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Why did they die? Analysing the cause of death of grounded seabirds lodged at an avian rescue centre in Auckland, New Zealand

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Abstract: Procellariiform seabirds are vulnerable to numerous threats, including the growing issue of urban light pollution. Seabirds that are found grounded are often treated by avian/wildlife rehabilitation centres, but approximately 30% do not survive. Here, we necropsied 19 grounded Cook's petrels (tītī, *Pterodroma cookii*) that did not survive and report the cause of death and injuries. We also investigate potential risk factors, including association with light pollution, seabird sex, age, and sensory features. We found that a 70% of Cook's petrels had head trauma, internal bleeding, and/or wounds as the main causes of death ($p > 0.05$). These injuries are consistent with collisions, likely due to disorientation from light pollution. Most Cook's petrels were not stressed or in poor body condition, suggesting Cook's petrels are typically healthy before being affected by lights. In the sample of Cook's petrels studied, mortality was significantly biased towards young and male seabirds. Despite this apparent sex difference in collision risk, there was no detectable sex difference in measured sensory features, e.g. males did not have significantly larger eyes than females. The potential sex bias in death suggests male seabirds could be more vulnerable to light pollution, which warrants further research. Further research is also required to determine whether individual differences in sensory features relate to grounding risk, as our study only included a subset of dead seabirds. We also recommend that all grounded seabirds are taken to rehabilitation centres rather than released immediately.

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INTRODUCTION

Artificial light at night (ALAN) or light pollution, a by-product of human urban development, is a growing concern for many animal species as it affects different aspects of behaviour and migration patterns (Lorne & Salmon 2007; Eisenbeis *et al.* 2009; Bocetti 2011; Rodríguez *et al.* 2017b; Van Langevelde *et al.* 2017; Hudecki & Finegan 2018). In particular, natural and anthropogenic factors threaten seabirds, including light pollution (Croxall *et al.* 2012; Dias *et al.* 2019).

Sensory ecology is the study of how an animal interacts with its environment using its sensory features, such as vision and olfaction and can be used to mitigate threats to seabirds (Madliger 2012; Friesen *et al.* 2017). Sensory ecology could also be used to understand light attraction in seabirds. ALAN interacts with the seabird's sensory ecology, and as a result, seabirds may become disorientated and attracted to lights causing them to land and become grounded (Rodríguez *et al.* 2015; Rodríguez *et al.* 2017a; Heswall *et al.* 2022). Fledgling seabirds are especially at risk, potentially due to underdeveloped vision from a lack of exposure to visual information while underground (Mitkus *et al.* 2018; Atchoi *et al.* 2020).

Records of seabird groundings are widespread, spanning locations such as Hawai'i (Telfer *et al.* 1987; Rodríguez *et al.* 2015), Canary Islands (Rodriguez & Rodriguez 2009), Maltese Islands (Laguna *et al.* 2014), Canada (Wilhelm *et al.* 2021), the United Kingdom (Syposz *et al.* 2018), and New Zealand (Deppe *et al*. 2017; Whitehead *et al.* 2019; Fischer *et al*. 2021). Once a seabird is grounded, the likelihood of mortality may increase, with susceptibility to predators, starvation, dehydration, and mammalian predator control traps (Imber 1975; Blight & Burger 1997; Darby & Dawson 2000; Troy, Holmes & Green 2011; Merkel & Johansen 2011; Rodriguez *et al.* 2012; Rodriguez *et al.* 2014). Furthermore, recent seabird studies have reported bleeding and brain damage from colliding with anthropogenic structures (Travers *et al.* 2021; Coleman *et al.* 2022).

Auckland (Tāmaki Makaurau) (36.8509°S, 174.7645°E) is a large New Zealand (Aotearoa) city (1.4 million people), geographically located next to one of the world's most important seabird hotspots (Barbera 2012; Gaskin & Rayner 2013; Whitehead *et al.* 2019). The Hauraki Gulf (1.2 million hectares) is in the north of the New Zealand North Island (Te Ika-a-Māui) and is home to approximately 27 native and endemic seabird species (Barbera 2012; Gaskin & Rayner 2013; Whitehead *et al.* 2019). In Auckland, the associated light pollution from the city likely threatens marine and terrestrial native ecosystems (McNaughton *et al.* 2021). Seabird groundings correlate significantly with Auckland city's lighting, with more seabirds grounded near brighter locations (Heswall *et al*. 2022).

