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Developing Best Management Practices for Interior Least Tern Habitat Restoration on the McClellan-Kerr Arkansas River Navigation System

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DEVELOPING BEST MANAGEMENT PRACTICES FOR INTERIOR LEAST TERN
HABITAT RESTORATION ON THE MCCLELLAN-KERR
ARKANSAS RIVER NAVIGATION SYSTEM

By

JOHN GORDON T. ROSS

Submitted to the Faculty of the Graduate College of
Arkansas Tech University
in partial fulfillment of the requirements
for the degree of
MASTER OF SCIENCE IN FISHERIES AND WILDLIFE SCIENCE
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DEVELOPING BEST MANAGEMENT PRACTICES FOR INTERIOR LEAST TERN
HABITAT RESTORATION ON THE MCCLELLAN-KERR
ARKANSAS RIVER NAVIGATION SYSTEM

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Title: Developing Best Management Practices for Interior Least Tern Habitat
Restoration on the McClellan-Kerr Arkansas River Navigation System

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Degree: Master of Science

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Abstract

The interior least tern (*Sternula antillarum athalassos*) is an endangered shorebird that nests on sandbars in river systems throughout the central United States, and which has lost habitat due to damming and channelization of these rivers. My study sought to quantify the status and trends of the population nesting in the McClellan-Kerr Arkansas River Navigation System (MKARNS) within Arkansas, and to establish best practices for nesting habitat management. The local population of terns remained steady between 2010 and 2014, with approximately 450 adults breeding in this section of MKARNS.

Regression tree analysis and principal component analysis showed that colonies on unconnected islands at wide spots in the river away from dike fields and the downstream side of dams had the highest yearly measures of productivity. I make recommendations for dredge spoil deposition in locations matching these characteristics in order for the U.S. Army Corps of Engineers to meet its legal requirement to manage least tern habitat within MKARNS.

Keywords: interior least tern; habitat analysis; habitat management; regression trees; river impoundment

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INTRODUCTION

The least tern (*Sternula antillarum*) is a small, piscivorous bird closely related to other small white terns such as the little tern (*S. albifrons*), which was once considered a subspecies. There are three subspecies of least tern: the Atlantic subspecies (*S. antillarum antillarum*) breeds on beaches and rivers within 80.5 km of the coast of the Atlantic Ocean and Gulf of Mexico, from northern Mexico to New England. The endangered California subspecies (*S. a. browni*) nests on the coast of California and extreme northern Baja California; and the threatened interior subspecies (*S. a. athalassos*) breeds on rivers and lakes in the central United States (U.S.), east from the Cimmaron River in New Mexico to the Ohio River in Illinois, and south from the Missouri River in Montana to the Rio Grande in Texas.

Interior least terns (hereafter ILT), or rather “the populations of Least Terns occurring in the interior of the United States,” defined as those nesting more than 80.5 km away from any ocean, have been listed as endangered by the U.S. Fish and Wildlife Service (hereafter USFWS) since 1985 due to declining numbers and rapid habitat degradation from large-scale river alterations (USFWS 1985). The USFWS defined ILT in this way because its sub-specific status was in question due to the paucity of information about genetic interchange, and therefore information about isolation of the interior population from the Atlantic population. Indeed, some morphological studies and recent genetic studies have called into question traditional subspecies designations of least terns (Thompson et al. 1992; Whittier et al. 2006; Draheim et al. 2010). Other studies seem to confirm traditional subspecies classification based on morphology (Burleigh and Lowry 1942) and colorimetry (Johnson et al. 1998). Regardless of actual

subspecific status, the interior population has been and remains at risk of extinction unless action is taken to preserve them (USFWS 2003).

In the 1950s, the McClellan-Kerr Arkansas River Navigation System was designed with the goals of reducing flooding and making the river navigable year-round for commercial barge traffic. In 1963, work began with major construction and ended in 1969, and the system officially opened in 1971. The entire system spans 445 river miles, from the Port of Catoosa (near Tulsa, Oklahoma) through 18 locks to the mouth of the Arkansas Post/White River canal on the Mississippi River. An extensive system of levees and reservoirs in Oklahoma provides flood control, while dams, extensive spur diking, and occasional dredging limits erosion and maintains a consistent navigable channel with a depth of at least 3 m even during periods of low or no flow. The U.S. Army Corps of Engineers (henceforth USACE) is responsible both for maintaining the river as a viable navigation corridor and managing it for the good of the organisms that depend upon it. However, a biological opinion by the USFWS (2005) has cited the management of interior least tern habitat on the Arkansas River as insufficient in meeting the government's obligations under the Endangered Species Act. This is attributable in part to a lack of established best management practices for ILT on the Arkansas River. My research is intended to help fill this gap in institutional knowledge. I achieved this by continuing and attempting to improve monitoring efforts on the river from 2013-2014, which is the subject of the first chapter of this thesis, and by incorporating the data collected in these years into a longer-term dataset, which I then analyzed in order to make management recommendations in the second chapter of this thesis.

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CHAPTER 1

INTERIOR LEAST TERN POPULATION STATUS AND TRENDS WITHIN MKARNS IN ARKANSAS

Prerequisites for studies focusing on a fragmented habitat such as rivers, which have a limited number of sandbars, are estimates of population size and habitat occupation. Interior least terns (hereafter ILT) are a relatively easy animal to collect habitat occupation data, because they are not cryptic and nest colonially on exposed ground. However, monitoring the ILT populations was limited in scope until a range-wide survey in 2005. As a result, the size of the interior least tern population in Arkansas prior to the 1971 opening of the McClellan-Kerr Arkansas River Navigation System (hereafter referred to as MKARNS) is unclear, but it is certain that they were present. Within MKARNS, monitoring was inconsistent until 2006, and high water prevented monitoring in 2007 and 2008. Accordingly, it is difficult to make direct comparisons of population size prior to this time. According to a USFWS biological opinion (USFWS 2005), a consistent methodology for surveying terns must be established and followed rigorously to discern trends in the population and habitat of ILT in the Arkansas River Valley.

According to the USFWS interior least tern recovery plan (USFWS 1985), the target breeding population for the whole Arkansas River system (including Oklahoma) was just 400 birds, and 150 on the Arkansas stretch. Lott (2006) suggested that the recovery plan relied on incomplete counts to make its target population recommendations. Data collected in Arkansas prior to this study supported Lott. Even the incomplete counts from 2001-2003 indicated that the total number of terns counted on

MKARNS within Arkansas never dropped below the recovery target population (Nupp 2013). The interior least tern population in the Arkansas River Valley between 2009-2012 was consistently above 400 adults.

Most birds (80-90% of total adults) nested at riverine sites, but I also found 3-4 colonies on gravel rooftops within 5 km of the river. Rooftops provided habitat for nesting terns, but may have lower fledging rates than a nearby natural habitat. This may largely be due to greater exposure to extreme weather and heat (Krogh and Schweitzer 1999, Forys and Borboen-Abrams 2006, Butcher et al. 2007, Watterson 2009). Maximum daily high surface temperature has a negative linear relationship with hatching rates, and maximum daily high temperatures on rooftops are an average of 8.5 °C warmer than riverine colonies (Watterson 2009). However, during years when the river had high flows and riverine habitat was scarce, rooftop colonies provided an alternative source of nesting habitat. Thus, rooftop colonies likely had a positive effect on the population by reducing the effect of such temporary habitat losses.

The population of ILT in Arkansas, similar to the broader ILT population, appears to be steady or trending slightly upward (Lott 2006, Nupp 2013). In Arkansas, intentional management actions other than monitoring the Little Rock district only began in 2013, with the initiation of a program of vegetation control on formerly suitable sandbars that had been lost to succession. Unintentional management, in the form of dredge spoil islands creations had occurred as long as MKARNS was open, and may be partly responsible for the stability of the ILT population in this stretch of the river. According to Lott et al. (2013), the population of ILT within MKARNS below Little Rock is part of the population fragment that includes the lower Mississippi River. Therefore, it is possible

that management on the lower Mississippi River may have increased populations locally, with positive effects propagating up the river to the Arkansas ILT population. Regardless, the 2005 USFWS biological opinion makes it clear, that in order to meet its legal obligations, USACE must continue to monitor and manage the habitat for ILT within MKARNS.

Flooding, extreme weather, predation, and human disturbance are the most important sources of mortality in our study area (Urbanic 2003; Watterson 2009; Nupp & Petrick 2011, 2012; Nupp 2013). Since 2005, flooding has been responsible for a majority of the mortality and colony abandonment on the Arkansas River for years. This happened when flooding occurred after the initiation of nesting and in years when flooding did not occur. Predation has been the largest cause of mortality, during years when flooding prevents riverine nesting initiation. Extreme weather has been the largest cause of mortality (Urbanic 2003; Watterson 2009; Nupp & Petrick 2011, 2012; Nupp 2013).

These sources of mortality are similar to those found in other river systems and other habitats. Predation, flooding, and weather dominate mortality on the Platte River in Nebraska (Kirsch 1996; Jenniges and Plettner 2008), the Red River in Louisiana (Hervey 2004), and the lower Mississippi River (Dugger et al. 2000). The limited habitat and small ILT population within the Arkansas segment of MKARNS compared to other river systems results in any given mortality event affecting a larger portion of the ILT present. The minimum sustainable productivity suggested by Kirsch and Sidle (1999) of 0.5 fledglings per breeding pair (henceforth FBR) is less likely when a single colony failure may reduce productivity within MKARNS that year by as much as 0.22 fledglings per

pair, as happened in 2013 (Nupp and Ross 2014).

The above-mentioned FBR of 0.5 (Kirsch and Sidle 1999) is widely cited as the replacement breeding rate for ILT. However, this number is usually claimed to originate from Kirsch (1996), but she does not explicitly mention this number anywhere in the discussion of replacement rates. It seems likely that this number instead comes from Kirsch's (1992) dissertation on ILT habitat and productivity on the Platte River in Nebraska. The deterministic model from which this FBR replacement rate is derived conservatively assumes an adult survival rate of 0.85 annually. This was based on previous least tern banding studies in other habitats ranging from 0.83 to 0.89. The high annual survival of adults and the relatively long lifespan of terns suggested that single-year measurements of FBR were not necessarily appropriate. Rather, we should consider rolling averages of FBR over several years. Lott et al. (2013) suggested approximately 6 years as the median breeding lifespan of ILT. This would be a reasonable length for a rolling average to determine trends in local ILT productivity, by taking into account the natural boom and bust cycle of ILT breeding on ephemeral habitats such as riverine sandbars.

My objectives for ILT monitoring for the U.S. Fish and Wildlife Service and the Army Corps of Engineers were: first, to get robust estimates of the numbers of adults and fledging rates throughout MKARNS within Arkansas in order to help the US Army Corps of Engineers fulfill the requirements of the 2005 USFWS biological opinion; second, to collect habitat data about individual nests including height, colony area, and nest substrate; and third, to be able to compare these counts to counts from previous years, and discover any trends in the causes of mortality.

STUDY AREA

My study took place along roughly 270 river miles of the Arkansas River within the McClellan-Kerr Arkansas River Navigation System (MKARNS), from Wilbur D. Mills Dam (Dam 2) near Pendleton, Arkansas, to James W. Trimble Lock and Dam 13 near Fort Smith, Arkansas (Figure 1.1). The lower 30 river miles of MKARNS, consisting of the Arkansas Post Canal and the lower White River to its mouth at the Mississippi River, were excluded from my study. This was because there were no sandbars in this narrow, highly-regulated stretch of the navigation system.

The Arkansas River within MKARNS has been completely impounded; extensive diking and bank armor maintain its relatively straight flow. Dams every 15-25 river miles along its length regulate flow to maintain the navigation channel at a depth of at least 3 m. Sandbars were distributed unevenly throughout the river, but the barest sandbars were associated with dike fields. Sandbars suitable for tern nesting were not present during the years of my study within Pools 4 or 6 (roughly corresponding to the river as it passes Pine Bluff and Little Rock, respectively), and we saw no terns nesting in these sections. Terns were also commonly seen nesting on gravel-covered rooftops near the river. A previous study (Watterson 2009) searched rooftops in the study area, and identified a number of potential rooftop colony sites in Clarksville, Conway, North Little Rock, and Little Rock, which we continued to monitor during the two years of my study.

METHODS

For initial surveys to determine tern nesting colony locations at the beginning of each season, I first used Google Earth to identify suitable sandbars (i.e. sandbars with bare sand or gravel present) throughout the study area. During the last week of May or

the first week of June (weather allowing), at least one technician and myself used a 4.9 m motorboat and binoculars to check each of these possible colony locations for terns in nesting posture. All locations where terns were seen in a nesting posture were assigned a name based on approximate river mile (e.g. RM 283). We also checked rooftops where terns were seen in previous years.

After this initial extensive survey, we performed intensive nest counts at all identified colony locations. Each colony was checked weekly, while adults, eggs, and chicks were counted. at least one technician and myself searched for ILT in the characteristic brooding posture, flushed them from their nests, and counted the number of eggs present. We used a Trimble GeoExplorer 6000 GeoXT GPS unit to map nests, then collected and averaged over 45 locations for each nest point. I also used post-hoc differential correction to increase the accuracy of each nest location and height. All surveys were done as quickly as possible to limit impacts of heat and decrease the chance of nest abandonment. No individual tern was flushed from their nest for longer than 5 consecutive minutes. For the same reason, all surveying took place before 1100 CDT when possible. However, due to long travel times to some sites, and the need to survey multiple colonies on a single day, some sites were sometimes surveyed as late as 1300 CDT to avoid repeating long trips. Extra precautions were taken when chicks were present, because chicks are less hardy in temperature extremes than eggs (Dawson et al. 1972, Bennett and Dawson 1979). We attempted to limit disturbance to ≤ 3 minutes, after which time we exited the colony and sat down for approximately 5 minutes to permit adults to thermoregulate eggs and chicks. Nisbet (2000) suggested that the intensity of disturbance caused by researchers will produce little or no negative effect on breeding

success. Indeed, throughout my study, I observed only one possible case of chick or egg death attributable to our monitoring.

In each survey, we checked known nest locations for hatching, predation, or abandonment, and we recorded new nest locations in our GPS unit. Because ILT eggs are camouflaged such that they are almost indistinguishable from the coarse to medium gravel common on banks and sandbars, our methods differed based on the primary substrate in each colony. In colony sites where terns nested primarily on sand or very fine gravel (less than 1 cm average diameter), we walked transects across each colony site at approximately 5 m intervals. In colony sites on small sandbars (less than 1 acre) where most nests were on gravel, we walked transects at approximately 2 m intervals. On large sandbars where most nests were on gravel, we started outside of the colony boundary. Each observer picked the closest 2-3 adults in nesting posture and identified landmarks for each. When all observers were ready, the colony was entered, adults flushed, and each observer moved to the nests they had identified and either took GPS data (if holding the GPS unit) or placed a marker, generally a golf ball, near the nest. This method allowed us to find all or most of the nests on a large sandbar, while limiting the total time of disturbance for each nest. This search method is also well-suited to very large area sandbars, such as the sandbar at RM 35, where even when walking 5 m transects, we may have taken more than an hour to completely search the colony site.

