Determining strategies for the protection of nesting Interior Least Terns

(*Sternula antillarum athalassos)* in Indiana

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This project is dedicated to my late grandparents, Sue and Dave, who instilled in me a love and respect for birds that had much more impact than I think they would have expected.

To anyone reading this that suffers from mental illness, doesn't think they're good enough, or smart enough, didn't do well in undergrad, doesn't know what they're doing or what they want – I see you. I hear you. You can do it and you will figure it out.

This project was completed on Native lands of the Shawnee, Cherokee, Osage, Kaskaskia, Kickapoo, and Miami tribal nations.

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ABSTRACT

Interior least tern (*Sternula antillarum athalassos*) populations and productivity have been declining in Indiana for the past ten years, which is thought to be the result of predation. Methods for protecting nesting Interior least terns include fence exclosures and artificial shelters for chicks, but their effectiveness is unknown. Each Indiana nesting colony is protected by a different type of exclosure, and preliminary data suggests that some may be more effective than others. This study quantifies the efficacy of these strategies used to protect nesting Interior least terns at three sites in southern Indiana. I found that the exclosure made of electrified chain link with aluminum flashing at the Goose Pond Fish and Wildlife Area was 100% effective at deterring predators, followed by the chain link-only exclosure used at Cane Ridge Ray's and Tern Islands at 76 and 86%. Finally, the electrified fence with additional safety fencing at the American Electric Power site was 50%. I documented 77 events of chicks using artificial shelters at the American Electric Power colony, but I found no correlation between air temperature and shelter use or productivity (fledglings/pair) and shelter use. These results provide an in-depth look at protection strategies that can inform managers and stakeholders about ways to improve productivity of Interior least terns and other birds that nest similarly.

INTRODUCTION

Interior least terns (hereafter, ILT) are a small, charismatic member of the *Laridae* family. They are the smallest tern species in North America, about the size of a robin, with a 20-inch wingspan and a distinctive black cap and loral stripe contrasting with their white forehead (Thompson et al. 2020). Three subspecies of least terns are recognized in North America, the coastal least tern (*S.a. antillarum*), California least tern (*S.a. browni*), and the Interior least tern (*S.a. athalassos*). There has been much debate on the genetic and ecological differences between these subspecies. A study by Massey (1976) found differences in behavior and vocalization between the least tern and its sister species in Europe, the little tern (*Sternula albifrons*), but no differences between the coastal and California least tern. The main difference between least terns in North America is attributed mostly to geography. The California least tern breeds from the San Francisco Bay to Baja California, the coastal subspecies breeds along the entire eastern coast and southern coast to Texas, while ILTs breed in inland rivers from the Northern Great Plains to Texas and northern Louisiana (Thompson et al. 2020). Migration and wintering populations, however, have significant overlap through Mexico and South America. Distribution in wintering ranges along with a lack of morphological and genetic differences call into question the current designations of the North American subspecies (Draheim et al. 2012, Thompson et al. 1992, Whittier et al. 2006). Whittier et al. (2006) also found that genetic exchange between eastern and Interior least terns occurs at a rate greater than three migrants per generation per populations. However, Draheim et al. (2012) found that genetic diversity throughout all North American least tern subspecies appears to be declining, causing conservation concern for the species overall.

Within the ILT subspecies, four major subpopulations have been identified (Figure 1). These include 1) the lower Mississippi River, Arkansas, Canadian, and Cimarron Rivers; 2) the

Red and Trinity Rivers; 3) the Platte, Niobrara, and associated Missouri River reaches; and 4) the northern Missouri River (Lott et al. 2013, USFWS 2017). ILTs that breed in Indiana are associated with the lower Mississippi subpopulation and are the most peripheral colony east of the Mississippi. A single historical nest record exists for the Ohio River on the southeastern border of Indiana and one at the Falls of the Ohio State Park near Louisville, Kentucky from 1967 (Johnson and Castrale 1993, Mumford and Keller 1984). Regular nesting in Indiana began in 1987 at Gibson Lake, a man-made cooling lake near the Wabash River, at the Gibson Generating Station (Mills 1987). Since then, ILTs have expanded to several other locations in Indiana.

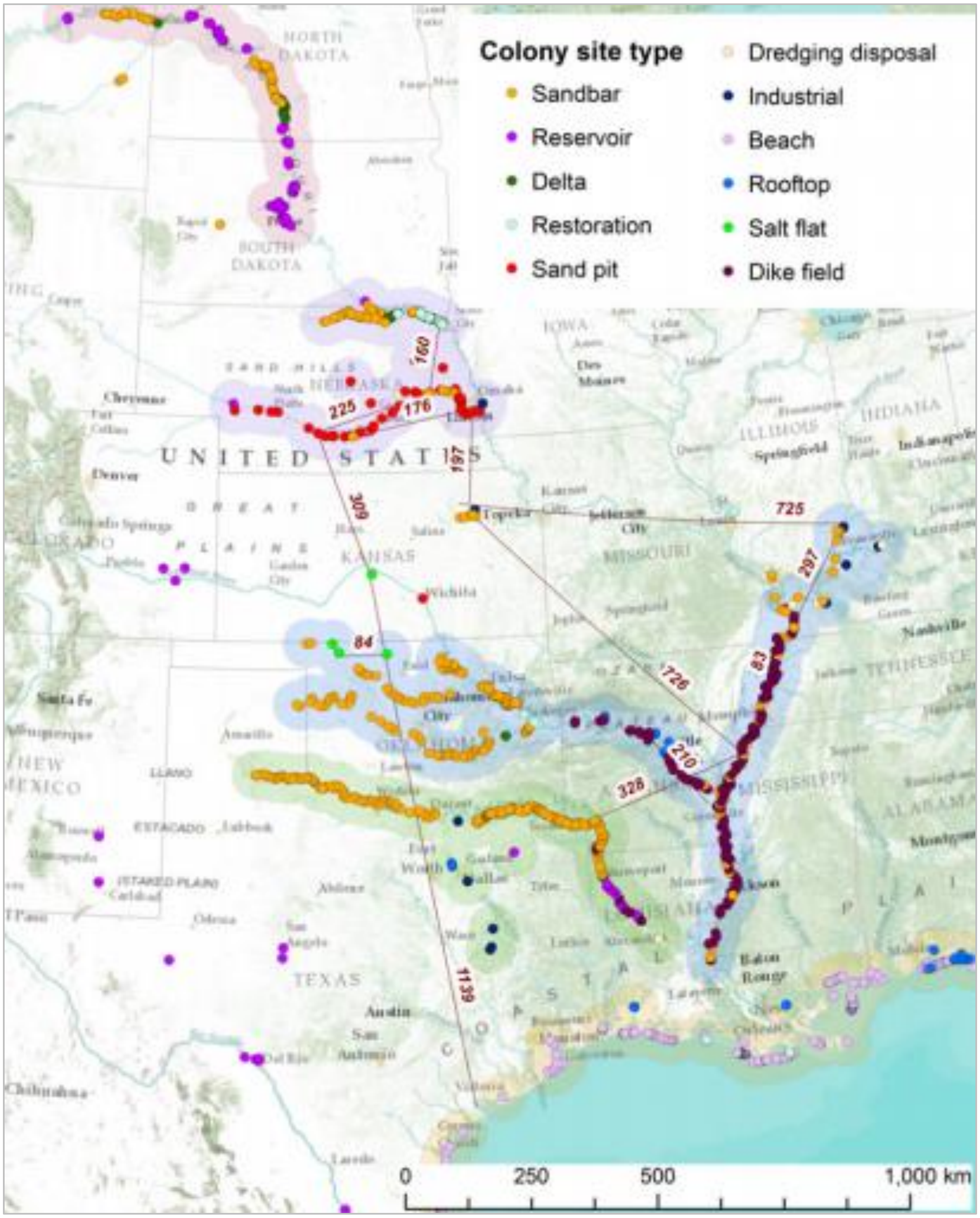


Figure 1: Four major subpopulations of Interior least terns from Lott et al. 2013. Blue shading represents the Lower Mississippi, Arkansas, Canadian, and Cimarron Rivers population, green represents the Red and Trinity Rivers, Purple the Platte, Niobrara, and Missouri Rivers, and pink the Northern Missouri River. Beige shading represents the coastal least tern population.

