The Pathway ahead for hoiho
Te ara whakamua

Impacts on hoiho:
Literature review and recommendations

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IMPACTS ON HOIHO:
LITERATURE REVIEW AND RECOMMENDATIONS

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Whakataukī
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Whakataukī means proverb.
The Southern Ocean is the marae of hoiho.

The Yellow-eyed Penguin Trust has endeavoured to capture and reference faithfully the work of others up until February 2018 in this document, and acknowledges that not every research finding will be included.

This report is a living document intended to support hoiho species work, and provide scientific information to enable optimal species management, highlight potential research options and inform policy and strategy.

Acknowledgements | He mihi:

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EXECUTIVE SUMMARY | HE WHAKARĀPOPOTOTAKA

Yellow-eyed penguins / hoiho cross the boundaries of terrestrial and marine ecosystems and as such are exposed to a diverse range of stressors (Trathan et al. 2015). Terrestrial threats to hoiho are well known and their impacts relatively well studied. Threats in the marine system are less well understood, and due to the complexity of the environment, their impact on hoiho is harder to resolve conclusively. Hoiho are reliable indicators of local environmental conditions and human induced changes (e.g. pollution and overfishing) because they are long-lived, mobile predators, and central place foragers.

The cumulative impact of threats in the marine and terrestrial environments may make hoiho less resilient to additional impacts. Interactions between impacts, particularly when one confounds the other, make it more difficult to disentangle and separate issues. Determining the exact role of each impact, and quantifying the effects in terms of breeding or foraging success, or survival for hoiho can be problematic. It is increasingly being recognised that an ecosystem approach is required to fully understand the impacts; as populations decline and fragment, and ecosystem diversity decreases, so too does an ecosystem's resilience to future impacts (Elmqvist et al. 2008).

We are at a critical point where hoiho on the mainland are subject to an ongoing serious decline in abundance. Unabated, this decline has the potential to result in the functional extinction of hoiho on Otago Peninsula by 2060 or sooner (Mattern et al. 2017). To stem the decline and turn around the fate of these birds we must act quickly. In the short-term, focus needs to be on the survival of individual birds, particularly breeding females, to ensure that we have a future population. Longer-term our focus must shift to addressing and eliminating as many of the marine impacts as we can whilst continuing to manage and remove terrestrial stressors.

TERRESTRIAL IMPACTS | KĀ PĀKA UTA

Hoiho use specific land areas around the coast for nesting and roosting, particularly in Otago, Southland and the sub-Antarctic. Terrestrial stressors continue to impact hoiho if they are not managed effectively. Predation events from a suite of terrestrial predators (including mustelids, pigs, dogs and cats) are often sporadic (Moller et al. 1995). Hoiho chicks are particularly vulnerable to predation 5-20 days after hatching (Darby & Seddon 1990) and unguarded eggs may result in predation attempts.

Historical habitat degradation through large-scale clearance and fragmentation of coastal forest was thought to be a major impact (Roberts & Roberts 1973; Smith 1987), but whilst the changing landscape has likely influenced their nesting habits, hoiho are able to breed successfully in highly modified environments (McKay et al. 1999). Large grazing stock (e.g. cattle) have the potential to trample nest sites and hoiho (particularly chicks) (Marchant & Higgins 1990). The introduction of roads adjacent to penguin habitat comes with a heightened risk of injury and mortality from vehicles.

Tourism (particularly that which is unregulated) causes disturbance at breeding areas negatively affecting energy budgets, fledgling weight and probability of survival (McClung et al. 2004; Ellenberg et al. 2007). Short-term human disturbance causes an increase in corticosteroid levels and heart rate of hoiho (Ellenberg et al. 2007; 2013). Duration of human presence was the most important factor, and elevated rates were sustained while a person remained within sight (Ellenberg et al. 2013). Unsurprisingly, capture and handling for research and monitoring caused the highest elevation in heart rate and longest recovery times (Ellenberg et al. 2013); although no long-term negative effects were associated with investigator disturbance (Goldsworthy et al. 2016; Stein et al. 2017a). Associated recreation activities such as trail- or quad-biking, horse-riding, dog walking or driving across penguin habitat can be particularly high risk.

Infectious diseases and parasites may compromise the survival of individual penguins or at worst can cause mass mortality events (Grimaldi et al. 2015a). Avian cholera (de Lisle et al. 1990; Leotta et al.

2006; Cooper et al. 2009), avian pox (Munro 2006; Pistorius 2009) and Newcastle disease virus (MacDonald & Conroy 1971; Pierson & Pfow 1975) have all been implicated in mass mortality events in penguins. Disease can be opportunistic if the immune system is suppressed and has the potential to become a bigger issue in the future, as the climate warms, food is reduced and human disturbance and stress on penguin populations' increase. Disease can be especially problematic at rehabilitation facilities where birds live in close quarters. Frequent outbreaks of diphtheric stomatitis in wild hoiho cause the death of young chicks, and outbreaks are more regular and severe on the Otago Peninsula and in North Otago (Alley et al. 2017). Avian malaria is of current concern for hoiho, likely due to an increase in insect vectors, and has the potential to seriously affect hoiho populations.

Fire can be locally catastrophic; a scrub fire was responsible for the mortality of more than 60 adult hoiho at a reserve in the Catlins in 1995 (Sutherland 1999). Risk of fire increases with a warming climate due to high temperatures and strong winds.

The specific demographic makeup of a population (e.g. sex, age, breeding status) becomes increasingly important as a population declines and has a significant influence on the ability of that population to increase. Small populations with restricted ranges, particularly ones that have suffered additional anthropogenic impacts, are more likely to experience demographic issues.

MARINE IMPACTS | KĀ PĀKA KI TAI

Hoiho use coastal waters for foraging and thus overlap with human activities in the coastal zone up to 50km offshore and depths of 150m. Hoiho are vulnerable to bycatch in set nets and have also been recorded as trawl bycatch, although to a lesser extent. Modelling using data from the Ministry for Primary Industries estimates that the total annual potential fatalities (APF) for all fishing methods is 44 hoiho (95% CI: 17-90) (Richard & Abraham 2015). Hoiho have been caught across their mainland range and there appear to be a number of hotspots, including off the Waitaki River and in Foveaux Strait. Fisheries observer coverage has typically been low (<3%), although recent focus has improved effort locally (off Otago coverage was *c.* 30-35% in 2016, and the aim was for *c.* 65% in 2017). Set netting has been prohibited along the east and south coasts of the South Island and offshore to 4 n.mi since October 2008 to protect Hector's dolphin. The exclusion zone covers some of the inshore foraging range of hoiho, although Rakiura / Stewart Island and areas out to 25 km (13.5 n.mi) remain unprotected.

The ecosystem and competition effects of fisheries are not well known, and require further study. Hoiho eat a wide range of prey, although key species accounted for *c.* 95% of the dietary mass (including blue cod, arrow squid and red cod in the 1980s/90s; van Heezik 1990; Moore et al. 1995) which are also caught commercially. Hoiho predominantly take small juvenile fish (van Heezik 1990; Moore & Wakelin 1997), generally smaller than those targeted by fishers. Hoiho are however capable of taking fish up to 35+cm (van Heezik 1990), so there may be some overlap at the top end of the size range. The capture of adult fish may affect recruitment by reducing the spawning stock, or by altering its age or size composition. Overfishing particular species (target or non-target) can also affect marine food webs, leading to trophic cascades or ecological regime shifts, and generally destabilising the ecosystem.

Hoiho spend a large proportion of their time feeding near the seabed and require healthy intact benthic communities to provide an adequate abundance and variety of benthic prey species. The destruction of fragile biogenic bottom structures through dredging or bottom-trawling activities can therefore have detrimental effects. There is evidence that benthic degradation by commercial oyster dredging has affected hoiho habitat in the Eastern Foveaux Strait (Mattern et al. 2007; Browne et al. 2011; King et al. 2012).

Numbers of breeding pairs of hoiho fluctuate from year to year (Seddon et al. 2013), and in part this can be linked to climate, in particular changes in SST (Peacock et al. 2000; Mattern et al. 2017). Typically, El Niño conditions are good for hoiho productivity as they bring cool SST and good feeding conditions to the Otago coast; under La Niña, the sea is warmer and starvation issues may occur.

Fledgling success increases in seasons that are slightly cooler and wetter than average (Peacock et al. 2000). Adult survival is low in periods with warmer than normal SST, and vice versa; and a third of the variation in population numbers was explained by SST alone (Mattern et al. 2017). Other human factors are likely responsible for two thirds of the variation in hoiho numbers (Mattern et al. 2017).

Hoiho are exposed to a range of pollutants that cross the boundaries of both the marine and terrestrial environments. Pollutants released on land often end up in the sea through storm water, sewage effluent and run-off, and thus affect hoiho via ingestion or contact where they forage. Point sources of pollution include marine outfalls for sewage, factories and storm-water outflows and non-point sources include run-off from farms, gardens, septic tanks and industrialised areas. Sedimentation due to dredging and deforestation practices likely reduce light and may smother benthos which has potential implications for productivity and effects higher up the food chain.

Unexplained mortality events affecting large numbers of seemingly healthy hoiho are a major concern. The 1989/90 event on Otago Peninsula and in North Otago resulted in the deaths of 150 birds and reduced the breeding population by 40% (Gill & Darby 1993; Efford et al. 1996) and 67 birds died in 2012/13 on Otago Peninsula (Gartrell et al. 2016). Nine dead birds in 2016/17 between North Otago and the Catlins exhibited mass red blood cell destruction consistent with the 2012/13 event, as did a further two birds in January 2018. The deaths were unrelated to prey availability or nutrition as birds were in good body condition and no other species were known to be affected. Acute exposure to a toxin (e.g. toxic algal bloom) was suspected due to the rapid onset of death, lack of major gross pathological changes, constrained geographic area and limited time period (Gartrell et al. 2016), although it has not been proven.

Marine predation of hoiho is exclusively by native animals (e.g. pinnipeds, sharks). Depredation of hoiho by sea lions has been documented on the mainland (Schweigman & Darby 1997; Lalas et al. 2007) and in the sub-Antarctic (Moore & Moffat 1992), at sites where both species co-exist. Penguin predation appears to be a learned behaviour of a few individual sea lions, rather than a stereotyped behaviour (Moore & Moffat 1992; Lalas et al. 2007). Such events although natural, can have a significant local impact on small colonies (Lalas et al. 2007) and increased pinniped numbers at some sites may have an impact. Barracouta, although they are not considered to predate penguins as such, are responsible for accidental maiming incidents (typically between January and February), the resulting injuries of which are sometimes fatal.

RECOMMENDATIONS | KĀ WHAKATAUKA

Gaps in knowledge

In the marine environment, one of the major pieces of missing information regarding impacts are the triggers and specific causes of mass mortality events. Associated with this are the limited knowledge of pollution levels around the coast; and plankton species, abundance and their potential for toxicity in hoiho habitat. Low observer coverage on set net vessels continues to limit knowledge of the overlap between hoiho and the fishery. Coverage needs to be high (>50%) to be sufficient for such a rare species to enable the likely impacts to be determined with certainty. Little is known about the exact extent of seabed disturbance from bottom fisheries, and whether oyster dredging alone affects hoiho, or whether it also extends to bottom trawling. Recent data on the diet of hoiho is lacking. Such data are required for comparison to data from the 1980s/90s and are key for examining overlap with fisheries. Diet and foraging are however being investigated by the Otago University, Massey University and researchers at Penguin Rescue. Information on fish stocks, including the life-history of certain species and location of nursery grounds is also lacking. A greater understanding about the specific mechanisms of climate change affecting hoiho and the nature of the interactions with plankton, their prey and the whole ecosystem are missing. The current extent of New Zealand sea lion predation across the range of hoiho is another gap in the knowledge.

The terrestrial environment and impacts on hoiho are reasonably well understood. Further knowledge about the impact of land use changes on the local sediment and hydrology regimes would assist in determining the potential for habitat degradation and impacts on the food web. Little is known about the effect of tourism in the sub-Antarctic, although this is currently being addressed by Massey University. The specific causes, mechanisms and treatment for particular diseases, for example, avian diphtheria, are poorly known which hinders effective management and mitigation of the disease. No recent accurate population numbers or trends exist for the sub-Antarctic populations of hoiho, although given the current decline on the mainland; this is a slightly lower priority.

Research implications

Current diet, nutritional and foraging information are required so that we can quantify and analyse the overlap with fisheries and other impacts, and determine the likely effectiveness of marine protection measures. An understanding of the whole ecosystem and how hoiho fit into the food web and the strength of interactions between species will also help to assess overlap with fisheries and other impacts. Importantly, we need to characterise available data on hoiho and fishing (effort, landings and bycatch) to examine the likelihood of captures and the risk from the fishery. This is particularly urgent for set net fisheries, but should be carried out for bottom fisheries too (e.g. dredging and trawling). The effects of a range of fisheries mitigation measures warrant further investigation, for example the likely effectiveness of temporal and spatial closures, the implications of a shift from set netting to bottom longlining, and fisheries enhancement. An economic viability analysis of set net fisheries to assess the effect of reduced penguin numbers on tourism operators and the local economy could also have value.

The impacts of climate change on hoiho are interesting, but findings are unlikely to result in management changes that will improve the outcome for hoiho. Investigation of underlying coastal and oceanographic processes and mechanisms (e.g. fronts, currents, upwelling, eddies, stratification) will however help to establish their effect on nutrients and productivity reaching the surface or seabed and consequently higher trophic levels.

Continuation of investigations into unexplained adult mortality events are continuing, and should including further testing of tissues for toxins and the potential influence of environmental conditions. Sedimentation caused by runoff and dredging is an important stressor, may impact hoiho foraging behaviour and influence different trophic levels of the foodchain and warrants further investigation. Eutrophication of coastal waters has the ability to cause algal blooms some of which are capable of producing toxins and require further research.

Collecting scat and cast samples for potential pinniped predators is one method of working out the extent of predation on hoiho. Follow-up assessment of the survival and breeding success of hoiho that have received surgery and rehabilitation due to marine predation is also important.

Continued evaluation of the effectiveness of current trapping regimes including discussion of coverage, spacing, diversity of trap/bait types and target pests is warranted. A simple comparison of the breeding success and productivity of hoiho from artificial nest boxes and vegetated sites could prove useful. Evaluation of the impact of tourists in the sub-Antarctic warrants further investigation, as does the assessment of the effectiveness of signage and other measures for managing tourist behaviour.

Birds involved in any future mortality events should be examined and tested for disease. Investigation of the temporal and spatial occurrence of diphtheria cases and examination of links with environmental factors, breeding success and individual history is important. Research into antibiotic use for treatment of diphtheria and any long-term impacts, as well as the development of alternative treatments are valuable. Also important is the examination of the effectiveness of treatments (e.g. lesions debriding, or antibiotics) and rehabilitation in general on long-term survival and breeding success of birds. Findings from avian malaria events in 2017/18 should be analysed and investigation into the effectiveness of various prevention and treatment techniques are of value.

Comparison of mark-recapture methodology and nest counts may present another option for estimating abundance at well-monitored sites. Investigation of potential options for different levels of translocation may become increasingly important as hoiho populations decline. Work should continue with DOC's seabird prioritisation programme to investigate key parameters that regulate the hoiho population and the effect of various impacts. Further work on the identification of super-breeders and the potential for prioritising their care is another potential research avenue.

Conservation management implications

Broadly speaking, we know what needs to be done to manage terrestrial impacts effectively. Trapping and control of mammalian predators should continue at mainland sites and their effectiveness should continue to be evaluated. Ideally, the eradication of pigs and cats from Auckland Islands will eventuate. We need to ensure sufficient habitat is available for nesting and moulting, including the maintenance of access routes, and protection from the sun and erosion. Restricting dog access, or ensuring that dogs are restrained at breeding colonies continues to be important. Exclusion of cattle from breeding areas is also warranted. Unregulated tourism requires more effective controls at some breeding locations (e.g. fencing, signage, closed areas and limited access). Penguins are however, a valuable tourism drawcard and result in huge economic benefits to New Zealand and its regional economies, so regulated tourism is encouraged in certain areas. Researchers and managers should also be mindful of minimising disturbance to hoiho. Disease is an exception to the terrestrial impacts that are relatively easy to manage in wild populations. Some options are available for the management of diphtheria (e.g. lesion removal, antibiotics) and other diseases, and require ongoing discussion. Strict protocols and cleaning precautions must be adhered to in rehabilitation, veterinary practices and when monitoring nests in the field to avoid further spread of disease.

In an ideal world, hoiho colonies would be self-regulating and require minimal human intervention. Unfortunately, the life histories of most seabirds and the sustained impacts mean that hoiho are not conducive to passive recovery. Active seabird restoration techniques can effectively overcome such issues and reduce recovery times for seabird populations (Jones & Kress 2012; Kappes & Jones 2014). The dramatically declining hoiho population and the problems that are associated with low population numbers (fragmentation, genetic bottlenecks, sex biased ratios) highlight a need for proactive terrestrial management particularly at critical times (e.g. chick rearing and moult). Regular monitoring is required combined with effective management interventions (e.g. rehydration, supplementary feeding) to ensure that adults survive to breed the following year and that chicks and juvenile survive to provide future breeders. Underweight, sick and injured birds should be brought in for treatment and rehabilitation as required. Unfortunately, we are at a stage where each individual bird counts, and any deaths that can be prevented, should be.

The conservation management strategies for marine threats are more demanding, although many have positive effects on hoiho. It is possible to address fisheries impacts although politically challenging. There is an urgent requirement for observers on fishing vessels in hoiho habitat (especially set net and trawlers), as the hoiho population, given its current fragility, cannot sustain even small numbers of bycatch. Long-term there needs to be significant consideration of a set net prohibition in hoiho foraging areas, assessing the impact on hoiho, fishers and the economy. Consideration of appropriately sized Marine Protected Areas to protect hoiho in their critical foraging and breeding habitats is important given the ongoing decline of these birds. Local liaison with fishers to reduce bycatch and other fisheries impacts and gain a greater understanding of the specific circumstances of fisheries interactions is important.

Climate change is more challenging to manage, but at a local level, managers can ensure provision of shade, rehydration, unimpeded access to colonies and protection from erosion as required. At a governmental level, a focus on large-scale strategies to reduce carbon emissions would be required.

One of the urgent conservation management requirements is the immediate development of an unexplained mortality response plan to address potential toxin issues. This process is underway in collaboration between YEPT and DOC. Disaster preparation for oil spill events should continue. Effective water pollution monitoring schemes should be discussed with appropriate managing bodies.

Stage 2 of the hoiho stocktake (the species recovery plan or threatened management plan) should be developed promptly with the major four partners (Department of Conservation, Ministry of Primary Industries, Te Rūnanga o Ngāi Tahu and YEPT) and in consultation with the other hoiho stakeholders. Once completed this should underpin and support the work of conservation management groups. It should also provide direction and focus using specific achievable actions aimed at decreasing the effect of anthropogenic impacts and increasing the survival, breeding success and abundance of hoiho populations. Management recommendations should be reviewed regularly to assess progress and implement required changes. A series of immediate conservation recommendations for action (presented by YEPT to DOC, TRoNT and the Conservation Minister) are to be progressed in the meantime.

Continued development of tools to support the management of hoiho including the Yellow-eyed Penguin database and a Geographical Information System (GIS) detailing anthropogenic impacts, and management measures would also be preferable. A YEP database containing population data and individual life history information is critical for both operational management and facilitating research. GIS is a common tool for investigating seabird–environment interactions and can assist with identification of gaps in the data, and decision making (e.g. identifying hotspots for seabirds, Barraquand & Benhamou 2008, and areas for promotion as Marine Protected Areas, Lascelles et al. 2012).

INTRODUCTION | HE KUPU WHAKATAKI

Globally, seabirds are becoming increasingly endangered and monitored populations have declined by 70% between 1950 and 2010 (Paleczny et al. 2015). Seabirds are important as top predators in the marine environment (Croxall & Davis 1999), and as such changes in penguin populations are good indicators of long-term and large-scale change in marine ecosystems. The fact that they are long-lived, mobile and respond to anomalies in the environment, enhances their role as indicators (Lyver et al. 1999).

As nearshore foragers and inhabitants of temperate regions, yellow-eyed penguins (*Megadyptes antipodes*) / hoiho come into regular contact with anthropogenic activities (Boersma 2008). Hoiho are classified globally as *endangered* (Birdlife International 2016) and in New Zealand were recently reclassified as *nationally endangered* (Robertson et al. 2017). In at least part of their range hoiho are undergoing a serious continued decline in abundance (DOC 2017a). Historically, populations have bounced back after a downturn in numbers, but there is no indication of that currently, despite current terrestrial conservation management efforts. If the current rate of decline continues, hoiho could be functionally extinct on the Otago Peninsula by 2060 or sooner (Mattern et al. 2017).

Hoiho rely on the marine environment for foraging and dispersal, but require land for breeding and rearing chicks. Our understanding of impacts and the implications for conservation management should therefore consider both the terrestrial and marine habitat. Multiple stressors act directly and indirectly (Trathan et al. 2015) and as the population of hoiho declines and the ecosystem in which it lives is increasingly impacted, hoiho become less resilient to future impacts (Elmqvist et al. 2003).

USE OF THE MARINE ENVIRONMENT | KĀ MAHIKA KI TAI

All seabirds share a common dependence on the marine environment for most of their lives and are an integral part of the marine ecosystem (Tasker & Reid 1997). Hoiho are well adapted to life in the marine environment which provides foraging habitat, and allows for movement and dispersal between land areas. Their use of the marine environment remains relatively poorly understood, compared to our knowledge of land-based colonies and nest sites.

There is no information available on exactly what proportion of the life of a hoiho is spent at sea, but this is likely to differ with age class, time of the year, and behaviour (e.g. breeding season, moulting). Individuals that are not tied to nest sites (e.g. juveniles and non-breeders) are able to spend much more time at sea; during winter months individuals do not return to shore every night, sometimes absent for one or more days (Richdale 1941; Moore 1999).

Physiological tolerances mean that distributions of marine species tend to track temperature boundaries in the ocean (Sunday et al. 2012). This may apply to hoiho as the breeding range is adjacent to cooler Sub-Antarctic Water (SAW) and extends into the Sub-tropical Frontal Zone (STFZ), but not Subtropical Water (STW). Likely their distribution relates directly to temperature of the water masses (SAW is 8-15 °C; STW is >15 °C in summer), or because SAW is nutrient rich compared to STW, or a combination.

Feeding mechanisms of seabirds are either: *dynamic* (e.g. around a frontal system), or *static* (e.g. around a feature such as a sandbank or reef) (Lascelles et al. 2012). A range of oceanographic processes (e.g. tidal currents, frontal zones, gyres and upwellings) combine to enhance productivity and food availability at foraging sites (Lascelles et al. 2012). Hoiho typically exhibit reliable foraging routes and ranges (Moore 1999; Mattern et al. 2007; 2013), which is more consistent with a *static* foraging strategy associated with a benthic structure.

Foraging and diet studies provide essential information on prey, foraging ranges, susceptibility to different fishing gear, spatial overlap with anthropogenic impacts and may also indicate competition with fisheries. Hoiho foraging ranges are generally reduced during nesting, with penguins relying on available prey within close range of their land-based nest sites. As central place foragers penguins are good ecosystem indicators, for without a healthy functioning marine ecosystem, penguin foraging behaviour, body condition, reproductive performance, survival and distributions can alter (Chiaradia et al. 2010; Browne et al. 2011).

Hoiho (at least from the mainland population) are thought to be predominantly benthic foragers (87%, Mattern et al. 2007), although both pelagic (sprat, silverside and arrow squid) and benthic (opalfish, blue cod, red cod and ahuru) species are observed in their diet (van Heezik 1990; Moore & Wakelin 1997). Considerable temporal and spatial variation in species composition exists in hoiho diet (van Heezik 1990; Moore & Wakelin 1997). Recent penguin tracking work at the Auckland Islands suggest that hoiho exhibit mixed dive types (Muller 2017). Stable isotope research in the sub-Antarctic shows that hoiho rely on food webs fuelled by pelagic productivity and feed at a relatively low trophic level (Wing et al. 2014). Pelagic foraging has been observed off Saunders Canyon (G Loh *pers. comm.*), off Boulder Beach (T Mattern *pers. comm.*), and regular surface foraging of large groups of conspecifics feeding on sprat has been observed during the winter in Port Ross, Auckland Islands (*pers. obs.*).

