Spring 2023

MS ENVIRONMENTAL BIOLOGY CAPSTONE PROJECT

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MS ENVIRONMENTAL BIOLOGY
CAPSTONE PROJECT

by

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A Project Presented in Partial Fulfillment
of the Requirements for the Degree
Masters of Science
in Environmental Biology

REGIS UNIVERSITY
May, 2023

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has been approved

May, 2023

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The Kemp's ridley sea turtle: A comprehensive review of human-induced threats

Introduction

Widely recognized as the most endangered sea turtle species, efforts to safeguard Kemp's ridley from extinction have been ongoing since the 1960s (NOAA). Population size has declined dramatically since the 1940s when roughly 40,000 females were captured on film in a single day engaging in "arribada" nesting (Wibbels & Bevan, 2016), with an estimated 99.4% decrease between 1947-1985 (Wibbels & Bevan, 2019). The restricted distribution and complex life stages (NMFS and US Fish and Wildlife Service) of this highly migratory species make them especially vulnerable to a host of outside threats, furthering their population's decline. This decline is largely attributed to anthropogenic sources such as fishing gear, coastal development, climate change, and pollution which consequently result in their injury or mortality. Despite implementing a binational plan specifically designed to protect them (NMFS and US Fish and Wildlife Service), the current population size of Kemp's ridley remains unsustainable (Turtle, K. S. R. S, 2015). This paper serves as a comprehensive review of the major anthropogenic sources that restrict the population growth of the Kemp's ridley sea turtle. The following assessment identifies the major human-induced threats to this species and subsequently advises the direction of future research. This review is structured into five key sections *(i) History, (ii) Life Stages, (iii) Distribution/Migration, (iv) Major Anthropogenic Threats,* and *(v) Future Research.* Ultimately, future research for the conservation of the Kemp's ridley should focus on (1) the developmental response to warming temperatures, (2) the impacts of coastal development near primary nesting beaches, (3) the effectiveness of TEDs in bycatch reduction for varying vessels, and (4) the effectiveness of current regulations to mediate incidental impacts from oil exploration and extraction.

History

Until the establishment of a secondary nesting colony in Padre Island National Seashore, Texas (PAIS), Kemp's ridley nesting sites were exclusively restricted to shores along the Gulf of Mexico (GoM) (Shaver et al., 2020; Wibbels & Bevan, 2016). A joint effort between Mexico and the US established the PAIS colony in 1978 to help sustain the species in the event of a natural or human-induced catastrophe along their primary nesting site in Tamaulipas, Mexico (Shaver et al., 2020). The two countries then implemented a binational recovery plan in 1984, which was revised in 1992 and 2011 (NMFS and US Fish and Wildlife Service). The recovery efforts in the latest 2011 revision are primarily focused on enforcing the protection of nests and their associated habitat, increasing hatchling survival, decreasing mortality in gill-net fisheries, maintaining the regulated use of turtle excluder devices (TEDs) in previously established fisheries, and expanding TED-use to the necessary trawl fisheries (NMFS and US Fish and Wildlife Service). However, the current recovery goals and strategies of the plan were based on a predicted continual exponential increase in population growth. This revision does not consider the sharp decline in Kemp's ridley nesting sites that began in 2010. While the 2010 Deepwater Horizon oil spill is the most likely cause of this decline, - (Wibbels & Bevan, 2016), others argue that the timing of the oil spill would have had little impact on 2010 nesting sites (Turtle, K. S. R. S, 2015), and thus speculate that there are additional unknown factors contributing to this species' regression. The basis of the binational plans recovery goals and strategies, along with the unknown causes for the current stagnancy (Turtle, K. S. R. S, 2015) of Kemp's ridley nesting sites, calls for an updated policy if there is any hope to delist this critically endangered species in the future.

At the domestic level, NOAA Fisheries and the U.S. Fish and Wildlife Service (USFWS) co-maintain the responsibility of sea turtle protection under the Endangered Species Act (ESA). NOAA is responsible for regulating sea turtle conservation and recovery efforts in the marine environment, while the USFWS regulates nesting beaches (NOAA). Current efforts to conserve sea turtles at this level include habitat protection, bycatch reduction, rescue/rehabilitation, and efforts to eliminate turtle disturbance on beaches and foraging habitat (NOAA). Current regulations require the use of TEDs for the following: most shrimp fisheries, any vessel using otter trawls, and vessels 40 ft or greater using skimmer trawls (NOAA). Smaller skimmer trawl vessels can also utilize TEDs as an alternative to complying with maximum tow time limits (NOAA). This document does not encompass proposals that were made in 2016 to extend this rule to various gear types due to push back from fisheries and insufficient data for other types of vessels (NOAA). Further studies to address how these other gear types (e.g., small skimmer trawls, pusher-head trawls, wing nets) impact the Kemp's ridley population are necessary to support the required use of TEDs for all fishing vessels.

Distribution

Nesting sites for the Kemp's ridley are found almost exclusively along the Gulf of Mexico coastline, with 80-90% concentrated in Rancho Nuevo, Tamaulipas, Mexico (Shaver, 2020). Roughly 1% of their annual nesting takes place within the secondary nesting colony in Padre Island, Texas (Shaver et al., 2016), with rare nesting occurrences observed in other parts of Texas, Florida, Alabama, Georgia, and the Carolinas (NMFS and US Fish and Wildlife Service). While the range of Kemp's ridley extends to the northwest Atlantic Ocean (with observed isolated occurrences along the northeast), their presence in US waters is only seasonal (Renaud et al., 2005).

Life stages/Migration

The life history pattern of Kemp's ridley can be characterized by three fundamental ecosystem zones: terrestrial, neritic, and oceanic (NMFS and US Fish and Wildlife Service). Females reach maturity at around 12 years of age and return to shore every 1-3 years (Snover, 2002) between April-July to nest, laying on average 2.5 nests per season (NMFS and US Fish and Wildlife Service). Eggs hatch roughly 45-58 days following oviposition, though hatchling emergence can vary due to incubation conditions such as temperature (NMFS and US Fish and Wildlife Service). Upon hatching, their movement and distribution are widely dependent on environmental factors such as currents and winds, but magnetic orientation cues can aid in their positioning and therefore, their successful transport (Bolten, 2003). The first two years of juvenile development occur within the oceanic zone, remaining primarily in the northern and western GoM or the Gulf Stream of the Northwest Atlantic (NMFS and US Fish and Wildlife Service). Skeletochronology techniques used to determine the timing of these ontogenetic shifts have shown that juveniles then move from the oceanic to the neritic zone, settling into nearshore areas within the GoM and the Northwest Atlantic (Snover, 2002). As adults, Kemp's ridley continue to inhabit these shallow areas. While this stage primarily resides in the GoM, they are periodically spotted along the US Atlantic coast in water less than 40 meters deep (NMFS and US Fish and Wildlife Service).

The oceanic-neritic developmental pattern of the Kemp's ridley is also observed in the Loggerhead sea turtle, whose life history pattern has been extensively studied (Bolten, 2003; Bolten, 2011). A stage-based population model found that novice and mature breeders have the highest annual survivorship and fecundity compared to all other life stages of Loggerhead turtles (Crouse et al., 1987). While adults prove critical for population growth, Crouse et al. (1987) argue that very few turtles make it to this stage to reproduce, and therefore advocate for conservation efforts of larger juveniles to improve reproductive value at the adult stages. Later studies further recognize the significance of these older life stages (larger juveniles and adults) in promoting the highest population growth in sea turtle species (Bolten et al., 2011; Heppell, 2005; Gerber & Heppell, 2004; Grand & Beissinger, 1997). Applying this model to Kemp's ridley, conservation efforts geared towards reducing mortality in more developed stages can further aid in population recovery.

Climate change

Impacts from climate change, specifically those occurring as a consequence of global warming, extensively threaten the conservation of Kemp's ridley. Projected increases in temperatures and sea levels have the potential to decrease hatchling rates, reduce accessible nesting habitats, and cause disproportionate sex ratios (Griffin et al., 2019). Sex determination in Kemp's ridley is temperature dependent, which results in skewed sex ratios- producing more females at higher temperatures (Tomillo & Spotila, 2020). The thermosensitive period refers to the embryo's middle third of development at which sex determination occurs (Turtle, K. S. R. S, 2015). During this period, an equal proportion of males and females are produced at temperatures around 30 °C, though this temperature is slightly higher for Kemp's ridley compared to other sea turtle species (Turtle, K. S. R. S, 2015). A study performed by Leblanc et al. (2012) on sex-determination of the Kemp's ridley found that temperatures at or greater than 32.5 °C produced 100% female hatchlings, while temperatures below 29 °C resulted in mostly male hatchings. The upper thermal limit for embryo development is estimated to be around 35

°C (Ackerman, 1997). The impact of rising temperatures on hatchling success has further been studied in Loggerheads, with growing temperatures resulting in a short-term increase in the number of nests as more females are produced (Laloe et al., 2017). However, with predicted air temperatures expected to be 1.5-2.9 °C warmer during the months of embryo development by the year 2100, - researchers predict a drastic decrease in nest abundance within the next century as temperatures will begin to enter the upper thermal tolerance limit for incubation (Laloe et al., 2017). While it is likely that this relationship is applicable to related species such as the Kemp's ridley, there is limited data to confirm this connection.

Another long-term consequence of climate change for this species is cold-stunning events. Looking at cold-stunning events for Kemp's ridley in the Northwest Atlantic, Griffin et al. (2019) found that warmer sea surface temperatures are pushing younger juveniles farther north along the Atlantic coast for neritic development grounds. This movement is consequently leading to an increase in cold-stunned turtles as they struggle to migrate back south before winter temperatures drop. While the number of cold-stunning events currently has minimal impact on Kemp's ridley population size, Griffin et al. (2019) argue that these events will only become more common as sea surface temperatures (SST) continue to rise.