Many seabirds that breed on the islands of the Hauraki Gulf, including Cook's petrels (tītī, *Pterodroma cookii*), must fly over Auckland to reach foraging grounds in the Tasman Sea (Gaskin & Rayner 2013). The risk to seabirds is further intensified because the region is rich in breeding sites and colonies and is especially rich in burrow-nesting procellariiforms (Gaskin & Rayner 2013; Whitehead *et al.* 2019). Due to the differences in visual development, burrow-nesting procellariiforms are highly sensitive to ALAN (Atchoi *et al.* 2020), and especially at risk of disorientation and collision with infrastructure (Rodríguez *et al*. 2019). For example, in 2018 a major ALAN incident occurred when 64 Buller's shearwaters (*Puffinus bulleri*) and four flesh-footed shearwaters (*Ardenna carneipes*), were attracted by vessel lights and grounded on a cruise ship near Little Barrier Island/Te-Hauturu-O-Toi in the Hauraki Gulf (Morton 2018).

Cook's petrel, a burrow-nesting procellariiform, is especially affected by light pollution (Heswall *et al.* 2022). This species breeds on the east side of the Auckland Isthmus, on Te-Hauturu-O-Toi and Great Barrier Island/Aotea, but must cross the city to reach their foraging grounds in the Tasman Sea (Gaskin & Rayner 2013; Heswall *et al.* 2022). During their flight over Auckland city, they are exposed to light pollution and are sometimes found grounded (Heswall *et al.* 2022).

Rehabilitation is very important for the conservation of seabirds; many are injured from bycatch, pollutants, and light pollution (Montesdeoca *et al*. 2017; Costa *et al.* 2021). A study in Portugal showed that over 2000 seabirds were admitted into a rehabilitation centre over a seven-year period (Costa *et al.* 2021). Another study in Spain showed that ~1,900 seabirds were admitted into a rehabilitation centre in a ten-year period (Montesdeoca *et al*. 2017). In Auckland, when birds are found grounded or injured, they are often taken to BirdCare Aotearoa, a Department of Conservation permitted avian rehabilitation centre. The centre received 184 grounded Cook's petrels from 2020 to 2022 (The Wild Neighbours Database Project 2021). Almost 70% of these Cook's petrels survived and were released, but approximately 30% died due to injuries (Table 1). Understanding the cause of death will help us determine whether light pollution-related collisions and injuries are important sources of mortality and improve our understanding of the impact of ALAN on seabirds.

Here we document and analyse the types of injuries and the likely cause of death of the Cook's petrels taken to BirdCare Aotearoa that did not survive. We determine whether their injuries are likely associated with light pollution events, i.e. collisions with anthropogenic structures. We did not include seabirds which died from other causes such as animal or fisheries interaction. We also determine whether some individual characteristics may increase the risk of death, such as sex, age, and size of sensory features.

MATERIALS AND METHODS

This research was conducted at BirdCare Aotearoa. Established in 2009 and located in Green Bay, Auckland, New Zealand, this rehabilitation centre receives ~6,500 native and non-native avian patients each year (The Wild Neighbours Database Project 2021). From January 2020–December 2021, of those Cook's petrels that died (N = 56), 19 individuals were kept frozen for study (The Wild Neighbours Database Project 2021).

Study species

For this study, we focussed on Cook's petrels, the procellariiform most commonly admitted to BirdCare Aotearoa (184 Cook's petrels were found during 2020–2021 compared to 29 grey-faced petrels; Table. 1). Procellariiformes are the seabird group most often associated with groundings due to light pollution (Telfer *et al.* 1987; Rodríguez *et al.* 2015; Heswall *et al*. 2022). Grounded Cook's petrels were found along urban areas near streetlights, roads, and buildings (The Wild Neighbours Database Project 2021). We did not include individuals that had been found injured during an animal or a fisheries interaction, i.e. hook in bill, so we just focused on those found grounded.

Table 1. Seabird species, including their population sizes and the numbers admitted to BirdCare Aotearoa (2020–2021) and those which survived and were released. [1] Taylor & Gaskin 2013, [2] Miskelly 2013, [3] Taylor 2013a, [4] Taylor 2013b, [5] Bell 2013, [6] Sagar 2013, [7] Southey 2013, [8] The Wild Neighbours Database Project 2021.