ILTs were listed as federally endangered under the Endangered Species Act (1973) by the U.S. Fish and Wildlife Service from May 1985-February 2021 because of low numbers and scattered distribution (USFWS 2021). Intensive surveys throughout 1985-1987 counted fewer than 5,000 adults throughout their historical range (Sidle et al. 1988). In 2005, the population estimate was 17,500 adults, with evidence of expansion into new territories and segments. This estimate was well above the proposed population size of 7,000 individuals for delisting across the entire ILT range (Lott 2006, USFWS 2021). While no rangewide survey was conducted at the time of delisting in 2021, populations are thought to have continued to increase in size. However, in Indiana, ILT populations have declined overall for the past ten years (Figure 2). Predation of nests and chicks from mammals, raptors, and reptiles is one of the most significant threats to ILT populations in Indiana, although other factors such as habitat destruction from river channelization and the bioaccumulation of pesticides in fish also have negative impacts (Thompson et al. 2020).

Typical ILT nesting habitat is flat, open spaces that are close to water, such as beaches and river sandbars, at low risk from ground predators and distant from trees that serve as perches for avian predators. Habitat decline and growing human development has led ILTs to nest in less traditional environments such as ash flats (an area where coal by-products are disposed of at industrial sites creating flat, open areas that are similar to sandy beaches), rooftops, agricultural fields, and manmade islands (USFWS 2017). There are four colonies in Indiana: two at man-made islands in public wildlife areas and two on gravel dikes at power plants. ILT nests have also been found in agricultural fields and on rivers. However, the rivers in Indiana are typically past flood-stage during the late spring and early summer when ILTs arrive, providing little to no sandbar habitat for nesting.

Nests of ILTs consist of a shallow scrape on the ground. Incubation begins after the first egg is laid and lasts on average 21 days. Females do most of the incubation (approximately 80%) and males bring the female food while on the nest (Thompson et al. 2020). Typically, females will only leave the nest if disturbed. Once hatched, chicks spend two days in their nests and then leave, but generally stay within 200m of their nest. On average, first flight (fledging) occurs 20 days post-hatching, and dispersal within two to three weeks of fledging (Bailey and Servello 2008, Thompson and Slack 1984). There are 40 days of exposure from egg-laying to fledging, which represents the time the young are most vulnerable to extreme weather events and predation.

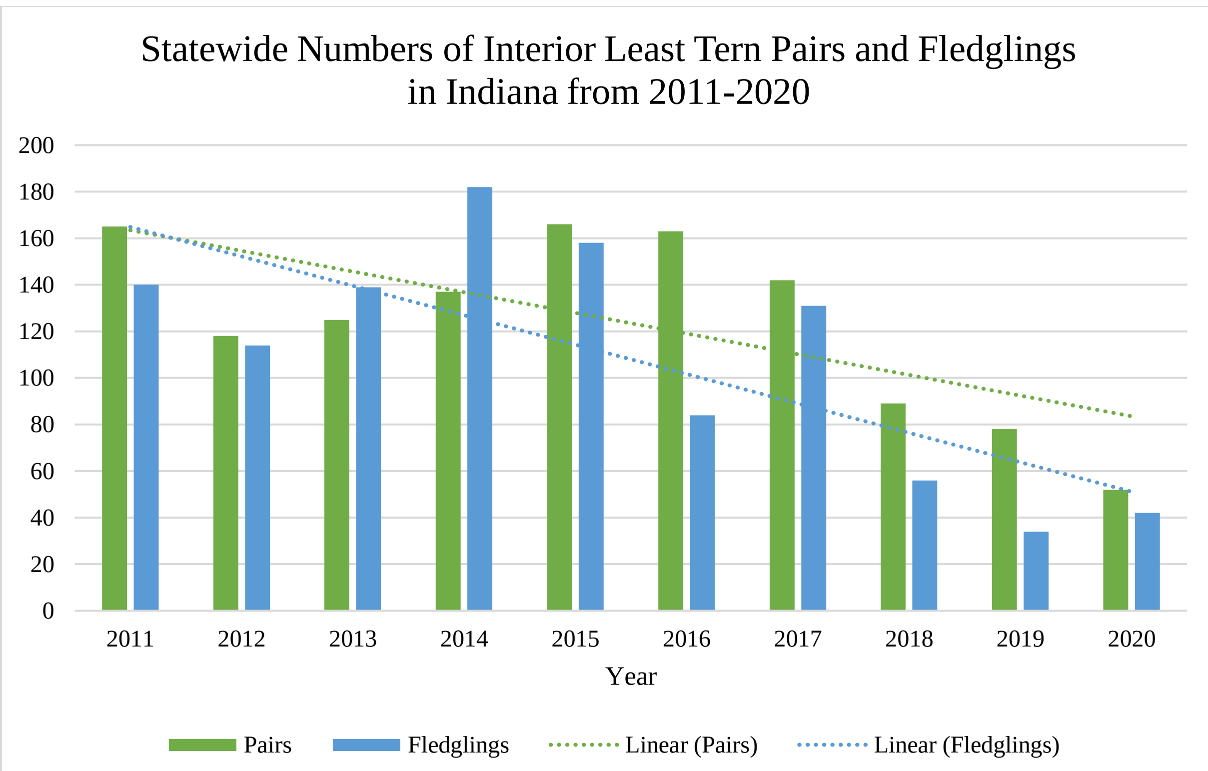


Figure 2: Statewide Numbers of Interior least terns in Indiana from 2011-2020. Linear trendlines for pairs and fledglings show an overall decline in numbers (Gillet, InDNR, unpublished data).

The major threat that ILTs face in Indiana is thought to be predation, which is based on trail camera evidence from the 2018 and 2019 breeding seasons (Williams 2018, Espick 2019). Their atypical nesting habitat in Indiana often places them in closer proximity to predators and makes them more accessible to land predators than they would have faced in historical, ephemeral habitat. ILTs also have an ineffective response to predators. Their main responses are mobbing, alarm calls, and desertion depending on the predator. If adult ILTs are in danger, they will desert their nests and chicks and fly high above the predator, and if only eggs and chicks are vulnerable, adults will dive, attack, and defecate on the predator (Thompson et al. 2020). Mobbing has been found to be effective against crows but is less so with gulls and mammals. However, most predators affecting ILTs in Indiana are mammals (Burger 1989, Jackson and Jackson 1985). Studies of other tern species found that adults deserted colonies for several hours every night when disturbed by predators (Greenwell et al. 2019, Nisbet 1975, Nisbet and Welton 1984).

Predator management in Indiana began in 1992 at the Gibson Lake colony using predator exclosures that were based on Mayer and Ryan's (1991) finding that electric fences increased nest and chick survival of piping plovers (*Charadrius melodus*) (Johnson and Castrale 1993). In the early years of ILT management, predation on the colony was from Norway rats (*Rattus norvegicus*), black-crowned night herons (*Nycticorax nycticorax*), and ring-billed gulls (*Larus delawarensis*) (DeVault et al. 2005, Johnson and Castrale 1993). Since ILTs expansion to new locations in Indiana, most predation events have been from coyote (*Canis latrans*), mink (*Neovison vison*), raccoon (*Procyon lotor*), opossum (*Didelphis virginiana*), American kestrel (*Falco sparverius*), and great horned owl (*Bubo virginianus*). Throughout the years, trapping, rat poisoning, strobe light systems, and various predator exclosures were used to protect ILTs with varying results (Mills 2020). The last predator study in Indiana was conducted by Devault et al. (2005) in 2003-2004. Predator dynamics have changed since then from mostly heron and gull predation to mostly coyote and other mammalian predation. With that information, it became clear that a new predator evaluation was necessary.