Coastal Development

Urban development along coasts can directly affect turtle populations by introducing artificial light that disorients post hatchlings dependent on visual cues to find the ocean (Stanley et al., 2020; Bolten, 2011) and deters nesting females from coming onshore, which could subsequently lead them to choose less hospitable nesting sites for oviposition (Deem et al., 2007). Further, the expansion of coastal development can indirectly affect their population by increasing human presence and activities which can consequently attract predators that feed on eggs and hatchlings (NMFS and US Fish and Wildlife Service). Despite serving as a major anthropogenic threat for sea turtle species, there is limited data available on coastal development within the Kemp's ridley limited nesting range. Rancho Nuevo, Mexico is relatively undeveloped and as a result anthropogenic stresses are minimal on this prime nesting spot for Kemp's ridley (Turtle, K. S. R. S, 2015). However, nesting females are increasing their distribution farther north and south of Rancho Nuevo where larger and more commercialized cities are present, which will likely make these nesting sites more prone to impacts of coastal development (Turtle, K. S. R. S, 2015). The secondary nesting site for Kemp's ridley in PAIS is unlikely to be significantly impacted by coastal development being that it falls within protected public lands (Turtle, K. S. R. S, 2015). This is further supported by Fuentes et al. (2016) who analyzed the impact of coastal development in the US on four sea turtle species (Kemp's ridley, Loggerhead, Green, Leatherback) and found that high density nesting areas for the Kemp's ridley (including only those in Texas) were not exposed to coastal development. Though impacts of coastal development appear relatively insignificant in primary Kemp's ridley nesting habitat, impacts on population growth will become more visible as this species distributes further from their prime nesting range.

Pollution

The GoM is a hotspot for offshore oil extraction, making the Kemp's ridley population especially vulnerable to accidental spills due to having only a single primary nesting beach. Though the DWH oil spill was initially hypothesized to cause the stunt in population growth for this species, it has since been deemed inconclusive (NMFS and US Fish and Wildlife Service). Twelve hundred sea turtles were recovered (alive and dead) from the DWH oil spill, 70% of which were Kemp's ridley (Turtle, K. S. R. S, 2015). While the oil spill is an unlikely cause of the 2010 decline in nesting, the spill could affect Kemp's ridley turtles in the future, subsequently shifting the population's age distribution (Caillouet, 2014). Researchers have also speculated that events such as oils spills could indirectly affect this species by reducing prey availability and disturbing habitat and major foraging grounds (Shaver, 2020; Shaver et al., 2016). For instance, juvenile Kemp's ridley regularly use floating Sargassum algae, accumulated via surface convergence zones, in open water habitat as a source of protection, foraging, and rest (Shaver et al., 2016). Witherington et al. (2012) found that the three juvenile Kemp's ridley in their study averaged most of their time spent within pelagic Sargassum habitat (97% during the day, 87% at night). A later study by McDonald et al. (2017) found that the DWH oil spill led to aggregated floating oil within these Sargassum habitats. Time spent in these habitats coupled with broad diets increases these turtles' chances of ingesting harmful material, such as petroleum and other inedible matter (McDonald et al., 2017).

Commercial/Recreational Fishing Gear

Despite the proven effectiveness of TEDs (Valdivia et al., 2019; Shiode & Tokai, 2004; Lewinson et al., 2002), very few vessels are required to use them. Kemp's ridley have the highest injury and mortality rate for skimmer trawl fisheries (Turtle, K. S. R. S, 2015) out of all sea turtle species. TEDs were not required for skimmer trawls until the year 2021, which today still only applies to vessels 40 feet or greater (Sea Turtle Conservation, 2019). Tow time restrictions are used as a mitigation effort for sea turtle bycatch in these smaller vessels not required to use TEDs, however, data have shown that these times are frequently exceeded (Gahm, 2019). The regional fisheries that do strictly follow these extensive regulations (i.e., shortening gillnet lengths, reducing the amount of time gillnets are in place) are the ones taking the brunt financially (Putnam et al., 2020). Putnam et al. (2020) found that despite the restrictions placed on the gillnet fishery in NC, reported catch per trip of Kemp's ridley from 2001-2016 increased by over 300%. Though these regulations prove effective in increasing reproductive output, management to limit fishing will also continue to strengthen as bycatch increases. An internet survey quantifying expert opinion on the anthropogenic hazards to sea turtle populations at the regional level found that fisheries bycatch and coastal development are the leading human-induced threats to the Kemp's ridley population in a geographic region (Donlan et al., 2010). While these results exclude the bulk of the Kemp ridley population in the GoM, they provide insight into the human-induced factors that are likely limiting the Atlantic population. Fisheries also threaten Kemp's ridley inhabiting the GoM (Heaton et al., 2016). Shaver et al. (2017) found that the nearshore waters of the western GoM are essential inter-nesting habitat for this species that frequently overlap with areas used for shrimp trawling (as well as oil and gas extraction).

The impact of recreational fishing on Kemp's ridley populations should also not be overlooked. Juvenile and subadult turtles that used estuarine foraging habitats in the Northeastern GoM during warmer months were often captured via hook and line and recaptured upon release (Rudloe, 2005). This issue is further illustrated in a study by Heaton et al. (2016), where radiographs of 882 Kemp's ridley turtles rehabilitated from the Mississippi Sound over a three-year period showed that 12.5% had previous interactions with anglers and 864 were bought into the facility specifically for treatment related to recreational fishing and contact with hooks and lines. The stress caused by interactions with hooks and lines can potentially lead to decreased survival and growth rates (Witzell & Schmid, 2004).

Conclusions

Understanding the impacts that human-related activities have on this highly endangered and charismatic species is key to mitigating these disturbances. While the impacts of rising temperatures on nest abundance have been studied in other turtle species (Laloe et al., 2017), similar analyses are lacking for the Kemp's ridley (Howard et al., 2014). To bridge this knowledge gap, future studies should explore the relationship between Kemp's ridley hatchling survival rates in relation to varying temperatures. Understanding this species' adaptability to increased temperatures, specifically within their primary nesting grounds, is essential for creating future management interventions for their preservation.

Pollution also serves as a major disturbance to Kemp's ridley populations (Turtle, K. S. R. S, 2015). This species' limited range and the inability to predict the timing or intensity of these disturbances makes Kemp's ridley especially vulnerable to pollution. The GoM is currently a prime area for high-density oil exploration and extraction, though regulations to mediate these incidental impacts are currently in place (NMFS and US Fish and Wildlife Service). The effectiveness of current implementation (i.e., mandatory use of 500-m exclusion zone, monitoring, strategic placement of spill cleanup equipment (NMFS and US Fish and Wildlife Service) to limit impacts on sea turtle species should therefore be an area of future study.

Coastal development can negatively impact the Kemp's ridley population as they distribute farther outside of these protected prime nesting sites. Observed Kemp's ridley nests outside of Rancho Nuevo and PAIS should be a focus of future study to determine the extent of human impact from coastal development. Continuing to monitor and regulate these primary terrestrial habitats for the Kemp's ridley is essential to maintain their population.

While extensive research has been directed towards commercial fisheries bycatch, there is still a lack of data analyzing the effects of bycatch and its reduction techniques for artisanal fleets and small-scale fisheries (SSF) (Wildermann et al., 2018; Turtle, K. S. R. S, 2015). Future research should also be directed towards the effects that TEDs have on SFF if there is any chance in extending their mandated use to all vessels. Immediate management efforts and changes to legislation should focus on increasing monitoring and inspection in vessels not required to use TEDs. Enforcing implementations put in place for these vessels is crucial for these methods to be effective, while also limiting increased regulations on larger fisheries who are strictly following current guidelines. This review should serve as a catalyst for future research that will help shape more effective policies to protect the Kemp’s ridley population moving forward.

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CHAPTER 2. GRANT PROPOSAL

Reducing Kemp's ridley bycatch in the Southeast Region: Mandating turtle excluded devices (TEDs) as a strategy for conservation

Section 1. Abstract

Kemp's ridley sea turtles (*Lepidochelys kempii*) are a keystone species that play a vital role in maintaining their environment's health and sustainability. Yet, despite continued federal protection over the last fifty years, Kemp's ridley remains the most imperiled sea turtle species (NOAA). The largest threat to this species' recovery is accidental bycatch in commercial and recreational fishing gear (NOAA). Throughout their restricted range in the Gulf of Mexico (GoM) and northwest Atlantic Ocean, Kemp's ridley experience more interaction with fisheries than any other sea turtle species (Finkbeiner, 2011). In particular, shrimp fisheries operating in the Southeast region are estimated to capture 76,954 Kemp's ridleys annually, and approximately 60% (44,247) of these captures results in death (Turtle, K. S. R. S, 2015). To date, there is insufficient research on turtle excluder device (TED) effectiveness in limiting sea turtle bycatch that would help extend the mandated use of TEDs on skimmer trawl (less than 40 ft), pusher-head trawl, and wing net (butterfly trawl) vessels operating within the Southeast region (Shaver et al., 2015; Seney and Landry, 2011). I plan to help bridge this knowledge gap by conducting a cooperative study with small commercial fisheries using shrimp trawlers, employing skimmer nets both with and without TEDs to determine their effectiveness in limiting sea turtle bycatch at two identified Kemp's ridley hot spots. The knowledge gained from this study aims to provide further evidence in support of the mandated use of TEDs in smaller skimmer trawls to sustain the Kemp's ridleys population and potentially other sea turtle species present throughout this range.

Section 2. Anticipated Value, Literature Review, Objective, & Hypotheses

Anticipated Value

Sea turtles are not only vital in preserving the marine food chain (Luschi et al., 2006), but they also introduce a significant amount of nutrients and energy into coastal environments via egg deposits (Lovich et al., 2018; Bouchard & Bjorndal, 2000). As one of the only two sea turtle species that engage in arribada nesting, Kemp's ridley populations likely contribute an even greater amount of nutrients and energy to beach ecosystems than other species (Bouchard & Bjorndal, 2000). These turtles play an integral role in both marine and coastal ecosystems, and it is crucial to address the knowledge gaps and research needs to implement effective sea turtle conservation strategies. The anticipated value of this research is to advocate for the mandated use of TEDs in small skimmer trawl vessels operating throughout the Kemp's ridleys primary range. Further, this research could also be beneficial for other sea turtle species that share similar life history traits and habitats with the Kemp's ridley.

Literature Review

The early life history of Kemp's ridleys is primarily restricted to the northern and western GoM or the Gulf Stream of the Northwest Atlantic, with the first two years of juvenile development occurring within the oceanic zone (NMFS and US Fish and Wildlife Service). Skeletochronology techniques used to determine the timing of these ontogenetic shifts show that juveniles then move from the oceanic to the neritic zone, settling into nearshore areas within the GoM and the Northwest Atlantic (Snover, 2002). As adults, Kemp's ridley continue to inhabit these shallow areas. While this stage primarily occurs in the GoM, turtles in this stage are also periodically spotted along the US Atlantic coast in water less than 40 meters deep (NMFS and US Fish and Wildlife Service).

