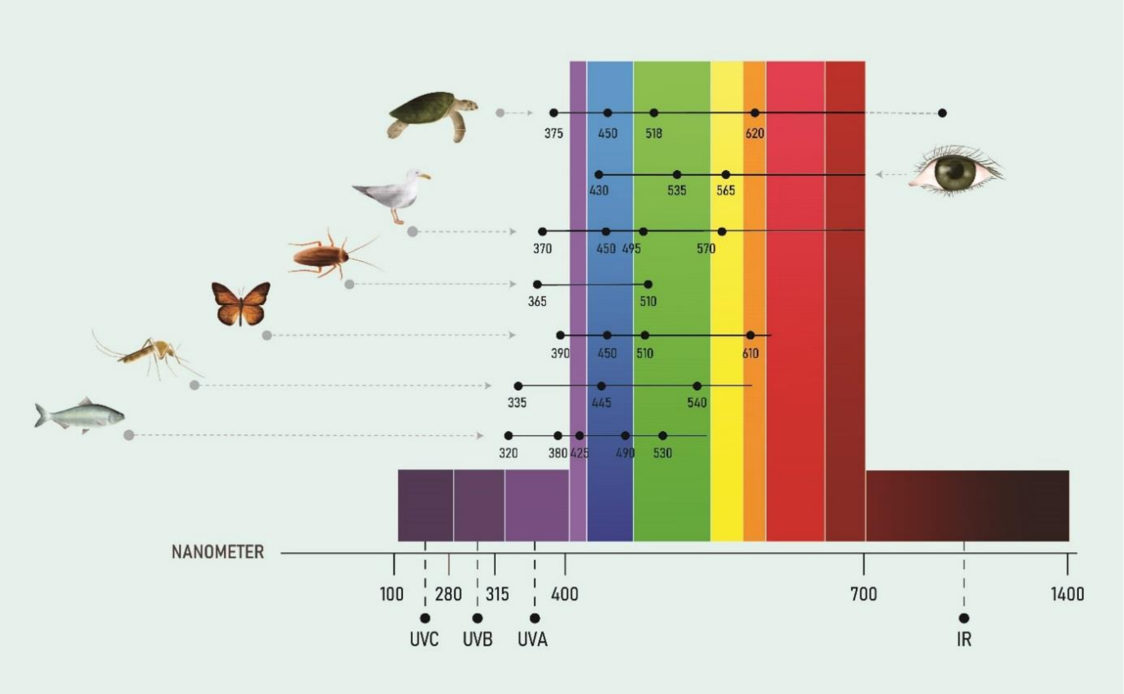
MIT2019-03: Lighting adjustments to mitigate against deck strikes/vessel impacts

Milestone 2 – land-based island trials

This report has been prepared by **Kerry Lukies** (Northern NZ Seabird Trust), **Dr Anne Gaskett** (University of Auckland), **Ariel-Micaiah Heswell** (University of Auckland), **Chris Gaskin** (NNZST) and **Dr Megan Friesen** (St Martins University).



DRA

Cover: Cook’s petrels ‘trapped’ in the light beam during trails on Te Hauturu-o-Toi Little Barrier 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 SUMMARY

Artificial light at night (ALAN) can negatively impact the behaviour of nocturnally active seabirds by causing disorientation, exhaustion, and injury or mortality from light-induced collisions. Procellariiformes are disproportionately attracted to ALAN compared to other seabird groups, fledglings on their maiden flight are most at risk. The Hauraki Gulf has one of the world's highest diversities of seabirds, many of them vulnerable to light pollution, including threatened species. While most of these species breed on uninhabited offshore islands, the extensive shipping activity in this region puts seabirds at great risk of light-induced collisions with vessels as they pass or are anchored nearby. This would include fishing vessels working at night. This study, undertaken on two seabird islands, tested which light intensities and colours were least attractive to seabirds through behavioural experiments where we shined lights into the sky and recorded seabird attraction. We also modelled the lights into the visual system of seabirds to identify how seabirds perceive lights differently. Our island-based experiments showed an equal statistical attraction to the light types we tested but provided anecdotal observations where more research and larger sample sizes are required. The number of seabirds trapped in the light beam differed by island and moon phase. The number of seabirds observed in thermal imagery differed by island and moon phase when comparing small LED lights only. Fifteen birds were grounded, most on Pokohinu Burgess Island during the flood LED treatment. Differences between islands likely reflected the local seabird diversity at each island. Future vessel-based and further land-based behavioural experiments should be timed for peak fledging period of common diving petrels, a seabird particularly vulnerable to light-induced collisions and should incorporate a greater range of moon phases and increase sample sizes for each lighting treatment.

DRAFT

2 INTRODUCTION

2.1 Seabird attraction to artificial light at night

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 & 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). 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 & Rich, 2004).

Light attraction and disorientation are well documented in nocturnally active seabirds and ALAN has been found to disproportionately affect some Procellariiform species including petrels, prions, shearwaters and storm petrels, and especially fledglings on their maiden flight (Fontaine et al., 2011; Montevecchi, 2006; Rodriguez & Rodriguez, 2009). 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-Juric, 2016). It is this visual system that is adapted to low light levels that make some nocturnal seabirds likely more sensitive to short-wavelength blue light (including white light) and less sensitive to long-wavelength red light (Tanaka, 2015).

The visible light spectrum as determined by the human visual system includes the wavelengths: red (700 nm), orange (630 nm), yellow (600 nm), green (550 nm), blue (470 nm), indigo (425 nm) and violet (400 nm). Generally, this is not how animals see light. Unlike mammals, birds are able to detect ultraviolet wavelengths (UV, 300-400nm; Kelber, 2016). Some groups of birds, including seabirds, have UV Sensitive (UVS) vision where the photoreceptors are specifically tuned to UV wavelengths (Hart, 2004; Håstad et al., 2005). UVS birds such as seabirds are therefore highly responsive to UV.

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 (Rodríguez et al., 2017b). 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 (Rodriguez 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).

2.2 Seabirds of Northern Aotearoa New Zealand

Aotearoa New Zealand is a seabird hotspot 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 centre of seabird diversity with breeding colonies of 27 species found primarily on offshore islands and rock stacks (Gaskin & Rayner, 2013). Protecting the seabirds of the Hauraki Gulf is therefore of local, national, and international value. Artificial light at night has been identified as a threat to seabirds in many locations around the world, including northern New Zealand (Barros et al., 2019; Glass & Ryan, 2013; Imber, 1975; Le Corre et al., 2002; Merkel & Johansen, 2011; Miles et al., 2010; Rodriguez et al., 2014; Rodriguez & Rodriguez, 2009; Whitehead et al., 2019). While seabird colonies on islands in the northern New Zealand 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 in the vicinity of seabird breeding colonies that pose a risk to the many species found in the region, especially to those listed as threatened (Black, 2005; Merkel & Johansen, 2011).

