Master's thesis

Testing Red Paint as a Deterrent to Arctic Terns (*Sterna paradisaea*) on Roads
A Case Study in Bolungarvík, Iceland

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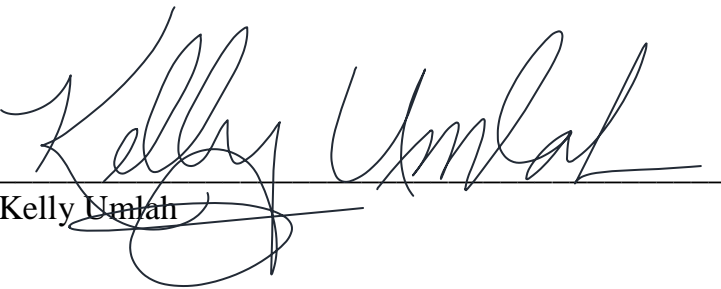
Declaration

I hereby confirm that I am the sole author of this thesis and it is a product of my own academic research.

Kelly Umlah

Abstract

As human development increases, the threat of fatal interactions between vehicles and animals on roads will likely increase. Both young and adult Arctic terns (*Sterna paradisaea*) nesting near roads, as is common in Iceland, are at considerable risk of death by collision. This study tests the effectiveness of a visual deterrent, red painted road surfaces, in keeping Arctic terns off of roads in a case study in Bolungarvík, Iceland. Population data on the study colony was sampled during an on-foot nest survey. Dead terns on the road were counted on thrice daily roadkill surveys. The number of terns sitting on the road, whether or not they sat on the painted sections, the outside temperature, weather, time of day, and presence of predators were all recorded during the thrice daily observational periods. The colony was found to be comprised of 4 950 adult terns, breeding at a density of 0.07-0.14 nests/m^2. As only six dead terns were found during roadkill surveys, no analysis could be done on the data. However, the observations found that significantly fewer terns sat on the painted sections of the road than the unpainted sections (p=0.007). The effects of outside temperature (p=0.434), weather (p=0.866), time of day (p=0.883), and presence of predators (p=0.529) on the number of terns sitting on each section were insignificant. The results imply that red paint may be an effective deterrent to Arctic terns on roads. Although further research is required to affirm this method's effectiveness, the implication of red painted roads, especially in combination with other effective management strategies, would most likely be successful in mitigating bird roadkills on Icelandic roads.

Útdráttur

Samfara vaxandi umsvifum mannsins aukast líkur á að dýr láti lífið í árekstum við farartæki á vegum. Þar sem Kría (Sterna Paradisaea) gerir sér hreiður nálægt akvegum, eins og víða má sjá á Íslandi, er töluverð hætta á að bæði fullorðnar kríur og ungar þeirra drepist í árekstum við bíla. Í þessari rannsókn var gerð tilraun til að fæla kríur frá vegkafla við Bolungarvík á Íslandi með þeirri aðferð að lita hluta af yfirborði vegarins með rauðri málningu. Gagna um fjölda einstaklinga í kríuvarpi við tilraunakaflann var aflað þannig, að gengið var um varpið og hreiður talin. Á meðan á tilrauninni stóð var farið þrisvar daglega meðfram umræddum vegkafla og dauðar kríur taldar. Jafnframt var skráður fjöldi kría sem sátu á máluðum hluta tilraunakaflans og ómáluðum, auk þess sem lofthiti, veðurfar, tími dags og viðvera afræningja var skráð hverju sinni. Fjöldi fugla í varpinu reyndist vera 4.950, og þéttleiki hreiðra 0,07-0,14 hreiður/m^2. Gögn um fjölda dauðra kría á tilraunakaflanum uppfylltu ekki kröfur um tölfræðilega greiningu. Marktækt færri kríur kusu að sitja á máluðum hluta tilraunakaflans heldur en ómáluðum samanburðarkafla (p=0.007). Áhrif lofthita (p=0,434), veðurfars (p=0,866), tími dags (p=0,883) eða viðvera afæningja (p=0,529) á veru kría á hvorum hluta tilraunakaflans um sig reyndust ekki marktæk. Niðurstöður þessarar rannsóknargefa til kynna að rauðmálað yfirborð fæli kríur frá vegum. Frekari rannsókna er þörf til þess að staðfesta skilvirkni aðferðarinnar, en ætla má að rauðmálað yfirborð vega, samhliða öðrum ráðstöfunum sem vinna að sama marki, geti stuðlað að því að minnka fugladauða á vegum á Íslandi.

To my family,

for always supporting me in everything I do.

Table of Contents

List of Figures

List of Tables

Acknowledgements

1 Introduction

Roads, and the subsequent traffic on them, have numerous impacts on the surrounding natural areas and animal species. The most significant impacts are population and habitat fragmentation, habitat loss, pollution, noise, behaviour modification, poisoning, decreased population density, diversity, and/or breeding success, and collisions with vehicles (Husby, 2016; Kociolek & Clevenger, 2011). The most commonly used mitigation measures for reducing animal collisions on roads focus on mammal, reptile, and amphibian species; however, bird species are greatly affected by the presence of roads, and are commonly found struck or crushed by vehicles on Icelandic roads (Glista, DeVault, & DeWoody, 2009). This study explores a new method for managing and mitigating bird roadkills on Icelandic roads by using red paint to deter Arctic terns (*Sterna paradisaea*) from sitting on road surfaces in Bolungarvík, Iceland.

Arctic terns are small, long-lived, ground-nesting seabirds that breed on Arctic and sub-Arctic coastlines and migrate to and from the Antarctic each year (Egevang, Stenhouse, Phillips, Peterson, Fox, & Silk, 2010). Although they are not considered a species at risk by the International Union for the Conservation of Nature (IUCN), many populations have been cited as declining (Provencher, Braune, Gilchrist, Forbes, & Mallory, 2014; Vigfúsdóttir, 2012; Furness, 2015). Garðarsson (1999) suggested that the breeding population in western Iceland is not well known; studies have since extensively researched the large colonies throughout the Snæfellsnes peninsula, but smaller colonies in more remote locations, such as in the Westfjords, have not been studied to the same extent. Additionally, human disturbances to Arctic terns nesting in Iceland, such as vehicular collisions, are likely to grow, as coastal development and tourist traffic increase (Weston & Elgar, 2007). Chicks and fledglings are most at risk of collisions, as their flight skills are not yet sufficient to fly out of the way of vehicles, and they are the least experienced with roads (Husby, 2016).

Management strategies for minimising roadkills of nesting Arctic terns in Iceland, especially for chicks, therefore, is the main outcome this study hopes to achieve. The only current management measure in place for birds nesting near roads in Iceland is the

presence of signage to inform drivers of the nesting area and to warn them that birds may be on the road; there are currently no strategies in place to try to keep birds off roads.

This study is based off a pilot project from 2016 (Jónsdóttir & Kristinsson, 2017), which was one of, if not the first attempt in the world to use coloured paint as a visual deterrent to get Arctic tern chicks off roads. The researchers tested, and subsequently compared the effectiveness of red, green, and blue paint in deterring Arctic tern chicks from the road on the Snæfellsnes peninsula, West Iceland. The study also looked at the effects of road surface temperature, among other factors, to help determine why the paint could have worked as a management strategy. The findings of their study showed that red paint resulted in the fewest chick roadkills over the entire study period, suggesting that red may be the most effective colour to keep Arctic terns off roadways. Hence, red paint was used in this study to further explore that theory. The results of this study will be used to make recommendations for the management of Arctic tern colonies in Iceland.

1.1 Research Questions and Aims

1.1.1 Nest Survey

1. What is the current population and nest density of the breeding Arctic tern colony in Bolungarvík, Iceland?

Aim:

- To estimate the density of Arctic tern nests in the study area and extrapolate this data to estimate size of the breeding population, and to estimate to what extent roadkills affect the colony's health.

1.1.2 Roadkill Surveys

1. Do red painted roads have an effect on the number of roadkills of Arctic tern chicks in Bolungarvík, Iceland?
   - *H0: Roadkills of Arctic tern chicks will be the same on painted and unpainted sections.*

- H1: Roadkills of Arctic tern chicks will be lower on painted sections than on unpainted sections.

Aim:

- To determine the effectiveness of red painted roads in reducing chick roadkills.

1.1.3 Red Paint Observations

1. Is there a difference between the numbers of Arctic terns sitting on the painted and unpainted sections of the road in Bolungarvík, Iceland?
   - *H0: There will be no difference between the medians of Arctic terns sitting on painted or unpainted sections.*
   - H1: The difference between the medians of terns sitting on paint and terns sitting on asphalt is not equal to zero.
2. How do other factors, such as outside temperature, weather type, time of day, and the presence of predators affect the numbers of Arctic terns siting on the painted or asphalt sections of road?
   - *H0: Outside temperature, weather type, time of day, or the presence of predators will not influence whether the Arctic terns sit on painted or unpainted sections.*
   - H1: One or more of these factors: outside temperature, weather type, time of day, and/or the presence of predators will affect whether the Arctic terns sit on painted or unpainted sections.

Aims:

- To determine the effectiveness of paint as a visual deterrent to Arctic terns on roads.
- To determine what factors are most likely to attract Arctic terns to road surfaces in this location.
- To develop a set of recommendations for the future management of the Arctic tern colony in Bolungarvík, and other colonies in Iceland.

1.2 Data and Methods

A literature review into the relevant information on the species was included in the data collection to effectively understand the biology and ecology of the Arctic tern, and how the recommended management strategy might affect a breeding colony. The field methodology was split into three sections: nest survey, roadkill surveys, and observations in order to adequately approach each research question. The nest survey was comparatively analysed using datasets of nesting densities from two other colonies in Iceland, on Hrísey (Þorsteinsson & Thorstensen, 2014) and in Seltjarnarness (Hilmarsson, 2017). All maps were made using the Google Earth Pro 7.3.2.5491 program. The roadkill surveys and the observations, when appropriate, were analysed in the statistical computing program, R. Specific information on the methods is expounded in Chapter 3, Methods.

1.3 Study Scope

This study only examines the effect of red paint at deterring Arctic terns on roads, not of any other species. Other species are mentioned or discussed only regarding their effects on or interactions with Arctic terns in Iceland. All data or anecdotal evidence collected only reflects the state of the colony being studied. The nest survey only determined the nest density and population size of the colony before chicks hatched; the success of breeding, hatching, or fledging were not explored in the data collection, but fledging success was speculated on in Chapter 5: Discussion due to the anecdotal evidence observed. The colony was only studied so long as they were present in the nesting area, from June to August of 2018. Only the Arctic terns observed sitting within the stretch of road designated as the study segment were counted, and only the dead Arctic terns observed on or next to the study segment were counted. Significant results will be extrapolated to include other Arctic tern colonies in Iceland but are only conclusively significant for the study colony. Only one colony was included in the study due to funding, time, and access restraints.

1.4 Thesis Structure

This thesis begins by exploring the general biology, ecology, and relevant information on the Arctic tern (2 Species Overview) that provides context for the reader later in the thesis.

I review the literature on the most notable senses, and the flight patterns of Arctic terns (2.1), which relate to the choice of colour for the paint and important the colour is to the effectiveness of the paint, and how their senses or flight patterns may put them at extra risk to human activities. Arctic tern breeding biology is explained in section 2.2, which provides all relevant background information needed to understand the results of the nest survey. Interactions with other species (2.3) both hostile and friendly, help to explain the nesting and location choices of the study colony. The current conservation status and strategies (2.4) and the threats to survival due to human activity (2.5) both help to express the extent to which management of roadkills is needed in Iceland and elsewhere. The following three chapters follow a typical thesis structure: Chapter 3 describes the steps taken and methods used to obtain and analyse the data, Chapter 4 introduces the results obtained from the analysis, and Chapter 5 discusses the implications of the results. A review of general management strategies that minimise bird roadkills is not explored until Chapter 6. Chapter 6 provides background into management strategies, their effectiveness on various road types and for different bird species, then recommends a set of best practices for the study location and Iceland as a whole. Finally, Chapter 7 declares the conclusions of the study and reiterates the management requirements for Arctic terns in Bolungarvík and Iceland.

2 Species Overview

The Arctic tern is a small to mid-sized seabird (Figure 1 and Figure 2) which has the longest known migration of any species; they migrate from the Arctic to the Antarctic and back each year (Egevang et al., 2010), most often between 20-150 degrees East (Provencher et al., 2014). Arctic terns are a long-lived species, usually with around 90% of adults surviving each year, resulting in many adults - especially females - living for over 20-30 years (Devlin, Diamond, Kress, Hall, & Welch, 2008). Arctic terns, like many seabirds, are specialised, central-forage feeders; they forage at the water's surface (Mallory, Boadway, Davis, Maftei, & Diamond, 2017) at short ranges from the colony (Suddaby & Ratcliffe, 1997). Their diet is mainly comprised of small forage fish such as capelin (*Mallotus villosus*) and sand eel (*Ammodytes*), crustaceans, and marine invertebrates such as krill (*Euphausiacea*) (Vigfúsdóttir, Gunnarsson, & Gill, 2013), but can change depending on their location and by the season (Vigfúsdóttir, 2012).

Figure 1. An adult Arctic tern flying at sea (Photo by Chloé Guillerme, 2016).

Figure 2. An adult Arctic tern sitting on land (Photo by K.U., 2018).

Provencher et al. (2014) claim that the species is not currently at any risk that requires conservation efforts on a global scale. However, despite having an extensive range and being an easily recognisable seabird, it has historically been difficult to study because most of its time is either spent in migration, or at sea (Egevang et al., 2010). Therefore, population estimates usually come from their time on land in breeding colonies. Population declines have been observed in Canadian, Greenlandic, Icelandic, and United Kingdom (UK) colonies (Provencher et al., 2014; Vigfúsdóttir, 2012; Furness, 2015); if this trend continues to spread to other colonies, the species may soon require conservation efforts at a larger scale.