Key foraging habitats have been identified for post-nesting females along the northern GoM (Turtle, K. S. R. S, 2015). Similarly, post-nesting Kemp's ridleys also utilize migratory corridors that extend throughout the coastal areas of the GoM (Turtle, K. S. R. S, 2015). Key foraging grounds for neritic juveniles are much less understood, but they are often found within seagrass beds, oyster reeds, and sandy and mud bottoms (Shaver, 2013). Alternatively, young oceanic juveniles rely heavily on sargassum habitat for foraging, protection, and rest (Turtle, K. S. R. S, 2015). The Mississippi sound has proven to be a central developmental habitat for juvenile Kemp's, while also providing key foraging grounds and migratory corridors for adults during the summer, autumn, and spring months (Coleman et al., 2016). Similarly, the waters off the coast of Louisiana serve as a foraging hotspot for adult females (Shaver et al., 2013). Several studies tracking the movement of this species have confirmed their preference for nearshore waters (Seny & Landry, 2011; Schmid & Witzell, 2006; Coleman et al., 2016; Shaver et al., 2013), with juveniles most commonly found in water depths less than 50 meters (Coleman et al., 2016) and adults frequently inhabiting waters depths less than 5 meters (Seney & Landry, 2011).

Despite the increased interest and action taken to conserve sea turtles over the past several decades, management actions are at a standstill due to insufficient research (Hamann et al., 2010). A research program aimed at producing gear to limit turtle bycatch in shrimp trawls was initiated by the NMFS in 1978 (Hamann et al., 2010). This led to the development of the turtle excluder device (TED); a simple grid that consists of metal bars positioned into a trawl net (NOAA). The device allows turtles and other larger animals to escape through an opening in the net, while shrimp pass through to a mesh bag inside the trawl (NOAA). Current NOAA regulations require the use of TEDs for the following: most shrimp fisheries, any vessel using otter trawls, and vessels 40 ft or greater using skimmer trawls (NOAA). Smaller skimmer trawl vessels can also utilize TEDs as an alternative to complying with maximum tow time limits (NOAA). This legislation does not encompass proposals that were made in 2016 to extend this rule to various gear types due to push back from fisheries and insufficient data for other types of vessels (NOAA).

Despite the proven effectiveness of TEDs (Valdivia et al., 2019; Shiode & Tokai, 2004; Lewinson et al., 2002), very few vessels are required to use them. Kemp's ridleys have the highest injury and mortality rate for skimmer trawl fisheries (Turtle, K. S. R. S, 2015) out of all sea turtle species. Shrimp fisheries operating in the Southeast region are a major concern to the Kemp's ridley population. These fisheries are estimated to capture 76,954 Kemp's ridleys annually, and approximately 60% (44,247) of these captures results in death (Turtle, K. S. R. S, 2015). Tow time restrictions are used as a mitigation effort for sea turtle bycatch in smaller vessels not required to use TEDs, however, data have shown that these times are frequently exceeded (Gahm, 2019). Within the coastal waters of Louisiana, skimmer trawls are the sole gear type used for commercial fishing (Coale et al., 1994). Likewise, the Mississippi sound also serves as a hot spot for fisheries using skimmer trawls (Hataway et al., 2016).

While fisheries typically bear a negative connotation towards the mandated regulations and techniques implemented to protect sea turtles, (Thomas, 2019; Brotmann, 1999; Margavio et al., 1996) research has proven that the use of TEDs can benefit shrimp fisheries by excluding tow time requirements, easing the restrictions on fishing areas that serve as sea turtle hot spots, and minimizing time and effort spent discarding unwanted bycatch (Carr et al., 2016). Similarly, decreasing discarded bycatch in shrimp fisheries could benefit other struggling commercial and recreational fisheries that specifically target these species (Carr et al., 2016).

Objective

The primary objective of this study is to determine the effectiveness of TED use in minimizing Kemp's ridleys injury and mortality by commercial fisheries operating in the Southeast region using small skimmer trawls.

Question & Hypothesis

Question: Does the use of TEDs by small skimmer trawl vessels operating in the Southeast region significantly minimize fishery-induced injury and mortality of Kemp's ridleys and other sea turtle species located throughout this range?

Hypothesis: TED use by small skimmer trawl vessels operating in Southeast region will significantly minimize fishery-induced injury and mortality of Kemp's ridleys and other sea turtle species located throughout the Southeast region.

Section 3. Methods

Study site

This study will be conducted within two study sites: the Mississippi Sound and Louisiana Coast. My research assistants and I will act as observers on a typical trawling operation in order to maintain a representation of the normal bycatch caught in shallow nearshore waters within the Mississippi Sound and along the Louisiana Coast. The experimental study will span a total of four days during late May or early June- allowing for two whole days of data collection at each study site.

TED specifications

To assess the effectiveness of TEDs in small skimmer trawl vessels, I will perform a cooperative study with small trawl fisheries operating out of the Southeast region. The configuration of the TED will follow a prototype developed by Gahm (2019) that was proven to be effective in reducing sea turtle bycatch in various small trawl gears. A 28 x 28-in TOTS TED will be utilized for this study (See Gahm 2019 for more details).

Trials

I will use an approach similar to Lucchetti et al (2016) to perform this experimental study. With the help of my research assistants, I will act as an observer aboard a vessel smaller than 40 ft in length, recording all sea turtle bycatch caught within the experimental and control nets. We will perform a total of two hundred trials each at the two study sites, accounting for nets inserted with and without the specialized TED configuration. Trials will be run over a four-day period in the summer of 2023- the first two days at the Mississippi sound and the second two days off the coast of Louisiana. The skimmer net inserted with the TED will serve as the experimental net, while the net excluding the TED device will serve as the "control". Both the experimental and control net will be cast out at the same time for each trial throughout the duration of the study.

Statistical Analysis

A Poisson generalized linear model will be utilized to determine how sea turtle bycatch varies between nets with and without the TED insertion. Poisson regression is used to model count variables, which will be useful to determine sea turtle bycatch being that this response variable refers to whole numbers. Each sea turtle species that is caught within the trials will serve as a response variable in separate regressions, incorporating net type (treatment or control) and their affiliated sites as independent variables. If over dispersion is present, a quasi-Poisson regression will be used to meet model assumptions. The model will report whether sea turtle bycatch varies considerably between TED inserted nets (treatment) and TED absent nets (control).

Potential Negative Impacts

Negative impacts could potentially arise if sea turtles are trapped in the control nets for extended periods of time, which could result in their injury and mortality. Cooperation with the fisherman we are working with to ensure tow time restrictions are adequately followed will aid in protecting any sea turtles caught in the nets. Sea turtles could also be negatively impacted during the experimental trials if the TED is installed improperly. To avoid any potential human-error, TEDs will be installed in the nets by qualified personnel at the site of purchase. Since this project will be in done in cooperation with small-scale shrimp fisheries, no additional negative impacts will occur from this experimental study.

Project Schedule

Date	**Activity**	**Deliverables**
May-June, 2023	100 casted skimmer nets of both treatment and control (first site)	Data to analyze
May-June, 2023	100 casted skimmer nets of both treatment and control (second site)	Data to analyze
August 15, 2023	Analyze data	Information regarding results
July, 2023	Complete data analysis	Information regarding results
September, 2023	Draft, edit, and complete report	Final report

Section 4. Budget

Item	**Justification**	**Cost**	**Quantity**	**Total**
TED	To insert into fishing net	$550	1	$550
Skimmer net	For experimental trials	$600	2	$1200
Flight to Gulfport, Mississippi	To get to and from study site	$350	1	$350
Gas	To get to second study site	$150	1	$150

Hotel stay	Housing for duration of data collection	$120/night	5	$600
Compensation to fisheries (Amount will be split between two fisheries)	Letting us onto their boat and using nets inserted with TEDs	$3000	1	3,000
Total Proposal Request				$5,850

TEDs and nets will be donated to the commercial fisheries that assisted us in conducting this research project.

Appendix

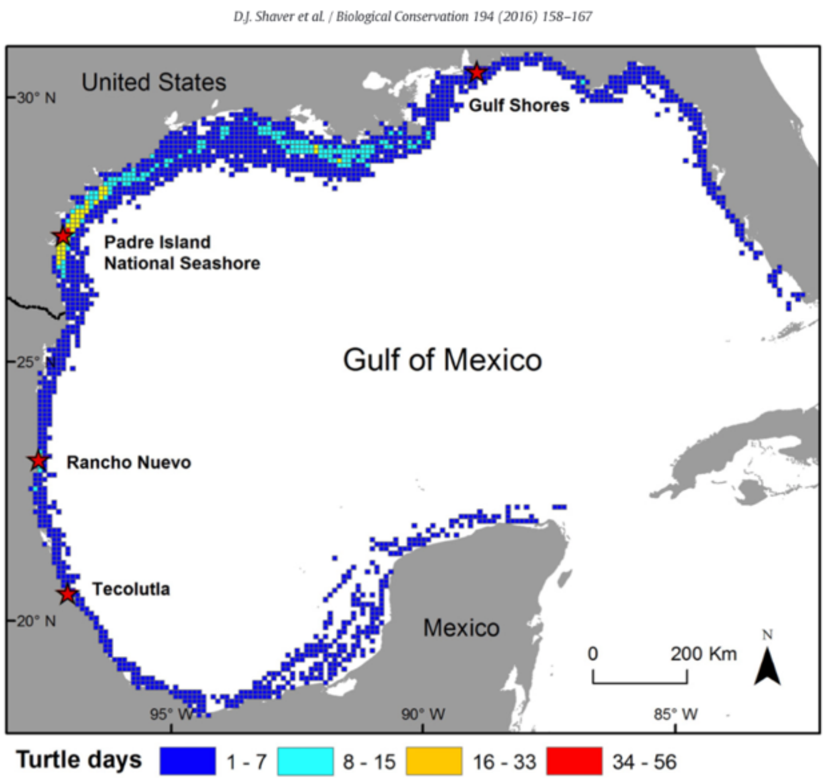

Figure 1. Migratory habitats utilized by Kemp's ridley turtles (n=66), based on the number of days spent at each site.