2.3 Light-induced collisions in the Hauraki Gulf

There is considerable anecdotal and documented evidence for seabird-light collisions in northern New Zealand. One recent light-induced collision event saw 64 endemic Buller’s shearwater (rako, *Ardenna bulleri*) and four threatened flesh-footed shearwater (toanui, *Ardenna carneipes*) collide with a cruise ship in the Hauraki Gulf (Morton, 2018). While many of these birds were released alive, 20 birds died from incorrect restraint and release measures by crew members. This event, combined with deck strike data collected by fisheries observers, highlighted the need for research to minimise light-induced collisions in the Hauraki Gulf (Department of Conservation, 2019). Other reports of light-induced collisions in the region include birds colliding with the lighthouse on Pokohinu Burgess Island (Mokohinau Islands) and being grounded by lights in Auckland city and various coastal towns (Sandager, 1890; Whitehead et al., 2019).

2.4 Types of lights used on vessels

The lighting types used by humans use different wavelengths within the visible light spectrum. The intensity or brightness of the light, as well as the colour or wavelengths emitted, are likely to be important in seabird attraction (reviewed in Commonwealth of Australia, 2020). Since 2000, the most prevalent light types in use in the terrestrial environment include light-emitting diode (LED), metal halide and high-pressure sodium (HPS) lights (Rodríguez et al., 2017a), whereas on vessels, LED, metal halide, halogen and fluorescent lights are the most common (Nguyen & Winger, 2019). Artificial lights on vessels are commonly used for crew safety, setting fishing gear at night, navigation or to attract nocturnal species of fish and squid (Black, 2005; Nguyen & 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, 2020) 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, 2020).

3 PROJECT AIMS

This study aims to test which light intensities and colours are least attractive to seabirds, to facilitate understanding of how to minimise the impact of light-induced collisions with vessels in the Hauraki Gulf. These land-based seabird behavioural trials will inform our choices of which lighting to use in our future vessel-based trials. Ultimately, we intend to explore whether alternative or modified lights will result in fewer bird attractions (e.g. overhead fly-bys) than for lights used previously.

Our specific aims are to:

- Characterise the wavelengths and intensity of lights used on boats and model how these are perceived by seabirds.
- Carry out land-based behavioural trials to test seabird responses to these lights and alternative options such as different colours/filters.
    - It is predicted the greatest attraction will be to more intense lights, especially if they involve UV wavelengths.

DRAFT

4 METHODS

4.1 Lighting characteristics and how they are perceived by seabirds

We measured light types that were used by fishing vessels in New Zealand identified in a previous survey. We used an Ocean Optics Jaz Spectrophotometer with a PX-2 pulsed xenon light source (Ocean Optics Inc., Dunedin, FL, USA) to take three measurements per light, indoors. Spectrophotometers measure biologically relevant light in the bird detectable range of 300 to 700nm and are recommended for wildlife-ALAN studies (Commonwealth of Australia, 2020). We calibrated the spectrophotometer with a white and a black standard and took measurements with a reflectance probe held at a 45° angle, ~15cm away from the light.

We calculated mean hue and brightness, and the UV brightness using the *pavo* package in R (Maia et al., 2013; R Core Team, 2019) and compared the results using an ANOVA with post-hoc Tukey tests. Then, we used the *pavo* function 'sensmodel' to model the spectral reflectance of the lights into a seabird vision system. We used the spectral sensitivities of wedge-tailed shearwaters (*Ardenna pacificus*; Hart, 2004), the average receptor densities for UV sensitive (UVS) birds (Håstad et al., 2005; Holveck et al., 2017), the D65 standard ambient light measure, and the widely-used 'receptor-noise' model for tetrachromat vision (Vorobyev & Osorio, 1998). We calculated colour contrasts (the degree to which the lights would look different to a seabird) and these are provided in units of JND ('just noticeable differences'). Lower JND values mean the lights look more similar. When values are close to or less than 1, a seabird likely could not distinguish between the lights.

Visual modelling was based on the spectral sensitivities of wedge-tailed shearwaters (Hart, 2004), which is UV sensitive (UVS; ie. has photoreceptors tuned to UV rather than violet wavelengths; Holveck et al., 2017). This is the best available choice for our study because it is the sole procellariform for which visual spectral sensitivities have been calculated, and is burrow-nester, like the study species in our field experiments. Burrow nesting seabirds are the birds most often affected by light pollution (Atchoi et al., 2020), and burrow and surface-nesters can have different visual systems (Mitkus et al., 2016).

4.2 Seabird attraction to artificial light at night – behavioural experiment

The behavioural experiment was carried out on two islands in the Hauraki Gulf: Pokohinu Burgess Island, Mokohinau Islands; 35.9167° S, 175.1167° E) for five nights in December 2019 and Hauturu (Little Barrier Island; 36.1946° S, 175.0753° E) for seven nights in January 2020. These islands were chosen due to their remote locations, and multiple species of breeding seabirds. Behavioural trials were timed to particularly assess the impacts on common diving petrels (kuaka, *Pelecanoides urinatrix*), white-faced storm petrel (takahikare, *Pelagodroma marina*) and Cook's petrel (tītī, *Pterodroma cookii*) as these species are all considered "At Risk" (NZTCS) and are vulnerable to artificial light attraction.

Lights were attached to a horizontal wooden beam positioned approximately 1m above the ground facing skyward. These were connected by an extension cord to a petrol-powered generator 30m away. A 20m x 20m plot was marked around the lighting set up as a boundary for the ground-based observations.

A random lighting schedule was cycled where the light type tested varied in placement from sunset each night to control for times of greater seabird activity. Starting half an hour after sunset, each light was projected skyward for 10 minutes followed by an interval of 10 minutes of darkness to avoid potential attractiveness effects of the previous light treatment. Trials continued through the night depending on weather conditions and seabird activity levels. Because nocturnal seabirds are social and attracted to vocalisations, light experiments were carried out in silence except for unavoidable generator noise.

Figure 3. Light array set up on Hauturu – lights from left, halogen, fluorescent, LED flood, and LED (white, blue, green and red) . *Photo: Chris Gaskin*

4.3 Ground observations

Observers were positioned at ground level just outside of the 20m x 20m plot. Each bird observed flying through the plot was counted and recorded during each trial, including control periods. The plot was checked after each treatment for grounded birds. Birds were considered 'trapped' in the light beam if they hovered or flew in circles repeatedly within the light beam.

4.4 Thermal imaging

Two Pulsar Helion Thermal Imaging Scopes (Yukon Advanced Optics Worldwide, Vilnius, Lithuania) with standard lens at 2.5x magnification were used to record seabird activity during each trial, including control periods. Two scopes were required because the memory capacity could not cover the full nights' experiments – up to 6 hours. When the memory of one was full, the second one replaced it on the tripod.

The scope was positioned 60m from the lighting set up and recorded a frame directly above the lights. Recordings were filed with the light type, time of night, and island and provided a reference for the behavioural response to light types. Each bird observed in the thermal recordings was counted and recorded during each trial, including control periods. Samples sizes for each treatment were smaller than originally planned (n = ~12) as inconsistencies in video magnification meant some videos had to be excluded from the analysis. Videos recorded at 2.5x zoom were included in the analysis (n=74), those recorded at 1.9x, 3.3x and 5x zoom were excluded (n=40).