2.1 Senses and Flight

2.1.1 Colour Interpretation

Avian eyes are constructed with rods and cones like human eyes, with the addition of a fourth type of single cone that makes birds tetrachromatic, and double cones that make up most of a bird's retina (Blackwell, 2002). The purpose of the double cones is not well known, but they do contain pigments used for interpreting long wavelengths of light. Additionally, birds' eyes are lined with oil droplets that filter light and shift their light sensitivity to be higher at longer wavelengths (Rubene, 2009). The organisation of a birds' eye suggests that they likely interpret colours differently than we do as humans (Rubene, 2009), even though birds see the same maximum wavelengths as humans do (up to 700 nanometers on the visual light spectrum) (Endler & Mielke, 2005). Humans have only

8

recently been able to develop the technology capable of revealing what tetrachromatism may look like (Troscianko & Stevens, 2015).

Blackwell (2002) discusses that birds may be capable of seeing additional mixes of colours, some of which are not even close to one another on the visible light spectrum. The colours that are relevant to this study include green-red, blue-red, UV-red, UV-green-red, UV-blue-red, and green-blue-red. Blackwell also discusses that birds may not be able to discern the visual cues that come from the colour of an object from visual cues of danger from said object. The misinterpretation of colour cues by birds could indicate that if a certain colour is considered threatening by a species, then they will avoid that colour to the best of their ability. Colour interpretation is different by species, therefore, the extent to which Arctic terns specifically are affected or deterred by certain colours is yet to be determined.

Aposematism is the use of vibrant colours or patterns, usually on harmful organisms, to show predators that it is dangerous to consume or attack said organism (Prudic, Skemp, & Papaj, 2007). The colours most commonly used for aposematism are the bright reds, oranges, and yellows, often in contrast with darker colours and black, which, together stands out from the duller colours often found in the natural environment. Aposematic patterns may also deter species from attacking a certain prey; however, colour contrast is more effective in deterring avian predators than patterns are (Prudic et al., 2007). Blackwell (2002) suggests that the interpretation of aposematic colouring is innate, so aposematic colours or patterns may deter any bird species from consuming aposematically coloured prey, to some extent.

2.1.2 Hearing and Flight

The frequency in which Arctic terns can hear ranges from around 1 kHz to 15 kHz (Golubeva, 1994); within this range lie the majority of passenger vehicle frequencies (2-16 kHz) (Bryan, 1976). Acoustic signals between adults and offspring are important for development, even within the egg (Golubeva, 1994), but continue to be pivotal for adult-offspring communication throughout the fledging process.

As small, lightweight seabirds, the majority of the Arctic tern's time in the air is spent gliding on the wind. Consequently, terns generally have to either follow the direction of

the wind or expend energy to go against the wind (West & Ramroop, 2011). However, their size and light weight does allow them to quickly take off in little space (Erritzoe, Mazgajski, & Rejt, 2003). These traits make Arctic terns well adapted to their long migration, and to quickly leaving an area in the case of a predator, but susceptible to having to change their direction quickly to compensate for a gust of wind.

2.2 Breeding

Arctic terns are ground nesters that breed in dense colonies near or on the coast (Vigfúsdóttir et al., 2013). The breeding distribution of Arctic terns range from 42-84 degrees North (Mallory et al., 2017), but they are most commonly found breeding in the Arctic and sub-Arctic (BirdLife International, 2018). Similar to many other seabird species, their nesting range is shifting northward (Anderson & Devlin, 1999). Due to their long migrations, the time Arctic terns have to breed is very short; nesting typically occurs three to four weeks after their initial arrival to the breeding area (Vigfúsdóttir et al., 2013). Increasingly, studies have shown that the probability of survival for Arctic tern chicks gets higher if nesting occurs earlier in the season; within the last 70 years, Arctic terns breeding in Denmark have advanced their average breeding date by over 18 days, likely as a result of climatic or environmental changes (Møller et al., 2006).

Adult terns usually start breeding when they reach three to four years old (Cullen, 1957) and only nest once per year (Mallory et al., 2017). The courtship ritual begins with the males filling their beaks with fish, flying passed the female, and offering her his fish; if she accepts, she will follow him and they fly together in the air (Cornell University, 2017). The male continues to feed her until a pair bond is established and mating occurs. Arctic terns, like many other seabird species, are monogamous, keeping the same mate their entire lives (Levermann & Tøttrup, 2007).

Arctic terns have high site fidelity; therefore, the colony will often return to the same location to nest every year (Devlin et al., 2008). Nests are initiated between June and early July; a female tern can lay one egg per day, and each clutch contains 1-3 eggs (Figure 3), rarely ever 4 (Mallory et al., 2017; Møller et al., 2007). The male feeds the female during the time she is laying her eggs, after this time, however, the pair take turns incubating the nest and foraging (Vigfúsdóttir, 2012). Nests are incubated for up to 25 days (Figure 4);

10

hatching success is variable depending on the environmental conditions of the year, such as weather, predators flushing adults from the nest, and food availability for the nesting adults (Mallory et al., 2017). Terns will delay laying their eggs if the environmental conditions are not suitable, but if it gets too late and they still have not laid eggs, they will simply abandon the attempt for the whole season (Levermann & Tøttrup, 2007; Monaghan, Uttley, Burns, Thaine, & Blackwood, 1989).

Figure 3. An Arctic tern nest with two eggs (Photo by K.U.).

Figure 4. An Arctic tern chick recently hatched from the egg (Photo by K.U., 2018).

The average time from hatching to fledging is 22-23 days (Cramp, 1985). Arctic terns most commonly choose to breed on predator free land, but will defend their eggs and chicks ferociously against both avian and land predators (Egevang & Frederiksen, 2011). Juveniles have dark coloured beaks throughout their first year and whenever they are not breeding, but during their second, third, or fourth spring migration, both males' and females' beaks will begin to turn a deep, vibrant red that remains during the breeding season. The terns will leave the nesting area sometime during the month of August depending on the weather cues and the fledging success of the season (Møller at al., 2007).

The breeding season is a stressful season for Arctic terns, especially regarding food availability and foraging effort. A lack of food or ineffective foraging strategies can directly result in poor breeding success (Vigfúsdóttir et al., 2013; Suddaby & Ratcliffe, 1997). Seabirds are all central-place foragers during their breeding season, leaving from the central nesting area to forage, then returning to the nesting area to eat, or to feed their partner and young (Ceia & Ramos, 2015). Compared to other seabird species, Arctic terns are one of the most vulnerable species to food shortages due to their lack of behavioural plasticity specifically in regard to their highly specialised feeding techniques (Suddaby & Ratcliffe, 1997). Consequently, breeding success is frequently very low, as breeding

attempts are often deserted from lack of food; total breeding failure by year in Icelandic colonies can be up to 90% (Vigfúsdóttir et al., 2013).

Human disturbances like noise or pollution can contribute to fledging failure; but if Arctic tern's prey abundance, size, or nutritional value is too low, or if there are changes in the spatial or temporal distributions of the prey species, fledging success will definitely be impacted (Vigfúsdóttir et al., 2013). The small size and foraging range of the Arctic tern make them especially vulnerable to changes in prey availability, and if an adult Arctic tern perceives their own life to be at risk, they will desert their nests for their own survival (Monaghan et al., 1989). Consequently, it is common for Arctic tern adults to desert their nests and for their chicks to starve to death, more so than other seabird species (Egevang & Frederiksen, 2011).

2.3 Interactions with Other Species

Arctic terns in Iceland interact with other non-prey species usually in one of two ways: ignoring the other species in their territory, or attacking the other species in and around their territory. It is uncommon that Arctic terns will ignore the other species in the area, except for the case of some smaller birds and Eider ducks (*Somateria mollissima*). Eider ducks prefer the same nesting area criteria as Arctic terns do: similar vegetation, locations, food availability, etc., and often initiate their nests earlier than Arctic terns; thus, Arctic terns often have to nest around the ducks (Pratte, Davis, Maftei, & Mallory, 2016). As they do not see Eider ducks as a threat to their young's survival, they often will not attack them or any other small bird that the terns do not view as a threat. Additionally, Arctic terns may benefit from nesting near Eider farms, as farmers often kill predators like foxes and mink.

In the case of most other species, however, Arctic terns use group defense to ward off the animal they deem a threat. If the creature moves within the breeding area, odds are it will be attacked, regardless of its age or size (Mallory, Boadway, Boadway, & Akearok, 2010). The defense strategy is different for avian and land threats; for avian threats, the colony will simply mob and chase away the threat. For land threats, the colony will mob and will also dive on the threat, pecking the highest point, often hard enough to draw blood (Mallory et al., 2010).

The main predators to Arctic terns in Iceland include Arctic fox (*Vulpes lagopus*), the common raven (*Corvis corax*), American mink (*Neovision vision*), various gull species, humans, and common housecats (Mallory et al., 2017). Lemmings (*Lemmus lemmus*) in the Canadian Arctic, although not a predator of Arctic terns, are sometimes picked up by a member of the tern mob and dropped from a height of three meters, which occasionally results in death. These instances lead researchers to believe that the ability of Arctic terns to differentiate between species that pose a threat and species that do not, is imperfect (Mallory et al., 2010).

2.4 Conservation

Until the early 20th century, Arctic terns, along with other tern species, were hunted in North America for the feather trade which diminished many populations worldwide. The Migratory Bird Treaty Act that was established in 1918 between the United States of America (USA) and Great Britain (on behalf of Canada), with amendments later including Japan, Mexico, and the Soviet Union (now the Russian Federation); this act stated that it is unlawful to capture, kill, possess, or transport any part of any migratory or native bird's body, egg, nest, or any product containing them (Migratory Bird Treaty Act of 1918, 2004), therefore, their populations were able to return to equilibrium (Cornell University, 2017). Similarly in Iceland, all bird species are protected from being intentionally killed or harmed except for some gull, goose, ducks, and other seabird species; Arctic terns, therefore, are officially protected. However, it is legal to take Arctic tern eggs from their nests for personal use before the 15th of June each year (Umhverfisráðuneytið, 1994).

The most recent conservation assessment by the IUCN in early August of 2018 classified the Arctic tern as a species of least concern on the Red List (Birdlife International, 2018). Despite a declining global population trend, the decrease is not substantial enough to warrant a higher conservation status, as the population is shrinking less than 25% in 40.2 years, or 3 generations (Birdlife International, 2018). In 2004, the European Union (EU) reported the conservation status of Arctic terns to be unfavourable (Birdlife International, 2004); the steps for determining conservation status in the EU is outlined in Figure 5. In North America, various organisations exist that classify the conservation status of bird species; the conservation concern of Arctic terns can range from high to low depending on the organisation (Cornell University, 2017), so the best estimation for the conservation status in North America as a whole would be the IUCN Red List classification.
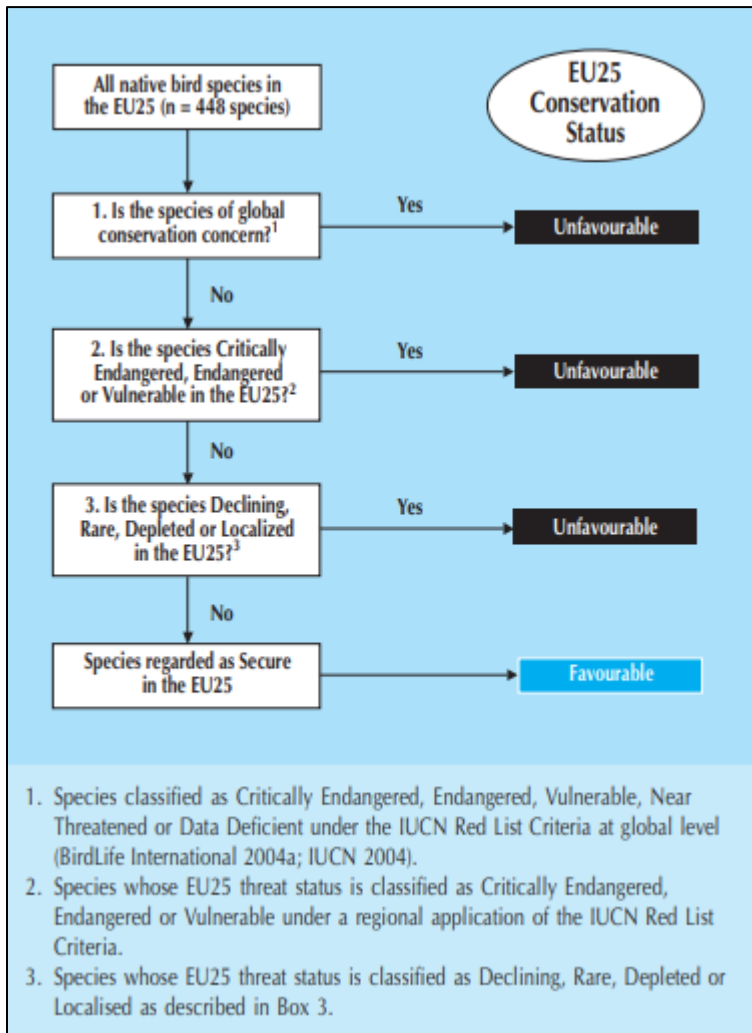
Figure 5. Classifications steps of favourable or unfavourable conservation status in the EU25 (European Union 25) directive (Birdlife International, 2004).

2.5 Human Threats to Arctic Tern Survival

Human disturbance to coastal birds is currently high; contact will likely only increase with sea level rise, and as human development, population, and coastal recreation increase globally (Weston & Elgar, 2007). Climate change is often cited as the major concern for seabirds (Carey, 2009), especially in polar regions (Keogan et al., 2018); although climate change will greatly affect the survival of many seabird species, Arctic terns have the potential to also be highly affected by pollution (Provencher et al., 2014) and vehicle collisions (Erritzoe et al., 2003). Understanding the causes and effects of these threats to Arctic terns is important for making management decisions regarding the conservation of Arctic tern populations.