CURRICULUM VITAE

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EDUCATION

Master of Science in Environmental Biology — May 2023
Regis University, Denver, CO 80221
Graduate Advisor: Amy L. Schreier

Bachelor of Science in Biology — May 2019
University of Mount Olive, Mount Olive, NC 28365

RESEARCH EXPERIENCE

Regis University — Fall 2022 - Spring 2023
Avifauna Rehabilitation Research Project

- Evaluated rehabilitation data to assess the relationship between anthropogenic-induced admission and avian mortality and migratory behaviors
- Found that natural causes of avian mortality outnumbered human causes, and greater human-induced admission for nocturnal migrants

Elephant Behavior Research Project

- Analyzed Denver Zoo elephant video footage to assess conspecific interactions and evaluate captive elephant welfare

Daniel’s Park Grassland Management Study

- Assessed the effectiveness of one-rock dam structures in mitigating erosion within mixed-grass prairies along the Front Range Denver, CO
- Found limited effectiveness of one-rock dam structures following one-year of implementation

Denver Mountain Park (DMP) Management Plan

- Composed a literature review in collaboration with Denver Mountain Parks to aid in the management of fire mitigation along the human-wildland interface in Bell Park, Evergreen CO

City of Louisville Coal Creek Bioassessment Project

- Assessed the impact of the 2022 Marshall Fire on stream biological integrity of Coal Creek in Louisville, CO
- Found that the physical habitat and biotic integrity of Coal Creek was not impaired one-year post-fire

Nova Southeastern University — July 2019

- Evaluated the impact of human activities on elasmobranch’s ability to navigate

WORK EXPERIENCE

Graduate Assistant Cross Country Coach August 2021 – May 2022
Regis University

Veterinary Assistant July 2019 – May 2021
Banfield Pet Hospital
Animal handling, samples collection, diagnostics assessments, client communication, and administrative work.

Student Ambassador December 2016 – May 2019
University of Mount Olive
Interacting with donors and community members of the university, while building both leadership and communication skills.

INTERNSHIPS

Rocky Mountain Wildlife Alliance (RMWA) January 2023 – April 2023
Sedalia, CO

- Evaluated rehabilitation data to assess the relationship between anthropogenic-induced admission and avian mortality and migratory behaviors
- Assisted with wildlife patient restraint and handling

Greenwood Wildlife Rehabilitation Center Intern August 2021 – October 2021
Longmont, CO

- Performed tasks related to husbandry care and diet preparation

SKILLS & CERIFICATIONS

Certifications

- SSI Open Water Diver Certification
- CITI Program: IACUC Certification

Writing Skills

- Literature Reviews
- Grant Proposals
- Technical/scientific writing
- Familiarity with the NEPA process and documentation

Software Skills

- R programming
- ArcGIS
- MS Excel
- Data Standardization

Field Skills

- ID experience of freshwater fish, macroinvertebrates, prairie grasses/forbs
- Behavioral data collection techniques (scan sampling, ad libitum, focal sampling, one-zero sampling)

- Ability to identify wetland boundaries using hydric soil indicators/soil classification for environmental permitting and wetland delineation

Veterinary Skills

- Utilization of lab equipment (Catalyst, VETSCAN, centrifuge)
- Administration of IV and subcutaneous fluids
- Administration of medications and injections
- Digital Radiographic Imaging experience
- Experience acquiring blood samples and placement of IV catheters
- Sample analysis using compound microscopes (fecal floats, urinalyses, ear cytologies)
- Filling/administering prescriptions

LEADERSHIP

University of Mount Olive Women's Cross Country August 2015 – August 2019
University of Mount Olive Indoor and Outdoor Track & Field August 2015 – August 2019
Indoor National Championship appearance (2019)
First team All-Conference (2018)
National Championship appearance (2017)
Second team All-Conference (2017)

Student-Athlete Advisory Committee August 2016 – May 2019
Addressed various issues impacting the student-athletes at the University of Mount Olive.

NCAA Leadership Program August 2018
Represented the University of Mount Olive student athletes at NCAA leadership conference.

ACHIEVEMENTS

Dean's List, Regis University May 2022
Department of Athletics Honor Roll, University of Mount Olive August 2017 – May 2019
Conference Carolinas All-Academic Team August 2017 – May 2019
Dean's List, University of Mount Olive August 2015 – May 2019
Outstanding Championship Performance May 2019

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CHAPTER 3. JOURNAL MANUSCRIPT

Identifying Anthropogenic Threats to Avifauna in the Denver-metropolitan Area Using Wildlife Rehabilitation Data

Abstract

The majority of research used to detect the leading anthropogenic threats to avian biodiversity is performed using salvaged specimens. Wildlife rehabilitation centers house a plethora of data relevant to wildlife conservation, however, these data sources are frequently overlooked as a valuable resource for identifying key threats to biodiversity. I obtained data from a rehabilitation center in Douglas County, CO, just east of the Colorado Front Range, to assess the relationship between human-induced admission and avian mortality, migratory behaviors, and urbanization intensity. Specifically, I found that (1) natural causes of mortality were slightly greater than anthropogenic-induced mortality, (2) cause of injury was more likely to be human-induced when patients were admitted from areas of higher urbanization intensity, and (3) resident species were less likely than migratory species to be admitted for a human-induced cause, with the likelihood of human-induced admission significantly greater for nocturnal migrants. Thus, these findings provide further support of wildlife rehabilitation data as a valuable tool for understanding key threats to avian biodiversity.

Keywords: birds; avian conservation; rehabilitation; migration; anthropogenic; urbanization

Introduction

The staggering rise of human-related pressures holds profound implications for biodiversity, which is essential to maintain fundamental ecosystem processes and services (Sekerciglu et al., 2004). Habitat conversion, overexploitation, and the introduction of predators, invasive species, and pollutants are major drivers of the global biodiversity crisis - each a consequence of drastic environmental modifications arising from human-induced disturbances (Storch et al., 2022). Recognized as one of the most substantial direct drivers of biodiversity loss, habitat conversion as a means for urban expansion poses a disproportionately large impact on native species (Marzluff et al., 2012). Landscapes that are altered from their natural state restrict wildlife dispersal, access to mates, and resource acquisition (Xu et al., 2018). Understanding how human activities impact wildlife is key to maintaining ecosystem functioning and stability, which are critical for sustaining wildlife populations and human well-being (Hausmann et al., 2015).

Avifauna in particular provide a host of regulating and supporting ecosystem services including insect pest control, seed dispersal, scavenging, and nutrient cycling (Wenny et al., 2011). Avian species also generate economic growth through provisional services such as bird watching, with birdwatchers in the United States alone spending over $30 billion annually on travel and equipment (Wenny et al., 2011). Despite the critical role of avifauna in providing fundamental ecosystem functions and services, they are suffering drastic population declines worldwide as a consequence of anthropogenic stressors that serve as both direct and indirect sources of mortality (Loss et al., 2015). Since 1970, its estimated that avian abundance across North America has decreased by roughly 29% - a net loss of around 3 billion birds (Rosenburg et al., 2019). This drastic decline in avian abundance is attributed to a host of introduced human activities and development, with resident and migratory species now having to navigate new surroundings, adjust to urban soundscapes, and expend additional energy on domestic predator avoidance (Phillips et al., 2018).

Compared to other wildlife, avifauna are at an even greater risk of encountering stressors associated with human-dominated landscapes due to their flight capabilities (Arnold & Zink, 2011). Various anthropogenic sources are known to drive avian mortality. In the United States alone, domestic cat (*Felis catus*) and dog (*Canis lupus*) predation, collisions, and powerline electrocutions are jointly responsible for the death of over one billion birds annually (Loss et al., 2015). Cat predation is overwhelmingly projected as the leading anthropogenic driver of avian mortality (Willson et al., 2015; Loss et al., 2015; Cooper et al., 2009). Along with direct predation, indirect bird predation from cats following bird-window collisions serves as a significant source of fatality (Rebolo-Ifrán et al., 2021). While increasing urbanization introduces various anthropogenic stressors that can have profound implications on native bird populations, these impacts are not proportionately distributed among avian species (Tomasevic et al., 2017; Jokimäki et al., 2016).

While some bird species are able to exploit anthropogenic resource subsidies and thrive in urban life, others- typically characterized as migratory, having low natal dispersal, and fear toward humans- are not so resilient (Isaksson, 2018). Species responses to urbanization vary, with long-term migrants being the most heavily influenced (Sabo et al., 2016; Arnold & Zink, 2011; Møller, 2008). This finding is likely the result of the increased likelihood of encountering man-made developments (Arnold & Zink, 2011). Areas with greater urbanization intensity pose a much greater threat to nocturnal than diurnal migrants, who are 30x more likely to collide into man-made structures such as towers (Nichols et al., 2018; Arnold & Zink, 2011). Research of anthropogenic impacts on avian biodiversity is primarily performed using salvaged specimens

(Schmitt et al., 2019; Ibáñez-Álamo et al., 2017; Loss et al., 2014), with other data sources often being overlooked (Duffy, 2020).

Wildlife rehabilitation constitutes the temporary care of injured, diseased, orphaned, and displaced wildlife for the purpose of release back into their natural habitat upon recovery (Hanson et al., 2021). Wildlife rehabilitation centers house a surplus of records related to avifauna morbidity and mortality. Upon intake, facilities collect information detailing the patient's species, sex, age, site found, any treatments that were performed, and cause of morbidity or mortality. Currently, research on threats to avian species using data from wildlife rehabilitation centers is scarce (Panter et al., 2022; Long et al., 2020; Duffy, 2020). This often-underexploited information could be a valuable resource for wildlife conservation - aiding in the identification of key stressors and targeting mitigation measures (Duffy, 2020). To help fill this knowledge gap, I will demonstrate the potential for these data sets to aid in our understanding of avian threats and mitigation opportunities.

This study will answer the following questions: (1) How is anthropogenic activity related to avian mortality relative to natural causes? (2) How is distance from urbanized areas related to likelihood of human-induced admission? and (3) How are species migratory behaviors related to likelihood of human-induced admission? To address these questions, I obtained data from a rehabilitation center in Douglas County, CO, just east of the Colorado Front Range. My predictions are that (1) Anthropogenic activities will outnumber natural causes in being the primary source of avian admission and mortality (2) There will be more avian admissions coming from cities with higher human population densities and (3) Nocturnal, long-distance migrants will be more prone to human-induced injury and mortality. In answering these questions, I will further support the usability of wildlife rehabilitation records for identifying anthropogenic threats to avian biodiversity.

