Yellow-eyed penguin - review of population information

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Draft Report

Abstract

The yellow-eyed penguin is endemic to New Zealand and considered to be one of the rarest penguins in the world. It is a long-lived species and population viability analysis shows that even a small increase in adult mortality augments extinction probability dramatically. Fisheries bycatch may be substantial, particularly in the commercial set net fisheries; however, the information currently available does not allow assessing the full extent of fisheries impact. Here we have reviewed and collated information existing to date on yellow-eyed penguin population parameters including range and distribution, population levels and trends, adult survival, juvenile survival, age of first breeding and fecundity. Furthermore, we

summarised our current understanding of yellow-eyed penguin marine ecology and foraging patterns. Important gaps in our knowledge have been identified and we provide recommendations for future research in order to better assess the direct and indirect effects of commercial fisheries on yellow-eyed penguins. Most importantly we need to increase independent observer coverage on commercial set net and inshore trawl fisheries to quantify numbers caught and document operational details affecting the likelihood of capture. Such data is essential for the development of mitigation measures.

Keywords

Megadyptes antipodes, yellow-eyed penguin, distribution, abundance, population trends, survival, fecundity, foraging ecology, future research, bycatch, fisheries impact

Species scientific and common names

The Yellow-eyed penguin, *Megadyptes antipodes* ("large southern diver"), was first described by Hombron and Jacquinot in 1841 at the Auckland Islands as *Catarrhactes antipodes*.

Maori common name: Hoiho ("noise-maker")

Rationale

The endemic Yellow-eyed penguin is classified as endangered (B2b(iii)c(iv), IUCN 2011) internationally and as threatened (nationally vulnerable) following the New Zealand internal threat classification system (Miskelly et al. 2008). This species may live to more than 25 years (own observations, John Darby unpublished data). Generally, adult mortality is low (0.09-0.17; Richdale 1957; Efford et al. 1996; Edge et al. 1999; Ratz et al. 2004). Population

viability analysis shows that even a small increase in yellow-eyed penguin adult mortality rate leads to a dramatic increase in extinction probability (McKinlay 1997).

We have a reasonable idea about the terrestrial factors influencing population parameters at least on the New Zealand mainland (e.g. introduced predators, human disturbance, disease, terrestrial habitat quality etc.) and appropriate management measures. However, we know very little about sea-based factors affecting yellow-eyed penguin populations, such as oceanographic conditions, food supply, fisheries interaction (e.g. via competition or habitat alterations) and bycatch.

In 2007 an initial attempt was made to evaluate fisheries impact on a yellow-eyed penguin population using mark-recapture data within a population dynamics model by Mark N. Maunder, Alistair Dunn, David M. Houston, Philip J. Seddon, and Terese H. Kendrick. Unfortunately, the authors had to conclude that there is currently "not enough information to determine the impact of fisheries on the YEP population" (Maunders et al. 2007).

Purpose of this report

1. Describe the range and distribution (Section 1), population level and trend (Section 2), adult survival, juvenile survival, age of first breeding and fecundity (Section 3) of yellow-eyed penguins.

2. Collate and summarise available information on yellow-eyed penguin marine ecology (Section 4).

3. Provide recommendations for future research to allow a better understanding of the impacts of commercial fishing on yellow-eyed penguins (Section 5).

1.   The current range and distribution of yellow-eyed penguins

Summary

Yellow-eyed penguins breed in the sub-Antarctic on Campbell and Auckland Islands, on Rakiura/ Stewart Island and adjacent islands, and along the southeast coast of the New Zealand South Island. Yellow-eyed penguins on the New Zealand mainland are genetically distinct from yellow-eyed penguins in the sub-Antarctic (inferred immigration rate of 0.003 per generation). Therefore, yellow-eyed penguins breeding on the New Zealand South Island, Stewart Island and outliers have to be managed separately from sub-Antarctic populations.

1.1   Introduction

Recent research revealed that yellow-eyed penguins were restricted to the Auckland and Campbell Islands up until AD 1500 (Boessenkool et al. 2009a). Only after their sister species *Megadyptes waitaha* disappeared (probably hunted to extinction) yellow-eyed penguin stragglers from the sub-Antarctic gained foothold on the New Zealand mainland. The decimation of seals and sea lions (i.e. predators of penguins) and change in human harvest pattern allowed them to establish and expand into the population we see today (Boessenkool 2009, Boessenkool et al. 2009a). Hence, the colonisation of the New Zealand mainland by yellow-eyed penguins happened during very favourable conditions.

