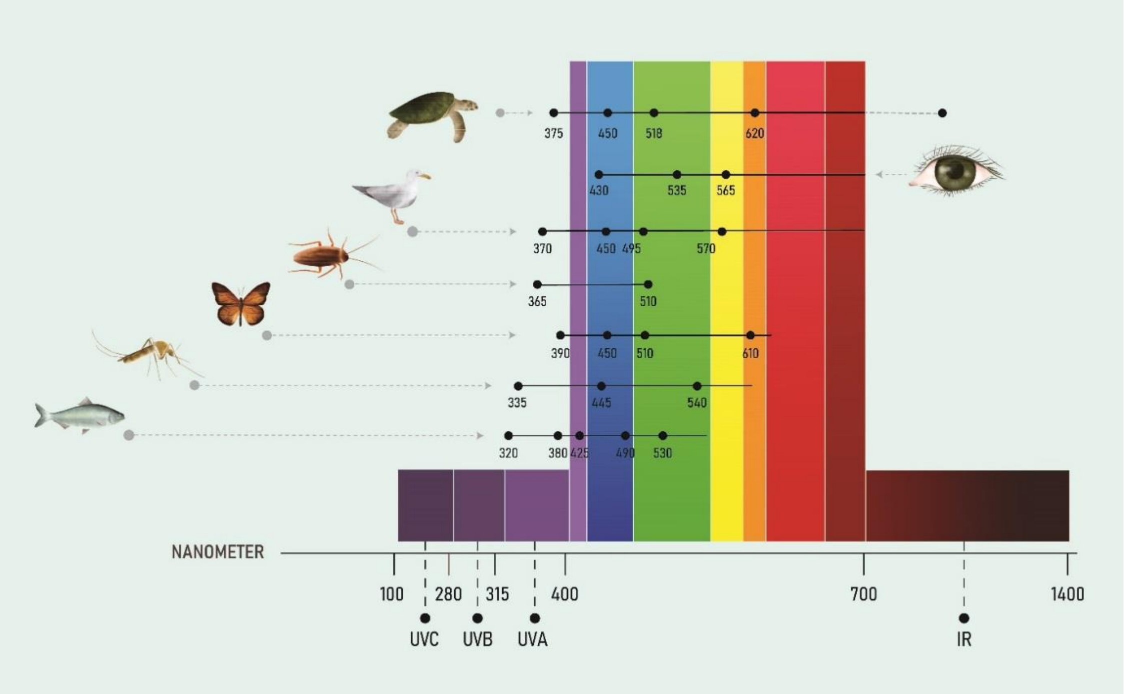
MIT2019-03: Lighting adjustments to mitigate against deck strikes/ vessel impacts

Milestone 1A – Proposed methodology of land/sea-based testing

This report has been prepared by: **Dr. Megan Friesen** (St. Martins University/University of Auckland), **Dr. Anne Gaskett** (University of Auckland), **Chris Gaskin** (NNZST).



Cover: Fluttering shearwaters in lights on Taranga Hen Island. *Photo: Edin Whitehead*

Figure 1 (this page). Ability to perceive different wavelengths of light in humans and wildlife. Note the common sensitivity to ultraviolet, violet and blue light across all wildlife. *Image: © Pendoley Environmental, adapted from Campos (2017).*

1 Metanalysis

Objective

Analyse deck strike data from Hauraki Gulf for patterns in fishery types, species impacted. Survey fisheries for operational lighting types and deployment methods.

Using data provided by Ministry of Primary industries our investigation into New Zealand seabirds' response to artificial light will begin with analysis of deck strikes in the Hauraki Gulf. Specifically, we will analyze seabird species impacted by deck strikes, the fishery type, ecoregion, and light type (if possible). We will carry out this aspect of the project by sending a survey to industry people to obtain data on lights used on vessels, scheduling, and lighting accessories (e.g. filters) that might impact seabirds (Table 1). We will use the data collected during the survey to include in our metanalysis. To analyse significant trends between species, impacted by artificial lights, light types, fishery type, and regions we will do a multivariate linear regression to find significant correlations that will help us to better understand trends of light impacts on seabirds.

Table 1. Survey sent to industry parties to identify light types used for metanalysis and experimental set-up.

Survey question	Definitions
Fishery type	E.g. trawl surface longline, etc.
Target catch	Fish species targeted
Vessel type	Size and type of vessel
Fisheries zone	Where fisheries are taking place
Light purpose	What is the lighting type used for
Brand of light	Manufacturer's details
Light type	Light details e.g. LED, flood, etc.
Lighting schedule	Time light goes on/off/ intermittent
Light accessories	Any filters, etc. (NA if none used)
Number	How many of this light type are used
Anecdotal observations	What types of lights appear to attract more or less seabirds? What types or species of seabirds?

2 Spectral and behavioural experiments

2.1 Light analysis

Objective:

Measure the spectral reflectance and profiles of different anthropogenic lights. Model the spectral profiles to identify how well seabirds can distinguish light types.

We will measure the spectral reflectance of light types identified during our survey of industry parties (Table 1) and other lights that seabirds might encounter (e.g. vessel navigation lights) as well as natural lights that seabirds use to navigate (e.g. moonlight) to obtain a baseline measure of differences between light types. These differences between spectral reflectance of light are important as the ability to perceive light and colour is different in different species based on their unique physiology. Specifically, we will use a spectrophotometer (Ocean Optics Jaz, Ocean Optics Inc.) to measure spectral reflectance. We will obtain 5 measures of reflectance for each light type in order to calculate a mean reflectance value for each sample. We will analyze if there is a significant difference between light types tested.

Using the 'receptor- noise' model (Vorobyev & Osorio 1998) we will identify detectable differences as perceived by seabirds. Chromatic contrasts will be measured as Just Noticeable Differences (JNDs) and used to identify if seabirds can perceive differences between light types. The physiological spectral sensitivity for short-tailed shearwaters (*Ardenna tenuirostris*), will be used as a proxy for modeling procellariiform visual sensitivity to light types (the only species in this order with data for cellular visual anatomy). We will also take a number of background measurements at night in different moon phases, to indicate what difference these lights show against a natural background.

Table 2. Example of light types that will be measured for spectral reflectance based on light types described in 'National Light Pollution Guidelines for Wildlife Including Marine Turtles, Seabirds and Migratory Shorebirds, Commonwealth of Australia 2019'. Actual light types tested will vary depending on results of survey.

Example of lights to be tested
Moonlight
LED Warm
LED Cool
High pressure sodium
Fluorescent
Metal halide

2.2 Land-based behavioural experiments

Objective

Perform land-based and at-sea behavioural trials to understand how lights impact seabirds, and measures that can be taken to prevent deck strikes and confusion by artificial lights.

During the first year of our study we will focus our behavioural response experiments terrestrially, in order to obtain initial data on how seabirds respond to light types with minimal disturbance. Land-based behavioural experiments will take place on Burgess Island, and Hauturu (Little Barrier Island). These islands have been chosen due to their remote locations, and access to multiple species of Hauraki Gulf seabirds. For behavioural trials we are particularly aiming to assess common diving petrels (*Pelecanoides urinatrix,* NZTCS 'At risk'), white-faced storm petrel (*Pelagodroma marina,* NZTCS 'At risk') and Cook's petrel (*Pterodroma cookii,* NZTCS 'At risk'). We may also encounter other nocturnal seabirds and will also assess their behavioural response to light types when possible (i.e. grey-faced petrel *Pterodroma gouldi,* little shearwater *Puffinus assimilis,* fluttering shearwater *Puffinus gavia,* flesh-footed shearwater *Ardenna carneipes,* fairy prion *Pachyptila turtur*, Buller's shearwater *Ardenna bulleri*, black-winged petrel *Pterodroma nigripennis,* New Zealand storm petrel *Fregetta maoriana,* black petrel *Procellaria parkinsoni).*

Behavioural experiments will begin at sundown (varying for time of year) and will continue for ~ four hours after sunset (with potential for more hours depending on activity or weather conditions make experimentation unsafe). Each behavioural experiment will be set up at 15-minute intervals, where lights are projected for 15 minutes followed by a period of 15 minutes with no lights (including no researcher headlamps). Prior to island trips, a lighting schedule will be cycled, where the light type tested will vary in placement from sunset each night to control for times of greater seabird activity (Table 3). Because nocturnal seabirds are social and attracted to vocalizations, light experiments will be done in complete silence (no acoustic attraction measures and no researcher noise).

During behavioural trials, researchers will follow an ethogram to obtain complete data on how lights impact the behaviour of seabirds (Table 4). In addition to researchers recording behavioural observations on the ground, we will also use a thermal imaging camera to record the activity during each of the trials. Recordings will be filed with the light type, time of night, and island and will provide a reference for behavioural response to light types.

Table 3. Example experimental set-up with minutes from sunset and rotating schedule for light types.

	Night One	**Night Two**
0 mins	LED warm	Metal Halide
15 mins	No light	No light
30 mins	High Pressure Sodium	Fluorescent
45 mins	No light	No light
60 mins	LED Cool	LED Cool
75 mins	No light	No light
90 mins	Fluorescent	High Pressure Sodium
105 mins	No light	No light
120 mins	Metal Halide	LED Warm
135 mins	No light	No light
150 mins	LED Warm	Metal Halide
165 mins	No light	No light
180 mins	High Pressure Sodium	Fluorescent
195 mins	No light	No light
210 mins	LED Cool	LED Cool
225 mins	No light	No light
240 mins	Fluorescent	High Pressure Sodium

2.3 At-sea behavioural experiments

Behavioural experiments at-sea will take place primarily during the second year of our study. We aim to get permissions from vessels using specific lights, and when needed will make use of alternate vessels to test out specific lights. Timing of at-sea experiments will be set-up according to fisheries' activity times (as determined in our survey, Table 1). Behavioural analysis will take place using the same parameters as our land-based trial with a researcher recoding behaviours and using thermal imaging to record additional behaviours for later analysis. The lighting schedule when on fishing vessels will be at the will of the captain. When using an alternate vessel for testing lights, we will use a rotating method to randomize the time of night lights are projected as was done in terrestrial experiments (Table 3).

During at-sea trials, researchers will have bird boxes on deck and any seabirds attracted to the vessel deck will be captured and safely contained in a box to avoid injury until the light can be turned off and the bird released back into the water. Light trials will aim to be done away from boat hazards that could provide harm to seabirds.

Data from land-based and at-sea trials will be analyzed using multivariate methods to identify significance between, species, light type, and behavioural response. We expect these results to indicate which light types have the least impact on altering seabird behaviour and attraction and will provide best-practice guidelines for vessels active at night.

Table 4. Example ethogram that will be used to record behaviours during terrestrial and at-sea behavioural surveys .