Typically, hoiho forage on the mid-shelf out to 25 km from the coast (Moore 1999; Mattern et al. 2007). Most of the data available is for breeding birds, but in one study failed-breeders or non-breeders travelled further (females) and for longer (males) (Moore 1999). The maximum distance birds have been observed to travel offshore is almost 60 km (Mattern 2007). Individual foraging trips tend to be fairly consistent with birds revisiting the same areas in consecutive trips, but there is much variability amongst individuals some using inshore, mid-shelf or further locations (Moore 1999; Mattern et al. 2007).

Mean dive depths off the mainland are approximately 40m (Seddon & van Heezik 1990; Mattern et al. 2007). Maximum dive depths off Otago are typically shallower (80m, Seddon & van Heezik 1990; Moore 1999; Mattern et al. 2007) than off the Catlins coast (120 m; Moore et al. 2001), although in 2016/17 a depth of 156m was attained off Otago (Young 2017). During recent tracking work from Enderby, Auckland Islands hoiho foraged at a max depth of 130m, up to 50km offshore (Muller 2017). Broadly speaking the foraging range of hoiho is restricted by the 150m contour.

Post-fledge in February/March juveniles typically disperse north from their natal sites (Seddon et al. 2013), potentially this is linked to the prevailing currents or food source. Movements of known individuals have been documented between Banks Peninsula and Kaikoura, Otago Peninsula and North Otago, and Rakiura to Otago (DOC 2017a). Juveniles have been sighted as far north as Hawkes Bay and Taranaki. In good food years however, juveniles may remain in the vicinity of their natal colony (Darby unpub data in Seddon et al. 2013). Long-term monitoring data reveal that only 20.5% of chicks now survive until maturity (2 years old; Stein et al. 2017b), due to foraging inexperience and lack of predator avoidance skills. Estimates of survival rate have decreased, from 32% for the same age group between 1936 and 1952 (Richdale 1957). Of the birds surviving to adulthood, the majority (83%) return to their natal site (Stein et al. 2017b).

USE OF THE TERRESTRIAL ENVIRONMENT | KĀ MAHIKA KI UTA

Although penguins are dependent on the marine environment for food, the terrestrial environment is important for nesting, roosting and loafing, and during the moult penguins are completely restricted to land for up to a month. However, this reliance on the land allows penguins to be more easily monitored, in particular their distribution, abundance, breeding success and survival rates.

Hoiho breed on the south-east coast of New Zealand’s South Island, Rakiura, and in the sub-Antarctic Auckland and Campbell Islands. There is negligible movement between populations in the sub-Antarctic and the mainland; genetically they are distinct and should be managed as separate units (Boessenkool et al. 2009a; 2010).

There are four major breeding regions in the South Island: Catlins, Otago Peninsula, North Otago and Banks Peninsula at the northernmost extent of their breeding range. The terrestrial habitats currently used by hoiho are varied and include native forest, coastal scrub and grazed pasture (Seddon & Davis 1989; McKay et al. 1999).

Since 1980 the number of hoiho breeding around mainland New Zealand has fluctuated inter-annually between 300 and 600 pairs, dipping to a low of 141 in 1990 (DOC 2017a). In recent history, periods of decline were followed by recovery, but since 2008, there has been a steady decline. The number of breeding pairs are currently at their lowest level since 1990 with estimates of *c*. 250 and *c*. 263 pairs in the 2015/16 and 2016/17 seasons, respectively (DOC 2017a). Regular nest surveys at specific sites on Rakiura also indicate a decline (King 2017). Population trends on the sub-Antarctic Islands remain unknown. A census was last completed at Campbell Island in 1992 and estimated a population of 350-450 breeding pairs (Moore 1992). A partial survey was completed at the Auckland Islands estimating 520-570 breeding pairs (Moore 1992). The total estimate of breeding pairs of hoiho was 1700 (Seddon et al. 2013), although given the ongoing decline of the mainland population this is now likely to be an overestimate.

The average lifespan of hoiho is approximately 9 years, but some individuals can live for up to 24 years (Stein et al. 2017b). The mean number of chicks per breeding pair on Otago Peninsula was 1.16 (Richdale 1957), but this is highly variable, likely dependent on prey availability, and in recent years production has been as low as 0.6 in some areas (e.g. Whenua Hou, King 2017). Survival rate of adults is the principal determinant of seabird population size (Daunt & Mitchell 2013) and is about 0.87 (95% CI: 0.83-0.9; Mattern et al. 2017). Even very small reductions in adult survival (*c.* 1%) can have dramatic effects on the probability of extinction (McKinlay 2001).

The breeding season extends from September to February. A clutch of two eggs is laid on the mean laying date of 24 Sept, although often later further south. Both parents assist with incubation (mean 43.5 days, Richdale 1957). Hatching is mostly synchronous (Seddon 1990), after which chicks are constantly attended for 40 to 50 days (*guard phase*). *Postguard* chicks are left alone during the day and are fed when adults return to shore. Chicks fledge in February at approximately 106 days old (Marchant & Higgins 1990). Adult birds then have a few weeks to effectively double their body weight to prepare for moult, during which they do not feed. Post-moult birds are not tied to the land and can spend longer at sea.

MARINE IMPACTS | KĀ PĀKA KI TAI

Hoiho face a number of marine based threats which impact their survival and ultimately lead to population declines. The cumulative impact of a range of threats (Halpern et al. 2008) mean that hoiho are less resilient to additional impacts. As a central place forager, penguins reflect local and regional oceanic conditions extremely well, including changes induced by human activities (Trathan et al. 2015). They can therefore be used to monitor local ecosystems, and have been identified as marine sentinels (Boersma 2008).

In places such as Codfish Island / Whenua Hou where terrestrial impacts are largely absent, a decrease in the hoiho population is evident, indicating marine agents of decline. Marine impacts are typically harder to manage, but the identification of impacts causing population declines is critical to the ongoing conservation management of hoiho. Marine impacts can be a direct result of human activity, for example, the accidental capture of penguins in fishing nets; or indirect, for example, fisheries influencing the distribution and availability of prey which in turn impacts penguins.

FISHERIES

Fisheries are rarely considered to be sustainable and global landings have been in decline since the late 1980s exceeding all other human impacts to coastal ecosystems, including pollution, degradation of water quality, and anthropogenic climate change (Jackson et al. 2001; Pauly et al. 2005; Lotze et al. 2006; Costello et al. 2010). Unfortunately, stock depletions can also be masked by improved technology, spatial changes and a switch to previously unexploited species (Pauly et al. 2002). There is growing evidence of the impact fisheries have had globally on seabirds species, in particular albatross, petrels and penguins (Tasker et al. 2000; Lewison et al. 2004; Trathan et al. 2015). Fisheries can impact seabirds, including hoiho, directly through bycatch, or indirectly through prey depletion resulting in competition or alteration of the functioning of the ecosystem, or habitat disturbance.

Given the availability of sufficient data, the direct impact of fisheries is relatively easy to ascertain. The indirect effects on a species can be more challenging to establish, but differences in prey quality and quantity can reflect environmental or anthropogenic changes, including fisheries impacts (Trites & Donnelly 2003, Fritz & Hinckley 2005; Collie et al. 2017). These differences can result in nutritional stress which can be acute or chronic. Acute stress may occur due to a lack of food, or a change in the availability of prey (e.g. season, location, depth), or inappropriate size of prey (e.g. too large for offspring) (Gremillet & Boulinier 2009). Chronic stress follows the collapse or disappearance of usual high quality prey where animals switch to a lower energy prey (i.e. junk food hypothesis; Chiaradia et al. 2003). Nutritional stress in seabirds can result in low productivity, high mortality of chicks and juveniles, reduced body size, changes in behaviour, altered blood chemistry and lowered immune response (Wanless et al. 2005; Kitaysky et al. 2010).

Fisheries activities appear to affect prey availability and prey quality of hoiho (Mattern 2007; Browne et al. 2011), and influence foraging behaviour (Mattern et al. 2013), but determining whether this is due to competition, other ecosystem effects or seabed disturbance is challenging. Starvation and nutritional stress used to be uncommon in hoiho (van Heezik 1988, Darby & Seddon 1990), but are increasingly evident (Browne et al. 2011). Annual variation in the quality and quantity of prey can result in considerable variation in the fledging weights of hoiho (van Heezik & Davis 1990), breeding success (van Heezik 1990; Moore & Wakelin 1997), growth rates (van Heezik 1990) and an overall decline in local populations (King et al. 2012).

Bycatch

Bycatch in fishing nets is a significant direct threat to seabirds and has played a role in the decline of several marine species (Tasker et al. 2000; Cuthbert et al. 2009). Of the world's 18 species of penguin, 14 have been recorded as bycatch, and catches of Humboldt, Magellanic and hoiho are of particular concern (Žydelis et al. 2013; Trathan et al. 2015).

Hoiho are very vulnerable to bycatch in set nets (gill nets), and have also been recorded as trawl bycatch, although to a lesser extent. There are no known bycatch incidents in the bottom longline fishery, although a crested penguin has been caught on a bottom line targeting ling (Abraham et al. 2016). Surface longlining is not known to be a significant issue as there is little overlap between fishing effort and hoiho foraging habitat.

The Ministry for Primary Industries' (MPI) risk assessment for incidental seabird mortality categorises the entanglement risk to hoiho from gillnets as "medium" (Richard et al. 2015). Hoiho are most often caught in gillnet fisheries targeting school shark and rig, but have also been observed in fisheries for moki and butterfish (Abraham et al. 2016). Gillnets for rig and school shark are set near the seabed, overlapping with benthic foraging dives of hoiho. Rig and school shark are largely sold overseas in Australia for the fish and chips market and unprocessed fish from set netting on the East Coast South Island was worth approximately $6 million in 2016 (M. Geytenbeek *pers comm*).

More than a hundred hoiho have been bycaught in gillnets off New Zealand, including 72 deaths between 1979 and 1997 (Darby & Dawson 2000) and 35 reported between 1998 and 2016 (Abraham et al. 2016; DOC 2017a; 2017b; RDM 2017). MPI estimates that the total annual potential fatalities (APF) for all fishing methods is 44 hoiho (95% CI: 17-90) (Richard & Abraham 2015). Anecdotal evidence from several fishermen suggests that bycatch is far higher than reported; for example, more than 30 hoiho were caught in one season by a set netter around Otago Peninsula (Ellenberg & Mattern 2012). Unfortunately, bycatch of hoiho continues today, although likely at a reduced rate, due in part to the declining penguin population. Four penguins were reported as bycatch in 2016, including two off the Waitaki River, one off Rakiura, and one off Kaka Point, Catlins (Abraham et al. 2016; RDM 2017).

Annual potential biological removal (PBR), the number of penguins (excluding natural mortalities) that can be removed whilst allowing a population to be sustainable has been calculated at 164 (95% CI: 113-231) for mainland hoiho (Richard & Abraham 2015). Considering that the population is estimated to be approximately 260 breeding pairs of hoiho on the mainland, this PBR is completely unrealistic and unsustainable.

All documented set net captures to date are from mainland New Zealand, largely because there is minimal set net effort in the sub-Antarctic. Bycatch incidents have occurred from inshore in shallow waters (3 m) out to depths of 144 m and to 22 km offshore (Darby & Dawson 2000). Penguins have been caught in set nets off Otago Peninsula, elsewhere in Otago, Canterbury, Kaikōura, Southland and Rakiura (Darby & Dawson 2000). There are a number of bycatch hotspots, including offshore from the Waitaki River and in Foveaux Strait. Adults and juveniles of both sexes have been reported as bycatch (Darby & Dawson 2000) and all birds were recovered dead from nets (Rowe 2009; 2010; Ramm 2010).

The number of commercial fishers engaged in set netting has reduced in recent years. Approximately 25 vessels actively set nets along the east coast between Kaikōura and Southland, although 100+ are registered with set net capability (Fishserve 2016). In the main hoiho foraging areas up to seven vessels work off the Otago coast and eight off Southland (including Rakiura). Set net effort is high north of Otago Peninsula towards Ashburton, around Kaikōura and in Foveaux Strait (Abraham et al. 2016) and is highly seasonal between October and March, with a peak in January and February. The peak coincides with the end of the breeding season and pre-moult; a time when hoiho are under pressure to feed chicks and gain weight to sustain themselves during the moult. Nets set overnight close to shore pose a serious threat, particularly at dawn and dusk when penguins transit to and from colonies (MPI 2013). Hoiho parents alternate at the nest providing care; the loss of one parent, typically results in reproductive failure (i.e. death of up to two chicks; Darby & Dawson 2000). In addition, the loss of a parent may cause its mate to skip the subsequent breeding season (Setiawan et al. 2005).

Fisheries observer coverage is planned by MPI and DOC, and has typically been low <1% and sporadic for set net fisheries (Ramm 2010). A lack of observer data leads to a poor understanding of the temporal and spatial extent and rate of captures. Since 2008/09, observer coverage in the set net fishery has increased (2.2% in 2008/09, 2.4% in 2009/10 and 3.4% in 2013/14), largely due to monitoring requirements for Hector's dolphins (Ramm 2010). More recently MPI have focused on improving observer effort locally, particularly on vessels deemed to be high risk. Observer coverage off Otago was increased further to ~30-35% in 2016, and the aim is for 65% in 2017 (M. Geytenbeek *pers. comm.*). Previously much of the effort has been outside hoiho foraging habitat; for example, between 2002/03 and 2013/14, there was no effort in foraging areas in seven of those years (Abraham et al. 2016). During the same 13 year period, ten hoiho were "officially" reported as bycatch and used for risk modelling (Abraham et al. 2016); a search of two other databases (DOC 2017a; WMIL 2017) revealed another 16 bycaught hoiho in the same period. This highlights a problem with data consistency and availability, which likely leads to a low bycatch mortality estimate. To obtain an unbiased sample of the fishery, observer coverage levels should be at least 20% for common species and 50% for rare species (Babcock et al. 2003).

Another issue is the lack of incentives for commercial fishermen to report bycatch. The proportion of banded birds reported in bycatch was significantly higher than the proportion in the wider population which suggests that under-reporting of unmarked hoiho likely occurs (Darby & Dawson 2000).

New Zealand is unusual in that it still allows recreational gillnetting, a practice known to catch hoiho (Darby & Dawson 2000). Recreational fishing hotspots are typically located around population centres and holiday spots. Recreational fishers are far less likely to report bycaught birds than commercial fishers, as there is no motivation for reporting and no observer programme in place (Darby & Dawson 2000). Few birds (*n*=3) have therefore been reported as bycatch in recreational set nets, although the actual catch is likely to be far higher (Darby & Dawson 2000). It is likely that regulations for Hector's dolphins banning the use of set nets offshore to 4 n.mi (excluding harbours) (MPI 2016) have helped reduce bycatch of penguins since their implementation in 2008, assuming that fishers abide by the regulations.

Hoiho have been caught in trawl fisheries; one was recorded off Green Island, Otago in February 1990 (DOC 2017a) and another in a bottom trawl for hoki north of the Auckland Islands in February 2012 (Abraham et al. 2016). Observations of trawl bycatch are limited, in part due to low observer effort off Otago, Southland and Rakiura (Abraham et al. 2016). Trawl effort is high north and south of the Otago Peninsula, in the Canterbury Bight north to Kaikōura and in Foveaux Strait. Between 2002/03 and 2013/14 observer effort was between 5 and 15% on trawl vessels (Abraham et al. 2016), but this included the entire trawl fishery, not just those overlapping with penguin habitat. Very little effort occurred on inshore trawls where there was overlap with foraging hoiho. Although trawl bycatch is lower than set net bycatch, trawl effort throughout the range of hoiho is higher, leading to increased risk through greater exposure.

Seabirds can also become entangled in 'ghost' or lost fishing gear, although there are few systematic studies examining the extent of this (Laist & Wray 1995; Kaiser et al. 1996; Matsuoka et al. 2005). Lost fishing gear is certainly found washed up on beaches within penguin habitat, particularly after storm events and could potentially pose a problem for hoiho.

Ecosystem effects

Commercial fisheries may target fish or invertebrate species that are consumed by seabirds resulting in competition, or may otherwise impact the marine ecosystem by altering trophic pathways and affecting its functioning (Pikitch et al. 2004; Cury et al. 2011). Over-exploitation of fish stocks has been implicated in the decline of many seabirds, but it is difficult to quantify the extent of the impact in the dynamic marine environment (Tasker et al. 2000) and disentangle them from interacting impacts (e.g. climate change) and physical variables (Botsford et al. 1997). The impacts of fishing and knock-on effects to the rest of the marine ecosystem are only just beginning to be understood (Pitcher 2001; Pauly et al. 2005; Coll et al. 2016).

There is compelling evidence that competition exists between some commercial fisheries and seabirds, in particular those targeting lower trophic level forage fish (e.g. herring, sardines, sandeels) and euphausid crustaceans (Grémillet et al. 2016; Sydeman et al. 2017). Fisheries for sardine and anchovy off South Africa, for example, significantly reduce stocks, and compete with seabirds further up the food-chain, including African penguins (Crawford et al. 2014). Seabird-fisheries interactions can be exploitative whereby fisheries outcompete seabirds, or interference based whereby fisheries prevent seabirds from using a resource (Sydeman et al. 2017). In the latter, fishing may influence the availability of prey, and the spatial distribution and density of prey aggregations (either vertically or horizontally) thus disrupting the foraging patterns of seabirds. Fishing pressure on fish stocks may force birds to work harder for their food by travelling further or diving deeper, or may produce limited returns or force them to shift the focus of their foraging to less-nutritious species. Birds with diverse foraging strategies are impacted differently; for example, surface-feeding kittiwakes are disrupted by the sandeel fishery whereas diving species like common murres are not (Frederiksen et al. 2008).

Whether competition between fisheries and hoiho exists is currently unknown, but knowledge of foraging ranges and diet, and fisheries effort is essential for assessing any impact. Direct competition can only occur if there is spatial and temporal overlap of target fisheries and penguin foraging areas, evident in this case due to bycatch of hoiho in inshore fisheries (Abraham et al. 2016); however, overlap alone does not constitute competition.

Hoiho eat a wide range of prey, at least 43 different species have been documented (Moore & Wakelin 1997). Seven key prey species accounted for 94% of the dietary mass in the late 1980s (sprat, red cod, silverside, blue cod, ahuru, opal fish and arrow squid) (van Heezik 1990); and nine fish and one squid species for 95% of the dietary mass in the 1990s, in particular opalfish, blue cod, arrow squid and silverside (Moore et al. 1995). Diet varies with location (van Heezik 1990) and there has been an increase in blue cod in the diet of hoiho more recently whilst red cod, sprat and ahuru have become less important (Moore & Wakelin 1997). During seasons of food shortage in the South Island when hoiho chicks and adults starved, the proportion of blue cod in the diet increased significantly (van Heezik 1990), suggesting either that it is a less preferred and profitable prey, or that other species are unavailable so there is a greater reliance on blue cod. Adult penguins selectively provisioned their chicks with significantly less blue cod and more opalfish, than the adults themselves consumed (Browne et al. 2011), which may be due to a size difference rather than preference.

Hoiho are not exclusively dependent on commercial species, however, they prey on a small number of species that vary in terms of catch, quantity and importance. Blue cod are the most important finfish in Otago and Southland, for the inshore commercial and recreational fisheries. The catch of blue cod often exceeds the Total Allowable Catch (163 tonnes for the East Coast South Island, BCO3); in 2011/12, 285 tonnes of blue cod was fished in BCO3 (119t recreational, 166t commercial; MPI 2017). Blue cod are a benthic species with small home ranges (typically <1km) and are distributed on foul ground to 150m depth (similar to the depths used by hoiho). They spawn in late winter / spring and catches peak in autumn / winter. There is a commercial trawl (and jig) fishery for arrow squid in depths <300m, overlapping with hoiho. Squid are caught between December and May (peak: January to April). The species is short-lived (1 year), hatches in July/August and spawns in June/July; therefore, most squid are caught before spawning. The amount of arrow squid caught by recreational fishers is unknown. Red cod are targeted in the inshore trawl fishery and also caught recreationally in depths of 30-200 m between November and May/June (peak: January and May). During spring and summer, red cod are caught inshore before moving into deeper water during winter. Abundance is highly variable (in relation to environmental parameters), however the length and magnitude of the decline in commercial and recreational catches of red cod indicates fishing pressure has significantly reduced abundance (MFish 2007). This is consistent with the decline of red cod in the diet of hoiho (Moore & Wakelin 1997). Red cod are a fast-growing and short-lived species (MPI 2010). The fishery is based almost exclusively on 2-3 year old mature fish and is highly dependent on recruitment success, where a strong or weak single age class has a big impact causing annual fluctuations in the fishery (MFish 2007). There are no known nursery grounds for red cod (MPI 2010), however juveniles have been observed on bryozoan beds (Batson & Probert 2000), consistent with hoiho foraging ranges. Juvenile red cod were found throughout Otago Harbour and adjacent waters in the early 20th century

(Thomson 1913). There are insignificant commercial fisheries for silverside and sprat, and no targeted commercial or recreational fishery in New Zealand for either opalfish or ahuru.

Fishing typically targets adult fish, however, it is the juveniles that are often vital forage food to a wide range of dependent predators, including seabirds (Field et al. 2010). Whilst there are some similarities in the species targeted by fishermen and hoiho, there is little cross-over in terms of size. Hoiho predominantly take small, juvenile fish (<25 cm, van Heezik 1990; Moore & Wakelin 1997), smaller than those targeted by commercial and recreational fishers (e.g. 30-33cm minimum legal size for blue cod, 45-55cm 2-3 year old red cod that constitute the bulk of the fishery). Although juvenile fish are not targeted by fishermen, the capture of adult fish may affect recruitment by reducing the spawning stock, or by altering its age, size or genetic composition (Planque et al. 2010). The use of unselective fishing methods (e.g. trawling) can lead to indiscriminate bycatch of non-target species and non-commercial sized fish. Juvenile fish may be caught incidentally alongside the target adult fish, although features like large mesh sizes may enable a proportion of juveniles to escape.

Overfishing of particular species (target or non-target) can also have major effects on marine food webs, leading to trophic cascades or ecological regime shifts and generally destabilising the ecosystem (Baum & Worm 2009). The removal of top and mid-trophic level predators via fishing alters the flow of biomass and energy through the marine system (Einoder 2009) and modifies the intricate trophic interactions of their ecosystems (Jackson et al. 2001). The removal of particular species via fishing may lead to a reduction of the number and length of pathways linking higher level fish to primary producers. Any loss of biodiversity could contribute to a ripple effect, changing the pattern of interaction strengths and thus threatening to unbalance the stability of the ecosystem (O'Gorman & Emmerson 2009). Removal of strong interactors (analogous to keystone species) can result in trophic cascades and a change in the availability of energy (O'Gorman & Emmerson 2009). The simplification of food webs means that predators cannot switch between prey easily as their abundance fluctuates, and thus compensate for prey fluctuations induced by environmental fluctuations (Neutel et al. 2002). Top-down controls on community organization typically involve the loss of a top predator from a system; the consequent release from predation allows prey species to expand their range and/or abundance, leading to enhanced competition and displacement of less competitive species (Cury et al. 2003). Marine reserves in New Zealand provide evidence that fishing of snapper has cascading effects through the food web causing an increase in kina and consequently a decrease in kelp (Shears & Babcock 2002). As large trophic level fish are removed and depleted, fisheries progressively target fish further down the food-chain; a process known as "*fishing down the food web*" (Pauly et al. 1998). Between 1950 and the mid-1990s the mean trophic level of fish catches has declined globally (Pauly et al. 1998).