It is unlikely current losses on the mainland could be compensated by the arrival of new birds from the sub-Antarctic. Only one of the >500 birds banded on Campbell or Auckland Islands has ever been found (dead) on Stewart Island, and none of the >10,000 birds banded on the New Zealand South Island has ever been recorded on Campbell or Auckland Islands (Seddon et al. *in press*). Studies confirmed that sub-Antarctic and mainland populations are genetically distinct (Triggs and Darby 1989, Boessenkool 2009, Boessenkool et al. 2009a, b, 2010a, b)

i.e. interchange between populations is negligible (inferred immigration rate of 0.003 per generation, Boessenkool et al. 2010a).

Therefore, the New Zealand mainland (including Steward Island) and sub-Antarctic populations need to be managed and thus are presented as separate units.

1.2   Methods – current range and distribution

I have reviewed all studies cited in our yellow-eyed penguin book chapter (Seddon et al. *in press*). I have then searched the Web of Science, Scopus, and Google scholar, for both peer-reviewed papers and grey literature using the keywords "yellow-eyed penguin" or "Megadyptes" or "Hoiho". Furthermore, I have gathered the relevant Conservation Services Programme and internal DOC Reports and have been in contact with all related Department of Conservation Area Offices. Finally, I have approached the Yellow-eyed Penguin Trust, which maintains a library attempting to cover everything ever written on yellow-eyed penguins including grey literature. My current literature database for the yellow-eyed penguin review of population information contains 211 publications, and counting.

After consultation with Igor Debski and Russell Harding, Marine Conservation Services Programme, we decided to not give away individual breeding areas in a public document. Instead we present the range and distribution of Yellow-eyed penguins as a line following coastal contours where Yellow-eyed penguins are present and recorded as breeding. Additionally, depicting breeding regions rather than individual breeding sites has the advantage to account for natural dynamics: Some breeding areas may get abandoned for a variety of reasons whereas others may get newly established in the future.

1.3   Results – current range and distribution

Yellow-eyed penguins breed in the sub-Antarctic on Campbell and the Auckland Islands, on Rakiura/ Stewart Island and outliers, and along the southeast coast of the New Zealand South Island (Figure 1.1).

1.3.1 Yellow-eyed penguins on the New Zealand Mainland

South Island New Zealand

Between 400 and 600 pairs currently breed in four distinct regions along the southeast coast of the New Zealand South Island: the Catlins, Otago Peninsula, North Otago, and Banks Peninsula (Department of Conservation Coastal Otago Area Office, Figure 1.2). The Otago Peninsula hosts nearly half of these pairs. The few Yellow-eyed penguins on the Banks Peninsula breed with little success and recruitment appears to come from mainland breeding areas further south (Parker 2009, 2010). In recent years, a single breeding pair has attempted twice to breed near Kaikoura (in 2008/09 and 2009/10, Mike Morrissey, DOC, pers. comm.).

Traditionally, yellow-eyed penguins nested in lowland podocarp/ hardwood forests prevailing along the coasts of southern New Zealand (Darby & Seddon 1990). Since penguins nesting in warm temperate climates tend to be overinsulated for life on land (Stonehouse 1967) nesting within a cool forest will help maintaining thermal balance (Darby & Seddon 1990).

However, with habitat degradation and the destruction of most natural forest cover along the South East coast of the South Island penguins are now forced to breed in a variety of human shaped remnant scrub habitats including gorse, flax and native shrubs such as hebe, ngaio or tree nettle, that provide to some extent shelter from thermal stress (Darby & Seddon 1990; Clark et al. 2008). Even nests in open grassland habitat without overhead cover have been observed (McKay 1999). Habitats such as gorse and tree nettle may additionally provide

protection from human and dog disturbance (own observations). Still, penguins appear to breed less successfully in such replacement habitats (Darby & Seddon 1990).

Yellow-eyed penguins are the least colonial of all penguin species and nests are spaced up to 150m apart with some pairs travelling up to 700m (even 1km, John Darby pers. comm.) inland in search of suitable nest sites (Darby & Seddon 1990). Densities may range from 1-5 (in exceptions more, own observations) nests per hectare depending on the density of vegetation (Darby & Seddon 1990).

Yellow-eyed penguins are specialised benthic foragers which rely on a stable and predictable year-round food source within reach of their colonies (Moore & Moffat 1990; Mattern et al. 2007). Hence, the width of the continental shelf and the level of marine productivity may be important predictors of yellow-eyed penguin presence and success.