Behaviours	**Definition**
Birds present- beginning	Number of birds present at beginning of light trial
Light attraction	Movements toward light source
Call & type	Vocalizations made and type of call
Conspecific agonistic behaviour	Fighting or aggression toward conspecifics
Heterospecific agonistic behaviour	Fighting or aggression toward heterospecifics
Foraging	Attempts to capture prey (during at-sea trial)
Attraction to conspecifics	Preening or attraction to conspecifics
Birds present- end	Number of birds present at end of light trial

3 Applications and Further Questions

We see this project as critical in seabird conservation and understanding the visual acuity of seabirds (an area of little scientific research). Our aim is for this project to be set-up as PhD research at the University of Auckland, with further sensory anatomy and physiological studies furthering our understanding of seabird attraction to stimuli.

While our initial analysis of deck strike data focuses on the Hauraki Gulf seabirds, our aim is to expand this to all data that has been collected on light attraction to vessels in New Zealand waters in later years of the study. We will also aim to test behavioural response to more lights on different species in subsequent years as our understanding of light attraction and the physiology of seabird visual systems is strengthened.

4 References

National Light Pollution Guidelines for Wildlife Including Marine Turtles, Seabirds and Migratory Shorebirds, Commonwealth of Australia 2019

Vorobyev, M., Osorio, D., 1998. Receptor noise as a determinant of colour thresholds. Proceedings of the Royal Society of London – Series 265, 351–358.

MIT2019-03: Lighting adjustments to mitigate against deck strikes/ vessel impacts

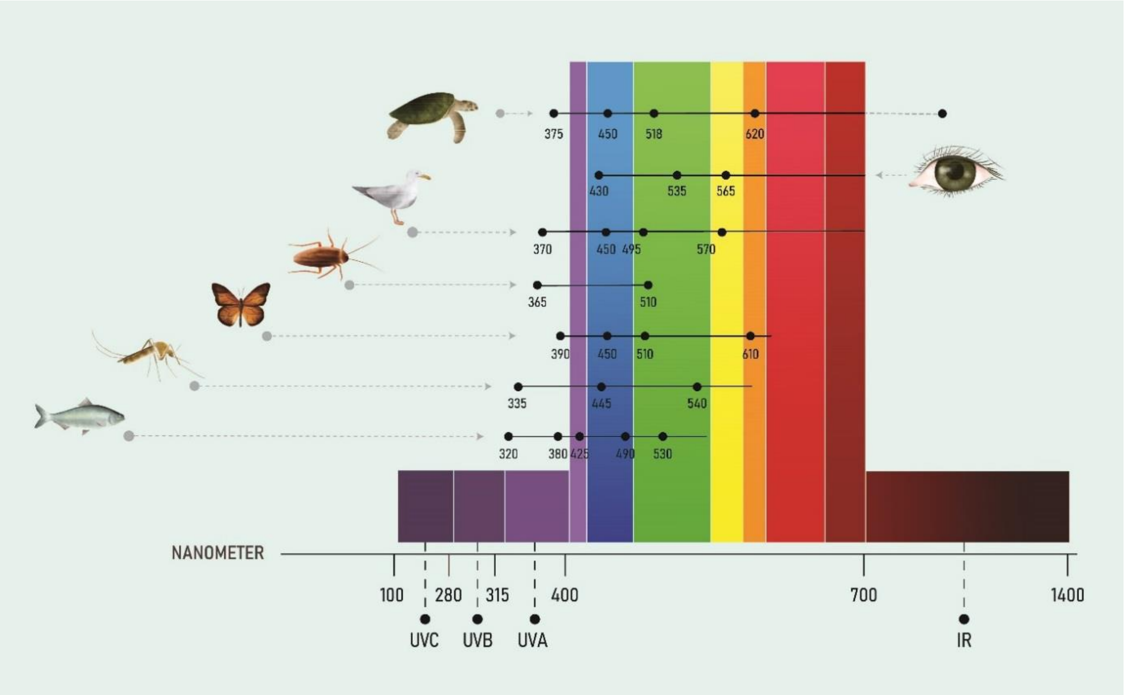
Milestone 1B – Seabird attraction to artificial lights – reducing seabird injury and death from deck-strike literature review

THE UNIVERSITY OF AUCKLAND
Te Whare Wānanga o Tāmaki Makaurau
NEW ZEALAND

Saint Martin's UNIVERSITY

NORTHERN NZ SEABIRD TRUST

This report has been prepared by **Kerry Lukies** (NNZST) with **Dr. Megan Friesen** (St. Martins University/University of Auckland), **Dr. Anne Gaskett** (University of Auckland), and **Chris Gaskin** (NNZST).



Cover: Fluttering shearwaters in lights on Taranga Hen Island. Photo: Edin Whitehead
Figure 1 (this page). Ability to perceive different wavelengths of light in humans and wildlife. Note the common sensitivity to ultraviolet, violet and blue light across all wildlife. Image: © Pendoley Environmental, adapted from Campos (2017).

1 Introduction

Artificial light at night (ALAN) is intensifying globally as a result of human activities and is increasingly recognised as a threat to biodiversity (Kyba et al., 2017; Longcore and Rich, 2004). Most animals have circadian clocks governed by the night-day cycle and it is because of this that ALAN can disrupt behaviours such as foraging, migration, communication, rest and recovery (Hölker et al., 2010; Longcore and Rich, 2004; Longcore et al., 2018). Advances in technology have promoted a shift towards more energy-efficient lighting systems without first understanding how these artificial lights impact the nocturnal activities of animals (Longcore and Rich, 2004).

Light attraction and disorientation are well documented in nocturnally active seabirds and ALAN has been found to disproportionately affect Procellariiformes (e.g. petrels and shearwaters), and especially fledglings on their maiden flight (Fontaine et al., 2011; Le Corre et al., 2002; Montevecchi, 2006; Rodriguez and Rodriguez, 2009). The collective term 'fallout' is used for seabirds in both marine and terrestrial environments that crash land due to the disorientation, exhaustion, injury or mortality caused by light-induced collisions (Glass and Ryan, 2013; Reed et al., 1985; Ryan, 1991). Between 4% and 40% of collisions result in mortality due to the impact itself, predation, vehicle strike or because birds are unable to get airborne again and seek shelter where they may starve or dehydrate (Aubrecht et al., 2010; Rodríguez et al., 2014; Telfer et al., 1987). It is because of these risks and high mortality rates that ALAN is becoming an increasing concern for seabirds (particularly the 31% listed as globally threatened; Dias et al., 2019; Rodríguez et al., 2019).

'Deck-strike' is defined as the collision between an animal, primarily seabirds, and a vessel that results in the animal being unable to leave the vessel unaided due to disorientation or injury (Ramm, 2010). This excludes seabirds that collide with or land on vessels but can take off again. While the majority of studies have focussed on attraction to and disorientation by lights in terrestrial environments (e.g. Fontaine et al., 2011; Le Corre et al., 2002; Miles et al., 2010; Rodríguez et al., 2017c), seabird attraction to lights at sea have also been reported. This has mainly been to the lights of fishing vessels (Black, 2005; Dick and Donaldson, 1978; Glass and Ryan, 2013; Merkel and Johansen, 2011; Ryan, 1991) but lights on cruise ships (Bocetti, 2011) and oil and gas platforms (Ronconi et al., 2015; Sage, 1979; Wiese et al., 2001) also feature in the literature.

New Zealand is a seabird mecca with 86 species breeding throughout the country (Forest & Bird, 2014), approximately one-quarter of the global population (370 species). New Zealand also has the highest number of endemic and threatened seabirds with 36 species listed (Croxall et al., 2012). The northern New Zealand region and Tīkapa Moana/Hauraki Gulf in particular is a global seabird hotspot with breeding colonies of 27 species found primarily on offshore islands and rock stacks (Gaskin and Rayner, 2013). Artificial light at night has been identified as a threat to seabirds in northern New Zealand and while seabird islands in the region are often remote and may lack the intensity of light pollution present in cities, their locations frequently border shipping lanes where illuminated fishing vessels, cargo ships and cruise liners travel when visiting local ports and harbours (Whitehead et al., 2019). It is the lights of these vessels near seabird breeding colonies that pose a risk to the many species found in the region, especially to those listed as threatened (Black, 2005; Merkel and Johansen, 2011).

2 Methods

2.1 Databases & keyword search

Google Scholar was used for peer-reviewed literature on seabird deck-strike and attraction to artificial light by combining targeted keyword searches for: 'seabird' OR 'marine bird' OR 'petrel' OR 'shearwater' 'marine environment' AND 'deck-strike' OR 'artificial light' OR ' light attraction' OR 'light disorientation' OR 'light-induced mortality' OR 'collision'. This produced a search total of 89 papers in addition to reports of deck-strike in the grey literature. I chose which papers to include in my review based on title and abstract relevance.

The table of petrel and shearwater fledging dates in northern New Zealand was amended from that listed in Department of Conservation (2019) to include the tītī/sooty shearwater (*Ardenna griseus*) and tītī/black-winged petrel (*Pterodroma nigripennis*) as these species are also known to breed in the region (Gaskin and Rayner, 2013). Fledging dates were retrieved from New Zealand Birds Online (2019) and Gaskin and Rayner (2013). The second table retrieved the conservation status of seabird species in northern New Zealand from the IUCN Red List of Threatened Species (IUCN, 2019) and from the Conservation Status of New Zealand Birds, 2016 (Robertson et al., 2017).

2.2 Deck strike data analysis

Deck-strike data from fishing vessels in the Auckland/Hauraki region were retrieved from the Protected Species Captures (PSC) dataset by Dragonfly Science (2019). Data were sorted by seabird species, fishing method, fishing year, vessel size, fishery target species and these are presented in bar graphs.

3 Findings

3.1 Impact of artificial light at night on seabirds

3.1.1 The species most vulnerable to artificial light at night

Procellariiformes (hereafter 'petrels and shearwaters') are disproportionately attracted to ALAN (Rodríguez et al., 2017a; Rodríguez et al., 2017b; Rodriguez and Rodriguez, 2009). At least 56 species of petrels and shearwaters are negatively impacted by ALAN globally (Rodríguez et al., 2017b); an increase from the 21 known species in the 1980s (reviewed in Reed et al., 1985). The majority of the literature agrees that small, nocturnal, planktivorous species are more vulnerable to ALAN than other species (Dick and Donaldson, 1978; Imber, 1975; Montevecchi, 2006; Wiese et al., 2001) for several potential reasons discussed below. Species with a high wing loading and rapid flight speed such as kuaka/common diving petrels (*Pelecanoides urinatrix*) and little shearwaters (*Puffinus assimilis*) are more likely to experience light-induced injury or mortality due to the increased force of collision than species with a small wing loading and slower flying speed (e.g. storm petrels) (Glass and Ryan, 2013; Ryan, 1991).

3.1.2 Nocturnal behaviour and seabird vision

Many seabirds are active at night on their breeding colonies, and some species also forage nocturnally (Imber, 1975). This behaviour is thought to be an adaptation to avoid diurnal avian predators such as gulls and skua (Montevecchi, 2006). It is during nocturnal migration, foraging or when returning to colonies that petrels and shearwaters are most at risk of artificial light attraction as their eyes are suited to seeing in low light levels (Commonwealth of Australia, 2019). Many of these species exhibit phototrophic feeding behaviour, where they forage at night on bioluminescent prey (Imber, 1975) and this foraging strategy is discussed below as a potential reason for the high rate of light attraction in nocturnally foraging species.

