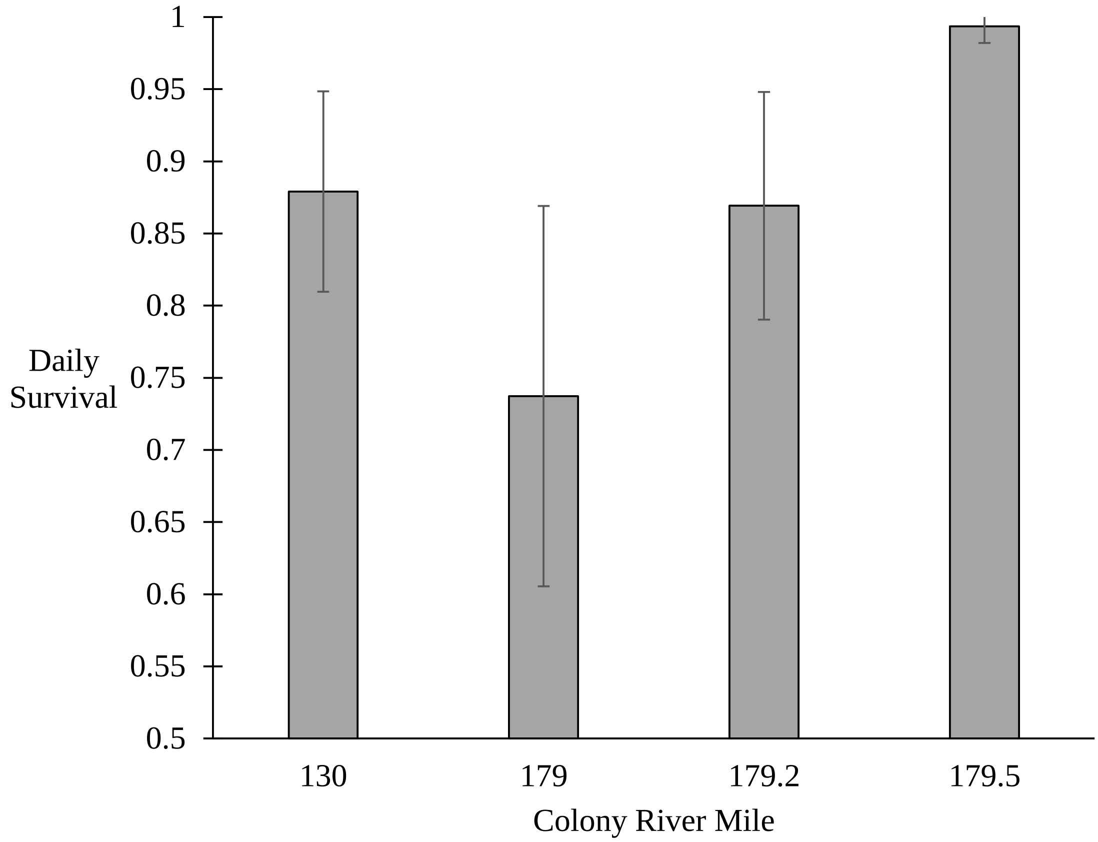


Figure 8. Daily survival probability estimates of Least Tern chicks when colony was incorporated into calculations for the 2017 breeding season on the Arkansas River with standard error bars.

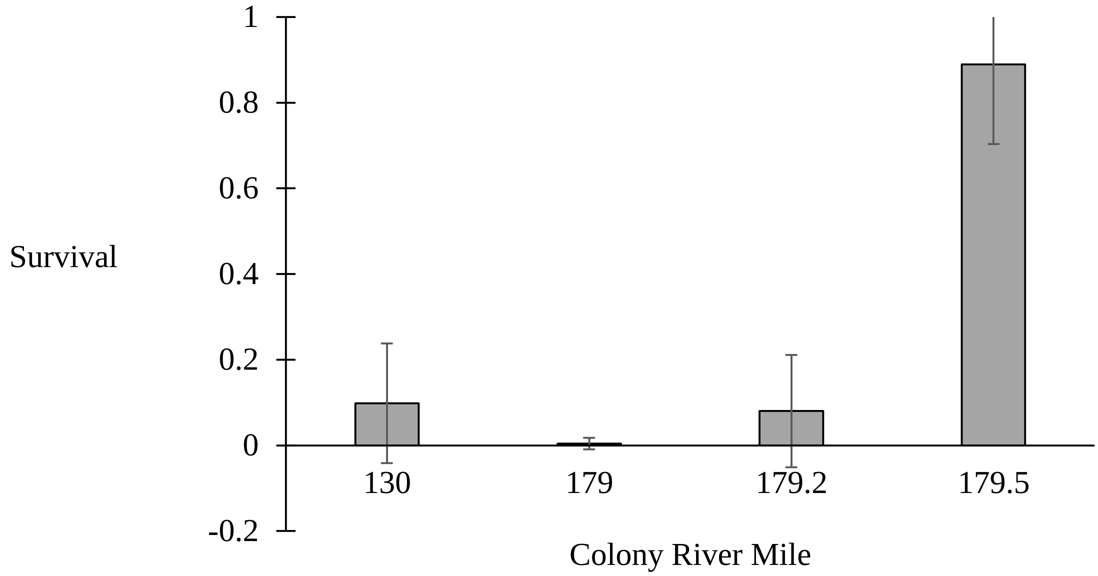


Figure 9. Survival estimates of Least Tern chicks, from hatch to fledge (18 d), when colony was incorporated into calculations for the 2017 breeding season on the Arkansas River with standard error bars.