Common Name	Latin	Te Reo Māori	Population size in New Zealand	Numbers admitted to rehab centre [8]	% survived [2]	Number of birds used in this study
White-faced storm petrel	*Pelagodroma marina maoriana*	Takahikare	>1,000,000 [7]	5	50	-
Grey-faced petrel	*Pterodroma gouldi*	Ōi	~300,000 [4]	29	54.6	-
Cook's petrel	*Pterodroma cookii*	Tītī	>300,000 [1]	184	69.9	19
Fairy prion	*Pachyptila turtur*	Tītī wainui	>8,000,000 [2]	3	0	-
Grey petrel	*Procellaria cinerea*	Kuia	~100,000 [5]	1	0	-
Sooty shearwater	*Ardenna grisea*	Tītī	>20,000,000 [6]	4	0	-
Flesh-footed shearwater	*Ardenna carniepes*	Toanui	<24,000 [3]	2	0	-

Preparation

Necropsies on 19 individual Cook's petrels (Table 1) were performed from January to May 2022. Specimens were stored in freezers at approximately -20°C and defrosted before dissections. First, we conducted an external examination of the body, assessing the overall body score from 1 to 5 based on pectoral muscle mass (Fig. 1). For this study, we used the body score conditions (Fig. 1) used by the veterinarians at BirdCare Aotearoa as a proxy of bird health (Kaytee n.d.). Age recorded was based on plumage condition and categorised as either juvenile – fresh feathers and no evidence of moult, or adult – frayed feathers at various moult stages (Spear *et al.* 1995). Any external injuries, whether deep or superficial, including bruises and broken or dislocated limbs were recorded as wounds (Table 2). We conducted necropsies starting from the head and working toward the distal end of the body.

On completion of external examinations, the head was examined for trauma. We classified head trauma as any bruising or bleeding to the head and/or brain (Table 2). Morphometric measurements including the skull length - from the Supraoccipital to the end of the nasal, the skull width – from the left extended part of the Squamosal to the right extended part of the Squamosal, and the depth – from the top of the Frontal to the base of the Basioccipital, were taken using digital callipers (mm). Eyeball volume was calculated according to the equation:

$$\text{Eyeball volume (cm}^3) = 2 * 1.33\pi a^2 b$$

Used to calculate the volume of an oblate spheroid (Garamszegi *et al.* 2002; Martínez-Ortega *et al.* 2014), where a represents the equatorial (largest) radius, and b represents the polar (smallest) radius.

Specimens were then dissected by means of a transverse incision below the rib cage and opened through lateral incision to access the internal

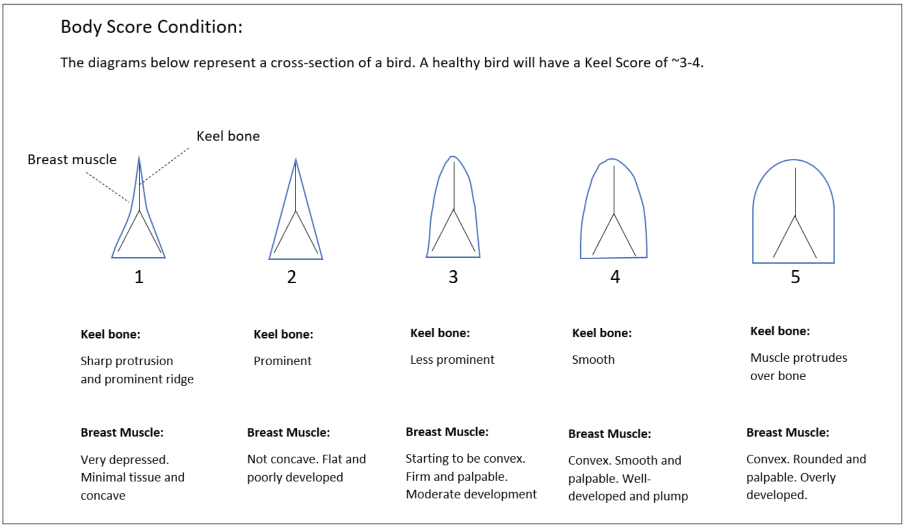

Figure 1. Description of the different body score conditions used to assess overall Cook's petrel (*Pterodroma cookii*) health. Ventral view of the keel (inner, black straight lines) and pectoral/breast muscle (blue outer perimeter lines), greater muscle mass indicates better condition.