Figure 4. Setting up the thermal imaging scope, Hauturu Little Barrier island. *Photo: Edin Whitehead*

Figures 5-7. Three of the different light types used – flood LED, fluorescent, and red LED. *Photos: Edin Whitehead*

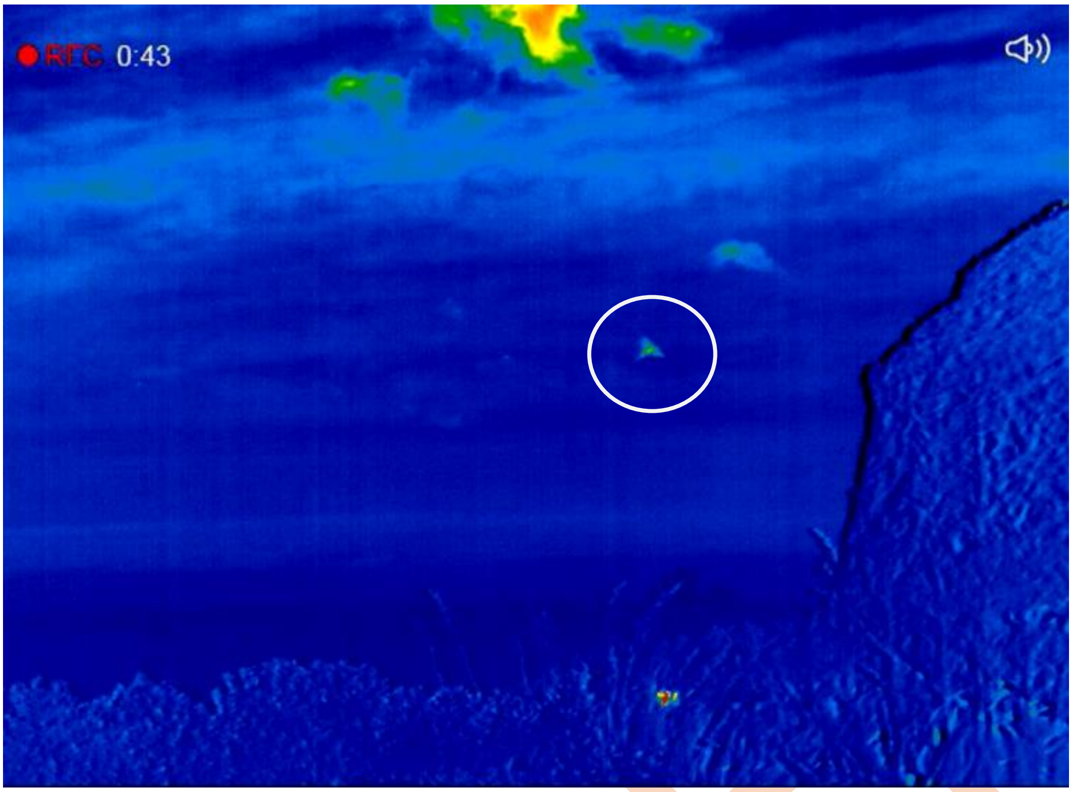


Figure 8. White-faced storm petrel (circled) ‘trapped’ in the beam of a halogen light on Pokohinu Burgess Island, 20 December 2019. Heat from the halogen light can be see through the flax leaves at bottom of the picture. *Screenshot from thermal imaging scope videography.*

DRAFT

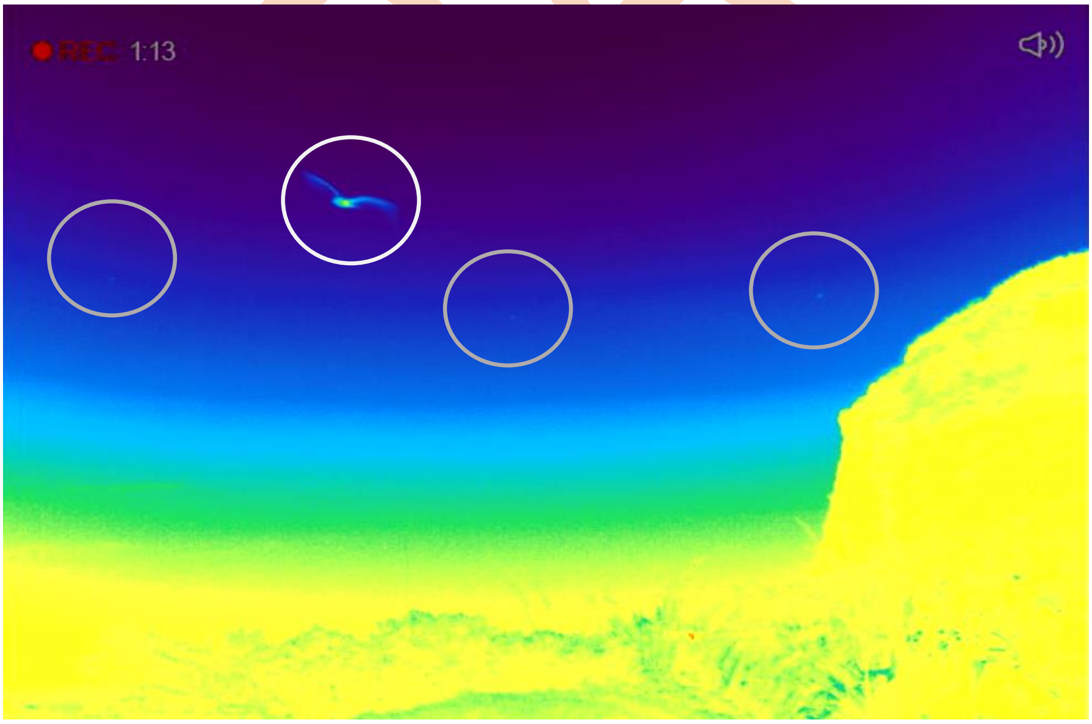


Figure 9. Four birds, one a grey-faced petrel circling above the halogen light, the three other birds distant, unidentified, and not attracted, Pokohinu Burgess Island, 20 December 2019. *Screenshot from thermal imaging scope videography.*

4.5 Statistical analysis

The behavioural experiment data were analysed using multiple multivariate regression analysis. The analysis accounted for island, day number, time of night, before or after midnight, weather, moon phase, lumens, and lighting treatment. All six lighting treatments were compared as was the sub-set of three small LED lights (white, red, green). We chose to also compare the small LED lights separately due to the increasing prevalence of LED lights on vessels, therefore, any difference in seabird attraction to different wavelengths could have important conservation implications. Statistical analyses were carried out using R version 3.5.0 (R Core Team, 2019).