3.1.3 Fledgling attraction to artificial light

Fledgling petrels and shearwaters are particularly vulnerable to land-based artificial lighting on their maiden flight and are the focus of much of the literature (Fontaine et al., 2011; Imber, 1975; Le Corre et al., 2002; Miles et al., 2010; Montevecchi, 2006; Reed et al., 1985; Rodríguez et al., 2017a; Rodríguez et al., 2017c; Rodríguez et al., 2012; Telfer et al., 1987; Troy et al., 2013). Adult birds may have learned to avoid artificial light sources (Montevecchi, 2006) and differ to fledglings in that they are not attracted to light from a distance, with adult birds only becoming disorientated if flying directly past the source (Imber, 1975). This pattern appears untrue for storm-petrels however, as adults are more vulnerable to light-induced grounding than fledglings (Rodriguez and Rodriguez, 2009).

For each species, juveniles will typically fledge over a period of a few weeks in a synchronised mass exodus from their nesting sites and will generally fledge early in the night, between one to four hours after sunset (Reed et al., 1985; Telfer et al., 1987; Rodriguez et al. 2015). Peak fledging dates coincide with increased fallout throughout the world with examples from New Zealand, Australia, Hawaii, Réunion Island, Canary Islands, Azores, the UK and Chile (Barros et al., 2019; Deppe et al., 2017; Fontaine et al., 2011; Imber, 1975; Le Corre et al., 2002; Miles et al., 2010; Reed et al., 1985; Rodríguez et al., 2017a; Rodriguez and Rodriguez, 2009; Telfer et al., 1987). Some studies suggest fallout is reduced on moonlit nights as fledging is inhibited by the full moon (Imber, 1975; Le Corre et al., 2002; Rodriguez and Rodriguez, 2009) whereas others suggest it is because ambient light from the moon diminishes artificial lights and thus limits the attraction (Miles et al., 2010).

The nocturnal and cryptic nesting behaviours of petrels and shearwaters make population estimates difficult and thus the proportion of fledglings attracted to ALAN is often difficult to determine (Rodriguez and Rodriguez, 2009). Le Corre et al. (2002) suggest between 20 - 40% of Barau's petrel (*Pterodroma baraui*) fledglings are attracted to light on Réunion Island whereas Fontaine et al. (2011) have a much lower estimate with approximately 6.5% of Cory's shearwater (*Calonectris diomedea*) fledglings grounded by urban lights each year. Species-specific differences likely influence attraction to ALAN but in general, between 1% and 60% of fledgling petrels and shearwaters are thought to be attracted to ALAN globally (Rodríguez et al., 2017b). Fledglings frequently contribute to greater than 90% of the birds grounded by artificial lights. For example, 96% of the almost 10,000 birds found grounded over eight years in the Canary Islands were fledglings from nine species (Rodriguez and Rodriguez, 2009). Similarly, 94% of grounded birds on Réunion Island were fledgling Barau's petrels (Le Corre et al., 2002) and almost all of the 3,099 grounded birds in Azores were fledgling Cory's shearwaters (Fontaine et al., 2011). Under experimental conditions, less fledglings grounded when lights were shielded compared to unshielded lights over two fledgling seasons on Hawaii (Reed et al., 1985) and this is suggested as a potential mitigation method in section 6.

Three hypotheses have emerged as to why fledglings are generally more vulnerable to light attraction than adult birds. Most seabirds appear to be independent once fledged and for Procellariiformes this is especially so, i.e. they are not taught how to forage by their parents (Imber, 1975; Warham, 1990). It was first suggested that fledgling petrels and shearwaters may be instinctively attracted to light at night as bioluminescent prey contribute to their diet, thus they may associate light with food (Imber, 1975; Le Corre et al., 2002; Montevecchi, 2006). Secondly, it is thought that fledglings possess an innate behaviour to navigate using the moon and stars, and that these navigational cues get confused with artificial lights (Reed et al., 1985; Rodriguez and Rodriguez, 2009; Telfer et al., 1987). The navigational cue hypothesis is supported by the lower fledgling grounding rates during the full moon as it is easier to distinguish between natural and artificial light sources (Rodríguez et al., 2017b; Rodriguez and Rodriguez, 2009). An alternative and relatively new explanation is that chicks may learn to associate light with food as parents enter the burrow entrance during provisioning, altering the amount of moonlight entering the burrow (reviewed in Rodríguez et al. (2017b).

3.1.4 Global seabird grounding events

In the terrestrial environment, seabirds may be attracted and become 'grounded' by street lights, stadiums, resorts and other well-lit buildings in coastal settlements on their path between inland colonies and oceanic foraging grounds (Le Corre et al., 2002; Reed et al., 1985). Grounded birds are vulnerable to predation and vehicle collisions along with exposure if not found and released (Deppe et al., 2017; Reed et al., 1985; Rodríguez et al., 2017a; Rodríguez et al., 2012). The location of lights along the birds' flightpath appears an important consideration. For example, no petrels or shearwaters were attracted to the lights of towns located inland or greater than 400m above sea level Rodriguez and Rodriguez (2009) whereas the lights of a town located 1500m above sea level but directly below a Barau's Petrel colony were found to attract birds (Le Corre et al., 2002).

Artificial light attraction and disorientation was identified as a threat to petrel and shearwater populations as early as the 1980's when more than 1,000 Newell's shearwaters (Puffinus newelli), Hawaiian (formerly dark-rumped) petrels (Pterodroma sandwichensis), and band-rumped storm-petrels (Oceanodroma castro) were attracted to resort and street lights on Kauai, Hawaii (Reed et al., 1985; Telfer et al., 1987). Similarly, artificial light from coastal communities in the Azores was identified as an increasing threat to Cory's shearwaters since 1990's (Fontaine et al., 2011). In an effort to reduce the mortality of grounded petrels and shearwaters, many coastal areas where seabirds are attracted to light have community rescue efforts in place and these appear to be very successful, with more than 80% of grounded birds rehabilitated and released in most instances (Deppe et al., 2017; Fontaine et al., 2011; Le Corre et al., 2002; Miles et al., 2010; Rodriguez and Rodriguez, 2009; Telfer et al., 1987).

3.1.5 The conservation status of seabirds

Seabirds are the most threatened group of birds in the world (Croxall et al., 2012) and light-induced mortality is thought be contributing to the decline of a number of petrel and shearwater species (Fontaine et al., 2011; Le Corre et al., 2002; Rodriguez and Rodriguez, 2009; Rodríguez et al., 2012). Artificial light at night is increasing globally (Kyba et al., 2017) and it is easy to see why light-induced mortality is being recognised as an increasing issue for seabird species listed as threatened or endangered. For example, of the 2,348 birds grounded by lights on Réunion Island over four years, 70% were endangered Barau's petrels and several were endangered Mascarene petrels (*Pseudobulweria aterrima*) (Le Corre et al., 2002). Similarly, light-induced collisions have contributed to the mortality of endangered Newell's shearwaters which have declined at a rate of ~13% each year since the 1990's (Raine et al., 2017). Any increase in mortality caused by ALAN can negatively impact the population dynamics of these endangered species (Rodriguez and Rodriguez, 2009).

3.2 Artificial light in marine environment

3.2.1 Historical overview of artificial light impacts on seabirds

Although deck-strikes have been long documented in the marine environment, little data collection has taken place (Black, 2005) and information on light-induced collisions with vessels is scarce in the literature. Artificial light is primarily produced on land, but sources in the marine environment are the lights of fishing vessels, cruise ships, tankers, lighthouses and oil rigs (Black, 2005; Glass and Ryan, 2013; Merkel and Johansen, 2011; Allen, 1880; Ronconi et al., 2015; Wiese et al., 2001). Seabird attraction to ALAN was first mentioned concerning collisions with lighthouses in both the United States (Allen, 1880) and New Zealand (Sandager, 1890). Other early records of light attraction were made by Mailliard (1898) who discussed how petrels in Alaska were attracted to an island campfire in such numbers as to extinguish the flame and by Clark (1910) who mentioned how fire was used to hunt Cassin's auklets (*Ptychoramphus aleuticus*) in 1906. One of the earliest records of deck-strike comes from Dick & Donaldson (1978), where the bright lights of a crab fishing vessel in Alaska attracted 1.5 metric tons of crested auklets (*Aethia cristatella*) which threatened to sink the boat.

Birds attracted to artificial light in the marine environment risk collisions with vessels and other infrastructure which may cause direct mortality, injury or the inability to get airborne again without a runway (Glass and Ryan, 2013). On vessels, birds that seek shelter in deck crevices risk dehydration or starvation and may become hypothermic if feathers are waterlogged or oiled (Glass and Ryan, 2013; Ronconi et al., 2015; Ryan, 1991). Not all deck-strikes land on the deck however, as some birds strike the vessel and land in the water (Merkel and Johansen, 2011). In these instances, whether injury or mortality occurr as a result of the collision is often unknown. In urban environments, mammalian predators and vehicles pose a greater risk and contribute greatly to the mortality of grounded birds (Deppe et al., 2017; Rodríguez et al., 2017c), whereas in the marine environment, avian predators such as gulls, skua, or giant petrels may prey upon injured or stunned birds (Ryan, 1991). Like on land, petrels and shearwaters are the most common species to collide with vessels and other infrastructure at sea (Black, 2005; Glass and Ryan, 2013).

3.2.2 Deck strike incidents with different fishing methods and fisheries

White lights on deck are commonly used for crew safety, setting fishing gear at night, navigation or to attract nocturnal species of fish and squid (Black, 2005; Hammerschlag et al., 2017; Nguyen and Winger, 2019). The amount of light used by vessels depends on the type of fishing method, target species and location. The types of lights used on fishing vessels have changed over time, with a shift from oil and acetylene lights in the early 1900's to the Light Emitting Diode (LED), metal halide, fluorescent and halogen lights currently in use (Nguyen and Winger, 2019).

Of the different fishing methods, trawling is most commonly mentioned in the literature regarding seabird attraction to ALAN on fishing vessels (Abraham et al., 2016; Black, 2005; Glass and Ryan, 2013; Merkel and Johansen, 2011). This may, however, be an artefact of increased observer coverage on trawl vessels, which appears to be true for inshore fisheries in New Zealand (Ramm, 2010). One of the largest deck-strike events was recorded on a trawler near South Georgia Island in 2004 where 900 petrels struck the vessel in one night (Black, 2005). Many were waterlogged and 215 birds died as a result of collisions, hypothermia or drowning, which was far higher than the 5.4% mortality rate observed by Glass and Ryan (2013). Powerful searchlights used to navigate through ice were the cause of light-induced collisions in a study of deck-strike on trawlers, navy vessels and tankers in southwest Greenland where minimal sunlight meant the frequent use of artificial lights (Merkel and Johansen, 2011). Four-hundred and eighty birds of five species collided with the vessels over three seasons (Merkel and Johansen, 2011). The majority (78%) of the collisions occurred less than 4 km from the coast and 95% of the birds attracted to the lights were common eiders (*Somateria mollissima*). Navigational ice lights were also mentioned as the main cause of deck-strikes in the Southern Ocean (Black, 2005).