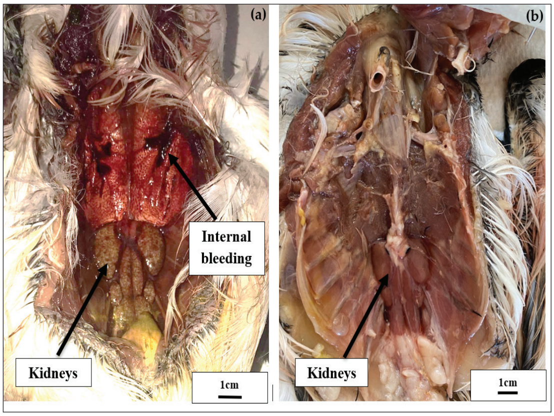

Figure 2. Image of (a) kidney failure and internal bleeding compared with (b) functional kidney and no internal bleeding from Cook's petrel (*Pterodroma cookii*) necropsies. Arrows indicate the location of kidneys and internal bleeding. Image credits: Agustina Dominguez.

organs. Lifting the skin (epidermis and dermis) allowed assessment of any bruises on the pectoral muscles. Lateral cuts on the ribcage were used to enter the cavity and evaluate the internal organs. Any punctures or internal bleeding were recorded (Fig. 2).

We inspected each organ internally and then removed it to assess it for abnormalities in shape and colour. We first examined the liver and the gastrointestinal (GI) system. The GI system was then removed by means of cutting the mesenteries, and each part was cut open to reveal the contents. We also recorded gut contents, identifying any unusual items such as plastics and parasites. The heart was examined for external abnormalities. We removed the heart from the connecting arteries and veins and dissected it to check for internal parasites. We then examined and removed the lungs and kidneys. If the kidneys, heart, or liver were discoloured and/or calcified, we classified that as stress (L. Miller *pers. comm.* 17 February 2022) (Table 2; Fig. 2). Birds were sexed by inspecting the gonads.

Statistical Analysis

Statistical analysis was carried out using R Studio version 4.2.1 (RStudio Team 2020). We used both the Chi-squared test as well as general linear models with Poisson distribution. We used both these tests to determine which type of injury was more prevalent, if body score condition was related to death, and if there was a sex and age bias in mortality numbers.

To test for any correlations between sensory ecology (absolute and relative eyeball volume) and the age and sex group, we used general linear models with Poisson distribution. The packages we used included 'ggplot2' (Wickham 2011) and 'tidyverse' (Wickham *et al.* 2019).

Table 2. Description of each category of injury for Cook's petrel (*Pterodroma cookii*).

Injury	Description
Head Trauma	bruising or bleeding to the head and brain
Internal bleeding	bleeding found inside the internal cavity
Wounds	fractures, cuts, punctures, open wounds, dislocations
Long term stress	emaciation and abnormal discolouration and/or calcifications of the liver, kidney or heart, and parasites

RESULTS

Cause of death

Grounded seabirds generally had four types of injuries (Table 2), and some seabirds displayed more than one category of injury (Fig. 3a,b). 7% of Cook's petrels showed signs of a combination of head trauma, internal bleeding, and wounds, while 17% displayed only internal bleeding with no other injuries (Fig. 3a). All four categories of injuries were equally common ($p > 0.05$; Appendix 1). 70% of seabirds had collision-related injuries such as head trauma, wounds, internal bleeding, or a combination of all three (Fig. 3a,b). However, 17% of seabirds in this study had signs of stress, with 3% having a combination and stress and internal bleeding (Fig. 3a,b).

Body score

Body score condition was not significantly related to death as roughly half of the seabirds that died were in good condition (3–5 body score) at death (body score condition of 3, $p = 1$; body score condition of 4, $p = 0.219$). This suggests that pre-existing poor health before being grounded was not the main driver of mortality (Fig. 4a; Appendix 2).

Sex and Age

There was a significant difference between sexes, with more males identified in the necropsies ($n = 12$) compared to females ($n = 3$) (GLM; $p < 0.057$; Appendix 3; Fig. 4b). This result was replicated using Chi-squared test ($\chi 2 = 6.107$, df = 1, $p = 0.013$).

All 19 Cook's petrels necropsied were juveniles (GLM; $p < 0.048$; Appendix 4; Fig. 4b). As above, this result was replicated using a Chi-squared test ($\chi 2 = 19$, df = 1, $p < 0.0001$).