Methods

Avian Rehabilitation Patient Data

In this study, I analyzed the medical records of all avian patients admitted to the Rocky Mountain Wildlife Alliance (RMWA) in Sedalia, Colorado. The majority of patients admitted were found within the Denver metropolitan area along the Front Range of Colorado. Three hundred and eighty-six records were included in the analysis, comprising all avian patients that were admitted upon the center's opening in July 2020 to March 2023. All patients that were admitted into the facility were brought in by the public, unless endangered, or staff was immediately available to transport the patient to the center. A triage assessment was performed upon each intake to determine the patient's injuries, needs, and overall health. The rescuer was required to fill out a form detailing where the animal was found, indications the animal needed help, and any unusual behaviors that were observed. Additional information relating to the patient (i.e., species, sex, age, diagnoses, treatments performed, disposition – i.e., whether the animal died or was released) was then documented by staff and input into the Wildlife Rehabilitation Medical Database (WRMD).

Processing Patient Admission Data

Categorizing Anthropogenic vs. Natural Admission Causes

To determine how avian injury and mortality varied from anthropogenic to natural sources, cause of injury and/or mortality was first summarized based on the reason for admission. This was standardized using notes provided by the rescuer, notes taken upon exam, and diagnoses. I classified reason for admission into at least one of eleven categories: dog interaction, cat interaction, trapped/entangled, window strike, car strike, human intervention, miscellaneous human-induced admission, miscellaneous natural reasons for admission, disease, displaced/orphaned, and unknown collisions. I further aggregated these eleven categories into two for later analyses: (1) anthropogenic-induced admission (i.e., dog interaction, cat interaction, unknown collisions, trapped/entangled, window strike, care strike, human intervention, and miscellaneous human-induced admission and (2) natural causes of admission (i.e., disease, displaced/orphaned, and miscellaneous natural reasons for admission). All reasons for admission that were inconclusive (i.e., unable to detect if admission was due to natural or anthropogenic sources) were labeled as undetermined. Some patients were admitted for multiple reasons, and thus, have up to three reasons for admission recorded. In the few instances that a patient was admitted for both a natural and anthropogenic reason, only the anthropogenic source was accounted for. If a patient was admitted for a disease, the specific disease was documented as well with a specific emphasis on bird flu (HPAI), West Nile Virus (WNV), or Avian Pox.

Quantifying Urbanization Intensity

To assess how human-caused admission varied by urbanization intensity, I recorded the population density per square mile of the city each individual patient was found. Population density data was obtained from the U.S. Census Bureau, which included the 2021 population density for each city in Colorado (U.S. Census Bureau, 2022). A total of 43 cities were included in the analysis, 32 of which fell into the Denver Metropolitan area.

Categorizing the Migratory Behaviors of Each Admit

I documented two aspects of migratory behavior for each species admitted to RMWA: (1) migratory distance (i.e., long-distance migrant, short-distance migrant, or resident) and (2) migratory timing (diurnal or nocturnal). Species that winter in South America were classified as long-distance migrants, while all other migratory species were classified as short-distance migrants. Similarly, avian species that stay within their breeding range year-round or those restricted to lower elevational movements during the winter months were classified as resident. Migratory timing was categorized based on the time of day a species migrates – characterized as either (1) diurnal or mostly diurnal or (2) nocturnal or mostly nocturnal. Migration behavioral data for all 85 avian species that were admitted to RMWA was obtained from The Birds of the Word database managed by the Cornell Lab of Ornithology (Schulenberg, 2022).

Statistical Analyses

Relationship between Mortality and Anthropogenic Induced Admission

To quantify whether anthropogenic admission reasons are associated with increased patient mortality, I analyzed patient disposition and admission data using generalized linear mixed effects models. The disposition of each individual (response) was converted into a binary variable – 0 representing survival and 1 representing mortality, along with the reason for admission (predictor) – 0 representing natural and 1 representing anthropogenic. I fit a total of three models, with the fullest model including human-induced admission as a fixed effect, taxonomic family as a random effect on the intercept, and taxonomic family as a random effect on the intercept and slope to account for additional variability in mortality.

I compared the fit of these three models by examining AICc scores, with a ∆AICc score greater or equal to 2 as a significant cutoff. Moreover, I considered tests to be statistically significant at a threshold p-value of 0.05 and I used the bootstrap method to compute the standard error for all mixed effects models. Due to the avian flu outbreak (H5N1) that began in 2021, I analyzed the data both with and without bird flu admits to understand how the results of these questions vary when accounting for this atypical event. All statistical analyses were performed in the R programming language (R Core Team, 2013).

Relationship between Urbanization Intensity and Human Induced Admission

To assess the influence of urbanization on the frequency of anthropogenic patient admissions, I analyzed admission data and population density using generalized linear mixed effects models. Reason for admission, which I converted into a binary variable in the previous analysis, was used as the response in this model. The fullest model included human population density (per square mile) as a fixed effect, taxonomic family as a random effect on the intercept, and taxonomic family as a random effect on the intercept and slope. To meet the assumption of normality, I log transformed population density prior to conducting these analyses.

Relationship between Migratory Behaviors and Human Induced Admission

I used a binomial generalized linear mixed model (GLMM) to assess whether the odds of human-induced admission varied based on migratory behavior. I used the previously converted binary admission variable as the response in this model. I converted the migratory behavior – migratory timing (predictor), into a binary variable, with 0 representing diurnal migration and 1 representing nocturnal migration and treated migratory distance as a categorical variable with three levels. The fullest model included migratory behavior (i.e., migration timing or migration distance) as a fixed effect, taxonomic family as a random effect on the intercept, and taxonomic family as a random effect on the intercept and slope to account for additional variability in anthropogenic admission.

Results

Relationship between Mortality and Anthropogenic Induced Admission

With HPAI admits included

After removing all patients transferred, pending, and/or admitted for an unknown cause, 332 of the 386 admits remained for analysis. Including random effects did not help to further explain the variation in mortality between natural and anthropogenic avian admission. Therefore, the final model used to quantify this relationship included only the admission reason variable (AICc=377.0, ΔAICc > 3.4).

This model depicts a significant logistic relationship between mortality and human-induced admission (Figure 1). Patients admitted for an anthropogenic cause were significantly more likely to survive than those admitted for a natural cause, with the odds of dying 44% lower for anthropogenic compared to natural admits (p= 0.034; 95% CI: 67% decrease to 5.4% increase). An independent analysis of each admission variable using generalized linear models found that car strikes, dog interactions, entanglement/entrapment, window strikes, unnecessary human intervention, orphaned and/or displacement, and patients admitted for a miscellaneous anthropogenic cause (i.e., tar exposure, lead toxicity, electrocution, methane burn) were all reasons for admission less likely to result in mortality - while cat interactions, disease, undetermined collisions, and admits that were brought in for a miscellaneous natural cause (i.e., weather, maladaptation, predator attack) depicted an increased likelihood of mortality. However, the only significant predictor of mortality included disease. The odds of a patient dying are over 6x, or 500% more likely if they are admitted for a disease compared to all other reasons for admission (p=<0.001; 95% CI: 175% decrease to 1793% increase).

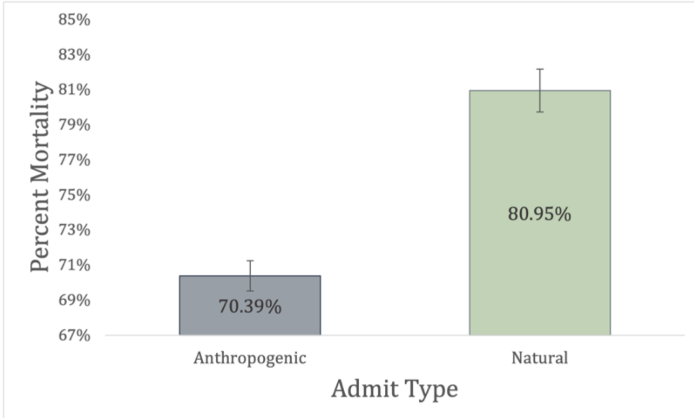

Figure 1. Mortality significantly differs between anthropogenic and natural admission cases when HPAI admits are included. Error bars represent standard error of the proportion.

With HPAI admits excluded

After removing all patients that were transferred, pending, and/or admitted for an unknown cause, 293 of the 386 admits remained for analysis. Including random effects in the model did not help to further explain the variation in mortality between natural and anthropogenic avian admission. Therefore, the final model used to quantify this relationship included only the admission reason variable (AICc=356.79, ΔAICc >1).

This model depicts a weak and insignificant logistic relationship between mortality and human-induced admission after removing all avian flu admits (Figure 2), with the odds of a patient dying from an anthropogenic cause 9.4% lower than a patient admitted for a natural cause (95% CI: 49% decrease to 51% increase; p=0.727). An independent analysis of each admission variable using generalized linear models found that car strikes, entrapment/entanglement, window strikes, unnecessary human intervention, and orphaned and/or displacement were all reasons for admission less likely to result in mortality - while cat interactions, dog interactions, disease, undetermined collisions, and admits that were brought in for a miscellaneous anthropogenic (i.e., tar exposure, lead toxicity, electrocution, methane burn, gunshot) or natural cause (i.e., weather, maladaptation, predator attack) depicted an increased likelihood of mortality. However, the only significant predictor of mortality included disease, with the odds of a patient admitted for a disease dying almost 3x greater than all other reasons for admission ($p=0.033$; 95% CI: 18.7% decrease to 775% increase).

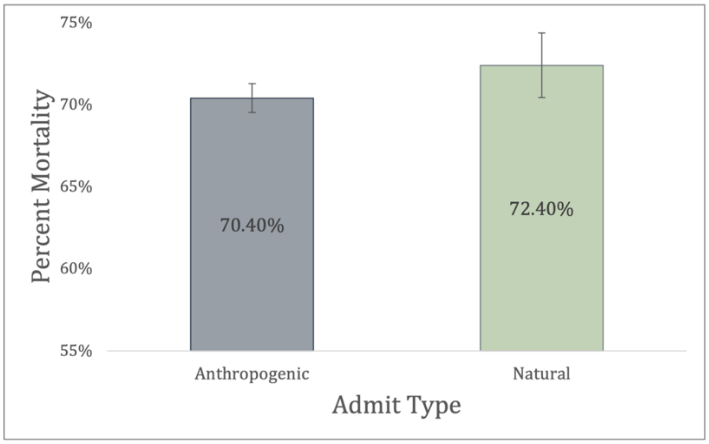

Figure 2. Mortality does not notably differ between anthropogenic and natural admission cases when HPAI admits are excluded. Error bars represent standard error of the proportion.