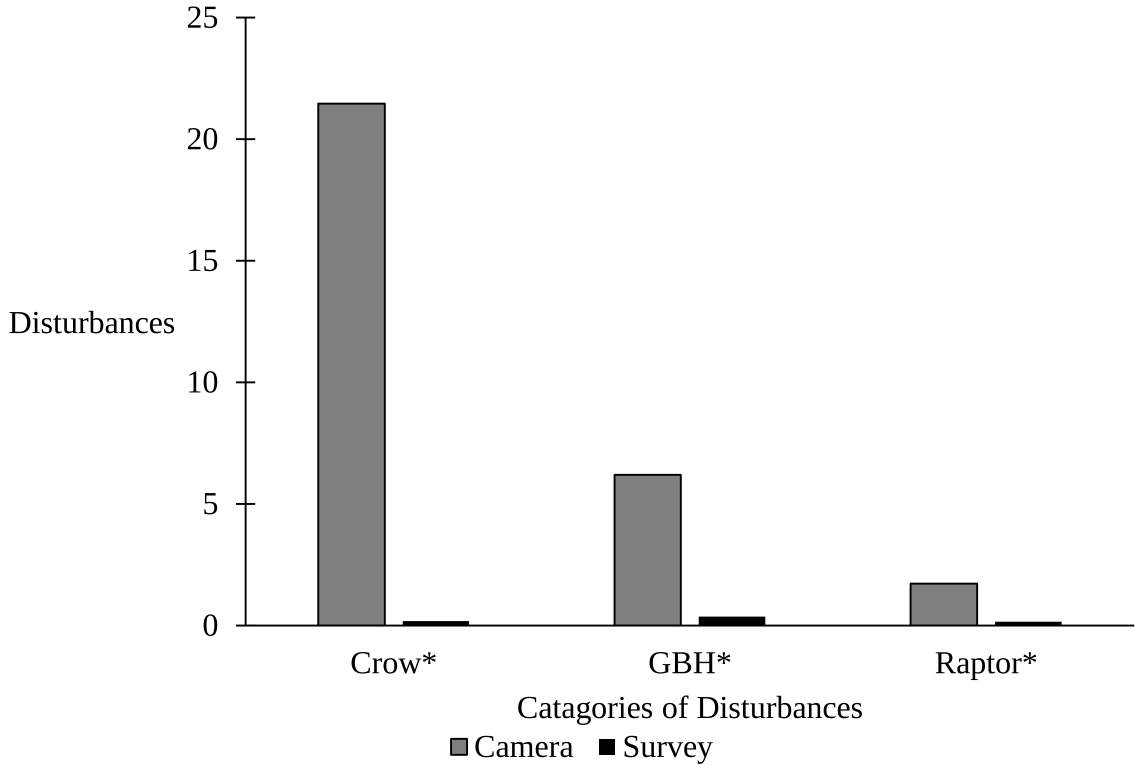


Figure 10. Observed by camera and estimated by survey disturbance events at Least Tern colonies for the 2017 breeding season. Great Blue Heron is abbreviated as GBH.

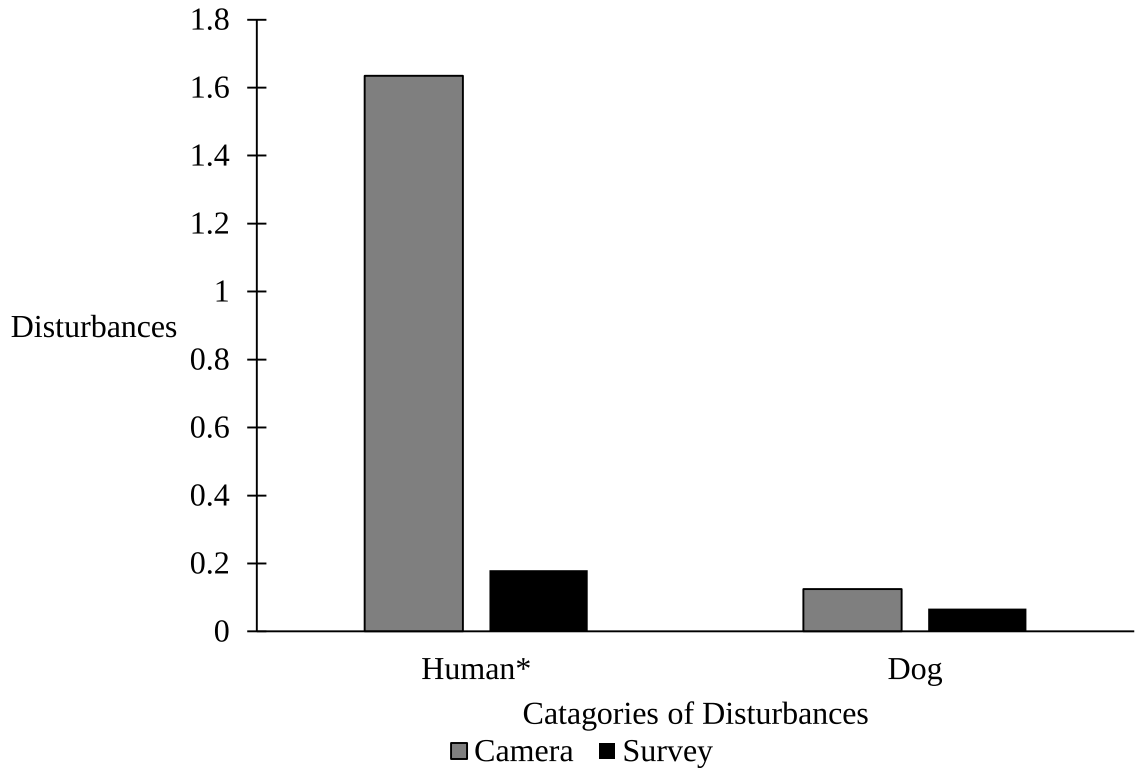


Figure 11. Observed by camera and estimated by survey disturbance events at Least Tern colonies for the 2017 breeding season.