An example of ecosystem effects are the increase in jellyfish blooms in the marine environment globally, often to the detriment of other marine organisms. Jellyfish outbreaks can be driven by overfishing, as well as nutrient enrichment, habitat modification and climate change, and will become more prominent in the future (Purcell et al. 2007; Richardson et al. 2009). Pelagic ecosystems can rapidly change from a fish to jellyfish dominated one which has serious ecological, economic and social consequences (Richardson et al. 2009). Jellyfish have advantages over fish in stressed environments including: a broad diet, fast growth rates, the ability to shrink when starved, the capacity to fragment and regenerate, and the ability to tolerate hypoxia (Richardson et al. 2009). An increase in jellyfish has the potential to further unbalance the marine food web by affecting the abundance of zooplankton, fish larvae, and eggs (Purcell et al. 1994; Purcell 2003) and thus recruitment of fish populations (Lynam et al. 2005). Jellyfish predation is thought to affect cod recruitment in the North Sea (Atrill et al. 2007) and such a top-down control has been suggested for other fisheries (Purcell et al. 1994; Lynam et al. 2005). Jellyfish are rarely the preferred prey item (Moline et al. 2004) and are considered "trophic dead-ends", yet have become the dominant top predator in some overfished systems (Brodeur et al. 2002; Hughes et al. 2005). A large-scale increase in the occurrence of jellyfish could have major consequences for pelagic ecosystems and fisheries (Attrill et al. 2007). Jellyfish have recently been found to represent a widespread and previously under-represented prey source for penguins including hoiho (Thiebot et al. 2017). It is not known whether the routine consumption of jellyfish is a recent development, potentially resulting from a regime shift in food webs (Richardson et al. 2009), or whether it occurred previously; however penguins consumed gelatinous organisms even when other prey items were available (Thiebot et al. 2017).

It is unknown whether ecosystem effects resulting from fishing impact hoiho, but it can be considered likely. Historical literature on fish abundance and availability in Otago Harbour and adjacent waters (Thomson 1913; Graham 1939; 1940) suggest an extremely modified current system with considerably reduced productivity. In the early 1900s, hapuka (groper) were caught throughout the year in Otago Harbour, and immature red cod were found in enormous numbers inshore throughout the year (Thomson 1913). Graham (1939) states that sprat, pilchard and, ahuru were hugely abundant and the main source of food for fish-eaters. There were already concerns about the serious declines in the numbers and size of fish in Otago by 1940, and recognition of the destructive effect of selling large (>4 kg) groper roes (totalling at least 300,000 million eggs annually; Graham 1940). Even at this time, it was recognised that "*at best, recovery from the damage already done* [by fisheries] *will probably be slow*" (Graham 1940). Interviews with local Maori communities revealed an overwhelming perception that New Zealand's inshore fisheries stocks have declined dramatically starting in the 1950s and 1960s and accelerating in the 1970s (McCarthy et al. 2014). Most New Zealand commercial species have been fished to between 25% and 70% of their original levels by 1997 (Craig et al. 2000). This is also in tune with what is known about historical abundances of fish globally; consumer species were fantastically large and assemblages of suspension feeders were dense in comparison with recent observations, and many species are now ecologically extinct over vast areas (Jackson et al. 2001).

Habitat disturbance

Destruction of biogenic habitat and associated benthic communities often have more important impacts on the ecosystem than the removal of fish (Botsford et al. 1997). Biogenic habitats, in addition to supporting fisheries, fulfil other essential ecological roles, including enhancement of biodiversity, increased primary production, nutrient cycling, control of water quality, carbon sequestration, storm protection and erosion prevention (Lotze et al. 2006, Airoldi & Beck 2007). Put into perspective, the global value of bio-services from coastal ecosystems is estimated to be ten times higher than that of any terrestrial ecosystem (Costanza et al. 1998).

Habitat loss and destruction is particularly severe in coastal marine ecosystems where human activities are concentrated. Bottom fishing alters the benthic landscape making it more homogenous and leads to a loss of biodiversity (Probert 2017). Depending on gear type, substrate and vulnerability, towed bottom-fishing gears typically kill 20–50% of the benthic invertebrates; epifaunal species that stabilize sediment and provide habitat for benthic invertebrates are particularly vulnerable (Collie et al. 2017). Species diversity typically increases with structural habitat complexity, so destruction of habitat typically leads to a decrease in the diversity of benthic species and reduction of important nursery and spawning habitat, for many species of demersal fish (Bradstock & Gordon 1983; Dayton et al. 1995; Jennings & Kaiser 1998). Other effects include re-suspension of sediment which may have smothering effects and impact filter feeding organisms, as well as disrupting the flow of nutrients between the sediment and water, redirecting flow away from a benthic towards pelagic system (Pitcher 2001; Probert 2017). Destruction of benthic habitat and effects on invertebrates and fish have knock-on effects up the food-chain, including on seabirds.

Understanding how biogenic habitats may contribute to fisheries production is at an early stage in New Zealand (Morrison et al. 2014). On the Otago shelf habitat forming bryozoan fauna is very diverse and extensive bryozoan beds interwoven with oysters and sponges were historically found throughout Foveaux Strait. These structures provide food and refugia for invertebrates (Batson & Probert 2000) and may play a role in the life history of commercially valuable fish and prey for hoiho.

Hoiho spend a large proportion of their time feeding near the seabed (Mattern et al. 2007) and therefore require healthy intact benthic communities to provide an adequate abundance and variety of benthic prey species (Turner et al. 1999). The destruction of fragile biogenic bottom structures such as bivalve reefs, sponge communities and bryozoan beds, through dredging or bottom-trawling activities can therefore have detrimental effects on hoiho. There is evidence to suggest that benthic habitat degradation from commercial dredging activities have impacted upon hoiho habitat (Mattern et al. 2007; Browne et al. 2011; King et al. 2012).

Benthic habitat such as bryozoan beds are easily damaged by benthic fishing (Wood et al. 2012). The Otago shelf bryozoan beds were fished commercially for a period of at least 50 years, although the intensity and distribution of fishing effort over time is unknown (Batson & Probert 2000). Biogenic reefs have diminished in their distribution, habitat complexity and benthic species diversity as a consequence of more than 140 years of commercial oyster dredging in Foveaux Strait (Cranfield et al. 1999; Turner et al. 1999; Collie et al. 2000; Beentjes & Baird 2004) and by 1998 none of the original bryozoan biogenic reefs remained (Cranfield et al. 2001). This has in turn affected prey availability and quality, therefore reducing the survival and productivity of hoiho inhabiting Rakiura and its offshore islands (Mattern et al. 2007; Browne et al. 2011; King et al. 2012). Initially, reefs in the eastern and central Foveaux Strait were exploited, before effort moved westwards once beds had been fished to commercial extinction (Cranfield et al. 1999).

Disturbance from fishing trawls has been shown to increase the density of mobile benthic scavengers and smaller opportunistic species which feed on broken molluscs, echinoderms, crustaceans, and polychaetes (Ramsay et al. 1998; Thrush & Dayton 2002). Blue cod are the most tolerant of reef-dwelling species to dredging (Cranfield et al. 2001) and are one of the few demersal fish species found on both recovering biogenic reefs and recently dredged areas (Carbines et al. 2004). This may explain their growing importance and occurrence in hoiho diet (Moore & Wakelin 1997). Despite their tolerance, however, blue cod are slower-growing in oyster dredged habitats (Carbines & Cole 2009). If benthic habitats are damaged by dredging and trawling, then hoiho may be significantly affected if they are unable to adapt to alternative foraging locations, habitats or species.

Aquaculture

Aquaculture is a growing industry in New Zealand particularly for king salmon, green-lipped mussels and Pacific oysters. The direct impacts of aquaculture on hoiho are expected to be minimal compared to wild fisheries, but there may be indirect impacts on penguins. Hoiho distribution currently overlaps with aquaculture enterprises in Paterson Inlet (Rakiura) and around Banks Peninsula.

The negative environmental impacts of mussel farming are generally lower than for salmon farming (Crawford et al. 2003), as this method requires no additional nutrients or chemicals. The impacts of salmon farms include modification of benthic communities, increased nutrient loads in coastal waters which may lead to harmful algal blooms, influx of chemicals into the environment, and modification of the natural food web caused by escaped fish (Buschmann et al. 2006). Significant impacts to the benthic community composition and extensive bacterial mats are known to occur under shellfish culture structures (Crawford et al. 2003).

Farming operations may directly displace seabird colonies or foraging areas, or indirectly affect seabirds by altering benthic conditions which reduces feeding opportunities (Callier et al. 2017). Occasional catches of seabirds in nets have also been reported (Carss 1993; 1994). Aquaculture sites may serve as a positive attractant for seabirds as high fish density in shallow water provides them easy access to food or escaped fish present easy prey (Scheel & Hough 1997; Manikowska-Ślepowrońska et al. 2016). Seabirds are attracted to such an extent at some aquaculture sites that anti-predator controls have been employed to control scavenging by seabirds (Carss 1994; Quick et al. 2004). The Bravo Islands, Rakiura are one of the few locations where the hoiho population has not declined as significantly as elsewhere. This is speculated to be related to the proximity of hoiho to the salmon farm in Paterson Inlet and the potential for supplementation of their natural diet, although this has not been tested. The effect of mussel and oyster farms has not been investigated. Although the closure of oyster dredge fisheries in Foveaux Strait may have had a positive effect on hoiho by allowing benthic habitat to recover it is unknown whether the closure of oyster farms at Big Glory bay, Rakiura in 2017 had any impact on hoiho.

Management of fisheries

Human induced impacts of fisheries can be mitigated given the appropriate political will. Ideally, the precautionary approach would be followed, with the onus on fisheries to demonstrate that there are no detrimental effects of the fishery to penguins, rather than the converse. Growing concern over the state of the marine environment and sustainability of some fisheries has led to a shift from a single stock approach to management of the whole ecosystem (Pilkitch et al. 2004).

The regulation of regional fisheries which overlap with hoiho distribution can be achieved through a range of techniques including spatial and temporal closures, catch restrictions, and modifications to gear and fishing practices. Mitigation measures require enforcement to ensure maximum benefits are achieved.

Observer programmes provide valuable data on where seabirds are caught, and the timing and circumstances of catches (e.g. gear type). This knowledge can be used to find solutions which minimise impacts to both penguins and fishers. Electronic monitoring is planned for installation on all vessels by 2018 to enable tracking and real-time collection of data on catches of fish and protected species.

Temporal and spatial closures

There are a variety of ways of regulating fishing practices through marine protected areas. Seasonal and area closures are the most effective way of mitigating bycatch, whilst also addressing habitat degradation and competition (Childerhouse et al. 2013). Marine Reserves are “no take” areas for commercial and recreational fishing, therefore protecting against both direct and indirect impacts. The only marine reserves currently within hoiho habitat are at the Auckland Islands (out to 12 n.mi offshore), and two small reserves at Banks Peninsula (Pōhatu and Akaroa). A no-take marine reserve off the coast of South Africa had immediate benefits for the African penguin by reducing foraging effort by 25-30% and decreasing daily energy expenditure by approximately 43% (Pichegru et al. 2010) within 3 months in a 20 km radius.

The exclusion of particular types of gear in the vicinity of hoiho nesting sites can be implemented via mechanisms other than the Marine Reserves Act. Banks Peninsula Marine Mammal Sanctuary, for example, was established under the Marine Mammal Protection Act for Hector’s dolphins. The small number of hoiho around Banks Peninsula likely benefit and its effectiveness has been proven to increase survival of Hector’s dolphin (Gormley et al. 2012).

Set netting has been prohibited since October 2008 along the east and south coasts of the South Island between Cape Jackson (Marlborough Sounds) and Sandhill Point (Southland) offshore to 4 n.mi and in Te Waewae Bay (MPI, www.fish.govt.nz). The area protects Hector’s dolphins from commercial and recreational gill netting under fisheries legislation, but excludes harbours, estuaries and inlets (e.g. Otago Harbour, Blueskin Bay). The exclusion zone covers some of the inshore foraging range of hoiho, although Rakiura and areas beyond 4 n.mi remain unprotected. Trawling has been prohibited since October 2008 along the same stretch of coast and offshore to 2 n.mi (MPI, www.fish.govt.nz), with an exemption for trawl nets with low headline heights of less than 1 m.

Other mechanisms for protection from fisheries impacts include taiāpure and mātaitai; area management tools available to Tangata Whenua to help them sustainably manage traditional customary fishing grounds (e.g. East Otago taiāpure, MPI 2010). Voluntary bans on set netting were in place at Porpoise Bay and Katiki Point before being superseded by fisheries legislation covering a wider area. Since 2002, an area of bryozoan thickets (about 110km^2) has been voluntarily closed for bottom fishing techniques on the Otago Shelf, although the closure is not publicly listed by MPI (Wood et al. 2012). No monitoring of the spatial distribution of fishing, or the extent and health of the bryozoans has occurred (Wood et al. 2012). Regional councils may also use regional plans to control fishing and protect native species, for example, the Bay of Plenty Regional Council application to protect Motiti Island and Otaiti (Astrolabe) Reef, which is now being appealed by the government.

The South East Marine Protection Forum (https://south-eastmarine.org.nz) are currently deliberating over proposals for marine protected areas (MPAs) for the Otago and Catlins coast. Appropriately designed MPAs can be effective for conserving mobile marine predators, including hoiho. Conservation benefits however would be highly dependent on the level of protection, effectiveness of design and compliance. Hoiho could be a model species for marine protection in New Zealand, as a high profile endangered species with consistent foraging areas, habitat protection could be designed which would have positive effects on the rest of the marine ecosystem.

Regulatory modifications

Regulatory modifications (e.g. bag, catch or size limits) have the potential to reduce competition between fisheries and species higher up the food chain that rely on them. In many of New Zealand's fisheries, however, overfishing or unsustainable fishing is occurring. Setting catch limits is carried out under the Fisheries Act. The Total Allowable Catch (TAC) is the total quantity of each fish stock that can be taken by commercial, customary and recreational fishery interests, to ensure sustainability of that fishery. Bag limits and size limits are also set for many fish species.

Concerns have been raised about the sustainability of red cod by MPI, "*the current substantial disparity between available catch and available Annual Catch entitlement (ACE) has created a "race for catch" fishery whereby there is (i) competition for access to local fishing grounds (ii) fishing in nursery areas (iii) discarding of non-marketable fish and bycatch and (iv) unnecessary sea bed damage caused by trawling for insignificant amounts of red cod. The disparity also distorts the ACE market. All these effects prevent RCO3 fishers from using the resource efficiently in a sustainable way*" (MFish 2007).

Blue cod supports a high value commercial fishery and is popular among recreational fishers, but is suffering due to increased fishing activity and a changing environment. MPI acknowledges that management issues are evident in the fishery and have started a process to develop a blue cod strategy to address them (www.mpi.govt.nz/law-and-policy/legal-overviews/fisheries/national-blue-cod-strategy).

Set netting is one of the few fisheries which currently has no regulatory requirements (Ramm 2010). A code of practice for recreational set net fishers highlights regulations, such as a requirement for nets to be less than 60m long and set more than 60m apart, no bait must be used and nets must be marked (MPI 2016). A number of practical suggestions for responsible fishing are made, such as staying with your net and using short soak times.

Discarding arises from the use of unselective fishing methods, e.g. gillnets and trawling. These methods result in low selectivity for species (including bycatch of hoiho) and very limited selectivity for size. Ideally, the unwanted catch should be retained and processed, and discarding of fish should be phased out. The European Union has recently introduced new legislation with regards to discarding and have initiated a landing obligation (Villasante et al. 2016). As part of these new regulations all catches have to be kept on-board, landed and are counted against quota; in addition undersized fish cannot be marketed for human consumption. This approach serves as a driver for fishermen to fish more selectively, as well as providing more reliable catch data and could be highly beneficial to fisheries if applied in New Zealand.

Operational and gear modifications

No fisher aims to catch seabirds. Avian bycatch is disadvantageous for fishers as it is costly in terms of time and money (removal of bycatch instead of fishing, damage to nets, increased paperwork). This therefore provides some motivation to reduce bycatch by ensuring good fishing practices. For example, reduction measures have been successfully implemented in the longline fishery because each bird hooked means fewer fish are caught.

Operational and gear solutions for bycatch mitigation are very much species- and fishery- specific. Broadly, methods consist of either deterring birds from coming into contact with the fishing gear (e.g. tori lines, water cannons, pingers), reducing the attractiveness of the vessel (e.g. managing offal discharge) or avoiding times when seabird interactions are most likely.

Set nets are an indiscriminate fishing method, are the primary cause of bycatch events for hoiho, and their impacts are difficult to mitigate. Potential solutions involve increasing the visibility of the net to birds without impacting fish catch, using olfactory deterrents or timing deployment and retrieval to reduce bycatch (e.g. avoiding sunset, sunrise). There has been some success at reducing turtle bycatch in Peru using LED lights and glow-sticks (Wang et al. 2010) and shark liver oil as an olfactory deterrent (Pierre & Norden 2006).

A gear switch, for example, from bottom set gillnets to bottom set longlines would likely reduce the number of bycatch events for penguins. Hoiho are not known to take dead bait, and so it is assumed that they would be less likely to get caught on longlines.

Mitigation methods exist for benthic trawling which reduce the amount of contact with the seabed and therefore have the potential to reduce damage to hoiho habitat. Disks added to bottom of trawl nets elevate it slightly from the seabed, and have been successfully implemented in the Alaskan flatfish trawl fishery (Rose et al. 2010).

Liaison with fishers is key to developing modifications or operational solutions to reduce bycatch. Successful liaison and bycatch reduction projects for longline fisheries have occurred in New Zealand and there is a government tender out for a set net liaison role.

Enhancement of fisheries

Fisheries enhancement involves manipulation of the physical or biotic environments to increase harvests, or supplementing recruitment by introducing new stock (Booth & Cox 2003). Typically techniques include “seeding” release of early life-history stages of an animal into a habitat, transfer of animals from one habitat to another or modification of the wild habitat (Booth & Cox 2003). Fisheries enhancement has occurred frequently in New Zealand as part of traditional management of kai moana.

Restoration of a diminished habitat, including artificial regeneration of reef habitat, is a potential restoration option. This would have be carried out in an area that is closed to fishing. A previously dredged area in Foveaux Strait saw some success with adding empty oyster shells to the seabed (on a reef that was not entirely depleted) (Cranfield et al. 2001).

Consumer driven mechanisms

Consumer or market-driven mechanisms have the potential to promote sustainable fisheries practices via labelling and increased consumer awareness (Jacquet & Pauly 2007; Selden et al. 2016). In particular, fish for sale which is labelled with the method of catch may promote the use of more sustainable methods of fishing. Sustainably caught high quality fish can command higher prices. The most prominent eco-labelling certification scheme is the Marine Stewardship Council which encourages the certification of sustainable fish catches through consideration of target species, bycatch and habitat destruction. Legitimate concerns about the certification process have been expressed (e.g. Jacquet et al. 2010), as well-known, but poorly studied fisheries such as orange roughy and Antarctic toothfish have gained accreditation. The Forest and Bird best fish guide is an independent consumer guide to sustainably caught seafood in New Zealand.

FISHERIES RECOMMENDATIONS

Gaps in knowledge

- The bycatch threat posed to hoiho, particularly from set net fisheries, remains relatively poorly known due to limited observer coverage.
- Fisheries effort throughout hoiho habitat. Extent of seabed disturbance from bottom fisheries (e.g. trawling, dredging).
- Recent hoiho diet data.
- Hoiho foraging ranges from different locations, including outside breeding season and different age groups.
- Basic information on fish stocks, life-history stages and location of nursery grounds for juvenile fish (likely to be prey of hoiho).

Research recommendations

- To investigate and quantify overlap of hoiho with fisheries, and consider effective marine protection measures, we need current diet, nutritional and foraging information:
    - Tracking data for foraging ranges at different times and locations, and different age and breeding classes, including consistency over time and proportion of time spent benthic versus pelagic foraging. New data are currently being gathered (e.g. Muller, Young).
    - Contemporary diet from different seasons, age classes and locations using a range of techniques (e.g. scat, cast, spilled food, DNA). Examine changes in prey species composition, and size differences over time. Some data exist (e.g. Lalas) but require analysis and others are currently being gathered (e.g. Young).
    - To assess the nutritional status of hoiho investigate the use of quantified blood biomarkers of malnutrition including blood glucose levels, body condition, white blood cell counts and serum antibody levels (e.g. Banuet-Martinez et al. 2017).
    - Examine feeding frequencies and investment of parents in chick rearing, using smart nest boxes or cameras (e.g. Young).
    - Foraging data, diet and parental investment could be used to look at differences between super-breeders (Stein et al. 2017b) and other breeders.
- To understand how fisheries overlap with and affect hoiho we need to understand more about how hoiho fit into the foodweb, the strength of interactions between species and the processes driving productivity:
    - Stable isotope analysis to compare historical and contemporary feather samples to look at implications for ecosystem changes and impacts, diet and trophic status, and changes in primary productivity. Data are currently being analysed (e.g. Harper, van Heezik and Webster).
    - Examine the marine foodweb from primary producers, zooplankton, fish, to predators and examine the strength of connections. Examine oceanographic conditions and processes driving primary productivity off the coast (e.g. Christianen et al. 2017). Distinguish between energy sources to understand function of ecosystem and how this changes at different locations and times. What drives success in prey species? Compare foraging *versus* non-foraging areas and undertake spatial analyses of prey availability and associations with habitat structure.
    - Compare and analyse penguin foraging, diet and trophic status in combination with the biotic and abiotic conditions to identify links and correlations between oceanography,

benthic habitat, primary productivity and foraging behaviour. Measure foraging success simultaneously to determine how much prey animals encounter and consume under different conditions (e.g. accelerometers on TDRs; Carroll et al. 2016).

  - Investigate the use of two measures estimated from fisheries landings (mean trophic level of fish landed and mean maximum length of the species) to examine the status of the underlying ecosystems (e.g. Pauly et al. 2005).
  - Examine relationships between hoiho parameters (e.g. breeding success, survival, weight), fisheries catches of important prey species and environmental variables. Red cod abundance for example varies in relation to environmental variables, which may be similar to fluctuations in hoiho.
- Quantify and investigate overlap with hoiho and set net fisheries:
  - Characterise available information on hoiho and set net fishing (effort, landings and bycatch) to examine the likelihood of captures and the risk from the fishery.
  - Continue to work with MPI and Dragonfly Science to improve modelling of fisheries bycatch and risks to hoiho for all fisheries. Potential Biological Removal (PBR) levels currently set for hoiho are excessive and urgently require re-assessment.
- Quantify and investigate overlap with bottom fisheries (e.g. oyster dredging, benthic trawling):
  - Characterise available information on benthic fishing (effort, landings) to examine overlap with hoiho foraging areas and potential for risk from the fishery.
  - Characterise and map benthic habitat to determine foraging habitat, investigate and identify impacts of dredging / trawling and design effective marine protected areas. A multibeam echosounder (MBES) can be used for this purpose, and to identify areas of epifaunal reef habitat which could be allowed to rebuild (e.g. Cranfield et al. 2001).
- Investigate the effects of fisheries mitigation measures:
  - Investigate the likely effectiveness of temporal and spatial closures during critical times of the year, day, or at specific locations for conservation of hoiho.
  - Conduct an economic viability analysis of set net fisheries within hoiho range to assess the effects on fishers and economy as well as the effect of reduced penguin numbers on tourism operators and the local economy.
  - Investigate the implications of a shift from set netting to other methods (e.g. bottom longlining) for species like rig and school shark. Consider the consequences for penguins, fishermen (cost, effort, price of fish) and other species (target and non-target).
  - Examine the potential of mitigation measures for minimising bycatch (e.g. net colours, LEDs), olfactory or acoustic (e.g. pingers) techniques.
  - Investigate options for fisheries enhancement. Trial artificial regeneration of biogenic habitat (e.g. Cranfield et al. 1999; 2001) that has been dredged/trawled and is within foraging range of hoiho. Investigate succession of benthic fauna, associated biodiversity and 3-D complexity over time – aim to provide refugia for fish and food for penguins.

Conservation management recommendations

- Increase observer coverage particularly on priority vessels (e.g. set nets) where risk to hoiho is high. Observer coverage >50% is recommended to provide reliable bycatch estimates for rare species (Babcock et al. 2003), although 100% coverage is recommended across the range of hoiho.
- A dispensation from DOC should be implemented to enable fishers to hold bycaught hoiho (protected species). MPI state that it is currently illegal for fishers to keep bycaught hoiho onboard

their vessel. Valuable information on bycaught birds (ID number, sex, age) could be gleaned if birds could be kept by fishers and passed on to the appropriate authorities.