5 RESULTS

5.1 Lighting characteristics and how they are perceived by seabirds

The flood LED, fluorescent, halogen and LED white lights all reflected across the range of bird visible wavelengths (Fig. 10). The green and red LEDs reflected only in their peak green and red regions

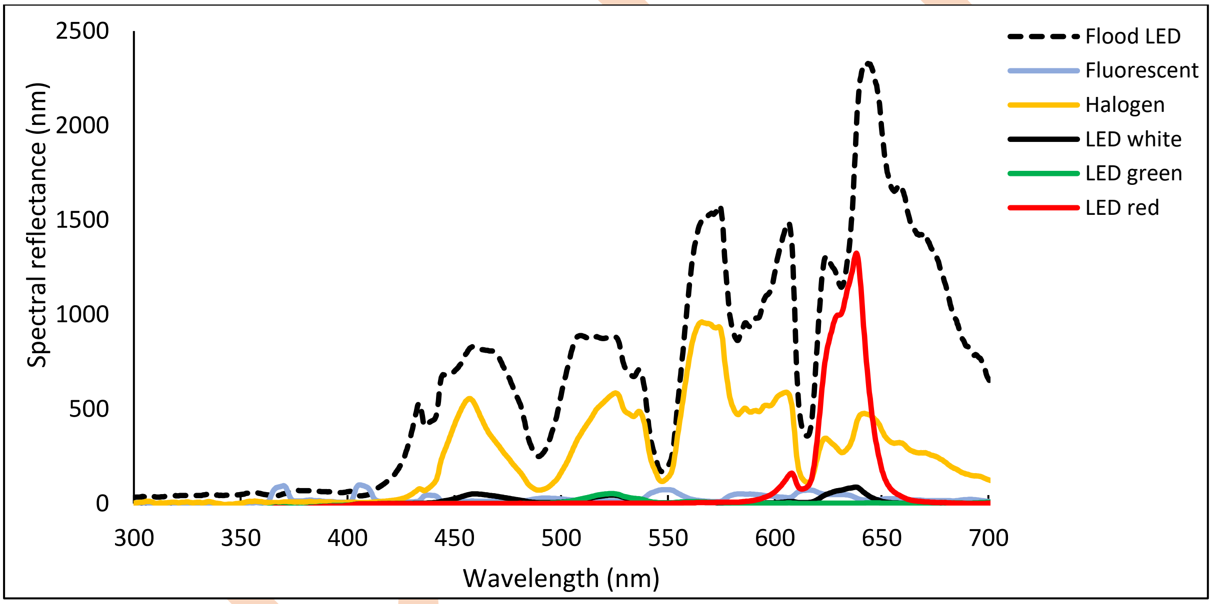


Figure 10. Spectral reflectance of each of the light types.

Overall, there were significant differences in the colour of the lights (i.e. the hue; $F_{5,18}$ = 17728.943, $p < 0.001$) and in brightness ($F_{5,18}$ = 56.26, $p < 0.001$).

All the lights had significantly different hues (all p values < 0.001). The flood LED (petrel light) was much brighter than the other lights (Fig. 11), followed by the halogen. The fluorescent, LED green, LED red and LED white were similar brightness’s (p values > 0.05).

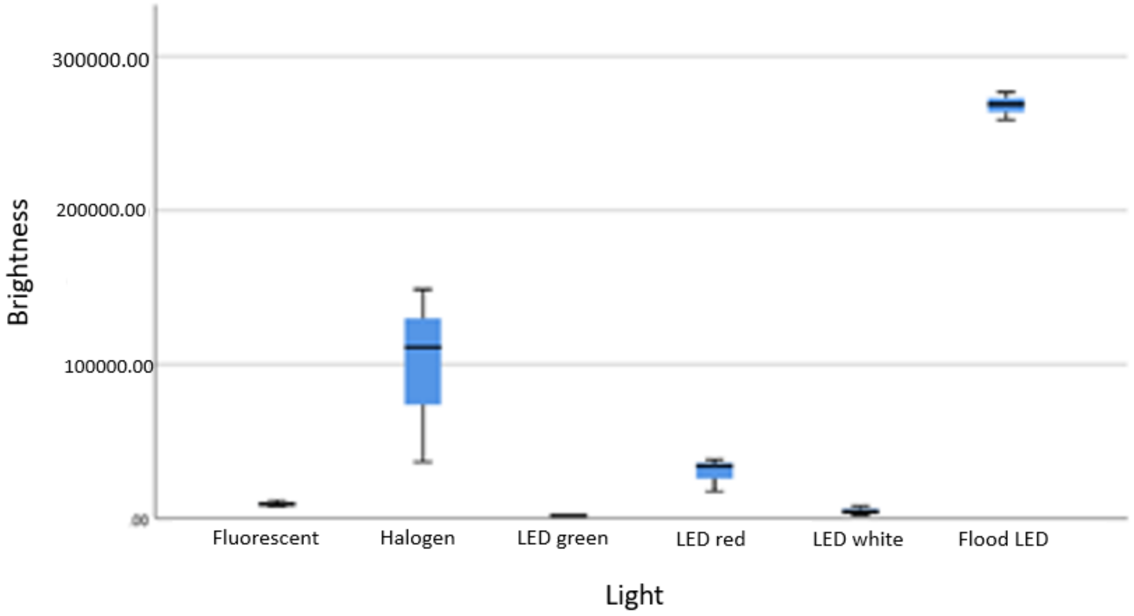


Figure 11. The brightness of each light type used in the behavioural experiments of seabird attraction to artificial light at night.

The lights differed in their UV reflectance ($F_{5,17} = 80.127$, $p < 0.01$). The flood LED, fluorescent and halogen lights all produced UV, the other LED lights did not. The flood LED had significantly more UV than the halogen and fluorescent lights (post-hoc Tukey tests, p-values < 0.05). The halogen and fluorescent lights reflected similar UV (p values > 0.05).

From a seabird perspective, the flood LED would likely appear very similar to the halogen light and the LED white (colour contrast values are low and approaching 1; see Table 1). A seabird could likely easily distinguish between all the other lights, especially those with the highest JND values, e.g. LED red, LED white and fluorescent lights.

Table 1. Tukey post-hoc pairwise comparison of colour contrast values of the different lights from a seabird perspective. Values are colour contrast values, in units of JND ('just noticeable differences'). As JND values approach 1, a seabird likely could not distinguish between the lights.

	Fluorescent	Flood LED	LED green	LED red	LED white
Halogen	9.227119254	**2.753929**	22.67938	43.32984	6.38864
LED white	9.606844729	**5.67293**	27.52597	43.82132	-
LED red	50.06587149	40.57953	32.91124	-	-
LED green	31.41956181	25.2914	-	-	-
Flood LED	**6.614459589**	-	-	-	-

5.2 Seabird attraction to artificial light at night – behavioural experiment

5.2.1 Thermal imaging and ground observations

Data were pooled from both islands. There was no difference in the number of seabirds observed in the thermal imagery or those observed from the ground for the variables of island, time of night, weather, moon phase, lumens or lighting treatment when comparing all light types (Table 2). There was a statistically significant difference in the number of seabirds trapped in the light beam for island and moon phase (both $p < 0.01$), but not for any of the other factors.

Table 2. Results of the multivariate regression analysis for seabird attraction to all light types in land-based behavioural trials. (*) denotes statistical significance.