We performed an extensive river survey, counting all adults seen regardless of presence at a colony site, as well as continuing intensive nest surveys, the third week after most colonies had initialized – generally occurring between the third week in June and the first week in July. We took our total counts for nests and eggs from this week of

surveys, because the maximum total nest count during this time should be an accurate, if conservative, estimate of the total breeding pairs present within the study area. This allowed us to make an estimate of the number of adult terns, breeding pairs, nests, and eggs present before hatching and renesting, which is directly comparable between years. However, this is almost certainly a conservative estimate of the total adults on the river, because it does not include all terns fishing in backwaters and lakes near the river outside of our view.

Because ILT chicks leave the nest after approximately three days, and because we could not survey more often than weekly at most, we could not track individual nest fates. However, I still wanted to obtain accurate life stage data. For this reason, it was vital that all eggs and all feathered chicks be accurately counted (Martínez-Abraín et al. 2003). We searched for chicks during transects, paying particular attention to the water's edge and vegetation on the other side of the sandbar from our initial landing site. Chicks were placed into one of four categories: 1) Downy chicks in nest: chicks believed to be \leq 2 days old, found in nest scrapes; 2) Mobile downy chicks: chicks believed to be 3-9 days old, found under cover or away from nest scrapes; 3) Feathered chicks: chicks believed to be 10-17 days old, with developing primary flight feathers; 4) Fledglings: chicks 18 days and older, with developed primary flight feathers. Chicks observed flying were automatically placed in the "fledglings" category.

While we did not have sufficient granularity of surveys to reliably track individual nest fates, we could generally ascertain causes for colony abandonment. For purposes of survival rate estimates, I defined the date of abandonment as halfway between the last date that adults or chicks were confirmed to be present on or near (< 250 m) the colony

site and the date when there were no live birds present. I designated colonies “completed,” if fledglings were sighted on the colony, or if feathered chicks > 12 days old were seen the week before abandonment of the colony site. I tried to attribute abandonments of unsuccessful colonies (colony failures) to one of a few causes: flooding, predation, and human disturbance. I counted colonies as “flooded” if signs of flooding were present such as wet sand, rippled sand, or a new or moved debris line. I counted colonies as “failed due to predation” if in conjunction with predator tracks, eggs had disappeared or egg fragments were discovered, or if eggs were found crushed, pierced, or otherwise broken. This is a typical predation pattern of rodents and predatory birds such as crows. I counted colonies as “human disturbed,” if there were human footprints not belonging to researchers or ATV tracks throughout the site; discarded fireworks on the shore; dog tracks associated with other signs of human presence such as beer cans and boat scrapes on the shore; or other signs of likely disturbance such as fresh shotgun shells or clay pigeons. Colony failures with no obvious cause were categorized as “other.”

Yearly Differences

Because of differences in weather patterns and equipment availability between years, our collection procedures were modified slightly from this general plan in both 2013 and 2014. In 2013, a heavy rain event from 30 May – 1 June submerged almost all colony sites and delayed survey activities until 17 June, when river levels returned to safely-navigable flows. We treated this as the beginning of a new season, repeating the initial survey to look for active colony sites, and delaying the timing of our full-river extensive survey by three weeks to coincide with the presumed maximum number of eggs. This season also ended with a high-water event during the second week of August,

so our surveys were slightly less certain regarding nest fate than initially planned. In 2014, we had less access to the GPS unit than initially planned due to sharing with another project. As a result, GPS locations were taken only once every two to three weeks. However, we do not expect this to negatively affect either our nest counts or any colony site data derived from collected GPS data.

In 2014, we were unable to find some, and possibly most, of the eggs in the colony at RM 152. RM 152 is located at the edge of a cow pasture that forms a steep, rocky slope down to the river. In 2013, most of the nests at this colony were on this slope and could be found using the method above for colonies on gravel substrate. In 2014, however, most nests were located higher in the vegetation of the cow pasture. We were unable to find many of these nests, partly because the adults in nesting posture were obscured by vegetation, and partly because I did not wish to trespass on actively-farmed land. We were still able to accurately count adults and fledglings, and estimate an FBR using the more error-prone adult numbers, which roughly matched the FBR for this colony from previous years.

Analyses

Raw numbers for comparison to prior years include the colony initiation dates and the numbers of adults, eggs, and nests present in colonies during the third week after initiation. Following the method of Kirsch (1996), colony initiation dates were backdated to the earliest of either 21 days from the date the first downy chick was found in a nest, or 5 days prior to the first observation of a full (3 egg) clutch. For some colonies, these methods gave nonsensical results, indicating that some early nesting was missed due to weather or small craft advisories during the 2013 nesting season. For these colonies,

colony initiation was backdated 42 days from the date the first feathered chick was observed. Forty-two days is the average incubation time plus the average fledging time (Kirsch 1996).

I also calculated the fledglings per breeding pair ratio (FBR), a standard measure of productivity in birds and the fledglings per egg ratio (FER), a measure of productivity that is more sensitive to egg and chick mortality rates (Verhulst et al. 1995; Pearce-Higgins and Yalden 2003). The FBR was calculated as the number of fledglings divided by the number of nests present the week before hatching begins, generally the third week of June except in colonies that represent renesting attempts. The FER was calculated as the total number of fledglings divided by the total number of eggs seen the week before hatching begins plus the number of eggs seen four weeks later, assumed to represent renesting attempts in the same sandbar. I calculated FER because it gives some insight into the mortality and abandonment rate of nests (Verhulst et al. 1995).

RESULTS

2013

During the 2013 season, we monitored 15 colonies on the Arkansas River from Lock and Dam 13 to just below Wilbur D. Mills Dam. In addition, 3 colonies were monitored on rooftops near the Arkansas River. The initial river survey suggested there would be 17 riverine colonies; however, the high-water event of 30 May – 14 June caused the abandonment of two of the initial sites. We counted 548 adult ILT during the extensive river survey from 24 June to 2 July. Of 18 active colonies (riverine + rooftop), 15 produced at least one fledgling. Eighty-one fledglings were produced among all colonies, with one third of those (27 fledglings) produced by one colony at RM 179. The

overall FBR was 0.273, with 81 fledglings produced in 297 nests (Table 1.1). The colonies with the highest FBR were RM 179 (1.08) and RM 152 (0.714). The colonies that produced the most fledglings were RM 179 (27) and RM 35 (9).

Most colonies were initiated from 17 June to 26 June, after the water receded from the 30 May – 1 June rain event. The exceptions were the rooftop colonies, all initiated around 29 May, RM 179, initiated 5 June, and RM 152 and RM 35, both initiated around 12 June. RM 179 and RM 152 were the two riverine colonies with the highest FBR this year, indicating a possible link between initiation date and fledging success. Three of the colonies, founded from 1 July to 13 July, probably represented renesting attempts, and only one of these three produced any fledglings (RM 283, which produced one fledgling).

The impact of flooding in 2013 is difficult to estimate due to our inability to survey during high-water events. However, we know that flooding had a major negative impact on many colonies this season. Six of the 15 colonies experienced significant flooding during the season, causing total colony failures in 3 of these colonies, and low success in the remaining 3. The colony at RM 35 was never flooded, but experienced high levels of predation. When it was first intensively surveyed, on July 2, there were 68 nests present. By 18 July, only 15 nests and 12 mobile chicks remained. Coyote, fox, and heron tracks were observed in the sand, in some cases leading directly from nest to nest.

We found 40 dead chicks, which 33 of these were found in rooftop colonies and 7 in riverine colonies. Based on their posture and location, the cause of death for all of these chicks appeared to be heat stress in both the riverine colonies and rooftop colonies.

Human disturbance probably caused at least some mortality at RM 276, 246, and

58, all of which had evidence of human disturbance within colony boundaries. Shattered clay pigeons at 276 suggested that shotgun blasts may have caused this colony abandonment, although there was also significant flooding in the same week. We found all-terrain vehicle (ATV) tracks running through the middle of the colony area at RM 246. Finally, we encountered people with dogs on RM 58 near the end of the nesting season.

2014

We found 16 active colonies on the Arkansas River from Lock and Dam 13 to Wilbur D. Mills Dam during the 2014 nesting season. In addition, we discovered 4 colonies on rooftops near the Arkansas River. We counted 434 adult ILT during the extensive survey from 28 June to 3 July. Of 20 total active colonies, 19 were monitored for reproductive output; 13 of these produced at least one fledgling. As mentioned previously, we were unable to secure permission to monitor the Maybelline rooftop for reproductive counts. We observed 84 fledglings produced, with 34.5% of those (29 fledglings) produced by one riverine colony at RM 179 and 17.8% (15 fledglings) produced at the Belk rooftop colony. The overall FBR was 0.297, with 84 fledglings produced in 276 nests. The colony with the highest fledging rate was RM 179 (1.16). The colonies that produced the most total fledglings were RM 179 (29) and Belk rooftop (15) (Table 1.2). The Belk rooftop numbers are likely to be a very conservative estimate. Fledglings immediately left the nesting site itself, but were seen resting on adjacent roofs we were unable to access. As a result, our counts of fledglings at Belk were necessarily estimates based on fledglings visible on adjacent rooftops between air conditioning units and other rooftop fixtures.

Overall, 68% of colonies (13 of 19) were successful this season, producing at least one fledgling. However, only 4 of these had fledging rates above the 0.5 fledglings/pair fertility rate that Kirsch (1996) estimated was necessary to maintain a stable population size. The overall fledging rate in the Arkansas stretch of MKARNS was well below this mark, at 0.39 fledglings/pair and 0.29 fledglings/nest.

In riverine colonies, the primary cause of chick and egg mortality in 2014 was predation and human disturbance. Human disturbance was likely responsible for the failure of three colonies and low productivity at two more. The colonies at RM 189 and 150 were found abandoned the week after July 4th weekend, with evidence of fireworks near the colony sites. The most notable human disturbance this season occurred on RM 100 near Wrightsville, AR, where at least 10 adult terns on the south end of the island were found dead on two separate occasions. Fresh shotgun shells, a single pistol-caliber case, and evidence of explosive (tannerite) targets were also found on the sandbar, along with dog tracks accompanying human tracks through the southern half of the colony. The colony was abandoned after the second disturbance. Human activity combined with pet dogs likely resulted in the colony at RM 58 declining from high of 35 nests at the start of the season to 10 nests by the end of June. Finally, as in 2013, someone drove an all-terrain vehicle (ATV) throughout the colony at RM 246 midway through the season, which likely resulted in some mortality.

On rooftops, productivity in 2014 was better than in 2013. We were unable to determine the cause of colony failure at Snap-On, where downy chicks expected to fledge were absent on our last visit. We found 12 dead chicks; 6 in rooftop colonies and 6 in riverine colonies. As in 2013, the cause of death for these chicks appeared to be heat

stress in both the riverine and rooftop colonies.

There were two waves of colony initiations. The rooftop colonies and RM 245, 189, 179, and 150 all initiated early in the season from 26 May to June 7. A minor flood event early in June probably prevented the majority of colonies from initiating until 13 June to 20 June. One colony, RM 39, founded 30 June was likely a renesting attempt by ILT at RM 35 that abandoned their nests due to predation.

Overall

Numbers of adults were comparable with levels seen since 2009 in both years (Figure 1.2). We cannot draw a strong conclusion about an overall population trend, given the variance over only six years, but to the naked eye it appears relatively stable at 500 ± 75 ($r^2 = 0.009$). Between 2010 and 2014, ILT utilized an average of 19 sites each year. Of these, 10 sites were utilized in all years, and overall, only 9 of 31 sites were used in only one year. On average, 79% of colony sites occupied each year were those occupied in the previous year. Sites used only once were all either low sandbars that were not exposed during colony initiation periods in following years, or freshly exposed sandbars that experienced rapid succession.

There was no significant difference between the years of our study in terms of FBR, with a mean fledging rate per colony of 0.34 ± 0.077 in 2013 and $0.25 \pm .078$ ($t = 0.763$, $df = 31.92$, $p = 0.45$). Mean colony initiation date in 2013 was June 18, and in 2014 was June 13. There was no significant relationship between initiation date and FBR in 2013 ($t = -1.95$, $df = 14$, $p = 0.072$), 2014 ($t = -0.398$, $df = 16$, $p = 0.70$), nor in the years combined ($t = -1.28$, $df = 32$, $p = 0.21$). However, the fledging rate of each colony

in 2014 was predicted by the fledging rate of the same colony in 2013 ($R^2 = 0.511$, $F_{1,14} = 14.64$, $p = 0.0019$).

DISCUSSION

Trends

Both years in this study were roughly average, compared to the prior three years, in terms of adults and fledglings sighted. Both years had a lower fledging rate than 2012, but a higher fledging rate than 2010. Both years were likely negatively affected by high water events at the beginning of the season, which delayed the start of nesting for most colonies. The FBR in the Arkansas River Valley was low compared to FBR in other populations during the two years of my study at 0.297. This is below the widely-cited replacement rate of 0.5, according to Kirsch and Sidle (1999).

The ILT population data since 2009 suggested that the population is stable for now. Apparent counts trended upwards from 2001; however, this is probably due to increasing survey effort and geographic scope. As noted in the introduction to this chapter, full-river surveys were not performed until 2006. 2007 and 2008 saw high water and flooding, resulting in incomplete counts. Since 2009, surveys have counted between 400 and 550 adults, and no trend is evident. Continuing surveys are necessary to draw any strong conclusions about population trends under the current management regime (Figure 1.2).

There is an apparent disconnect between low FBR and a stable population in the Arkansas River Valley. One possible explanation for this disconnect is life history. ILT have always nested in ephemeral habitats. They have long lifespans and high post-recruitment survival, averaging 0.88 in tagged California least terns in one two-year study

(Massey et al. 1992) and by no published estimate less than 0.8 (reviewed in Schweitzer and Leslie 2000). This high survival rate means that one or two highly successful breeding seasons every decade may be sufficient to maintain populations, even when most years are well below the expected replacement rate (Lott et al. 2013). Another possible explanation for this disconnect is immigration from other populations, particularly the large and consistently growing population on the lower Mississippi River (Lott et al. 2013). Banding-recapture studies are required to determine the effect of immigration on the population in the Arkansas River Valley. It is also possible that our study underestimated FBR in the study area, or that the widely-cited Kirsch (1996) estimate of the replacement rate was too conservative. Additionally, it is very likely that our fledgling survey method underestimated actual fledging rates (Bailey and Servello 2008), although this may be offset somewhat by low first-year fledgling survival (Keedwell 2003).

The colony at RM 179 was the most successful riverine colony in both years of my study. This may be due to the physical characteristics of this sandbar complex which may minimize mortality due to predation and flooding. Sandbars in this complex are elevated >2.5 m above low water level, which minimized flooding mortality in chicks. This complex is also far from the shore and from trees, minimizing mortality due to predation. Second, a local businessman who owns a private boat ramp and marina nearby and discourages people from landing on the islands when terns are present probably reduced human disturbance on this island. Other consistently successful riverine colonies such as RM 101 and RM 171 are similarly elevated islands, which were far from shore and trees. However, these colonies suffered higher levels of human disturbance than RM

179, and were thus less productive.