- Consider prohibition of set nets within hoiho habitat, particularly in areas where bycatch is high. Hoiho abundance is at a critically low level on the mainland and the birds are unable to sustain human impacts. Fisheries bycatch is one threat that we have the ability to eliminate.
- Consideration of appropriate marine protection measures to safeguard foraging ranges of hoiho, including: marine reserves and customary management options (e.g. taiāpure, mātaitai). Marine protected areas must be large enough and effective for the conservation of hoiho.
- Effective liaision with fishers to reduce bycatch and other fisheries impacts (e.g. set net liaison project). Provide information to fishers about hoiho and foraging habitat, so that fishers are better informed. Build relationships and encourage direct reporting of bycatch so that events can be learned from e.g. when (time of year / day), where (depth, site, proximity to reef/river) and how (type of gear, specific activity, operational details).
- Encourage improved consumer labelling, including detailing where and how fish were caught.

CLIMATE AND WEATHER RELATED IMPACTS

The global climate changes via natural mechanisms (e.g. variations in volcanic activity or solar radiation), but anthropogenic impacts (e.g. burning of fossil fuels, deforestation and animal-based agriculture) have accelerated the rate of change. Climate change alters the physical environment through increasing air and ocean temperatures, sea level rise, and changes in the frequency and severity of precipitation and extreme weather events (Timmermann et al. 1999; Cobb et al. 2003; Levitus et al. 2005). There is now substantial evidence of the ecological impacts of climate change (Walther et al. 2002; Parmesan 2006) which are well documented in the seabird literature (Grémillet & Boulinier 2009; Sydeman et al. 2012), including for penguins (Barbraud & Weimerskirch 2001; Forcada & Trathan 2009; Carroll et al. 2016).

A species' ability to respond and cope with climate change differs due to time and energy budgets, diet preferences, geographical location and specific life-history traits (Einoder 2009). Most species are well-adapted to short-term variability in climate or weather, but not to long-term shifts in climate and increased frequency or intensity of extreme events. Long-lived animals, such as penguins, are subject to environmental variability over extended time-scales. The high survival rates and longevity of seabirds tend to buffer populations against short-term changes and inter-annual fluctuations in prey (Furness & Camphuysen 1997). Climate change impacts many seabird species, particularly those with small populations, restricted distributions, inflexible feeding modes and limited ability to travel long distances (e.g. central place foragers). Typically, seabirds are negatively affected by climate change, but a few species have benefitted (Weimerskirch et al. 2012), including penguins (Lynch et al. 2012; La Rue et al. 2012).

The absence of long-term biological monitoring data makes it difficult to obtain direct evidence that climate change affects penguins (Trathan et al. 2015). It is likely that seabirds primarily experience climate change impacts indirectly via changes in their food webs or foraging ecology. Environmental variability has affected penguins through the distribution or availability of their mid-trophic-level prey (Trathan et al. 2007; Murphy et al. 2007). Penguins appear to respond to short-term changes to environmental conditions through modifications in breeding parameters, and long-term by altering their distribution and abundance (Forcada & Trathan 2009). If species cannot adapt to the pace of climate change, then major changes in distribution are likely, particularly for populations existing at the edge of suitable habitats (Hampe & Petit 2005). An inability to modify distribution or foraging ecology may lead to decreased survival and breeding success rates and an increased likelihood of extinction (Parmesan 2006).

The Pacific Decadal Oscillation results in patterns of climate variability over long (20+ year) time-scales (Mantua et al. 1997; Power et al. 1999; Newman et al. 2016). PDO is currently in a positive phase with strong westerlies and an enhanced frequency of El Niño events since the late 1970's. Atmospheric and ocean circulation are subject to natural variations in the medium term due to cyclical processes such as El Niño-Southern Oscillation (ENSO) and the Southern Annular Mode (SAM) (Forcada & Trathan 2009). ENSO currently has a 5 year period (Collins 2005), but its predictability is debated (Park et al. 2004). During an El Niño there is enhanced flow from the south in winter, and from the W / SW in spring and summer lowering mean air and sea temperatures (Bentjees & Renwick 2001). The opposite is true during La Niña with anomalous NE flow and above-normal temperatures. These oscillations are also influenced by long-term global climate change.

Despite New Zealand's small population and (globally) small contributions to climate change, it is the 5th highest emitter of greenhouse gases per capita and 2nd per GDP unit amongst Organisation for Economic Co-operation and Development (OECD) countries (OECD 2017). High rates of ocean warming (0.1˚C per decade) have been observed in southern New Zealand due to the warming of large current systems and strengthening sub-tropical gyres (Shears & Bowen 2017). In the marine environment, large climatological changes are predicted by 2100; mean SST is expected to rise by 2.5˚C, pH to decline by 0.33, resulting in a rate of change unprecedented in the last 25 million years, and primary production to decline by an average 6% (Law et al. 2016). Tide records show an average rise in relative mean sea level of 1.7 mm per year through the 20th century. Large-scale global projection models suggest a deeper mixed layer (-10 m), more ocean stratification and reduced chlorophyll off the east coast of New Zealand (Boyd & Doney 2002).

Changes are also likely to be evident on land in Otago: 0.6˚C to 0.9˚C warmer by 2040 and 0.6˚C to 2.8˚C warmer by 2090, with an increase of 4 to 25 days per year where maximum temperatures exceed 25˚C (Fitzharris 2010). Precipitation projections are highly variable, but Otago is expected to become wetter, particularly in winter and spring (increasing by 4-6% in Dunedin by 2090). Extreme rainy days are likely to become more frequent and spring melt will occur earlier which may increase the chance of floods. The frequency of extremely windy days in Otago by 2090 is likely to increase by between 2-5%, with an increase in the frequency of westerly winds over the South Island, particularly in winter and spring. Some increase in storm intensity and thunderstorms is likely.

Direct effects of weather and climate

Direct weather effects can cause disruptions to seabird productivity in both the terrestrial and marine environments. Short-term extremes in weather, for example, intense precipitation, storms and high temperatures, may affect seabirds directly (Jenouvrier 2013). Many climate models predict an increase in frequency of such events and thus provide an important mechanism whereby climate change can affect seabirds (Coumou & Rahmstorf 2012).

Breeding seabirds have strict thermoregulation requirements in their terrestrial (Ellis 1984) and marine habitats (Boersma 1976). Survival of chicks is dependent upon the prevailing weather conditions and temperature (Diamond & Devlin 2003). Incubation and brooding of chicks requires consistent temperatures to prevent thermal stress. Penguins have behavioural adaptations to compensate for heat (e.g. shaded nest sites, burrowing) or cold (e.g. huddling), but prolonged events or extreme conditions may test these. Hyperthermia (elevated body temperature) can result in death or deformity of an embryo or chick (Krausova & Peterka 2007), and even small increases in temperature can cause significant defects in Adélie penguins (Weinrich & Baker 1978). Dehydration can also occur in hot weather, particular if foraging conditions are poor. Small chicks in particular are susceptible to hypothermia (reduced body temperature; Boersma & Rebstock 2014). For hoiho, lower temperatures and increased rainfall are thought to provide preferable conditions especially during the critical nesting period. Heat stress at this time of the year is a key factor in breeding success; a cool and wet November maximises hatching success and reduces the potential for heat stress of neonate chicks (Seddon & Davis 1989).

High winds and increased precipitation can negatively impact seabirds (Frederiksen et al. 2008) and result in widespread breeding failure (Aebischer 1993; Mallory et al. 2009). For example, increased snowfall due to warm and wet conditions may contribute to Adélie penguin declines (Ducklow et al. 2007). Frequent intense storms soaking a chick's down and skin may ultimately result in reproductive failure of Magellanic penguins (Boersma & Rebstock 2014). Intense rainfall during the breeding season can also lead to flooding of penguin nests (Simeone et al. 2002), particularly for poorly chosen sites. A decrease in adult nest attendance as a result of storms or heat, can also increase predation risk for chicks (Frost et al. 1976; Stokes & Boersma 1998). Increased cloud cover and turbidity of water during storm events may affect the foraging success of visual predators such as hoiho. Prolonged difficulty finding prey could reduce the amount of food delivered to chicks, thus affecting their chances of survival.

Sea level rise and storm surges can lead to inundation and erosion of habitat, including nest and moult sites. Falling rocks and landslides due to intense periods of rainfall resulted in localised mortality of penguins at Tristan da Cunha (Cuthbert et al. 2009) and little penguins at Taiaroa Head, Otago Peninsula (Newshub 2017). Landslides may also lead to the loss of habitat for nesting and loss of access to nesting sites. Locations with unstable, erosion prone sediments may be particularly vulnerable; for example, large sections of Otago's coastline are at high risk of erosion. Otago's soft sediment shores are now retreating as rivers no longer replace sediment removed by currents and alongshore drift (Hils 2016). Human activities further exacerbate erosion (e.g. vegetation clearance for farming, sand and gravel mining, dredging, damming rivers). Extensive coastal retreat (~ 40m) was observed between 2000 and 2016 at Okia, a breeding site for hoiho on Otago Peninsula.

As relatively recent colonisers of mainland NZ, hoiho did not completely fill the niche left by the waitaha penguin (*Megadyptes waitaha)* (Boessenkool et al. 2009b; Collins et al. 2014). Rapid colonisation followed within a few decades of the extinction of the waitaha penguin in approximately 1500AD (Rawlence et al. 2015). There has been some speculation that the sub-Antarctic origins indicate that hoiho is used to a cooler climate and that thermal stress could be an issue (Waters & Grosser 2016). This is likely an oversimplification given all of the other terrestrial and marine impacts known to affect hoiho.

Indirect effects of weather and climate

Bottom-up effects (primary productivity driven)

Large-scale variation in climate can influence the productivity of marine ecosystems and thus indirectly impact seabird populations through a variety of mechanisms, which work their way bottom-up through the food web. Physical changes to temperature, salinity, nutrient gradients (e.g. upwelling) or changes in strength and direction of the wind can alter the depth of the mixed layer, and change the stratification of the water column (Sarmiento et al. 2004; Zeldis et al. 2005; Boyce et al. 2010). In turn these physical changes affect primary productivity in terms of timing, magnitude and species composition, which consequently has implications for food web dynamics (Sarmiento et al. 2004, Zeldis et al. 2005, Powell & Xu 2011). Simple marine food webs with few links and trophic levels can be fairly unstable, and climate change can trigger entire regime or community shifts (Walther et al. 2002). Seabirds are sensitive to changes that affect food supply, and as a consequence may suffer impacts on growth or reproductive success (Behrenfeld et al. 2006, Philippart et al. 2007, Grémillet & Boulinier 2009; Chambers et al. 2011; Powell & Xu 2011; Constable et al. 2014). There is also evidence that many marine populations are experiencing linear increases or decreases, rather than the cyclical patterns recorded historically perhaps due to climate change (Ainley & Hyrenbach 2010).

Low trophic level prey are most strongly influenced by the physical drivers of phytoplankton activity. Sea surface temperature (SST), wind stress and chlorophyll *a* are often used as a proxy for primary productivity and are the physical variables most easily and frequently quantified in climate change studies (Grémillet & Boulinier 2009). Climate driven oceanographic processes have a significant impact on the distribution and abundance of secondary consumers in upwelling ecosystems (e.g.

Humboldt and Benguela currents). The collapse of populations of small pelagic fish are accompanied by sharp declines in seabird populations (Pichegru et al. 2010).

Variations in SST (Fiedler 2002) can affect foraging behaviour and population dynamics of key predators (Bost et al. 2015). Many studies link changes in SST in particular with seabird productivity (Gjerdrum et al. 2003). During warmer events nutrient upwelling can cease, with consequent decline in primary productivity (Schreiber 2001; Ballance et al. 2006). High SST has been linked to a reduction in the availability of prey and consequently reduced reproduction, growth rates and increased chick mortality for seabirds (Bertram et al. 2001; Clausen & Putz 2002; Vargas et al. 2007; Irons et al. 2008; Crawford et al. 2008; Le Bohec et al. 2008; Carroll et al. 2016). SST anomalies may affect the position of fronts or the depth of the thermocline, thus increasing foraging distances or depths. In the last few years unusually warm water in the Gulf of Alaska merged with warm waters in southern California, transforming the coastal ocean, reducing the abundance of copepods that form the base of the food web, and consequently causing the death of many predators including common murres (Cavole et al. 2016).

Mass seabird mortality events have been linked to ENSO through its effects on SST. A strong El Niño in 1982/83 resulted in reduced breeding success for many seabirds in the Pacific (Schreiber & Schreiber 1984; Valle et al. 1987; Gibbs et al. 1987; Anderson 1989), as did the extended 1990–1995 event (Piatt & Van Pelt 1997). While strong events are catastrophic for some populations, the increasing frequency of weak El Niño events may also have a cumulative effect on reproductive success which may explain low recovery rates between strong events (Vargas et al. 2006). El Niño has impacted marine ecosystems around the Galápagos Islands, where the temperature of surface waters are indicative of the strength of the upwelling. Cold surface water conditions enhance the body weight of Galápagos penguins, but the warm unproductive waters associated with El Niño can cause the penguins to starve (Boersma 1998). After major temperature increases during strong events, penguin populations declined by more than 65% (Vargas et al. 2006; 2007).

There is growing evidence that breeding phenology is changing due to climate change, with seabirds becoming increasingly de-synchronised from their prey (Daunt & Mitchell 2013). Major changes in the abundance and species composition of plankton in the North Sea caused by warmer winter sea temperatures, for example, have contributed to the reduction in abundance and quality of species such as sandeels, with knock-on effects for seabirds (Daunt & Mitchell 2013). Time lags are expected between the physical effects of climate change and the biological effects on bird population dynamics. A time-lag depends on how far up the food chain birds feed. Timing mismatch can occur between important life-stages (e.g. chick rearing) and prey availability, so birds can’t maintain condition or provide resources for their offspring (Grémillet & Boulinier 2009). Decreases in hatching success and in survival of Southern rockhopper penguin chicks have been attributed to the increasingly poor condition of parents as they arrive to breed, likely because environmental change has led to poor feeding opportunities at overwintering grounds (Crawford et al. 2008).

Climate change is suspected to have played a part in the population declines of penguin species in New Zealand over the last century. Rising SST was implicated in a massive decline in the number of rockhopper penguins on Campbell Island, likely due to changes in the food supply (Cunningham & Moors 1994). Climate change and fluctuations in ocean temperatures affect prey composition which in turn affects little penguins (Perriman et al. 2000).

Numbers of breeding pairs of hoiho fluctuate from year to year (Seddon et al. 2013), and evidence suggests that these fluctuations (in part) can be linked to climate change, in particular changes in SST (Peacock et al. 2000; Mattern et al. 2017). Typically, El Niño conditions are good for hoiho productivity as they bring cool SST and good feeding conditions to the Otago coast; under La Niña the sea is warmer and starvation issues may occur. Fledgling success increased in seasons that were slightly cooler and wetter than average (Peacock et al. 2000). Adult survival was low in periods with warmer than normal SST, and high with cooler SST, and a third of the variation in hoiho population numbers was explained by SST alone (Mattern et al. 2017). Consecutive years with predominantly La Niña patterns increase stress on the penguins. SST itself however is not likely the mechanism for climate change impacts. As primarily benthic feeders, hoiho may be affected by a change in the location of the mixed (i.e. productive) layer; prey may be harder to reach, either too deep or far offshore, or unavailable at specific times (e.g. when feeding chicks).

In New Zealand, significant relationships exist between the spawning success of marine species and variability in the climate, in particular SST and mean wind strengths (Renwick et al. 1998). Strong winds may inhibit foraging, as well as the duration and intensity of foraging trips and associated diving (Finney et al. 1999). Conversely, oceanic winds can aid mixing processes and drive foraging success (Dehnhard et al. 2013). Temperature affects the annual biomass of many fish species in New Zealand (Beentjes & Renwick 2001), with warmer than normal conditions reducing recruitment (Takasuka et al. 2008). A strong correlation was observed between SST and red cod abundance, where good recruitment was correlated with lower SST and a prevalence of SW weather patterns (Bentjees & Renwick 2001). These conditions are associated with increased mixing and enhanced upwelling of nutrient rich cooler water (Renwick et al. 1998) which supports populations of plankton (Longhurst 1998). It is likely that these upwelling events enhance red cod survival and spawning success by increasing the available food supply during early life stages (Bentjees & Renwick 2001). There is some indication from fisheries catches and hoiho population counts, that a good year for red cod was also good year for hoiho, at least until the early 1990s. This is not necessarily because a reduction in the abundance of red cod causes the decline in hoiho, but that the same mechanisms most likely affect both species.

Top down effects of climate change (predators, invasions)

Less well documented are the top down effects of climate change on seabird productivity (Ainley et al. 2007). While climate forcing is usually regarded as a driver of bottom-up control, rapid climate shifts may also re-organise a system's trophic control (Baum & Worm 2009). The climate effects on the physical marine environment affect feeding rates and competition, thus favouring certain species over others (Ottersen et al. 2010). If ocean conditions are significantly different to 'normal' they may facilitate the introduction of novel species not typically found in an area. Invading species have the potential to outcompete natives, or may increase the predator load in a region (Worm & Myers 2003; Ainley et al. 2006).

Some species of fish have a preference for warmer waters; therefore high recruitment and faster growth rates are correlated with warmer conditions during La Niña events (Francis 1994; Renwick et al. 1998; Maunder & Watters 2003), with decreases in larval recruitment during El Niño events (Zeldis et al. 2005). Warmer waters could attract northern species of fish further south including tuna, mako shark and kingfish. Anecdotal information from local fishermen supports this. An increased presence of large predatory fish species due to increasing temperature may have consequences for local marine fauna.

Increased survival of pathogens may also occur due to changes to climatic conditions, resulting in greater incidence and prevalence of disease (Harvell et al. 2009). This is likely to be a consequence of several factors, including the expansion of pathogen ranges, increased host susceptibility due to increasing environmental stress, and the expansion of potential vectors (Hoegh-Guldberg & Bruno 2010).

Warmer regional waters and altered ecosystems particularly combined with an increase in nutrients may result in an increased frequency of algal blooms (Shumway et al. 2003). Algal blooms can produce toxins which have been identified as the cause of death for a large number of rockhopper penguins in the Falkland Islands (Uhart et al. 2004). See more on toxic algal blooms in the section on pollution.

Ocean acidification

Climate change and the effects of ocean acidification may reduce the abundance of habitat forming species (e.g. bryozoans, molluscs). The ocean absorbs CO_2 from the atmosphere lowering the pH of sea water, making it harder for shellfish to produce shells and reducing vital plankton populations. In New

Zealand the oceans have become 8% more acid between 1998 (8.103 pH) and 2014 (8.062 pH) (Ministry for the Environment & Statistics NZ 2016). Although not affecting hoiho directly, acidification impacts animals at lower trophic levels which support the food web. Acidification is an issue for bryozoan beds which provide important habitat for fish and other species off Otago and Southland (Batson & Probert 2000) and may be foraging areas for hoiho. A decrease in pH has also been suggested to potentially favour non-calcifying organisms such as jellyfish (Atrill et al. 2007). The potential impacts of jellyfish are discussed earlier in this report (see section "other effects of overfishing").

Management of climate

With knowledge that climate negatively impacts the hoiho population we can undertake some mitigation measures at a local level. For example, we can ensure hoiho have access to appropriate shade and shelter from the sun during hot weather. This means either provision of nest boxes or planting of trees and shrubs in penguin breeding and roosting areas. Planting trees has the additional benefit of reducing carbon dioxide in the atmosphere, thus helping to mitigate climate change. In the case of climate impacting the penguin's food supply (either in terms of abundance or quality) or heat stress, we can invest effort in supplementary feeding and rehydration. Knowledge of the driving forces help to predict and highlight months or years that are likely to be exceptionally problematic and therefore when we should intervene, particularly at critical times of the year (e.g. chick raising and moult).

We should not treat climate change as inevitable and as an excuse to do nothing. We need to manage other impacts more effectively making hoiho more resilient to climate change. It is problematic to manage the effects of climate change on a regional scale, although on a national level we should encourage all necessary steps to alleviate further global warming and sea level rise.

CLIMATE RECOMMENDATIONS

Gaps in knowledge

- Lack of understanding about the mechanisms of climate change impacting on hoiho and the nature of the interactions between climate, plankton and penguin prey species.

Research recommendations

- Investigate underlying coastal and oceanographic processes, including the role of fronts, temperature, currents, upwelling, eddies, island effects, stratification and their effect on nutrients and primary productivity. Specifically, examine the mechanism behind SST affecting prey of hoiho.
- Examine whether the SST impacts modelled for the Boulder Beach hoiho population (Mattern et al. 2017) are applicable to other sites, and how representative SST changes in Otago Harbour are to processes on the coast.
- Compare hoiho abundance and breeding success, to those for other marine vertebrates in similar locations (e.g. Hector's dolphin, sooty shearwater, NZ fur seal, NZ sea lion, red-billed gulls). Do trends for these species help elucidate mechanisms for climate influence?
- Examine changes over time to oceanographic variables (salinity, temperature, pH, dissolved O_2) using data from the Munida transect and the NZ Ocean Acidification Network measuring stations and remote sensing (nutrients, chlorophyll).
- Examine the impacts of large scale climate oscillations (PDO, ENSO and SAM) on primary productivity, higher trophic levels and ultimately hoiho populations.

- Examine temperature differences between the subantarctic and mainland, and physiological differences between the waitaha penguin and hoiho.
- Examine evidence for a regime shift in the marine ecosystem around NZ (e.g. Chavez et al. 2003).

Conservation management recommendations

Fewer conservation management options are available when it comes to mitigating climate change in the marine environment (Chambers et al. 2011).

- Land-based management options for buffering climate impacts include provision of adequate shade in nesting and moulting habitat to minimise thermal stress, and onsite rehydration of birds if required.
- Continue planting to reduce further coastal erosion, particularly on high-risk slopes in hoiho habitat and to help mitigate the impacts of climate change in general.
- Assessment of beach and coastal access points for hoiho in the face of erosion issues at some sites (e.g. Okia) and consider the most appropriate protection of penguins from landslips / rockfall in high risk areas.
- Use 3D ortho-maps (gathered using drone technology) to examine topographic changes, sea level and erosion over time, so we can plan appropriate management strategies (e.g. research at Okia).
- Encourage long-term governmental actions for mitigating climate change e.g. reducing and offsetting emissions.

POLLUTION

Hoiho inhabit marine and terrestrial environments and consequently are exposed to a range of pollutants which cross the boundaries of both habitats. Penguins are most vulnerable to pollution in the sea where they feed, and are therefore likely to ingest or come into contact with pollutants. Toxins or pollutants released on land often end up in the sea through storm water, sewage effluent and run-off. Put into context however, "*no form of ocean pollution is in any way comparable to the ecological removal of ca. 70 million tonnes per year of fish from the ocean ecosystem*" (Parsons et al. 1984), which has since been confirmed by numerous studies (e.g. Grémillet & Boulinier 2009).

Pollutants are generally classed as biodegradable (e.g. sewage effluent, organic matter) or non-biodegradable (e.g. heavy metals, plastics, detergents) (Wasi et al. 2013). Globally, the majority of organic pollutants originate from five major industrial categories: petroleum refining, organic chemical and synthetic industries, steel mining and coal conversion, textile processing, and pulp and paper milling (Wasi et al. 2013). Offshore ecosystems have not escaped urbanisation and industrialisation, with the extraction of mineral resources and pollution from vessel traffic (Halpern et al. 2008). The use of gasoline, pesticides and fertilizers leads to the release of pollutants directly into the environment (Richards & Shieh 1986), as well as effluent from wastewater treatment plants, storm-water from urban and industrial areas, accidental spillage, illegal dumping, seepage from landfill sites, effluent from farms, and uncontrolled hazardous waste sites.

The majority of pollutants are more likely to impact hoiho along the mainland New Zealand coast in proximity to humans, particularly larger settlements (e.g. Dunedin).

Oil pollution

One of the major anthropogenic causes of mortality in penguins globally is from oil spills which can have devastating localised effects particularly for small populations (García-Borboroglu et al. 2008).

Major oil spills from tankers carrying oil, vessels using oil, or leakage during extraction or drilling operations, can make for acute pollution events. Chronic oil pollution from small-scale but frequent discharges of oil (e.g. ballast water, spillage during loading at ports) can be as damaging to seabirds, but receives limited media attention (Gandini et al. 1994).

Penguins are at high risk from petroleum pollution as they spend lots of time at the sea surface, and near to the coast where spills are more likely to occur. There are two major pathways, oil ingestion and the physical effects of oiled feathers. Penguins require their plumage to be in prime condition; oiling reduces the waterproofing and insulation properties of feathers, reducing buoyancy and increasing risk of drowning or hypothermia. Ingestion of even small quantities of oil are enough to lower hormones and suppress breeding in penguins (Fowler et al. 1995), but in larger doses poisoning may occur. Petroleum can also irritate the skin, eyes, oral and nasal cavities.