Number of seabirds	Island	Time of night	Weather	Moon phase	Lumens (nm)	Lighting treatment (all lights)
In thermal imagery	0.144	0.753	0.238	0.144	0.541	0.984
Observed from the ground	0.987	0.988	0.073	0.987	0.168	0.289
Trapped in the lights	**0.001***	0.161	0.995	**0.001***	0.912	0.551

When the data is compared for just the coloured LED lights (white, red and green), there was no difference in the number of seabirds observed from the ground for all factors (Table 3). However, there was a statistically significant difference in the number of seabirds observed in thermal imagery and the number of seabirds trapped by the light beam, and (as when all lights were compared) for the factors island and moon phase (all $p < 0.05$).

Table 3. Results of the multivariate regression analysis for seabird responses to the white, red and green LED lights only. (*) denotes statistical significance.

Number of seabirds	Island	Time of night	Weather	Moon phase	Lumens (nm)	Lighting treatment (red, green, white LED)
In thermal imagery	**0.025***	0.551	0.893	**0.025***	0.439	0.794
Observed from the ground	0.422	0.806	0.768	0.422	0.506	0.959
Trapped in the lights	**0.047***	0.664	0.348	**0.047***	0.723	0.973

DRAFT

5.2.2 Island

More birds were trapped in the light beam on Pokohinu Burgess Island than on Hauturu Little Barrier Island when comparing all lights ($F_{3,24} = 7.15$, $p < 0.01$; Fig. 12). There was no difference in the number of birds observed in thermal imagery or from the ground between islands ($p > 0.05$).

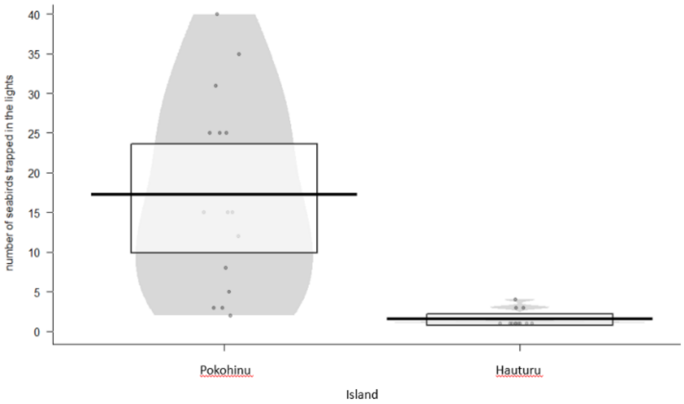


Figure 12. Boxplot showing the difference between islands for seabirds trapped by the light beam for all lights.

More birds were observed in thermal imagery (Figure 13a) and trapped in the light beam (Figure 13b) on Burgess than on Hauturu when comparing small LED’s only. There was no difference in the number of birds observed from the ground.

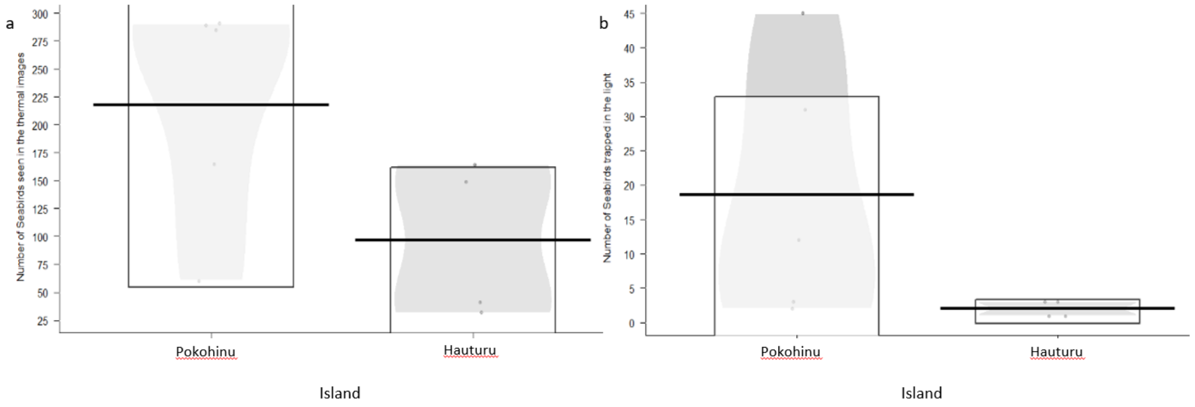


Figure 13. Boxplot showing the difference between islands for a) seabirds observed in thermal imagery and b) seabirds trapped by the light beam.

5.2.3 Moon phase

More birds were trapped in the light beam during the third quarter than during the new moon when comparing all lights ($F_{3,24} = 7.15$, $p < 0.01$; Fig. 14). There was no difference in the number of birds observed in thermal imagery or from the ground between moon phases.

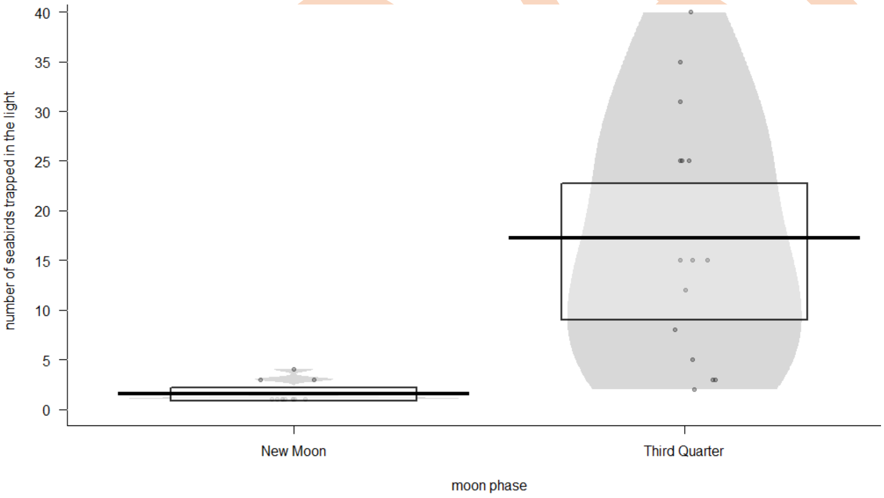


Figure 14. Boxplot showing the difference between moon phase for seabirds trapped by the light beam for all lights.

More birds were observed in thermal imagery (Fig. 15a) and trapped in the light beam (Fig. 15b) during the third quarter than the new moon when comparing small LED’s only. There was no difference in the number of birds observed from the ground.