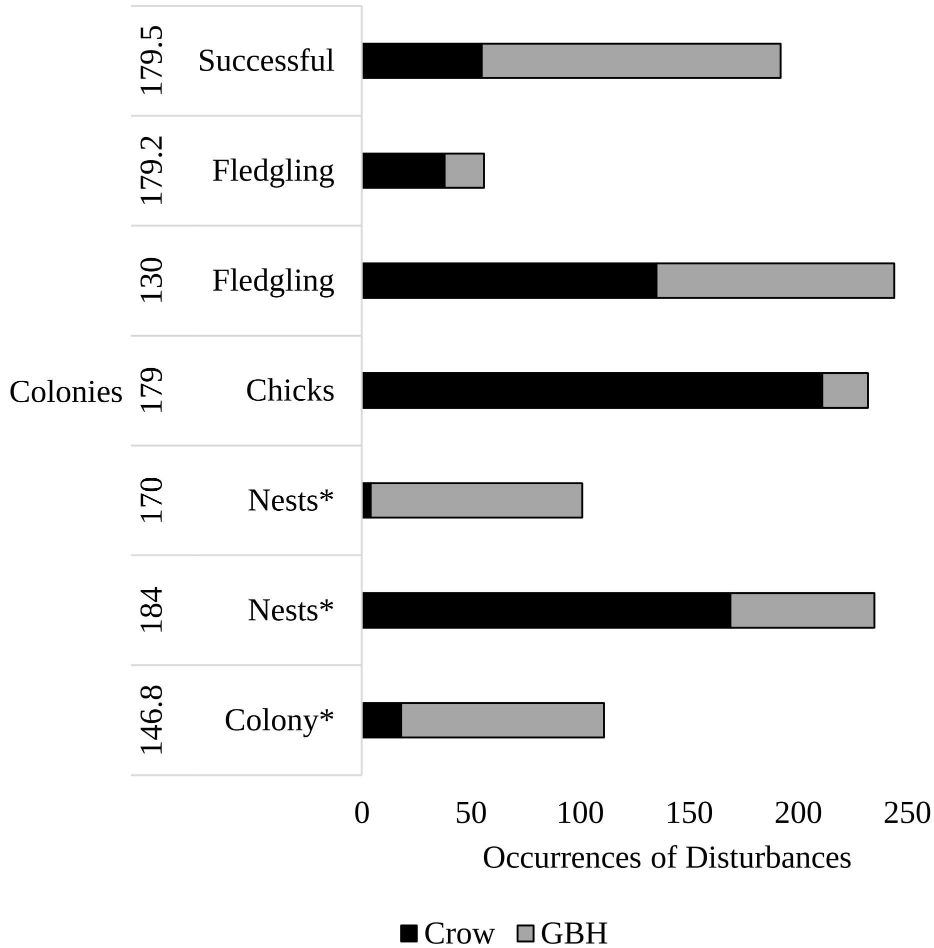


Figure 12. Occurrences of disturbances at each Least Tern colony during the 2017 breeding season.

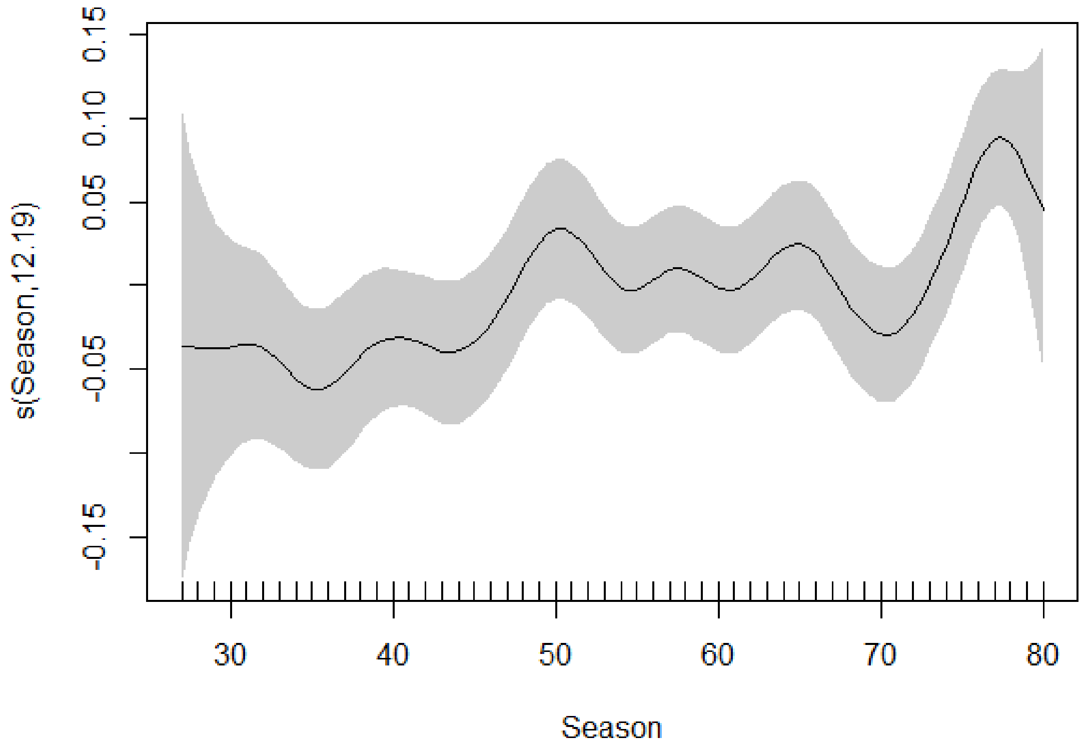


Figure 13. Graph of general additive model results for total minutes of disturbances per day and day of the season at Least Tern colonies during the 2017 breeding season. The first day of the season is considered the day of the first nest initiation. Records for disturbances began on the 27th day of the season.