Beginning in 2018, a Least Tern Monitor was hired by the Indiana Department of Natural Resources (hereafter, InDNR) to determine threats to ILTs during the breeding season. That year, trail cameras discovered a snake and coyote were partly responsible for the predation of nests and chicks at Gibson Lake and the American Electric Power Plant in Rockport (hereafter, AEP), respectively (Williams 2018). This pilot study was continued in 2019 and provided more evidence of the impacts of predation on ILTs. Statewide productivity in 2019 was at its lowest since 2004, with 0.41 fledglings per pair, which is below the threshold of 0.51 fledglings per pair required to maintain a stable population (Kirsch 1996). At AEP in 2019, there were individual predation events by American kestrel, red-eared slider (*Trachemys scripta elegans),* and coyote. The coyote visited the colony on 2 July when the peak number of chicks was reached and then came again two days later. After this predation event, no more chicks or adults were seen, and the colony was abandoned. Coyotes are extremely intelligent and efficient and will remember the timing of food sources for years. They may also participate in surplus killing, in which they kill more prey than they can immediately eat and either cache or abandon it (Lehner 1976). At the northernmost colony at Goose Pond Fish and Wildlife Area (hereafter, GP), predation occurred by great horned owls and mink. With only six nests, these predation events destroyed the colony. Like coyote, mink are extremely efficient predators and participate in surplus killing (Errington 1943). Great horned owls were frequently seen exhibiting “foot-hunting” behavior, where they actively search for prey by walking on the ground, which appears to be an adaptive hunting technique used to exploit prey in treeless habitats (McMillian 1998). Similar predation events were seen at Gibson Lake and Cane Ridge Wildlife Management Area (hereafter, CR); however, both of these colonies were able to produce 28 fledglings.

One of the main ways Indiana has attempted to protect ILT colonies is with the use of predator exclosures. Predator exclosures are fences that encompass the area where ILTs typically nest with the intent of excluding predators from the colony. Exclosures are often used as individual nest cages with plovers and sandpipers, who have similar nesting strategies to ILTs, however, individual exclosures are not possible with ILTs because of colonial nesting (Dinsmore et al. 2014, Estelle et al. 1996, Larson et al. 2002, Melvin et al. 1992, Murphy et al. 2003, Vaske et al. 1994). Data also suggest that individual nest cages may increase the amount of nest abandonment (Maslo and Lockwood 2009, Vaske et al. 1994). Along with nest cages, many Piping Plover and Southern Dunlin (*Calidris alpina schinzii*) projects also commonly erect a perimeter exclosure around the colony or groups of nests, which has been shown to increase nest survival rates even further (Larson et al. 2002, Maslo and Lockwood 2009, Melvin et al. 1992, Murphy et al. 2003, Pauliny et al. 2007, Vaske et al. 1994). Predator exclosures have been used in varying ways since predator management began at Gibson Lake in 1992 (Johnson and Castrale 1993, Mills 2020). In Least Tern specific projects, predator exclosures are proven methods that reduce predation rates and increase nest and chick survival (Burger 1989, Butchko and Small 1992, Lombard et al. 2010, Koenen et al. 1996, Minsky 1980, Rimmer and Deblinger 1992). In Indiana, however, each predator exclosure is slightly different and preliminary data suggests that some exclosures protect ILT colonies better than others (Espick 2019).

Chick shelters are another form of protection used for ILT management. Chick shelters can be temporary artificial or natural structures that provide shade and protection to young ILTs after they hatch. Shelters have been applied to many different avian species as a simple protection method with little disturbance to colonies (Burness and Morris 1992, Butcher et al. 2007, Jenks-Jay 1982, Kruse et al. 2002, Maguire et al. 2011, Voigts 1999). Along with emerging vegetation, shelters can offer another form of protection from predators and weather; and have increased survival rates in studies of least terns and other ground-nesting shorebirds (Burness and Morris 1992, Jenks-Jay 1982, Lee et al. 2006, Maguire et al. 2011, Voigts 1999). However, some studies have shown that chicks prefer natural vegetation and permanent landscape structures more than artificial shelters (Butcher et al. 2007, Kruse et al. 2002). Chick shelters have been used off and on at colonies in Indiana with no quantifiable data on how effective they are. At the GP and CR colonies, islands are treated with herbicide early in the year to discourage overgrowth but by the time chicks hatch, there is enough vegetation to provide natural cover. At AEP, very little vegetation grows where ILTs nest due to the substrate of the dikes. More information is needed on whether chick shelters are a useful strategy for protecting ILT chicks.

OBJECTIVES

Due to the decreasing numbers of ILTs in Indiana and poor productivity, it is important to determine what can be done to protect them for as long as they nest here. The goal of this project is to determine strategies that are effective in protecting ILT nests and chicks. I addressed this goal in three objectives. First, I address the question of exclosure effectiveness by comparing predator detection inside versus outside of the various exclosure types. Second, I determined the different nest survival and productivity (fledglings/pair) rates among colonies in relation to predator detection, and if the compared survival estimates differ with exclosure type. Lastly, I assessed the usefulness of artificial shelters are for increasing fledgling survival. I will do this by asking if the presence of artificial shelters has any correlation with higher productivity, and if shelters are used more during periods of high temperatures. Completing these objectives will allow biologists to have a better understanding of how to protect ILTs in the future and develop strategies to increase nest survival and productivity.

STUDY SITES

I conducted field research from May to August 2020 during the ILT breeding season. Research took place at three locations in southern Indiana (Figure 3): Goose Pond Fish and Wildlife Area (38.963497, -87.168611), AEP Rockport Power Plant (37.915585, -87.036394), and Cane Ridge Wildlife Management Area (38.332563, -87.770814).

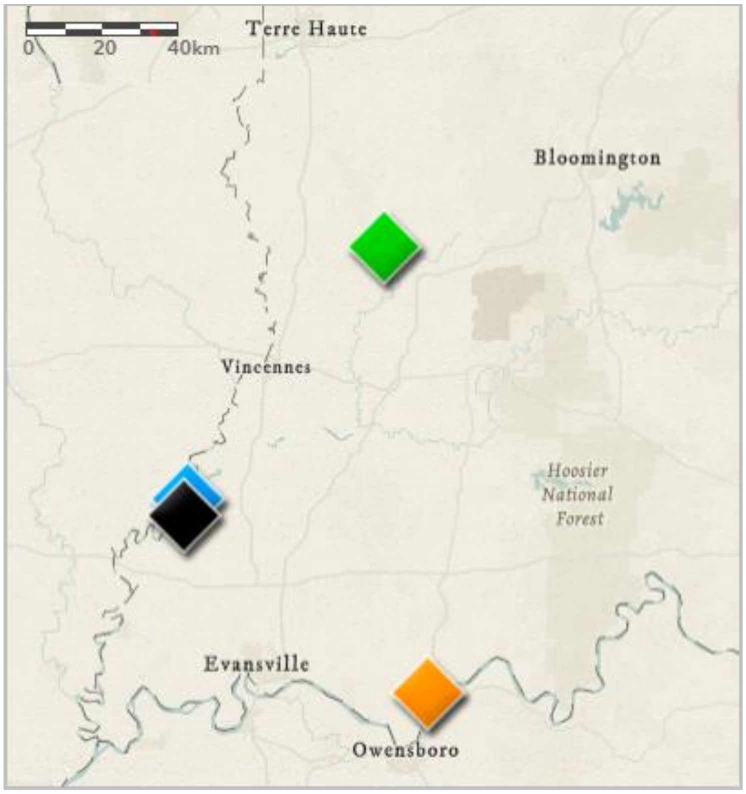


Figure 3: Locations of all four major Interior least tern colonies in southern Indiana. Green is Goose Pond (GP), blue is Gibson Lake (not part of this study), black is Cane Ridge (CR), and orange is American Electric Power (AEP).

Goose Pond Fish and Wildlife Area (GP)

GP is a state-owned wetland area that is actively managed for wildlife by the Indiana Department of Natural Resources. It hosts Tern Island, a three-acre island surrounded by water. Water is kept shallow (around one to two feet deep) and is full of wetland plants. The island is exclosed by a chain link fence (four feet tall) with two strands of electric wire on the outside of the fence and topped with brown aluminum flashing (Figure 4). Island substrate is made up of sand and gravel. The island is treated with herbicide in late spring, but vegetation typically begins to grow in the late summer. Outside the fence the island is surrounded by riprap (large rocks leading from the island to the water) of varying sizes.

Figure 4: Exclosure with aluminum flashing on top of chain link fence at Goose Pond Tern Island, southern Indiana. Exclosure at Cane Ridge is the same but without the aluminum flashing.