Montevecchi (2006) argues that fishing down the food web has resulted in a global increase in light-induced fisheries for invertebrates such as squid, crabs and lobster but this contrasts with Aubrecht et al. (2010) who suggest light induced-fishing has declined over time. The most well documented cases of deck-strike on fishing vessels have come from the Tristan rock lobster (*Jasus tristani*) fishery in the Tristan archipelago and Gough island in the Southern Ocean (Glass and Ryan, 2013; Ryan, 1991). Powerful spotlights used to illuminate the deck attracted seabirds from the surrounding islands who landed through exhaustion or collision after continuous circling. Nine-hundred and eight birds of eight petrel and shearwater species were recorded in deck-strikes over two weeks in 1991 (Ryan, 1991). In 2011, the deck-strike rate in the Tristan rock lobster fishery had decreased to less than two birds per night as a result of crew lighting mitigation and most of these incidents occurred when deck lights were on for maintenance, crew safety or to offload cargo (Glass and Ryan, 2013). Of the birds recorded as deck-strikes in 2010-2012, 41% were broad-billed prions (*Pachyptila vittata*), followed by common diving petrels at 23% and storm petrels (*Pelagodroma marina*, *Fregetta grallaria*, *Fregetta tropica*) at 36% (Glass and Ryan, 2013).

3.2.3 Other sources of artificial light in the marine environment

Other sources of artificial light in the marine environment that attract and disorientate birds are those of cruise ships, offshore gas and oil platforms and lighthouses (Allen, 1880; Bocetti, 2011; Morton, 2018; Ronconi et al., 2015; Sandager, 1890; Wiese et al., 2001). While the need for lighthouses has decreased with technology such as sonar and Global Positioning Systems (GPS) (Montevecchi, 2006) they still remain a significant presence on many coastlines and islands, including seabird islands (C. Gaskin, personal communication, Nov 13, 2019). Brightly lit cruise ships can act as beacons in featureless oceans at night and draw birds in from a distance (Montevecchi, 2006). Most of the literature on cruise ship attraction is anecdotal but one study estimated that greater than 700,000 migrating songbirds died as a result of light-induced collisions with cruise ships in the Caribbean Sea in one year (Bocetti, 2011). An example of seabird attraction to cruise ship lighting in New Zealand is discussed in section 5.4. Offshore oil and gas platforms have been recognised as a threat to seabirds since 1970 (Dick and Donaldson, 1978). In addition to external lights used for worker safety, surplus gas is burned off to separate oil (Sage, 1979) and can create a flare up to 20m in height (Wiese et al., 2001). Birds have been observed flying directly into the gas flare or colliding with infrastructure after becoming disorientated (Sage, 1979). Storm petrels, shearwaters and murres, in addition to songbirds on long-distance migrations, were recorded in such events on a platform in the northwest Atlantic by Wiese et al. (2001).

3.3 The impact of moon phase and weather condition on seabird fallout

Weather, season, age of bird and moon phase are all important factors influencing seabird collisions both on land and at sea (Montevecchi, 2006). Far greater fallout occurred during the new moon for Newell's shearwaters, Leach's storm-petrels (*Oceanodroma leucorhoa*), Manx shearwaters (*Puffinus puffinus*), Kaikōura tītī/Hutton's shearwater (*Puffinus huttoni*) and Cory's shearwaters (Deppe et al., 2017; Miles et al., 2010; Reed et al., 1985; Rodriguez and Rodriguez, 2009; Telfer et al., 1987). Several suggestions have been made as to why this may be. Ambient light from a full moon may limit the intensity of artificial light and allow birds to see structures, thus reducing the rates of collisions (Reed et al., 1985; reviewed in Montevecchi, 2006). Alternatively, petrels visit their colonies less on moonlit nights compared to dark nights which would reduce the likelihood of encountering artificial light (Imber, 1975; Montevecchi, 2006) and thirdly, fledging may be inhibited by a bright moon, as discussed in section 1.3.

Similar to the moon, the weather appears to play a key role in seabird grounding and deck-strike. Water droplets in the air refract light and increase the lit-up area which can attract a higher number of birds (Montevecchi, 2006; Telfer et al., 1987; Wiese et al., 2001). Lighthouse keepers noted that seabird collisions occurred more frequently in overcast and foggy weather as early as the 1870's in the United States (reviewed in Allen, 1880). Similar conditions were mentioned during peak collisions of tītī/Cook's petrels (*Pterodroma cookii*) and takahikare-moana/white-faced storm petrels (*Pelagodroma marina*) at the Mokohinau Island lighthouse in New Zealand in the late 1800's (Sandager, 1890). This pattern has since been observed globally, with increased seabird fallout rates during cloudy, misty and overcast weather in Hawaii (Telfer et al., 1987), Greenland (Merkel and Johansen, 2011), Wales (Guilford et al. 2019), Tristan archipelago and Gough Island (Ryan, 1991) and throughout the Southern Ocean (Black, 2005). Wind speed was mentioned in only one study as a factor influencing the grounding of short-tailed shearwaters (*Ardenna tenuirostris*) in Australia (Rodríguez et al., 2014).

3.4 Artificial light and seabird perception

3.4.1 What is light and how do seabirds perceive it?

Light is a form of electromagnetic radiation and falls within the spectrum that includes visible light, microwaves, gamma rays and radiowaves (Diffey, 2002). Electromagnetic radiation is classified into wavelengths and shorter wavelengths relate to higher frequencies (e.g. Gamma rays, X-rays) and longer wavelengths relate to lower frequencies of radiation (e.g. radiowaves, microwaves) (Diffey, 2002). 'Light' refers to the part of the spectrum visible to the human eye which is between the wavelengths of 400 and 700 nanometers (nm) (Commonwealth of Australia, 2019). Light 'colour' is determined by how humans perceive light and does not reflect how it is perceived by animals (Tanaka, 2015).

Little is known about vision in seabirds (Mitkus et al., 2016) but it is clear that how light is perceived by birds, particularly by those active at night, differs considerably to light perception by humans and other mammals (Withgott, 2000). Bird vision differs from human vision in part due to the different sensitivities of photoreceptors between the two groups (Tanaka, 2015). Humans have three photoreceptor cones that pick up long, medium and short wavelength light that is perceived by the human eye as the colours red (700nm), green (550nm) and blue (470nm) (Cuthill, 2006). Seabirds, on the other hand possess four cones responsible for colour processing, which allows them to see within the violet-blue spectrum (380nm – 440nm) (Bowmaker, 1991; Capuska et al., 2011; Ndez-Juricic, 2016). Nocturnal seabirds have special adaptations that allow them to see in low light levels such as large tubular-shaped eyes, increased retinal rods, oil drops and rhodopsin, the pigment sensitive to light (Bowmaker, 1991; Mitkus et al., 2016; Ndez-Juricic, E., 2016). It is this visual system that is adapted to low light levels that makes seabirds sensitive to short wavelength blue light (including white light) (Tanaka, 2015).

3.4.2 Types of artificial light

The lighting types used by humans utilise different wavelengths within the visible light spectrum and it is the wavelength of light, rather than colour, that is the most important factor in seabird attraction (reviewed in Commonwealth of Australia, 2019). Since 2000, the most prevalent light types in use in the terrestrial environment include LED, metal halide and high-pressure sodium lights (Rodríguez et al., 2017a), whereas on vessels, LED, metal halide, halogen and fluorescent lights are the most common (Nguyen and Winger, 2019). High-pressure sodium lights emit a higher wavelength light that is yellow or orange in colour, whereas LED lights emit more blue light of a lower wavelength (reviewed in Longcore et al., 2018) and metal halide emit a broad range of wavelengths (Rodríguez et al., 2017a). There is a shift toward the use of LED lights due to their energy-efficiency (reviewed in Commonwealth of Australia, 2019) but this may have a negative impact on nocturnally active species such as some seabirds due to their blue light sensitivity (reviewed in Commonwealth of Australia, 2019).

3.4.3 Studies of seabird attraction to different light types and colours

To reduce light-induced collisions in the future, we must increase our understanding of the types, colour and spectra of light that are attractive to seabirds. As it stands, only one study has tested seabird attraction to different types of lights. Rodríguez et al. (2017a) illuminated a sports field alternately with three common outdoor lighting systems during the short-tailed shearwater fledging period on Phillip Island, Australia (Rodríguez et al., 2017a). Forty-seven percent of fledglings were grounded during the metal halide light treatment, followed by 29% for LED lights and 24% for high pressure sodium lights. The authors went on to discuss how the orange light and narrower emission spectrum of high pressure sodium lights were likely less attractive to the shearwaters due to their nocturnal visual system compared to metal halide and LED lights that produce more blue light and have a wider spectrum (Rodríguez et al., 2017a). A different result was observed in Kaikōura however, as most Hutton's shearwater fallout was concentrated around high pressure sodium lights (150 watts) (Deppe et al., 2017). High wattage metal halide 150W and LED 252mA lights also attracted shearwaters in lower numbers (Deppe et al., 2017).

Changing the spectral reflectance of lights has also influenced the number of grounded birds in previous studies. Tropical shearwaters (*Puffinus bailloni*) on Réunion Island found red and yellow lights less appealing than green and blue lights in a study of different light colours by Salamolard et al. (2007). Similarly, using red filters on power station floodlights reduced light-induced avian mortality by up to 80% (reviewed in Wiese et al., 2001) and the replacement of white lights with green lamps on offshore oil rigs reduced collisions by nocturnally migrating songbirds (Poot et al., 2008). An opportunistic lighting experiment tested the collision rate of Manx shearwaters with a building in Wales when lights were turned on or off over the course of one night (Guilford et al., 2019). Collision rates were 25 times higher when light was present than in its absence. Identifying the types, colour and spectra of light that are less attractive to seabirds while still being sufficient for human safety will be crucial in decreasing deck-strike and grounding events in future (Troy et al., 2013).

3.5 Seabird attraction to artificial light at night – New Zealand context

Given the attraction of seabirds to ALAN and the diversity of seabirds in New Zealand, such species are ill-represented in scientific literature with the only examples from Westland, Kaikōura, Fiordland, Whakatane, the Kermedec Islands and the Hauraki Gulf (Abraham et al., 2016; Deppe et al., 2017; Holmes, 2017; Imber, 1975; Miskelly et al., 2017; Morton, 2018; Waugh and Wilson, 2017).