Relationship between Urbanization Intensity and Human Induced Admission

With HPAI admits included

After removing all admitted patients with an unrecorded city location and/or an unknown cause of admission, 326 of the 386 admits remained for analysis. The best model included family as a random effect on the intercept, indicating that different taxonomic families were more heavily impacted by anthropogenic activity than others (AICc=421.1, ΔAICc > 6.2). This model depicts that there is essentially no relationship between human-induced admission and human population density (Figure 3), with a doubling of population density causing a 5% decrease in the odds of human-induced admission ($p=0.549$; 95% CI: 75% decrease to 253% increase).

Figure 3. Reason for admission does not notably differ on log transformed human population density per square mile when HPAI admits are included. Shading represents 95% confidence interval.

With HPAI admits excluded

After removing all patients that were admitted with an unrecorded city location and/or an unknown cause, 286 of the 386 admits remained for analysis. The best model included family as a random effect on the intercept (AICc=340.3, ΔAICc > 6.2). This model depicted a borderline significant relationship between anthropogenic-induced admission and human population density (Figure 4), with a doubling of population density causing a 16% increase in the odds of human-induced admission (p=0.0741; 95% CI= 95% decrease to 196% increase).

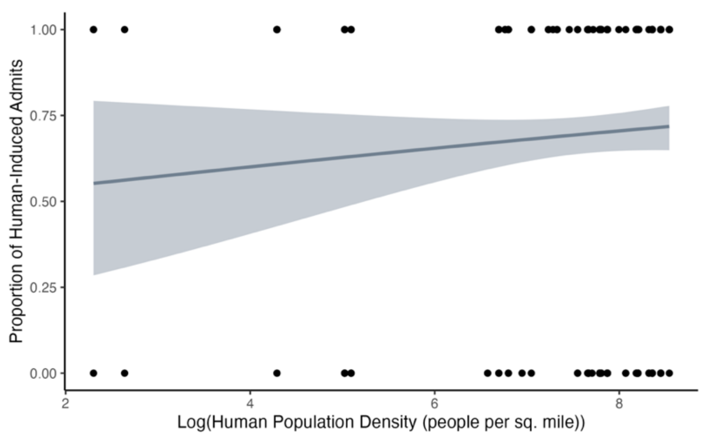

Figure 4. Reason for admission is borderline significant on log transformed human population density per square mile when HPAI admits are excluded. Shading represents 95% confidence interval.

Relationship between Migratory Behaviors and Anthropogenic Induced Admission

With HPAI admits included

Admits that were resident species and/or were admitted for an unknown cause or unknown migration timing were removed from the analysis of migration timing (i.e., diurnal vs. nocturnal), while only unknown causes of admission were removed from the analysis of migration distance (i.e., short, long, or resident), resulting in 237 and 348 of the 386 admits remaining for analysis, respectively. The best model for both migratory timing and migratory distance included family as a random effect on the intercept, with AICc values of 306.2 (ΔAICc > 10.4) and 448.3 (ΔAICc > 2.4), respectively.

The model for migration timing depicted a weak and insignificant relationship between human-induced admission and migration timing (Figure 5), with the odds of a patient being admitted for an anthropogenic reason being 4.3% greater for nocturnal compared to diurnal migrants ($p=0.939$; 95% CI: 67% decrease to 227% increase). Similarly, the model for migratory distance depicted a non-significant relationship between human-induced admission and both resident and short-distance migrants (Figure 6). The odds of a resident species being admitted for an anthropogenic reason are 62% greater than that of a long-distance migrant ($p=0.386$; 95% CI: 57% decrease to 552% increase), while the odds of a short-distance migrant being admitted for an anthropogenic reason are 113% greater than that of a long-distance migrant ($p=0.094$; 95% CI: 28% decrease to 461% increase).

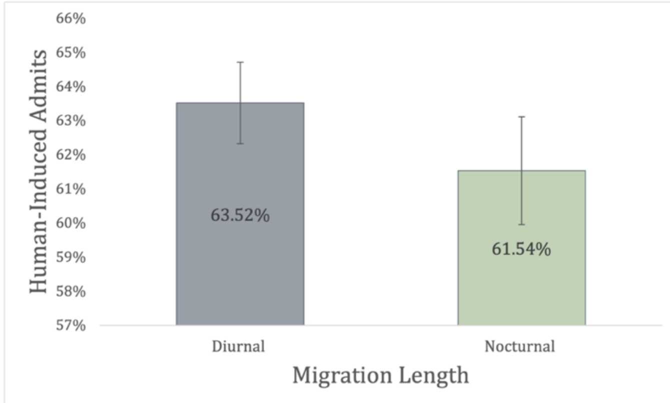

Figure 5. Human-Induced admission does not notably differ between diurnal and nocturnal migrants when HPAI admits are included. Error bars represent standard error of the proportion.

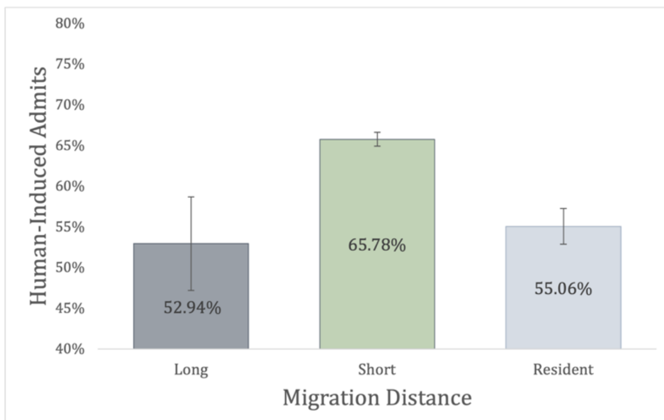

Figure 6. Human-Induced admission does not notably differ between resident and long- and short-distance migrants when HPAI admits are included. Error bars represent standard error of the proportion.

With HPAI admits excluded

Admits that were resident species and/or admitted with an unknown cause or migration timing were removed for the analysis of migration timing (i.e., diurnal vs. nocturnal), while only admits with an unknown causes of admission were removed for the analysis of migration distance (i.e., short, long, or resident), resulting in 203 and 308 of the 386 admits remaining for analysis, respectively. The best model for migration timing excluded all random effects (AICc=236.3, ΔAICc > 1.9), while the best model for migration distance included family as a random effect on the intercept (AICc=372.4, ΔAICc > 4.9).

The model for migration timing depicted a significant logistic relationship between human-induced admission and nocturnal migrants (Figure 7), with the odds of a patient being admitted for an anthropogenic cause being over 4x greater for nocturnal migrants than diurnal migrants (p=0.004; 95% CI: 63% decrease to 946% increase). In contrast, the model for migratory distance depicted a weak and insignificant relationship between human-induced admission and both resident and short-distance migrants (Figure 8). The odds of a resident species being admitted for an anthropogenic reason are 16% lower than that of a long-distance migrant (p=0.787; 95% CI: 83% decrease to 179% increase). Alternatively, the odds of a patient being admitted for an anthropogenic reason was roughly 9.6% greater for short-distance migrants than long-distance migrants (p= 0.870; 95% CI: 78% decrease to 201% increase).

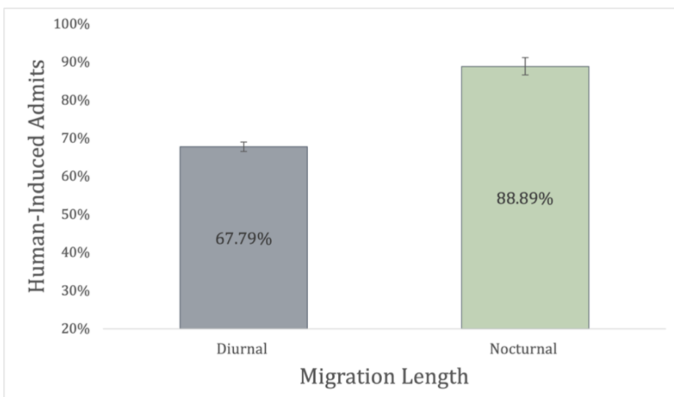

Figure 7. Human-Induced admission significantly differs between diurnal and nocturnal migrants when HPAI admits are excluded. Error bars represent standard error of the proportion.

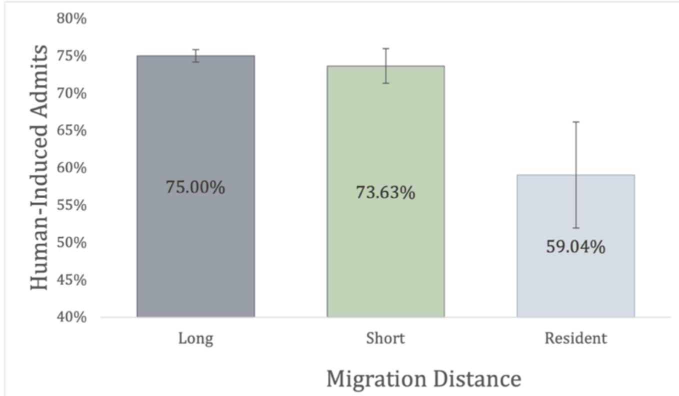

Figure 8. Human-Induced admission does not notably differ between resident and long- and short-distance migrants when HPAI admits are excluded. Error bars represent standard error of the proportion.

Discussion

The goals of this study were to answer the following questions using data from a wildlife rehabilitation center: (1) How is anthropogenic activity related to avian mortality relative to natural causes? (2) How is distance from urbanized areas related to likelihood of human-induced admission? and (3) How are species migratory behaviors related to likelihood of human-induced admission? To answer these questions, I obtained the records for all avian patients admitted to RMWA, a wildlife rehabilitation center located along Colorado's Front Range. I found that, after excluding avian influenza admits from the data set, (1) natural causes of mortality outnumbered anthropogenic causes, (2) cause of injury was more likely to be human-induced when admitted from high-urbanized areas, and (3) short-distance migrants were more likely than long-distance migrants and resident species to be admitted for a human-induced cause, with varied findings when avian flu admits were included.