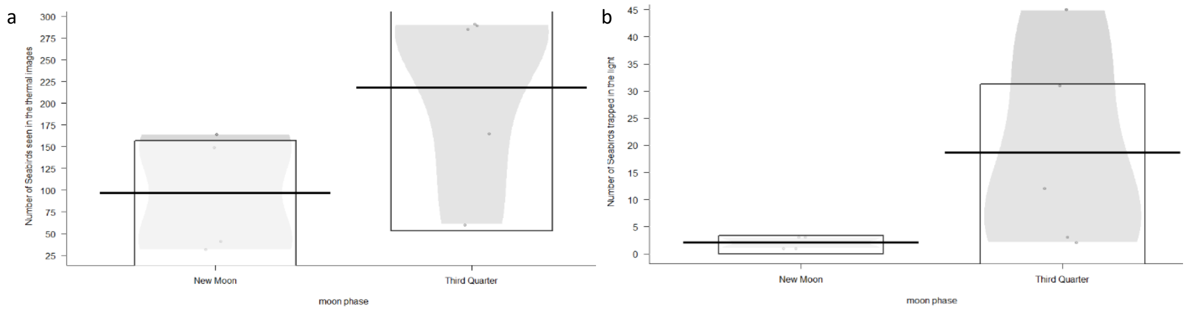


Figure 15. Boxplot showing the difference between moon phase for a) seabirds observed in thermal imagery and b) seabirds trapped by the light beam.

5.2.4 Lighting treatment

There was no difference in the number of birds seen in thermal imagery, ground observations or trapped when comparing all lights ($F_{3,24} = 0.461$, $p > 0.05$; Fig. 16) or the small LED lights only ($F_{3,5} = 0.02642$, $p > 0.05$; Fig. 17).

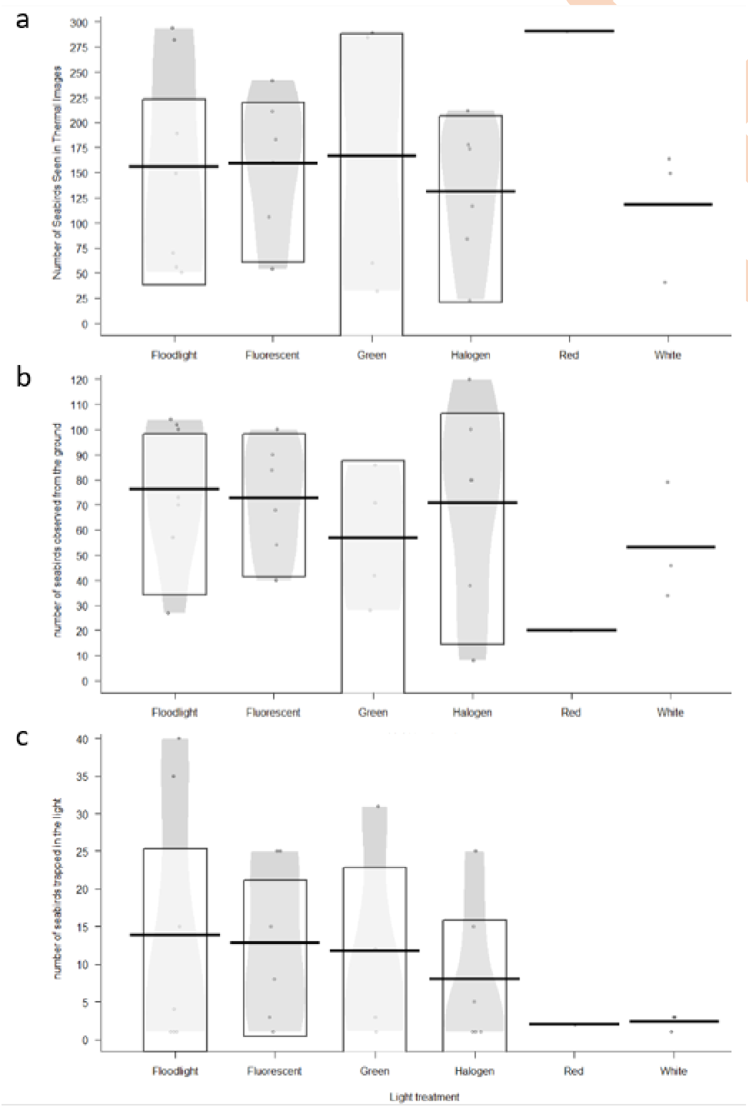


Figure 16. Boxplots showing the differences between light treatment – all lights for a) number of seabirds seen in thermal imagery, b) number of seabirds seen from the ground, c) number of seabirds trapped by the light beam.

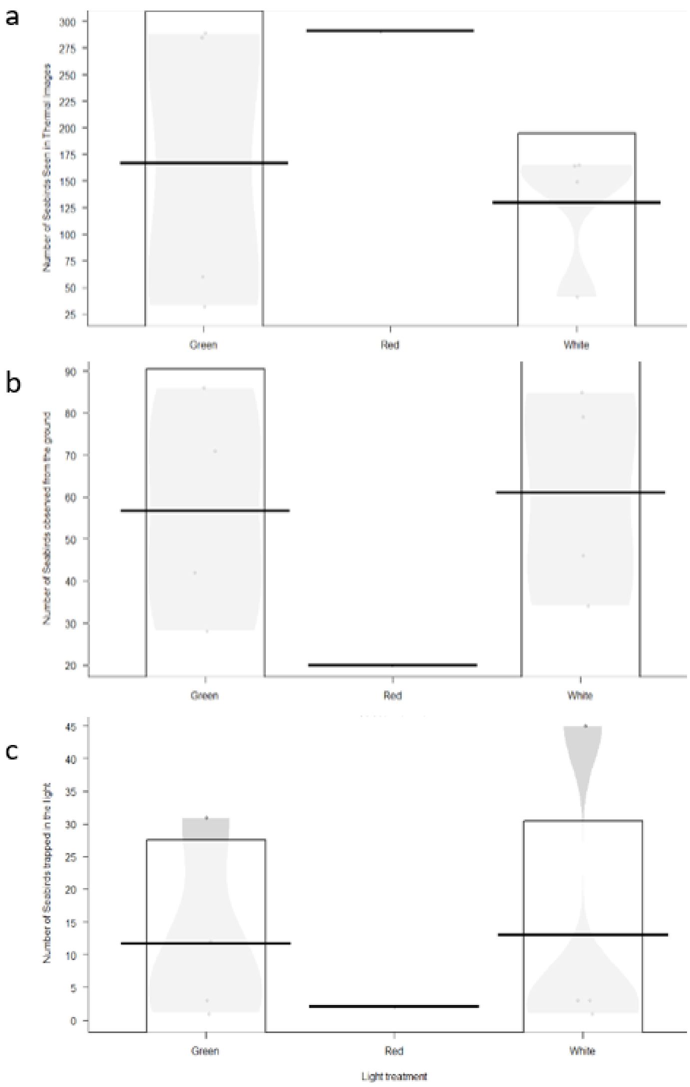


Figure 17. Boxplots showing the differences between light treatment – green, red and white LED's only for a) number of seabirds seen in thermal imagery, b) number of seabirds seen from the ground, c) number of seabirds trapped by the light beam.

5.2.5 Grounded birds

In total, eight of the light trials resulted in fifteen grounded birds (Table 4). Most groundings were on Pokohinu Burgess Island and most were during the flood LED treatment. Only one bird was observed on the ground at the end of the treatment, the grey-faced petrel (*Pterodroma gouldi*) on Pokohinu Burgess Island, the remainder took off unaided.