3.5.1 Seabird fallout in the urban environment

Similar to other countries around the globe, the majority of light-induced collision events in New Zealand have been recorded in the terrestrial environment. A brief mention was made of ōi/grey-faced petrel (*Pterodroma gouldi*) fallout in Whakatane coinciding with peak fledging dates by Imber (1975) and one grounded takoketai/black petrel (*Procellaria parkinsoni)* fledgling was mentioned as attracted to the lights of Auckland city (Imber et al., 2003). Another example is the grounding of Cook’s petrels in Auckland city when travelling between the Hauraki Gulf and their foraging grounds on the west coast (Gaskin and Rayner, 2013). Several takahikare-moana/grey-backed storm petrels (*Garrodia nereis*) were drawn to urban lights in Eglinton Valley in the South Island and three individuals were attracted to the spotlight of a research vessel in Fiordland during an attempt to determine their breeding location (Miskelly et al., 2017). Storm petrels and Kermadec petrels (*Pterodroma neglecta*) have also been attracted to the lights of the Department of Conservation (DOC) base on the remote Raoul Island, Kermadec Islands (C. Gaskin, personal communication, Nov 13, 2019).

Perhaps the most well-known examples of artificial light attraction in New Zealand come from Kaikōura and Westland in the South Island. The Hutton’s shearwater is a New Zealand endemic that breeds in two colonies more than 1,200 m above sea level in the Kaikōura ranges. The flight path for fledglings from one of the colonies passes directly over the town lights of Kaikōura, resulting in the grounding of up to 280 fledglings each season (Deppe et al., 2017). Similarly, several tāiko/Westland petrel (*Procellaria westlandica*) fledglings are grounded by town lights on their maiden flight each year (Waugh and Wilson, 2017). With an estimated population of 2,800 breeding pairs, the mortality caused by predation or vehicle collisions of grounded Westland petrels is cause for concern, but the community-led rescue campaign mean the majority of fledglings are recovered and released (Waugh and Wilson, 2017).

3.5.2 Deck strikes recorded by fisheries observers in the New Zealand Exclusive Economic Zone

The Ministry for Primary Industries (MPI), in collaboration with DOC, administer a Fisheries Observer Programme that record protected species captures including seabirds, marine mammals and turtles on board fishing vessels throughout the country’s Exclusive Economic Zone (EEZ). Deck-strikes are included as captures and these have been recorded in the Centralised Observer Database (COD) since 2007 (Abraham et al., 2016). Dragonfly Science Limited (Dragonfly) process the COD data into a “Protected Species Capture” (PSC) dataset that is publicly accessible and can be used to identify deck-strikes on fishing vessels in New Zealand waters.

The “Characterising Deck-strike” report by Holmes (2017) summarised the deck-strike data from the PSC dataset during the fishing years 2011/2012 to 2014/2015. During this period, 805 deck-strikes by 44 different species were recorded, including one event of 284 deck-strikes. Common diving petrels were the species with the highest number of deck-strikes (40%), followed by *Procellaria* petrels, prions and albatross (Holmes, 2017). Only 3% of recorded deck-strikes resulted in mortality with 95% of birds released alive and 2% unknown. The estimated deck-strikes from bottom longline vessels (4,195) far exceeded those of surface longline (118), setnet (550), purse seine (9) and inshore trawl (296) fisheries when fishing effort and the percentage of fishing trips observed were taken into account. Observed deck-strikes were more frequent on small vessels (<28m) and when using the fishing methods of bottom longline, surface longline and inshore trawl. Observed and estimated deck-strikes varied between fishery, fisheries management area and season which made characterisation difficult (Holmes, 2017).

During the 2016/2017 fishing season, 190 deck-strikes were recorded throughout New Zealand waters (Abraham and Richard, 2019). Of these, 186 were released alive and four died (Abraham and Richard, 2019). Again common diving petrels were in the top two species with 27 recorded incidents, followed by 36 white-faced storm petrels (Abraham and Richard, 2019). The largest event included 30 deck-strikes and occurred on a bottom-longliner targeting tamure/snapper (*Chrysophrys auratus*) off the west coast of the North Island (Abraham and Richard, 2019). No information was given regarding the lights used, time of fishing gear deployment or the time of year of this event. The following year 125 deck-strikes were recorded by observers across all vessels (Abraham and Berkenbusch, 2019). Of these, 119 birds were released alive, six died and no more than ten birds struck vessels in any one event (Abraham and Berkenbusch, 2019).

3.5.3 Seabird attraction to artificial light in northern New Zealand

The first record of light-induced collisions in northern New Zealand came from the Mokohinau Islands in the late 1880's following the installation of a lighthouse. Frequent collision events were recorded for several years and the main species affected were Cook's petrel and white-faced storm petrels, in addition to one black petrel (Sandager, 1890). Birds soon learned to avoid the lighthouse, but collisions continued over the same two-month period each year (Sandager, 1890), likely during the fledging season (Rodríguez et al., 2017c). One recent event saw 64 rako/Buller's shearwater (*Ardenna bulleri*) and four threatened toanui/flesh-footed shearwater (*Ardenna carneipes*) collide with a cruise ship in the Hauraki Gulf (Morton, 2018). While many of these birds were released alive, twenty birds died as a result of incorrect restraint and release measures by crew members. This event highlighted the need for the education of vessel staff about how to handle stunned or injured birds and DOC has since been working with the cruise industry to reduce light-spill and prevent future deck-strike events in the region (Department of Conservation, 2019). Whitehead et al. (2019) suggest vessels travelling near seabird islands in the Hauraki Gulf adopt the protocol of vessels operating in the Antarctic region by reducing light-spill and assisting birds off the vessel as soon as possible.

Given that most of the literature highlights petrels and shearwaters as the seabird groups most at risk of deck-strike and in particular fledgling aged birds, the tables below indicate the fledging dates of petrels and shearwaters (Table 1) and the conservation status (Table 2) of the species most at risk of deck-strike in northern New Zealand.

3.5.3.1 Petrel and shearwater fledging dates in northern New Zealand

Table 1. Fledging dates for seabird species in northern New Zealand at risk of deck-strike. Table adapted from Department of Conservation (2019), Gaskin and Rayner (2013) and New Zealand Birds Online (2019).

	Month											
Species	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug
Kuaka/Common diving petrel (*Pelecanoides urinatrix*)			🟦	🟦								

Little shearwater (*Puffinus assimilis*)			▨	▨	▨							
Ōi/Grey-faced petrel (*Pterodroma gouldi*)				▨	▨							
Pakahā/Fluttering shearwater (*Puffinus gavia*)				▨	▨							
Tītī wainui/Fairy prion (*Pachyptila turtur*)					▨	▨						
Takahikare-moana/ White-faced storm petrel (*Pelagodroma marina*)							▨	▨				
Tītī/Cook's petrel (*Pterodroma cookii*)							▨	▨				
Tītī/Pycroft's petrel (*Pterodroma pycrofti*)							▨	▨				
Tītī/Sooty shearwater (*Ardenna griseus*)								▨	▨			
Rako/Buller's shearwater (*Ardenna bulleri*)								▨	▨			
Toanui/Flesh-footed shearwater (*Ardenna carneipes*)								▨	▨			
Tītī/Black-winged Petrel (*Pterodroma nigripennis*)								▨	▨			
New Zealand storm petrel (*Fregetta maoriana*)									▨	▨		
Takoketai/Black petrel (*Procellaria parkinsoni*)										▨	▨	

3.5.3.2 The conservation status of petrels and shearwaters in northern New Zealand

Table 2. Conservation status of seabird species in northern New Zealand at risk of deck-strike. Conservation status retrieved from the IUCN Red List of Threatened Species (IUCN, 2019) and the Conservation Status of New Zealand Birds, 2016 (Robertson et al., 2017).

	Conservation status		
Species	**IUCN**	**DOC**	**Endemism**
Black-winged petrel (*Pterodroma nigripennis*)	Least Concern	Not threatened	Native
Ōi/Grey-faced petrel (*Pterodroma gouldi*)	Least concern	Not threatened	Native
Kuaka/Common diving petrel (*Pelecanoides urinatrix*)	Least Concern	At risk – relict	Native
Little shearwater (*Puffinus assimilis*)	Least concern	At risk – recovering	Native

Tītī wainui/Fairy prion (*Pachyptila turtur*)	Least concern	At risk – relict	Native
Pakahā/Fluttering shearwater (*Puffinus gavia*)	Least concern	At risk – relict	Endemic
Takahikare-moana/White-faced storm petrel (*Pelagodroma marina*)	Least concern	At risk – relict	Native
Rako/Buller's shearwater (*Ardenna bulleri*)	Vulnerable	At risk – naturally uncommon	Endemic
Tītī/Cook's petrel (*Pterodroma cookii*)	Vulnerable	At risk – relict	Endemic
Tītī/Pycroft's petrel (*Pterodroma pycrofti*)	Vulnerable	At risk – recovering	Endemic
Tītī/Sooty shearwater (*Ardenna griseus*)	Near threatened	At risk – declining	Native
Takoketai/Black petrel (*Procellaria parkinsoni*)	Vulnerable	Threatened – nationally vulnerable	Endemic
New Zealand storm petrel (*Fregetta maoriana*)	Critically endangered	Threatened – nationally vulnerable	Endemic
Toanui/Flesh-footed shearwater (*Ardenna carneipes*)	Near threatened	Threatened – nationally vulnerable	Native

3.6 Deck strike mitigation measures suggested in the literature

There are many measures suggested throughout the literature to reduce deck-strike. Firstly, special consideration of ALAN should be made within 20km of the breeding, roosting, foraging or dispersal habitat of threatened species to reduce mortality and injury caused by artificial light attraction (Commonwealth of Australia, 2019). This is a conservative distance based on the attraction of fledgling short-tailed shearwaters to a light source 15km away from the colony by Rodríguez et al. (2014). The synchronised mass fledging of many species suggests seasonal lighting adjustments to minimise deck lighting near seabird colonies may be an effective measurement to reduce the risk to birds on their maiden flight (Le Corre et al., 2002). Avoiding seabird islands completely on overcast or foggy nights (Merkel and Johansen, 2011), reducing light spill from vessels by closing blinds and curtains (Department of Conservation, 2019), covering crevices so birds cannot seek shelter and releasing birds overboard immediately once lights have been switched off (Ryan, 1991) are some of the suggestions to reduce deck-strike and associated mortality.

Artificial light is crucial for crew safety but measures can be taken to reduce or alter the amount of light produced by vessels at night. Eliminating artificial light completely when not needed, reduced lighting, or shielded lights that illuminate smaller and more directed areas are the most common suggestions to limit seabird fallout (Department of Conservation, 2019; Glass and Ryan, 2013; Merkel and Johansen, 2011; Montevecchi, 2006; Reed et al., 1985; Ryan, 1991). These approaches would likely be most effective during peak seabird fledging and migration (Barros et al., 2019; Commonwealth of Australia, 2019; Montevecchi, 2006; Telfer et al., 1987), on overcast or misty nights (Glass and Ryan, 2013; Merkel and Johansen, 2011) and when the moon is dim (Ryan, 1991). New technology means some lights do not require a warm-up period so can be switched on and off readily or can be motion activated, turning lights on only when required by vessel crew (Commonwealth of Australia, 2019; Rodríguez et al., 2017a). Several examples of lighting restrictions for fishing vessels are reviewed in Nguyen and Winger (2019) and include the complete ban of light-induced fishing in Ghana and maximum lighting outputs allowed by vessels in Norway, Japan and Vietnam. Although no comment was made on the impact such measures made on seabird attraction, any minimisation of ALAN would likely reduce light-induced mortality.