Visual sensory features

There was no significant difference between absolute and relative eyeball volume between sexes and age groups ($p > 0.05$; Appendix 5). The average absolute eyeball volume was 29.27 cm^3 (± 0.9 cm^3), and the average relative eyeball volume was 0.95 cm^3 (± 0.159) (Appendix 6).

DISCUSSION

The majority of Cook's petrels found grounded in Auckland city, and that later died in rehabilitation had head trauma and internal bleeding.

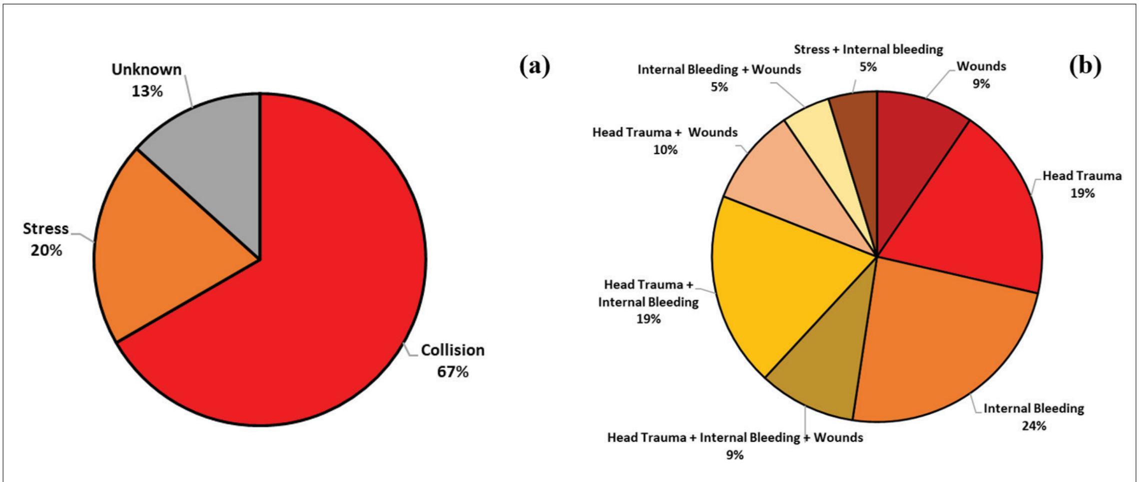

Figure 3. Cause of death and injuries which are collision-related, stress-related and unknown for each Cook's petrel (*Pterodroma cookii*) (a), and the percentage of the categories of collisional-related injuries (b).

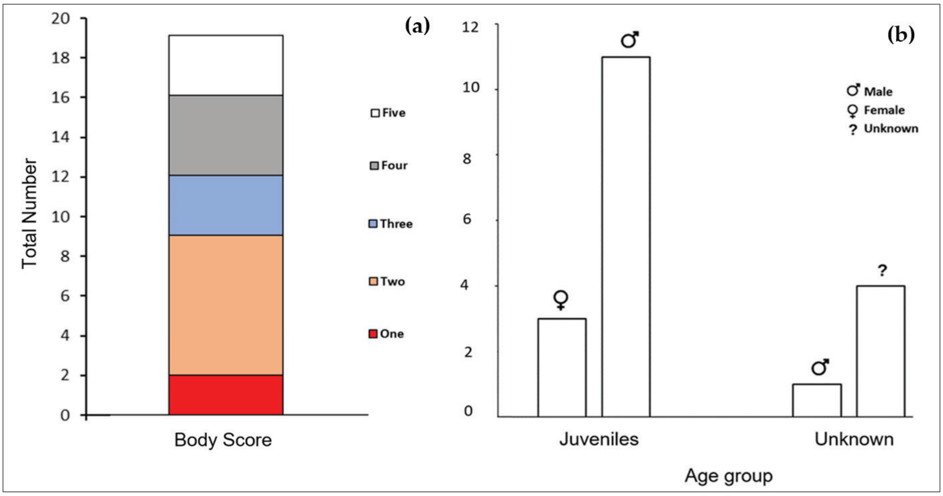

Figure 4. (a) The body score, and (b) the sex and age group of the 19 Cook's petrels (*Pterodroma cookii*) used in this study.