The Belk store in Conway, AR was the site of the most successful rooftop colony from 2012-2014. The majority of mortality on rooftops was due to weather, and this rooftop had retaining walls rather than gutters. This likely helped to prevent chick deaths due to sheet flooding and high winds. In addition, like other buildings, there were air conditioner units and vents on the rooftop, which provided shade. Unlike other buildings, condensation pipes for air conditioner units on Belk leaked directly onto the rooftop, which provided a constant source of cool water. This may have helped with thermoregulation. Adults were observed wetting breast feathers in this water before flying back to their nests.

Causes of Mortality

Previous monitoring has shown that flooding, heat, predation, and human disturbance were the largest sources of nest and chick mortality (Nupp and Petrick 2011, 2012; Nupp 2013). Flooding has historically been the source of most mortality, with predation and heat stress causing extensive mortality on connected sandbars and rooftops, respectively. In the years of our study, flooding was responsible for considerable but unquantifiable mortality in 2013. There was little in 2014 except for the very low islands at RM 253 and 39. The easiest management solution to flooding is increasing the height of sandbars through deposition of dredge spoil.

Mortality due to human disturbance was more important in both years of this study than in prior years (Nupp and Petrick 2011, 2012; Nupp 2013). The colonies at RM 246 and 58 experienced serious human disturbance in both years. The 2014 season appeared to have seen the worst effects of human disturbance since at least 2010. Human

disturbance was evident in 8 of the 16 riverine colonies monitored, and was responsible for the failure of two of the historically highest-producing colonies. It was unclear what caused this apparent rise in human disturbance.

Human disturbance is a serious problem in terns and in other shorebirds worldwide (McGowan and Simons 2006). Whatever the cause, simple fixes are available to limit human impact. First, sign posts on sandbars where terns are currently nesting, erected as early as possible in the season, should cut down dramatically on accidental human disturbance. For intentional human disturbance, the sign posts must be combined with enforcement of existing laws regarding disturbing endangered species and migratory birds by Arkansas Game and Fish Commission (AGFC). These two strategies together will not completely solve the problem, but they should have a positive impact over time.

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APPENDIX 1A: TABLES

Table 1.1: 2013 Interior least tern counts and nest monitoring in the Arkansas River Valley, Arkansas, during the intensive river survey from 24 June – 2 July. RM 103 and Lower Arkansas -5 were both resting sites that did not have active nesting colonies present.

Colony Location	Initiation Date	Nests	Eggs	Fledglings	Adults (late June-early July)	Fledging Rate (FBR)
283	1 July	2	5	1	0	0.5
276	19 June	8	17	0	20	0
275	17 June	25	55	1	35	0.04
246	17 June	5	10	1	5	0.2
244	3 July	3	6	0	11	0
189	19 June	9	22	3	6	0.33
179	5 June	25	47	27	60	1.08
171	25 June	12	22	5	20	0.42
152	12 June	7	18	5	35	0.71
146	20 June	4	6	2	18	0.5
103	N/A	0	0	0	4	N/A
100	22 June	27	62	4	45	0.15
58	26 June	19	46	8	22	0.42
39	13 July	28	48	0	16	0
35	13 June	68	156	9	137	0.13
Lower Ark. -1 mi.	26 June	9	18	3	20	0.33
Lower Ark. -5 mi.	N/A	0	0	0	16	N/A
Maybelline	29 May	18	37	8	34	0.44
LRAFB	29 May	6	12	1	6	0.17
Belk	29 May	22	47	3	38	0.14
Total		297	634	81	548	0.273

Table 1.2: 2014 Interior least tern counts and nest monitoring in the Arkansas River Valley, Arkansas, during the intensive river survey from 24 June – 2 July.

Colony Location	Initiation Date	Nests	Eggs	Fledglings	Adults (late June-early July)	Fledging Rate (FBR)
283	6/13/2014	17	44	2	38	0.118
276	6/15/2014	7	12	0	0	0
275	6/17/2014	21	45	9	30	0.429
246	6/3/2014	11	27	2	19	0.18
244	6/20/2014	4	9	1	8	0.25
189	6/3/2014	21	53	0	27	0
179	5/30/2014	25	58	29	37	1.16
171	6/18/2014	13	25	6	40	0.462
152	6/16/2014	3*	7*	8	11	0.8*
150	6/7/2014	8	14	0	17	0
146	6/16/2014	12	30	8	19	0.667
102	6/13/2014	4	9	0	0	0
100	6/16/2014	29	62	0	45	0
58	6/10/2014	12	20	1	20	0.0833
39	6/30/2014	30	56	0	21	0
35	6/16/2014	29	49	2	55	0.0690
Snap-on	6/2/2014	3	6	0	5	0
Maybelline	Unknown				4	
LRAFB	5/28/2014	5	12	1	8	0.2
Belk	5/26/2014	22	34	15	30	0.682
Total		276	572	84	434	0.297

*RM 152 used a different method for calculating the fledging rate; see Methods subsection “Yearly Differences” for explanation.

APPENDIX 1B: FIGURES

Figure 1.1: Interior Least Tern Colonies within the Arkansas River Valley, Arkansas, 2013-2014.

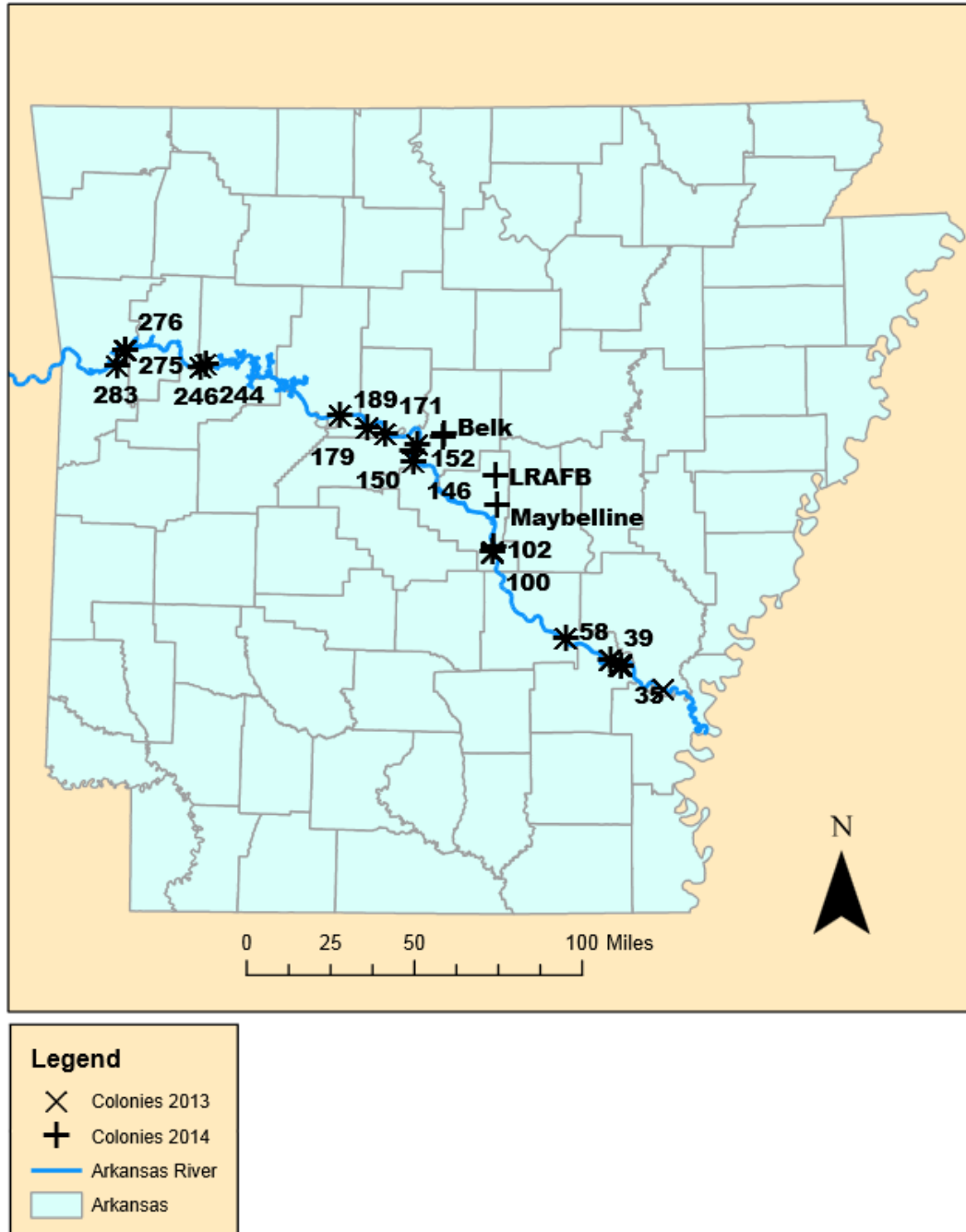
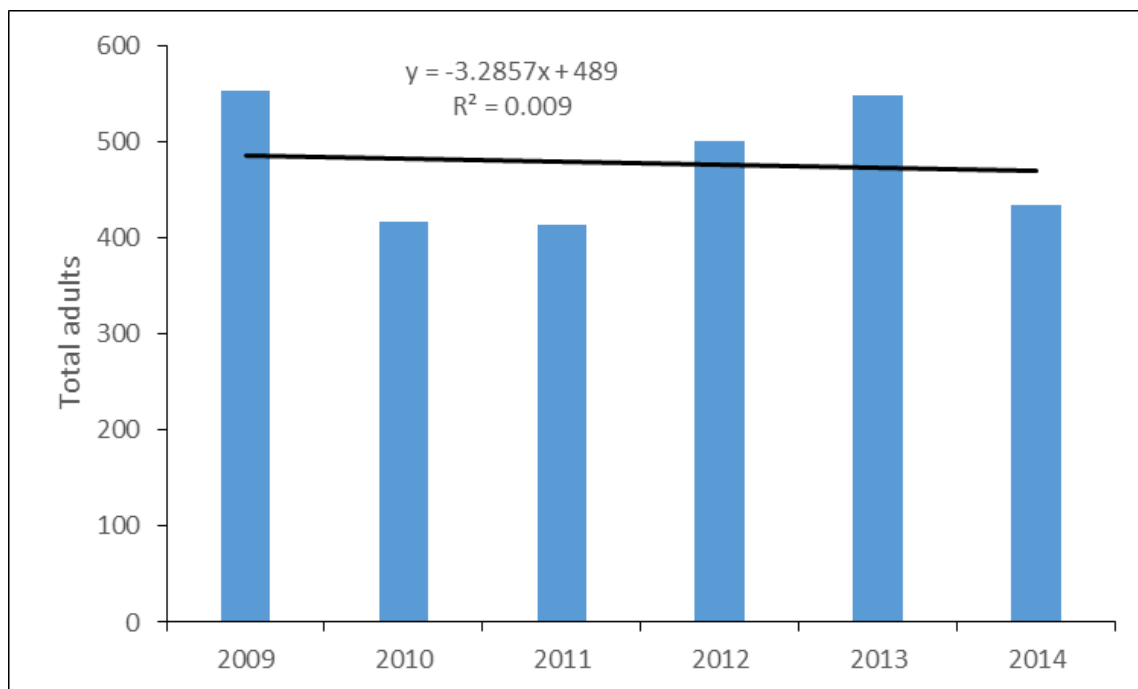


Figure 1.2: Interior Least Tern Population in Study Area, 2009-2014.



CHAPTER 2

EFFECTS OF HABITAT CHARACTERISTICS ON INTERIOR LEAST TERN REPRODUCTION IN A CHANNELIZED RIVER

Interior least terns are endangered due to habitat loss (USFWS 1985). Banding studies in California and Atlantic least tern populations have shown site fidelity as high as 89% in stable beach colonies in California and 85% in New Jersey (Burger 1984, Atwood and Massey 1988). Kirsch (1996) suggested that high colony stability was the result of limited habitat availability. California and Atlantic least terns in highly-developed areas nested in the same sites year-after-year because of limited undisturbed, undeveloped sand, rather than because nests at these colony sites consistently produced offspring. When nesting on rivers that have large numbers of ephemeral sandbars, such as the Platte River or lower Mississippi River, ILT displayed relatively low site fidelity, as little as 40% (Renken and Smith 1995). As established in Chapter 1, ILT on the Arkansas River Valley followed the pattern of California least terns rather than other ILT populations, with 79% site fidelity year-to-year. This high site fidelity may lead to terns nesting in low-quality habitat, perhaps even repeatedly nesting on sandbars that are ecological traps, while ignoring higher-quality sites available further upstream (Matthiopolous et al. 2005)

Ecological traps occur when a population sink, in which organisms do not produce enough offspring to replace adult mortality, is located in a habitat that is more attractive than more productive habitats. These ecological traps can negatively affect the long-term viability of populations, leading to population declines and extinction. Schlaepfer et al. (2002) suggested that ecological traps were more likely in human-

disturbed habitats because cues that were previously useful for determining habitat quality were no longer correlated to high-quality habitat. For ILT on the heavily channelized and extensively impounded Arkansas River, these decoupled cues might include lack of vegetation, large areas of bare sand, and adequate height above waterline. The focus in research on presence/absence surveys and the possibility of terns nesting in ecological traps together suggested that management guidelines ignored fledging success and temporal variation may not be useful on the Arkansas River, and may be actively harmful, as per Marcus et al. (2007) at gravel mines on the Platte River and Ward et al. (2011) on Missouri River sandbars. In these two studies, conspecific attraction was used to guide ILT colony establishment. In the Platte River study, conspecific attraction in combination with mylar streamers as a deterrent directed terns away from active gravel mining locations. Although attractive to terns, these locations were vulnerable to intermittent disturbance by heavy machinery (Marcus et al. 2007). Presence-only surveys would have likely judged colonies in active mining sites as successful because of the presence of large numbers of nests. In the Mississippi River study, conspecific attraction was used to ensure birds would nest on artificial sandbars made of deck barges covered in sand, which led to initial excellent fledging results. However, during the third year of the study, extremely high predation caused a total colony failure (Ward et al. 2011).

New habitat for least terns may be created using methods such as creation of new beach habitat *de novo* (Erwin and Beck 2007), anchoring a barge midstream and covering it with sand (Ward et al. 2011), regulation of river flow (Wiley and Lott 2012), or mid-stream/offshore deposition of dredge spoil (Spear et al. 2007, Duberstein and Downs 2008). Several authors agreed that interior least terns responded positively to low summer

flows (Bacon and Rotella 1998; Dugger et al. 2002; Lott and Wiley 2012). Lott and Wiley (2012) additionally suggested that terns on the Arkansas River responded positively to large flood events in the preceding years due to concomitant habitat revitalization. Tibbs and Galat (1998) showed that high spring flows and low summer flows were positively correlated with prey availability, and earlier tern nesting initiation dates on the Mississippi River. Although, they did not attempt to tie this to fledging success, it further supported the idea that hydrology was important to ILT nesting, and had both direct (flooding and bare sand availability) and indirect (forage availability and protection from predators) effects.