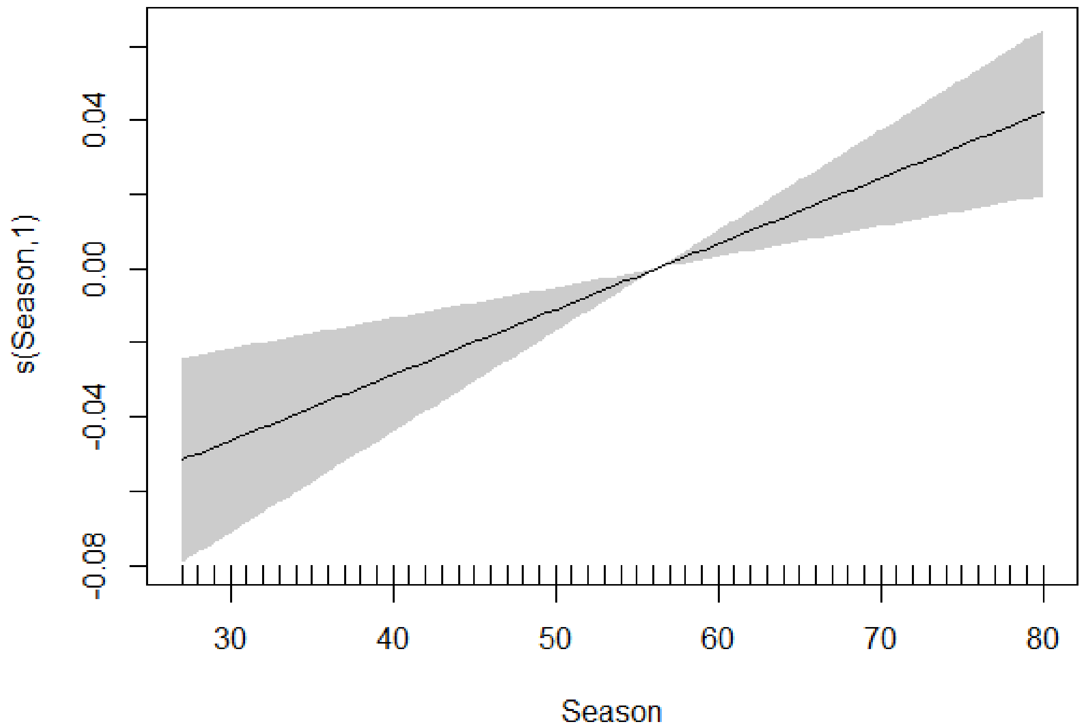


Figure 14. Graph of general additive model results for total minutes of disturbances per day and day of the season, without colony RM 146.8, at Least Tern colonies during the 2017 breeding season. The first day of the season is considered the day of the first nest initiation. Records for disturbances began on the 27th day of the season.

Appendices

Appendix A. Recorded intrusions in Least Tern colonies during the 2017 breeding season by crows observed with cameras, n = number of days with disturbances. Colony locations are in river miles.

Location	Individuals			Disturbance (min)			n
	max	mean	median	max	mean	median	
All	41	3.48	2	332	3.48	7	630
130	41	4.5	2	184	17.8	9	135
146.8	5	1.72	1	13	4.22	2.5	18
170	3	1.5	1	13	7.5	7	4
179	16	2.77	2	201	15.74	8	211
179.2	30	5.08	3	103	14.55	6.5	38
179.5	18	5.53	4	332	17.95	5	55
184	18	2.75	2	246	14.6	7	169

Appendix B. Recorded intrusions in Least Tern colonies during the 2017 breeding season by Great Blue Heron observed observed with cameras, n = number of days with disturbances. Colony locations are in river miles.

Location	Individuals			Disturbance (min)			n
	max	mean	median	max	mean	median	
All	8	1.23	1	267	25.06	12	541
130	2	1.01	1	176	22.32	12	109
146.8	2	1.25	1	195	30.97	20	93
170	4	1.27	1	259	44.55	25	97
179	1	1	1	44	7.19	4	21
179.2	1	1	1	48	12.56	4	18
179.5	2	1.06	1	109	14.19	9	137
184	8	2.02	1	267	24.3	11.5	66

Appendix C. Recorded intrusions in Least Tern colonies during the 2017 breeding season by raptors observed observed with cameras, n = number of days with disturbances. Colony locations are in river miles.

Location	Individuals			Disturbance (min)			n
	max	mean	median	max	mean	median	
All	11	1.59	1	227	27.82	14	113
130	11	2.83	2	73	22.92	19.5	12
146.8	3	1.46	1	68	15.54	14	13
170	3	1.54	1	69	18.15	9	13
179	8	1.64	1	116	22.43	13	14
179.5	6	1.45	1	117	25.4	14.5	20
184	4	1.34	1	227	39.22	21	41

Appendix D. Daily totals of recorded intrusions in Least Tern colonies during the 2017 breeding season by crows observed with cameras, n = number of days with disturbances. Locations are in river miles.