Avian Mortality

The analysis of avian mortality depicted slightly higher mortality rates for natural compared to human-induced admits. Due to the incessant rise of the human population, and thus, anthropogenic activities, much of the previous research on avian mortality has aimed at assessing the key human drivers of avian biodiversity loss (Richard et al., 2021; Shafer et al., 2019; Loss et al., 2015; Longcore et al., 2013; Drewitt et al., 2008). Moreover, little research has been directed towards analyzing how avian mortality compares between natural and human sources - and it is notable to mention that the few studies that do were performed using rehabilitation datasets (Duffy, 2020; Rodriguez et al., 2010). Due to the literature being highly skewed towards anthropogenic sources of injury and mortality for avian species, I hypothesized that human-induced mortality would outweigh natural causes. Though my hypothesis was not supported, my findings were consistent with previous studies on this topic, which depicted a significantly higher proportion of anthropogenic admits (Duffy, 2020; Rodriguez et al., 2010), and significantly lower mortality rates in patients admitted for anthropogenic compared to natural causes (Duffy, 2020). I found disease to be the only significant predictor of mortality, which has also been documented in other studies, with diseased patients depicting the lowest release rate compared to all other natural and anthropogenic-induced admissions (Hanson et al., 2021; Montesdeoca et al., 2017). My results, which align with previous literature on this topic, further support the usability of wildlife rehabilitation data sets in identifying primary threats to avian populations and therefore, their potential to aid in facilitating conservation techniques.

Urbanization

Though I hypothesized, and observed in the best model, that anthropogenic cases would be highly correlated with greater urbanization intensity, this relationship was not significant (Figure 4). Urbanization is detrimental to avian populations, particularly migratory (Loss et al., 2014; Hager et al., 2013) and specialist species (Pellissier et al., 2012). Urban development has a profound effect on bird community structure, favoring a limited number of species who can tolerate the stressors associated with human activity and development (Patankar et al., 2021).

These generalist species have learned to adapt to urban life, and even benefit from the anthropogenic resource subsidies they provide (Moller, 2008). Moreover, the accessibility of these resources in human-dominated landscapes has resulted in migrating species overwintering in urban areas (Brown et al., 2022).

Many of the avian urban exploiters common around the Denver metro area, such as American Crows and pigeons and doves, were highly represented in the RMWA data set. Similarly, some populations of migratory species known to overwinter in Colorado (i.e., Red-tailed hawk, Canada Goose) were also overly represented in the RMWA data set. While all of these species were admitted for both anthropogenic and natural reasons, the insignificant relationship between human-induced admits and high population density could potentially be due to low anthropogenic induced admission for urban-exploiters relative to their abundance in urban cities and/or migratory species that remain within their breeding range year-round, having adapted to urban life.

Migratory Behaviors

The analysis of admission cause after accounting for migration distance found that, while human-induced admission was greater for long-distance migrants compared to resident species, admission was highest among short-distance migrants. Lower anthropogenic threats to resident species were previously documented (Wittig et al., 2017), with threats exceedingly greater for both short- and long-distance migratory species who are frequently passing through and foraging in unfamiliar urban areas (Wittig et al., 2017; Loss et al., 2014; Hager et al., 2013; Arnold & Zink, 2011; Ogden, 1996). While this pattern was observed in my modeling approaches, the best model, which included family as a random effect on the intercept, found that short-distance migrants were slightly more prone to anthropogenic threats than long-distance migrants, indicating that anthropogenic impacts on bird migratory behavior is variable among different families. This result is conflicting with previous studies, with the majority of these having documented greater anthropogenic threats for long-distance migrants (Arnold & Zink, 2011; Loss et al., 2014; Wittig et al., 2017). Anthropogenic threats posing a greater risk to long-distance migrants is likely the result of further traveling distance, thus leading to increased encounters with buildings and other anthropogenic structures (Loss et al., 2014).

While my analysis indicated that short-distance migrants were more prone to anthropogenic threats than long-distance migrants, these findings are still fairly compatible to similar studies on this topic, despite data limitations. Of the 308 records that were analyzed, only 26 long-distance migrants (or roughly 8%) remained after removing all HPAI positive admits. With such a small data set, this trend was still observed in two of the three models, with the best model (which included family as a random effect) depicting an insignificant difference between anthropogenic-induced admission between short- and long-distance migrants.

The analysis of admission cause after accounting for migration timing found that nocturnal migrants were significantly more impacted by anthropogenic threats compared to diurnal migrants. Anthropogenic structures projecting artificial light are known to attract migratory birds, especially during weather events (Ogden, 1996). Similarly, unlike resident birds, migratory species are unfamiliar with their surroundings and therefore are more prone to hazards associated with developed areas (Ogden, 1996). While bird collision analyses are typically performed on salvaged specimens collected around large buildings in highly urbanized areas (Kahle et al., 2016; Ogden, 1996) rehabilitation facilities house a much broader record of collisions, including many that occur on residential property. For this reason, it is possible that current analyses of avian mortality stemming from migratory bird collisions is underestimated, further highlighting the value of wildlife rehabilitation data in understanding major threats to bird populations.

Conclusion

Each of my findings are comparable to previous work on the same topic, despite encountering data limitations. When excluding HPAI admits, including family as a random effect helped to explain additional variation in admission in relation to anthropogenic induced causes. Thus, this indicates that different groups of birds are more strongly affected by anthropogenic impacts than others. My findings further demonstrate the use of wildlife rehabilitation datasets as a valuable and yet, underutilized resource for bird conservation science. The plethora of information that is collected upon patient intake, and leading up to their release, has proven to serve as a valuable tool for identifying factors that pose the greatest threat to avian biodiversity.

Acknowledgements

I am extremely thankful to my professors for their instruction and support, specifically, Dr. Amy Schreier for overseeing this project, and Dr. Tyler Imfield for his statistical guidance. I would also like to thank Emily Davenport, the founder and director of Rocky Mountain Wildlife Alliance, for her support throughout this project and providing me with the data for this study.

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CHAPTER 4.

Saving the Sumatran Forests: Shifting to Ecotourism and away from Palm Oil Expansion

Introduction

The intense demand for palm oil has led to the rapid expansion of palm oil plantations globally in tropical regions (Qaim, 2020). The attractiveness of palm oil is largely due to its high yield and low production cost (Petrenko et al., 2016). Despite the economic benefits of the cultivation of this highly sought-after product, the rapid expansion of this industry has major environmental and social consequences (Poor et al., 2019; Vidal, 2013; Gaveau et al., 2009). Palm oil production causes deforestation, climate change, drastic changes in land use, and negative health implications (Obidzinski et al., 2012; Gaveau, 2009).

As the world's leading producer of palm oil (Petrenko, 2016), Indonesia continues to be the focal point of controversy surrounding the palm oil industry (Vidal, 2013; Gaveau, 2009). The western Indonesian island of Sumatra is the most significant region for palm oil production in the country (Paterson, 2019). Sumatra accounts for approximately 67% of total oil palm area in Indonesia and 74% of the country's crude palm oil production (Lee et al., 2013). Arguably the greatest controversy surrounding oil palm expansion in Sumatra is the unavoidable impacts it has on endemic wildlife, most of which are iconic species that are endangered worldwide (Rambe et al., 2021). To lessen the impacts of deforestation brought on by the mass invasion of palm oil plantations in Sumatra, Indonesia, I propose that local leaders execute a shift towards ecotourism to limit further degradation associated with oil palm expansion. This would require local engagement to aid in the growth of the tourism sector and governmental support to designate land for ecotourism development.

Endemic biodiversity loss as a consequence of oil palm expansion

Sumatra’s forests are being demolished at an alarming rate as evidence by the 70% loss in forest cover from 1990 to 2010 (Vidal, 2013; Margono et al., 2012; Uryu et al., 2008). Conversion of natural forests to palm oil plantations results in severe habitat fragmentation and degradation that poses problems for many organisms, including, limiting access to mates, resources, and favorable environmental conditions (Teoh, 2010). The unique and biologically diverse habitats that comprise the forests of Sumatra are home to some of the most critically endangered species on Earth (Gatti & Velichevskaya, 2020; Gaveau et al., 2009). This island houses endangered charismatic species such as the Sumatran rhino (*Dicerorhinus sumatrensis*), the Asian elephant (*Elephas maximus*), two species of orangutans (*Pongo abelii* and *Pongo tapanuliensis*), and the fewer than 400 remaining Sunda Island tigers (*Panthera tigris sumatrae*) (Gaveau et al., 2009; World Wildlife Fund). Currently in Sumatra, over 110,000 square kilometers are protected (i.e., land conversion and logging are prohibited), including three national parks and numerous nature and wildlife reserves (Gaveau et al., 2012; Gaveau, 2012). The islands three national parks, which encompass a total of 2.5 million hectares, were established in an effort to safeguard a portion of the world’s most biodiverse forests (Poor et al., 2019). However, high-intensity oil palm plantations have encroached into Sumatra’s carbon- and biodiversity-rich national parks and reserves (Xu et al., 2022; Vijay et al., 2016). Despite initiatives to preserve these ecosystems, protected areas have done little to prevent deforestation and the associated loss of charismatic species, largely because of inadequate law and park management enforcement (Poor et al., 2019; Linkie et al., 2013).

Stakeholders

Local Residents

The expansion of palm oil in Indonesia has generated employment opportunities and substantially improved the livelihood of many local residents (Kubitza et al., 2018). The perspectives of villagers on oil palm development largely stem from their connection to the business, with oil palm owners and workers serving as the primary advocates for its production, because of the direct economic benefits they reap (Apresian et al., 2020). Throughout Sumatra, 63% to 78% of household income is derived from the cultivation of palm oil (Budidarsono et al., 2012). For this reason, oil palm plantations are supported among the majority of residents, whose main source of livelihood depends on the crop's cultivation (Anwar & Sunesti, 2021).

Within the Jambi Province of Sumatra, non-farm households, whose income is predominantly acquired from independent non-farm businesses (e.g., trade, transport, handicrafts) or whose members work for the agricultural industry but do not own the land, are roughly 30% more impoverished than farm-owning households (i.e., smallholders) (Bou Dib et al., 2018). However, despite the income imbalance, the oil palm influx has generated higher wages for those non-farm owners who work in the oil palm industry compared to those employed by other agribusinesses such as the rubber industry (Bou Dib et al., 2018). Because it has increased income, and generated employment opportunities, palm oil expansion has alleviated poverty for many non-farm households (Qaim et al., 2020).