Unfortunately, while high off-season flow rates appear to be desirable, weather patterns are stochastic and therefore unpredictable. Historically, substantial rainfall produced the high flow events that were necessary for creating and renewing least tern habitat. A potential management strategy for least tern habitat on impounded rivers might be to simulate natural flow regimes via withholding water and then releasing it at high flows during non-nesting months. However, MKARNS was designed as a “run of the river” impoundment system. There were no available storage impoundments for the Arkansas stretch of the Arkansas River. Dams could in theory be closed to build up backwater for a flood pulse, this action would result in extensive flooding of agricultural and other private lands, causing large economic losses for stakeholders along the river (Mike Biggs, USACE, personal communication). Additionally, the need to store water for maintaining minimum depth for summer barge navigation posed another restriction on the possibility of using dam outflow to produce seasonal high flows for habitat renewal. Much of what would otherwise be renewal of sandbar habitat takes place below

the navigation waterline, which would be exposed if water levels were allowed to drop to those of a more natural flow regime.

The creation of a new habitat directly via vegetation removal and reshaping of shorelines was not an appealing option for most ILT habitat. Terrestrial predators such as coyotes are as common in mixed agricultural/forested land, which is most common to rivers and lakes in the range of ILT, as on beaches of the Atlantic coast where anti-predator fencing has been widely used (Rimmer and Deblinger 1990, Spear et al. 2007). This strategy would additionally require building anti-predator fencing to prevent the creation of new population sinks for ILT. Another problem with this strategy is that limiting stream bank erosion is one of the greatest engineering challenges facing managers of navigable rivers. The removal of bank vegetation would accelerate this process to the detriment of landowners, and USACE's core responsibility of navigation. Finally, most land along the Arkansas River is privately owned, and it may be difficult to obtain landowners' permission to bulldoze acres of their land, particularly in light of the aforementioned erosion this would cause.

Creating artificial islands, via either decommissioned barges or dredge spoil, is a promising answer because it should provide an efficient use of resources. Artificial islands would likely require maintenance every 2-3 years, primarily to keep sandbars in an early successional state. Freshly-deposited dredge spoil will experience slower succession than restored habitat due to an initial lack of viable seeds (Wiley and Lott 2012). With proper deposition placement, erosion should not be a significant factor until after the first year. Obviously, rates of erosion and succession on artificial sandbars, as in natural sandbars, depend upon stochastic environmental conditions such as cottonwood

irruptions, rain, river flows, and even whether or not geese roost on the sandbar.

Maintenance could take the form of additional spoil deposition, if there is dredging nearby, or herbicide application if not. As with any management strategy, however, artificial island creation is not expected to be a maintenance-free option.

Proper sandbar design has been found to be crucial to the artificial island strategy. However, quantitative support for specific management recommendations is sparse. Studies on least terns tying habitat characteristics to nesting or fledging success do exist, and are useful for suggesting data to consider in my analyses. However, these studies have not examined impounded, channelized river systems like MKARNS. Kirsch (1996) attempted to tie fledging success to habitat characteristics on the Platte River system in Nebraska. She found that terns preferred sandbars at locations with a wide river channel and large areas of open sand, but she found that colonization patterns on the Platte River were not consistent enough to allow reliable comparison of habitat between used and unused sandbars. Researchers at the U.S. Geological Survey Northern Prairie Wildlife Research Center (Duberstein and Downs 2008, Sherfy et al. 2012, Stucker et al. 2013) have extensively studied fledging success on both artificial and natural sandbars in relation to habitat measures. Their studies have included vegetation, substrate, debris around nest sites, and forage availability. They showed that artificial sandbars have a generally higher fledging rate than comparable natural sandbars. They tend to have characteristics, such as coarser substrate, more debris, and less vegetation, that are generally found in sandbars that are scoured by natural flow regimes. Gochfeld (1983) used substrate, slope, vegetation, width, and human disturbance levels to classify the quality of Atlantic least tern colony sites, although he did not attempt to tie this to

fledging success. Smith and Renkin (1993) tied height above water to tern nesting success, with sandbars exposed for >100 days during the breeding season performing better.

We can also look at closely-related species, such as the little tern and Peruvian tern (*S. lorata*), or species with similar habitat requirements, such as various plovers (genus *Charadrius*), to identify other variables that may also impact least tern use or success. Eason et al. (2012) looked at *S. albifrons* on Egypt's Sinai coast, and found that island shape, size, and isolation had an effect on little tern site selection. Paiva et al. (2008) showed a preference in little terns for sites with access to shallow-water estuarial channels and lagoons, presumably because of higher food availability in these habitats. Faanes (1983) looked at both macro- and micro-scale habitat usage in both ILT and piping plovers (*Charadrius melodus*), including distance to nearest riverbank, sandbar area, vegetation cover, and height of each nest above river stage, but he did not compare these measures to fledging success. Instead, he compared the two species, finding that on average, terns prefer nesting sites that are higher above river stage than *C. melodus*, but otherwise the two species had largely similar habitat requirements. Piping plover habitat requirements are roughly as well-studied as ILT habitat requirements. Unfortunately, both have the same knowledge gaps. Relatively little of the published research has been done on riverine habitats, and in the case of plovers, none of that research to date includes heavily-managed riverine habitat like MKARNS.

Another concern when managing ILT habitat is the implications of long-term management of the same colony locations. Historically, ILT nested in ephemeral habitats were created by frequent flooding. The controlled nature of most river systems now leads

to taking into consideration the long-term degradation of specific ILT colony locations. Ward et al. (2011) and Lott and Wiley (2012) established that predation risks may accumulate overtime, and succession at both natural and artificially created sandbars could reduce habitat quality over time. To date, little direct management of colony locations for ILT has taken place within MKARNS (USFWS 2005). The Army Corps of Engineers recently begun exploring vegetation removal options for restoration of degraded habitat. This includes some experimentation, but has just begun vegetation control on a scale that should meaningfully increase ILT nesting habitat. Dredge spoil deposition has coincidentally created some good habitats for terns, but sandbar location and design has been primarily dictated by practical considerations.

Predation abatement may take several forms, depending upon the stability of the nest site and the level of predation being experienced. In extreme cases (or with available funding), predators may be trapped or shot, as per Whelchel and Lansford (2006) and Jenniges and Plettner (2008). Whelchel and Lansford (2006) found a pair of greater roadrunners (*Geococcyx californianus*) that preyed upon California least tern chicks at a rate of approximately one per day, which culminated in the shooting of the male roadrunner. Jenniges and Plettner (2008) included predator trapping and removal as part of a multi-faceted program to increase survival of least tern chicks on the Platte River. Less extreme predation has been combated by the provision of overhead cover and anti-predator fencing (Butcher et al. 2007, Spear et al. 2007). Although, overhead cover has not been conclusively shown to provide protection from its intended target of avian predators. It does have the side effect of providing shade, which is used by least tern and other shorebird chicks for thermoregulation (Jenks-Jay 1982, Gochfeld 1983, Butcher et

al. 2007). Anti-predator fencing has been effective in California (Whelchel and Lansford 2006, Elliott et al. 2007), on the Atlantic coast (Rimmer and Deblinger 1990, Spear et al. 2007), and has been used with ILT on the Platte River (Jenniges and Plettner 2008). In coastal areas, stable, consistently-used colony sites allow managers to enclose entire colonies in anti-predator fencing. However, most riverine nesting sites are inundated annually, making permanent fencing problematic. Additionally, while fencing on the Platte River seems to have worked well for Jenniges and Plettner (2008), the Arkansas River has seen early- and late-summer flows high enough to inundate all, but the highest sandbars during the last 4 nesting seasons. This makes replacing washed-away or damaged fencing a concern. Predation control would require high-intensity, and therefore high-cost maintenance, as fences would need to be rebuilt every year at the beginning of the nesting season, and rebuilt or repaired after high water events mid-season.

Some level of vegetation on sandbars provides overhead cover and shade for chicks, potentially increasing survival rates. Sparse vegetation may act as an attractant for terns seeking nesting sites, but dense vegetation can provide cover for small predators, such as raccoons, foxes, and skunks, that prey on tern eggs and chicks (Koenen et al. 1996). Generally, terns will not nest near dense vegetation or trees, or in locations with > 20% ground cover (Gochfeld 1983, Koenen et al. 1996, Busby et al. 1997, Krogh and Schweitzer 1999, Marcus et al. 2007). Trees provide perches for avian predators, which prey on adult terns, and may also prey on chicks. Spear et al. (2007) investigated a coastal habitat in Georgia, and found that mechanical vegetation removal (via disking) improved daily survival rates of nests, and a combination of vegetation removal with anti-predator fencing improved survival even more. Similarly, Koenen et al. (1996) found

that tern nests located close to vegetation had higher losses than those further away. Whelchel and Lansford (2006) suggested that nearby vegetation was providing cover for avian predators, while McMillian (1998) documented great horned owl (*Bubo virginianus*) predation upon chicks. It is possible to remove vegetation from sandbars that were formerly good ILT habitat. However, management to restore previously-suitable sandbars to an early successional state is expensive. Depending upon the stage of succession, it requires significant labor, the use of chemical herbicides, and potentially heavy equipment. Wiley and Lott (2012) suggested maintaining sandbars in an early successional state. This might involve regulating flows to scour sandbars regularly, but also will involve herbicide application and manual labor. Another possible way to reset sandbar succession is the deposition of fresh dredge spoil over an existing sandbar. This method kills existing vegetation via suffocation.

My objective for this research was to identify habitat characteristics that are most closely tied to productivity for ILT within MKARNS. To accomplish this, I collected geophysical data from various sources and tern productivity data collected during each breeding season from 2010 to 2014. I then analyzed this data using regression trees, and other statistical methods in R.

METHODS

Habitat Characteristics

I examined habitat characteristics that have been shown or suggested to explain variation in fledging success and nest-site selection. Included were both landscape-scale habitat features and habitat-scale features that would be important considerations for artificial island design. At the landscape scale, I analyzed river width (Kirsch 1996),

sinuosity (Bacon and Rotella 1998), distance to nearest tree patch (Lott and Wiley 2012), area of shallow water nearby (Paiva et al. 2008), surrounding land use type, and as a proxy for human disturbance, distance to nearest public boat ramp. At the fine or sandbar scale, I used primary substrate (Kirsch 1996), vegetative cover (Gochfeld 1983, Stucker et al. 2013), connectedness to land (Kirsch 1996), and area and height above slack water of colonies (Gochfeld 1983, Mazzocchi and Forys 2005, Eason et al. 2012). See Table 2.1 for a summary of these variables.

I used ArcGIS 10.1 (ESRI 2014) and Google Earth Pro (Google 2015) to analyze various environmental aspects of ILT colony sites. I procured relevant third-party data, including historical lidar data, colony observation data, aerial photographs provided by the US Army Corps of Engineers (USACE), a river centerline shapefile provided by USACE, and colony fledging success and GPS data from previous studies. All landscape-scale measurements were made at a radius of 3 km from each colony, because the majority of tern foraging occurs near colony sites. Foraging radii between 1-4 km are most common, around 70% of foraging occurs within 3.2 km of colony sites (Atwood and Minsky 1983; Jones and Kress 2011). However, see Sherfy et al. (2012) for an exception.

I calculated three different measures of river geometry: shallow water area, river width, and river sinuosity. Total area of shallow water within 3 km of the colony centroid is a proxy for availability of foraging habitat. To calculate it, I found the area of spatial intersections between buffer polygons and polygons of area classified as < 5 ft. deep by USACE river navigation charts, in addition to any ponds or oxbow lakes outside of the river channel, which I manually delineated. River width was measured from bank to bank

at right angles to the river centerline shapefile at the colony centroid location using the most recent available digital orthophoto quarter quadrangle (DOQQ) aerial photographs and the Measure tool in ArcGIS. The river sinuosity index was calculated for a straight line 5 km either side of the sandbar, using the centerline path length over the straight line length. I used the average GPS height of the nests in each colony to determine the height of sandbars (lidar data were not available). I calculated the height of each colony above slack water by subtracting mean nest height from the average river level at zero flow for each pool. For substrate material analysis, I used data from previous studies to put each sandbar into one of three categories: sand/silt, sand/gravel mixture, and gravel/rock. Landuse within 3 km of each colony was categorized by proportion of land occupied by trees or agricultural fields; buffers with area >30% trees were classified as “agricultural land,” while buffers with area >30% trees but <60% were classified as “mixed use land,” and colonies surrounded by >60% trees were classified as “forested land.”

Measures of Colony Productivity

I calculated the fledglings per breeding pair ratio (FBR), a standard measure of productivity in birds; and the fledglings per egg ratio (FER), a measure of productivity that is more sensitive to egg and chick mortality rates (Verhulst et al. 1995; Pearce-Higgins and Yalden 2003). I chose to calculate FBR as the number of fledglings divided by the number of nests present the week before hatching begins, generally the third week of June except in colonies that were renesting. This method intentionally excludes renesting, because renests are not representative of distinct breeding pairs. I am using nests as an easily-quantified surrogate for actual breeding pairs. I calculated FER as the total number of fledglings divided by the total number of eggs seen the week before

hatching begins, plus the number of eggs seen four weeks later, which assumed to represent renesting attempts on the same sandbar. FER was calculated because it gives some insight into the mortality and abandonment rate of nests (Verhulst et al. 1995).

Statistical Analysis

My intent in performing these analyses was exploration of the data, rather than deductive hypotheses testing. “Fishing” for significant results is generally bad statistical practice, but in this case was the intent of my study from the beginning. However, it was still important to avoid “data peeking,” so that I would not unconsciously bias the results of my exploratory analysis. To this end, I first performed the actual model-building, pared down the results, and only then did I compare these results to a correlation matrix to discover broader relationships among predictor variables.

The primary statistical analysis I used for this data set is regression trees, using the “rpart” package (Therneau and Atkinson 2015) in R. Regression trees are a machine-learning analysis technique that produces predictive models via recursive partitioning of data into groups by levels of predictor variables, with each division selected by an information loss criterion called “altered priors.” This is a two-step process. First, to find a splitting point, the algorithm divides the data such that there is the largest possible difference between two groups. The probability of obtaining similarly-sized differences in the response variable, in this context called “risk,” was compared for splits between each level of each predictor variable. This comparison produces the altered priors coefficient, also called the complexity parameter or C_p , which is very similar to the Mallows’ C_p of other model selection techniques. This coefficient was then calculated for each remaining possible split, a new split chosen, and so on. This recursive

partitioning ends when no reduction in risk is possible. The “leaves” at the end of each branch in the tree represent an expected mean value of the response variable for the group that follows that branch’s binary decisions. Though this procedure naturally creates over-fitted models, the second step called “pruning” the tree, the user specifies what change in the cross-validation error was considered significant. This is similar to the more traditional forms of model selection selects models based on differences in AICc and Mallows’ C_p . A general guideline for cross-validation is that if the improvement in the error is less than 0.1, the split is not a significant improvement.