Location	Occurrences			Individuals			Disturbance (min)			n	sampled
	max	mean	median	max	mean	median	max	mean	median		
All	16	3.54	3	80	12.31	8	409	55.28	29	178	330
130	9	3.29	3	80	14.83	8	247	58.61	39	41	52
146.8	3	1.38	1	7	2.38	2	28	5.85	2	13	40
170	2	1.33	1	4	2	1	20	10	7	3	43
179	16	5.28	4	74	14.6	9	303	83.05	40.5	40	55
179.2	4	1.73	1	35	8.77	7.5	110	25.14	22.5	22	42
179.5	8	3.24	2	49	17.88	15	370	58.06	26	17	50
184	11	4.02	4	31	11.07	8.5	409	58.76	34.5	42	48

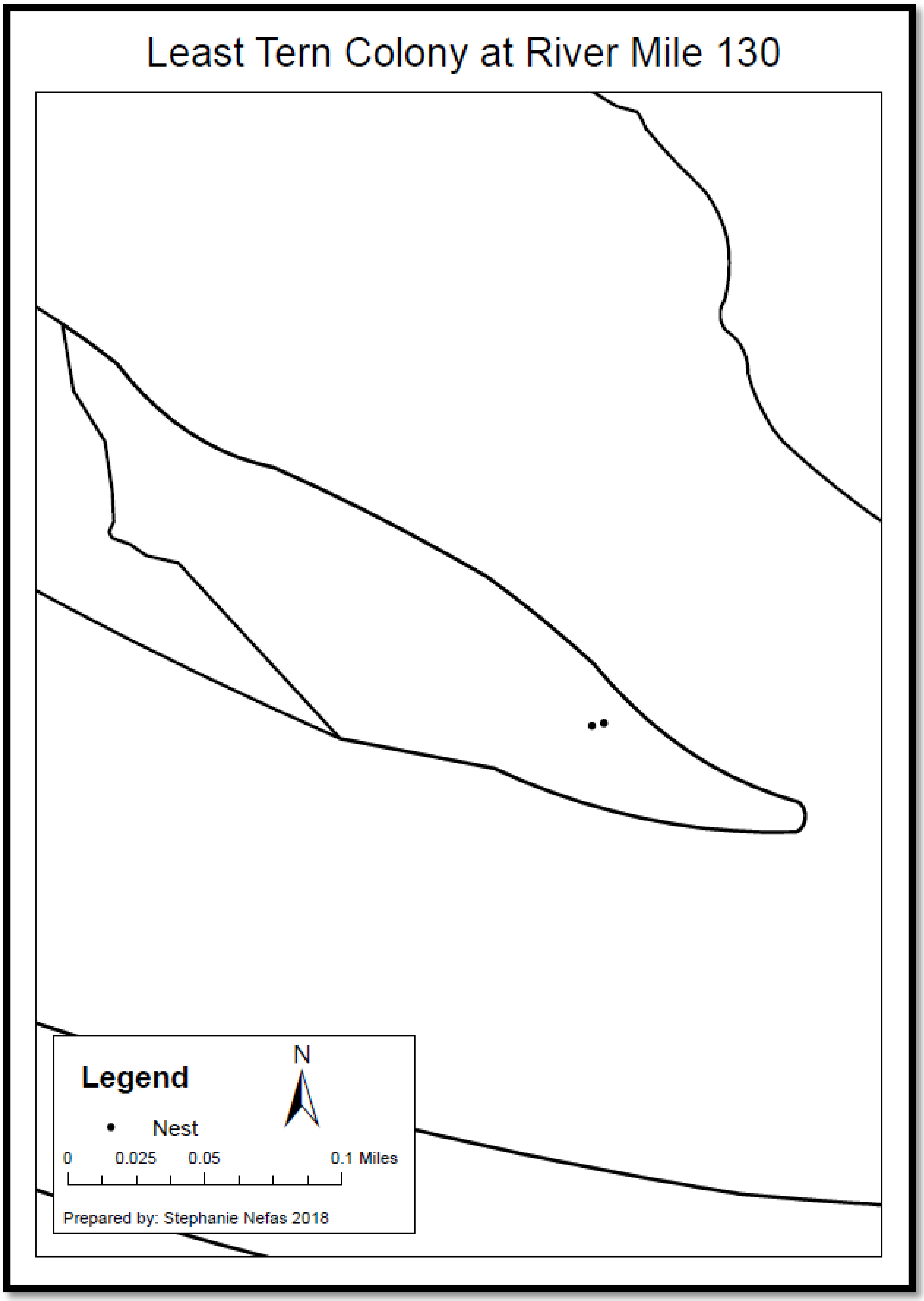
Appendix E. Daily totals of recorded intrusions in Least Tern colonies during the 2017 breeding season by Great Blue Herons observed observed with cameras, n = number of days with disturbances. Locations are in river mile.

Location	Occurrences			Individuals			Disturbance (min)			n	sample
	max	mean	median	max	mean	median	max	mean	median		
All	18	2.79	2	20	3.42	2	434	69.89	38	194	330
130	7	2.95	3	8	2.97	3	265	65.76	46	37	52
146.8	8	2.82	2	10	3.52	3	270	87.27	66	33	40
170	13	2.69	2	14	3.42	3	434	120.03	78	36	43
179	6	1.91	2	6	1.91	2	44	13.73	7	11	55
179.2	2	1.2	1	2	1.2	1	58	15.07	4	15	42
179.5	18	3.91	2	20	4.14	2	261	55.54	29	35	50
184	7	2.44	2	17	4.93	3	418	59.41	31	27	48