Cane Ridge Wildlife Management Area (CR)

CR is a federal property actively managed by the U.S. Fish and Wildlife Service. It has two islands, Tern and Ray's, both of which are managed for ILT nesting. Each island is identical: approximately 2.4 acres with substrate made up of sand and gravel and surrounded by riprap. The islands are treated with herbicide in late spring but have some native vegetation that grows in the late summer. Each island is exclosed by a chain link fence (four feet tall) with four strands of electric wire on the outside of the fence, however, due to restrictions imposed by COVID-19 protocols, the electric fence at CR was not repaired and activated in 2020. The islands are in a 50-acre pool of shallow water (about one to three feet deep, depending on the time of year). The

Duke Energy Gibson Generating Station nesting area lies directly north of CR but was not able to be monitored because of COVID-19 and Duke Energy restrictions.

American Electric Power - Rockport (AEP)

AEP Rockport is a coal-fired power plant in southern Indiana near the Ohio River. ILTs nest on gravel dikes that bisect four separate ash ponds to the south of the plant (Figure 6). The South Dike (hereafter, AEP-SD) is a fenced section that is actively managed for ILT nesting. AEP-SD is 1,000 feet long and 20 feet wide, exclosed by a four-foot-tall electric fence made up of four strands (Figure 5). At each end of the dike is a safety fence made up of orange, flimsy snow fencing attached to six-foot-tall U-posts inside the electric fence. All dikes have riprap leading from the road to the water. The other dikes (hereafter, AEP-NF for "no fencing") on the ash ponds have no exclosures aside from wooden barriers with signs to prevent foot and vehicle traffic from entering the nesting area.

Figure 5: American Electric Power- South Dike exclosure from a perimeter trail camera.

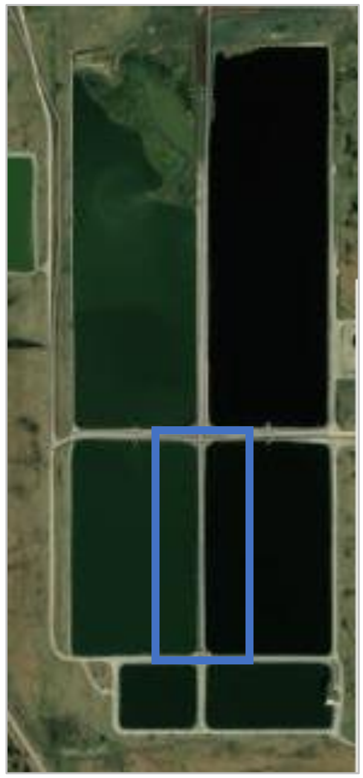


Figure 6: Map of American Electric Power dikes and ash ponds. Blue area is American Electric Power – South Dike which is actively managed for ILT. All other dikes between the ash ponds have been used at some point by Interior least terns for nesting, however, they do not have exclosures around them and are all considered American Electric Power – No Fence. Typically, the dike directly north of American Electric Power – South Dike is most used for additional nesting.

METHODS

Weekly location checks at each colony began the week of 11 May. I and other contractors observed colonies at a distance to check for adults and activity throughout the season. While observing colonies, we counted the total number of adults, chicks, and fledglings seen through the spotting scope or binoculars during our survey time (approximately one hour). When counting adults, we took an average of the total adult count from multiple people (if present) at different times to avoid double counting and to get the best estimate possible.

Objective 1 - Comparing predator detection inside versus outside by exclosure type

To compare predators and predation inside and outside of exclosures, trail cameras (Browning Strikeforce 850HD) were placed inside and outside exclosures at each colony. Four perimeter cameras were placed at AEP. Two were placed at the north and south end of AEP-SD, one inside and one outside (Figure 7). At GP and CR islands, perimeter camera locations were decided by placing the first group of cameras by the gate, then dividing up the area of the islands by thirds to determine placement for the two other groups of cameras (Figure 8).

Cameras were set at a five-second delay between captures and a four-shot standard for each capture, meaning it took four pictures in a row when motion was detected. Memory cards in perimeter cameras were replaced and reviewed monthly. The following data were recorded when reviewing the pictures: date, species of predator, duration on camera, and if there was a predation event on a nest camera that corresponded with the timing (see Methods – Objective 2). If multiple predator events ("events" defined as an identifiable predator detected by camera) occurred in one day on one camera, they are defined as separate events if the predator is a different species, obviously different individual, or if the event occurs 30 minutes after the previous event. Avian predation events were omitted from this analysis because there is no way to exclude other birds from accessing colonies. Exclosure effectiveness was determined by dividing the number of predator events seen outside the exclosure by the total number of predator events (out and in) captured on cameras per location.

Figure 7: Locations of perimeter cameras at American Electric Power – South Dike. Each camera icon represents one camera.

Figure 8: Perimeter camera placement at Goose Pond. Each camera icon represents two cameras, one inside and one outside the exclosure. Both islands at Cane Ridge had a similar setup.

Objective 2 – Determining survival among colonies in relation to predator detection

Pedestrian surveys and trail cameras were used to monitor nests at AEP and CR Ray's Island (CR-RI). GP and CR Tern Island (CR-TI) were not included in the nest monitoring due to no ILT nesting and USFWS protocols, respectively.

Pedestrian surveys at AEP and CR-RI occurred weekly. Prior to walking the colony, we surveyed by spotting scope for the number of adults, any possible new nests, and number of chicks or fledglings. Survey time in the colonies was limited to a maximum of 20 minutes and when the temperature was below 90°F. In that time, we changed memory cards on cameras, checked for new nests, recorded the number of eggs or chicks per nest, and noted anything that could be linked to predation or failure of a nest.

Nest cameras were placed six feet away from every nest found at AEP and CR-RI during incubation. Memory cards were replaced and reviewed once a week. Cameras were set at a five-second delay between captures and a four-shot standard for each capture. The following data were recorded from the pictures: date, nesting activities (e.g., incubating, hatching, chicks present), and any predators present. Nests were considered successful if at least one chick hatched. In some cases, chicks were obviously depredated as seen on cameras after hatching, and those nests were assigned to the "confirmed predation" category but were still considered as successfully hatched. If a predator visited a nest the following was also recorded: species of predator, duration on camera, behavior or events, and if predation occurred (confirmed, probable, or no evidence). Confirmed predation is defined as a predator captured on camera with an egg or chick in its mouth or claws/talons; probable predation is defined as a predator captured on camera with no confirmation of predation, but with eggs or chicks absent at the next site visit; and no evidence is defined as seeing a predator on camera, but no predation occurred as evidenced by eggs or chicks present at the next site visit, or no predator seen on corresponding cameras. If multiple predation events occur in one day, they are defined as separate events if they occur at different nests, if the predator is a different species or obviously different individual, or if the event occurs 30 minutes after the previous event. I estimated productivity (also called fledgling success) as the number of fledglings counted divided by the total numbers of chicks, hatching success (number of chicks counted divided by the total number of eggs), and chick success (number of fledglings counted divided by the total number of chicks). I used the Nest Survival Method (Dinsmore and Dinsmore 2007) in Program MARK to yield Mayfield nest success estimates for each colony. The Mayfield nest success estimate indicates the probability that a nest will survive 21 days to hatching.

Objective 3 – Determining if artificial shelters are a useful tool for increasing fledgling survival

Figure 9: Young Interior least tern chick in shelter.

Artificial shelters were made by cutting white, five-gallon plastic buckets in half lengthwise. We decided on white so that shelters would reflect heat rather than absorb it. While nests were still being incubated, shelters were placed at AEP six to ten feet away from nests in a north/south orientation. If there were two or more nests within six feet of each other, only one shelter was placed. Cameras were placed on shelters once the eggs in the nearby nests hatched. Memory cards were changed and reviewed weekly. During review of pictures the following was recorded: date, time entered and exited the shelter, number of chicks in the shelter, temperature, weather, and any comments about activity or events that may have triggered use. Shelter events were defined as separate if more than 30 minutes occurred of the chick not in the shelter. All separate shelter events were then combined into a total number of hours chick(s) spent in artificial shelters. If multiple chicks were in the shelter, it was treated as if only one was. I assessed the association between hours chicks spent in shelters and temperature with the Pearson correlation test.

Due to USFWS protocols, shelters could not be moved or added at CR-RI. A few terra cotta shelters and pieces of driftwood were left over on the island from the previous year, between 10- to 40-feet away from nests. Data from CR-RI was ultimately left out because of few detections of ILT chicks on cameras overall. I analyzed productivity at AEP between 2019 and 2020 to see if there was an improvement with the addition of artificial shelters.