2.5.1 Climate Change

The effects of human-induced climate change on long-distance migrant birds are well documented. As spring and summer in the Arctic is constantly shifting ahead in time (Keogan et al., 2018), weather cues for the migration of Arctic terns and their prey are increasingly mismatched (Carey, 2009; Howard et al., 2018). Arctic terns are among the most vulnerable seabird species to starvation from mismatching peak prey availability with nesting, as their small body cannot expend the energy required to forage further from the colony (Keogan et al., 2018. Additionally, they only feed at the surface and carry single loads of prey, limiting the types of prey available to them, and increasing their vulnerability to changes (Vigfúsdóttir, 2012). Worst case scenario, Carey (2009) asserts that climate change could affect seabird breeding so much that species could go extinct if they are not able to adapt to their changing environment. Seabirds have adapted to have longer lives to minimise the likelihood of extinction from low prey availability (Vigfúsdóttir, 2012), but climate change may still put them at great risk.

2.5.2 Pollution

The long migration of Arctic terns put them at risk for high exposure to multiple sources of pollution (Provencher et al., 2014) from the air, water, and food at any part of their migration (Wayland, Gilchrist, Marchant, Keating, & Smits, 2002). Concentrations of toxic trace elements like mercury (Hg) and lead (Pb) are often higher in marine species than freshwater or terrestrial species (Furness & Camphuysen, 1997), and are especially high in Arctic tern tissues - so high that other species would have reproductive issues or even die from the toxins (Provencher et al., 2014). Arctic terns can break down organic pollutants faster than other seabird species because of their fast metabolism and small size; however, this also means the exposure of Arctic terns to pollutants may be more severe than scientists are able to predict (Lemmetyinen, Rantamäki, & Karlin, 1982).

2.5.3 Roads

Roads can impact nesting birds in numerous ways: through habitat fragmentation, disturbances such as light and noise, indirect deaths from habitat loss, pollution, or maintenance practices, and direct death from vehicle collisions (Jacobson, 2005; Kociolek, Clevenger, St. Clair, & Proppe, 2011). While each of these impacts might affect different

bird populations to different extents, most studies argue that noise causes the largest decline in species richness and abundance by roads (Summers, Cunnington, & Fahrig, 2011). The main concerns regarding noise have to do with interfering with communication between adult pairs and their chicks (Rheindt, 2003), distracting chicks so that they are more open to predation (Yim-Hol Chan, Giraldo-Perez, Smith, & Blumstein, 2010), and increasing the amount of time spent defending against perceived predators, thus reducing the amount of time spent foraging and feeding chicks (Quinn, Whittingham, Butler, & Cresswell, 2006). The main cause of negative impacts to bird populations from roads, however, is actually roadkills (Summers et al., 2011). There are two ways in which birds are roadkilled: birds sitting on the road that get crushed by a vehicle, and birds flying across the road at a low height getting struck by a vehicle (Husby, 2016).

There are numerous reasons why birds may sit or walk onto roads; Erritzoe et al. (2003) suggest that the asphalt absorbs high levels of solar heat, so the road surface can be 7-10°C hotter than the surrounding ground which could help birds to conserve energy and maintain body heat. Roads are generally flat open spaces, so taking off from the road would be easier than from uneven ground topped with vegetation (Erritzoe et al., 2003); these flat spaces are usually also higher than the surrounding area, making it easier to watch for predators. Arctic terns specifically may sit on the road is to rest and gather together on the flat space after foraging.

Collisions with cars kill several hundreds of millions of birds worldwide each year, and these individuals are usually juveniles or healthy adults (Husby, 2016). The loss of juvenile and healthy individuals will likely cause huge demographic consequences, and fitness degradation for populations and colonies (Orłowski, 2008). The risk increases for ground nesting species (Jacobson, 2005), species that nest in open areas (Kociolek et al., 2011), and birds with territory near roads (Summers et al., 2011; Varga, Monoki, & Barsony, 2006), all of which describe the nesting behaviours of Arctic terns in Iceland. The death of adult individuals in long-lived species such as the Arctic tern will have the greatest effect on the survival of the colony (Vigfúsdóttir, 2012). Thus, it is important to monitor roadkills and survival of both adults and juveniles in Arctic tern colonies in Iceland. The negative effects of roads could be reduced with effective management and the implementation of roadkill mitigation strategies.

3   Methods

The study design was both exploratory and experimental, which was set to determine the breeding population, nest density of the colony, and if colouring roads reduced Arctic tern roadkills and/or deterred them from sitting on roads. The suggested methods for the roadkill survey were mainly derived from a study report by Jónsdóttir and Kristinsson (2017) that attempted to determine if painting the road various colours on the Snæfellsnes peninsula deterred Arctic tern chicks from sitting on the road and subsequently being crushed by motor vehicles. However, methods were adapted to only include a 120-meter section of road, roadkill surveys and observations to accommodate for budget, study size, and location-specific purposes.

The location of the Arctic tern colony's nesting site was just outside of the town limit of Bolungarvík, in the Westfjords of Iceland (Figure 6). The nesting area was a relatively flat, open space with short, grassy vegetation, to the north-east of the incoming road to Bolungarvík. Remnants of an old dirt road system within the area included a slope of land from the nesting area up to the shoulder of the road that was shallower than the slope of the ditch. The nesting area spanned from the edge of the road to the drop off of the beach, from the edge of the buildings on the north side to a single building on the other side, and was intersected by a mostly unused dirt road.
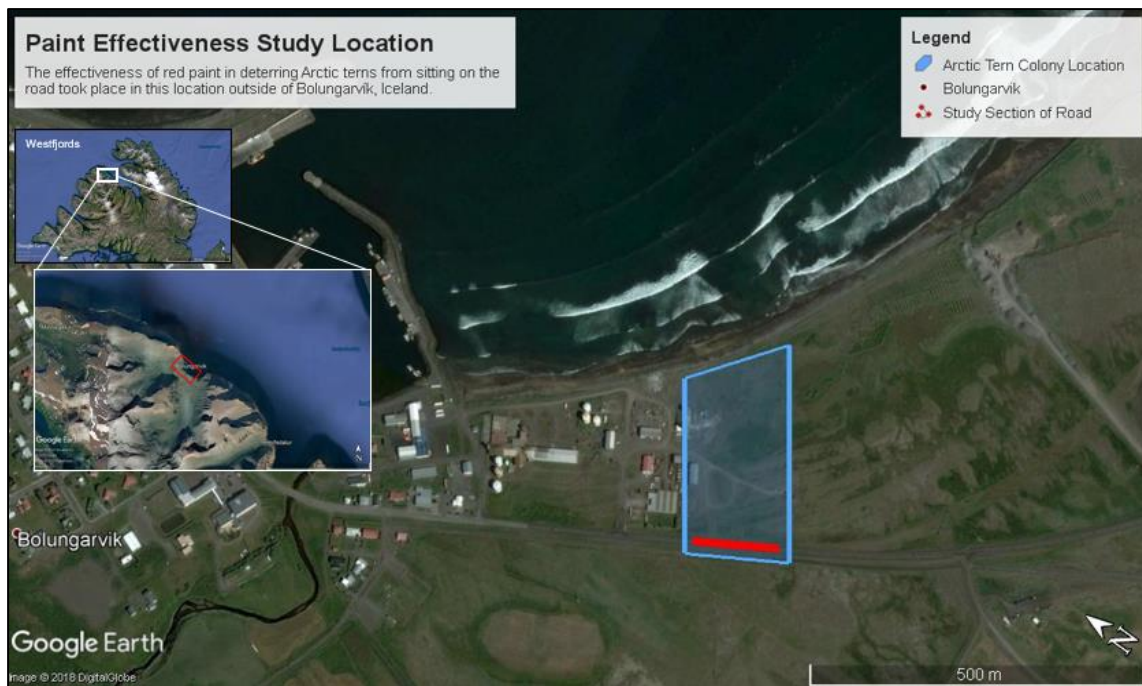
Figure 6. Study location just outside of Bolungarvík, Iceland (Google Earth, 2018a).

3.1 Nest Survey

The survey was conducted on the nesting grounds adjacent to the road on July 3, 2018, on the first day of the summer that myself and the ecologist at Náttúrustofa Vestfjarða was available for the survey, and after the Arctic tern colony had enough time to establish nests and lay eggs. The method for collecting the nest data came on advice from the ecologist at Náttúrustofa Vestfjarða. Six random points were selected as the sample areas within the 23 488m^2 nesting area; three between the study road and the dirt road that split the nesting area (Area A), and three between that same dirt road and the beach (Area B). Figure 7 is a map of the study area showing the location of the sample sites.

Figure 7. Map of Arctic tern nest survey area with sample sites in the two areas (Google Earth, 2018b).

The coordinates were recorded using a Global Positioning System (GPS) at each center point; the GPS was using WGS 84 as its coordinate system. A wooden stake was placed into the ground where the coordinates were taken, and a five-meter-long string was attached. At the other end of the fully-extended string, I carefully walked back and forth along the string in a complete circle and recorded the number of nests found between myself and the stake (Figure 8 and Figure 9). The two colleagues I had helped to count the nests within the circle, as they walked around on either end of the string. The total area for each sample was 78.54m^2, making the total area sampled 471.24m^2.

Figure 8. Sample site setup for nest survey data collection (Photo by Elena Lebedef, 2018).
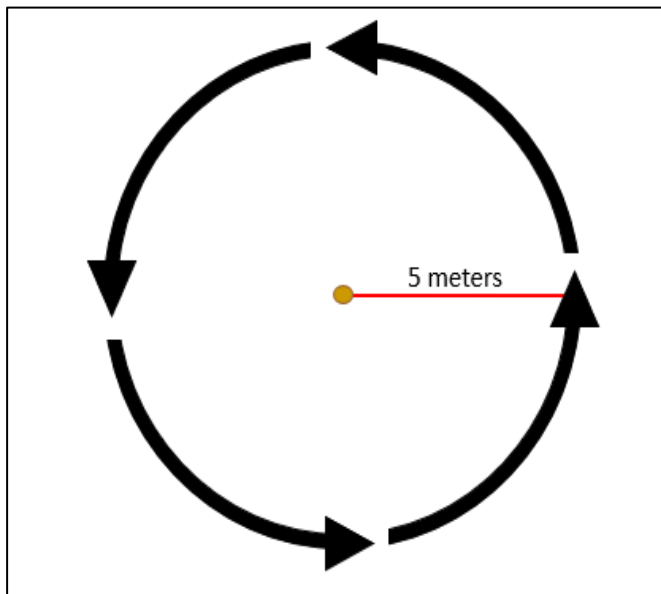
Figure 9. Diagram of the dimensions of each nest sample site; the center is the stake, the red line is the 5-meter string, and the black arrows indicate the path taken for each sample. Diagram created using Microsoft PowerPoint 2016.

I ensured that the weather during the nest survey was favourable enough so that if the parents flushed from the nests for a short period of time, the eggs would not be exposed to

any weather conditions that might negatively affect their development or success. The weather on July 3, 2018 was partly sunny with light showers (less than 2mm), and the outside temperature was 8-9°C, with the wind reaching no more than 5 meters per second.

3.1.1 Analysis

Using the data collected from the survey, the nesting density was calculated within each sample by dividing the number of nests found in each sample site by the size of the sample site. The samples were then split into the two sections, with Area A being comprised of Sites 1-3, and Area B being comprised of Sites 4-6; the mean of the three samples per area was found. I also calculated the mean number of breeding pairs in each area by multiplying the mean nests per square meter by the area of each section. By multiplying the number of breeding pairs per section by two, and adding the two sections together, I subsequently estimated the size of the colony for the entire nesting area.

3.1.2 Observations

During the roadkill surveys and observational periods, if I observed anything regarding breeding success or apparent changes in colony size throughout the summer, I recorded this information. There is no analysis for this part, but this anecdotal evidence, when cross-referenced with the literature, may have insights into the true size and success of the colony in this location, and could have implications for future years of study in this area.

3.2 Road and Walkway Painting

3.2.1 Paint Criteria

To ensure vehicular safety on the study road, the coarse, slip-resistant Vitretex paint was chosen in a bright red colour. Vitretex is an outdoor acrylic paint, mainly used on concrete and brick, but is suited for use on asphalt. Additionally, Vitretex paint has excellent resistance to water and the adverse weather conditions commonly experienced in Iceland (Slippfélagið Málningarverksmiðja, 2014).

3.2.2 Method

My walkway design incorporated many aposematic inspired patterns in an attempt to best deter Arctic terns from sitting on it (Figure 10). Prudic et al. (2007) note the importance of colour contrast for aposematism; the dominant hues, such as red, orange, and yellow, stand out from the typical green, brown, and black backgrounds. They also mention that colour contrast is a more effective form of aposematism for avian predators than patterns are. Additionally, since aposematism is a phenomenon having to do with prey and not simply deterring predators, aposematism is not relevant. Therefore, my design, whilst incorporating many aposematic patterns into it, is mainly aesthetically pleasing for the people rather than just a deterrent the birds. I painted the walkway on July 19, 2018.

Figure 10. Walkway design incorporating aposematic patterns such as stripes, spots and eyes, and contrasting colours painted in the study site outside of Bolungarvík (Photo by K.U., 2018).

In conjunction with the road administration, Vegagerðin, I developed a design for the road that minimised the chance of vehicles slipping on the painted surface by leaving two unpainted strips as tire tracks (Figure 11). I used Microsoft Paint 3D to create and visualise

24

the design. I measured the dimensions of the road using a measuring tape to determine how much paint I would need. One lane was 3.3 meters in width, and tires are approximately 0.5 meters in width and approximately 1 meter apart from each other. The tire measurements and width from each other were measured on a 1998 Toyota Corolla Touring, which is a relatively average car size for this location. Using these dimensions, the design had 0.6 meters of paint on either side of the lane, 0.5 meters without paint for the tire tracks, and 1 meter of paint in the middle, making a total of 2.2 meters of paint per section allowing for a small amount of extra space on each side of the lane to avoid painting over the lane markers.

Figure 11. Example diagram of road painting design from Microsoft Paint 3D (not to scale).