Spills continue to be a major issue for penguins particularly off South America and South Africa where the path of major shipping lanes are in close proximity to colonies. Oil pollution has been a major issue for Magellanic (Gandini et al. 1994; Fowler et al. 1995; García-Borboroglu et al. 2006) and African penguins (Erasmus et al. 1981).

Key factors influence the level of impact of an oil spill, including: the type of oil, spread of the slick and weathering characteristics, sensitivity of the local environment, timing of the incident (during breeding or migration periods) and the species present at the spill location. The shipping lanes around New Zealand are not busy in global terms, but shipping did impact little penguins during the MV Rena grounding in 2011 on Astrolabe reef (Chilvers et al. 2015; Schiel et al. 2016). Even a small vessel has the potential to cause destruction of a hoiho colony, due to their restricted range. Risk is increased if spills occur adjacent to nest sites during the breeding season as birds may swim repeatedly through the contaminated site. Two ports within hoiho habitat, Lyttelton and Otago, are amongst the six largest in New Zealand for container traffic (Ministry of Transport 2017) and smaller ports on the mainland include Timaru and Bluff. An increasing number of cruise ships visit Otago Harbour, and the sub-Antarctic Islands (e.g. Enderby and Campbell Island) in proximity to large hoiho colonies.

Marine debris

Marine debris, is a major issue for seabirds via two main pathways - ingestion and entanglement (Derraik 2002; Ryan et al. 2009). Even in remote locations, such as the Antarctic Peninsula, Falkland Islands and South Georgia, beach surveys have revealed substantial amounts of marine debris (Otley & Ingham 2003). A large proportion of waste is discarded from ships, including fishing vessels (Otley & Ingham 2003), and lost fishing gear (or ghost gear) is a cause of mortality in air-breathing seabirds. Plastic dominates marine debris and persists in the marine environment as it is slow to biodegrade (Ryan et al. 2009). Plastic now forms 72.4% of the litter on coastlines in New Zealand (Brown et al. 2015).

Prior to 2012, direct ingestion of plastics was reported in 80 of 135 species (59%) of seabird and on average 29% of individuals; and this rate is increasing (Wilcox et al. 2015). Surprisingly, ingestion of marine debris was higher in seabirds feeding at intermediate (3–6 m) and deep (20–100 m) waters than those feeding at the surface (<2 m) (Tavares et al. 2017). Ingestion of plastic may cause a physical blockage in the gut, and transmission of toxic chemicals (Tanaka et al. 2013; Lavers et al. 2014).

A small proportion of penguins are killed at South Georgia due to ingestion of or entanglement in plastic debris, and plastic yokes from canned drinks have been a problem for little penguins (Trathan et al. 2015). Plastic marine debris has not specifically been observed during necropsies of hoiho (Biz Bell *pers. comm.*), but should not be discounted as a risk.

Small pieces (< 5mm) of microplastics may be ingested secondarily via prey (Provencher et al. 2017), however the rate of ingestion by fish is currently low in the Southern hemisphere compared to the Northern hemisphere (Cannon et al. 2016; Rummel et al. 2016).

Sedimentation

Sedimentation occurs naturally due to earthquakes, volcanic eruptions and natural deposition from rivers, but there are also numerous anthropogenic causes which impact coastal waters, including roads and buildings, deforestation and erosion, agriculture, storm water runoff, mining and dredging of harbours and shipping lanes. In New Zealand, sedimentation is arguably the most important land-based stressor (Morrison et al. 2009).

In estuaries, sedimentation over an extended period can be captured in stratified layers, and used to calculate sediment accumulation rates (SAR). Waikawa estuary (Catlins) shows the increase in sedimentation; an average SAR rate of 1.5 mm/y occurred between 1878-1967, increasing to 3.1 mm/y from 1967–1996, and to 10.7 mm/y from 1996-2007 (Morrison et al. 2009). Many rivers discharge to the coast, where freshwater flow creates a buoyant, low salinity plume which typically contains large quantities of nutrients, sediment and potentially pathogens. Large rivers on the South Island east coast (e.g. Clutha) have plumes that can extend northwards for at least 100 km during high flow events, merging with plumes from other rivers (e.g. Taieri and Kaikorai); resulting fine sediment is deposited to the north of the Otago Peninsula (Morrison et al. 2009).

Sedimentation can cause suspended sediment and deposition effects, and associated decreases in water clarity. Water turbidity may reduce prey availability and is likely to affect foraging behaviour particularly for visual predators. For example, the large-scale release of sediment into coastal waters from inshore mining operations along Namibia's southern coast threatens foraging habitats of African penguins (Trathan et al. 2015). Sedimentation may directly impact fish and invertebrates by clogging the gills of filter feeders decreasing their filtering efficiency, reducing settlement success and survival of larval and juvenile phases and reducing the foraging abilities of finfish (Morrison et al. 2009). Indirect impacts may include the modification or loss of nursery habitats, especially those composed of habitat-forming (biogenic) species (e.g. horse-mussel, bryozoan, tubeworm, sponge and kelp beds) (Morrison et al. 2009). Sedimentation can disrupt, obliterate or re-organise nearshore habitats in particular (McFadgen 2007) and has contributed in some cases to the formation of temporary land bridges allowing land predators access to islands (Kemper 2006).

Within hoiho habitat, sedimentation issues are more likely to be from anthropogenic causes. Deforestation and agriculture occur throughout hoiho habitat, and Dunedin has a concentrated human population with associated impacts from storm-water run-off, outfalls and coastal development. Localised sedimentation occurs off Otago Peninsula due to the dredging of the Otago Harbour shipping channel and the dumping of dredge spoil at a number of coastal locations off Aramoana. Benthic effects associated with spoil dumping include smothering of fragile communities, and re-suspension of sediment and turbidity increases with wind and wave action (Fenwick & Stenton-Dozey 2016). Dredging may thus affect the foraging capability of hoiho due to reduced visibility or impacts on prey in benthic environments.

Increased nutrients and eutrophication

Pollution may occur at point-sources such as marine outfalls for sewage, factories (e.g. dairy and meatworks) and storm-water outflows. Outfalls are known to increase nitrogen loading in their immediate proximity (Costanzo et al. 2001) which can result in concentrating food and attracting seabirds (O'Sullivan 1971) or in high quantities can overload the marine system with nutrients. Pollution from outfalls, particularly those that are poorly treated, have potential implications for hoiho along the mainland coast. Mattern et al. (2017) suspected that the Tahuna sewage outfall (alongshore from Boulder beach, Otago) played a role in the die-off of adult hoiho in 2012/13, as it coincided with the malfunction of the sewage plant. The majority of deaths occurred downstream of the sewage outfall, although one was at Blackhead and another at Kuri Bush (both slightly upstream of the outfall, birds may however have fed downstream). Ineffective biological treatment resulted in a spike in *E. coli* concentrations during the malfunction. Similar hoiho mortality events in 1989/90 and 2016/17 with the same underlying symptoms (see HABs section) had a wider spatial spread (Catlins and North

Otago), suggesting that a localised sewage outfall was not the sole cause. Sewage may also impact benthic fauna, and habitat-forming bryozoans in particular are sensitive to the effects of sewage (Wood et al. 2012).

Non-point source pollution is the result of run-off from farms (dairy effluent, pesticides, fertiliser), gardens, septic tanks and industrialised areas. Increased discharge in rivers due to rain and storm events leads to a rise in nutrients, particularly nitrates and phosphates in the coastal environment. Eutrophication is the enrichment of a water mass, usually with excess nutrients which induces growth of plants and algae. The resulting formation of an algal bloom can be an indicator of ecosystem health. The impact of a bloom ranges from death or illness of humans and animals, to suffocation of fish, blocking of light to bottom-dwelling plants, or depletion of oxygen in the water, discoloration of the water, and fouling of land with foam or weed. An algal bloom resulting in the formation of dense green water was visible on a penguin camera (in November 2016) and is therefore known to occur in hoiho habitat.

Toxins released into the coastal system via point or non-point sources are discussed below.

Heavy metals

Heavy metals are naturally present in the environment but concentrations are increased through industrial activity. Metals can be toxic at certain concentrations, although in small quantities some are essential for body metabolism and can be absorbed via water, sediment or diet (Bosch et al. 2015). Accumulation may depend upon the trophic level of an animal (bioaccumulation), other biological factors and the chemical or physical state of the metals. The effects of metals are not always independent and can interact, with either positive (increasing uptake of other metals and minerals) or negative results (decreasing the uptake)(Bosch et al. 2015). Different species and individuals accumulate metals at varying rates in various body tissues (Lock et al. 1992). Heavy metal accumulations are an increasingly prevalent environmental contaminant, even for remote and isolated seabird communities (Jerez et al. 2011; Blévin et al. 2013; Trathan et al. 2015).

During a mass mortality event of hoiho in Otago in 1989/90, samples were analysed for heavy metals (copper, zinc, iron, lead, arsenic, selenium, cadmium and mercury), however none were found (Gill & Darby 1993). Hoiho were also tested for heavy metals (mercury, lead and selenium) during an investigation of a rare mass outbreak of craniofacial deformity (Buckle et al. 2014). Eight chicks were seriously affected at Okia reserve on Otago Peninsula and mild cases were reported in ten chicks elsewhere in Southland and Otago in the same year (Buckle et al. 2014). None of the metals was identified as a causative factor, but the research was hindered by a lack of baseline data (Buckle et al. 2014).

Lock et al. (1992) examined the metal concentrations in seabirds in New Zealand, including four penguin species (Fiordland crested, erect-crested, rockhopper and little). The South Pacific likely has low lead deposits because of the distance from industrial sources; hence lead was typically low in most seabirds apart from scavengers (e.g. gulls) (Lock et al. 1992). Levels of lead in African penguins were consistent with background exposure and declined between 2007 and 2011, potentially due its reduction in vehicle fuel (Summers 2012).

Squid and crustaceans contain high levels of cadmium (Martin & Flegal 1975; Fenaughty et al. 1988) and so it follows that seabirds feeding on these prey groups exhibited the highest levels of cadmium (Lock et al. 1992). Levels of cadmium in African penguins were consistent with background exposure, although levels increased between 2007 and 2011 (Summers 2012); the cause is unknown but potentially could reflect a change in diet. Kidney damage can occur in seabirds at 100-200 μg/g of cadmium, similar to levels found in New Zealand and thought to indicate chronic low-level exposure (Scheuhammer 1987). Squid, in particular arrow squid, are known prey of hoiho (van Heezik 1990).

Large inter-species variation exists in the mercury concentrations in seabirds, but was relatively low in four species of penguin (Lock et al. 1992). Mercury concentrations reported in penguins, particularly those in the Antarctic, are currently below the threshold for adverse impacts (Brasso et al. 2012). Mercury is eliminated annually in penguins when feathers are replaced (Lock et al. 1992).

Embryonic or foetal malformations (similar to the deformities observed) have been reported in avian species exposed to selenium (Ohlendorf et al. 1990; Spallholz & Hoffman 2002), however low accumulation rates of selenium were found in hoiho livers (Buckle et al. 2014).

Persistent organic pollutants

Persistent organic pollutants (POPs) are compounds that are highly resistant to environmental degradation. In 1995, the United Nations Environment Programme recognised POPs for their adverse effects on human health and the environment and placed a global ban on twelve particularly harmful and toxic compounds, including Hexachlorobenzene Polychlorinated biphenyls (PCBs), Dichlorodiphenyltrichloroethane (DDT) and Polychlorinated dibenzofurans. Many of these substances are herbicides and pesticides (e.g. DDT, hexachlorobenzene) which are used in agriculture and can cause localised impacts where they are sprayed or get into the water system via run-off. PCBs have many uses, including paint and plastics, and careless use results in them entering rivers and stormwater drains, and eventually the sea. The Stockholm Convention on Persistent Organic Pollutants was adopted in 2001 (Stockholm Convention 2009), and since then the list of POPs has been expanded to include some polycyclic aromatic hydrocarbons (PAHs), flame retardants and other compounds.

POPs may affect the immune system of seabirds, for example they may acquire higher parasite loads when exposed to high pollution concentrations (Jara et al. 2018). POPs are prevalent even for remote and isolated seabird communities including Antarctica (Trathan et al. 2015; Jara et al. 2018). Although research has indicated the presence of POPs in penguins (Corsolini et al 2007, Jara-Carrasco et al. 2017), little is still known about the potential adverse effects on such species (Jara et al. 2018). Like heavy metals, POPs can be a serious threat to penguins because they bioaccumulate and biomagnify in marine food webs, particularly species which feed at a high trophic level (Szopińska et al. 2016).

Little is known about the effect of POPs on hoiho. The investigation of an outbreak of craniofacial deformity in hoiho included testing for four major toxin groups; polychlorinated dibenzo-p-dioxins and polychlorinated dibenzofurans, polychlorinated biphenyls, organochlorine pesticides, and polybrominated biphenyl ethers (Buckle et al. 2014). None of these toxins was identified as an obvious causative factor, but again there was a lack of baseline data (Buckle et al. 2014). Hoiho at the Okia reserve were potentially exposed to toxins, as the beach was used historically as a bombing range, and is adjacent to farms which use petrochemicals (Buckle et al. 2014).

Marine biotoxins

Mass mortality events involving seabirds can be the result of deleterious conditions at sea, which include biotoxins (Shumway et al. 2003). The impact of biotoxins on marine life is well documented (Landsberg 2002) and may accumulate following ingestion of prey (bioaccumulation); or directly through contact with the water (e.g. preening feathers).

Harmful algal blooms

Algae that grow very fast can form dense populations or blooms. There are thousands of species of phytoplankton, but only ~2% are capable of producing toxins. Harmful algal blooms (HABs) can be the result of excess nutrients in the marine environment, or a combination of environmental conditions (e.g. reduced water circulation, high temperatures, hurricanes, floods or drought). Toxic phytoplankton blooms occur naturally and are thought to be increasing in frequency and intensity (Shumway 1990; Smayda 1990; Hallagraeff 1993; Burkholder 1998) particularly where there is an influx of anthropogenic nutrients into coastal waters. Algal blooms are good indicators of marine ecosystem health.

Ecosystem effects can occur as toxins are transferred through the food chain, affecting larval and adult forms of marine organisms. HAB toxins may kill fish or shellfish directly, or affect animals higher up the food chain if they ingest sufficient toxins (Lefebvre et al. 1999; Scholin et al. 2000).

A range of HAB groups are capable of producing toxins, including dinoflagellates, diatoms, raphidophytes and hapophytes (marine) and cyanobacteria (freshwater). A number of toxins derived from micro-organisms have been implicated in HABs; okadaic acid and dinophysis which cause diarrheic shellfish poisoning (DSP), saxitoxins cause paralytic shellfish poisoning (PSP), domoic acid is associated with amnesic shellfish poisoning (ASP), brevetoxins cause neurologic shellfish poisoning (NSP), azaspiracids cause azaspiracid shellfish poisoning (AZP), ciguatoxins and maitotoxins are linked to ciguatera fish poisoning (CFP), and tetrodotoxins cause pufferfish poisoning (Campas et al. 2007).

There is some knowledge of toxic algal poisoning in penguins. A HAB caused PSP and resulted in mortalities of a large number of Southern rockhopper penguins and other seabirds in the Falkland Islands (Uhart et al. 2004). HABs are also suspected to have killed 13,000 Magellanic penguins in Chubut, Argentina (Shumway et al. 2003). A mass mortality of little penguins and other seabirds in New Zealand in summer 1992/93 was not conclusively linked to algal toxins although presence of toxins in the general vicinity was suspicious (Rhodes et al. 1993; Smith et al. 1993). Such events may become a greater problem in the future as a result of regional warming and altered ecosystems (Shumway et al. 2003). The food supply of Gentoo penguinswas poisoned during a HAB in 2002 (Pistorius et al. 2010).

No characteristic or diagnostic gross lesions have been described for most algal toxin poisonings of wild birds. Many toxins, particularly neurotoxins, have a chemical effect that does not produce a grossly observable lesion. Evidence is often circumstantial, for example, visible blooms of red tides or cyanobacteria in the vicinity of dead birds. Factors triggering toxin production in freshwater and marine algae are poorly understood, but may include temperature, turbidity, nutrient input, solar radiation and bathymetry. Algal blooms, for example, can follow summer storms which disrupt the summer thermocline and cause upwelling of nutrients.

Toxic algal blooms were one of major suspects in the unexplained mortality events of adult hoiho in 1989/90 and 2012/13, although there was no direct evidence. The 1989/90 event on Otago Peninsula and in North Otago resulted in the deaths of 150 birds and reduced the breeding population by 40% (Gill & Darby 1993; Efford et al. 1996). A mass mortality centered on Otago Peninsula in 2012/13 resulted in the deaths of 67 birds (Gartrell et al. 2016). The deaths were unrelated to prey availability as birds were found in good body condition not indicative of poor nutrition (Gill & Darby 1993). In 2016/17, nine deaths occurred between North Otago and the Catlins, of which five showed lesions consistent with the 2012/3 event (four were too decomposed to test). Red blood cell destruction particularly in the lungs, liver and spleen were common symptoms (erythrophagocytosis and haemosiderosis). The rapid onset of death, lack of major gross pathological changes, constrained geographic area and limited time period are consistent with acute exposure to a toxin (Gartrell et al. 2016). However, the 2016/17 event had a much wider geographical spread (from Moeraki to the Catlins) and it seems unlikely that a toxin would target an individual species, typically affecting other birds and animals further down the food-chain (Rhodes et al. 1993; Smith et al. 1993). Potentially hoiho are more sensitive to a toxin, or it is of a benthic nature meaning they are more susceptible. Toxins are notoriously difficult to isolate from seabirds, as death is quick, and often nothing remains in the stomach. Waters off the Otago coast are not thought to be a particular hotspot for algal blooms, although short-lived blooms of the harmless *Myronecta rubra* (Smith 1994) and several species of *Pseudonitzchia* (which is not always toxic) have been observed.

Cyanobacteria (blue-green algae) in rivers and lakes can become highly toxic under certain conditions. Blooms are more likely during summer due to favourable conditions, including warm temperatures, ample sunlight, low or stable river flows and nutrient inputs, and can develop very rapidly. In Otago, water is routinely sampled at some sites where cyanobacteria is commonly found, including Lake Pegasus, Roxburgh, Lake Waihola and Tomahawk lagoon. There may be some risk of hoiho ingesting freshwater directly, or using it to cool down, splashing it on feathers and ingesting it during preening. Hoiho also use streams to access nest sites.

Toxic marine creatures

Several marine creatures contain toxins. There are no sea snakes in New Zealand except for the occasional vagrant north of hoiho habitat, but several fish contain toxins (e.g. lionfish) and some potential exists for hoiho to ingest, or come into contact with poisonous spines.

Jellyfish are another source of toxins and their venom can produce a mixture of haemolytic, cardiovascular, antioxidant, and cytotoxic effects (Long & Burnett 1989; Kim et al. 2006; Li et al. 2014; Kang et al. 2009). The components of jellyfish venoms and the mechanism for action is still far from being understood (Gopalakrishnakone et al. 2016). Juveniles of some fish species find refuge from predation under jellyfish (Lynham & Brierly 2007) and hoiho are known to exploit this opportunity. Camera footage shows individuals feeding on small fish underneath jellies (Mattern, *pers. comm*) as well as ingesting jellyfish directly (Thiebot et al. 2017).

Invasive species

Marine invasive species (e.g. seaweeds, invertebrates and fish) are on the increase and are a threat to biodiversity (Bax et al. 2003). At least 158 invasive marine species have been identified in New Zealand; the majority were accidentally introduced on the hulls of vessels, in ballast water or intentionally (Cranfield et al. 1998). Invasive species may not directly impact hoiho, but may have indirect impacts via prey competition or habitat modification. It is likely that a changing climate and increasing ship traffic will increase the spread and establishment of marine invasive species.

Sound

Unlike many species of marine mammal and fish, it is unknown whether seabirds use underwater sound for essential functions such as communication and navigation (Crowell 2016). The underwater hearing capability of penguins remains untested, although recent work has examined the hearing of other seabirds (Crowell 2016). The impact of underwater sound on penguins is unknown, but it may cause stress and avoidance of particular areas. Anthropogenic activities are increasing in the marine environment, including seismic testing, mining and shipping; and since penguins cannot fly they are unable to escape easily from underwater sounds.

Management of pollution

Pollution does not recognise boundaries so marine protected areas are ineffective for management of pollution, instead it needs to be tackled at the source. Identification of the polluter is easier for some forms of pollution than others but ultimately regulation and enforcement are required, for which the appropriate regional and district councils have responsibility.

In terms of oil pollution, prevention should be considered more important than rehabilitation. Successful cleaning and rehabilitation of little penguins was carried out after the Rena oil spill in New Zealand with post-event monitoring revealing no difference in behaviour between rehabilitated and non-rehabilitated birds (Chilvers et al. 2015). To deal with pollution incidents effectively preparation is key. A disaster management plan, kit and wildlife response teams should be established in advance. Massey oiled wildlife response team, for example, are in place to co-ordinate efforts in the event of a spill (including de-oiling), and provide training and put in place support networks in preparation for a pollution event. The best outcome if oil is threatening hoiho habitat may be to remove individual birds ahead of oil making landfall.

Early detection and routine monitoring is the most effective way to mitigate the effects of HABs. Detecting HAB species is typically done using settling chambers and visual inspection which can be tedious and time consuming. Remote sensing can be used for blooms that are coloured. Satellite ocean colour sensors' data are widely used for the detection, mapping and monitoring of phytoplankton blooms. Since the late 1970s, various ocean colour satellite sensors (e.g. CZCS, SeaWiFS, MODIS and MERIS) have been used and algorithms developed. Present challenges include overcoming the limitation of these algorithms in coastal waters (due to sedimentation and turbidity) and refining detection limits in various oceanic and coastal environments. To understand the spatio-temporal patterns of algal blooms and their triggering factors, it is essential to consider the effects of environmental parameters (e.g. temperature, turbidity, solar radiation and bathymetry).

POLLUTION RECOMMENDATIONS

Gaps in knowledge

- The causes and triggers leading to unexplained mortality events.
- Phytoplankton and cyanobacteria species composition and abundance within hoiho habitat, potential for toxicity and likely symptoms of contact with toxin.
- Pollution levels around the coast and in rivers within hoiho habitat.
- Levels and effects of Persistant Organic Pollutants (POPs) in hoiho.

Research recommendations

- Continued investigation of unexplained mass mortality events (potentially related to marine toxins) by DOC, YEPT, Massey University and appropriate researchers.
- Examine the direct and indirect impacts of sedimentation and eutrophication on hoiho and the wider ecosystem.
- Investigate the potential impact of dredge spoil on hoiho using a Multibeam Echosounder (MBES) system to examine the benthic impacts, as well as sediment in the water column.
- Investigate the levels of POPs in hoiho (e.g. Jara-Carrasco et al. 2017) and their impact (e.g. Jara et al. 2018).
- Research into trace metal levels in penguin scat and feather samples and their impact (e.g. Abdullah et al. 2015).
- Examine hoiho for any evidence of plastic ingestion during necropsies.

Conservation management recommendations

- Development of an unexplained mortality response plan for future events, including triggers, event coordination, field assessments, sampling priorities, roles and responsibilities and stakeholders.
- Continued disaster preparation for oil spills, including training, a disaster management plan and a kit for clean ups.
- Ensure that an effective sewage and water pollution monitoring scheme is established (with appropriate managing bodies).
- Continued support of waste reduction and beach clean-up operations and advocacy.

MARINE PREDATION

Predation of hoiho in the marine environment is exclusively by native animals (e.g. pinnipeds, sharks), unlike terrestrial predation which is predominantly due to invasive mammals. It is impossible however, to estimate the population wide impact of marine predation, as quantitative accounts of seabird predation are rare (DuToit et al. 2004), and a large proportion of predation events go unobserved.