Although seabird vision and light attraction is poorly understood, changing the type, intensity or colour of vessel lights have been suggested as potential solutions to reduce the attraction of birds to vessels and limit deck-strike events. More research is needed into seabird attraction to artificial light (Rodriguez and Rodriguez, 2009) but high-pressure sodium lights were suggested as the most suitable lights to use near petrel breeding colonies (Rodríguez et al., 2017a). Other suggested light types include low pressure sodium, filtered white LED (Commonwealth of Australia, 2019), filtered LED and metal halide (Commonwealth of Australia, 2019; Rodríguez et al., 2017a). The filters suggested for LED lights would reduce or remove the short wavelength blue light (Commonwealth of Australia, 2019) that is particularly attractive to seabirds (Tanaka, 2015). Using colour filters has been shown to reduce avian collisions with power stations (reviewed in Wiese et al., 2001) and oil rigs (Poot et al., 2008) and may have a similar effect on seabird deck-strike.

4 Conclusion

Most of the literature on seabird attraction to ALAN discusses petrels and shearwaters as the group of seabirds most impacted and in particular fledgling aged birds. Of the two main hypotheses for why fledglings are more attracted to ALAN than adult birds, the literature seems to support either the bioluminescent prey hypothesis or the navigational hypothesis, with few studies supporting both. Almost every study mentioned the moon phase, weather or both as factors determining seabird fallout events. Studies of deck-strike were comparatively scant in the literature despite the frequency in which they occurred during specific deck-strike observations (e.g. nightly in some cases) in addition to being described as 'common' in one study.

As artificial light increases globally the need to understand how this impacts biodiversity becomes even more pressing. Little is known about the visual system of many species of petrels and shearwaters or how ALAN impacts on their nocturnal activities such as foraging, migration or returning to the colony. This review has highlighted the need for more studies on seabird physiology and anatomy which would provide important conservation information for seabirds. Additionally, a greater knowledge of the light types, colours and wavelengths that seabirds are attracted could help reduce light-induced injury and mortality in future. With 86 species found breeding in New Zealand and almost half of those threatened, we have an international obligation to reduce seabird injury and mortality from deck-strike in our territorial waters.

5 References

Abraham, E., & Berkenbusch, K. (2019). *Preparation of data for protected species capture estimation, updated to 2016–17*. (234). Wellington, New Zealand: Fisheries New Zealand

Abraham, E. R., & Richard, Y. (2019). *Estimated capture of seabirds in New Zealand trawl and longline fisheries, to 2016–17*. (266). Wellington, New Zealand: Fisheries New Zealand

Abraham, E. R., Richard, Y., Berkenbusch, K., & Thompson, F. N. (2016). *Summary of the Capture of Seabirds, Marine Mammals, and Turtles in New Zealand Commercial Fisheries, 2002-03 to 2012-13*. (169). Wellington, New Zealand: Ministry for Primary Industries

Allen, J. (1880). Destruction of birds by light-houses. *Bulletin of the Nuttall Ornithological Club, 5*(3), 131-138.

Aubrecht, C., Elvidge, C., Ziskin, D., Rodrigues, P., & Gil, A. (2010). *Observing stress of artificial night lighting on marine ecosystems-a remote sensing application study*: na.

Barros, R., Medrano, F., Norambuena, H. V., Peredo, R., Silva, R., de Groote, F., & Schmitt, F. (2019). Breeding Phenology, Distribution and Conservation Status of Markham's Storm-Petrel Oceanodroma markhami in the Atacama Desert. *Ardea, 107*(1), 75-84.

Black, A. (2005). Light induced seabird mortality on vessels operating in the Southern Ocean: incidents and mitigation measures. *Antarctic Science, 17*(1), 67-68.

Bocetti, C. I. (2011). Cruise ships as a source of avian mortality during fall migration. *The Wilson Journal of Ornithology, 123*(1), 176-178.

Bowmaker, J. (1991). Photoreceptors, photopigments and oil droplets. *Vision and visual dysfunction, 6*, 108-127.

Capuska, G. E. M., Huynen, L., Lambert, D., & Raubenheimer, D. (2011). UVS is rare in seabirds. *Vision research, 51*(12), 1333-1337.

Commonwealth of Australia. (2019). *National Light Pollution Guidelines for Wildlife Including Marine Turtles, Seabirds and Migratory Shorebirds*. Australia

Croxall, J. P., Butchart, S. H., Lascelles, B., Stattersfield, A. J., Sullivan, B., Symes, A., & Taylor, P. (2012). Seabird conservation status, threats and priority actions: a global assessment. *Bird Conservation International, 22*(1), 1-34.

Cuthill, I. C. (2006). Color perception. *Bird coloration, 1*, 3-40.

Department of Conservation. (2019). Cruise ships protecting seabirds [Press release]. Retrieved 03/11/2019 from https://www.doc.govt.nz/news/media-releases/2019/cruise-ships-protecting-seabirds/

Deppe, L., Rowley, O., Rowe, L. K., Shi, N., Gooday, O., & Goldstien, S. J. (2017). Investigation of fallout events in Hutton's shearwaters (Puffinus huttoni) associated with artificial lighting. *Notornis, 64*(4), 181-191.

Dias, M. P., Martin, R., Pearmain, E. J., Burfield, I. J., Small, C., Phillips, R. A., . . . Croxall, J. P. (2019). Threats to seabirds: A global assessment. *Biological conservation*.

Dick, M. H., & Donaldson, W. (1978). Fishing vessel endangered by crested auklet landings. *The Condor, 80*(2), 235-236.

Diffey, B. L. (2002). What is light?. *Photodermatology, photoimmunology & photomedicine*, *18*(2), 68-74.

Dragonfly Science. (2019). Protected species bycatch in New Zealand fisheries. Retrieved 01/11/2019, from https://psc.dragonfly.co.nz/2019v1/.

Fontaine, R., Gimenez, O., & Bried, J. (2011). The impact of introduced predators, light-induced mortality of fledglings and poaching on the dynamics of the Cory's shearwater (Calonectris diomedea) population from the Azores, northeastern subtropical Atlantic. *Biological conservation, 144*(7), 1998-2011

Forest & Bird (2014).*New Zealand Seabirds: Important Bird Areas and Conservation*.The Royal Forest & Bird Protection Society of New Zealand, Wellington, New Zealand. 72 pp

Gaskin, C., & Rayner, M. J. (2013). *Seabirds of the Hauraki Gulf: natural history, research and conservation*. Retrieved 24/10/2019 from: https://www.aucklandcouncil.govt.nz/about-auckland-council/how-auckland-council-works/harbour-forums/Documents/seabirds-hauraki-gulf.pdf

Gineste, B., Souquet, M., Couzi, F.-X., Giloux, Y., Philippe, J.-S., Hoarau, C., . . . Le Corre, M. (2017). Tropical shearwater population stability at Reunion Island, despite light pollution. *Journal of Ornithology, 158*(2), 385-394.

Glass, J., & Ryan, P. (2013). Reduced seabird night strikes and mortality in the Tristan rock lobster fishery. *African Journal of Marine Science, 35*(4), 589-592.

Guilford, T., Padget, O., Bond, S., & Syposz, M. M. (2019). Light pollution causes object collisions during local nocturnal manoeuvring flight by adult Manx Shearwaters Puffinus puffinus. *Seabird*, *31*.

Hammerschlag, N., Meyer, C. G., Grace, M. S., Kessel, S. T., Sutton, T. T., Harvey, E. S., . . . Cooke, S. J. (2017). Shining a light on fish at night: an overview of fish and fisheries in the dark of night, and in deep and polar seas. *Bulletin of Marine Science, 93*(2), 253-284.

Håstad, O., Ernstdotter, E., & Odeen, A. (2005). Ultraviolet vision and foraging in dip and plunge diving birds. *Biology Letters, 1*(3), 306-309.

Hölker, F., Wolter, C., Perkin, E. K., & Tockner, K. (2010). Light pollution as a biodiversity threat. *Trends in ecology & evolution, 25*(12), 681-682.

Holmes, M. (2017). *Characterising Deck-strikes*. Retrieved from

Imber, M. (1975). Behaviour of Petrels in relation to the moon and artificial lights. *Journal of the Ornithological Society of New Zealand*, 302.

Imber, M. J., McFadden, I., Bell, E. A., & Scofield, R. P. (2003). Post-fledging migration, age of first return and recruitment, and results of inter-colony translocation of black petrels (Procellaria parkinsoni). *Notornis, 50*(4), 183-190.

IUCN. (2019). The IUCN Red List of Threatened Species. Retrieved from https://www.iucnredlist.org/. Retrieved 20/10/2019, from International Union for the Conservation of Nature https://www.iucnredlist.org/

Kyba, C. C., Kuester, T., De Miguel, A. S., Baugh, K., Jechow, A., Hölker, F., . . . Guanter, L. (2017). Artificially lit surface of Earth at night increasing in radiance and extent. *Science advances, 3*(11), e1701528.

Le Corre, M., Ollivier, A., Ribes, S., & Jouventin, P. (2002). Light-induced mortality of petrels: a 4-year study from Réunion Island (Indian Ocean). *Biological conservation, 105*(1), 93-102.

Longcore, T., & Rich, C. (2004). Ecological light pollution. *Frontiers in Ecology and the Environment, 2*(4), 191-198.

Longcore, T., Rodríguez, A., Witherington, B., Penniman, J. F., Herf, L., & Herf, M. (2018). Rapid assessment of lamp spectrum to quantify ecological effects of light at night. *Journal of Experimental Zoology Part A: Ecological and Integrative Physiology, 329*(8-9), 511-521.

Merkel, F. R., & Johansen, K. L. (2011). Light-induced bird strikes on vessels in Southwest Greenland. *Marine Pollution Bulletin, 62*(11), 2330-2336.

Miles, W., Money, S., Luxmoore, R., & Furness, R. W. (2010). Effects of artificial lights and moonlight on petrels at St Kilda. *Bird Study, 57*(2), 244-251.

Miskelly, C., Stahl, J.-C., & Tennyson, A. (2017). Do grey-backed storm petrels (Garrodia nereis) breed in Fiordland, New Zealand? *Notornis, 64*, 109-114.

Mitkus, M., Nevitt, G. A., Danielsen, J., & Kelber, A. (2016). Vision on the high seas: spatial resolution and optical sensitivity in two procellariiform seabirds with different foraging strategies. *Journal of Experimental Biology, 219*(21), 3329-3338.