Stewart Island and outliers

Stewart Island/ Rakiura and adjacent islands host about 180 breeding pairs along the north-eastern (Anglem coast) and eastern shores, with population strongholds on Codfish Island/ Whenua Hou, around the exit of Paterson Inlet (including Bench Island) and in Port Pegasus (Massaro and Blair 2003, King 2008a, King 2009, Figure 1.3).

Stewart Island still maintains much of its original coastal forest and large scale human induced modifications similar to the New Zealand South Island have not occurred. However, the introduction of herbivorous mammals has altered the understorey and more open forests on the main island could make it more difficult for yellow-eyed penguins to find suitable nest sites (Darby 2003). Yet the current low population numbers (compare section 2) can not be explained by such habitat alterations alone. Today many potentially good nesting sites on Stewart Island remain unoccupied.

1.3.2 Yellow-eyed penguins in the New Zealand sub-Antarctic

It is thought, that about 60% of yellow-eyed penguins are found in the sub-Antarctic. Despite being considered a stronghold for the species, to date very little research has been done on the sub-Antarctic yellow-eyed penguin population.

Campbell Island

Between 350-540 breeding pairs were estimated for Campbell Island during the most recent population census in 1991/92 (Moore et al. 2001). Beach counts at landing sites revealed most birds (79% in 1988 and 83% in 1992) were present in the four main bays (in decreasing order of abundance): Perseverance Harbour, North East Harbour, Northwest Bay, and Southeast Harbour (Moore and Moffat 1990, Moore 1992, Amey and Moore 1995, Moore et al. 2001, Figure 1.4).

Penguins generally preferred more sheltered harbours with 61% of the landing sites located on shingle/small boulder beaches (Moore 1992). Nest searches at selected breeding sites during the breeding season 1987/88 found nests "isolated and scattered amongst the coastal scrub-shrubland association, dominated by *Dracophyllum*. The density of nests was approximately 1.5 pairs/ha in penguin habitat (3.8 in Northwest Bay), or 44 birds per accessible kilometre of coastline. Most nests were within 500m of the shore." (Moore and Moffat 1990).

Campbell Island lies at the southern end of the Campbell Plateau and is surrounded by a large expansion of productive continental shelf at less than 200m depth which makes it a very favourable place for a primarily benthic forager such as the yellow-eyed penguin (Smith 1987; Moore & Moffat 1990; Mattern et al. 2007).

Auckland Island group

The Auckland Islands host an estimated minimum of 520-570 breeding pairs (1989 census of the northern part of the Auckland Island group, followed by a brief reconnaissance of some sparsely populated eastern bays, Moore 1990b, 1992.) Predator-free Enderby Island, in the north of the Auckland Island group, appears most important with an estimated 260-290 breeding pairs (Moore 1992). This is despite the fact that it is also an important breeding site for a yellow-eyed penguin predator, the New Zealand sea lion *Phocartcos hookeri*. There are no recent estimates of the yellow-eyed penguin population size on the Auckland Island group. However, beach counts during the breeding season 2008/09 at all known landing sites on Enderby Island (25, Moore 1992) found them still active (Young 2009a, b). In 2009 a survey of Port Ross and the northern Coast and adjacent Islands (excluding Enderby) as well as the extensive but more sparsely populated eastern and southern coastline including Carnley Harbour and Adams Island identified a total of 306 active landing sites (Beer 2010). This indicates the Auckland Islands remain an important population stronghold for Yellow-eyed penguins (Figure 1.5).

The outlying predator-free islands (free of the feral pigs *Sus scrofa*, cats *Felis catus* and mice *Mus musculus* which are found on the main island) appear to have greater penguin densities with 3.5 landing sites per kilometre searched coastline compared to only 1.2 landing sites per kilometre on the main Auckland Island (Beer 2010).

Breeding habitat was predominantly "southern rata (*Metrosideros umbellata*) forest and scrub vegetation such as *Myrsine divaricata*. Other habitat used for breeding included *Olearia lyallii* forest (Ewing Island) and *Poa litorosa* tussockland. The landing sites varied from rocky shores (64%) to boulder beaches (32%) and sandy beaches (4%)" (Moore 1992, about the northern parts of the Auckland Island group). Further south the most prevalent vegetation at landing sites was scrubland, dominated by *Dracophyllum* and *Hebe*. Most landings were

found on rock platforms, boulder beaches, and combination of both, with very few sandy beaches (0.7%, Beer 2010).

The marine regions particularly to the North East of the Auckland Islands are dominated by reasonably shallow (<200m) water depths which would support the benthic foraging strategy observed in Yellow-eyed penguins on the mainland and may explain the importance of Enderby Island as a population stronghold. Further South, water depths drop to depths >200m relatively close to the coast, which is indicative of suboptimal foraging conditions and, hence, resident Yellow-eyed penguins may employ different foraging strategies in those regions.