Pinnipeds

New Zealand sea lions are known to depredate several penguin species, including rockhopper (Morrison et al. 2016), gentoo and hoiho (Moore & Moffat 1992; Schweigman & Darby 1997; Lalas et al. 2007). Predation by sea lions is often touted as one of the reasons for the decline in hoiho numbers, however, both species have co-existed in the marine environment for decades and historically there were larger populations of both (Childerhouse & Gales 1998). The number of sea lions inhabiting mainland Otago (Lalas et al. 2007) and the Catlins (DOC/MPI 2017) has increased in recent years. The number of pups born at Rakiura almost qualify this location as a breeding colony (>35 pups per year for five consecutive years; DOC/MPI 2017). Sea lions at the Auckland Islands are in decline (Robertson & Chilvers 2011) and Campbell Island pup counts have been too infrequent to infer any trends (DOC/MPI 2017). In terms of the overall breeding population, the Auckland Islands still accounts for the vast majority of pup production (86%), Campbell Island hosts 14%, and <0.1% of pups are born in Otago (Chilvers et al. 2007).

Depredation of hoiho by sea lions has been documented on the New Zealand mainland (Schweigman & Darby 1997; Lalas et al. 2007) and in the sub-Antarctic (Moore & Moffat 1992), at sites where both species co-exist. Only rare predation events have been documented at the Auckland Islands, despite penguins having to pass through large numbers of sea lions daily to access their nest sites (Moore & Moffat 1992). Several penguin deaths in Northwest Bay, Campbell Island were attributable to sea lions (two kills were observed, and several skins and skeletons found; Moore & Moffat 1992). Twenty mortalities observed on the Otago Peninsula between 1996 and 2005 (Pipikaretu Beach, Ryans Beach, Victory Beach, Papanui Beach and Sandfly Bay) were attributable to sea lions (Schweigman & Darby 1997; Lalas et al. 2007).

Evidence of sea lion depredation also exists from diet studies. Unidentified penguin remains have been found in sea lion scats at Campbell Island (Roberts & Lalas 2015). Regurgitated remains of two hoiho were recovered opportunistically at Victory Beach and a further ten during a systematic study at the same location (Lalas et al. 2007). However, no remains of penguins were found during 14 years of systematic diet sampling from sea lions at Papanui Beach (Lalas et al. 2007) which suggests that penguins are not a consistent part of their diet. Penguin predation appears to be the learned behaviour of a few individuals rather than a stereotyped behaviour in all pinnipeds (Moore & Moffat 1992; Lalas et al. 2007), as is the case for fur seals in South Africa (Du Toit et al. 2004). Such predation events although natural occurrences, can have a significant impact on small colonies of hoiho (Lalas et al. 2007), particularly if these colonies are already subject to other impacts.

There are no known observations of New Zealand fur seals depredating hoiho. Fur seals are known to take smaller penguin species; Snares crested penguin has been detected as prey in a diet study of NZ fur seal (Lalas & Webster 2013). The congeneric Cape fur seals are known predators of African penguins and are responsible for the mortality of 2-7% of adults at Dyer Island, South Africa annually (Johnson et al. 2006; Makhado et al. 2013).

Leopard seals are known predators of Adélie penguins (Ainley et al. 2005; 2012) and emperor penguins, but no records exist of predation on hoiho. There are occasional sightings of leopard seals hauled-out around Otago and vagrant seals have been observed feeding on seabirds, in particular Stewart Island shags and tītī during the austral winter (McKinlay et al. 2014). The potential for predation of hoiho exists, but this is likely to be opportunistic and limited in spatial and temporal extent.

Depredation of penguins by pinnipeds is known to occur on land within the surf zone (Moore & Moffat 1992; Lalas et al. 2007) and also at sea (Moore & Moffat 1992; Du Toit et al. 2004; Johnson et al. 2006). Predation attempts tend to be crepuscular as birds depart and in particular return from foraging grounds (Johnson et al. 2006). At sea, pinnipeds approach penguins from below, grabbing them by the chest, neck or head (Du Toit et al. 2004) before thrashing them on the surface to de-glove them (Marks et al. 1997).

As well as direct impacts of predation, pinnipeds may indirectly impact penguins through competition for fish and other prey, competition for space (Crawford et al. 1989), impedance of access to nests causing behavioural changes, or increased stress. NZ sea lions use similar habitat to hoiho and indirect impacts may occur where the species coexist, particularly on sandy beaches e.g. Okia, Papanui Beach and Sandfly Bay (Otago Peninsula), Sandy Bay (Catlins) and Sandy Bay (Auckland Islands).

Sharks and cetaceans

Sharks are known to predate hoiho (Seddon et al. 2013), and birds are sometimes found with large jagged edged wounds that are consistent with shark attack. There is no direct evidence, but it is likely that shark species commonly found off the coast prey on hoiho, including great white, blue and seven-gill sharks. It is possible to examine which species predate penguins from the spacing of puncture wounds, and therefore the size of teeth and bite marks. It is however impossible to say how many penguins are attacked and killed by sharks as many likely die at sea where bodies are not observed.

Evidence exists of an African penguin in the stomach of a great white shark in South Africa (Bass et al. 1975), and they are considered regular predators (Randall et al. 1988; Johnson et al. 2006). Puncture wounds and arcs of regularly spaced cuts in the lateral and ventral regions as well as on the penguin's legs and feet are characteristic of predation by sharks (Randall et al. 1988).

Orca have been reported to frequently predate Adélie penguins (Ainley 2002) and kill other sub-Antarctic and Antarctic penguin species on rare occasions (Pitman & Durban 2010). Typically this occurs in the vicinity of seal rookeries where whales are actively hunting seals (Ainley 2002). Orca and hoiho may encounter each other very occasionally, so low level predation may occur opportunistically.

Barracouta

Barracouta *(Thyrsites atun)* have been included here although they are not considered to predate penguins as such. Barracouta are thought to be responsible for accidental maiming incidents, the resulting injuries of which are sometimes fatal. There is no direct evidence of barracouta causing injury to hoiho, although barracouta are often described as voracious predators and have been observed to "*strike at a lure regardless of their motivational or behavioural state*" (O'Driscoll 1998). Barracouta were first implicated as a potential cause of hoiho injuries on the Otago Peninsula by Richdale (1942). Galapagos penguins sometimes present with slashes on their flippers, legs and feet which are assumed to be inflicted whilst feeding in mixed foraging assemblages containing large fish such as tuna, sierra mackerel and sharks, and cetaceans (Boersma et al. 2013).

Barracouta bites are thought to result in sharp-edged lacerations located on the lower limbs and flippers, often involving the underlying tendons (Hunter et al. 2015). Typically, three to four lacerations run in parallel, 20-30 mm apart and up to 40 mm in length (Hunter et al. 2015). There has been a perceived increase in the prevalence of this type of wound since 2014 (Hunter et al. 2015), but this may be due to increased rehabilitation efforts. Data from Penguin Rescue suggests that approximately 37-46% of injured hoiho that have been rehabilitated each year at Moeraki since 1985 have slashed feet consistent with barracouta injuries (Lalas et al. 2017).

The occurrence of these type of injuries is seasonal and the majority of cases occur between January and April (Lalas et al. 2017). This is consistent with what is known about habitat use by barracouta, which are semi-pelagic and are observed regularly off Otago from January to April (O'Driscoll 1997).

A number of studies have examined the diet of barracouta. Mehl (1969) examined barracouta off the NE South Island and the SE North Island and found that the two main prey items were *Nyctiphanes australis* and hoki, as well as sprat and other euphausids. An earlier study in Otago Harbour examined the stomach contents of 400-500 barracouta and listed pilchard, sprat, red cod, ahuru, warehou, blue cod, ling, pigfish and red gurnard as prey, which shows considerable overlap with hoiho diet (Graham 1939). Thomson (1913) found barracouta in large shoals with their stomachs often full of sprat (their major prey) and other shoaling fish; also mentioned as prey were red cod, hake and *Nyctiphanes*. Later work states that barracouta exhibit two main modes of foraging – either individually or via schooling (O'Driscoll 1998). Schooling appears to be a feeding strategy for exploiting surface swarms of *Nyctiphanes* providing a mechanism for increasing consumption (O'Driscoll 1998). In schools barracouta feed almost exclusively (98.6% by mass) on krill (O'Driscoll 1998) which are a common feature of Otago inshore waters in late summer and autumn (Murdoch 1989). Barracouta forage in relatively small schools (<500 m^2) from the surface to 15m depth (O'Driscoll 1998). Whilst foraging individually they fed on krill (>50% by mass), but also small fish (sprat, and pilchard, (O'Driscoll 1998).

Potentially hoiho acquire barracouta bites due to a simple spatial and temporal overlap in habitat (e.g. travelling between nest sites and foraging grounds), or they may both feed at the same location. *Nyctiphanes* have been found in the diet of hoiho, occurring in 37% of all stomach samples in one study; one hoiho in particular ate large numbers of *Nyctiphanes* (Moore & Wakelin 1997). Hoiho may also be feeding on another species that feed on *Nyctiphanes*, for example, both hoiho and barracouta feed on sprat (van Heezik 1990; Moore et al. 1995; O'Driscoll 1998).

Management of marine predation

Marine predation is natural, by species native to New Zealand that have evolved in each other's presence. It is possible that human actions have unbalanced the marine ecosystem, increasing the prevalence of certain predatory species. The possibility that one endangered species may jeopardise the viability of another presents an issue for conservation management in New Zealand (Lalas et al. 2007), as it has for penguins at other locations (Whittington et al. 1996).

It is not a viable option to cull NZ sea lions or fur seals; this would be illegal under the Marine Mammal Protection Act 1972. In any case this would likely be ineffective, as the majority of pinnipeds are not depredating hoiho. It would be less than ideal to attempt to relocate sea lions to a beach where there are no hoiho. This would involve sedation and potential risks to the sea lion and there is nothing preventing them from travelling back to the original location. It is not reasonable to remove sharks and other higher level predators from the system either, as this may have knock on effects for the marine ecosystem.

Surgery and rehabilitation options for hoiho post-predation are available for birds on the mainland only. Immediate triage and veterinary care for deep lacerations and wounds reduces complications from infections of the tendons, joints (septic arthritis) and bones (osteomyelitis) leading to a greater chance of survival (Nijman 2016).

MARINE PREDATION RECOMMENDATIONS

Gaps in knowledge

- Extent of current NZ sea lion predation.

Research recommendations

- Diet studies of sea lions (and other pinnipeds) using scat and cast collection where there is overlap with penguins to assess the extent of depredation.

- Assessment of the survival and breeding success of hoiho that have received surgery and rehabilitation due to marine predation.
- Analysis of wounds using data (photographs, description, measurements, location on the body) from hoiho in hospital or rehabilitation, and during necropsy to determine likely predators to enable improved assessment of treatment options.
- Examine overlap between barracouta and hoiho diet, geographical location and timing, and any changes over time. Examine possible mechanisms for 'attacks' (e.g. overlap of prey, differing foraging patterns of individual hoiho) and any evidence for similar wounds on other species.
- Examine the influence of flipper tags by comparing wounded hoiho with and without tags, to the presence of tags in the wider population.

Conservation management recommendations

- Increased resourcing for the monitoring of key hoiho sites to identify and pick up injured birds.
- Support of the Dunedin wildlife hospital to enable urgent treatment of injured hoiho, reducing costs, travel time and risk to birds, thus increasing chances of survival.
- Support of rehabilitation facilities (e.g. Penguin Rescue, Penguin Place, Christchurch) for the post-surgery treatment and rehabilitation of hoiho.
- Consideration of an additional rehabilitation facility for hoiho within Murihiku (e.g. Long Point).
- Discussion with experts about options for effective management where sea lions and hoiho co-exist.

TERRESTRIAL IMPACTS | KĀ PĀKA UTA

In addition to the marine threats a range of terrestrial threats impact hoiho either directly or indirectly including predation from invasive mammals, disease and habitat degradation. Terrestrial impacts, can for the most part be managed relatively easily.

TERRESTRIAL PREDATION

Predation by invasive mammals is a major driver in species extinctions globally, but particularly for island nations like New Zealand where animals have evolved in the absence of such predators (Blackburn et al. 2004). One of the impacts on hoiho populations is predation from a suite of terrestrial predators, although events are often sporadic (Moller et al. 1995). Hoiho chicks are particularly vulnerable to predation 5-20 days after hatching (Darby & Seddon 1990) and unguarded eggs may also result in predation attempts.

Hoiho are found in greater densities on predator-free islands such as Adams, Enderby, Rose and Ewing, in comparison to the main Auckland Island (Beer 2010). In recent history, massive fluctuations in hoiho abundance were attributed largely to land-based predation, where annual chick mortality has been as high as 63% in the absence of effective predator control (Darby & Seddon 1990). More recently (as trapping efforts improve), direct evidence of predation is sparse, and predation is not the primary factor affecting population declines. This is particularly evident at predator-free islands such as Whenua Hou, where the decline of hoiho is precipitous (King 2017).

Mustelids

Mustelids including stoats and ferrets take small chicks and eggs, and are one of the major predators of hoiho (Darby & Seddon 1990; Moller et al. 1995; Hocken 2005). For example, at a single site on the Otago Peninsula in 1996, 53 eggs from 27 nests were lost to mustelids (Seddon et al. 2013). At one time a buffer of rank grass around a penguin colony was thought to inhibit mammalian predators such as mustelids because it supported fewer rabbits (Darby & Seddon 1990). Later, the converse was found to be true; buffer zones potentially attracted predators through an increase in the abundance of mice (Alterio & Moller 1997; Alterio et al. 1998). Mustelids still present a significant threat to hoiho on the mainland, although no mustelids occur on Rakiura or the sub-Antarctic islands.

Cats

Predation by cats is suspected, but there is no direct evidence (Darby & Seddon 1990; Moller et al. 1995; Massaro & Blair 2003). Feral cats are widespread on mainland New Zealand and were also introduced to Auckland Island (Challies 1975) and Rakiura in the 1800s (Karl & Best 2012). They are no longer present on the smaller islands adjacent to either Auckland Island or Rakiura, but are regularly sighted at many mainland hoiho breeding sites. No conclusive evidence was found of the effect of cats on the reproductive success of hoiho during a five year study on Rakiura (King 2008). However, little and crested penguins have been observed in cat scats from the same location (Karl & Best 1982). No penguins were observed in 11 stomach and 40 scat samples from cats in the Auckland Islands (Harper 2010). A penguin chick (species unknown) was found with canine puncture wounds to the skull on the east coast of main Auckland Island, assumed to be from a cat (S. Wing, *pers. comm.*).

Dogs

Dogs are one of the few land predators capable of taking adult penguins, and are a major threat to hoiho on the mainland (Hocken 2005). Uncontrolled dogs can have a significant impact on local populations of hoiho (McKinlay 2001). Dog attacks are usually fatal, causing extensive pectoral muscle damage, internal bruising and lacerations (Alley et al. 2004). Penguins are vulnerable to predation by dogs on landing beaches, especially during the nesting season and moult period when they are unable to escape to sea easily. Unfortunately, dog attacks still continue despite increased public awareness and in the 2017-18 season at least one hoiho and a creasted penguin were attacked by dogs.

Pigs

Feral pigs likely kill chicks and adult hoiho (Taylor 2000) where their habitat overlaps on main Auckland Island, in the Catlins and in North Otago. Pigs were introduced to Port Ross at the Auckland Islands in 1807; by 1880 they had spread throughout the main island (Challies 1975). The major impact on seabirds was thought to be highest in the mid-1800s before pig numbers declined (Challies 1975). A hoiho was found in the stomach of one of eight pigs analysed from the Auckland Islands (Challies 1975), and penguin feathers have been found in pig scat (Beer 2010). Pigs are also destructive and uproot vegetation, destroy nesting habitat and may take eggs (Challies 1975).

Rats and mice

Rats have the potential to prey on small chicks (Massaro & Blair 2003), and evidence of bite marks from rats have been found on chicks at Campbell Island (Amey & Moore 1995) and at Katiki Point (R. Goldsworthy *pers. comm.*). Rats have taken rockhopper penguin eggs, but research showed that they were only able to break into eggs that were already damaged (Cunningham & Moors 1994). Rats are found throughout mainland New Zealand and Rakiura, however, Campbell Island was declared rat free in 2005 and rats never made it to the Auckland Islands (Atkinson 1973).

Mice are found throughout New Zealand and most of its islands, although only small numbers have been observed at discrete locations on Rakiura (including Oban township and Big Glory Bay salmon farm). Mice were thought to pose little risk to large seabirds, until they were filmed killing and eating live and healthy chicks of the Tristan albatross and Atlantic petrel on Gough Island (Wanless et al. 2007). Previously, mice had been suspected of predation events on very small burrowing seabird chicks and of taking eggs, reducing abundance and breeding success (Campos & Granadeiro 1999; Bolton et al. 2014). Mice (as well as rabbits) influence the number of mustelids and cats in an area, potentially increasing the risk of predation to hoiho from other mammalian predators (Alterio & Moller 1997).

Other species

There is no information on the impact of possums and hedgehogs on penguins, though both are capable of taking unguarded eggs or small chicks (Taylor 2000). Hedgehogs are known predators of gulls and terns (Towns et al. 2011) and there is evidence of possums feeding on terrestrial birds and eggs (Brown et al. 1993). When in high densities and abundance there is the potential for disturbance of nesting hoiho by possums which may increase stress and reduce time spent resting.

Skua, giant petrels and gulls are known avian predators of penguins and will take poorly guarded eggs, chicks and sometimes adults (Emslie et al. 1995; Ainley 2002). Hoiho could be susceptible where their habitats overlap with large predatory seabirds, particularly in the sub-Antarctic Auckland and Campbell Islands.

There is evidence of depredation or scavenging of penguin eggs or chicks by weka which are sympatric with hoiho on the Bravo Islands, Rakiura (King et al. 2012). Weka are known predators of several seabird species and they have been reported stealing and destroying tawaki eggs (Harper 2006). There are also direct observations of weka pulling sooty shearwater chicks out of burrows and killing them (Harper 2006) and declines of small burrowing petrels have been concurrent with releases of weka (Imber et al. 2003).

Management of terrestrial predation

Of all of the impacts on hoiho, terrestrial predation, particularly from invasive mammals, is relatively straightforward to manage. Reduced predation increases reproductive success (Moller et al. 1995) and decreases extinction risk for hoiho (McKinlay 1997).

Predation from invasive mammals is now controlled via trapping at the major breeding sites for hoiho on mainland New Zealand. Protection of approximately 50% of hoiho nests in the South Island in any season was found to be the minimum necessary to ensure positive population growth (Ratz 1997). A suite of traps, including DOC200/250, Timms, Fenns, Goodnature A12/A24, Dave Allen traps and a variety of baits or attractants can be used, depending on the target predator. Trapping programmes need to be carefully designed to ensure that the traps are effective for the site, the target species (Moller & Alterio 1999) and that they are "penguin proof" i.e. do not catch protected species. Tracking tunnels, chew cards, trail cameras and other devices can be used to detect potential predators, target trapping effort accordingly and monitor the effectiveness of trapping efforts.

Many of the offshore islands have been part of large-scale predator eradication programmes. DOC are currently investigating options for the eradication of pigs and cats from the Auckland Islands. Landscape-scale programmes also exist on the mainland, for example, possums are being targeted on Otago Peninsula by the Otago Peninsula Biodiversity Group, and the Halo Project extends predation control activities out from Orokonui Ecosanctuary which has a predator-proof fence and trapping regime.

Dog predation can be managed via the exclusion of dogs, or a requirement to have dogs on a leash within hoiho habitat. This does however require the public to adhere to signage and regulations.

TERRESTRIAL PREDATION RECOMMENDATIONS

Gaps in knowledge

- Evidence of predation of hoiho from cats.
- Potential impact or disturbance of hoiho by hedgehogs and possums.

Research recommendations

- Evaluation of the effectiveness of trapping regimes via the collection of data on trapping success of different trap and bait types, and the detection of predators at different sites (e.g. using trail cameras, tracking tunnels, chew cards and hair tubes).
- Assessment of the current coverage and maintenance of trapping networks across hoiho habitat and whether it is sufficient or can be improved.
- Assessment of new predator control technology and methodology including traps, detection devices and baits as required.

Conservation management recommendations

- Eradication of pigs (and cats) on main Auckland Island, and control of pigs at certain mainland sites overlapping with hoiho (e.g. Catlins, North Otago).
- Continue site-specific management and control of terrestrial predators at hoiho breeding sites at an appropriate ecological scale following best practice protocols. Support for the improvement of trapping operations and expansion into unprotected areas.
- Increase use of trail cameras to alert managers to potential predation problems particularly in areas where there is concern about cats (e.g. Boulder beach). Trapping can then be targeted towards specific predators.
- Continue advocacy work on the impact of dogs on penguins.

HABITAT DEGRADATION

Human habitation in New Zealand has resulted in changes in land-use, the damming of rivers, the threat of fire and historically the harvesting of penguins.

Land use changes

Historical habitat degradation through the large-scale clearance and fragmentation of coastal forest was thought to be one of the major impacts on hoiho (Roberts & Roberts 1973; Smith 1987). Moreover, the loss and modification of habitat is considered to be a major threat to avian biodiversity globally (Gaston et al. 2003). Before humans arrived, forest covered 72% of the South Island of New Zealand (McGlone 1989), and by 2002 there was a 90% reduction in forest cover in Otago and 52% in Southland (Ewers et al. 2006).

Hoiho were thought to be more numerous on the South Island prior to the clearance of forests (Richdale 1942; Darby & Seddon 1990; Moore 2001). The influence of habitat destruction on the abundance of hoiho is thought to have occurred on Otago Peninsula before the Catlins (Moore 2001). The predominant land-use change has been the transformation from native vegetation to pasture. Whilst the changing landscape has likely influenced their nesting habits, hoiho are able to breed successfully in highly modified environments (McKay et al. 1999). Hoiho currently use a wide variety of habitats for nesting, including nest boxes in pasture, coastal scrub (both native and non-native) and forest (often under fallen trees or between tree roots). There are some specific nesting requirements however including lateral concealment, overhead protection from insolation and a solid nest back (Seddon & Davis 1989; Clark et al. 2015). Due to these requirements, hoiho nesting densities in open forest habitat are lower than in coastal scrub, flax, and tussock (Marchant & Higgins 1990; Moore 1992).

Aside from loss of habitat and associated loss of native species, farming practices also have other ecosystem impacts. An increased nutrient load in run-off from farmland into waterways (from effluent, fertilisers and pesticides) may lead to eutrophication (algal blooms and a reduction in oxygen levels) and a reduction of other life in the waterways. Farming (particularly dairy) has a considerable requirement for water, leading to reduction in river flow and the availability of freshwater. Deforestation and a shift to farming also leaves the dry land more susceptible to flooding and erosion during storm events. Eutrophication, sedimentation and algal blooms are discussed further in the pollution section of this report.

The introduction of stock releases methane which increases greenhouse gas emissions and has consequences for climate change (see earlier section in this report). Larger grazing stock (e.g. cattle, goats and deer) have the potential to trample nest sites and hoiho themselves (particularly chicks) (Marchant & Higgins 1990). Deer and other browsers damage vegetation, which has negative consequences for habitat restoration projects. Smaller grazing animals (e.g. sheep) pose less of a direct risk to hoiho, but do impact vegetation and make tracks, thus opening up nesting habitat. Sheep have less of an impact in areas which have established plantings, and nest boxes rather than natural nest sites. Sheep grazing may have some pros, however, potentially reducing the number of rabbits and mice and their predators (Alterio 1994; Moller et al. 1995) and increasing the ease with which penguins can access sites. Rank grass may potentially impede access routes to nest sites and reduce the availability of open areas for socialising. Open areas, particularly high points facing the ocean are often used by hoiho, and are thought to act as advertisement or social attraction sites.

Modification of land use from vegetation to tarmac roads and concrete settlements increases run-off and potential for flooding and erosion events. The introduction of roads adjacent to penguin habitat comes with a heightened risk of injury and mortality from vehicles. Hoiho have been known to cross roads to access nests and other sites, for example, at Nugget Point and Curio Bay in the Catlins and have been killed in the process. Now that the section of road leading into the Nugget Point/Tokatā Scenic Reserve has been sealed, the increased speed of traffic amplifies the risk to penguins.

Damming of rivers could negatively impact the hydrography in coastal areas downstream of the river catchment which may indirectly affect hoiho, for example, reducing water flow, changing the sediment regime and preventing movement of nutrients and certain species. Otago has three major river systems, the Clutha, Tokomairaro and Taieri. The construction of Roxburgh Dam (in 1956) reduced the primary source of sediments, the Clutha River, by half; leaving less sediment available to replenish Otago's coastal areas (Hils 2016). Solid substrate and high levels of water movement are important for the creation of habitat forming reefs such as bryozoan reefs (Wood et al. 2013), and coarser sediments such as riverine gravels appear to be preferred substrates for hoiho foraging (Berard 2016).