Montevecchi, W. A. (2006). Influences of artificial light on marine birds. *Ecological consequences of artificial night lighting*, 94-113.

Morton, J. (2018). Conservationists saddened after seabirds die in boxes. *New Zealand Herald*. Retrieved 20/10/2019, from https://www.nzherald.co.nz/nz/news/article.cfm?c_id=1&objectid=12057912.

Ndez-Juricic, E. (2016). The role of animal sensory perception in behavior-based management. *Conservation Behavior: Applying Behavioral Ecology to Wildlife Conservation and Management, 21*, 149.

New Zealand Birds Online. (2019). The digital encyclopaedia of New Zealand birds. Retrieved from http://nzbirdsonline.org.nz/

Nguyen, K. Q., & Winger, P. D. (2019). Artificial light in commercial industrialized fishing applications: a review. *Reviews in Fisheries Science & Aquaculture, 27*(1), 106-126.

Poot, H., Ens, B. J., de Vries, H., Donners, M. A., Wernand, M. R., & Marquenie, J. M. (2008). Green light for nocturnally migrating birds. *Ecology and society, 13*(2).

Raine, A. F., Holmes, N. D., Travers, M., Cooper, B. A., & Day, R. H. (2017). Declining population trends of Hawaiian Petrel and Newell's Shearwater on the island of Kaua'i, Hawaii, USA. *The Condor: Ornithological Applications*, *119*(3), 405-415.

Raine, H., Borg, J. J., Raine, A., Bairner, S., & Cardona, M. B. (2007). *Light pollution and its effect on Yelkouan Shearwaters in Malta; causes and solutions.* BirdLife Malta, Malta. Retrieved 27/10/19 from: http://ec.europa.eu/environment/life/project/Projects/files/book/light-pollution.pdf

Ramm, K. (2010). *Conservation Services Programme Observer Report: 1 July 2008 to 30 June 2009*. Wellington, New Zealand: Department of Conservation

Reed, J. R., Sincock, J. L., & Hailman, J. P. (1985). Light attraction in endangered procellariiform birds: reduction by shielding upward radiation. *The Auk, 102*(2), 377-383.

Robertson, H.A.; Baird, K.; Dowding, J.E.; Elliott, G.P.; Hitchmough, R.A.; Miskelly, C.M.; McArthur, N.; O'Donnell, C.F.J.; Sagar, P.M.; Scofield, R.P.; Taylor, G.A. 2017: *Conservation status of New Zealand birds, 2016.* New Zealand Threat Classification Series 19. Department of Conservation, Wellington. 23 p

Rodríguez, A., Arcos, J. M., Bretagnolle, V., Dias, M. P., Holmes, N. D., Louzao, M., . . . Rodríguez, B. (2019). Future directions in conservation research on petrels and shearwaters. *Frontiers in Marine Science, 6*, 94.

Rodríguez, A., Burgan, G., Dann, P., Jessop, R., Negro, J. J., & Chiaradia, A. (2014). Fatal attraction of short-tailed shearwaters to artificial lights. *PLoS One, 9*(10), e110114.

Rodríguez, A., Dann, P., & Chiaradia, A. (2017a). Reducing light-induced mortality of seabirds: high pressure sodium lights decrease the fatal attraction of shearwaters. *Journal for nature conservation, 39*, 68-72.

Rodríguez, A., García, D., Rodríguez, B., Cardona, E., Parpal, L., & Pons, P. (2015). Artificial lights and seabirds: is light pollution a threat for the threatened Balearic petrels? *Journal of Ornithology, 156*(4), 893-902.

Rodríguez, A., Holmes, N. D., Ryan, P. G., Wilson, K. J., Faulquier, L., Murillo, Y., . . . Rodríguez, B. (2017b). Seabird mortality induced by land-based artificial lights. *Conservation Biology, 31*(5), 986-1001.

Rodríguez, A., Moffett, J., Revoltós, A., Wasiak, P., McIntosh, R. R., Sutherland, D. R., . . . Chiaradia, A. (2017c). Light pollution and seabird fledglings: targeting efforts in rescue programs. *The Journal of Wildlife Management, 81*(4), 734-741.

Rodriguez, A., & Rodriguez, B. (2009). Attraction of petrels to artificial lights in the Canary Islands: effects of the moon phase and age class. *Ibis, 151*(2), 299-310.

Rodríguez, A., Rodríguez, B., Curbelo, Á., Pérez, A., Marrero, S., & Negro, J. J. (2012). Factors affecting mortality of shearwaters stranded by light pollution. *Animal Conservation, 15*(5), 519-526.

Ronconi, R. A., Allard, K. A., & Taylor, P. D. (2015). Bird interactions with offshore oil and gas platforms: review of impacts and monitoring techniques. *Journal of Environmental Management, 147*, 34-45.

Ryan, P. (1991). The impact of the commercial lobster fishery on seabirds at the Tristan da Cunha Islands, South Atlantic Ocean. *Biological Conservation, 57*(3), 339-350.

Sage, B. (1979). Flare up over North Sea birds. *New Scientist, 81*(15), 464-466.

Salamolard, M., Ghestemme, T., Couzi, F.-X., Minatchy, N., & Le Corre, M. (2007). Impacts des éclairages urbains sur les pétrels de Barau, Pterodroma baraui sur l'Ile de la Réunion et mesures pour réduire ces impacts. *Ostrich-Journal of African Ornithology, 78*(2), 449-452.

Sandager, F. (1890). *Observations on the Mokohinou Islands and the birds which visit them.* Paper presented at the Transactions of the New Zealand Institute.

Tanaka, K. D. (2015). A colour to birds and to humans: why is it so different? *Journal of Ornithology, 156*(1), 433-440.

Telfer, T. C., Sincock, J. L., Byrd, G. V., & Reed, J. R. (1987). Attraction of Hawaiian seabirds to lights: conservation efforts and effects of moon phase. *Wildlife Society Bulletin (1973-2006), 15*(3), 406-413.

Troy, J. R., Holmes, N. D., Veech, J. A., & Green, M. C. (2013). Using observed seabird fallout records to infer patterns of attraction to artificial light. *Endangered Species Research, 22*(3), 225-234.

Warham, J. (1990). *The petrels: their ecology and breeding systems*. A&C Black.

Waugh, S. M., & Wilson, K.-J. (2017). Threats and threat status of the Westland Petrel Procellaria westlandica. *Marine Ornithology, 45*, 195-203.

Whitehead, E., Adams, N., Baird, K., Bell, E., Borelle, S., Dunphy, B., . . . Russell, J. (2019). *Threats to seabirds of northern Aotearoa New Zealand*. Retrieved 20/10/19 from https://www.aucklandcouncil.govt.nz/about-auckland-council/how-auckland-council-works/harbour-forums/Documents/threats-to-seabirds-northern-aotearoa.pdf

Wiese, F. K., Montevecchi, W., Davoren, G., Huettmann, F., Diamond, A., & Linke, J. (2001). Seabirds at risk around offshore oil platforms in the North-west Atlantic. *Marine Pollution Bulletin, 42*(12), 1285-1290.

Withgott, J. (2000). Taking a Bird's-Eye View… in the UV: Recent studies reveal a surprising new picture of how birds see the world. *BioScience, 50*(10), 854-859.

6 Appendix

A brief analysis of Dragonfly deck-strike records in northern New Zealand

Please note the following graphs do not take MPI observer coverage into account so the data is biased towards vessels with increased cover.

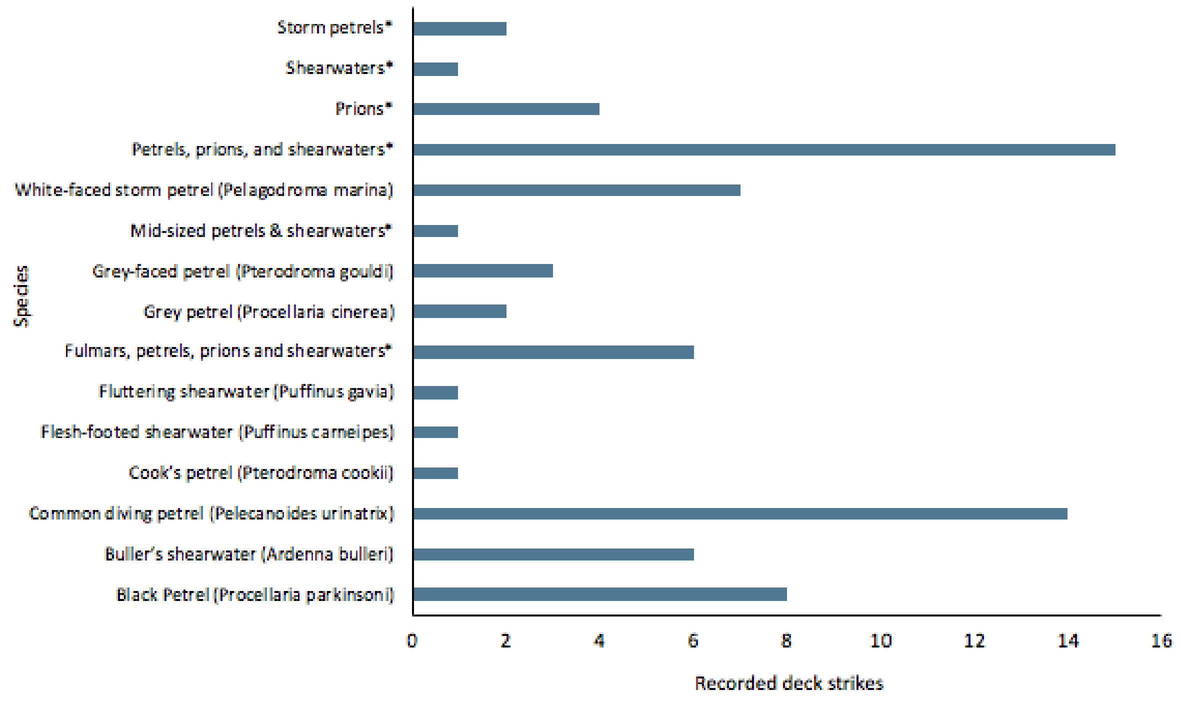


Figure 1. Recorded deck-strikes per seabird species in the Auckland/Hauraki region from 2002–03 to 2017–18. Data retrieved from the Protected Species Captures database (https://psc.dragonfly.co.nz/2019v1/). (*) denotes groups of birds where the species was not listed.