Of the 120 meters of road next to the study site, I decided to split the single lane into six, equal sized, 20-meter sections, with three painted and three not painted. Each section was $3.3m \times 20m = 66m^2$. The total amount of paint required to cover one section would be $2.2m \times 20m = 44m^2$, multiplied by the three sections of paint would make a total of $132m^2$ of paint required for one lane. I decided against painting both lanes of the road because preliminary observations suggested that just the lane closest to the nesting site, the Bolungarvík incoming lane, would be sufficient for this study. Each section, painted or unpainted, was assigned a number; 1, 3, and 5 were painted, and 2, 4, and 6 were unpainted asphalt. Roadkill surveys and red paint observations began the next day, July 28, 2018.

3.3 Roadkill Surveys

3.3.1 Literature

Bishop and Brogen (2013) suggested that before any roadkill surveys begin, the researcher should obtain information via local people from the study area on how many birds they estimate are killed by motor vehicles per day, and adjust the number of sample times per day based on that information. Ecologist C. Gallo at the Westfjords Nature Research Centre, Náttúrustofa Vestfjarða, noted that the main high traffic times in the study site were between 07:00-08:00, 12:00-13:00, and 16:00-17:00 during weekdays; he suggested sampling 30 minutes after each high traffic time because the area sees high rates of Arctic Tern roadkills (personal communication, April 25, 2018). The bodies of smaller birds, such as Arctic terns and their chicks, found on the roads in high traffic areas can become unrecognizable after only 90 minutes due to repeatedly being driven over (Erritzoe et al., 2003). While the traffic in the study area had been higher at certain times than others, it was still very low in general; therefore, conducting surveys three times a day was sufficient in providing an accurate snapshot of daily roadkill at this site.

Erritzoe et al. (2003) provided multiple tips for carrying out bird roadkill surveys along roads. The authors suggested that the best method for counting the number of dead birds on the road is on foot rather than by bicycle or car, as up to one third of the smaller individuals are overlooked when travelling at higher speeds. Based on their review of other bird roadkill studies, Erritzoe et al. (2003) express the need to justify the length of time and the season in which the surveys are carried out, and the need to do two to three surveys in one day for better accuracy. Lastly, the authors list all the other information that should be recorded other than just the number of dead individuals found on the road: the date, start and finish times of the survey, a short description of the weather, taxon of bird found, age of bird (chick/juvenile or adult), the section of the road it was found on, the condition of the bird, and if it was found on the road or just off the road. For the purposes of this study, the last two suggestions were the least relevant, and were not recorded.

3.3.2 Method

Roadkill surveys took place along the entire stretch of road adjacent to the nesting ground. Three times per weekday after each rush of traffic, and once per day on weekends, I

walked along the entire 120-meter stretch of road. Before beginning, I recorded the date and the time I began, the outside temperature using the thermometer on my car (and cross-checking that with the temperature for Bolungarvík on the Icelandic Meteorological Office's online weather forecast at "vedur.is"), and recorded whether I considered the weather to be sunny or cloudy, calm or windy, rainy or stormy. I also noted anything that was peculiar about the weather, such as high wind speed, or if the weather changed during the sample time.

I then began walking along the entire 120-meter stretch, looking closely for any crushed or struck Arctic terns on the road or on the shoulder. If any were found, I recorded whether they were an adult, a chick, or another species, and the section of road on which they were found. Using rubber gloves, I respectfully moved the carcass from the road or shoulder into the ditch so that predators or scavengers could still access the potential food source, and so that I would not double count any dead individuals. After the 30-minute observation period explained in section 3.4 Observations, I recorded the end time.

3.4 Observations

Immediately following the roadkill surveys, I observed the terns' activity around the road and recorded the number of terns sitting on the painted and unpainted sections. The methodology for this section arose mainly from observations in the preliminary site visits, where I familiarised myself with the terns' behaviour towards me and the road. Using this information, I chose the methods that worked best for the location, budget, and time-scale. Observations took place at a vantage point far enough away from the road so as to not influence the terns' behaviour toward the road and so the terns would not see me as a threat, but close enough to be able to see which section of the road they sat on and if the individual was a chick or adult.

I also recorded the presence or absence of both avian and land predators if they entered the nesting area and triggered a response from the adult Arctic terns. I took notes on any unusual but relevant behaviour that would not be explained by the analysis of the number of terns sitting on painted or unpainted sections. The weather was recorded during the roadkill surveys were used for the analysis of the behavioural observations.

3.4.1 Analysis

R 3.4.3 and R Studio 1.1.419 were used to analyse all the data, and to visually represent the paint versus asphalt data. Microsoft Office 365 Version 1809 Excel was used to visualise the temperature, weather, and predator data. I first used the 41 data points of terns sitting on painted and unpainted sections to determine if there was a significant difference between the appropriate measure of central tendency of the two variables. The data was not normally distributed even when transformed; the non-parametric, Wilcoxon Rank-Sum test was used to determine if there was a location shift in the median between the painted and unpainted datasets (Wild, 1997).

The hypotheses for the Wilcoxon Rank-Sum Test are as follows:

- *H0: The difference between the medians of terns sitting on paint and terns sitting on asphalt is equal to zero.*
- H1: The difference between the medians of terns sitting on paint and terns sitting on asphalt is not equal to zero.

Charts were created in R Studio using the ggplot2 package. To represent the statistical distribution of the data and the differences between those distributions, I created a notched boxplot. To visualise the frequency of each observation size, I created a violin plot, within which also had a box plot to represent the distribution of the data.

Second, I used a Kruskal-Wallis Test to determine if the outside temperature had a significant impact on the number of terns sitting on the road, as cooler temperatures may attract the birds to the warmer road surface. The Kruskal-Wallis Test was used because the distribution of the data was not normal, and as the Kruskal-Wallis is a nonparametric test, the assumption of normality did not have to be met. I visualised the data using a connected scatter plot of the average number of terns sitting on the road by each temperature.

I then ran two tests, one for the relationship between temperature and paint and the other for the relationship between temperature and asphalt. The hypotheses for this test are as follows:

- *H0: There are no significant differences between the number of terns on the road (paint or asphalt) by the outside temperature.*

- H1: There is a significant difference between the number of terns on the road (paint and/or asphalt) by the outside temperature.

I used a Chi-Square analysis to determine the dependence or independence of the tern observations to the various categories of weather: sun, cloud, calm, wind, rain, or storm. Chi-Square was used for this analysis and the following two analyses because the data is nonparametric and was separated into multiple categories. I used a bar chart with standard error bars to visualise the data, and calculated the standard error by hand. I created a five by two matrix to be used as the contingency table in R Studio, and then ran the Chi-Square test without Yates' correction, because although Yates' correction is the default in R, it is widely known to decrease the accuracy of results (Haviland, 1990). The hypotheses for this specific test were as follows:

- *H0: The type of weather and the number of terns sitting on each section of road are independent of each other.*
- H1: The type of weather and the number of terns sitting on each section of road are not independent of each other.

Fourth, I again used the Chi-Square test to analyse if the occurrence of Arctic terns on the road was significantly affected by the time of day of the observation (morning, afternoon, or evening). I visualised the data in another bar chart with standard error bars. The data was not normally distributed, and therefore, nonparametric, making the Chi-Square test the best choice for the data. I created a three by two matrix for the contingency table in R and ran the Chi-Square test without Yates' correction. The hypotheses for the time of day test were:

- *H0: The number of terns sitting on either section of the road is independent to the time of day.*
- H1: The number of terns sitting on either section of the road is not independent to the time of day.

Lastly, I used the same test to determine the dependence or independence of the tern observations to the presence or absence of predators. To visualise this data, I created a percentage bar chart; I used the total number of terns found when predators were present and when they were absent, then split that data into proportions by which section of road

they were sitting on. For the statistical test, I created a two by two matrix as the contingency table in R, then ran the Chi-Square without Yates' correction. The hypotheses for this specific test were:

- H0: *The presence or absence of predators and the section of road on which the terns sat are independent of each other.*
- H1: The presence or absence of predators and the section of road on which the terns sat are not independent of each other.

4   Results

4.1 Nest Survey

The number of nests per site ranged from 5 to 15; thus, the estimated pairs per square meter range from 0.06 to 0.19 (Table 1). The average density computed from the three sites in Area A is 0.14 nests and pairs per square meter. The average density in Area B is 0.07 nests and pairs per square meter. The density of each area determined the number of pairs per area: 1663 in Area A, and 812 in Area B. From the number of pairs, I could determine the total number of individual birds per area: 3326 in Area A, and 1624 in Area B, which combined made approximately 4950 individual adult birds in the entire breeding colony (Table 2). Few to no nests were found outside of Areas A and B.

Table 1. Number of nests and estimated pairs per square meter (with standard deviation) by site. Each site was 78.54m2.

Site	Area	Coordinates		Nests	Estimated pairs/m²
		°N	°W		
1	A	66 08.976	23 14.604	9	0.11
2	A	66 09.007	23 14.594	8	0.10
3	A	66 09.017	23 14.654	15	0.19
4	B	66 09.041	23 14.500	7	0.09
5	B	66 09.072	23 14.502	5	0.06
6	B	66 09.064	23 14.417	5	0.06

Table 2. Calculation results for determining breeding colony size by area.

Area	Mean Density (Nests/m²) ±SD	Size of Area (m²)	Estimated # of Pairs	Estimated # of Birds	Estimated # of Breeding Birds
A	0.14 ± 0.05	12 240	1663	3 326	4 950
B	0.07 ± 0.01	11 248	812	1 624	

4.1.1 Observations

All evidence observed was recorded between August 10-15, 2018. However, this evidence is purely anecdotal, and therefore, any discussion regarding this information is entirely speculative, and should be read with a critical eye. I observed dwindling numbers of adults flying above the nesting area as the season progressed, even though there appeared to be many chicks still around their nests (Table 3). Most notably, however, is the final observation, where numerous dead chicks of all developmental stages were found throughout the nesting area. Unfortunately I was not able to count them, therefore, I cannot make an estimate as to how many remained and if fledging could have been deemed a success or a failure based on that estimate. However, this anecdotal evidence is used in the discussion to speculate the success of the fledging season; as this is merely speculations, no conclusions will be drawn from this information.

Table 3. Anecdotal observations that may provide background information for the monitoring of the Arctic tern colony in this location.

Date	Observation
02/08/2018	Very few birds flying around. Most are sitting, but total numbers seem to have reduced.
10/08/2018	No more than 30 adults flying around at once, another approximately 30 adults sitting on the gravel within nesting area; chicks still around nests.
12/08/2018	Few birds even remotely close to the road, mainly on the beach.
14/08/2018	1-3 adults patrolling area; numerous chicks still around their nests, chirping, highly exposed; the generator building is making constant loud noise.
15/08/2018	The colony has officially left the area; numerous dead chicks of all ages are found within the nesting area

4.2 Roadkill Surveys

The roadkill surveys found a total of six dead individuals in the study site, four of which were found on asphalt sections, and two of which were found on painted sections (Table 4). Table 4 included the time period in the event any patterns could be determined from

this data; however, the roadkill surveys did not produce enough data points to allow for any accurate analyses, therefore, the results for this section are inconclusive.

Table 4. Observations when dead Arctic tern chicks were found.

	Date	Time Period	Section	Paint or Asphalt
1	28.07.2018	Afternoon	4	Asphalt
2	01.08.2018	Evening	4	Asphalt
3	02.08.2018	Evening	6	Asphalt
4	08.08.2018	Evening	3	Paint
5	10.08.2018	Morning	4	Asphalt
6	17.08.2018	Morning	5	Paint

4.3 Observations

The approximately 25 total hours of observation revealed an overall number of 191 Arctic terns sitting on the road; 42 were found on the painted sections of the road, and 149 were found on the unpainted (asphalt) sections of the road. At this study site, the estimated number of terns on the road is 7.63 individuals per hour. As only five terns were observed sitting on the walkway, that data will be incorporated into the road data. Additionally, nine terns were observed sitting on the unpainted tire tracks of the painted sections; whilst these individuals could technically have been considered sitting on "asphalt" they were still counted as having sat within the painted section. For full tables of all observations (and roadkill data), see Appendix B.

4.3.1 Painted versus Unpainted

As shown by the shape of the boxplots in Figure 12, the variation in observations for the two variables, paint and asphalt, are very different. As the two notches do not overlap, there is evidence that the two medians significantly differ (Potter, 2006). From the plot it is clear the asphalt median is larger than the paint median, indicating that the number of terns sitting on the unpainted sections was higher than the number sitting on the equally sized painted sections. The median for the paint observations was zero, indicating that for at least half of these observations, zero terns were found sitting on the road. The distributions of these two variables are also very different; it appears that 95% of the paint observations equalled below 4, whereas 95% of the asphalt observations equalled below 11, but outliers reached as high as 24.