Fire

Fire was historically used as a method of clearing vast tracts of land for easy access and travel as well as a method of hunting (Stevens et al. 1988). Fires can be ignited via natural (e.g. lightning strike) or unnatural (e.g. forest clearance, machinery) sources and could be devastating for a local penguin population. Extended drought and extreme weather conditions greatly enhance the risk of fire and may increase its extent and severity. A catastrophic scrub fire was responsible for the mortality of more than 60 adult hoiho at the Te Rere Reserve in the Catlins in 1995, which at that time was the most significant mainland colony of hoiho (Sutherland 1999).

Harvest

Historically, collection of hoiho eggs was common practice (Fyfe & Davis 2015; Trathan et al. 2015). Penguins were also hunted and hoiho bones have been found at midden sites in New Zealand from early Polynesian settlers (e.g. Worthy 1997). Genetic evidence suggests that the cogeneric Waitaha penguin became extinct on mainland NZ in approximately 1500AD after being harvested to extinction (Boessenkool et al. 2009b). The harvesting of penguins generally declined between the18th and early 20th century consistent with the decline of seals and whales (Trathan et al. 2015). Hoiho are considered a taonga species, and are of cultural significance and importance to Ngāi tahu (DOC 2006). Each runaka has individual responsibility for hoiho in their rohe, and exercise kaitiakitanga (guardianship).

Management of habitat degradation

Land use changes have historically reduced habitat and may have had an impact on the overall abundance of hoiho, but these changes are not continuing at the same rate today. Land management takes many forms from planting and revegetation of sites, provision of nest boxes, fence maintenance and fire prevention. (N.B. terrestrial predator control was covered in an earlier section of this report).

On a large-scale, restoration and revegetation initiatives provide some compensation for changes in land-use, reducing erosion, sedimentation and flooding. Severe weather events have shown that planted areas are less vulnerable to landslips. Vegetation can be used to provide shade and shelter for penguins whilst roosting, nesting and moulting on land. On a smaller-scale there are theories on the best strategies for encouraging nesting, for example, planting in small clumps instead of mass planting, as hoiho tend to nest at edge of vegetation zones rather than in the middle (Lalas *pers. comm.*). The density of planting may also restrict the movement of penguins, for example, if flaxes are planted too close together. Nesting and socialising habitats should be provided at sites where predation and other impacts are effectively managed so that hoiho remain protected.

Artificial nests can be provided where habitat does not fulfil hoiho nesting requirements, for example, lack of shade or lateral concealment. Nest boxes have been used successfully for hoiho for a number of years (Lalas et al. 1999). Artificial nests can sometimes be preferred to natural sites, particularly, artificial nests led to an increase in breeding productivity in African penguins as they do not collapse like natural nests (Sherley et al. 2015).

Trampling by large stock is a direct impact which can easily be managed by removal of cattle, deer and goats, and the fencing off of stock from hoiho habitat. Careful consideration should be given to the pros and cons of sheep grazing on a site by site basis.

To mitigate the impact of roads penguin-proof fences can be erected and maintained to prevent birds crossing and interacting with vehicles. Fire can be managed in high risk areas by building firebreaks (e.g. Okia reserve), or providing immediate access to water (e.g. fire ponds). If fire was deemed an imminent risk to a hoiho colony, temporary relocation to a rehabilitation facility, returning them once danger had passed and assuming that the habitat remained intact would be preferable.

HABITAT DEGRADATION RECOMMENDATIONS

Gaps in knowledge

- Impact of land use changes on the coastal sediment and hydrology regimes and wider ecosystem.

Research recommendations

- Assess the sediment and hydrology regimes, changes over time and potential consequences for movement of nutrients, eutrophication and sedimentation and ecosystem implications for hoiho.

- Compare breeding success and productivity of artificial (nest-boxes) *versus* natural nest sites.

Conservation management recommendations

- Renewal and ongoing maintenance of the penguin proof fence on the road leading into the Nugget Point/Tokatā Scenic Reserve.
- Enable exclusion of large stock (e.g. cows, deer, goats) in hoiho habitat to avoid trampling of nests and birds, as well as destruction of vegetation and infrastructure.
- Continue management of fire in high-risk areas (e.g. fire breaks, fireponds).
- Site-specific management should be employed to ensure availability of adequate nesting, moulting and loafing habitat (including open areas for advertisement, vegetation and nest-boxes which satisfy specific nesting criteria, and access ways).
- Maintenance and targeted planting of natives to fulfil specific requirements for hoiho (e.g. shade, concealment) rather than mass planted areas. Seed sourcing to facilitate ongoing spread of native plants.

HUMAN DISTURBANCE

The degree to which disturbance is an issue tends to be site specific; some penguin breeding sites are within reserves without public access and receive minimal research, and others have a constant stream of visitors.

Tourism

Tourism is New Zealand's largest export industry and the hoiho is one of the flagship species for tourism, particularly in Otago and the Catlins. Nature tourism has seen considerable growth over recent decades with a shift towards close-up encounters (Burgin & Hardiman 2015). In 2007, wildlife viewing on the Otago Peninsula, was estimated to generate $6.5 million in direct revenue, and $100 million in flow-on expenditure to the Dunedin economy annually (Tisdell 2007), and this has likely increased in recent years. Wildlife on the Otago Peninsula has also been estimated to support 800-1000 full-time equivalent jobs (Tisdell 2007). Wildlife tours to the sub-Antarctic (which include penguin viewing) have also gained in popularity.

Tourists often become ambassadors for penguins, which in turn enhances prospects for the conservation and protection of hoiho. However, there is a need to balance the positive effects of tourism and public access to penguins, against protection from disturbance and stress. Penguin-viewing operations have already been flagged as a "*particular area of vulnerability*" due to elevated tourist numbers in Dunedin (Morris 2016). Social media increasingly highlights places to go and observe penguins for free, including Sandfly Bay, Katiki Point and Curio Bay and so such sites are associated with high numbers of tourists. The visitor count at Katiki Point over a 3 month period in 2017 (3 April to 29 June) was 11,369 (DOC 2017c); numbers are estimated to be far higher during the summer.

Long-term human disturbance may cause a bird to perceive an event as predation, and thus focus on survival rather than reproduction (Frid & Dill 2002). Additional consequences of disturbance may include an increased risk of nest abandonment, hormonal stress responses affecting adult fitness and survival, and juveniles failing to recruit to a disturbed site. There are a number of studies examining the impacts of tourism on hoiho, particularly from unregulated tourists (McClung et al. 2004; Ellenberg et al. 2007; 2009; 2013). Human activity levels are important when considering impacts; a simulated wildlife photographer elicited a significantly higher response than a motionless human spending the same time at the same distance from a penguin nest (Ellenberg et al. 2013). Tourism disturbance at breeding areas has been shown to negatively affect energy budgets, fledgling weight and probability of survival (McClung et al. 2004; Ellenberg et al. 2007). Stress-induced corticosterone concentrations were significantly higher at a tourist-exposed site, suggesting birds are sensitive to frequent disturbance (Ellenberg et al. 2007). Hoiho do not always run away but may exhibit increased stress levels, elevated heart rate and energy consumption whilst remaining motionless (Ellenberg et al. 2013). Unregulated tourism resulted in reduced breeding success, with only 0.75 chicks per pair fledging at a disturbed site versus 1.39 chicks per pair at a neighbouring undisturbed site on the Otago Peninsula (Ellenberg et al. 2007). A comparison of nesting success between the centre of Katiki Point Reserve (away from humans) and the edge of the reserve (adjacent to tourist walkways), and with Okahau Point (no tourist visitation) suggested that uncontrolled tourism had an impact on nesting success in north Otago (Ratz et al. 2016). Recent observations of hoiho at the Auckland Islands suggests that 50m is an appropriate minimum distance for wildlife viewing as birds react to the presence of humans at closer distances (French et al. 2017).

Research

Consideration needs to be given to the impact of research of hoiho, in the short-term (e.g. stress hormone levels, increased heart rate) and long-term (e.g. survival and reproductive success). Potential disturbance from researchers however needs to be assessed against the positive outcomes of monitoring nests and individuals, to improve management and conserve the wider population.

Short-term human disturbance causes an increase in corticosteroid levels and heart rate (Ellenberg et al. 2007; 2013). Heart rate responses of hoiho measured using artificial eggs found that duration of human presence was the most important factor, and that an elevated rate was sustained while a person remained within sight (Ellenberg et al. 2013). Unsurprisingly, capture and handling caused the highest elevation in heart rate and longest recovery times (Ellenberg et al. 2013)

The long-term effects of research efforts were investigated at Boulder Beach, a site where hoiho have been exposed to research efforts since 1981 (Goldsworthy et al. 2016; Stein et al. 2017a). Research into the impact of stomach flushing found that there were no long-term effects on adult survival or productivity, unless it was undertaken during a year of poor food availability (Goldsworthy et al. 2016). No long-term negative effects were associated with investigator disturbance of banding / band maintenance, handling, blood sampling, stomach flushing or device deployment on breeding success or reproductive success (Stein et al. 2017a).

Researcher disturbance has however only been examined during the breeding season (Goldsworthy et al. 2016; Stein et al. 2017a), so potentially impacts may occur during other critical times such as moulting, pair-bond formation or mate prospecting. It is also likely that birds with poor body condition resulting from unfavourable environmental conditions (e.g. weather events, food availability, disease), or populations that have declined substantially, may be more vulnerable to disturbance (Stein et al. 2017a).

Disturbance can also result from management interventions, for example, visits to administer antibiotics, hydration fluids or debride lesions. This however needs to be balanced against the benefits, if the intervention means that the bird survives then disturbance is outweighed.

Both researchers and managers need to take care during capture and handling processes. In extreme cases, individual circumstances and human error could lead to the death of a bird. For example, in locations with steep cliffs care should be taken to avoid scaring a bird towards the edge. Overheating is a real possibility when handling or holding birds, and can happen very quickly. The importance of experience when handling endangered species is paramount, and should not be underestimated.

Recreation

Recreational activities (e.g. walking, surfing, or water sports) within the marine and terrestrial habitats of hoiho have the potential for disturbance and birds are likely to exhibit stress responses similar to those seen for tourism generally (McClung et al. 2004; Ellenberg et al. 2007; 2009; 2013). Disturbance is likely to be an issue at critical times when the birds are nesting – when the presence of people on beach or in the water may prevent adults from getting back to shore feed chicks, or during moult when birds already stressed and cannot readily escape.

In addition, certain recreational activities (e.g. motorbikes, quadbikes, horses, dog walking and driving on beaches to deploy watercraft) are less compatible with penguins and have the potential for increased harm and mortality. High risk activities may cause the trampling of nests, eggs, chicks or adults. Recreation activities are site specific, for example, trail riding is a particular issue in colonies bordering sand dunes (e.g. Aramoana). More detail on the impacts of dogs is covered in the terrestrial predation section of this report.

Historical cases of hoiho being shot for sport are hopefully a thing of the past (Richdale 1957).

Management of human disturbance

Human disturbance is a pressure that is able to be mitigated and managed relatively easily, although it needs to be balanced against the positive effects of advocacy and data gathering for management and research purposes.

A number of site specific visitor management strategies can be employed to mitigate tourist pressure at hoiho colonies. Spatial and temporal distribution, and behaviour of tourists can be managed by implementing fences, defined pathways, signs, hides, closures, guided tours or volunteer wardens. In addition signage, tours and wardens (e.g. Curio Bay, Sandfly Bay and Nugget Point) can also be used as an education tool. Control and restriction of access to sensitive areas is employed at sites such as Bushey Beach, Nugget Point and Katiki Pt using a system of tracks, fences and gates to direct visitors. At places where disturbance levels are high, closures may be necessary, for example, at a particular time of day (7:30pm to 7:30am at Katitki Pt), or for longer periods of time 1 December to end Feb (Boulder Beach, Otago Peninsula) and 1 Nov to end Feb (Tavora Reserve, North Otago). Some private beaches can only be visited as part of an official tour, thus restricting the number of tourists, time spent with birds and managing tourist behaviour. Tourist behaviour can be managed more successfully using a tour, rather than signage alone, and for effectively conveying conservation messages (Marion & Reid 2007). Private tours (e.g. Elm Wildlife, Penguin Place) enable guides to manage distance from birds, noise and photography amongst other behaviours. Hides reduce the visibility of tourists, but may be more effective when teamed with signage and especially with a warden.

Prohibition of high risk activities on beaches can be managed using similar methods employed to manage visitors in general. Activities such as trail-biking, quad-biking, horse-riding or driving in dunes or on beaches with penguins are particularly high risk and should be high priorities for management.

All researcher and conservation management activities are carefully managed via a permitting system via DOC. A variety of protocols and best practices are also in place, for example, for transpondering birds. Decision rules regarding when researchers should avoid access to colonies at particular times (e.g. courtship) can be implemented to minimise impact. A simple code of conduct should be employed around nests and moulting birds, including remaining quiet, minimizing contact time and not approaching birds unless necessary. For example, obtaining data via a quick direct nest-check is more reliable, and less disturbing than determining nest status via prolonged observation from a distance (Ellenberg et al. 2013). Future diet studies of hoiho should preferably use non-invasive techniques (analysis of scats, casts and spilled food) rather than stomach flushing.

Tourist, research, and management activities should be evaluated carefully and managed spatially and temporally to reduce cumulative effects of disturbance (Ellenberg et al. 2013).

HUMAN DISTURBANCE RECOMMENDATIONS

Gaps in knowledge

- There is little known about the impact of tourism in the sub-Antarctic, although research at Massey University is beginning to address this.

Research recommendations

- Evaluate the impact of tourism on hoiho in the sub-Antarctic.
- Assessment of the effectiveness of signage and other methods for managing and modifying behaviour of tourists.

Conservation management recommendations

- Support management of uncontrolled tourism at important hoiho breeding sites, including the provision of rangers to manage tourists and minimise impacts on the birds, appropriate signage, fencing and pathways.
- Site closures (e.g. Tavora Reserve, Boulder Beach, Curio Bay platform) should be considered during key times if impacts on hoiho are deemed significant.
- Translocation of individual birds from beaches with major human disturbance issues to safer areas away from humans / dogs.
- Development of appropriate infographics to educate and inform the public about their potential impacts on hoiho.
- Researcher disturbance should be managed under permits and appropriate protocols.
- Use of decoys and sounds to attract hoiho to protected areas away from human disturbance could be considered. As hoiho decline at many mainland sites, numbers may need to be increased at designated sites to retain diversity and social factors.

DISEASES AND PARASITES

Diseases are a challenge to the conservation management of wildlife (Deem et al. 2001). Infectious diseases and parasites may compromise the survival of individual penguins and at worst can cause mass mortality events (Kincaid et al. 1988; Grimaldi et al. 2015a). Penguins are susceptible to a range of infectious and parasitic diseases but clinical signs are rarely obvious and often go unreported (Clarke & Kerry 1993). Nutrition is critical to maintaining a functioning immune system, and stress and pollutants are capable of altering the function of the immune system (Briggs et al. 1996; Fairbrother et al. 2004). Diseases can therefore be opportunistic if a bird's immune system is suppressed, particularly when a bird is stressed either environmentally or nutritionally. Disease has the potential to become a bigger issue in the future as the climate warms, food resources decrease, and human disturbance increases stress on penguin populations (Tryland et al. 2009; Grimaldi et al. 2011). Geographical isolation may mean that certain penguin populations have limited resistance to certain diseases, so heavy losses may be incurred, if and when such a disease is introduced (Munro 2006).

Viral infections

Some viral diseases are widespread among species of penguin, including avian paramyxoviruses (Morgan et al. 1981; Alexander et al. 1989). Viral diseases have been identified as the cause of mass mortalities in Adélie, Gentoo and rockhopper penguins including avian pox (Munro 2006; Pistorius 2009), Newcastle disease virus (Pierson & Pfow 1975) and other unknown viral agents (MacDonald & Conroy 1971).

Newcastle virus (Thomazelli et al. 2010; Ganar et al. 2014) Newcastle disease virus is a highly pathogenic paramyxovirus, presenting primarily as an acute respiratory disease. This disease is problematic for poultry farmers in many developing countries, and disease free countries can be prone to accidental outbreaks (Ganar et al. 2014). In addition to poultry, more than 230 bird species are known to have been affected by Newcastle disease virus (Friend & Franson 1999), including African penguins (Haddas et al. 2013).

Avian pox is the common name for a mild to severe, slow-developing disease that is caused by a virus belonging to the genus *Avipoxvirus*, a subgroup of the poxviruses (family Poxviridae) (Friend & Franson 1999). The avian pox sub-group contains several similar such virus strains; some have the ability to infect several groups or species of birds, but others appear to be species-specific (van Riper & Forrester 2007; Gyuranecz et al. 2013). There are two different forms of avian pox: cutaneous (or dry) pox and diphtheritic (or wet) pox (Friend & Franson 1999). Cutaneous is more common where wart-like lesions occur on the unfeathered parts of the body. Secondary bacterial and other infections are common with this form of the disease, and these infections can contribute to bird mortality. Transmission can occur via insect vectors (e.g. mosquitoes), direct contact with infected birds (via broken skin, or mucous membranes), or indirectly via ingestion or inhalation of scabs or feather debris shed from an infected bird (Munro 2006). The virus is highly resistant to drying and can survive months to years in the dried scabs.

Poxvirus infections have been found in 232 species in 23 orders of wild and domestic birds worldwide in both terrestrial and marine environments. The exact number of existing avipoxvirus species, strains, and variants is unknown (Bolte et al. 1999; Gyuranecz et al. 2013). Avian pox is known in Gentoo penguins (Munro 2006), Humboldt penguins (Reddy et al. 2017), Magellanic penguins (Kane et al. 2012) and African penguin (Stannard et al 1998; Carulei et al. 2009; Offerman et al. 2014), but has not been reported for hoiho (de Lisle et al 1990)

Eighteen hoiho were tested at Campbell Island for infectious avian diseases (de Lisle et al. 1990). There was no antibody response to a range of viruses, including bronchitis virus, reticuloendotheliosis virus, Newcastle disease virus, infectious laryngotracheitis virus, avian encephalomyelitis virus, infectious bursal disease virus, avian influenza, Marek's disease virus, fowl pox virus or the unclassified RNA virus isolated from ticks (de Lisle et al. 1990).

Feather loss in adult hoiho, in particular on the flippers and sometimes at the base of the beak has been observed at different sites in North Otago and in the Catlins (pers. obs). A feather loss condition in Adélie penguins reported no link with ectoparasites or haemoparasites, but a new putative astrovirus was detected through cloacal swabs in birds exhibiting feather loss (Grimaldi et al. 2015b).

Bacterial and fungal infections

Avian diphtheria (also known as diphtheric stomatitis) is a seasonal disease that has been recognised as a syndrome (Alley et al. 2017). It can affect chicks up to nine weeks old, but more typically infection occurs before four weeks old (Alley et al. 2017). Bacterial plaques in the mouth are characteristic of the disease and can be inhaled, causing aspiration pneumonia or a physical blockage which prevents feeding, causing starvation and dehydration. The causative agent that facilitates diphtheric stomatitis remains unknown, despite thorough investigation and frequent outbreaks of the disease (Alley et al. 2004; 2017). A novel corynebacterium (*Corynebacterium hoiho*) has been isolated from the oral lesions (Saunderson, unpublished data), and is naturally present in 34% of healthy penguins (Alley et al. 2004; 2017). The bacteria is not known to possess diphtheric toxins (Alley et al. 2017). It is unclear whether *Corynebacterium* constitutes the primary or secondary infection. Potentially it may be triggered by a viral infection (e.g. poxvirus) (Alley et al. 2004; 2017), although any stressor that weakens the immune system could be responsible (Seddon et al. 2013). The method of transmission has not been established, but insect vectors are suspected (Alley et al. 2017). Diphtheric stomatitis was first officially identified in 2002/03 (Alley et al. 2004), but was reported as early as 1999. Hoiho are affected throughout their mainland range, although outbreaks are more regular and severe on the Otago Peninsula and in North Otago. High seasonal mortalities continue intermittently (Alley et al. 2017). The pattern of occurrence suggests that there may be changes in vector numbers or movement, or that environmental factors such as warmth and humidity may contribute to outbreaks (Alley et al. 2017).

Aspergillosis is a respiratory tract infection caused by the fungus (*Aspergillus* sp.) and has been identified as a cause of death in hoiho (Graczyk & Cockrem 1995; Alley et al. 2004). Aspergillosis is more commonly found in juvenile birds, can be acute and rapidly fatal or chronic, and is opportunistic following immunosuppression (Graczyk & Cockrem 1995).

Klebsiella is a bacterium found in most animals and has been reported in captive penguins, but not in the wild (Stoskopf & Beall 1980). Epizootic outbreaks leading to high pup mortality in NZ sea lions, has been observed on Enderby, Auckland Islands (Wilkinson et al. 2006), but it is unknown whether there is any possibility of transfer to penguins.

Discospondylitis is an infection of the vertebrae which has been observed in a juvenile hoiho, potentially as a consequence of diphtheric stomatitis (Bergen & Gartrell 2010).

Pasteurellosis (aka avian cholera), caused by the bacterium *Pasteurella multicoda,* has been identified as a cause of mass avian mortality in penguins (Leotta et al. 2006; Cooper et al. 2009), including Southern rockhopper penguins on Campbell Island in New Zealand (de Lisle et al. 1990).

Parasites

Ectoparasites are common on wild penguins (Clarke & Kerry 1993) and fleas, ticks, biting lice and mites occur on most penguin species (Duignan 2001). Hoiho likely have a lower ectoparasite burden than other penguin species, due to their solitary nesting behaviour, but biting lice and fleas have been recorded (Murray et al. 1991), particularly on birds living in the subantarctic and on Stewart Island. Ectoparasites can be vectors of diseases, particularly ticks (e.g. *Ixodes uriae,* Morgan et al. 1981). Research suggests that lice and fleas have little pathogenic importance, but numbers may increase on birds that are sick or not preening effectively (Duignan 2001).

Endoparasites are common in most penguin species and higher loads tend to be found in juvenile birds. It was thoughout unlikely that endoparasites directly contribute to population declines observed in several NZ penguin species, although they may be a factor when combined with starvation and other forms of stress (Clarke & Kerry 1993; Duignan 2001) and may increasingly contribute in the future. Intestinal parasites are not thought to threaten the survival of hoiho, with infestation levels generally at low levels and no pathology observed (Ranum & Wharton 1996; Hocken 2000). Coccidiosis has been detected in hoiho in Otago, but low prevalence suggests that it is not significant (Duignan 2001).

Blood parasites can affect the breeding success of penguins and ultimately lead to mortality (Jones & Shellam 1999; Vanstreels et al. 2016). Leucocytozoan is a blood parasite common in hoiho from Rakiura and the Auckland Islands, although prevalence is low in Otago and Campbell Island (Hill et al. 2010; Argilla et al. 2013). The parasites are thought to be transmitted by black flies (*Austrosimulium* sp.) compromising the immune system, particularly for chicks (Hill et al. 2010). A high prevalence of *Leucocytozoon* sp. has been noted in older chicks associated with chick mortality, but the specific role of this parasite remains unclear (Argilla et al. 2013).

Avian malaria is a widespread, seasonal disease caused by parasites in the genus *Plasmodium* and transmitted by insect vectors, including mosquitos and black flies. Several non-specific clinical symptoms include lethargy, loss of appetite, respiratory distress, vomiting, greenish faeces and in more severe cases, convulsions and paralysis (Grilo et al. 2016). Blood smears are required for a conclusive diagnosis (Grilo et al. 2016). Penguins are highly susceptible to avian malaria and it has been observed in wild hoiho populations (Fantham & Porter 1944), although the implications for the fitness and health of populations in the wild is unclear (Grilo et al. 2016). Avian malaria outbreaks in captivity can be acute and associated with high mortality rates (Bueno et al. 2010; Grilo et al. 2016), and have the potential to cause issues for hoiho at rehabilitation facilities, particularly in relation to pooling water. Reproductive success was reduced for chronically infected penguins in a rehabilitation centre in Brazil and there was a 44% higher mortality rate due to stress (Vanstreels et al. 2015). Disease prevalence may increase in the future due to climate change with higher temperatures, increasing vector numbers (e.g. mosquitoes) which may become more active and reproduce rapidly (Harvell et al. 2002; 2009). Naïve birds, chicks, juveniles and adults that have not previously been exposed to the insect vectors are most susceptible to the disease (Grilo et al. 2016).