This statistical method, although not traditional, was appropriate for this analysis for several reasons. First, it is exploratory by design. Regression tree analysis, unlike its most commonly used frequentist equivalents, MANOVA and principal components analysis (PCA), specifies neither preexisting hypotheses nor sampling procedures, and thus ideally suited to exploratory analyses (De’ath and Fabricius 2000). Second, regression tree analysis is more intuitively interpretable and applicable to real-world habitat design than its alternatives. Regression tree model outputs for habitat analysis are very similar to a habitat suitability index (HSI), and indeed might be used to statistically validate these indices within a given population. By comparison, PCA results are difficult to interpret: the “principal component” that most parsimoniously predicts a response might include interactions between disparate and unrelated environmental variables. In order to use this model for management, these complex correlations must be sensibly explained. Third, I expected significant multicollinearity, non-normal distributions, and non-linear correlations within this data set. In the absence of valid ecological reasons, the removal of variables for ease of analysis before performing the analysis in frequentist

statistical procedures was not readily justifiable, but their inclusion seriously complicated both interpretation and execution of analyses (Graham 2003). Regression tree analysis is non-parametric and holistic in its approach to multicollinearity, similar to PCA. However, PCA assumes linear correlations and is dependent upon scaling, while regression trees rely upon Bayesian methods that are less sensitive to these issues (De'ath and Fabricius 2000). Finally, regression tree analysis is not negatively affected by broad data sets; that is, data sets which have a relatively large number of variables compared to the sample size (De'ath and Fabricius 2000).

I created regression trees by crossing the full range of independent variables against each of the three dependent variables using the “rpart” function from the “rpart” package in R. After performing the initial analysis on the full data set, I removed year as a predictor variable by pooling results for all years in order to determine which habitat characteristics best predicted productivity across all 5 years of my study. I then averaged habitat characteristics and productivity for colonies across all years, and ran a regression tree analysis on this averaged dataset to limit the effects of repeated measurements in colonies used in multiple years. I also pooled “good years” (2011 and 2012) and “bad years” (2010, 2013, 2014) to determine whether any differences in productivity among the years were attributable to certain habitat characteristics. Finally, I ran pooled-year regression tree with each measure of productivity excluding the colony at RM 179 in order to determine whether or not results were consistent without this high-productivity colony.

I then ran a heterogeneous correlation matrix on all numeric independent variables using the “hetcor” function in the “polycor” R package, which uses linear correlation for

continuous variables and polychoric correlation for categorical variables. This allowed me to build clusters of related variables. Finally, I used the most-correlated predictor variables from each cluster as a stand-in for the whole cluster to determine whether they were valid simplifications. I set out expecting to find at least some predictors in agreement across all three dependent variables, which I would base my management recommendations because they are robust to different measures of tern productivity.

I also wanted to run some standard frequentist analyses on this data set. I first back-converted the categorical variable “landuse” into a pair of numeric variables, proportion of land converted to agricultural use, “agprop,” and proportion of land with forest, “forprop.” I ran a PCA on this and the other continuous independent variables with the “PCA” function in the “FactoMineR” package. I also transformed each dependent variable to make them as close to linear as possible. Fledgling count was cube root transformed, while FBR and FER were square root transformed. I then performed GLMs with those principal components with an eigenvalue ≥ 1 and all categorical variables for each dependent variable. I reduced the variables in this naïve model with the “step” function in R, a stepwise model-selection algorithm utilizing AICc to find the most parsimonious model. I then compared the results of these PCAs and GLMs to those of my regression tree analyses.

RESULTS

How to Read Regression Trees

In order to understand regression tree results, it is important to know how to interpret regression tree graphs. The “trees” are upside down, with “branches” leading to “leaves” at the bottom representing groups of individual results - in this case, productivity

measures in each colony. The branches split at binary decision points presented as inequalities of predictors - in this case, habitat characteristics. The direction of the inequality at each split is chosen such that the leaves at the bottom are organized in order of lowest to highest from left to right. Thus, following the rightmost series of branches will lead to the group of results with the highest average value. The topmost split is the one that explains the most variation in the measure of productivity; lower splits explain less variation and cover smaller subsets of the data. Thus, the higher a habitat variable appears, the more important it may be considered in predicting productivity. Finally, the length of the line for each branch indicates how sure the model is of that split.

Exploratory Model-building

Naïve model-building using regression trees on the full data set for each measure of productivity showed that year was consistently important (Figure 2.1, 2.2, 2.3). 2011 and 2012 were positively associated with higher levels of all measures of productivity. Distance from the closest dam downriver was an important node for both FBR and FER, appearing twice in the FBR model at the second level. Distance from the nearest tree appeared in the models for FER and fledgling count.

Pooling year, the most important single variable in the naïve model-building, resulted in little change for the fledgling count regression tree, but major restructuring for FBR and FER. Width, distance from trees, and height above low water level remained positively related to fledgling count, while sandy substrate was negatively related (Figure 2.4). For FBR, a negative association with distance from downstream dams was promoted as most important. Sinuosity appears, and is positively related to FBR (Figure 2.5). For FER, height above low water level appeared and rose to become the most

important predictor, with a positive relationship. Distance to the nearest tree and nearest boat ramp appeared, positively and negatively related to FER respectively. Distance to the nearest upstream dam appeared with a negative association (Figure 2.6).

Averaging habitat and productivity measures across years resulted in significant changes as compared to the year-pooled trees. The fledgling count tree simplified to sinuosity and distance from downstream dam (Figure 2.7), while the FBR tree changed very little (Figure 2.8) and the FER tree changed to become very similar to FBR (Figure 2.9). Both have distance to downstream dam as their most important predictors with other variables being shuffled around somewhat as compared to the year-pooled trees.

The trees for pooled high-productivity years (2011 and 2012) are similar or identical to those for pooled years for all three measures of productivity; I include only the fledgling count tree here for the sake of brevity (Figure 2.10). The trees for pooled low productivity years (2010, 2013, 2014) are somewhat less similar, but mostly contain the same predictor variables as the trees for all data averaged across years (Figure 2.11; c.f. Figure 2.7).

The trees for pooled year excluding RM 179 were approximately a combination of the trees for years pooled and for all data averaged, with somewhat different ordering (Figure 2.12; c.f. Figure 2.4, Figure 2.7). This suggests that the results from my initial trees are robust to the removal of the outlier colony at RM 179.

Correlation Matrix

Important variables from naïve model building — All the measures of nesting success were highly correlated with each other ($R^2 = 0.63$ to 0.88 ; Figure 2.12). Year was not significantly correlated with any predictor except area, and was not strongly

correlated with any predictor ($R^2 < 0.3$ for all comparisons). This was not surprising, since all habitat-based predictors should have been roughly the same from year-to-year and site fidelity was quite high in this population of terns. Distance from the closest dam upriver was correlated with connectedness ($R^2 = 0.59$) and colony presence in a dike field ($R^2 = 0.48$). Distance from nearest tree was negatively correlated with both connectedness ($R^2 = -0.59$) and colony presence in a dike field ($R^2 = -0.47$). Height above low water level was correlated with shallow water area ($R^2 = 0.57$), shallow water area ($R^2 = 0.53$), and negatively correlated with river width ($R^2 = -0.39$). Substrate was correlated with river width ($R^2 = 0.43$). Land use was correlated with distance to the nearest dam downstream ($R^2 = 0.49$) and boat ramp proximity ($R^2 = 0.45$).

Variable clusters — There was one obvious cluster in the correlation matrix of my data, which I chose to call the dam-dike field cluster. This was because all variables were either associated with sandbars in the dike fields presented just below each dam within MKARNS, or were variables known to have decreased with the impoundment of the river (Arkansas Water Resources Center 1978). The dam-dike field cluster consisted of positive correlations between shallow water area, colony location in a dike field, distance from the nearest dam upstream, connectedness, and height above low water level, but negative correlations between most of these and river width, distance to the nearest tree, and sinuosity. The dam-dike field cluster's best-connected variable, and therefore its most representative variable was distance below an upstream dam. This correlated positively with shallow-water availability, dike fields, and connectedness, and negatively with distance to the nearest tree, sinuosity, and width.

Principal component analysis

Principal component analysis yielded very similar results to regression trees, with the clustering from the correlation matrix in mind. There were four principal components (see Table 2.1), which roughly described four habitats: PC1 was positive when describing habitat characteristics of areas immediately below dams; PC2 was positive when describing habitat characteristic of areas immediately above dams, similar to the habitat of RM 179 colonies; PC3 was positive when describing habitat characteristic of areas in the middle of pools; and PC4 was positive when describing isolated colonies.

A regression performed with these principal components as predictors followed by a stepwise model selection that used AICc supported the results of regression tree analysis. Principal component 2, which described habitat immediately below dams (see Table 2.2), was negatively related to fledgling count with a slope of -0.170 (GLM, $F_{1,64} = 6.50$, $p = 0.0133$, $R^2 = 0.201$) and to FBR with a slope of -0.173 (GLM, $F_{1,64} = 6.79$, $p = 0.0116$, $R^2 = 0.254$). Principal component 4, describing habitat in the middle of pools, was negatively related to FER with a slope of -0.0866 (GLM, $F_{1,64} = 5.45$, $p = 0.0230$, $R^2 = 0.289$), and there was weak evidence that it was negatively related to FBR with a slope of -0.195 (GLM, $F_{1,63} = 2.77$, $p = 0.102$, $R^2 = 0.254$). All models included year (acting as a proxy for climate and other environmental and human factors); specifically, 2011 and 2012 had higher fledgling counts, FBR, and FER.

DISCUSSION

Model-Building Trends

Year was the strongest predictor for naïve regression trees, which was not surprising. It encompasses a broad spectrum of stochastic effects for which I did not

control. Perhaps most important among these was weather. High temperatures, storms, and flooding were consistently among the greatest causes of ILT mortality within MKARNS (Nupp and Ross 2014), and were essentially stochastic events that affected all colonies roughly equally.

Throughout the exploratory model-building, a few variables were consistently correlated in one direction with the measures of productivity. These variables continued to appear throughout my exploratory manipulation of the data, suggesting that they are quite robust to both outliers such as RM 179 and particularly good or bad years. Positively-correlated variables were width, distance from the upstream dam, height above low water, and distance to the nearest boat ramp. Negatively-correlated variables were distance from the downstream dam, substrate type (with increasing proportions of sand resulting in worse outcomes for all variables), area, and shallow-water area. These variables roughly mirror existing least tern habitat suitability indices (henceforth HSI) used by USFWS and USACE (Carrecker 1985; Duberstein and Downs 2008; Wiley and Lott 2012), which are based on Gochfeld's work on Atlantic least terns (*S. antillarum antillarum*) nesting on Long Island, NY (Gochfeld 1983). However, they do suggest refinements and the addition of sandbar and river characteristics that are significant in heavily diked and dammed river environments.

Positively Correlated Variables

Width was part of the “natural river” cluster, and was strongly predictive for fledgling count. As distance from the upstream dam increased and the river slowed, there were fewer river control structures that allowed for increased sinuosity and increased width. As height increased, colonies become less susceptible to flooding. However, many

of the highest colonies within MKARNS were connected to shore and suffered high predation. Additionally, higher colony sites were less likely to be scoured of vegetation in high winter and spring flows, resulting in rapid succession and loss of the site, as a viable ILT colony site.

Distance to the nearest boat ramp was puzzling. I included this variable as a proxy for human disturbance, the reasoning being that easier access would increase the amount of disturbance seen, particularly on July 4th weekend. However, it appears that colonies close to boat ramps actually do better than colonies that were far away from boat ramps. This may be a purely stochastic effect due to the extremely high-performing colonies at RM 179 and 101, which were both less than 3 km from the nearest boat ramp, or it may be that distance to the nearest boat ramp was not a good proxy for human disturbance. I suspected that the latter of these was the case. Both of these high-performing colonies were in otherwise relatively remote parts of the river, despite their proximity to a boat ramp. One possible explanation was that all dams have boat ramps, and for many colonies the boat ramp at the nearest dam was the closest ramp. Therefore, the distance to dam and distance to boat ramp were closely correlated. Distance to dam strongly affected tern productivity, and distance to upstream dam may be subsuming most of the expected negative variance.

Negatively Correlated Variables

Distance from the downstream dam was probably negatively correlated with measures of productivity for the same reasons outlined above regarding distance from the upstream dam. The river generally becomes wider, calmer, and less controlled closer to the downstream dam, the conditions encouraged the formation and maintenance of a

sandbar in midstream. The relationship with substrate was most likely explained by predation. Gravel and river rocks provide excellent camouflage for tern eggs and chicks, while they are easily spotted on bare sand. Shallow water area's negative relationship with productivity was probably another case of a proxy variable that poorly reflects the habitat characteristic it was intended to replace. Rather than reflecting availability of forage fish for ILT, as was intended, shallow water area appears to be mostly affected by the presence of dike fields and closeness to upstream dams. This was because dike fields act as sediment traps, causing the water between dikes to be generally shallower than undiked sections of the river. Shallow water area could still be indicative of foraging area, but the negative effects of connectedness and closeness to an upstream dam were likely stronger than any positive effects from easy access to forage. Finally, although not immediately apparent from the data, the largest colony sites were connected and in dike fields, while the most successful colonies have mostly been on fairly small mid-stream sandbars. The exception was the large sandbar at RM 101, which was the second-largest colony site in our study area with an area around 90,000 m². Except for the colony failure in 2014 caused by someone shooting adult ILT, it was a consistently high-productivity colony.

Agreement with Frequentist Statistics

Principal components analysis gave similar results to regression tree analysis. Principal components summarizing habitat characteristics found in the upper and middle parts of pools were negatively correlated with productivity. This agreed fully with the negatively correlated habitat variables found by regression tree analysis, including area, closeness to upstream dams, and shallow water area. There were no statistically

significant positive correlations found between the principal components isolated from PCA and any measures of productivity. However, only one of these principal components (PC1, approximately the inverse of the dam-dike field cluster identified with the correlation matrix) would be expected to be positively correlated.

Possible Data Issues

The most obvious problem with the data accuracy for the years included in my study was the data from 2012. Multiple colonies had FERs greater than 1, which suggested that either nest counts from these colonies were incomplete, or fledgling counts on these colonies were inaccurate. It was most likely that both problems occurred. One colony (RM 190) had only two observations, one in late May (5 eggs present) and one in early August (9 fledglings present). Another closely monitored colony (RM 146) probably had complete egg and nest counts (consistent egg and chick counts totaling about 16), but 23 fledglings were sighted on the colony late in the season. It was most likely that these were fledglings from another colony upriver, but it was also possible that adult ILT or black terns (*Chlidonias niger*) in non-breeding plumage were accidentally counted as fledglings. Both species were quite easy to mistake for late-summer fledglings in non-breeding plumage.