The violin plot in Figure 13 represents the probability that each observation will occur; the width of the plot is greatest at zero, helping to confirm that the majority of the observations were zero. The probability of finding that number of terns on the road decreases as the number gets larger, shaping the paint data as almost triangular. The probability of observations in the paint data is much wider than in the asphalt data. As the distribution of the asphalt data is larger than paint, the violin plot is longer, and the values with the highest probability are around 1-2 rather than zero. However, the largest probability is not much larger than the probabilities of the surrounding values. The probability of observation decreases above a value of about 5 and becomes infinitesimal between 11 and 24.
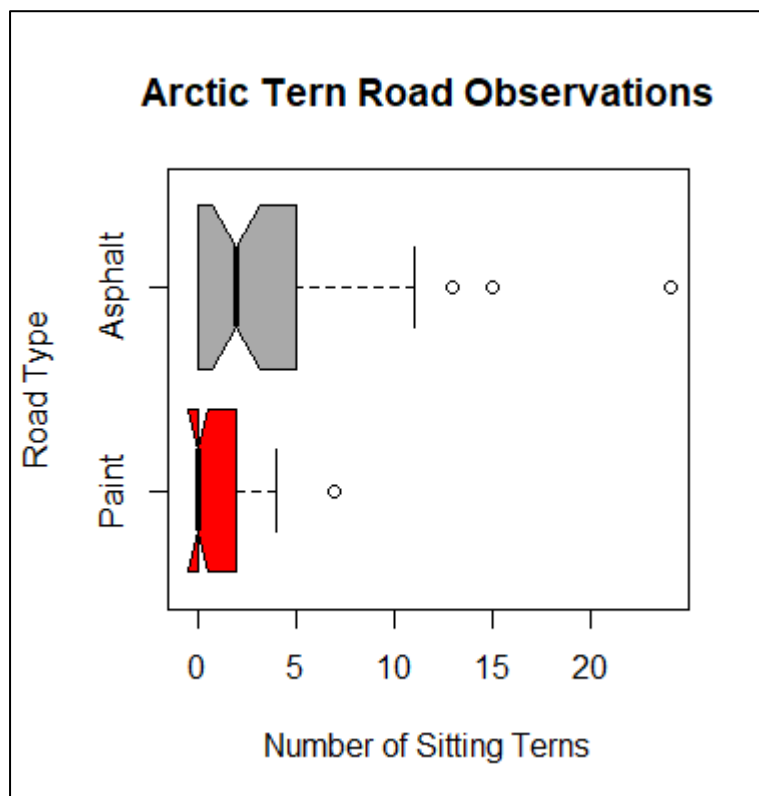
Figure 12. Notched box plot showing the differences in the statistical distribution of the observations by road type. The notches in the box plot represents the confidence interval at 95%.
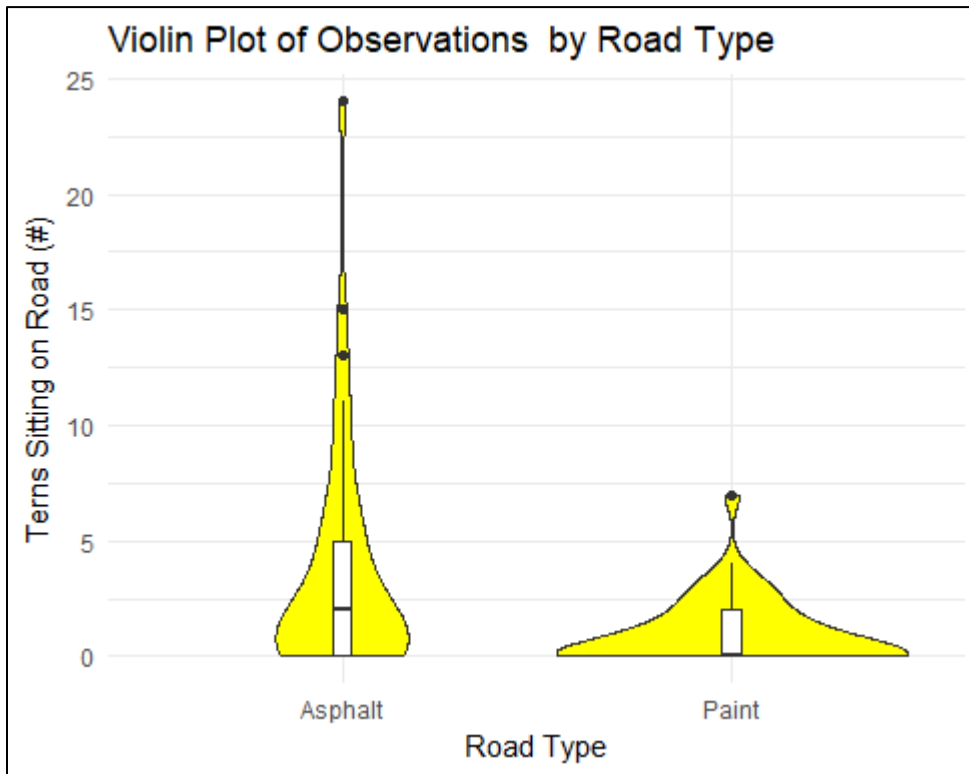
Figure 13. Violin plot showing the statistical distribution of the observations by road type on the vertical axis, and the probability that each value on the vertical axis will be observed is represented by the width of the plot on the horizontal axis.

Wilcoxon Rank Sum Test

The visualisation of the data suggested that the two medians are significantly different. At a significance level of $\alpha=0.05$, the Wilcoxon Rank Sum Test determined that there was a significant difference between the medians of the painted and asphalt observations when the data are unpaired (W=561, p=0.007). When the data are paired, the significant difference between the medians of the paint and asphalt observations was even stronger (V=24, p=4.198e-05). I, therefore, reject the null hypothesis (H0): The difference between the medians of terns sitting on paint and terns sitting on asphalt is equal to zero, and accept the alternate hypothesis (H1): The difference between the medians of terns sitting on paint and terns sitting on asphalt is not equal to zero. As the visualisations show that the asphalt median is higher than the paint median, after the test I can say with confidence that the asphalt median is significantly higher than the paint median.

4.3.2 Outside Temperature

The mean temperature recorded during observations was 12.46°C, and the mean temperature for the entire month of August (including nights) was 9.1°C (Veðurstofa Íslands, 2018). All results regarding weather observations - both outside temperature and weather type - were visualised and calculated using the mean number of terns found on the road for each variable rather than the total, as the frequency of each variable's observation varies greatly. When choosing how to visualise the data, the mean number of terns per variable appeared to be more effective for showing trends in this case than the total per variable.

The mean number of Arctic terns found sitting on the road per degree of outside temperature is outlined by Figure 14. I expected that more terns would be drawn to the warmer road when the temperatures were lower. Due to the sporadic nature of the points on the graph, I cannot discern any trends in the data specifically regarding temperature by visualising them in a plot. The plot does, however, reiterate that asphalt sections generally saw more terns sitting on them than did paint sections.
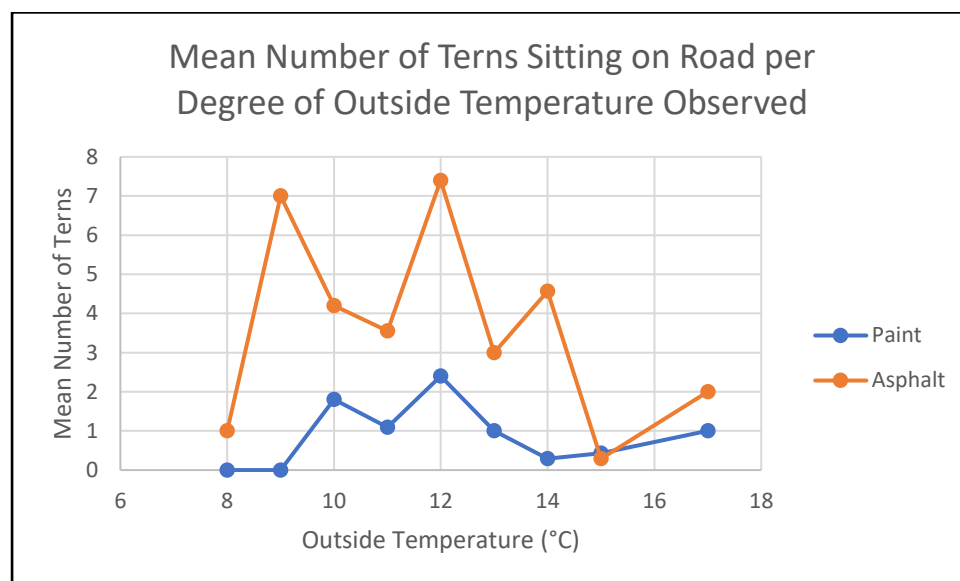
Figure 14. Plot of mean numbers of Arctic terns sitting on both the painted sections and asphalt sections by the temperature observed outside. There were no observations where the outside temperature was 16°C.

Kruskal-Wallis Test

The Kruskal-Wallis test at a confidence level of α=0.05 produced a p-value of p=0.434 for both the relationship between temperature and paint, and temperature and asphalt. Consequently, I must accept the null hypothesis (H0): There are no significant differences between the number of terns on the road (paint or asphalt) because of the outside temperature.

4.3.3 Weather Type

Figure 15 shows the mean number of Arctic terns found for each category of weather by both road types. By visualising the data, I can clearly see that all the error bars on the same road type overlap, suggesting that the statistical test will produce an insignificant p-value (Cumming, Fidler, & Vaux, 2007). However, none of the error bars for the same weather category overlap between painted sections and asphalt sections, further reiterating that more terns sat on asphalt than paint.
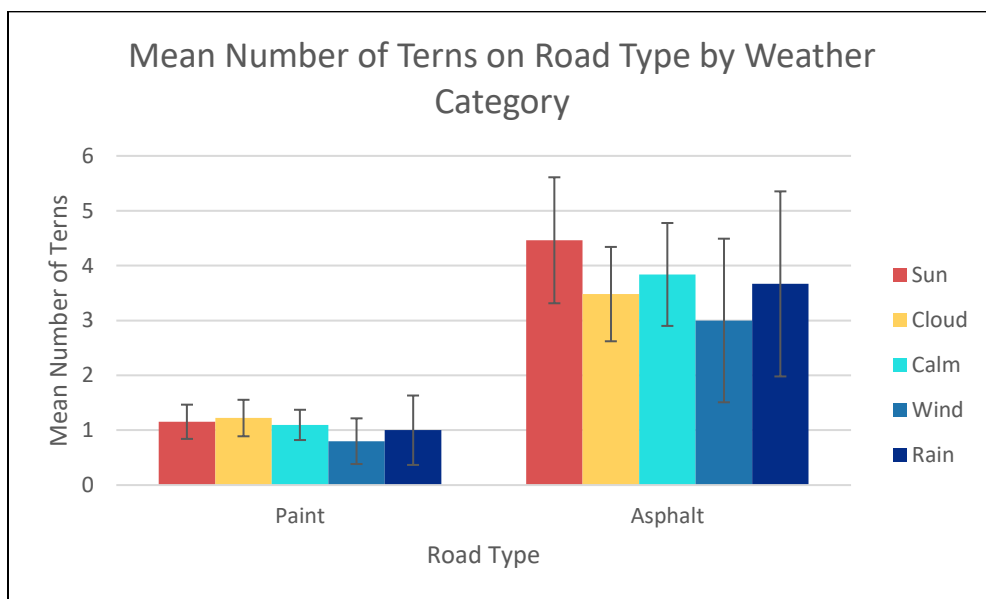
Figure 15. The mean number of terns found sitting on the road type by the category of weather recorded during observations. The number of observations in each category were as follows: Sun n=26, Cloud n=27, Calm n=31, Wind n=10, and Rain n=6. Standard errors are represented by the error bars on each column.

Chi-Square Test

The chi-square test without Yates' correction produced: X^2=1.27, df=4, p-value=0.866 at a confidence level of α=0.05. The test results help to confirm that which was speculated from visualising the data. Therefore, I accept the null hypothesis (H0): The type of weather and the number of terns sitting on each section of road are independent of each other.

4.3.4 Time of Day

The highest total raw numbers of terns found on the road were during the evening for both sections, but the average number of terns was slightly higher in the afternoon on the paint sections whereas it remained highest in the evening for the asphalt sections (Table 5). The mean number of terns on the road per 30 minutes was used in the analysis to similarise the data.

Table 5. Raw and averaged observations of terns on road sections by the time of day.

Time of Day	Raw Paint (Total)	Raw Asphalt (Total)	Average Paint	Average Asphalt	# of Observations
Morning	11	41	0.92	3.42	12
Afternoon	14	30	1.08	2.31	13
Evening	17	78	1.06	4.88	16

The mean number of terns on the road at the various times of day were visualised in Figure 16. The number of terns found on the paint was practically the same for each time of day, but varied to a greater extent on the asphalt. It does appear, however, that the error bars between all times of day for both paint and asphalt sections overlap, indicating that the results of the statistical test will likely not be significant.
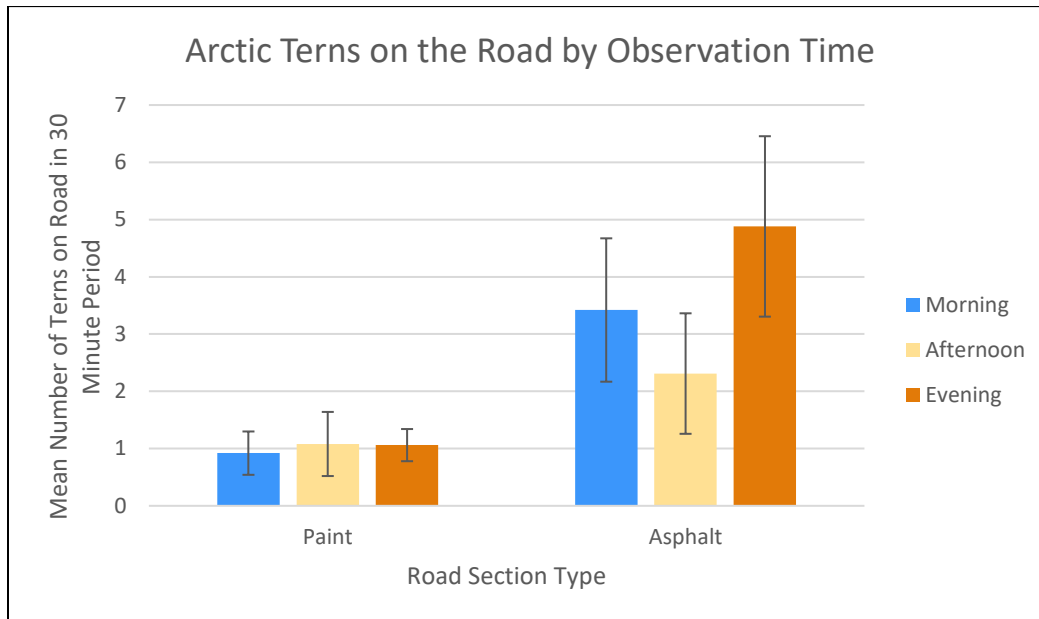
Figure 16. A bar chart displaying the mean number of Arctic terns on both types of road depending on the time of day of the observation. The observations at each time of day were as follows: Morning n=12, afternoon n=13, evening n=16. Standard errors for each column were calculated by hand and are represented by the error bars attached to them.