These are injuries consistent with collisions rather than other threats such as fisheries bycatch. Our results support previous research, which found that grounded seabirds in other parts of the world typically have injuries associated with collisions from anthropogenic structures due to disorientation by lights (Travers *et al.* 2021; Coleman *et al.* 2022).

Body Score and stress

We did not find any associations between mortality and body condition scores, indicating that seabirds are not necessarily stressed or in poor condition prior to being affected by ALAN. Indeed, a study on short-tailed shearwaters (*Ardenna tenuirostris*) showed that the fledglings grounded by light pollution often had a better body condition than those that were beach wrecked (Rodriguez *et al.* 2017a). Another study researching a variety of other seabird species also noticed this trend (Cuesta-García *et al.* 2022). We do not have any data on the body score condition for seabirds which survived and were released by BirdCare Aotearoa or for seabirds that were never grounded, limiting our ability to contrast recovered and dead bird body condition. Collecting such data in the future would facilitate comparisons of those that died and those that were released.

Only 17% of the seabirds in this study had signs of long-term stress. A potential cause of this could be a lack of food, which can affect seabird survival and breeding cycles. This has been studied in seabirds, including the little blue penguin (*Eudyptula minor*), and yellow-eyed penguin (*Megadyptes antipodes*) where both studies showed that prey availability influenced survival (Perriman *et al*. 2000; Muller *et al.* 2022). Although the vast majority of seabirds had collision-related injuries rather than signs of long-term stress, stress was evident in some of the seabirds. Therefore, it may be beneficial in the long term to study why seabirds experience stress and ways to potentially mitigate this.

Sex and age

We found that juvenile males were the most likely to be fatally injured. This illustrates that sex and age are contributing factors to collision death. There have been sex and age differences recorded in seabird foraging patterns, migratory patterns, and bycatch numbers (Taylor *et al.* 2002; Deakin *et al.* 2019; Beck *et al.* 2021; Schultz *et al.* 2021). For example, in northern gannets (*Morus bassanus*), breeding females tended to forage further offshore compared to breeding males (Stauss *et al.* 2012; Lewis *et al.* 2022), and a difference in timing of departure between male and female northern gannets has also been described (L. Miller *pers. comm.* 23 March 2023). However, to our knowledge, there has been no record in the literature of a seabird sex bias for light attraction. The only other study that examined sex in relation to ALAN found no sex bias in Cory's shearwater (*Calonectris borealis*) (Rodríguez *et al*. 2012). Our results may be the first record of a potential sex bias for seabird mortality in New Zealand from light pollution. This sex bias could be a result of differences in behaviour and migratory patterns between males and females. However, there is little research on Cook's petrel life history, indicating that more research is required.

Regarding age differences, it is relatively well-established that fledglings are more susceptible to light attraction, especially during their first flights (Telfer *et al.* 1987; Rodriguez *et al.* 2014; Deppe *et al.* 2017; Travers *et al.* 2021). Fledglings are inexperienced but potentially curious (Telfer *et al.* 1987; Isangedighi *et al.* 2020), which could result in their attraction to, and disorientation by lights, leading to a higher chance of collision and injuries. Our findings corroborate this as many juvenile fledglings, especially Cook's petrel fledglings, were admitted to the rehabilitation centre. Recent studies in Gran Canaria Island, Spain, recorded that the majority of seabirds admitted were because of light pollution and that many were juveniles (Montesdeoca *et al.* 2017). We report for the first time in New Zealand that there was a greater proportion of juvenile Cook's petrel with fatal injuries compared to adults since no adults were found from our necropsies of the Cook's petrels.

Sensory features

Although we found age and sex differences in mortality, there was no difference in the size of the visual organs according to age and sex. Thus, any differences in the attraction rates or risk of mortality are unlikely to be due to age or sex differences in the size or sensitivity of the seabirds' visual or sensory organs. Further research is required to compare the visual capacity of seabirds grounded by light pollution and those which were not grounded by light pollution.

Across species, the number of groundings from light pollution could be related to species differences in sensory features (Heswall *et al*. 2022). This could be because those with larger eyeball volumes relative to their body size have a greater visual capacity to be attracted to the lights (Kiltie 2000). Therefore, seabird species with larger eyeballs could be more likely to be disorientated and collide with buildings and/or land on the ground. Similarly, a study on bycatch numbers has shown that seabird species with larger sensory features, such as a larger eye socket volume relative to their body size, were more likely to be attracted to fishing vessels and become bycatch (Heswall *et al.* 2021).