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APPENDIX 2A: TABLES

Table 2.1: Variables Used in Analyses

Variable	Shortened Data Code	Predictor or Response	Variable Type
Fledgling count	fle	Response	Numeric
Fledgling to breeding pair ratio (FBR)	fbr	Response	Numeric
Fledgling to egg ratio (FER)	fer	Response	Numeric
Year	year	Predictor	Categorical
Land use	landuse	Predictor	Categorical
Connectedness to land	connect	Predictor	Categorical
Presence in dikefield	dike	Predictor	Categorical
Substrate	subs	Predictor	Categorical
River mile	rivmil	Predictor	Numeric
River width	widthc	Predictor	Numeric
Height above low water	halw	Predictor	Numeric
Distance from upstream dam	damdistu	Predictor	Numeric
Distance from downstream dam	damdistd	Predictor	Numeric
Shallow water area	forage	Predictor	Numeric
Distance to nearest tree	treedist	Predictor	Numeric
Sinuosity	sinu	Predictor	Numeric
Distance to nearest boat ramp	boatrkm	Predictor	Numeric
Colony area	area	Predictor	Numeric
Proportion of land forested	forprop	Predictor	Numeric
Proportion of land cultivated	agprop	Predictor	Numeric

Table 2.2: Composition of Principle Components for all Continuous Variables. This table includes all major factors contributing >10% of each principle component.

Name	Title	Eigen-value	% Variance Explained	Major factors	Correlation	% Factor Loading
PC1	Bottom of pool	3.30	27.5	Distance from USD	0.839	21.3
				Shallow water area	-0.830	20.8
				River width	0.755	17.2
				Colony height above water	-0.589	10.5
PC2	Top of pool	2.54	21.1	Distance from DSD	0.804	25.5
				Proportion forested	0.708	19.8
				Proportion cultivated	-0.658	17.1
				Distance from boat ramp	0.599	14.1
				Sinuosity	-0.522	10.7
PC3	RM 35-ness	1.84	15.3	Colony area	0.700	26.6
				River mile	-0.622	21.0
				Proportion cultivated	-0.457	11.5
				Proportion forested	0.430	10.1
PC4	Middle of pool	1.19	9.95	Colony area	0.579	28.1
				Distance from boat ramp	0.529	23.4
				Distance from DSD	0.431	15.6

Note: For this table, “DSD” means “downstream dam” and “USD” means “upstream dam”.