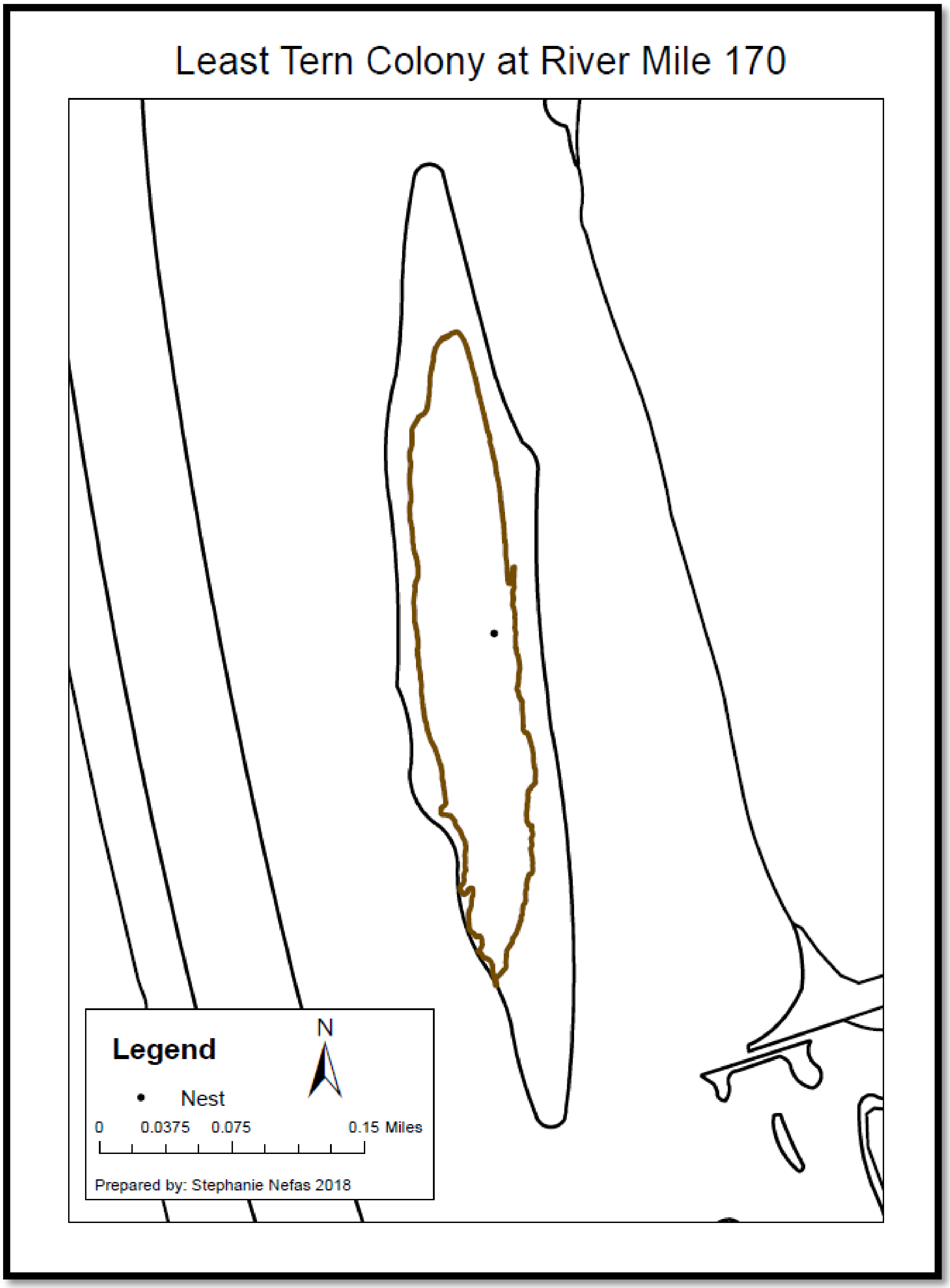
Appendix F. Daily totals of recorded intrusions in Least Tern colonies during the 2017 breeding season by raptors observed with cameras, n = number of days with disturbances. Locations are in river miles.

Location	Occurrences			Individuals			Disturbance (min)			n	sample
	max	mean	median	max	mean	median	max	mean	median		
All	4	1.53	1	14	2.43	2	227	42.49	20	74	288
130	2	1.33	1	14	3.78	2	84	30.67	20	9	52
146.8	2	1.44	1	4	2.11	2	68	22.44	20	9	40
170	2	1.44	1	5	2.22	1	120	26.22	9	9	43
179	2	1.27	1	10	2.09	1	118	28.55	14	11	55
179.5	4	1.54	1	6	2.23	1	150	39.08	14	13	50
184	4	1.78	1	7	2.39	2	227	69.91	56	23	48