Rehabilitation

Our study highlights the importance of rehabilitation centres in mitigating the effects of these threats and risks to wildlife such as seabirds (Lalas *et al*. 2023). These organisations offer the possibility of helping individuals in distress, in this case, grounded seabirds attracted by anthropogenic light pollution (Rodriguez *et al.* 2017b; Heswall *et al.* 2022). It also highlights the importance of admitting seabirds to rehabilitation centres for health assessments and care. This is because if some seabirds are not assessed, they could be released with injuries which could reduce their chances of survival. Furthermore, these centres provide resources and data for future studies to explore the impact of threats to seabirds and other species.

Conclusion

In conclusion, our results show that a large majority of grounded seabird deaths were due to injuries associated with collisions. Many of these seabirds were healthy outside of collision injuries, suggesting that collisions with anthropogenic structures due to disorientation from light pollution are an important source of mortality. This research is one of the first studies in Auckland and Aotearoa to describe the injuries of seabirds from light pollution, and the effects of age and sex. Since all of these Cook's petrels in this study were fledglings, once a year during the fledging season (March-May), turning off non-essential lights could potentially minimise risks to seabirds. Furthermore, it confirms the necessity of bringing all grounded seabirds to rehabilitation centres rather than releasing them immediately as they could have underlying trauma, which upon immediate release, could be fatal.

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Appendix 1. Output of the general linear model where the predictor variable are 'Injuries' and the base category is the 'wounds' group. The response variable is the number of each 'Injury' group. Bold and * indicates significance.

Injuries	Estimate	Std. Error	Z value	P value
Head Trauma	0.47	0.570	0.824	0.409
Internal Bleeding	0.47	0.570	0.824	0.409
Long term stressor	0.00	0.632	0.000	1.000

Appendix 2. Output of the general linear model where the predictor variable is the 'body score' and the base category is the 'five' group. The response variable is the number of each 'body score' group.

Variable	Estimate	Std. Error	Z Value	P value
One	2.88E-01	7.64E-01	0.377	0.706
Two	-4.06E-01	9.13E-01	-0.44	0.656
Three	-1.46E-16	8.17E-01	0	1
Four	8.47E-01	6.90E-01	1.228	0.219

Appendix 3. Output of the general linear model where the predictor variable is sex and the base category is 'unknown' sex group. The response variable is the number of each sex group. Bold and * indicates significance.

Variable	Estimate	Std. Error	Z Value	P value
Sex – Male	1.098	0.577	-0.377	**0.057 ***
Sex – Female	-0.287	0.763	-0.377	0.706

Appendix 4. Output of the general linear model where the predictor variable is the 'Age' and the base category is the 'unknown' age group. The response variable is the number of each 'Age' group. Bold and * indicates significance.

Variable	Estimate	Std. Error	Z Value	P value
Age – Adult	-19.368	4356.881	-0.004	0.996
Age – Juvenile	1.029	0.521	1.976	**0.048 ***

Appendix 5. Output of the general linear model where the predictor variable is both 'sex' and 'age' and the base category is 'unknown' group. The response variable is the absolute and relative eyeball volume.

	Absolute eyeball volume				Relative eyeball volume			
Variable	Estimate	Std. Error	T value	P value	Estimate	Std. Error	T value	P value
Sex – Female	-6.278	5.7836	-1.085	0.296	-0.194	0.206	-0.948	0.359
Sex – Male	-0.944	4.983	-0.018	0.852	-0.076	0.177	-0.428	0.675
Age – Juvenile	2.691	4.675	0.576	0.574	0.153	0.166	0.919	0.374

Appendix 6. Morphological and sensory measurements of the 19 juvenile Cook's petrels used in the necropsies.

Variable	Mean	Standard Deviation	Standard Error
Skull length (mm)	68.83	7.59	0.91
Skull width (mm)	36.68	53.68	8.86
Skull depth (mm)	21.09	1.86	0.40
Bill length (mm)	28.38	1.27	0.24
Bill depth (mm)	6.67	0.45	0.17
Bill width (mm)	8.98	0.95	0.32
Wing length (mm)	231.07	8.11	0.53
Eyeball volume (cm^3)	29.27	4.57	0.85
Relative eyeball volume (cm^3)	0.95	0.16	0.16