RESULTS

Objective 1 - Comparing predator detection inside versus outside by exclosure type

The electrified chain link with aluminum flashing exclosure at GP had the highest exclosure effectiveness, 100%, with all predator events detected outside the exclosure (Table 1). The electrified with safety fence exclosure at AEP was the least effective at excluding predators, with an effectiveness of 50%. The chain link only exclosure type at CR-TI and CR-RI had effectiveness of 86 and 76%, respectively. The most frequently detected predator was raccoon at GP, CR-RI, and CR-TI, and opossum at AEP.

	AEP: electrified with safety fencing		CR-RI: chain link only		CR-TI: chain link only		GP: electrified chain link with aluminum flashing	
Species	**In**	**Out**	**In**	**Out**	**In**	**Out**	**In**	**Out**
Coyote	2	0	0	0	0	0	0	3
Mink	0	1	0	0	0	0	0	1
Opossum	4	3	0	0	0	0	0	1
Raccoon	2	3	56	167	26	149	0	130
Turtle sp.	0	1	1	16	0	12	0	8
Totals	***8***	***8***	***57***	***183***	***26***	***161***	***0***	***143***
Exclosure Effectiveness	***50%***		***76%***		***86%***		***100%***	

Table 1: Number of predator observations from perimeter cameras at each colony. Cane Ridge is split into its two separate islands. Each predator species is listed including the totals of all species events. "In" signifies inside exclosures and "out" signifies outside exclosures. Exclosure effectiveness is out/(in+out).

Objective 2 – Determining survival among colonies in relation to predator detection

Mayfield nest success estimates indicated that probability of nest survival to hatching at 21 days was highest at the site with the electrified with safety fencing exclosure type (AEP-SD), and lowest at the site with chain link only (CR-RI; Table 2). When looking at hatching success, the percentage of nests total that survived to hatching, a different representation of success can be seen. Forty percent of nests hatched at the electrified with safety fencing (AEP-SD) and chain link only (CR-RI) exclosure types ($n=6$), and 46.6% in the unfenced area (AEP-NF; $n=7$), which is below the estimates for each location of Mayfield nest success. After hatching, survival estimates decreased with the number of chicks and number of fledglings seen. The six nests in the electrified with snow fencing exclosure type (AEP-SD) produced 17 chicks, which was 44.7% of the total number of eggs; and of those 17 chicks, only one fledgling was seen on cameras and in person, making the productivity the lowest at 0.06 fledglings/pair. The colony at the unfenced area of AEP (AEP-NF) had seven successful nests that produced 15 chicks, 46.8% of the total eggs; and of those 15 chicks, three fledglings were detected, making the productivity slightly higher than AEP-SD at 0.20 fledglings/pair. The chain link only exclosure type (CR-RI) had the lowest number of chicks hatched at only nine out of 38 eggs (23.7%). However, of those nine chicks, four fledglings were detected, making the productivity the highest of the three groups at 0.40 fledglings/pair. Predation at the electric with safety fencing exclosure type (AEP-SD) was the highest, with six out of nine nests with confirmed or probable predation by an opossum, and the remaining three events were by avian predators. Only one nest in the unfenced area of AEP had probable predation, making it the lowest predation rate of the three colonies. Seven nests at CR-RI with chain link only fencing had confirmed or probable predation.

Table 2: Productivity at American Electric Power 'South Dike' and 'No Fence', and Cane Ridge Ray's Island for the 2020 Interior least tern breeding season, May through August.

	AEP-SD: electrified with safety fencing	AEP-NF: no fencing	CR-RI: chain link only
Estimated # of pairs[1]	15	15	10
Total number of eggs laid	38	32	38
Total number of nests	15	15	15
Number of nests successfully hatched	**6 of 15 (40%)**	**7 of 15 (46.6%)**	**6 of 15 (40%)**
Total number of chicks hatched (%)[2]	17 (44.7%)	15 (46.8%)	9 (23.7%)
Total number of fledglings seen (%)[3]	1 (0.05%)	3 (20%)	4 (44.4%)
Productivity (fledglings/pair)	**0.06**	**0.20**	**0.40**
Mayfield estimates			
Daily survival rate ± standard error	0.993 ± 0.006	0.984 ± 0.009	0.974 ± 0.014
Nest success[4] probability	**87.2%**	**71.0%**	**58.4%**
Nest fate			
Number of nests with confirmed predation (%)	**7 (46.6%)**	**0 (0%)**	**4 (26.6%)**
Number of nests with probable predation (%)	**2 (13.3%)**	**1 (0.06%)**	**3 (20%)**
Number of nests with no evidence of predation (%)	3 (20%)	7 (46.6%)	4 (26.6%)
Number of nests abandoned (%)	2 (13.3%)	6 (0.40%)	1 (6.6%)
Number of nests with unknown fate (%)	1 (0.06%)	1 (0.06%)	3 (20%)

[1] Estimated # of pairs is defined by the highest number of nests present at once, indicating how many pairs should have been present. For AEP-SD and AEP-NF the estimated pairs do not reflect the total amount of adults because many of the AEP-NF nests were second nest attempts.
[2] Number of chicks hatched divided by the total amount of eggs laid.
[3] Number of fledglings seen divided by the total amount of chicks hatched.
[4] Daily survival rate raised to the 21st power accounting for a 19 – 25-day incubation period – average in Indiana this year 21 days.

Objective 3 – Determining if artificial shelters are a useful tool for increasing fledgling survival

The first detection of an ILT chick at an artificial shelter at AEP-SD was on 17 July, shortly after several nests hatched. Six chicks spent time in artificial shelters from 17 July to 21 July. During the early morning of 21 July, one of the shelter cameras was triggered by a chick running by, and an opossum was detected a few minutes later. Although there were no pictures that confirmed chick predation during this event, it is likely that it occurred. The opossum returned again the next night, after which just three chicks were seen. Chick numbers appeared to dwindle even more, with only one chick appearing frequently on shelters cameras until 2 August.

At AEP-NF, the first instance of artificial shelters being used is on 24 July by five chicks. Chicks were seen consistently until 31 July, when a great horned owl was detected on shelter cameras. Though there was no confirmed predation, it is likely that any predation event was simply not caught on camera. After 1 August, which was the last time chicks were detected inside an artificial shelter, three chicks were frequently seen walking through the colonies and loafing on other dikes in the area until the end of the survey period.

Chicks spent a total of 49.4 hours in artificial shelters during the 16-day period. Despite the amount of time chicks used the artificial shelters, there was not significant improvement between productivity rates from 2019 to 2020 (0 to 0.20 fledglings/pair) to say that shelters improved productivity.

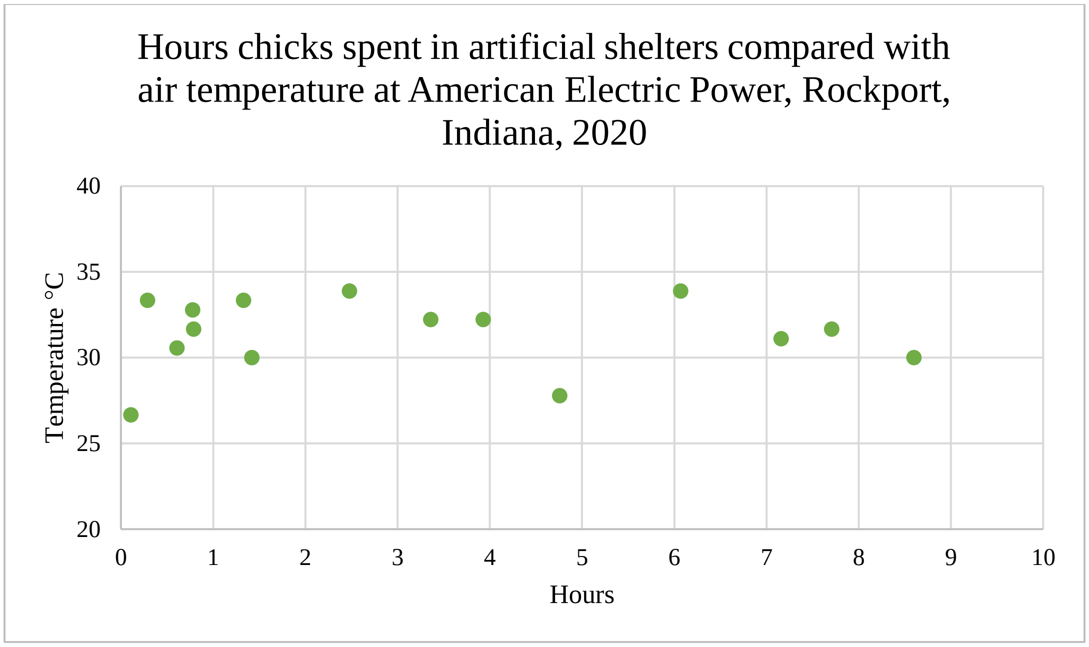


Figure 10: Total number of hours chicks spent in artificial shelters (summed across all chicks) compared with air temperature at American Electric Power in Rockport, Indiana during the 2020 breeding season. There is no correlation between higher temperatures and time spent in artificial shelters.