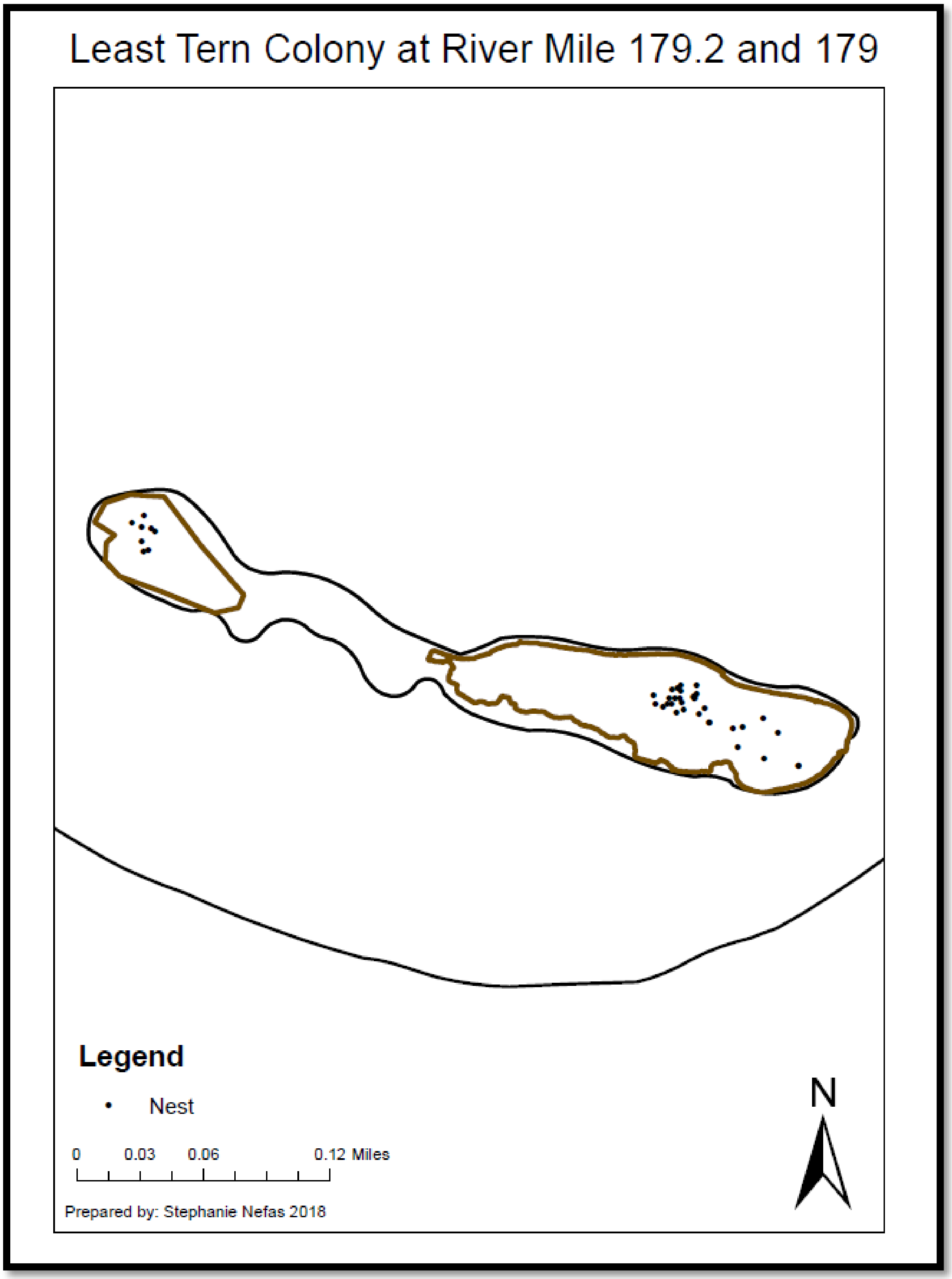
Appendix G. Map of Least Tern colony at RM 130 displaying nest locations during the 2017 breeding season.



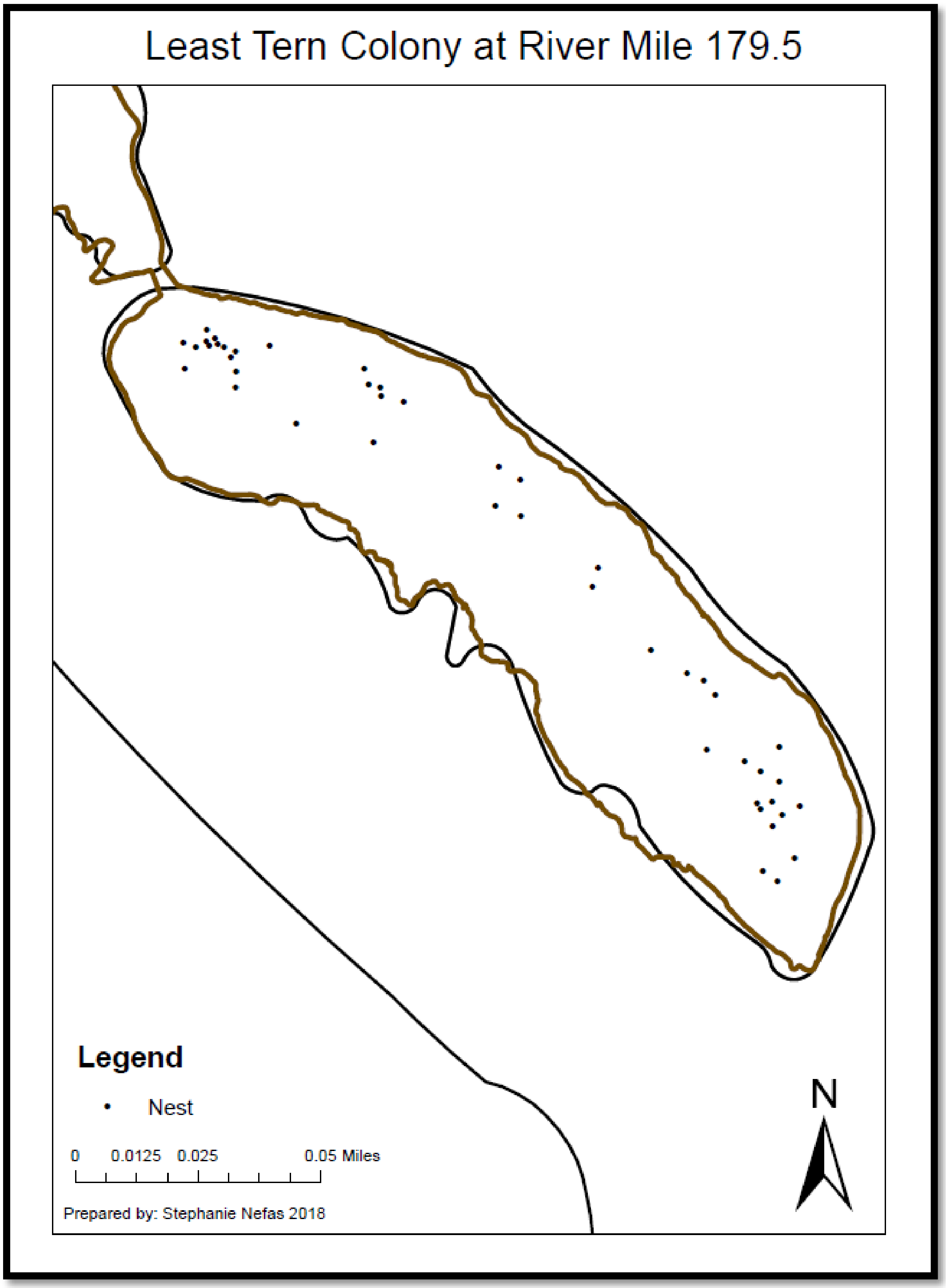
Appendix H. Map of Least Tern colony at RM 170 displaying nest locations during the 2017 breeding season.