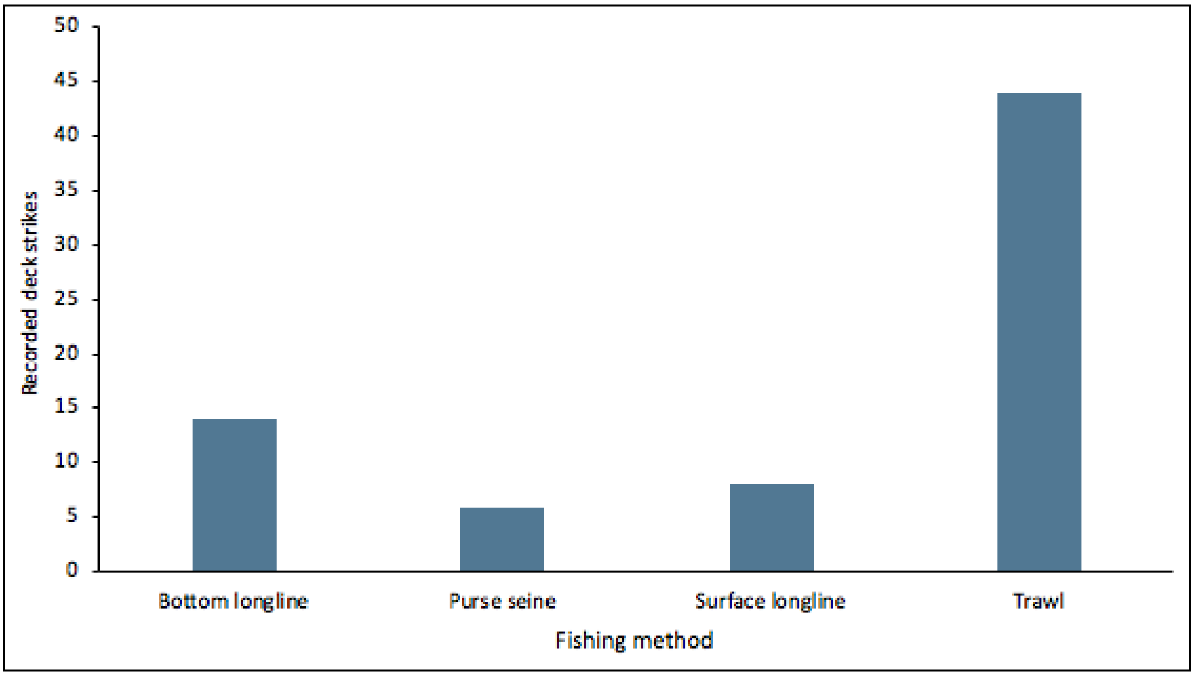


Figure 2. Recorded deck-strikes per fishing method in the Auckland/Hauraki region from 2002–03 to 2017–18. Data retrieved from the Protected Species Captures database (https://psc.dragonfly.co.nz/2019v1/).

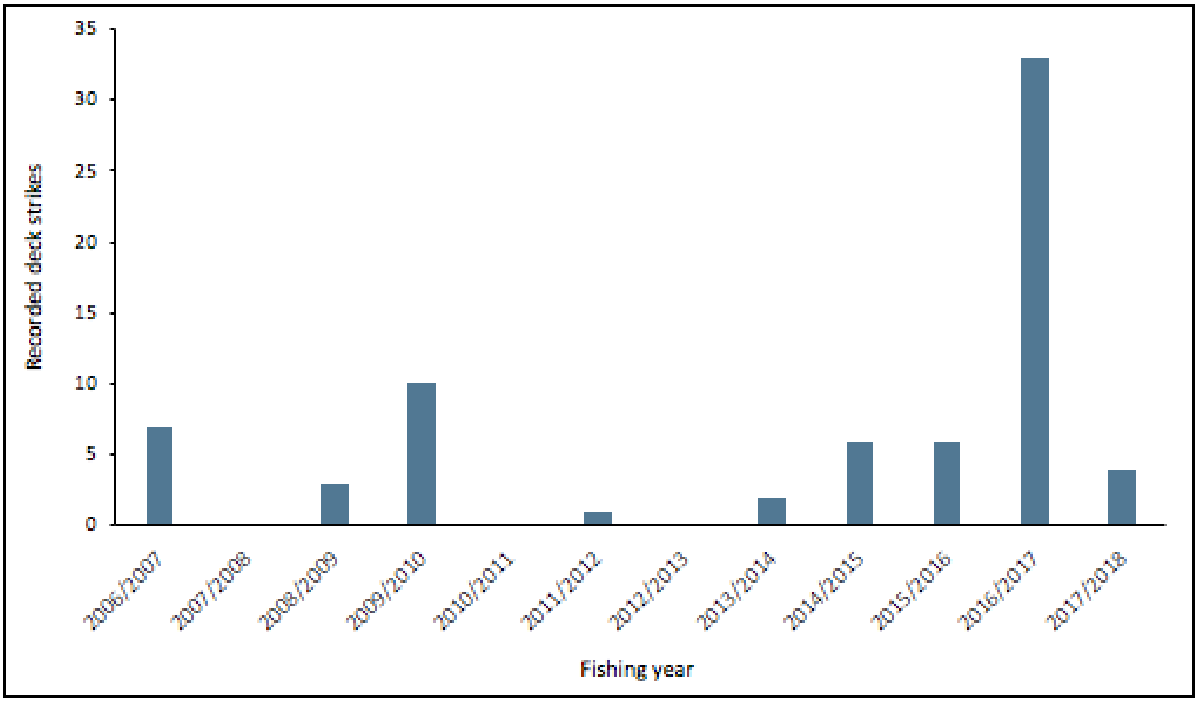


Figure 3. Recorded deck-strikes per fishing year in the Auckland/Hauraki region from 2002–03 to 2017–18. Data retrieved from the Protected Species Captures database (https://psc.dragonfly.co.nz/2019v1/).

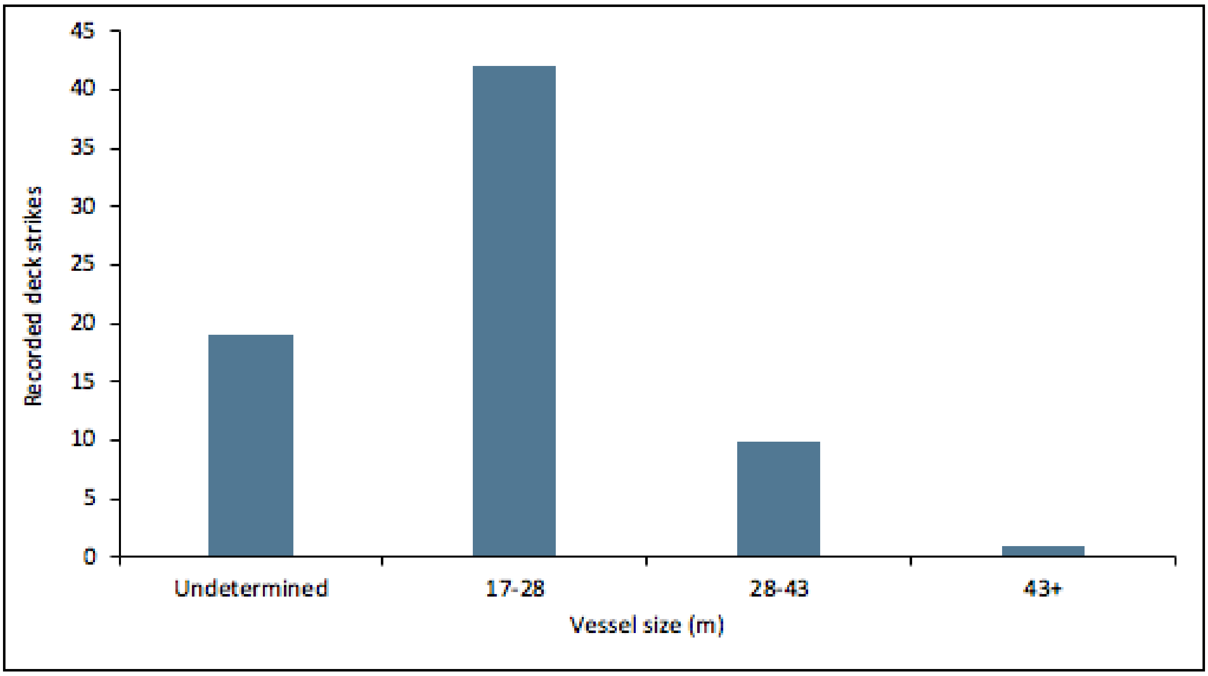


Figure 4. Recorded deck-strikes per fishing year in the Auckland/Hauraki region from 2002–03 to 2017–18. Data retrieved from the Protected Species Captures database (https://psc.dragonfly.co.nz/2019v1/).

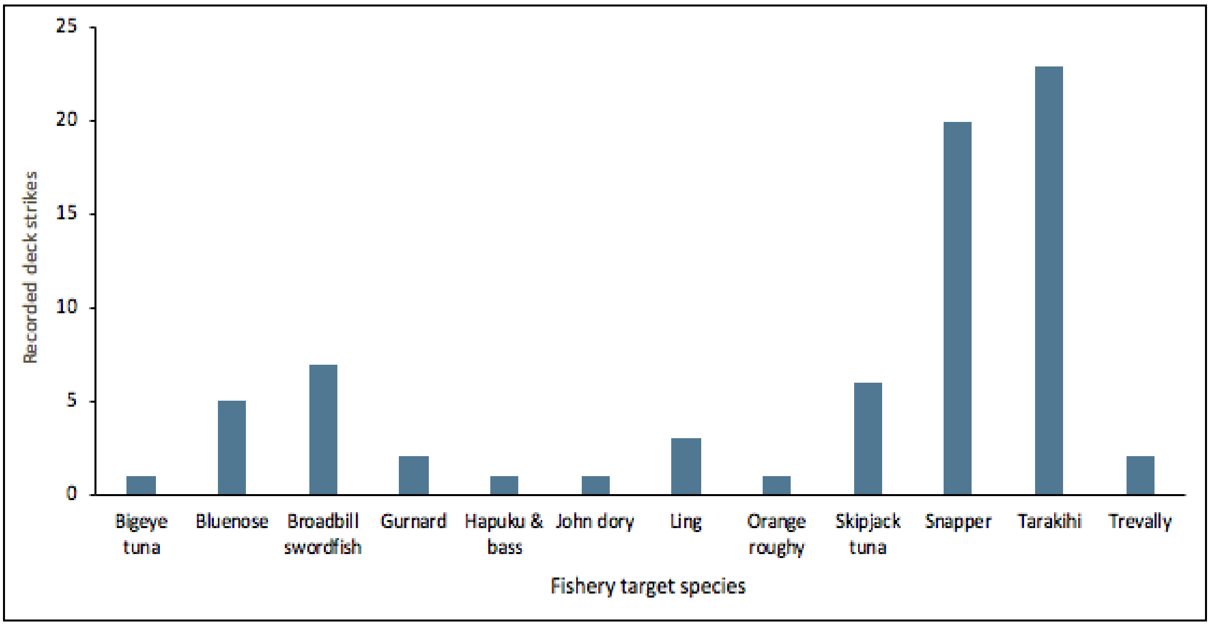


Figure 5. Recorded deck-strikes per fishery target species in the Auckland/Hauraki region from 2002–03 to 2017–18. Data retrieved from the Protected Species Captures database (https://psc.dragonfly.co.nz/2019v1/