APPENDIX 2B: FIGURES

Figure 2.1: Naïve Fledgling Count Regression Tree

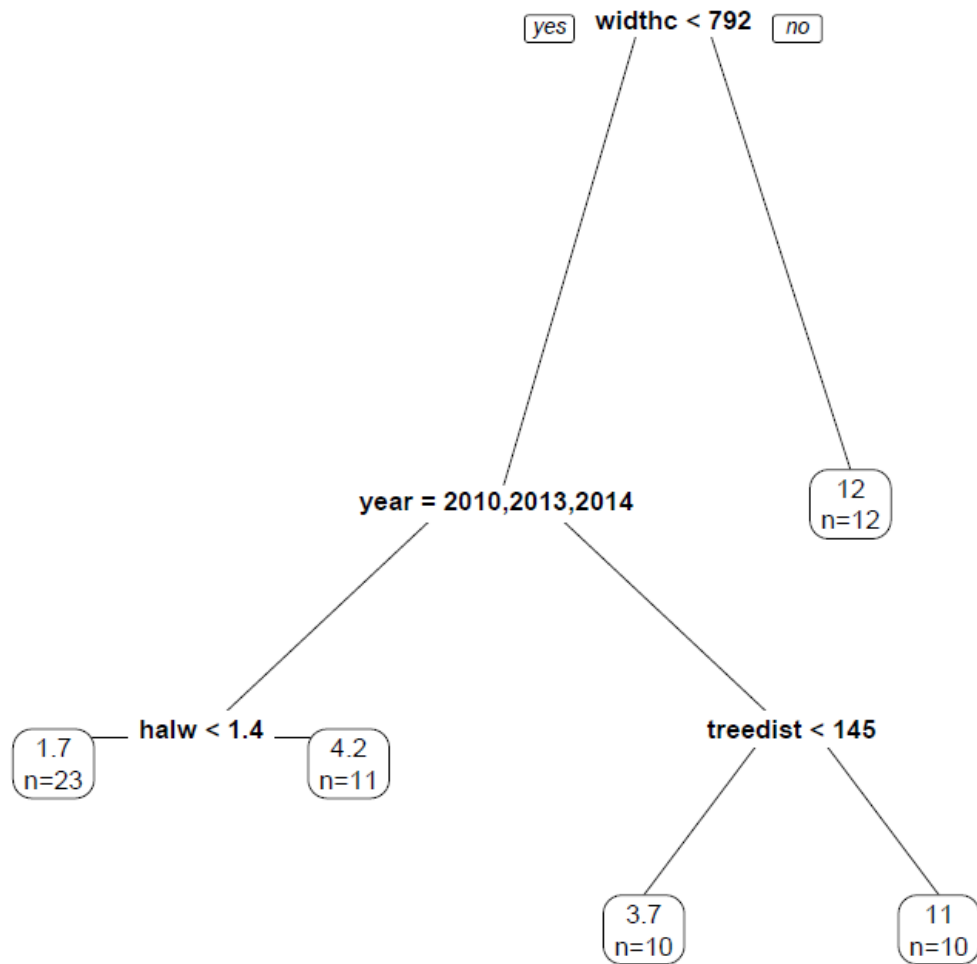


Figure 2.2: Naïve Fledgling/Breeding Pair Ratio Regression Tree

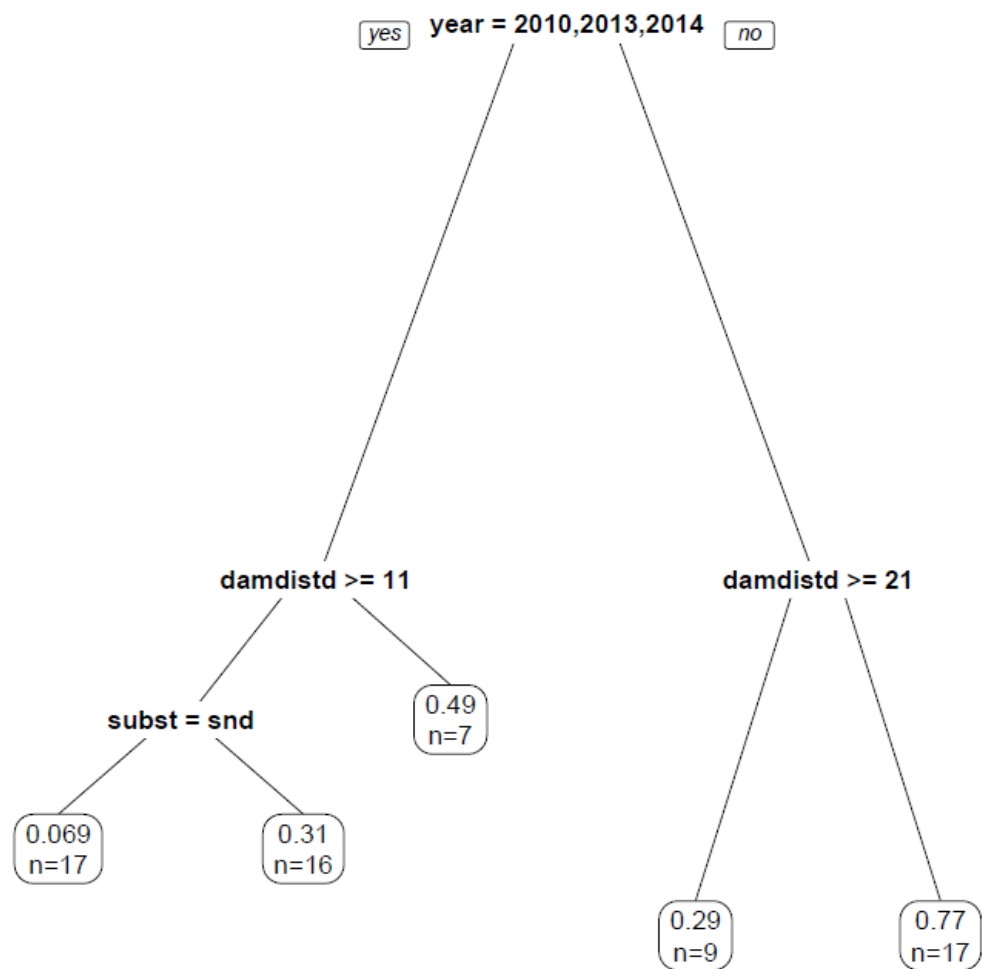


Figure 2.3: Naïve Fledgling/Egg Ratio Regression Tree

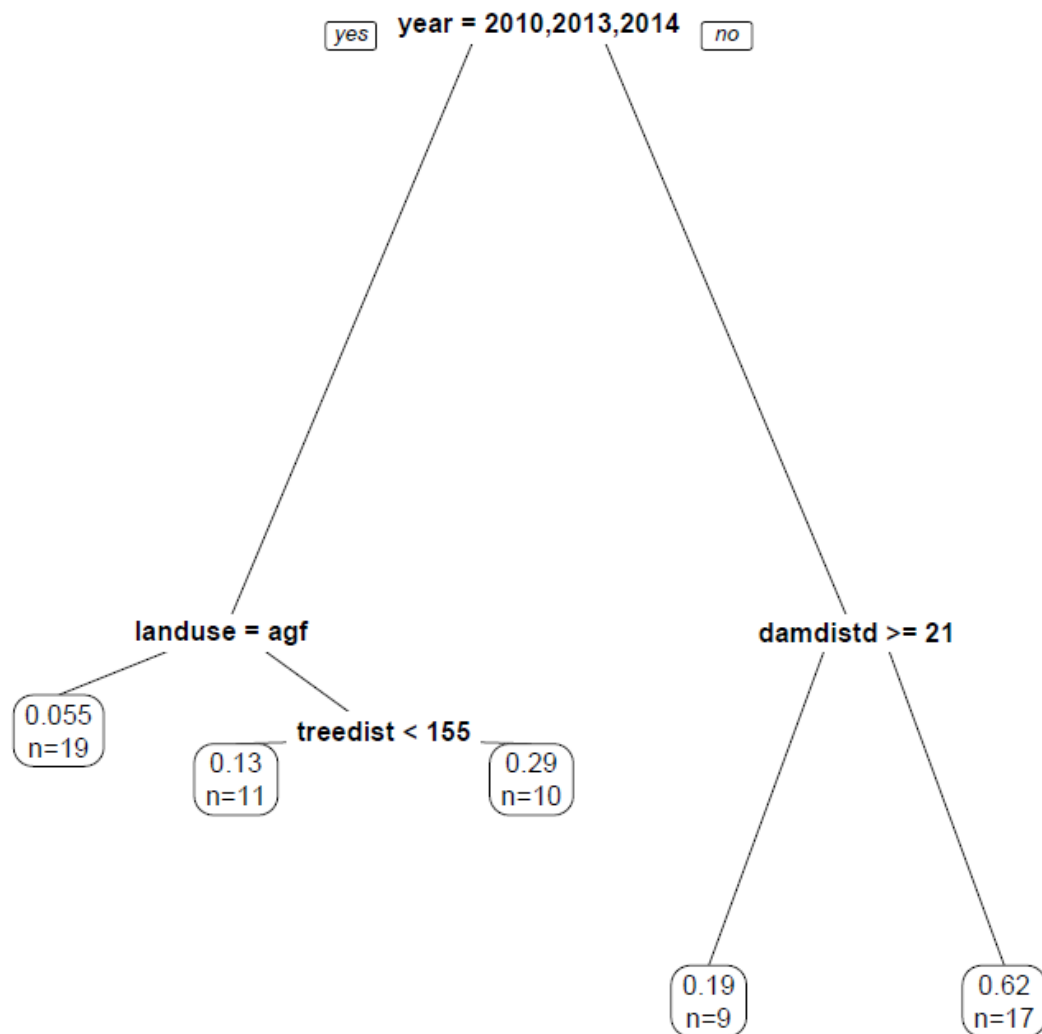


Figure 2.4: Fledgling Count Regression Tree Pooling Years

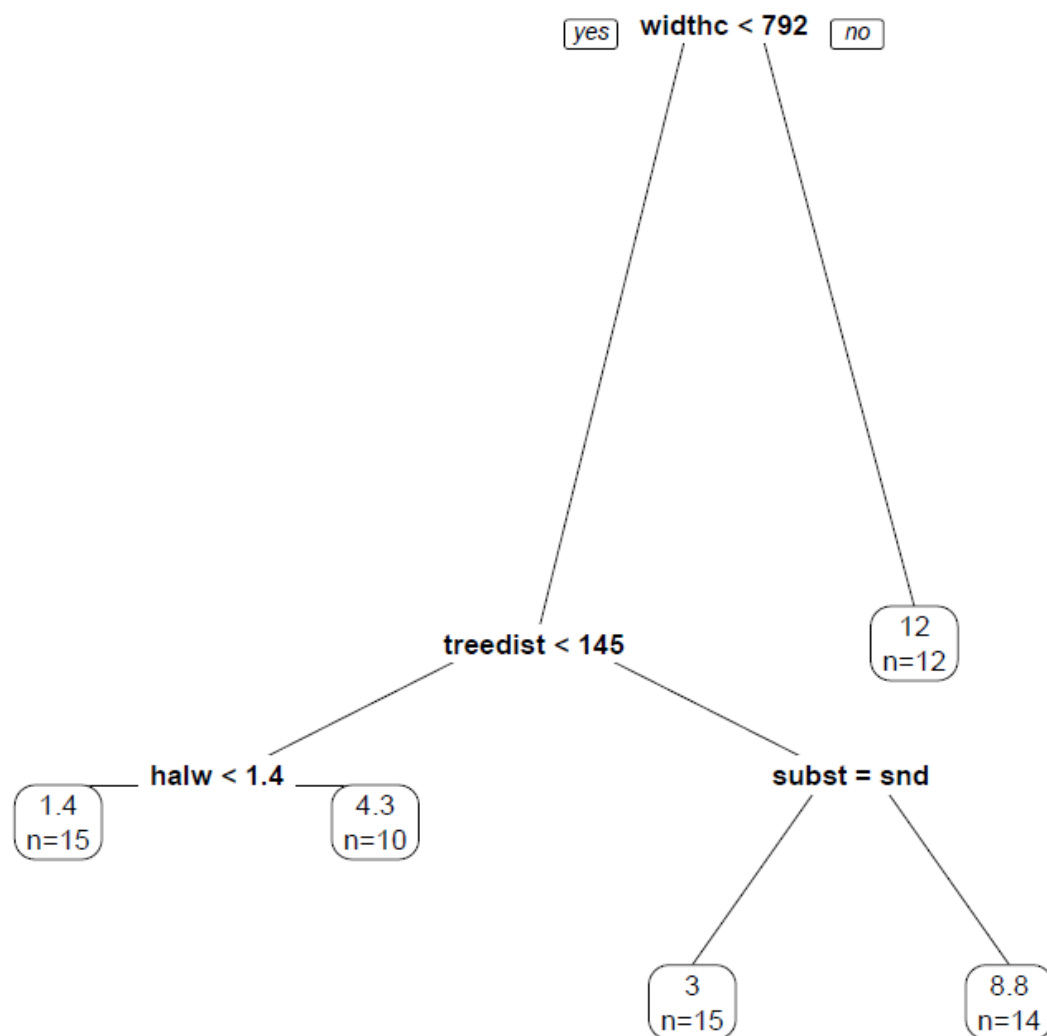


Figure 2.5: Fledgling/Breeding Pair Ratio Regression Tree Pooling Years

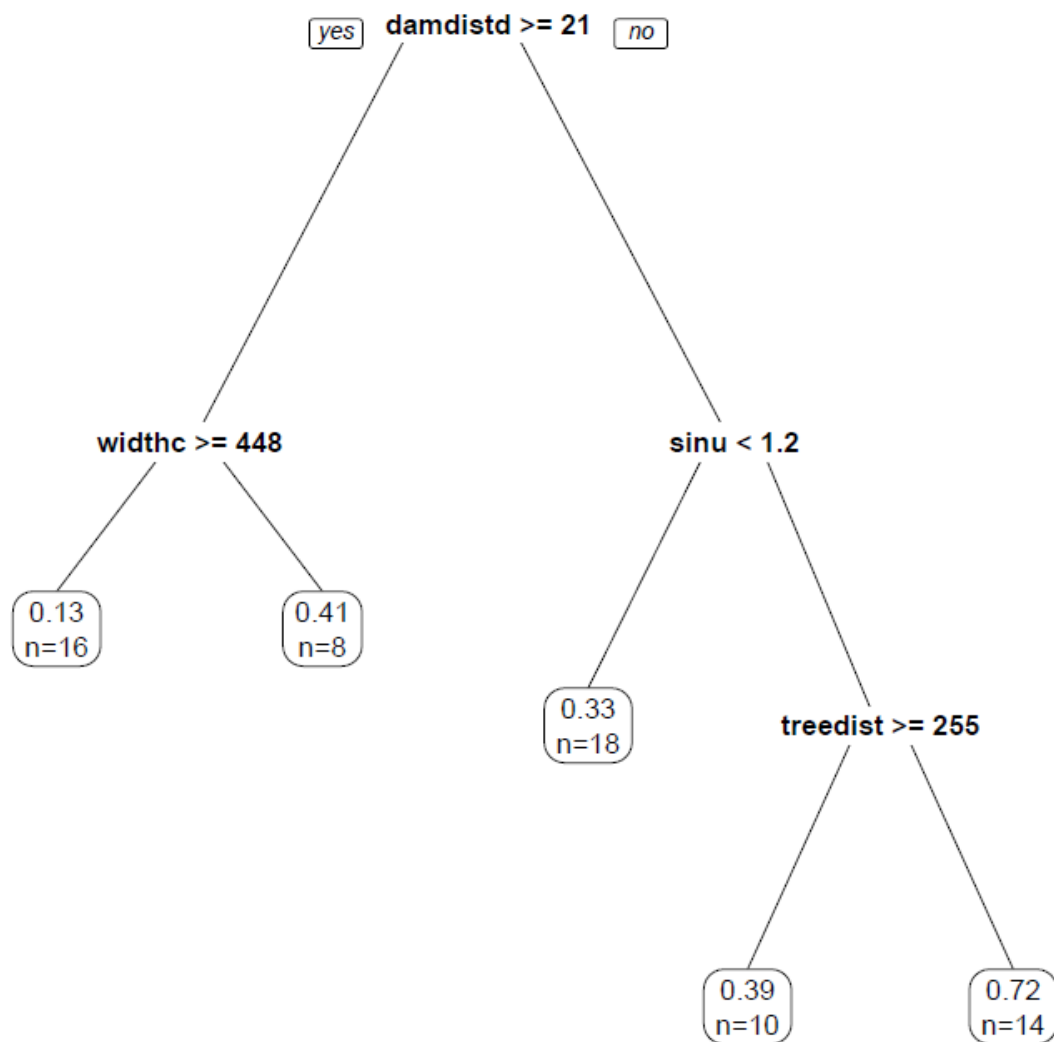


Figure 2.6: Fledgling/Egg Ratio Regression Tree Pooling Years

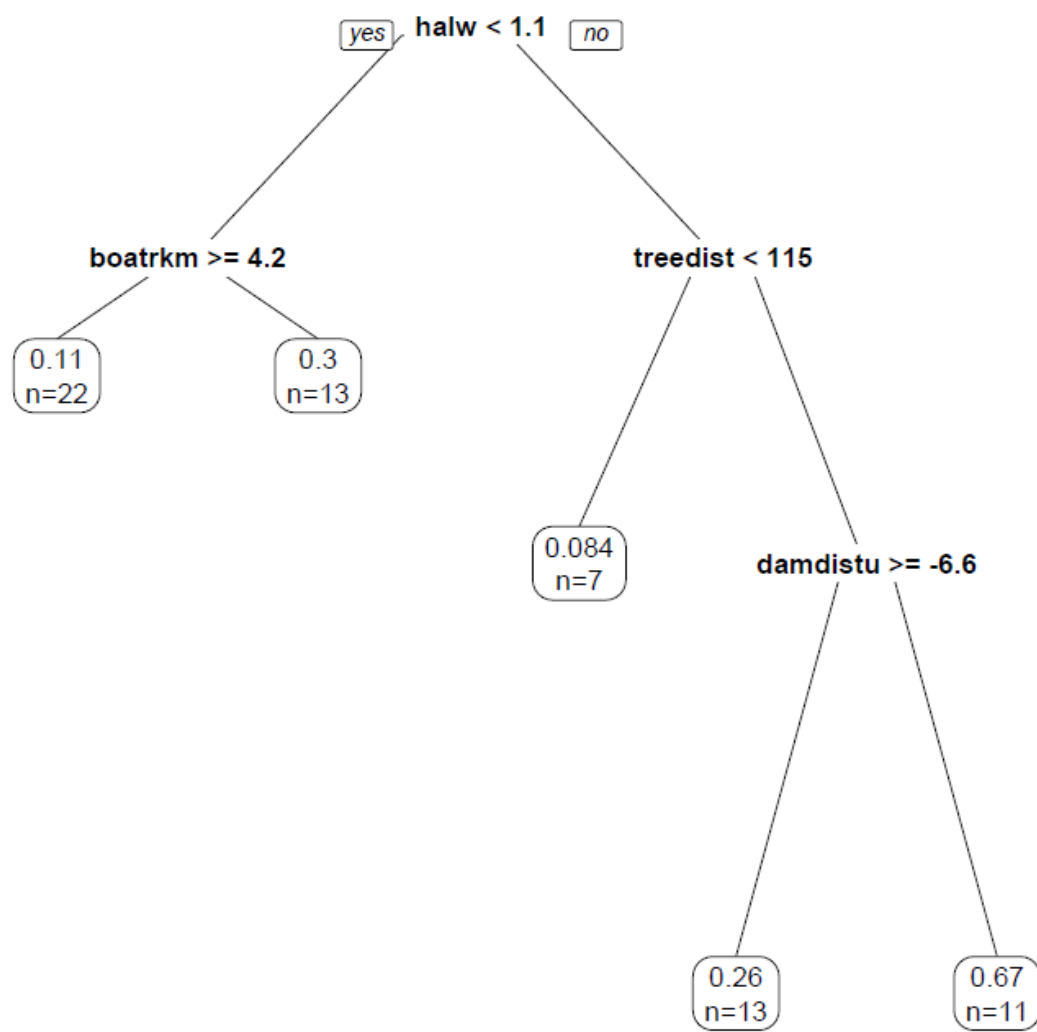


Figure 2.7: Fledgling Count Regression Tree for Averages Across All Years

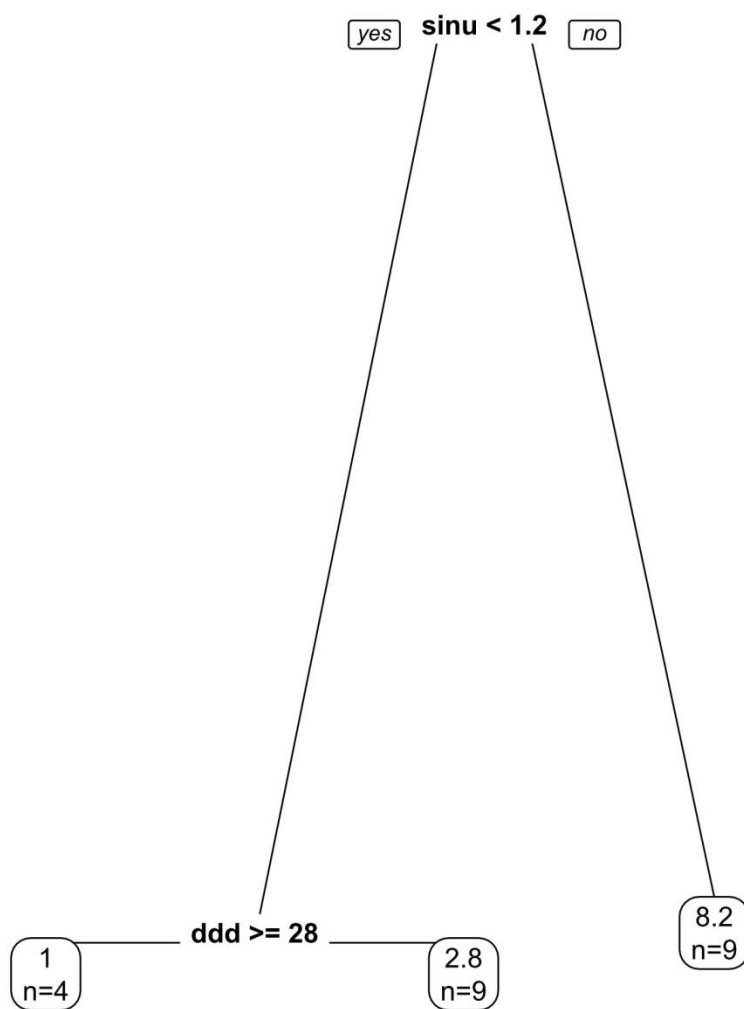


Figure 2.8: Fledgling/Breeding Pair Ratio Regression Tree for Averages Across All Years