Table 4. Birds grounded by different light types on Pokohinu Burgess Island and Hauturu Little Barrier Island. (*) denotes the only bird observed on the ground following the treatment, the reminder took off unaided.

Light type	Species	Number of birds	Island	Moon phase	Grounding event
Flood LED	White-faced storm petrel	4	Burgess	Full moon	1
Flood LED	Not determined	2	Burgess	Third quarter	5
Flood LED	Cook's petrel	1	Hauturu	New moon	8
Fluorescent	Cook's petrel	1	Hauturu	New moon	7
Halogen	Not determined	2	Burgess	Third quarter	3
LED white	White-faced storm petrel	3	Burgess	Third quarter	2
LED white	Fluttering shearwater	1	Burgess	Third quarter	4
LED white	Grey-faced petrel*	1	Burgess	Third quarter	6

6 Discussion

This study aimed to test which colours and intensities of lights are least attractive to seabirds to minimise the impact of light-induced collisions in the Hauraki Gulf, a region of high seabird diversity. Modelling the seabird visual system showed how differently seabirds view artificial light which is crucial when aiming to reduce light-induced collisions near seabird islands in the region. There were some differences observed in seabird behaviour dependent on the moon phase and island and the potential reasons are discussed below.

This study faced several limitations. Firstly, and most importantly, different lenses on the thermal scope meant some of the thermal imagery was not easily comparable. This meant 35% videos were excluded from these initial analyses resulting in small sample sizes which likely influenced the results. Secondly, we could not tell what was happening outside of our study plot and whether a "distant light effect" was attracting birds from afar. Thirdly and unavoidably, the ground-based observations were more reflective of our human-visual system thus this was not the most robust measure of light attractiveness to seabirds, which is why we also used thermal imagery in this study. Fourthly, counts from the extensive thermal imaging videography was conducted by one person only (funded through a student grant), whereas the ideal would be to have at least three persons undertake the task and take means of the combined counts. We will look at repeating these counts before the contract ends.

6.1 Lighting characteristics and how they are perceived by seabirds

The differences in the lights' hue and brightness were not reflected in significant differences in seabird attractiveness to the light types. From a seabird perspective, the flood LED was more similar in hue to the halogen light than the white LED and the fluorescent light. This was surprising as from a human perspective the flood LED produced a whiter light more similar to the white LED and fluorescent lights than the halogen light which was more yellow. The flood LED was the brightest with the highest peak in the red spectrum, followed by the halogen and red LED lights. The visual modelling shows the red LED light is perceived by seabirds as bright, whereas from a human perspective the red LED was dimmer than both the green and white LED's. Ground-based observations saw considerably fewer seabirds during the red LED treatment (Figure 6b).

6.2 Seabird attraction to artificial light at night – behavioural experiment

6.2.1 Difference between islands

The observed difference in birds trapped in the light beam and observed through thermal imagery (small LED's only) between islands may have been due to the different species on each of the islands. A wider variety of seabird species were seen and heard on Burgess Island than on Hauturu where almost all birds observed were Cook's petrels. Of the fifteen bird groundings observed, thirteen birds grounded on Burgess Island and included several species.

DRAFT

White-faced storm petrels were the most common species observed on Burgess Island. Chicks of this species fledge in March-April, therefore, the individuals we observed would have been adult birds. While fledglings of many species are more attracted to artificial light than adults, this pattern appears untrue for storm-petrels as adults are more vulnerable to light-induced grounding than fledglings (Rodriguez & Rodriguez, 2009) which may explain why this species was observed so frequently. Frequent collision events of Cook's petrel and white-faced storm petrels, in addition to one black petrel (takoketai, *Procellaria parkinsoni*), were recorded for years after the lighthouse was installed on Burgess Island in the late 1880s (Sandager, 1890).

Similar to our results on Burgess Island, other examples of storm-petrel attraction to artificial light in New Zealand include several grey-backed storm petrels (takahikare-moana, *Garrodia nereis*) who were drawn to lights in Eglinton Valley and at Milford Sound 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). Kermadec storm petrels (*Pelagodroma albiclunis*) and Kermadec little shearwaters (*Puffinus kermadecensis*) have also been attracted to the lights of the Department of Conservation (DOC) base on the remote Rangitāhua Raoul Island, Kermadec Islands (CG).

In contrast to the white-faced storm petrels on Pokohinu Burgess Island, few New Zealand storm petrels (*Fregetta maoriana*, NZSP) were attracted to the lights on Hauturu Little Barrier Island. LED floodlights in conjunction with acoustic recordings of NZSP calls have been used to attract this species for a mark-recapture study on Hauturu Little Barrier Island (Ismar et al., 2015), therefore, NZSP may be more attracted to artificial light when combined with sound recordings than lighting alone or this difference may be due to contrasting population sizes between the species.

Common diving petrels are probably the species in the region most impacted by ALAN and frequently appear in deck strike records (e.g. Abraham & Richard, 2019; Glass & Ryan, 2013; Holmes, 2017). This species is common on Burgess Island and fledge in November - December. The experiment was carried out in late December and missed peak-fledging for common diving petrels. Had the experiment occurred several weeks earlier we would likely have observed more common diving petrel fledglings attracted to the lights on their maiden flight. An earlier trip to Burgess Island was not possible as the island was periodically closed to researchers for tītī harvesting but would be useful to look at in the future.

The majority of birds observed on Hauturu Little Barrier Island were Cook's petrels. Chicks of this species fledge in March-April, therefore, the individuals we observed would have been adult birds. Juvenile Cook's petrels are grounded by lights in Auckland city when travelling between the Hauraki Gulf and their foraging grounds on the west coast (Gaskin & Rayner, 2013). Poor record-keeping by bird rescue centres means little information is collected on when or where groundings occur making it difficult to pinpoint lighting hotspots. Three Cook's petrels grounded by streetlights in Green Bay, Auckland were reported to Birds NZ in April 2020 (I. McLean, pers comm, 9th May 2020) and were likely young birds due to the time of year. All three were predated before being found. Given the prevalence of Cook's petrel grounding in anecdotal evidence, it was surprising how few birds were trapped by the light

DRAFT

beam during this study. This was probably due to the abundance of adult birds which, in general, may have learned to avoid artificial light sources (Montevecchi, 2006) and lack of juveniles present during the experiment.

6.2.2 Difference between moon phases

More birds were trapped in the light beam and observed in thermal imagery (small LED's only) during the third quarter moon phase than during the new moon. This is in contrast to other studies where greater fallout occurred during the new moon for Newell's shearwaters (*Puffinus newelli*), Leach's storm-petrels (*Oceanodroma leucorhoa*), Manx shearwaters (*Puffinus puffinus*), Hutton's shearwater (Kaikōura tītī, *Puffinus huttoni*) and Cory's shearwaters (*Calonectris borealis*) (Deppe et al., 2017; Miles et al., 2010; Reed et al., 1985; Rodriguez & Rodriguez, 2009; Telfer et al., 1987).