1.4   Conclusions

We have a reasonably good idea about the current distribution of yellow-eyed penguin breeding areas and we begin to learn more about fine scale habitat requirements. In order to optimise current habitat restoration efforts on the New Zealand mainland previous activities should be evaluated in terms of achievements.

In contrast, our knowledge about yellow-eyed penguin distribution at sea such as the location of important foraging areas remains superficial. In order to better assess potential effects of commercial fisheries we need a better understanding of yellow-eyed penguin marine ecology and foraging ranges, particularly around breeding areas that have little continental shelf available such as the Catlins and the Southern regions of the Auckland Island group. Improving the quality of at-sea-distribution data would greatly increase the reliability of risk assessments.

2.   Population levels and trends of yellow-eyed penguins

Executive Summary

Accurate population census data is lacking for the majority of yellow-eyed penguin breeding areas. Despite being considered the population stronghold, information about yellow-eyed penguins breeding on the **sub-Antarctic Campbell and Auckland Islands** is scarce and outdated. Campbell Island has been surveyed twice, in 1988 and 1992, and this latest population census has not been repeated to date. For the Auckland Island Group the information is even sketchier and a first population census is urgently needed.

The first comprehensive population census on **Stewart Island** and neighbouring islands during 1999-2001 found 178 breeding pairs, considerably less than expected from previous population estimates. This prompted research into the threats affecting yellow-eyed penguins on Stewart Island. High chick mortality documented during a five year study (2003-2008) along the Anglem Coast, Northeast Stewart Island, suggests that recruitment is insufficient to sustain the population which has declined considerably since the initial survey.

Yellow-eyed penguins breeding of the **New Zealand South Island** have received more scientific attention and some breeding areas have now been monitored continuously over more than 30 years. The current population on the New Zealand mainland is small, 400-600 breeding pairs, and has experienced extreme fluctuations. While the number of breeding pairs in the Catlins or North Otago appear stable or even increased (2 colonies) over the last 20 years the number of yellow-eyed penguins breeding pairs on the Otago Peninsula is declining.

In addition to long recognised dangers new threats are emerging such as increasing human disturbance, novel disease outbreaks, marine pollution, changes in oceanographic conditions and food supply. We are just beginning to realise the effects of benthic habitat degradation via commercial fisheries activities that act on top of penguin bycatch in the commercial set net

and trawl fisheries. Sea-based threats remain little understood and need to be quantified in order to make informed anticipatory management decisions to safeguard yellow-eyed penguin populations.

2.1   Introduction

Population sizes of yellow-eyed penguins on the New Zealand mainland are assessed via annual counts of active nests. This is a prevalent survey method to assess the populations of seabirds and waterfowl (Nettleship 1976; Hutchinson 1979; Thomas 1996). Nest counts provide a direct estimate of the breeding population at relatively low cost. However, challenges include the difficulty of finding nests particularly in non-colonial species, the possible disturbance of nesting birds and correct timing of nest searches (Erwin 1981; Walter & Rusch 1997; Bart et al. 2004).

The yellow-eyed penguin is the least colonial of all penguin species. They nest at low densities and well concealed by coastal vegetation in often reasonably steep and sometimes difficult to access areas (Seddon & Davis 1989; Moore et al. 2001; Poole 2005; Clark 2007; Clark et al. 2008). Hence, a number of nests are likely to be missed during each survey (e.g. Hegg et al. 2012), and accuracy will depend on prior knowledge of the site, nest search experience and effort. Information on these parameters have only recently been included into nest search protocols but are still not recorded in the yellow-eyed penguin data base and corresponding nest summary spreadsheets. These two electronic references safeguard productivity and abundance data of yellow-eyed penguins breeding on the New Zealand mainland and are maintained by the Department of Conservation Coastal Otago Area Office. The numbers presented and discussed here (section 2.3.1) provide a minimum estimate of breeding pairs with no measure of nest count reliability and comparability between years.