While the growth of oil palm has aided in the economic advancement of many non-farm households, (Bou dib et al., 2018) these plantations have simultaneously deteriorated local socio-economic dynamics (Moreno-Penaranda et al., 2015). For instance, the expansion of oil palm has substantially polluted local rivers (Colchester, 2011), reduced air quality (Obidzinski et al., 2012), decreased water availability, and reduced local food production (specifically rice cultivation) (Moreno-Penaranda et al., 2015). In addition, Native Customary Rights (Petrenko et al., 2016) have frequently been ignored by oil palm companies when these plantations are established (Petrenko et al., 2016). When land is converted to oil palm plantations, indigenous groups have been coerced to travel greater distances for limited forest resources and, in some instances, to switch professions when the necessary resources are scarce (Petrenko et al., 2016; Obidzinski et al., 2012).

Smallholders

Indonesia's smallholder oil palm plantations can span up to 50 ha in size – and are primarily managed by independent smallholders or scheme smallholders, who work in association with and receive direct assistance from an oil palm company (Lee et al., 2014). The experiences of smallholders vary considerably throughout Sumatran communities (Hidayat et al., 2015). For instance, all smallholders face the common challenge of milling palm oil fruit within 24 hours of harvest to sustain fruit quality (Hidayat et al., 2015). Proximity to a mill therefore constrains smallholders; those who are closer to mills ultimately achieve higher yields (Hidayat et al., 2015). Another factor that lends to different smallholder experiences is the management type of the plantation (Lee et al., 2014). For instance, scheme smallholdings, in which a smallholder works in conjunction with an oil palm company, receive greater gross monthly incomes than independent smallholdings, which are managed entirely by the landowner (Lee et al., 2014). In addition to management structure, smallholder financial returns are also highly dependent on land size (Apriani et al., 2020; Shigetomi et al., 2020).

Regardless of these income differences, oil palm cultivation has enabled smallholders to considerably improve their standard of living (Dharmawan et al., 2020; Kubitza et al., 2018; Rist et al., 2010). The production of oil palm has generated higher household income for smallholders, which has improved nutrition and led to a greater investment in education (Chrisendo et al., 2022).

Government

The Indonesian government has played an instrumental role in the development of the palm oil sector (Varkkey, 2012). In an effort to surpass Malaysia as the world's leading oil palm producer in the 1980s, the Indonesian government began rapidly establishing plantations on the islands of Sumatra and Kalimantan (Varkkey, 2012). The government also facilitated the growth of the oil palm sector by encouraging local involvement, providing incentives such as grants, loans, and interest subsidies (Casson, 2000). Governmental support for the palm oil plantation sector is largely driven by its success in generating domestic revenue and promoting foreign exchange, which in turn, has provided rural employment opportunities and alleviated poverty for many Sumatran households (Varkkey 2012; Rist et al., 2010).

Tourists

Following palm oil exports, tourism is the primary source of income for Indonesia (Buiskool, 2020). Despite this, Indonesia's tourism potential is exceedingly underutilized (Purkwoko et al., 2022; Ollivaud & Haxton, 2019). Northern Sumatra attracts foreign tourist, specifically within and around Leaser National Park (Wiratno et al., 2022). This area encompasses the Bohorok district, which is recognized for its pristine river, orangutans, and other wildlife, and Lake Toba, which is situated in the largest caldera in the world (Wiratno et al., 2022). Similarly, Batu Kata, just adjacent to Mount Leuser National Park, is a popular tourist destination that provides visitors with the opportunity to spot charismatic wildlife and immerse in cultural experiences (Buiskool, 2020).

The majority of foreign tourists are drawn to Indonesia for its natural beauty and unique culture (Purwoko et al., 2022). Tourists visiting Medan, the capital of the North Sumatra Province, were most motivated by the natural attractions (94%), affordable costs (96%), and photography spots (91%) (Purwoko et al., 2022). Tourist satisfaction can be measured through their desire to return; within North Sumatra, visitors indicated that they were most satisfied by the natural scenery, while road conditions, traffic, and cleanliness were the primary factors that negatively impacted their experience (Agustini et al., 2022). Surveys in the West Sumatra Province showed that tourists responded positively to ‘green behaviors’ (e.g., development geared towards conserving natural resources and environmental integrity) and were willing to pay more for environmentally friendly accommodations and experiences (Lita et al., 2014). While tourists who have visited Sumatra generally hold positive attitudes towards their experiences, the island, filled with an abundance of exotic plant and wildlife species, scenic landscapes, and unique attractions, has yet to maximize its ecotourism potential (Kia, 2021).

Many challenges associated with ecotourism development in Sumatra’s protected areas that possess high tourism potential stem from threats associated with poaching, overexploitation, and deforestation, predominantly because of legal conversion of past logging sites to rubber and oil palm plantations (Van Beukering et al., 2003). Additional challenges arise in areas such as the West Sumatra Province that possess the potential to bring in tourists but currently lack the infrastructure to do so (SPOF INDONESIA, 2017). Furthermore, when tourists interact inappropriately with the surrounding ecosystem in protected areas, such as those in and around Leuser National Park, wildlife is negatively impacted (Nilsson et al., 2016).

Proposed Solution

Expansion of the oil palm industry is the primary driver of environmental degradation on many fronts in Indonesia. The loss of forest and peat lands as a result of palm oil development is frequently recognized as the leading source of Indonesia's greenhouse gas emissions (Shahputra & Zen, 2018). Similarly, land-clearing fires - which become increasingly prevalent with disturbance as the opened canopy dries and woody debris accumulates - serve as a large source of air pollution that has detrimental impacts on rainforest productivity (Shahputra & Zen, 2018). Depletion of natural resources, biodiversity declines, loss of ecosystem services, and introduced pollutants from agrochemicals also threaten Indonesia's unique ecosystems (Meijaard et al., 2020). Thus, as the demand for palm oil continues to expand, the need to address the environmental degradation caused by unsustainable palm oil cultivation becomes exceedingly important.

Encouraging ecotourism, a form of nature-based tourism that aims to conserve the natural environment and sustain the well-being of the local population (Stronza et al., 2019), has been a successful strategy employed by developing countries, both to protect unique ecosystems and to generate economic growth (Anup, 2016; Wood, 2002). In Costa Rica, through a combination of ecotourism and the establishment of national environmental protection policies, over 25% of forest cover was restored between 1985 and 2011 (Tafoya et al., 2020). Unlike the environmental degradation and social conflict that is widespread among the oil palm industry, ecotourism generates environmental preservation and socio-cultural conservation (Yfantidou & Matarazzo, 2017).

Tourism is recognized as one of the world's most rapidly growing industries, and due to steady growth over time, is viewed as a low-risk development choice (Telfer & Sharpley, 2015).

Investment in tourism, however, is not cost-free. It is necessary to allocate funds towards ecosystem restoration, endangered species protection, facility improvement, nature-based tours, accommodation, and transportation to aid in the industry's growth (Lee & Iwasa, 2020). Many developing countries that possess unique cultural and environmental value have followed a controlled tourism policy, adopting a 'high value, low volume' approach to increase revenue, while simultaneously ensuring minimal impact on the natural ecosystem (Stone, 2015; Rinzin et al., 2007). This strategy can consist of boutique hotels, high-end luxury resorts and ecolodges, (Rogerson, 2012) or specialist nature tours (Valentine, 1992). This specific ecotourism strategy could be employed within Sumatra's protected areas to aid in ecotourism development, while simultaneously supporting the need for increased enforcement by park managers.

While the outright eradication of oil palm cultivation in Sumatra is impractical, it is feasible to limit its expansion. To do this, governmental incentives would need to be directed towards those currently in the oil palm industry who would yield the greatest turnover by making a career shift towards ecotourism (e.g., workers, smallholders with little land, marginalized groups). Workers in plantations and mills are often exploited, making less than minimum wage, and experiencing repeated exposure to harsh chemical processes (Herzog, 2022; Shigetomi et al., 2020). Similarly, despite being met with promises of employment following the palm oil flux to the west- and central eastern coast of Sumatra, women are frequently discriminated against by being denied adequate protection from dangerous chemicals and consistently being compensated less than their male counterparts (Pradipta, 2017). While some previous workers for oil palm corporations throughout Indonesia have shifted to the conservation and ecotourism industry, many current oil palm workers still live well below the poverty line and continue to endure unjust treatment (Fair, 2021). By targeting these select groups to aid in the growth of the ecotourism sector, the government could effectively minimize palm oil-driven deforestation and biodiversity loss.

To facilitate the expansion of the ecotourism sector in Sumatra, the Indonesian government must provide incentives to initiate community involvement. Community members must be actively involved in decision-making surrounding ecotourism management and provided with the necessary education and training to be successful in the ecotourism sector (Palmer & Chuamuangphan, 2018). Government funded workshops should therefore provide conservation education, vocational training, and certification programs (Wood, 2001). Similarly, the Indonesian government should adapt strategies utilized by countries who have been successful in expanding their ecotourism sector. Countries within the Organization for Economic Cooperation and Development (OECD) (e.g., Brazil, the Philippines) have implemented a whole-of-government policy approach. This approach strives to structure tourism in a way that more equally distributes benefits, addresses disparities, and implements long-term strategies and policies that are geared towards the promotion of skill development and entrepreneurship (OECD, 2017). For this framework to be effective, an emphasis on environmentally sustainable growth, policy maker leadership and support, and communication among stakeholders is imperative (OECD, 2017).

Ecotourism development has primarily been limited by insufficient facilities, stakeholder apathy, and high management turnover in major wildlife conservation tourist hot spots on Sumatra Island, reflecting the governments blatant disregard for sustaining and strengthening ecotourism (Purwoko, 2022; Fauzi et al., 2020). Instead, the government has prioritized limiting illegal oil palm plantations in protected areas. These efforts, however, have been unsuccessful because of challenges associated with influential locals, corruption, and local resistance

(Pramudya et al., 2018). In order to achieve conservation goals within protected areas and increase ecotourism development, it is essential to strengthen governmental enforcement. Local communities play a major role in the decision to develop or conserve natural resources within the remote areas and islands tourists are attracted to (Kia, 2021). Therefore, their engagement is also critical for ecotourism to be successful.

While ecotourism is commonly perceived as a destructive conservation tactic (Lopez et al., 2020), it does have the potential to produce environmental and social benefits if designed and managed properly (Pegas & Stronza, 2008). Stakeholder involvement and communication is key to the ecotourism sectors growth (Kia, 2021). Not only can the ecotourism sector improve the local economy and provide opportunities for environmental education, but it empowers the community, helping to foster a sense of respect for local traditions and culture (Scheyvens, 1999). Growing ecotourism presence throughout the island of Sumatra will aid in preventing continued expansion of oil palm plantations, and thus, support the preservation of some of the world’s most diverse and unique ecosystems.

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