Air temperatures during the 16-day period artificial shelters were used ranged from 26.6 to 33.8°C (80 to 93°F) and the number of hours chicks spent in a shelter on one day ranged from 0 to 8.6 hours (Figure 10). On the day chicks the most time in shelters (8.6 hours), the air temperature was 30°C (86°F); and on the day chicks spent no time in shelters, air temperature was 31.1°C (88°F). Results from the Pearson correlation test indicate that air temperature and total number of hours chicks spent in artificial shelters was not correlated.

DISCUSSION

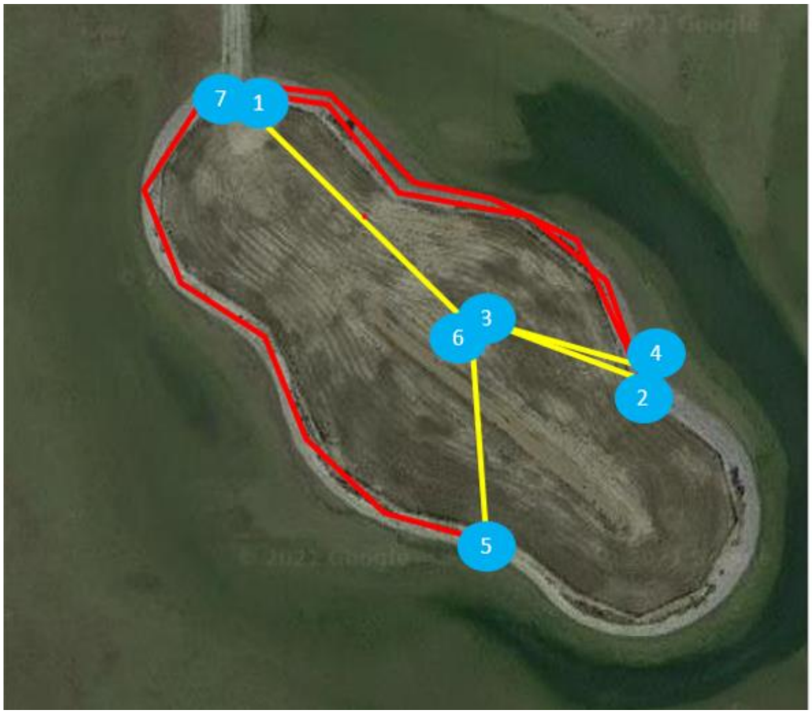
Objective 1 - Comparing predator detection inside versus outside of the different exclosure types

My findings suggest that fence-type may be an important factor for reducing predation rates on ILT colonies. The exclosure at GP was 100% effective, suggesting that electrified chain link with aluminum flashing may be the best way of discouraging predators. Predator rates inside exclosures were also lower than outside exclosures at CR and high at AEP, suggesting that chain link may be an important difference in how effective exclosures are at deterring predators, though more research should be conducted. These results are supported by other studies. In Mayer and Ryan (1991), electric fences were found to improve nest survival by 71%. Lombard et al. (2010), Maslo et al. (2009), Minsky (1980), and Rimmer and Deblinger (1992) all found that nest survival increased with the use of exclosures in general compared to unprotected nests. In my search of the literature, I did not find any other studies that compared the effectiveness of different types of exclosures.

There were several biases that arose within this objective which need to be addressed. First is that no ILTs nested at GP in 2020. Despite several observances of a pair flying over, they ultimately did not settle on the island. However, there was extensive nesting on the island by killdeer (*Charadrius vociferus)* and black-necked stilts (*Himantopus mexicanus*). Killdeer and black-necked stilts have similar nesting strategies to ILTs and may pose as a surrogate species. They also suffer greatly from nest and hatching mortality, despite their anti-predator distraction displays (Nol and Lambert 1984, Sordahl 1996). Second, vegetation at GP grew taller than previous years, up to five feet in some areas, which potentially compromised cameras' ability to detect predators inside and outside the exclosure. Predator detections decreased significantly in July and August when vegetation reached maximum height, compared with almost daily detections in May and June when vegetation was relatively low. Also, due to the large number of pictures taken during each month at CR and GP, several cameras' batteries expired, or the memory cards filled up before the cameras were checked both inside and outside exclosures, effectively truncating the survey period.

At both CR and GP, the main predators detected both inside and outside the exclosures were raccoon (92% of events at both colonies). Raccoons systematically search for their food using smell, sight, and touch; eating what is readily accessible (Zeveloff 2002). For example, Figure 11 illustrates that movements of a raccoon during one night CR-RI. This contrasts to my findings in the preliminary study during 2019, when at least two nests were depredated by a Great Horned Owl and no raccoons were spotted on nest cameras (Espick 2019). Survey effort was much lower, however, with only five nests covered with cameras compared to a maximum of 12 nest cameras plus 12 perimeter cameras out at one time during the 2020 season. Lower survey effort could be a reason for low detections rates of raccoons in 2019.

Many studies have found avian predation to be the highest cause of failure (Andes et al. 2018, Brunton 1999, Burness and Morris 1992, Voigts 1999). At Indiana colonies in 2020, avian predation was responsible for only 16% (2 out of 12) of nest failures and chick mortalities. The remaining were because of opossum at AEP and raccoon at CR-RI.



1 – 11:21 Raccoon captured on gate camera
2 – 12:58 Raccoon captured on camera outside exclosure, eating turtle eggs
3 – 01:32 Raccoon captured on nest camera, appears to be eating least tern eggs
4 – 01:56 Raccoon captured back outside exclosure, 02:03 then back at gate cameras
5 – 02:14 Raccoon captured on camera outside exclosure
6 – 02:30 Raccoon captured on nest camera
7 – 02:37 Raccoon captured inside gate camera

Red line – outside movements
Yellow line – inside movements

Figure 11: Raccoon movements at Cane Ridge Ray's Island on one night. Based on pattern of movement, this is assumed to be one individual. Similar movements were seen throughout the season. Movements 1-2 are outside, 2-4 are inside, 4-5 are outside, and 5-7 are inside the exclosure.

Objective 2 – Determining survival among colonies in relation to predator detection