Chi-Square Test

At the α=0.05 confidence level, the chi-square test without Yates' correction produced a X^2=0.25 result, with a p-value of p=0.883 and df=2. As gathered from Figure 16, the results of this test support that there is no significant difference between the number of terns on the road at each time of day. Thus, I accept the null hypothesis (H0): the number of terns sitting on either section of the road is independent to the time of day.

4.3.5 Predator Presence

More terns were found on the road when predators were present (Table 6). The presence of predators mainly included ravens flying over the nesting area, inciting a mob response from the terns, but in some instances, the predators were standing in the nesting area. Raw numbers are practically ineffective in this case to determine if the presence or absence of predators is an important factor for terns choosing to sit on the painted or unpainted sections.

Table 6. Observations of Arctic terns on the road sections by the presence or absence of predators.

Predators	Terns on Paint (#)	Terns on Asphalt (#)	Observations (#)
Present	26	100	30
Absent	16	49	11

The predator observations were visualised in Figure 17, a percentage bar graph. The total number of terns on the road for each of the predator observations is 100%; the proportions of which were found on the asphalt sections and the paint sections are denoted by the two colours in the graph. The graph does not show much of a difference between the proportions of terns found on asphalt and painted sections when predators were present or absent. Figure 17 implies that the results of the statistical test will not be significant.
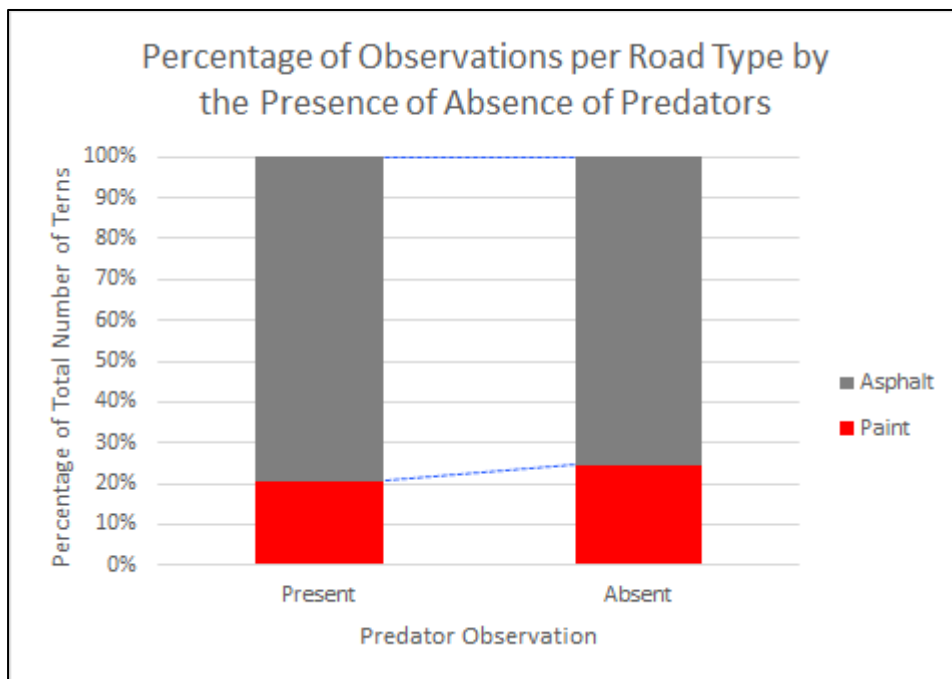
Figure 17. Percentage bar graph for percentage of total number of terns on each road type when predators were present and absent. The number of observations were: Present n=30, Absent n=11. The differences in proportions are emphasised using the blue series lines between the two groups.

Chi-Square Test

The results of the chi-square test without Yates' correction at the confidence level α=0.05 are: X^2=0.40, df=4, p-value=0.529. As Figure 17 suggested, the difference between the

presence and absence of predators for the total terns observed on the two road types was not significant. Therefore, I accept the null hypothesis (H0): The presence or absence of predators and the section of road on which the terns sat are independent of each other.

5 Discussion

5.1 Size and Density of Nesting Colony

Compared to my personal visual estimates of the study population, the size of the colony estimated by the nest survey is higher than anticipated. Previous estimates on the population size by locals was approximately 1 000 individuals (C. Gallo, personal communication, April 26, 2018). The estimated population from this study is almost five times the size of previous estimates. The nesting colony in Bolungarvík consists of approximately 4 950 adult terns; colonies in Iceland can be of various sizes, some as small as ten breeding pairs, some as large as tens of thousands of breeding pairs, so a colony of this size for this area could be possible (Vigfúsdóttir et al., 2013). However, the methods used in this study may have overestimated the number of breeding adults. The use of random sites to calculate the number of pairs per square meter fails to include the spread between the nests, suggesting that the number of nests (and therefore, pairs) found was uniformly spread throughout the whole area, when it was not.

Previous estimates could have been low because the study colony used to be much more spread out, and therefore, the colony appeared to have fewer birds (Local, personal communication, July 30, 2018), or because no actual surveys had been done on this colony before and so locals may had been just giving their best guess rather than an appropriate estimate. It is common for Arctic terns to have a high variation in colony size from year to year, meaning that previous estimates may have been correct for that specific year (Egevang & Frederiksen, 2011), but this is highly unlikely, especially given that the difference was thousands of breeding adults.

The study colony was breeding at an average density of 0.14 nests/m^2 in the area closer to the study road, and 0.07 nests/m^2 in the area farther from the study road. Compared to some Arctic tern colonies nesting elsewhere in Iceland, this colony is nesting relatively densely. In Seltjarnarnes, Iceland, Arctic terns nesting in relatively similar sized areas during the summer of 2017 were only nesting at a density of between 0.05 to 0.08 nests/m^2 (Hilmarsson, 2017), and on Hrísey island in Iceland, they nested at an even lower density,

approximately 0.02 nests/m^2 (Þorsteinsson & Thorstensen, 2014). The nesting density farther away from the road is similar to the densities found elsewhere in Iceland. The higher nesting density closer to the road could be due to space competition, because of human disturbance, or because of higher predation nearer to the beach.

Much of the area where the colony did not nest appears to also be an Eider duck farm. As mentioned in Chapter 2, Eider ducks and Arctic terns are often found nesting close together, as both species prefer similar nesting habitat, and each receive higher protection from predators (Mallory et al., 2010). Terns must avoid Eider nests when initiating their own, as the Arctic terns in the Bolungarvík nesting area likely did by nesting in a smaller area (Pratte et al., 2016). As the Eider nesting area is now a farm, the Arctic terns could have potentially avoided that area due to the human presence required to collect the Eider down; conversely, they may also have been attracted to the farm for its protection from predators.

Other possible reasons for the Bolungarvík colony's higher nesting density close to the road could be due to other human disturbances, such as the construction work happening on the other side of the Eider duck farm. Hilmarsson (2017) noted that Arctic terns nesting in Seltjarnarnes are moving to nest in smaller areas because of human disturbance, therefore, the movement to nest in a denser colony in Bolungarvík may be due to the same. Although Anderson & Devlin (1999) imply that Arctic terns are more likely to avoid human occupied spaces and buildings more so than other seabirds, the Arctic tern colony in Bolungarvík may have chosen their nesting area because the buildings on either side potentially provided protection from adverse weather conditions. Lastly, land-based predators like Arctic fox may have been more likely to approach the colony from the beach, therefore, fewer birds chose to nest near the beach.

5.2 Post-Study Observations

As the paint study went on, I observed dwindling numbers of adult Arctic terns patrolling the nesting area, until the terns officially left around August 15, 2018 (see Table 2). During the time that the majority of adults began leaving the area (around August 10), chicks that seemingly either had not been able to leave the nest yet (Erritzoe et al., 2003), or had been left behind by their parents (Egevang & Frederiksen, 2011), remained around their original nests. By the time the terns had officially left, no living adults or chicks remained within or

flew above the nesting area. Upon inspection, many dead chicks of all ages were found within the nesting area. No results or conclusions can be drawn from this anecdotal evidence, but the implications may still be relevant to discuss.

Although this study did not include an exploration into the hatching and fledging success of this colony, the speculated outcome of this breeding year may provide insight into this colony's future breeding years, and which indicators of success or failure are important to research further. In colonies on the Snæfellsnes peninsula, low fledging success has been a trend since 2005, and success can range from 0.05 to 0.5 chicks per breeding pair on average (Vigfúsdóttir et al., 2013). Levermann and Tøttrup (2007) explain that the breeding success of Arctic terns is highly dependent on the environmental conditions of the year; as the Arctic is a dynamic place where environmental conditions are always changing, observing a failed breeding season of Arctic terns is common. Suggested reasons why fledging success may be low for Arctic tern colonies in Iceland mainly include: frequent adverse weather conditions, high predation, and starvation (Vigfúsdóttir et al., 2013). Therefore, future management of this Arctic tern colony should consider these factors that may reduce the yearly breeding and fledging success of Arctic terns in this location, in addition to roadkills.

5.2.1 Success Speculation

Extended periods of poor weather conditions can impact the success of ground nesting birds (Robinson, Hamer, & Chivers, 2002). News sources reported that Iceland had the worst summer in a century (Jones, 2018). In Bolungarvík during the study period, the average temperature I recorded during observations (between 08:00 and 19:00) was 12.46°C, and the total average temperature (including nights) for the month of August 2018, was 9.1°C. The average temperature in August from 2000-2017 was 9.9°C, which is not a very large difference from the 9.1°C average for this year (Veðurstofa Íslands, 2018). The temperature this summer did not appear to be much different than average, therefore, should not have greatly affected the survival of fledglings alone. Instead, if fledging success was actually low, it was more likely a combination of factors rather than simply temperature (Vigfúsdóttir, 2012).

The amount of cloud cover over the summer, however, was high (Jones, 2018). Little available sunlight may have decreased primary productivity in the waters around the

colony's nesting area (Nixon & Buckley, 2002). Primary productivity directly relates to the amount of available food for nesting seabirds (Nixon & Buckley, 2002); if Ísafjarðardjúp's primary productivity was low because of high cloud cover, this could have been a factor in the colony's fledging success.

The survival of Arctic tern chicks might be more affected by being constantly wet and/or subject to wind rather than cold alone (K. Kristinsson, personal communication, January 10, 2019). The excessive periods of rainfall that were observed in Bolungarvík during the month of July 2018 could have had a serious impact on the survival of the colony's young. From 1995-2017, the amount of rainfall in July recorded in Bolungarvík was, on average, just 44mm, whereas in July 2018, there was 94.3mm of rainfall (Veðurstofa Íslands, 2018). As this year saw higher amounts of rainfall, it too could have experienced higher chick roadkills due to the weather conditions early in this study.

Not many different species of predators were spotted during observation periods; the most common species was the Raven (*Corvus corax*). Predators were found in the nesting area during 73% of observations (see Table 6), which could have affected the success of the colony. Considering that many dead chicks were found within the nesting area that did not die from predation, however, there must have been another cause for their deaths. Since starvation is cited as a common cause for chick death (Egevang & Frederiksen, 2011; Vigfúsdóttir et al., 2013), it was the most likely cause for these chicks' deaths; however, as this is merely speculation, no conclusion can be drawn for this colony other than suggestions for further study.

5.3 Roadkills

The small amount of roadkill data collected in this section did not allow for any analyses as to whether or not the paint had an effect on chick roadkills to be carried out. The small sample size was surprising, given that pre-study communication with locals and ecologists suggested that roadkills in this location were frequent. Very generic patterns that could have been determined from the table would be that the time of most deaths is most likely in the late afternoon and overnight, as most dead individuals were found after the evening traffic rush and in the morning. The absorption and slow release of heat by asphalt might attract the birds to the road for warmth in the colder nights, as the road can be up to 10 degrees warmer than the surrounding area (Erritzoe et al., 2003); the effects of asphalt

temperature, although not directly covered in this study, are still considered a main draw for birds to sit on roads. However, other than the asphalt road, the Arctic terns were found resting together on a flat, gravel surface within the nesting area throughout the day. The large group was likely resting after they had been out foraging and needed a large flat space to rest together; the road could have provided that space, but perhaps the space inside the nesting area was perceived to be safer. This could be another explanation for the low number of roadkills in this location.

Although pre-study communications had determined that vehicular collisions are an issue for the Arctic tern colony in this location, the extent to which collisions are an issue had not been studied previously. As I have experienced, some road stretches in Iceland experience hundreds of crushed Arctic tern chicks throughout the summer, thus, I expected this location to be similar; however, this was not the case in the 2018 study period. The stretch of road by which the Arctic tern colony breeds is extremely straight in both directions, and the speed limit decreases from 80 kilometres per hour to 50; vehicles are likely able to see Arctic terns on the road in the distance, and while they are slowing down they can adjust their speed or path to accommodate for the terns. Areas with a curve in the road see higher collisions with wildlife since drivers cannot react quickly enough to avoid collisions (Erritzoe et al., 2003); therefore, the location may have influenced the results of this section of the study. Additionally, it is possible that local drivers may also have learned to be more careful driving along this section throughout the years, especially this year, as there was bright red paint that may have reminded them to be careful of terns. However, the Arctic tern is not widely liked by locals, so drivers may continue striking terns in their path (C. Gallo, personal communication, April 25, 2018).

The period in which the chicks are most likely to be crushed by vehicles on the road is between when they are able to walk far from the nest and when they are fully fledged (Erritzoe et al., 2003). After they learn to fly, they are more likely to be struck by vehicles rather than crushed, as they are more likely to fly across the road rather than walk. It is possible that the number of roadkills was higher earlier in the season before the experiment began, before the chicks were experienced flyers, thus affecting the number of dead chicks found on the road during the study period. Obtaining the permissions required for the project hindered my ability to begin the data collection sooner; as adult Arctic tern behaviour within the nesting season can also change depending on the time within the

season (Devlin et al., 2008), so their use of the road and the number of roadkills could have been completely different in the earlier part of the season.