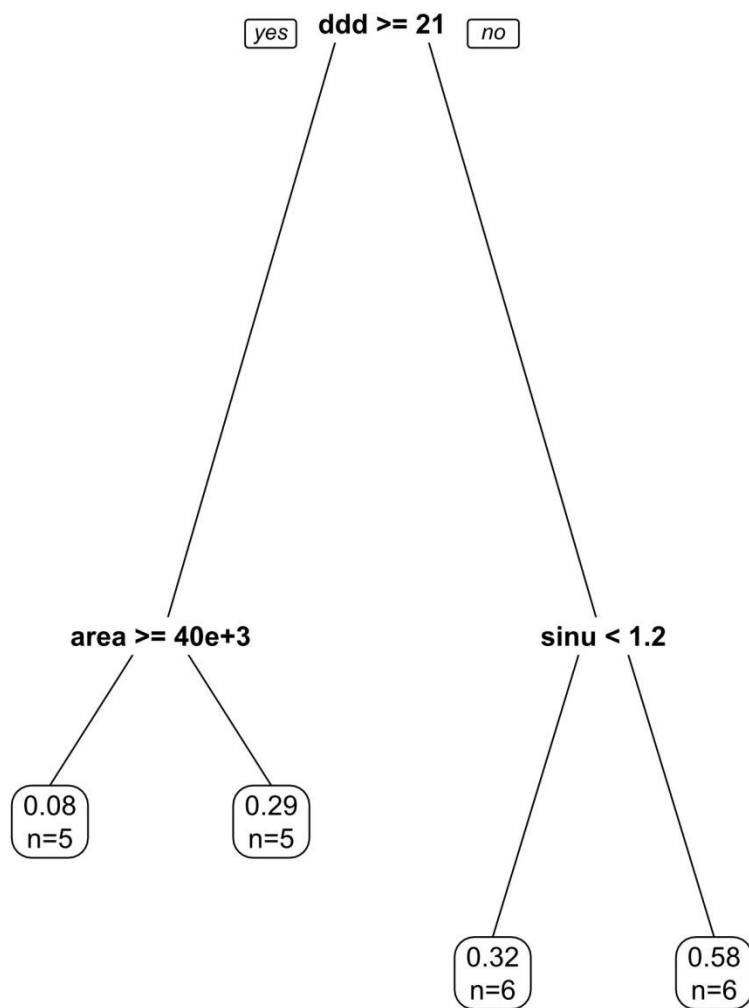


Figure 2.9: Fledgling/Egg Ratio Regression Tree for Averages Across All Years

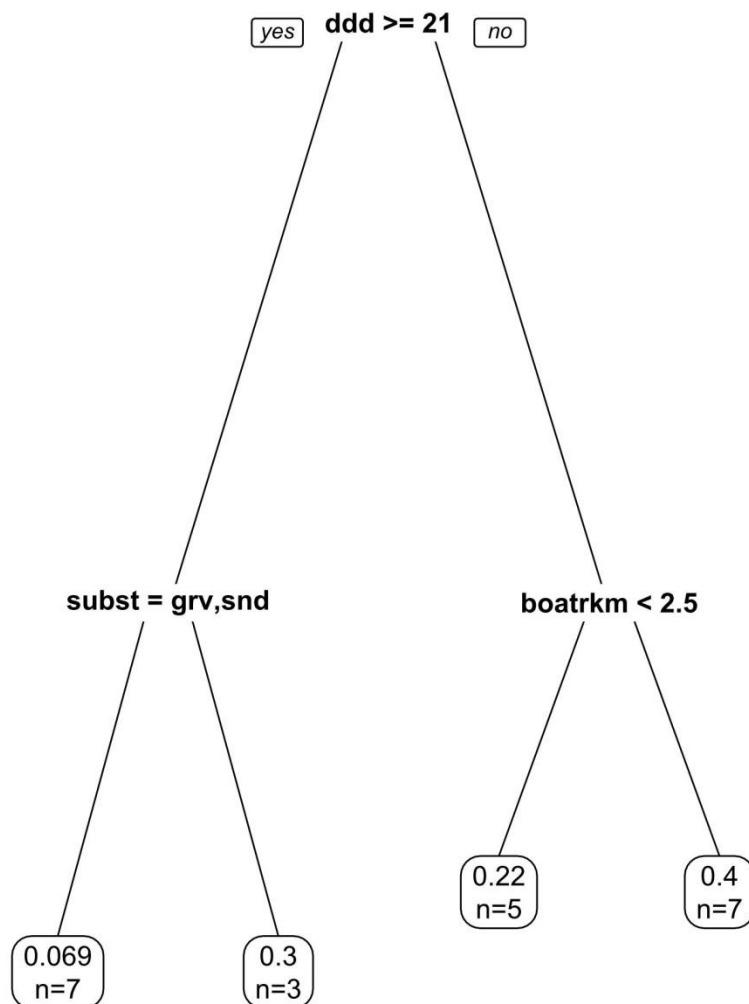


Figure 2.10: Fledgling Count Regression Tree for Only High Productivity Years

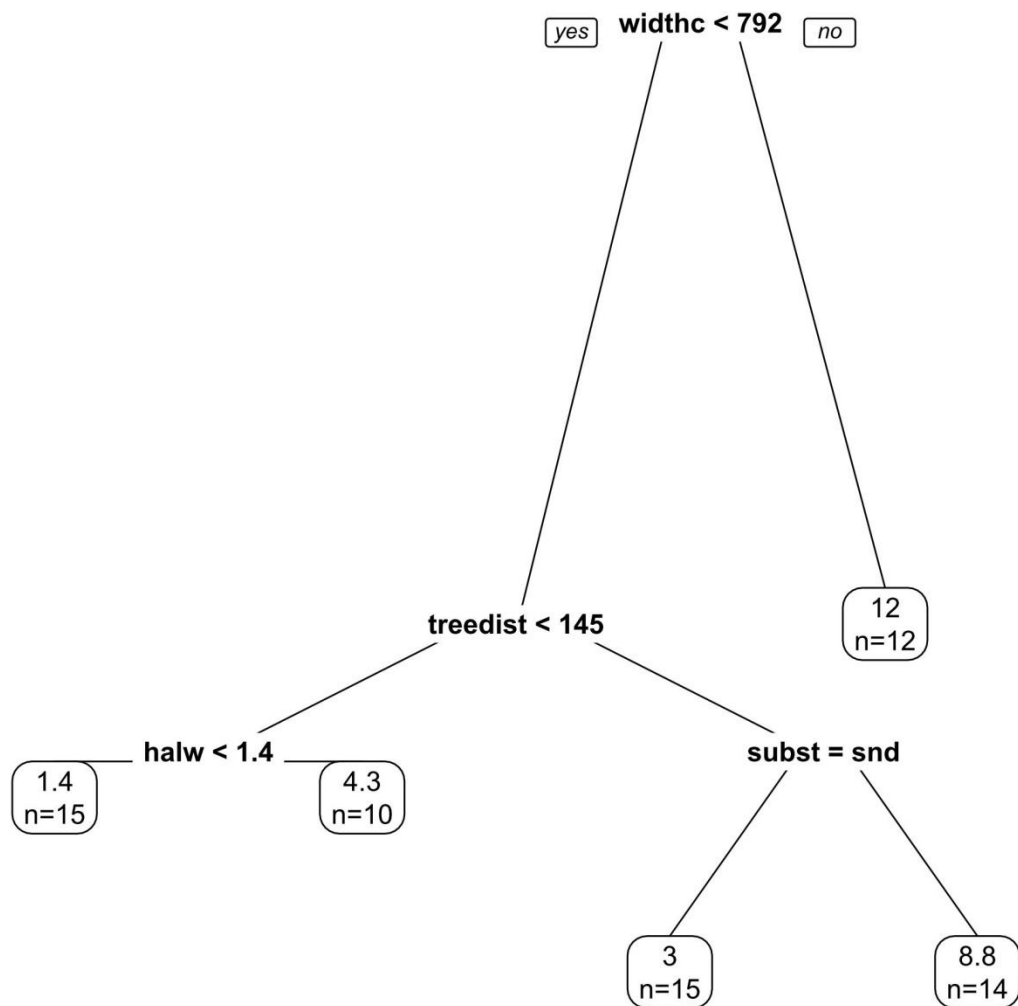


Figure 2.11: Fledgling Count Regression Tree for Only Low Productivity Years

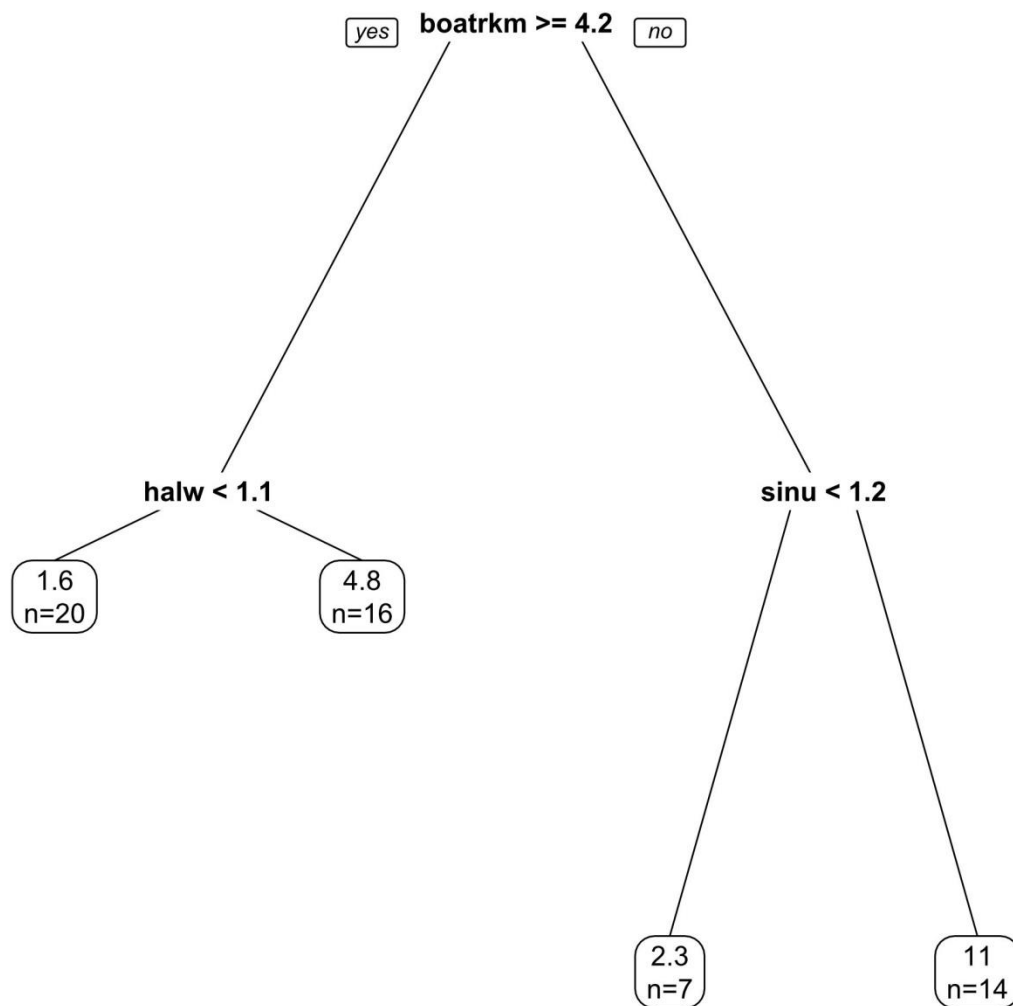
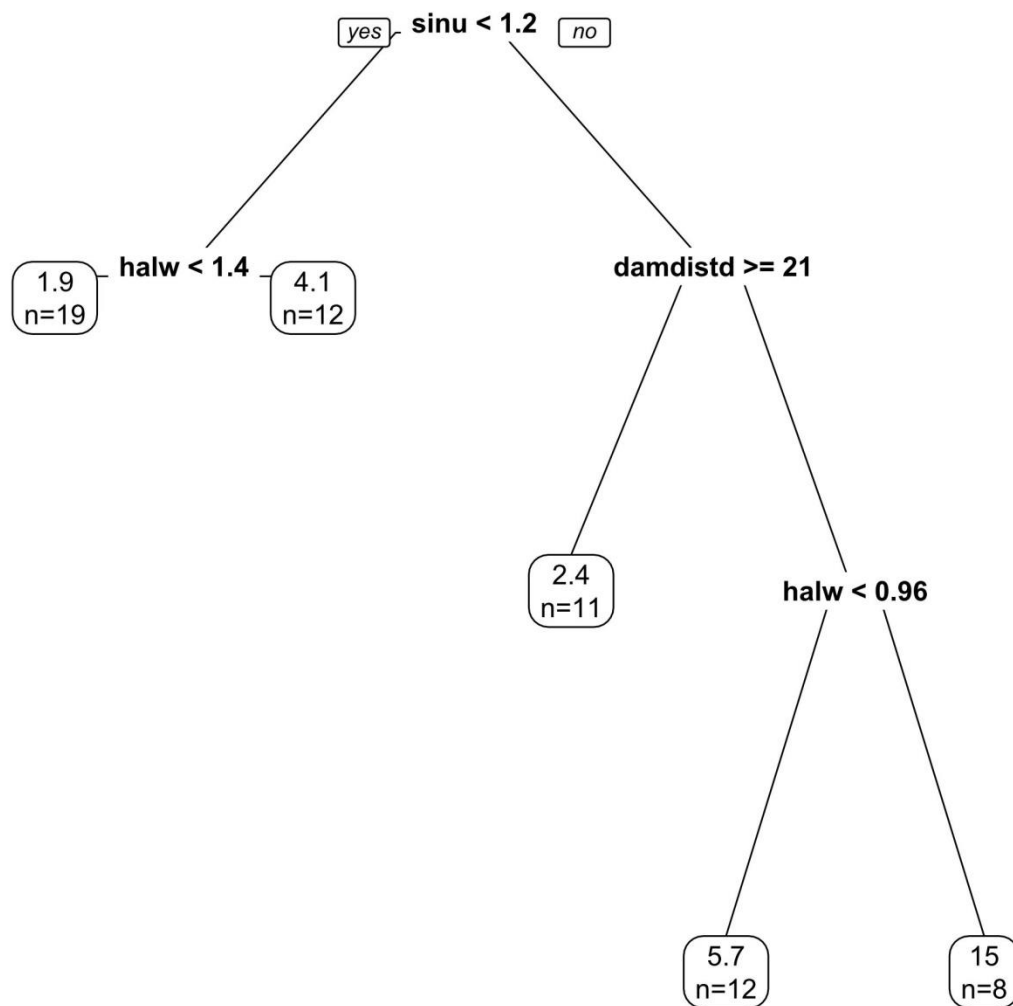
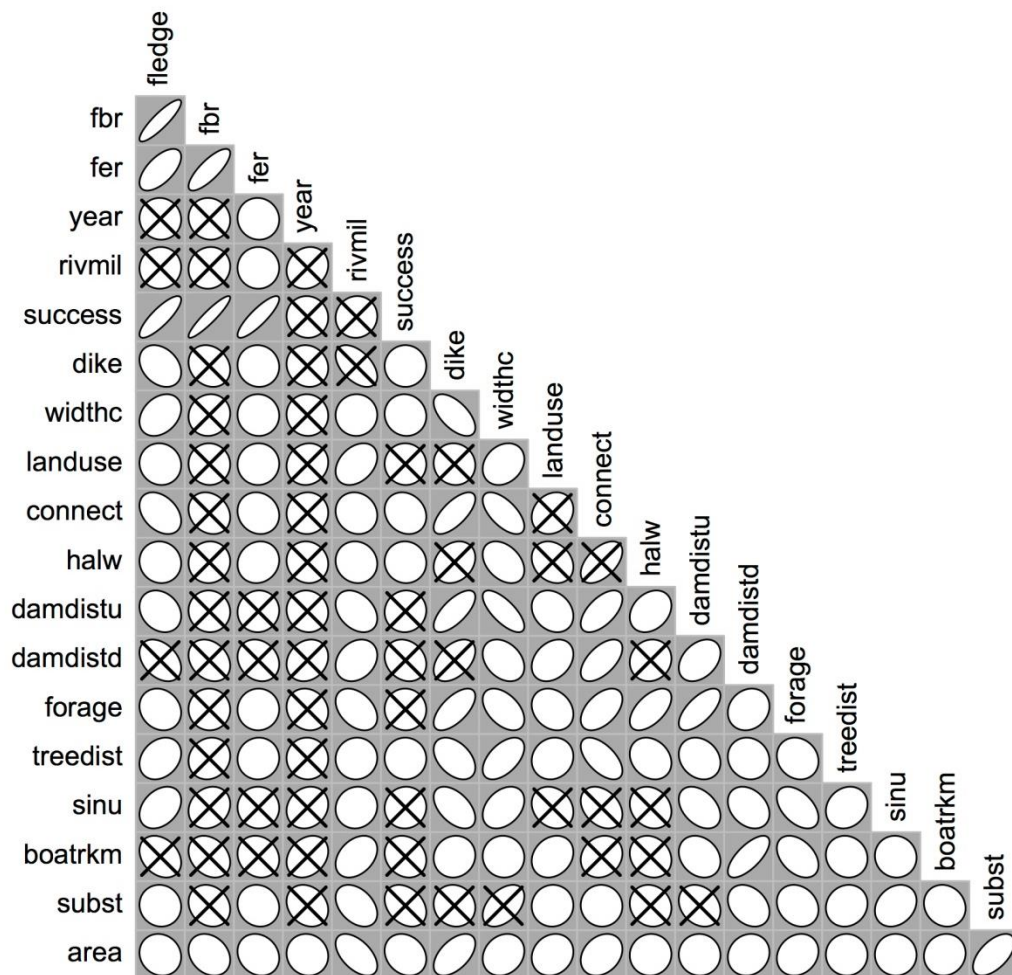


Figure 2.12: Fledgling Count Regression Tree for Pooled Years Excluding RM 179





CONCLUSION: MANAGEMENT RECOMMENDATIONS

The interior least tern population on the Arkansas River is stable, both in terms of population and habitat use. Intensive, methodical monitoring of least terns must continue so that managers can more accurately estimate the population trend of ILT within MKARNS. Site occupancy is high, and it is clear that at least one sandbar complex (RM 35 & 39) constitutes a population sink. This suggests that the best answer to increasing the population of ILT within my study area is to increase the amount of available nesting habitat. The best way to do this, given the U.S. Army Corps of Engineers' available resources, preexisting plans to dredge the MKARNS to a new navigable depth of 12 ft., and need to continue dredging operations indefinitely in order to maintain the navigation channel, is to build entirely new sandbars when possible and improve and maintain existing sandbars by depositing dredge spoil.

The outcomes of my statistical analyses were clearly heavily influenced by the highly-performing colonies at RM 179 and RM 101; these two colonies should be monitored and maintained to keep them elevated, unconnected, and in an early successional state. Additionally, new colonies with similar characteristics to these sandbars should be built and similarly monitored and maintained. Wide river bends, greater than 7 river miles downstream of the nearest dam, with a width of at least 750 m and a sinuosity at 3 km of at least 1.2, are an ideal setting for new sandbar creation. In order to minimize the risk of depredation by both avian and mammalian predators, dredge spoil intended for use as tern habitat should be deposited as far away from trees, the bank, and control structures as possible, and should include a top layer of gravel, shell, or small rocks where feasible. Dredge spoil should be deposited to a height of at least 1.1 m above

the average mid-July low water level in each pool; colony sites found to have dropped below this height should be supplemented with additional dredge spoil during the next off-season to avoid creating ecological traps for ILT.

Despite the low productivity of most colonies in dike fields, a few of these colonies have been productive in the past; every one of these colonies was a sandbar that is not connected to shore. Therefore, where feasible, dike notching and additional dike geometry may be used to disconnect existing sandbars in dike fields.

Furthermore, USACE should work with USFWS and AGFC to keep human disturbance at all least tern colonies to a minimum, particularly during the July 4th weekend, when many colonies disappeared in both 2013 and 2014. The 2014 erection of permanent informational signs at boat ramps is an excellent start, but the colonies themselves need to be clearly marked with signs and AGFC officers must enforce state and federal laws regarding disturbance of endangered species and nesting migratory birds.