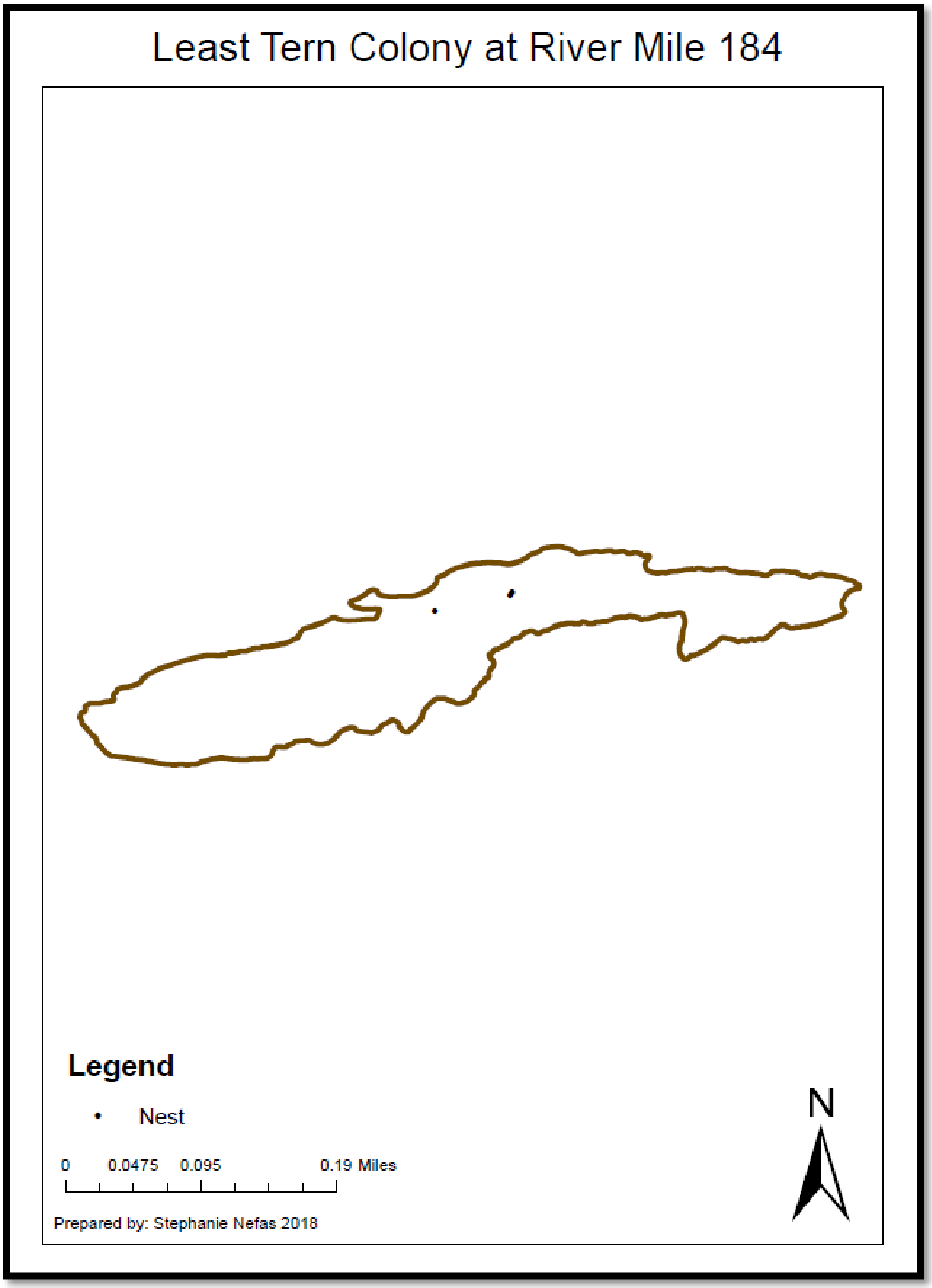
Appendix I. Map of Least Tern colony at RM 179.2 and 179 displaying nest locations during the 2017 breeding season.



Appendix J. Map of Least Tern colony at RM 179.5 displaying nest locations during the 2017 breeding season.



Appendix K. Map of Least Tern colony at RM 184 displaying nest locations during the 2017 breeding season.



Appendix L. Roof of the Belk with Least Tern nest locations during the 2017 breeding season.

Appendix M. Map of study area and locations of river sandbar Least Tern colonies during the 2017 breeding season.