5.4 Paint Effectiveness

The number of terns sitting on the painted sections of the study road was found to be significantly smaller than the number of terns on the asphalt sections. The significant difference between the paint and asphalt medians (p-value=0.007) implies that the paint was effective, to an extent, in deterring Arctic terns from sitting on those sections of road. The paint could have been effective for many reasons: the organisation of Arctic terns' eyes, the slow release of heat from asphalt, or because of any or all of the factors explored in the study.

Birds may be capable of learning to interpret vibrant, uncommon colours in the environment as warning signals for danger (Dell'Aglio, Stevens, & Jiggins, 2016). The contrast between the painted and unpainted sections of the road could have been a factor in deterring some terns from sitting on the road. Arctic terns interpret colour differently due to their tetrachromatism (Blackwell, 2002), therefore, their interpretation of the colour on the road may have been what deterred them from sitting on the road. However, the extent to which this may be true would be impossible to determine from this study.

The next potential explanation for the difference between the number of terns sitting on the different section types could be because of the slow release of heat from dark surfaces such as asphalt being reduced by the paint. Road surfaces are exceptionally capable of absorbing and storing solar heat, and of all paving materials, asphalt gets heated to the highest extent when exposed to sunlight all day (Asaeda, Thanh Ca, & Wake, 1996). A road surface can be up to 7-10°C warmer than the environment around it; birds can use the heat energy to maintain their body heat rather than spending their own energy to do so (Erritzoe et al., 2003). The painted sections may not have absorbed as much solar energy, and therefore, did not release as much heat as the asphalt sections, making them less desirable to sit on for the Arctic terns.

The additional aspects explored in this research - weather type, outside temperature, and the presence of predators – likely still factor into why the painted sections saw fewer terns sitting on them, despite these parts of my research having not obtained any significant

results. All of these factors are so interconnected in nature that attempting to isolate one of them and produce significant results is extremely difficult. Understanding the complexity of the road-tern system is important for implementing comprehensive management of Arctic tern roadkills in Iceland.

5.4.1 Chicks versus Adults

The paint was initially meant to deter chicks from sitting on the road; however, as the experiment went on, I observed that the majority of the terns sitting on the road during this time period were adults. All dead individuals found on the road in this area were chicks with many of their flight feathers already grown. Additionally, the carcasses seemed as though they had been struck by a vehicle, because they looked to have suffered injuries that would come from being struck mid-air. Therefore, at least for the latter half of the nesting season, I believe that the main issue in this location for chick roadkill has to do with strikes rather than being crushed. Contrastingly, the tern chicks on the Snæfellsnes peninsula were mostly found crushed on the road rather than having been struck (Jónsdóttir & Kristinsson, 2017). A possible explanation for this would be because all of the nests in the study location were on the ocean side of the road; had there been nests on the other side, the chicks could have been more likely to cross the road to get to the ocean at the end of the season. Research regarding how the chicks in each location die by vehicle is pivotal for determining which management measure, if any, should be implemented in each location. Areas where chicks are more commonly found crushed on the road would be better areas to study the effectiveness of red paint in deterring Arctic tern chicks (rather than all ages of terns) from sitting on the road.

5.5 Outside Temperature, Weather Type, Time of Day, and Predator Presence

The statistical tests for the next four factors that were explored to determine their effect on the number of terns found sitting on the road all resulted in insignificant findings ($p > 0.05$ for each factor). These results imply that the outside temperature, weather type, time of day, and predator presence had no significant influence on the number of terns observed sitting on the road. The number of observations in each of these sections was not

controlled, which could have affected the accuracy or precision of the results for this section.

5.6 Suggestions for Future Studies

5.6.1 Colony Studies

To best understand the breeding population size and nest density of a colony, repetition of the nest survey in as many years as possible should occur. The use of different methods for collecting the nest density, such as transects, could more accurately reflect the true nest density and population of colonies. The colony's breeding and fledging success should also be measured. From those results, long term population, density, and breeding success trends could be discerned, and management could reflect the needs of the colony. Understanding more information regarding the breeding, foraging, fledging, and deaths of the colony will allow managers to detect what factors may be affecting the colony, and whether intervention is required to minimise failure.

5.6.2 Roadkill Studies

Baseline data is crucial for this type of study. Collecting control data that determines whether or not the area is truly a roadkill "hotspot," then having that data to compare to after the paint has been applied would provide stronger results, which would help to determine the effectiveness of the paint in minimising chick roadkills. Furthermore, the addition of multiple roadkill "hotspots" into one study could look at the effectiveness of the paint for different colonies, locations, or even species, whilst also adding to the sample size, making the statistical analyses more powerful. Lastly, the effect of roads crossing between nesting tern colonies and the ocean should be studied to determine how roadkills could be reduced with placement of new roads. The majority of the suggestions in Section 5.6.3 could also be applied to future studies of Arctic tern chick roadkills.

5.6.3 Observations

All factors relating to why the terns may have been sitting on the road that were studied herein are worth looking into in further studies in Iceland, as many sources suggest that each factor could influence the number of terns on the road. Future researchers should take

the interconnectedness of the system and the interactions between each factor into account when designing follow up research, and more time should be focused on these behavioural observations of the colony to better understand this system and how it relates to roads and roadkills. Considering that many of the factors explored in this study influenced the temperature of the road surface (i.e. outside temperature; the various types weather such as rain, sun, cloud, wind, or lack thereof; and time of day) the differences in temperature of the painted and unpainted road surfaces specifically is worth investigating in further research. Jónsdóttir and Kristinsson's (2017) study found that asphalt was, on average, 3.6℃ warmer during sunny periods and 2℃ warmer in cloudy periods compared to their red painted roads. This research could be useful in creating an indicator for when Arctic terns would sit on the road in a specific location. For future studies, taking the temperature of the road surface in the different sections during observation may reveal more to support the idea that painted road surfaces are a lower temperature than regular asphalt, making it less desirable to sit on.

Researchers interested in the replication of any section in this study should control the number of observations for each variable to ensure that they are equal or very similar, that way they can maximise the strength of statistical tests. Finally, novel factors that previously had not been studied are worth testing in order to add to the knowledge base on why birds sit on roads, and how we can minimise the numbers found sitting or killed on these roads.

6 Management Recommendations

Currently, there is no global basic set of best practices when it comes to management solutions for mitigating bird collisions on roads, as the best practices for a certain area tend not to be the same for a different area (Kociolek & Clevenger, 2011). However, Kociolek and Clevenger's (2011) study recommends first identifying roadkill hotspots, determining what the design on the road is, if it is straight or curved, asphalt or other materials, then classifying the habitat surrounding the road in question before finally analysing the behaviour of the subject bird species. Erritzoe et al. (2003) also consider knowing local traffic patterns as an important step to ensure the best management measure is put in place. When it comes to management, Summers et al. (2011) express that it is pivotal to know what the main cause of death on the road that the subject species is facing, because the best management strategy will address and reduce or eliminate this cause.

For this study's location specifically, the area had been deemed a roadkill hotspot by local ecologists, the road was clearly straight and asphalt, the habitat surrounding the road was all the same, and the hours of peak traffic were known; the step required was to analyse the birds' behaviour further before implementing any roadkill mitigation methods. Future implementation of management strategies in Iceland in the future should obtain information regarding the species' behaviour towards the road before testing the management measure in order to choose the best strategy for the specific location and species.

The most common management strategies to mitigate avian deaths on roadways include flight deflectors such as walls, hedgerows, or poles, changing speed limits, signage, reducing or removing favourable habitat near roads, and using visual or auditory deterrents. The effectiveness of each method can vary depending on the location, species, season, habitat, road type, and numerous other factors not previously mentioned (Loss, Will, & Marra, 2014). When choosing one of these management strategies for a specific location, the benefits and disadvantages of each strategy should be well understood. Each strategy herein will be discussed in the context of this study's location so as to determine

the strategy or strategies best suited for this location, and this recommendation will be extrapolated to recommendations for the rest of Iceland.

6.1 Flight Deflectors

The first method is the use of flight deflectors; when designed properly, these structures force birds to fly higher over the road surface to avoid colliding with vehicles (Pons, 2000). There are three commonly used structures that deflect flight higher over roads: walls, hedges or hedgerows, and poles. According to Varga et al. (2006), walls are an entirely ineffective strategy for reducing roadkills for all avian species in open areas, such as in this study. In some cases, the number of roadkills actually increased with the presence of walls. Walls are also presumably more expensive to build and maintain, and they may be an aesthetically displeasing or seemingly out of place structure, for both this location and Iceland in general.

Hedges, hedgerows, and closely spaced trees under around three meters in height are reportedly effective, so long as there are no gaps through which birds could fly through (Orłowski, 2008; Erritzoe et al., 2003). The vegetation is especially effective when the road is of equal height or higher than the surrounding area (Erritzoe et al., 2003). The addition of vegetation to the sides of roads could also assist the reforestation and revegetation of barren areas of Iceland. However, this strategy has potential to have the opposite effect than desired: increased roadkills. Vegetation, especially plants that grow fruit or berries, could attract various species of birds to it, making more birds at risk of collisions with vehicles (Orłowski, 2008; Erritzoe et al., 2003; Kociolek et al., 2011). Arctic terns do not commonly consume berries or fruit, so adding approximately three-meter-tall vegetation to the side of the road in Bolungarvík may deflect the flight of these birds above vehicle traffic in the area.

Nevertheless, adding tall vegetation to the area may cause the colony to move their nesting habitat to an entirely different place. Species that locate their nests on the ground and away from tall vegetation do so because these nests are less likely to be predated on by avian predators (Mainwaring, Hartley, Lambrechts, & Deeming, 2014). As there are few land predators and very little tall vegetation in Iceland, it is expected that Arctic terns would nest in open spaces on the ground. The addition of tall vegetation might increase the perceived risk of predation by avian predators (Mainwaring et al., 2014), and if the

vegetation spreads further into the nesting area, the colony would likely move to a new location, rendering the strategy obsolete in this area. Therefore, using vegetation as a flight deflector could potentially be a useless investment; the use of other flight deflectors, however, might be more effective for this location.

Poles seem to be the most effective type of flight deflector to reduce the number of bird roadkills (Figure 18). The effectiveness of poles peaked for a causeway when the poles were 3 meters high and spaced 3.7 meters apart; immediately after implementation, the number of bird roadkills greatly decreased and continued to decrease by 64% annually (Bard et al., 2002). Bard et al. (2002) express how simple, effective, and inexpensive this solution is, and the authors recommend this solution for most areas. Icelandic roads often have yellow poles on the sides of the road to mark where the road is in times of heavy snowfall (Figure 19); extending the height to 3 meters and frequency of these poles to 3.7 meters could prove an even easier solution to managing avian roadkill on Icelandic roads. The only problem with this solution could be that the strong winds commonly found in Iceland might blow the poles out of the ground if they are not designed properly for the weather. If designed correctly, the additions of poles to the sides of Icelandic roads could be an excellent solution to implement.

Figure 18. Poles implemented in Florida to reduce royal tern (Thalasseus maximus) roadkills (from Bard et al., 2002).

Figure 19. The yellow markers on the side of the road by the Bolungarvík Arctic tern colony's nesting site (Photo by K.U., 2018).

6.2 Speed Limits

Reducing the speed limit in or before roadkill hotspots sounds like it would be an effective strategy, as birds will then have more time to avoid the vehicles, strikes will be less lethal, and vehicle drivers will have more time to avoid birds. Additionally, with harder strikes, birds might be thrown farther away from the road, making it difficult to actually determine how big the issue of roadkill is in an area (Husby, 2016). However, the effectiveness of lower speed limits is debatable; vehicles moving at higher speeds produce more noise, meaning birds can hear them from farther away and will subsequently move out of the way before the vehicle gets too close (Husby, 2016). Over my study period, I observed one chick sitting on the road that did not move out of the way of a car that was going slow. The car eventually stopped before reaching the chick and had to drive around the chick so as to avoid hitting it.

In my study location, the birds nest close to town where the speed limit changes from 80 kilometres per hour to 50; therefore, vehicles already have to reduce their speed within the study area. I do not believe that changing the speed limit before the nesting area would make any difference for this colony. Although Arctic terns have high nesting site fidelity

(Devlin et al., 2008), they could also move their site any year, making the speed limit change obsolete. Administrative tasks like changing a speed limit likely would take more time and effort than it would produce benefits for the tern colony, therefore, it would not be worth changing. Consequently, for the study location and Iceland in general, changing speed limits around Arctic tern nesting areas would likely not be effective enough to mitigate roadkills.

6.3 Signage and Habitat Alteration

Adding signage before vehicles enter a nesting area is a common practice in Iceland already, and is currently present in this study location (Figure 20). The addition of further signage is unnecessary and redundant, as the sign is clear, even for people who do not understand Icelandic, as there is a clear warning symbol and images of birds on it. When translated, the words say "Warning - breeding ground, Birds on the road" which, if anything could be added to make it clearer, would be to add an image of a bird on the road. However, the sign is effective enough as is.

Figure 20. A bird nesting road sign just outside of Bolungarvík, Iceland: Translates to "Warning - breeding ground. Birds on the road" (Photo by K.U., 2018).

Altering or removing favourable habitat by roads was suggested as a management strategy by Loss et al. (2014) but seems more like a last resort option rather than a management strategy. Removing natural habitat to minimise roadkill sounds counter-productive,

especially when intending to conserve a species' population. Habitat loss is one of the leading reasons for endangerment of species (Rutledge et al, 2011), and could potentially disrupt major systems for migratory sea and shorebirds (Wauchope et al., 2016). Therefore, I do not recommend removing or altering nesting habitat for Arctic terns anywhere, especially in Iceland, and definitely not at the Bolungarvík site.

6.4 Visual and Auditory Deterrents

Often, visual deterrents such as scarecrows or flashing lights, and auditory deterrents such as predator sounds are used to frighten birds away from a space commonly occupied by humans or used for human prosperity (Aust, 2010). Auditory deterrents can be effective, but considering that vehicles make their own noise, they may be enough to deter birds from sitting on the road better than any extra noise would. Visual deterrents, however, can be effective while also being non-invasive to the study population. Blackwell's (2002) paper suggests that light-based methods of managing avian response could be particularly effective with flashing warning colours like red, yellow, and orange. However, flashing lights on or around the road could be dazzling and confusing for birds, putting them at higher risk of collision with vehicles.