Mayfield nest success through the hatching stage (21 days) for each colony were typical compared to reviewed literature with a range of 49.4 – 87% (Farrell et al. 2018, Koenen et al. 1996, Kruse et al. 2002, Jenniges and Plettner 2008, Mohlman and Baasch 2019, Nefas et al. 2018, Smith and Renken 1993). At the electric with safety fencing exclosure type (AEP-SD), nest success was limited by predation. An opossum was detected on 18 June and was likely responsible for six of the nest failures during the incubation period. Opossums are omnivores and will opportunistically eat food that is abundant, including eggs (Gardner 1982). The other confirmed predation events happened after hatching, so although nests were successful according to the definition of Mayfield nest success, productivity was ultimately negatively affected. The other nest at AEP-SD was depredated by an American kestrel during the day and great horned owl at night while the chicks were still congregating near the nest. It is likely that more depredation of ILT chicks occurred by these predators that was not caught on camera. Two one-egg nests were abandoned and were never seen being incubated. Of the six nests that successfully hatched, 17 chicks were produced, but out of these, only one fledgling was seen that could have been from an AEP-SD nest. This makes productivity for ILT area protected by electric with safety fencing only 0.06 fledglings/pair, which is equal to the lowest productivity rate found in literature (range 0.06 to 1.60 fledglings/pair) (Jensen 2020, Kirsch and Sidle 1999, Kruse et al. 2002, Mohlman and Baasch 2019). The area with no fencing, AEP-NF, had lower nest success, but mostly as a result of abandoned nests. Interestingly, none of the AEP-NF nests had confirmed predation events and only one probable predation event (Table 2). Six nests were abandoned, and because incubation was never observed at these nests, I presumed the birds may have left the colony. Two new nests were found at the end of July, but on 6 August, a striped skunk (*Mephitis mephitis*) visited the colony and although no egg predation occurred, ILT adults were not seen afterwards. The successful nests produced 15 chicks and three fledglings, with a productivity of 0.20 fledglings/pair. While this is still a low level of productivity, it was higher than AEP-SD (electric with safety fencing). The average for the whole colony (AEP-SD and AEP-NF) was 0.13 fledglings/pair, which was higher than 2019 when the productivity was 0 fledglings/pair. One factor that could have contributed to this is that in 2019 a coyote decimated the colony right at the time most of the nests hatched. In 2020, the coyote visited at approximately the same time as the year before, but all of the nests were still being incubated. It is possible that this coyote prefers chicks rather than eggs and that it remembers the approximate time chicks are present, or that it hears chicks begging for food and locates them that way. The chain link only exclosure type (CR-RI) had the lowest Mayfield nest success at 58.4% but the highest productivity (0.40 fledglings/pair). Each of these groups is below the threshold of 0.51 fledglings/pair required to maintain a stable population as reported by Kirsch (1996). While still in the low range for ILT productivity, it suggests that there is some variable about the CR islands that makes chick survival higher, whether that be shelter (natural and artificial), the exclosure type, predator composition, or something not considered in my study.

When putting into consideration the results of predator rate from Objective 1, some sense can be made of why productivity (fledging success) was lower at sites with electric with safety fencing (AEP-SD) and no fencing (AEP-NF) than chain link only (CR-RI). Fifty percent of all predator events captured on camera at AEP-SD occurred inside the exclosure, while at CR-RI only 23% occurred inside the exclosure (Table 1). A change in the rate of predation from nest stage to fledging provides a reasonable explanation for initially high nest success, followed by a decline in number of chicks until fledging. Something else of note is that only 16 predator events were detected at AEP-SD (electric with safety fencing), whereas CR-RI (chain link only) had 240. The automatic assumption might be that higher predator detection would lead to lower productivity, but from these two areas we can see that that is not the case. This illustrates the fact that it only takes one predator event to destroy a colony and a high number of predators does not necessarily indicate that a colony will have low productivity. Productivity has been found to be extremely variable from year to year in the same locations (Kirsch and Sidle 1999). Many studies have found mammalian predation to be a major limiting factor on nest and chick survival (Hill 1985, Jenniges and Plettner 2008, Kruse et al. 2002, Smith and Renken 1993), while others have found avian predation to be more significant. Location and predator composition differences are likely to be a cause of poor nest and chick survival. With this in mind, it provides further that an exclosure made of electric with safety fencing, as at AEP-SD, is less effective at deterring predators than the chain link only exclosure at CR-RI.

Several undetected predators could have been responsible for low productivity as well. In one study, black-crowned night herons were responsible for 43% of nest failures, a previously known predator of ILTs at Gibson Lake (Brunton 1999, Johnson and Castrale 1993). However, I do not think black-crowned night heron contributed to depredation of ILT at AEP or CR because the last report of any at both locations are from 2018 (eBird 2021). Snakes have also been seen at colonies before but may not consistently be detected by cameras (Williams 2019). However, one study of a wildlife underpass had 275 detections of snake species on trail cameras indicating that cameras may be sufficient enough to detect snakes depending on the settings used (Pomezanski and Bennett 2018).

Other factors in addition to predation also contribute to chick mortality. At AEP, due to the steep nature of the riprap extending from the dikes to the water, it is possible that young chicks could get stuck in the riprap or fall into the water and perish. Chicks are often seen walking along and taking shelter in the riprap. High temperatures may also be a cause of chick failure as chicks have a limited ability for thermoregulation (Farrell et al. 2018, Hill 1985, Howell 1959, Krogh and Schweitzer 1999). Adult ILTs provide shade and cooling to eggs and chicks by standing over them or dripping water from the belly feathers onto them (Jackson 1994, Tomkins 1942). However, average temperatures during the 2020 season in Tell City, Indiana near AEP and Princeton, Indiana near CR, were similar to average historical temperatures from May to August (The Weather Channel 2021, U.S. Climate Data 2020). Surface temperatures on the dikes and islands can get much higher, up to 134°F (56.6°C), but the exact temperature which could be dangerous to chicks is unknown. Flooding is often cited as the main cause of nest and chick failures in locations that are more similar to historical habitat (Hill 1985, Koenen et al. 1996, Schweitzer and Leslie 2000, Smith and Renken 1993, Whittier and Leslie 2009); and Farrell et al. (2018) found that weather variables accounted best for how well nests survived. Flooding occasionally occurs at CR, however, since the water levels surrounding the islands can be managed it is not typically a problem. Despite many instances of heavy rain in 2020, no cameras captured nests or chicks being washed away because of it. Given all of these factors, it is my belief that predation is the leading cause of ILT chick mortality, and future management should continue to address ways to protect from this, such as improving fence exclosures and amount of cover.

Objective 3 – Determining if artificial shelters are a useful tool for increasing fledgling survival

Previous studies have shown that artificial shelters can increase productivity and survival in young birds (Burness and Morris 1992, Jenks-Jay 1992, Lee et al. 2006, Maguire et al. 2011, Voigts 1999). However, my single-year study of artificial shelters did not yield enough evidence to suggest that they improve productivity. While productivity was higher than 2019 (0 to 0.40 fledglings/pair) it was still not close to the numbers and productivity that was seen between 2013-2015 (Figure 12). 2013 was the first year that electric fencing was used to exclude predators at AEP, which was a record year for nesting for all colonies in Indiana with 255 adult ILTs. In 2016, productivity began to decline at AEP, despite setting a new record of nesting ILTs in the state at 292. The exact cause of this decline in productivity is unknown because camera trap studies and more frequent monitoring surveys were not started until 2019. It is possible that 2016 is the year the coyote and other predators began to seek out the colony as higher numbers of adults were present. While coloniality in birds is often thought to have evolved because more birds can mean better, more efficient antipredator behaviors; it has been found that coloniality does not necessarily protect birds and may actually increase predation risk (Varela et al. 2007). If predators became aware of the ILT colony at AEP while adult numbers were high, they could potentially remember the location and timing and continue to depredate the colony despite the decrease in numbers (Errington 1943, Gardner 1982, Lehner 1976, McMillian 1998, Zeveloff 2002).

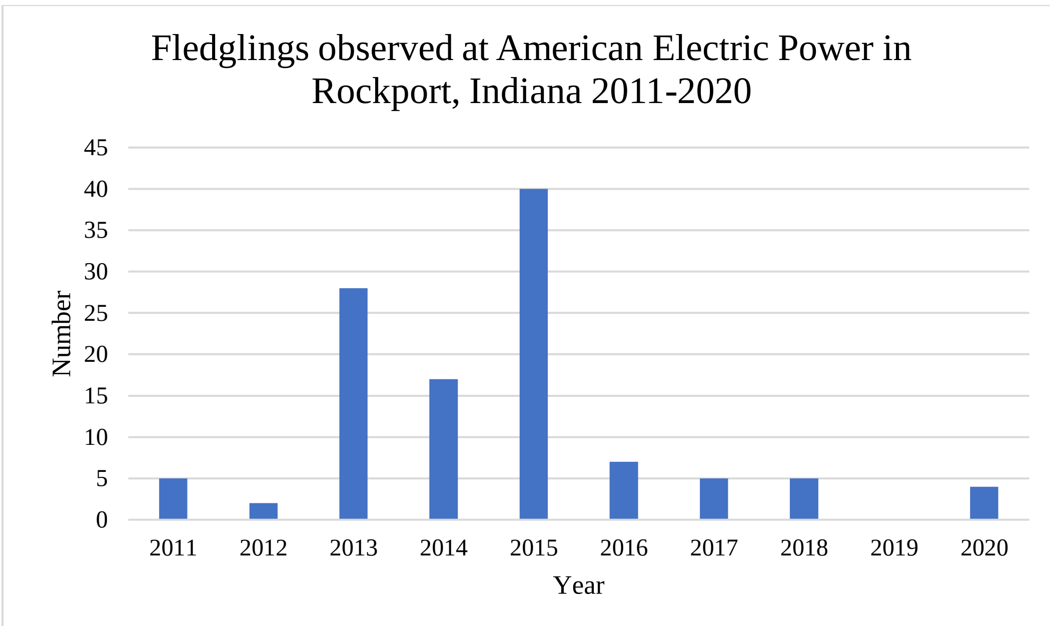


Figure 12: Fledglings observed at American Electric Power for the past 10 years. Fledglings seen from 2013-2015 were at an all-time high but numbers decreased sharply after that.