Several suggestions have been made as to why light-induced collisions are generally reduced on moonlit nights. 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 (Rodriguez & Rodriguez, 2009). Our results may reflect the number of treatments per moon phase.

6.2.3 Seabirds observed for all light treatments

We predicted the greatest attraction would be to more intense lights, especially if they involved UV wavelengths. However, from the analyses done so far this was not the case, however, as no difference in the number of birds seen in thermal imaging, ground observations or trapped were observed considering the differences in brightness and colour contrast of the different lights from a seabird perspective. The only other experimental study that tested seabird attraction to different types of lights found 47% of short-tailed shearwater fledglings were grounded during the metal halide light treatment, followed by 29% for LED lights and 24% for HPS lights on Phillip Island, Australia (Rodríguez et al., 2017a). The authors went on to discuss how the orange light and narrower emission spectrum of HPS 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. HPS lights would be most similar in hue to the red LED in this study whereas metal halide is probably more like the flood LED or halogen light.

Of the fifteen bird groundings observed in our study, three birds grounded during both the flood LED and LED white treatments, followed by one each for halogen and fluorescent. No birds were observed grounding during the red or green LED treatments.

DRAFT

6.2.4 Seabirds observed for LED's (white, red, green)

Due to the global shift toward energy-efficient LED lights, we wanted to test whether the colours red or green were less attractive to seabirds than the standard white light. The lights tested were the same light except for different colour filters. Using LED's where blue light (400-490nnm) is filtered out, as with the red and green LED's in this study, is discussed as a key mitigation measure for light-induced collisions in nocturnal seabirds (Commonwealth of Australia, 2020; Longcore et al., 2018; Rodríguez et al., 2017a), in addition to shielding lights.

However, from the analyses done so far, we found no difference in the number of birds seen in thermal imaging, ground observations or trapped, likely due to our small sample sizes. In contrast, other studies have found red light or red filters were less attractive to birds. For example, red and yellow lights were less attractive to tropical shearwaters (*Puffinus bailloni*) on Réunion Island than green and blue lights (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). Fewer migrating songbirds at sea were attracted to a continuous red LED light than yellow, white, green or blue LED's but blinking lights of each colour were less attractive than their continuous counterpart (Rebke et al., 2019). One fisher pointed out during the vessel lighting surveys carried out as part of this project that using a green light when on anchor in the northern New Zealand region reduced deck strikes by 90% and red lights were similar (Anonymous, pers comm, Dec 22nd, 2019).

Red lights (headlamps) are now mandatory for seabird researchers working on offshore islands in the northern New Zealand region as they are found to be less disruptive to nocturnal seabirds at their breeding colonies. There is a marked difference in birds' behaviours in response to different hues, most extreme for bright white LED (CG).

DRAFT

7 CONCLUSION AND RECOMMENDATIONS

The results of this study provided insight into the visual system of a nocturnal burrow-nesting seabird like those in the Hauraki Gulf which helped us to understand which lights seabirds view as more, or less intense. Our experiments showed an equal statistical attraction to the light types we tested but provided anecdotal observations where more research and larger sample sizes are required (proposed work by PhD student Ariel Heswall). The land-based behavioural experiments have helped to refine the methodology for the upcoming vessel-based trials near seabird islands and further land-based behavioural experiments. The recommendations for the next phase of this project are as follows. Vessel-based behavioural experiments should:

- Increase the sample size for each light type.
- Omit the white LED as it was like other light types in both brightness and hue. This would allow for increased sample sizes of the other lights.

- Time experiments to coincide with common diving petrel peak fledging at the end of November. This species is frequently mentioned in deck-strike literature and targeting a high-density period could help to determine the attractiveness of the different lights to a locally abundant and vulnerable species.
- Position the thermal scope beneath the lighting set-up pointing skyward to achieve a greater range of view.
- Time experiments to incorporate a greater range of moon phases as this is an important factor influencing artificial light attraction in seabirds.

8 REFERENCES

Abraham, E., & Richard, Y. (2019). Estimated capture of seabirds in New Zealand trawl and longline fisheries, to 2016–17. *New Zealand Aquatic Environment and Biodiversity Report, 226*, 85.

Atchoi, E., Mitkus, M., & Rodríguez, A. (2020). Is seabird light-induced mortality explained by the visual system development? *Conservation Science and Practice*, e195.

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

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

Commonwealth of Australia. (2020). *National Light Pollution Guidelines for Wildlife Including marine turtles, seabirds and migratory shorebirds*. Commonwealth of Australia Retrieved from https://www.environment.gov.au/biodiversity/publications/national-light-pollution-guidelines-wildlife

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.

Department of Conservation. (2019). Cruise ships protecting seabirds [Press release]. Retrieved 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*.

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. In: The Royal Forest & Bird Protection Society of New Zealand.

DRAFT

Gaskin, C., & Rayner, M. J. (2013). *Seabirds of the Hauraki Gulf: natural history, research and conservation*.

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.

Hart, N. S. (2004). Microspectrophotometry of visual pigments and oil droplets in a marine bird, the wedge-tailed shearwater Puffinus pacificus: topographic variations in photoreceptor spectral characteristics. *Journal of Experimental Biology, 207*(7), 1229-1240.

Håstad, O., Victorsson, J., & Ödeen, A. (2005). Differences in color vision make passerines less conspicuous in the eyes of their predators. *Proceedings of the National Academy of Sciences, 102*(18), 6391-6394.

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. In. Wellington, New Zealand: Department of Conservation.

Holveck, M.-J., Grégoire, A., Guerreiro, R., Staszewski, V., Boulinier, T., Gomez, D., & Doutrelant, C. (2017). Kittiwake eggs viewed by conspecifics and predators: implications for colour signal evolution. *Biological Journal of the Linnean Society, 122*(2), 301-312.

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

Ismar, S. M., Gaskin, C. P., Fitzgerald, N. B., Taylor, G., Tennyson, A., & Rayner, M. (2015). Evaluating on-land capture methods for monitoring a recently rediscovered seabird, the New Zealand Storm-Petrel Fregetta maoriana. *Marine Ornithology, 43*(2), 255-258.

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.

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.

Maia, R., Eliason, C. M., Bitton, P. P., Doucet, S. M., & Shawkey, M. D. (2013). pavo: an R package for the analysis, visualization and organization of spectral data. *Methods in Ecology and Evolution, 4*(10), 906-913.

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.

DRAFT

Miskelly, C. M., Stahl, J.-C., & Tennyson, A. J. D. (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 from https://www.nzherald.co.nz/nz/news/article.cfm?c_id=1&objectid=12057912

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

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.

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.

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.

Rodriguez, 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).

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

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.

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.

DRAFT

Vorobyev, M., & Osorio, D. (1998). Receptor noise as a determinant of colour thresholds. *Proceedings of the Royal Society of London. Series B: Biological Sciences, 265*(1394), 351-358.

Whitehead, E., Adams, N., Baird, K., Bell, E., Borelle, S., Dunphy, B., . . . Russell, J. (2019). Threats to seabirds of northern Aotearoa New Zealand.

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.

DRAFT