The method of managing avian roadkills used in this study, vibrant red paint on the road, is a novel method that has (to my knowledge) only been tested one other time in the study on the Snæfellsnes peninsula in 2016 (Jónsdóttir, & Kristinsson, 2017). Consequently, this method requires far more research before it can be recommended as an effective form of roadkill management for Arctic terns in Iceland. However, based on my results and the results of Jónsdóttir and Kristinsson's (2017) study, this method is worth putting more time and money into researching it. Red, slip-resistant paint was a comparably cheap material, that took little time to lay down and lasted for months after painting. The simplicity of this solution could make it a leader in Arctic tern - and potentially other species - roadkill mitigation if further research supports the theory that the red paint effectively deters Arctic terns from sitting on the road (and subsequently being killed).

6.5 Advice for Bolungarvík and Iceland Colony Management

Considering that the amount of roadkills over the latter half of summer 2018 was low - with six dead chicks found on or beside the road - this area does not require any additional management solutions. If the paint theory is supported by further research, this method would be more than sufficient to control Arctic tern roadkill in the area. The addition of flight deflectors could also be effective enough to reduce Arctic tern-vehicular collisions, if the paint theory is not supported by further evidence. However, management measures such as these are expensive, and considering the low number of roadkills in this location, especially of adults – which would be the greatest detriment on the health of the colony – adding mitigation measures would not be worth investing in. The biggest piece of advice I could give to the town of Bolungarvík regarding the management of the Arctic tern colony on the town's outskirts is to do more research on the colony and figure out what is the main stressor on the breeding adults and chicks. Additional research could reveal the extent to which management is needed year to year, and where resources should be put towards managing the colony. With that information, they can create more informed strategies regarding interactions between Arctic terns and the road, their habitat, people, and their food sources.

To manage Arctic tern roadkills in the rest of Iceland, I recommend following the steps outlined at the beginning of Chapter 6: identify hotspots, classify the road type, surrounding habitat, analyse the behaviour of the birds, then use that information to select the best mitigation strategy for that particular location. The areas in Figure 21 where large Arctic tern colonies overlap with paved roads, especially colonies located on or near high traffic areas, are of particular concern. These locations should be monitored for roadkills, and if hotspots arise – especially if the roadkills are adults – mitigation measures should be implemented. Generally, there is rarely ever one method that completely eradicates roadkill in an area, thus, multiple methods working together would likely produce the best outcome possible.
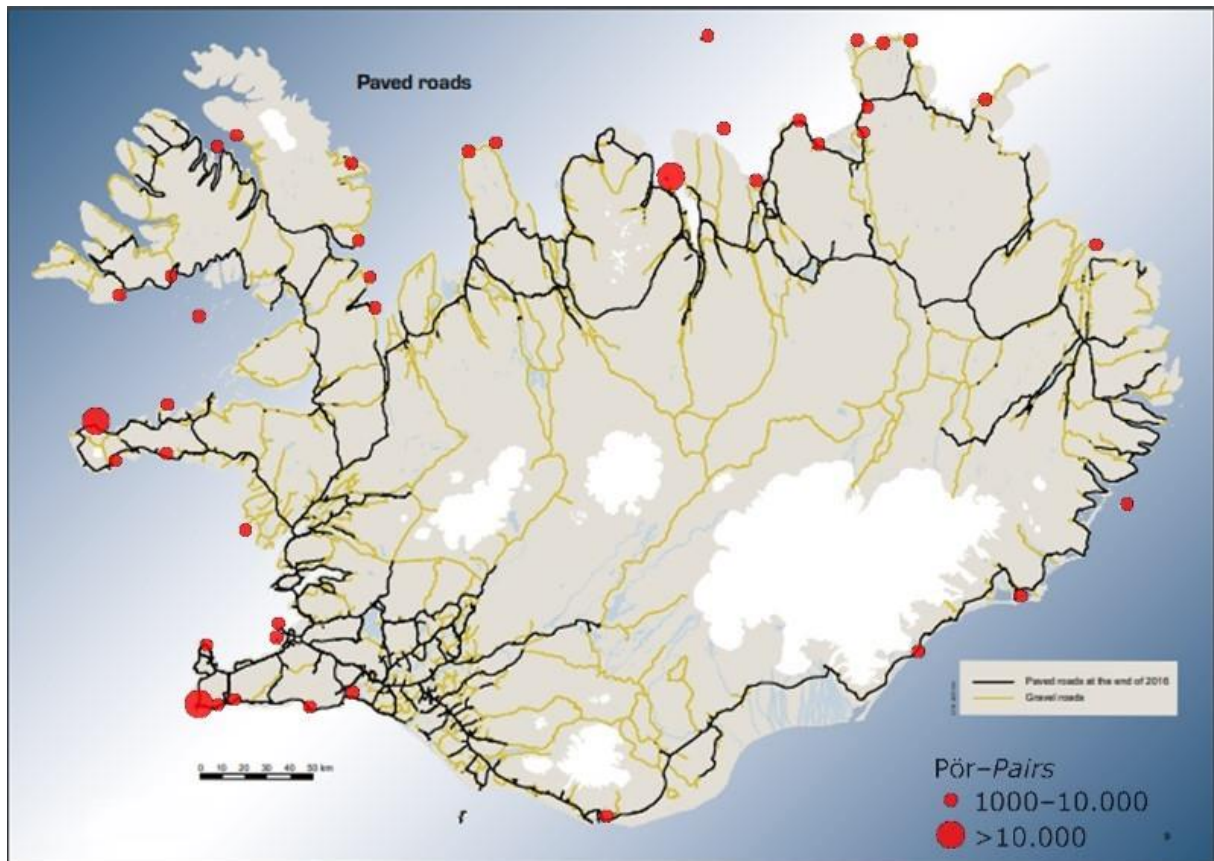
Figure 21. The Icelandic road system as of 2016 overlapped by the locations of large Arctic tern colonies in 2016 (Vegagerðin, 2017; Skarphéðinsson, 2018).

7 Conclusion

As the global Arctic tern population is declining and the threat of collisions between vehicles and birds is growing, the need for effective strategies to keep birds off roads is becoming increasingly evident. The nest density of the studied Arctic tern colony is high; continued monitoring of the colony will reveal local population trends, and the extent to which further management of the colony is required. The results of the experiment determined that red paint is an effective deterrent to avert Arctic terns from sitting on road surfaces. Although the reason for why red paint might have worked could not have been discerned from the variables explored in this study - the outside temperature, type of weather, time of day, or the presence of predators - the painted sections did have significantly fewer terns sitting on them than the unpainted, asphalt sections. The exploration into alternative management strategies determined that in areas where collisions are high, the combination of two or more measures would likely be more effective in minimising collisions. Most notably, flight deflecting poles in addition to red painted roads would reduce the two types of collisions that Arctic terns experience in Iceland: being crushed, and being struck during flight. However, the cost of management is high, and roadkill numbers in the study site are not high enough to warrant investment in further mitigation strategies at present. Exploration into Arctic tern roadkill elsewhere in Iceland may reveal hotspots where mitigation methods like those explored in this study would be worth implementing. By understanding and managing the roadkills of Arctic tern colonies in Iceland now, we can better conserve the health of the species and be one step ahead in conservation, before localised population declines endanger the species as a whole.

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Appendix A

Ethics Clearance.

Háskólasetur Vestfjarða
University Centre of the Westfjords

Research ethics training and clearance

University Centre of the Westfjords
Suðurgata 12
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This letter certifies that **Kelly Umlah** has completed the following modules of:

(X) Basic ethics in research
(X) Human subjects research
(X) Animal subjects research

Furthermore, the Master's Program Committee has determined that the proposed masters research entitled **How Can Painting Stretches of a Road Red Reduce Mortality of Arctic Tern Chicks and Adults from Vehicle Collisions? A Case Study in Bolungarvík, Iceland** meets the ethics and research integrity standards of the University Centre of the Westfjords. Throughout the course of his or her research, the student has the continued responsibility to adhere to basic ethical principles for the responsible conduct of research and discipline specific professional standards.

University Centre of the Westfjords ethics training certification and research ethics clearance is valid for one year past the date of issue.

Effective Date: 15 June 2018
Expiration Date: 15 June 2019

Prior to making substantive changes to the scope of research, research tools, or methods, the student is required to contact the Masters Program Committee to determine whether or not additional review is required.

Appendix B

All raw data, and descriptive statistics for both Arctic terns on the road and temperature, compiled.

DATE	START	END	TOD	RDKILL	SECTION	PAINT?	P.OBSV	A.OBSV	TEMP	SUN	CLOUD	CALM	RAIN	WIND	PRED
28-07-2018	14:45	15:30	AFT	Y	4	N	3	6	11		X	X	X		Y
29-07-2018	18:10	18:40	EVE	N			0	1	8		X	X		X	N
30-07-2018	9:50	10:32	MOR	N			4	15	11	X	X			X	Y
30-07-2018	13:40	14:30	AFT	N			1	1	11	X	X			X	Y
30-07-2018	17:48	18:20	EVE	N			0	7	9				X		N
31-07-2018	9:55	10:30	MOR	N			1	5	14	X		X			N
31-07-2018	13:45	14:15	AFT	N			1	3	17	X	X	X			N
31-07-2018	18:05	18:35	EVE	N			1	24	14	X	X	X			Y
01-08-2018	9:45	10:15	MOR	N			3	2	10		X	X			N
01-08-2018	14:00	14:30	AFT	Y	4	N	1	0	10	X	X	X			Y
01-08-2018	18:50	19:20	EVE	N			3	9	10		X	X	X		N
02-08-2018	10:15	10:45	MOR	N			1	5	11	X	X	X			Y
02-08-2018	13:45	14:15	AFT	Y	6	N	0	1	11		X	X			N
02-08-2018	18:15	18:45	EVE	N			2	10	10	X	X	X			Y
03-08-2018	10:25	10:55	MOR	N			0	3	12		X	X			Y
03-08-2018	14:00	14:30	AFT	N			0	0	15		X	X	X		Y
03-08-2018	18:25	18:55	EVE	N			1	0	15	X	X	X			N
04-08-2018	16:15	16:45	AFT	N			0	3	11		X	X			Y
05-08-2018	20:50	21:20	EVE	N			2	0	11		X		X		Y
06-08-2018	19:30	20:00	EVE	N			0	0	10		X	X			N
07-08-2018	10:30	11:00	MOR	N			0	13	12	X	X				Y
07-08-2018	14:00	14:30	AFT	N			7	2	11	X	X	X		X	Y
07-08-2018	18:40	19:10	EVE	N			1	7	12	X	X	X			Y
08-08-2018	11:05	11:35	MOR	N			1	5	13	X	X	X			Y
08-08-2018	14:25	14:55	AFT	N			2	2	14	X	X	X			Y
08-08-2018	18:10	18:40	EVE	Y	3	Y	0	3	12	X	X	X		X	Y
09-08-2018	10:55	11:25	MOR	N			1	1	11	X	X	X			Y
09-08-2018	15:00	15:30	AFT	N			0	11	12	X	X	X			Y
09-08-2018	18:50	19:20	EVE	Y	4	N	3	1	13	X	X	X			Y
10-08-2018	10:55	11:25	MOR	N			0	0	14	X	X	X			Y
10-08-2018	14:45	15:15	AFT	N			0	1	14	X	X	X			Y
10-08-2018	18:20	18:50	EVE	N			2	5	17	X	X	X			Y
11-08-2018	17:20	17:50	EVE	N			0	0	11	X	X	X			Y
12-08-2018	21:10	21:40	EVE	N			0	0	14	X	X	X			Y
13-08-2018	10:55	11:25	MOR	N			0	0	15	X	X	X			Y
13-08-2018	14:25	14:55	AFT	N			2	2	15	X	X	X			Y
13-08-2018	18:25	18:55	EVE	N			0	0	14	X	X	X			Y
14-08-2018	10:50	11:25	MOR	N			0	0	15		X	X	X	X	Y
14-08-2018	14:50	15:20	AFT	N			0	0	15		X	X			Y
14-08-2018	18:45	19:15	EVE	N			0	0	11						N
15-08-2018	9:25	9:40	MOR	Y	5	Y	0	0	11						
16-08-2018	10:10	10:40		N											
17-08-2018	17:40	18:10		N											
	11:00	11:30	MOR	Y											
TOTAL							42	149							
MEAN							1.02	3.63	12.46						
n							41	41	41						
SD							1.47	5.06	2.18						

71

Descriptive statistics for weather.

Weather Type	Number of Terns Sitting on Road			# of Obsv (n)	Paint.avg	Paint.SD	Asphalt.avg	Asphalt.SD
	Paint	Asphalt	Total					
Sun	30	116	146	26	1.154	1.592	4.462	5.853
Cloud	33	94	127	27	1.222	1.695	3.481	4.467
Calm	34	119	153	31	1.097	1.535	3.839	5.222
Wind	8	30	38	10	0.8	1.317	3	4.714
Rain	6	22	28	6	1	1.549	3.667	4.131
Total	111	381	492	100				

Descriptive statistics for time of day analysis.

	Number of Terns Sitting on Paint			Number of Terns Sitting on Asphalt		
	Morning	Afternoon	Evening	Morning	Afternoon	Evening
	4	3	0	15	6	1
	1	1	0	5	1	7
	3	0	1	2	3	24
	1	1	3	5	0	9
	0	0	2	3	1	10
	0	0	1	0	0	0
	1	0	2	7	0	3
	1	7	0	3	13	0
	0	2	1	1	5	2
	0	0	0	0	1	2
	0	0	3	0	0	11
	0	0	0	0	0	1
		0	2		0	1
			0			5
			2			2
			0			0
Total	11	14	17	41	30	78
# of Obsv (n)	12	13	16	12	13	16
Avg	0.92	1.08	1.06	3.42	2.31	4.88
SD	1.311	2.019	1.124	4.337	3.794	6.302