Management of diseases

At a basic level, care needs to be taken to prevent the transfer and spread of disease, particularly in rehabilitation centres where large congregations of penguins inhabit a restricted area. Strict cleaning and disinfection protocols should be in place in such centres and also for researchers and conservation managers in the field to minimise disease spread between nests, sites and birds. Cleaning hands, boots and equipment between nests and sites, nest boxes (between seasons), transport cages (between uses), and pools and enclosures at rehabilitation should be standard procedure.

Stringent quarantine procedures are in place in New Zealand's subantarctic Islands including restrictions on the movement of poultry products, to prevent the transmission of certain diseases which have the potential to cross between bird species (DOC 2013). Poultry pathogens are a known transmission risk for penguins (Travis et al. 2006).

Different treatments have been used for avian diphtheria including the removal of lesions, rehydration, oral flushes with chlorhexadene, probiotics and antibiotics. Antibiotics are used at sites where there is easy access to birds on a regular basis (e.g. Katiki Point). Two antibiotics have been used in the treatment of hoiho, clavulox and avian baytril. Baytril is more commonly used and dosage requirements are for administration over five consecutive days. A basic treatment protocol for managing diphtheria was developed by the DOC which entails removal of lesions, monitoring and supplementary feeding (DOC 2015). Lesion removal is undertaken using rounded tweezers, to prevent inhalation, choking and aspiration pneumonia. Young underweight chicks can be tube fed with a salmon smoothie (salmon smolts and electrolytes) depending on weight of the chick, to rehydrate and provide nutrition. Trials with a probiotic BLISS spray (developed for humans) led to increased weights for chicks that survived, but overall there were no improvements to chick survival (McInnes *pers. comm.*).

The management of avian malaria in captive penguins involves good protocols at rehabilitation facilities, for example, reducing standing water and spraying with insecticide to reduce vector numbers (Brossy et al. 1999). Malaria is not easy to treat effectively so the prevalence of insect vectors (e.g. mosquitoes) needs to be reduced.

Conservation managers should also be prepared for action in case of a mass mortality event. Preparation should include dealing with diseased carcasses, transport and logistics, protective clothing and cleaning, live animal relocation and treatment.

DISEASE RECOMMENDATIONS

Gaps in knowledge

- Effective treatment and prevention of avian diphtheria.
- Causes and mechanism for the spread of diseases e.g. avian diphtheria.

Research recommendations

- Examination and testing of birds involved in any future mass mortality events.
- Investigate the temporal and spatial occurrence of diphtheria cases and examine any links with environmental factors, breeding success and individual history of the disease.
- Investigate antibiotic use for treatment of diphtheria and whether there any impacts of long-term use of antibiotics. Investigate development of alternative treatments, such as single dose slow release antibiotics or a vaccine (Saunderson pers comm.).
- Examine long-term survival and breeding success of birds who have had lesions debrided or antibiotics administered for diphtheria.
- Examine disease prevalence between hoiho on the mainland, in the sub-Antarctic and those in rehabilitation.
- Investigate the potential link with Leucocytozoan and stress.
- Research into potential causes of feather loss in hoiho (e.g. Grimaldi et al. 2015b)

Conservation management recommendations

- Continue to send hoiho for necropsy at Wildbase, Massey University to investigate diseases and causes of death.
- Discussion group including vets, rehabilitation groups, managers discuss pros and cons of antibiotic and other treatments for hoiho, and work out the best method for treating avian diphtheria.
- Support field effort required for monitoring and treating avian diphtheria (either via antibiotics or debriding lesions).

POPULATION ISSUES - DEMOGRAPHICS

The specific demographic makeup of a population (e.g. sex, age and breeding status) becomes increasingly important as a population declines and may have a significant influence on the ability of that population to increase. The age of a seabird for example is an important factor for successful foraging (Daunt et al. 2007; Zimmer et al. 2011) and reproduction (Limmer and Becker 2009; Nisbet & Dann 2009). Low breeding success in young birds is often hypothesised to be due to lack of experience, poor foraging skills and physical immaturity and there is some evidence that younger hoiho have a lower reproductive success than older birds (Stein et al. 2017b).

Small populations with restricted ranges, particularly ones that have suffered additional anthropogenic impacts, are more likely to experience demographic issues which may affect overall population growth and reproductive success.

The minority of individuals within a population are more successful breeders and contribute disproportionately to the next generation (Annett & Pierotti 1999; Lescroël et al. 2010). This is also true for hoiho; 5.4% of the population at Boulder Beach contribute many more offspring to future generations than other birds, termed "*superbreeders*" (Stein et al. 2017b). In Adélie penguins, *superbreeders* foraged more efficiently than poor breeders under adverse environmental conditions and when offspring needs were high, thus increasing net energy profit for reproduction and survival (Lescroël et al. 2010). High reproductive success rates have also been linked to higher survival rates (Lescroël et al. 2009).

Genetic bottleneck

Inbreeding depression is a significant problem for endangered birds (Jamieson & Ryan 2000; Jamieson et al. 2008). Population bottlenecks or persistence at small population sizes leads to loss of genetic diversity and increased levels of inbreeding. In turn this may result in reduced individual survival and reproductive success thus lowering the biological fitness and adaptive potential of a population as a whole (Lande & Shannon 1996; Keller & Waller 2002).

Contemporary migration rates between the sub-Antarctic and mainland populations of hoiho are low (<2%) (Boessenkool et al. 2009a; Lopes & Boessenkool 2010), consequently they are recognized as two separate populations. The potential for natural replacement of individuals on mainland New Zealand from the sub-Antarctic is therefore low.

The sub-Antarctic population of hoiho has more unique alleles than the mainland population and genetic variability is considered to be low on mainland New Zealand (Boessenkool et al. 2009a). The effective population size of the mainland population is deemed to be below the critical threshold needed to maintain adaptive potential, which makes coping with environmental challenges such as disease, toxins and climate change potentially challenging (Boessenkool et al. 2010).

A recent study however showed no evidence of inbreeding affecting the productivity of the population of penguins at the Boulder Beach complex which suggests that the fitness of these birds is not affected by inbreeding (Menzies 2016). Female hoiho are slightly more outbred than males, which perhaps suggests that female-biased dispersion may occur to prevent inbreeding (Menzies 2016).

The continually declining population of mainland hoiho and the threat of catastrophic local declines (e.g. mass mortalities, fire, disease outbreak or starvation event) mean that inbreeding depression is however a serious concern.

Biased sex ratios

A review of sex ratios in wild birds found that on average males outnumber females by 33% and that the main driver of this was high female mortality (Donald 2007). High rates of female mortality have been observed in king penguins (Olsson & van der Jeugd 2002), Magellanic penguins (Walker & Boersma 2003; Vanstreels et al. 2013) and African penguins (Pichegru & Parsons 2014). An unbalanced sex ratio was evident after strong El Niño events suggesting that higher mortality occurs in female penguins because of poor body condition leading to skewed sex ratios (Boersma 1998). A sex skew is also evident in hoiho with higher rates of mortality in female penguins (Richdale 1957) which has the potential to cause problems for the viability of a species (Pichegru & Parsons 2014).

Increasingly, sex-biased ratios could be a problem for hoiho as the population decreases and will have an effect on the population's ability to recover. There are observations from across mainland breeding sites of lone hoiho adults at empty nest bowls, and of interference by multiple adults (likely males) attending nests. At Irahuka / Long Point in 2016/17 an attending adult was observed on camera abandoning its chicks, likely due to the presence of other adults. Subsequent nest checks found one chick missing and an otherwise large healthy chick dead outside the nest. Interference by other adults may slow any recovery of a population. Nest accidents where chicks are trampled occur particularly in the first couple of weeks when the chicks are small; these incidents may become more frequent if multiple adults visit a nest and hassle the attending adult. Nest accidents and starvation are often linked, as chicks may be more likely to be trampled when under-nourished / dehydrated. Harrassment of nesting penguins by other adults has been observed in erect-crested and Snares penguins where unpaired birds harass (peck and flipper beat) incubating females sometimes causing them to abandon the nest (Davis 2001).

Sex may play a significant role in the movement ecology and conservation of certain penguin species (Vanstreels et al. 2013). In birds, natal dispersal is typically female-biased (Dale 2001; Paris et al. 2016) and the same may be true for hoiho (Menzies 2016). Fragmented populations that are in decline lead to increased difficulties finding mates. Wider ranging animals may also be more susceptible to a wide range of impacts due to increased contact. Overall, sex-biased mortality can increase the risk of extinction of threatened populations (Dale 2001).

Breeding skips and consequences of unsuccessful breeding

Following the death of its mate during the hoiho breeding season, the surviving bird will often skip breeding in the following season (Setiawan et al. 2005). Analysis of life-history data from 200+ hoiho from Boulder Beach indicated that a lack of a mate through divorce or death was the most important contributor to breeding skips (Deans 2016). Successful breeders were less likely to skip the following season than other individuals perhaps indicating that the cost of reproduction is not a strong contributor to breeding skips in this species (Deans 2016).

Population size of hoiho is estimated using the annual number of breeding pairs (nests) and it is assumed that this trend reflects overall population trend (Moore 2001). Short-term changes may however be caused by variation in the proportion of birds that breed each year (Moore 2001). In recent history about 60-80% of adult hoiho bred but in anomalous years the proportion was lower (Efford et al. 1994). For example, in 1990/91, a year after a mortality event and population crash (Efford & Spencer 1996), there was a 55% decrease in nest numbers because the proportion of birds breeding was low (<30%, Efford et al. 1994). Correspondingly, the increase in nest numbers the following year was greater than would be expected from recruitment alone, as birds returned to breed. Following the 1990/91 mortality event, the average age of new breeders to the population also increased, suggesting that there were “excess” non-breeding birds ready to replace experienced breeders which had died (Mattern et al. 2017). After a subsequent mortality event in 2012 there was no longer a pool of birds available to take the place of breeders which had died (Mattern et al. 2017). This is similar to observations of great skuas where a rapid decline in numbers of non-breeders (significantly higher than the decline in breeding adults) is likely due to increased recruitment as a consequence of a reduction in adult survival rate (Klomp & Furness 1992). The numbers of non-breeders at the seabird colony may provide an early indication of environmental changes having adverse effects on the population, as non-breeders provide a buffer to such stress (Klomp & Furness 1992).

Population sinks

The habitats used by a species are never of equal quality. When demographic models take into account habitat heterogeneity (i.e. differences), a concept emerges where a surplus of individuals in good quality habitats is considered a source, whereas a sink occurs in poor quality habitats where there is a deficit (Dias 1996). If the productivity of a penguin colony is insufficient for it to be self-sustaining it represents a population sink, for example, an African penguin colony at Stony Point, South Africa (Whittington et al. 1996).

Typically, a population sink is due to some kind of impact (e.g. predation) but it could be the case that as a population declines so too does its ability to attract in new recruits. Hoiho, for example congregate in certain prominent locations at breeding sites. Local population growth may be magnified by the social attraction of recruits to busy areas; conversely, a formerly important habitat with few penguins currently living there may not attract new birds, even after it is protected (Moore 2001).

Management of population - demographic issues

As a species declines and moves towards extinction, active management interventions become more necessary (Clout 2001). There are many examples of intensive management schemes for endangered bird populations in New Zealand, including kakapo (Clout & Merton 1998; Elliot et al. 2001), black robin (Taylor et al. 2005) and takahē (Grueber & Jamieson 2008). A number of options are available for managing the hoiho population at some sites on the mainland in order to increase survival and boost local population numbers, and circumvent some of the demographic problems such as genetic bottlenecks.

Rehabilitation

Rehabilitation is defined as "*the managed process whereby a displaced, sick, injured or orphaned wild animal regains the health and skills it requires to function normally and live self-sufficiently*" (IWRC 2017) and is increasingly being used as a conservation management tool for endangered species.

Rehabilitated animals are individuals that would have died without intervention (Ress & Guyer 2004). Rehabilitation for conservation management purposes should be considered successful if an animal goes on to survive and breed (as opposed to only welfare needs where success is release of an individual).

Adult survival is the most important demographic parameter affecting population performance in long-lived species (Caswell 2001) and this has also been found to be true for hoiho (McKinlay 1997). The major reasons for rehabilitation efforts of hoiho are injured, emaciated, or diseased birds (Ratz & Lalas 2010). Supplementary feeding is one of the major interventions that occurs at rehabilitation centres for hoiho. Body size is arguably one of the most important traits of an animal as it influences sexual maturity, longevity, reproductive strategy, metabolic rate and abundance (Sauer & Slade 1987) and the mass of hoiho correlates with survival, especially during critical periods (e.g. the moult). Administering drugs, wound management and overall health monitoring may also occur in rehabilitation centres as hoiho recover from injury or disease.

There are three rehabilitation facilities for hoiho in Otago (Penguin Place, Penguin Rescue and Oamaru Blue Penguin Colony) and one in Canterbury (Christchurch Penguin Rehab). There are currently no such facilities in the Catlins or Rakiura (Southland). Approximately 300 hoiho were admitted to the rehabilitation facility at Penguin Place between 1997 and 2006; of which about 40% were chicks, 20% were juveniles, 15% were resident adults and 25% were non-resident adults (Ratz & Lalas 2010).

Some minor interventions can sometimes be carried out in the field, for example, supplementary feeding of chicks at the nest. This may avoid the need to bring young emaciated chicks into care, and result in chicks that fledge naturally. A DOC protocol for supplementary feeding of underweight chicks or where sibling weight disparity of nestlings exists is effective but labour intensive (DOC 2015).

Using an after the-fact analysis of three hoiho recovery treatments (trapping, revegetation and intensive management), only intensive management was significantly correlated with an increase in annual site-level hoiho population growth (Busch & Cullen 2009). Evidence from the rehabilitation centre managed by Penguin Rescue shows that rehabbed birds go on to breed (up to 40% of females breeding in 2015 had previously been rehabbed) (Ratz 2016). An increase in the annual survival rate of rehabilitated males (2%) and females (8%) was also evident although this was not statistically significant (Ratz 2016). It is not known whether rehabbed birds breed more or less successfully than non-rehabbed birds or whether chicks from these birds fledge more or less successfully.

There is a practical requirement from DOC and iwi to return birds to the location where they were found. Adults and juveniles can typically be 'hard-released' (i.e. released straight into the habitat) as they know the area and have been to sea before and can forage successfully. Chicks need to be 'soft-released' (i.e. slowly introduced to the habitat, in an enclosure first for a few days) as they have never been to sea and need to familiarise themselves with the area and watch other birds to learn what to do. This soft release process can only be undertaken at certain locations as birds require a certain level of supervision to ensure that they are successfully released and to avoid re-admission to rehab.

Rehabilitation of hoiho is however expensive (Busch & Cullen 2009), and preventing species from being at risk of extinction likely requires continuing, species-specific management into the future – termed "*conservation reliant species*" (Scott et al. 2005; 2010; Goble et al. 2012).

Translocations

Translocations of threatened birds have been an important part of conservation management strategies in New Zealand. Since 1895 many translocations have occurred, typically for threatened bird species, and including a species of penguin (Miskelly & Powlesland 2013). Two attempts to translocate little penguins in New Zealand were documented between 1863 and 2012, one of which was successful and one failed (Miskelly & Powlesland 2013).

There are different levels of translocation that could be considered for hoiho. Translocations of fertile eggs from unsuitable to suitable parents within a site already occur at one managed colony in North Otago. Parents may be considered unsuitable if they are very young and inexperienced, or if multiple adults are visiting a nest and putting eggs at risk, or if eggs are adandoned. This method is management intensive and requires a high level of monitoring and good knowledge of the fertility of the eggs (e.g. candling) as well as the age and status of the adults involved. Dummy eggs can be placed at potential "foster" nests to test the parenting abilities of the adults prior to translocation of the eggs.

Low level translocations of individual hoiho between mainland sites currently occurs when a bird is considered to be at risk from human disturbance or dog attack. Typically this occurs during the moult when a bird is unable to escape to sea, and so it is physically transferred to a protected site close by away from the public. This type of action could be considered for larger numbers of birds in the future if disturbance levels or human impacts are deemed to be particularly high in an area. Careful consideration would need to be given to whether the terrestrial and marine environment at the translocation site was sufficient to support the birds, and that there were no additional impacts at the site. Otherwise the translocated population may continue or accelerate its rate of decline. Transfer of eggs, chicks and adults from one province to another, for example, Catlins to Otago or the subantarctic to mainland, would require significant consultation and discussion. Any benefits in terms of increased genetic diversity and protection would need to be carefully weighed against the negative impacts.

Translocations are not without risk however. All handling and transportation of hoiho comes with an associated level of stress for birds, and risks of injury and overheating, and so needs careful management. Translocation may increase the risk or spread of infections to areas that are currently disease free or that have low levels of disease. This may be a particular risk if birds were transferred long distances between two sites that they would not normally travel between (e.g. mainland and sub-Antarctic) and could potentially cause a further decline in populations. For example, the incidence of ticks and lice appears to be higher on Rakiura and in the subantarctic than the mainland, and there is a higher prevalence of leucocytozoan in the subantarctic (Argilla et al. 2013).

The pros and cons of various forms of translocation may need to be considered in detail in the near future if the mainland population continues to decline, before inbreeding starts to occur.

Captive management

Ideally, hoiho populations would be self-sustaining in the wild, but currently we are seeing massive declines on the mainland and Rakiura.

There are a number of limitations with captivity of wild animals including high costs, poor reintroduction success and establishment of self-sufficient captive populations, domestication and disease (Snyder et al. 1996). Because the marine environment is unable to sustain birds in some years, there is not much point in raising populations for release into a system that is unable to support and provide for them. There is an increased risk of disease in captivity which may then be introduced into naïve wild populations (Brossy et al. 1999; Daszak et al. 2000). Long-term captivity is not an appropriate solution for long-ranging and long-lived animals. Behavioural traits that are learned or culturally transmitted may be lost in captivity (Griffin et al. 2000). Species may become progressively adapted to captivity and may be incapable of producing viable wild populations; domestication may be rapid (Snyder et al. 1996). The costs associated with captive breeding programmes and associated care are considerable.

Wild populations of hoiho are not thought to be suitable for permanent captivity or *ex-situ* management (McKinlay 2001). "*In many cases alternative, non-captive approaches may be more effective, economical and safe than captive approaches in achieving recovery*" (Snyder et al. 1996). Captive management should be considered the last resort in the management of hoiho.

Attraction techniques

Many seabirds exhibit strong mate and breeding-site fidelity, and site philopatry and because of this, individuals often fail to colonise new habitat or re-colonise former nesting sites once impacts have been removed (Parker et al. 2007). Social attraction aims to lure adult birds to restoration sites usually within a few miles of an existing source colony to establish a breeding colony (Jones & Kress 2012). Social attraction techniques including decoys (models of adults, chicks, and eggs), mirrors, scent and acoustic recordings (Friesen et al. 2017) have been successfully used for puffins, murres and terns (Kress 1983; Kress & Nettleship 1988; Parker et al. 2007). Typically, acoustic playback, decoys, and other attractants simulate a colony from a distance to lure prospecting seabirds to new nesting habitat (Parker et al. 2007).

Wooden cut-outs of adult hoiho have been used at various sites on mainland New Zealand in an attempt to entice penguins to colonies that employ predator control. The effectiveness of such decoy methods are often difficult to determine and remain to be tested.

Before a seabird restoration project can go ahead a site must be carefully selected considering biological constraints to breeding success (e.g. predation risk, food limitation, human disturbance) and logistic constraints (e.g. costs and practicality). The principal impacts (and actions in place to reduce them) should be known and a long-term management plan should be in place (Jones & Kress 2012; Kappes & Jones 2014).

Monitoring and database maintenance

In order to manage the hoiho population effectively and conduct quality research, comprehensive data needs to be collected at a population and individual level. Without effective monitoring of the hoiho population we cannot determine abundance, survival and breeding success.

Nest numbers give us an indication of population trends but are poor indicators of population viability. Without information about eggs laid, chick survival and fledging you know little about the success that season; there is a considerable difference between ten nests from which no chicks fledge, or ten nests with 20 chicks.

Collecting adult survival data as well as annual nest counts avoids misinterpretation of anomalous years in population trend data (Moore 2001). Without data on breeding success, survival and other population parameters it is very difficult to draw any conclusions about which threats are having an impact on the hoiho population. It is as important to understand the extrinsic causes of a decline as it is to determine their effects on population viability in the short- and long-term.

Interventions and conservation actions aimed at recovering populations become guesses if we don't possess individual life-history data needed to measure vital rates and other viability parameters.

Monitoring needs to be consistent (or the intensity needs to be quantified), otherwise a change in effort can result in a perceived increase or decrease in abundance. Without consistent monitoring data across a number of geographical sites, it is impossible to model, or understand which impacts are affecting hoiho.

POPULATION – DEMOGRAPHIC RECOMMENDATIONS

Gaps in knowledge

- Accurate population numbers or trends for hoiho at the sub-Antarctic Auckland Islands and Campbell Island due to the lack of an accurate, repeatable and achievable methodology.

Research recommendations

- Investigate the effectiveness of rehabilitation and surgical treatment in terms of long-term survival and breeding success of individuals.
- Continue work with DOCs seabird prioritisation team to investigate key parameters that regulate the population, and model the effect of various impacts on the hoiho population. YEPT have started this.
- Conduct mark-recapture (M-R) analysis using transpondered individuals at well monitored sites to work out colony population size, and compare to number of nests.
- Investigate sex bias in hoiho population, differences in diet, foraging, dives, chick provisioning, natal dispersal to examine why more males than females are surviving.
- Further work on the identification of "*super-breeders*" (Stein et al. 2017b) and investigation of the potential for prioritising their care, for example, using a H/L (heterophil to lymphocytes) ratio (e.g. Menzies 2016).
- Recent estimate of current hoiho population including the sub-Antarctic may be required for risk modelling, and to work out whether populations on the Auckland and Campbell Islands are stable.
- Revisit a Population viability analysis (PVA) following McKinlay (1997).
- Further research into potential conservation management options, including translocation (within sites, between sites on mainland, from sub-Antarctic).
- Double count methodology can be used every few years at a sample of breeding sites to assess reliability of nest count estimates and work out the proportion of nests missed (e.g. Hegg et al. 2012).
- Hoiho can be sexed using a combination of head / foot morphometrics (e.g. Setiawan et al. 2004). Expand the analysis to enable accurate sexing of individuals from Rakiura and the sub-Antarctic.
- Assess options for analysing the DNA on needles used for transpondering birds (e.g. Grosser et al. 2015)

Conservation management recommendations

- Continue nest monitoring to examine population trends and individual life-history parameters, including hatch / lay dates for some nests. This will enable improved management of chicks and allow analysis of impacts and effectiveness of management interventions.
    - Intensive monitoring is not required at all sites, but representative ones on the mainland (e.g. Irahuka, Catlins; Boulder/Otapahi, Otago Peninsula; Katiki Point, North Otago).
    - Green Island is the only site without human disturbance and terrestrial predators in Otago Peninsula, thus a good comparative site.
    - Penguin Beach and Papanui Beach (used to have a large proportion of the Otago Peninsula population) so preferable to know what is happening at these sites.
    - Whenua Hou, Bravo Islands, Neck and Anglem Coast are the only regularly monitored sites on Rakiura. In addition a survey on Bench could be useful to investigate whether it has declined like Whenua Hou (opposite sides of Rakiura).
    - Continue monitoring of Catlins sites 5 yearly and others annually.

    - Monitor sub-Antarctic Auckland Islands and Campbell Island every few years, using outcomes from Chris Muller's research on the best method to use.
- Invest in the maintenance and improvement of the hoiho database. Investigate alternative software to facilitate a move to an online system. The database is a key tool for research and conservation management of hoiho.
- Invest in monitoring of habitats to find underweight birds (particularly juveniles and adults going into the moult and underweight fledglings) and injured /sick birds. Investment in underweight birds particularly going through the moult increases survival of breeders for the following year.
- Support rehabilitation facilities to enable supplementary feeding, and recovery of birds following surgery or illness.
- Develop protocols and best practice for rehabilitation using knowledge from experts.

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