Studies have shown that chicks use shelters more frequently during extreme temperatures or weather events (Butcher et al. 2007, Maguire et al. 2011). However, I did not find evidence for an association of ILT chick shelter use and air temperature at AEP. Temperatures for these studies varied more (9.8 to 60.0°C) than the ones found in Indiana (26.6 to 33.8°C) when chicks were spending time in artificial shelters, so it is possible that the relative consistency of temperatures led to no correlation between hours spent in artificial shelters and temperature

(Butcher et al. 2007, Maguire et al. 2011). Although air temperature was not associated with chick use of artificial shelters, with 77 events and a total of 49.4 hours of chicks in shelters (Figure 10), it is clear that they provided some benefit and are therefore a useful tool for the protection of ILT chicks.

An interesting aspect to consider in the future is the lack of observations of chicks in artificial shelters at CR-RI versus AEP. Due to COVID-19 protocols, artificial shelters could not be added or moved at CR. A few artificial shelters were left over from the previous season. At AEP, the goal was for maximum shelter use so artificial shelters were placed within six feet of nests. Artificial shelters at CR ranged from 10 to 40-feet away from nests. Only six observations of two young ILT on two days occurred at CR. CR has much more natural shelter in the form of emerging vegetation than AEP does. At AEP, there is only one small area of vegetation. The only other form of natural shelter is the riprap on the sides of the dikes. A few studies have shown that chicks prefer natural vegetation over artificial shelters, which could indicate that late summer vegetation is more important at CR (Butcher et al. 2007, Kruse et al. 2002). Something else to consider is that placement of artificial shelters matters. All shelters placed near nests at AEP were used, whereas at CR there were no shelters within six feet of nests and very few observations of shelter use recorded. Compared with the 77 observations at AEP, this could suggest that artificial shelter placement is important for use and that artificial shelters placed closer to nests will be used more. More studies are needed to determine the effects of more extreme temperatures, shelter distance from nest, and availability of alternative natural cover on chick use of shelters.

CONCLUSIONS

Management of ILTs in Indiana has had many differing opinions and management strategies throughout its tenure. In order for ILT to return to their overall high productivity, management strategies need to be based on proven methods. Experienced managers of wildlife often do not base their decisions on scientific evidence and were found to be less likely to change their practices (Walsh et al. 2014). It is especially important to base decisions on proven methods or empirical data when dealing with a vulnerable population, as is the case for Indiana ILTs. While ILT populations throughout their range have increased tenfold, the colonies in Indiana remains vulnerable as is evidenced by the variation in numbers and survival rates since they started nesting in the state in 1986. The goal of most management plans may be to improve numbers so that conservation efforts can decrease or be stopped completely, however, this is unlikely to occur for this population of ILTs. ILTs in Indiana are likely a “conservation reliant” population, a species that will require some form of conservation management for the foreseeable future (Scott et al. 2010). All habitat that they nest on is human created which in and of itself warrants some type of management. The InDNR does not typically produce management plans for species, however, in the case of ILTs this might be something to take into consideration. A specific management plan can create concrete goals and possible exit strategies for decreasing monitoring effort. My hope is that this study will serve as a baseline of knowledge for management practices and best practices moving forward.

While this study did not employ experimental methods, the results nonetheless provide valuable insights into factors affecting nesting productivity and survival that can inform the management of ILTs in Indiana. With each type of exclosure represented only at one site, the results are not definitive, but my results suggest that electrified chain link with aluminum flashing is most likely to be effective in protecting nesting ILTs against terrestrial predators. Predator rate with electric with safety fencing at AEP was the highest among the three locations, possibly suggesting that exclosures comprised of only electrified with safety fencing does not effectively deter predators. Predation has been an issue at AEP for a few years, and in fact, the exclosure type is being changed for the 2021 breeding season. The new exclosure uses electrified gates at either end of the dikes, extending into the water and tall enough so that predators cannot jump over and is based on one that was employed at Gibson Station last year, at an area of dikes that is similar to that of AEP's. This new type of exclosure is thought to have been extremely successful, with a reported 30 fledglings and a productivity of 2.5 fledglings/pair, a substantial increase from the previous year at this location (4 fledglings at 0.15 fledglings/pair; Mills 2020). It was discovered this year at AEP that predators were simply walking along the riprap and entering the colony when there was space enough between the electric strands to get in. The implementation of these new exclosure gates will hopefully prevent predators from walking along the riprap to access the colonies.

Another change that will be occurring despite good results is that the flashing at GP will be removed. While it did likely play a role in the 100% exclosure effectiveness, it did not fare as well as expected in the wind and storms during the summer. The flashing had to be repaired in some spots every visit, which if ILTs were present, would be impossible to do based on the 20-minute time limit for pedestrian surveys. Because the exclosure effectiveness at CR was 76-86% without electrification, it is my belief that the electric fencing used at GP should be enough of a predator deterrent without aluminum flashing. This hypothesis should be tested in a future study.

Despite no empirical evidence that artificial shelters improved survival among ILTs, they will continue to be utilized in management. The number of events of chicks in artificial shelters exceeded my expectations at AEP and combined with promising results from other studies, it makes sense for management of ILTs to continue putting them out. Artificial shelters may be more important at locations with bare substrate similar to AEP, rather than islands with natural vegetation and driftwood cover such as CR and GP. If after the 2021 season, more evidence is found to suggest that artificial shelters do not improve survival, then a different shelter strategy may be needed. This could be in the way of a different shelter design, artificial vegetation or plants, driftwood, or rock piles. With evidence from other studies and the number of hours chicks spent in artificial shelters at AEP, I believe that they will be an important management tool for as long as ILTs nest in Indiana.

If the InDNR and their partners want to continue ensuring that ILTs nest successfully in Indiana, management will likely always continue. A comprehensive management plan could ensure that monitoring and protection of ILTs is simple and effective. This management plan should cement goals, provide explicit monitoring directives, and continue to test the effectiveness of predator exclosures and artificial shelters. It should be adaptive to allow for revision of goals, transition of monitoring, and outline exit strategies should the program need to be terminated. Future management goals should also outline new areas of research to be completed and potential habitat creation. The factors that ILTs use to decide on habitat in Indiana is relatively unknown, and a detailed study of habitat preferences could help managers create new colony locations that may naturally provide more protection from predation. While the presence of ILTs historically in Indiana is up for debate and less than one percent of the entire ILT population may not seem important - for a species that was just removed from the Endangered Species Act, all distinct population segments are important. Managing distinct populations is even more important if the genetic diversity of all Least Terns in North America has continued to decline as was found by Draheim et al. (2012).

FUTURE MANAGEMENT

It is my recommendation that future management for ILTs in Indiana should include:

1. Continuation of this study of exclosures, artificial shelter use, and survival to determine if any adjustments need to be made to exclosures and artificial shelters, or to implement any other methods of predator deterrence.
2. Continuation of current monitoring methods.
3. Development of population goals and methods used to determine when the population is stable.
4. Development of a less intensive monitoring plan when populations are stable.
5. Open dialogue between InDNR and project partners; specifically, American Electric Power and Duke Energy should the coal-fired power plants be decommissioned.
6. A detailed habitat preference study to outline key features for safe habitat that is more in line with historical ILT nesting and to lead to the creation of new habitat.
7. Discussion of banding adults and chicks to determine site fidelity; tagging of individuals to determine migratory patterns and connectivity, an area of all Least Tern populations that is unexplored.

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