Beach counts may provide an index of total population size depending on available reference areas and timing (e.g. Moore et al. 2001; section 2.3.2). On sub-Antarctic Campbell Island, Peter Moore (1992) used mark-recapture of previously banded birds during landing counts at a selected site (Middle Bay, Northwest Bay, 78 breeding adults banded in 1987-1988) to estimate the percentage of birds using the landing on any day. Assuming the percentage of birds using a landing site was similar among all sites around Campbell Island during a particular time (e.g. 81.4% SD 13. 5% during May – July; Moore 1992) the entire population can be estimated, i.e. the total count of 1625 individuals in 1988 would represent a population of "about 2000 birds" (Moore 1992) or 2277 ± 122 individuals when including further mark-recapture data of 72 breeding birds banded at Sandy Bay in 1991-1992 (Moore et al. 2001). From the estimated total number of individuals potential nest numbers/ breeding pairs could be projected assuming 60% (Richdale 1957) or 70% of the birds (Efford et al. 1994) were breeders (Moore et al. 2001).

Such estimates don't take into account that landing pattern may vary considerably even between days (probably weather dependent, own observations), and the proportion of breeders may vary substantially between years (<30-90%; Effort et al. 1996).

For logistic reasons winter beach counts are more manageable on Campbell Island, the days are short and thus penguins, being visual hunters, concentrate their departures and arrivals around sunrise and sunset (Moore & Moffat 1990, including graph; Moore 1992). Moore (1992, Moore et al. 2001) found a high and consistent proportion of birds used the study landings during winter with usually little variations between days, particularly during May and June. Hence, beach counts appear to be a practical approach to obtain an index of population size, especially for logistically difficult areas.

In the following I will summarise the information we have available to date and give recommendations as to how our current knowledge about yellow-eyed penguin population levels and trends can be improved in the future.

2.2   Methods – population levels and trends

A comprehensive literature review (compare Section 1), including grey literature, provided me with the little yellow-eyed penguin population data that is available for sub-Antarctic Auckland and Campbell Islands and for Stewart Island and outliers.

Additionally to previously published figures I was provided with the latest summary of yellow-eyed penguin nest numbers for North Otago, the Otago Peninsula, and the Catlins in a nest summary spreadsheet that is maintained separately from the yellow-eyed penguin database (by Bruce McKinley and Melanie Young, Department of Conservation Coastal Otago Area Office). The data includes nest numbers for most breeding sites during the breeding seasons 1992-2011 with estimates for the total mainland population from 1980.

While some breeding sites have been consistently monitored with similar effort and sometimes even by the same person over the past 20 years, other areas have been searched less consistently over the years and no record is available in regard to nest search experience, search effort, weather conditions during search days or even the area covered during the search.

For some breeding areas concern has been raised that searches with untrained volunteers and a high volunteer to expert ratio may greatly underestimate actual nest numbers. For example, 12 nests were found at Nugget Point in the Catlins by a group of volunteers with one experienced leader in 2001/02; a following more thorough search probably motivated by the 5 yearly Catlins census revealed at least 23 nests in the same area. Nest numbers in the season

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prior and after the Catlins census, 9 and 13 respectively, are likely considerable underestimates of true nest numbers. In recent years, this problem has been more carefully addressed, aiming at a ratio of two volunteers to one experienced leader knowing the site. Data from 2007 onwards appear to better reflect actual nest numbers at least in some areas.

Therefore, even data from breeding areas that get searched annually have to be taken with caution. However, many breeding areas get visited infrequently every few years, and interim numbers are educated guesses of how many nests would have been found if the area was searched. Unfortunately, it is not always clear in the nest data spreadsheet which data derived from real ground searches and which are mere guesstimates.

With help from Melanie Young and Dave Houston I cross checked data and we decided on breeding areas (i.e. all 8 in North Otago, 10 on the Otago Peninsula, and 5 in the Catlins) that appear to have the most reliable data for the analysis of long-term population trends (Appendix 1). General regional population trends were analysed using linear regression (Zar 1999) for the data available (years 1992-2012). Since yellow-eyed penguin populations undergo considerable fluctuations applying linear regression can be considered only preliminary. The factors affecting yellow-eyed penguin population size and productivity are complex and little understood and further research (see recommendations) is required before we can draw reliable conclusions.

2.3   Results

2.3.1 Population levels and trends on the New Zealand mainland

South Island New Zealand

Between 400 and 600 pairs currently breed along the southeast coast of the New Zealand South Island in four distinct breeding regions: the Banks Peninsula, North Otago, Otago

Peninsula, and the Catlins. The population has seen extreme inter-annual fluctuations over the last ~30 years (Figure 2.1).

The Otago Peninsula used to be the most important region hosting about half of the South Island breeding population. During the last breeding season 2011/12 six active nests were found on Banks Peninsula, 50 nests in North Otago, 184 nests were estimated for the Otago Peninsula, and 214 nests were found in the Catlins.

Lance Richdale focussed his population study (1936-1948) on yellow-eyed penguins breeding on the Otago Peninsula; hence, most historic records are from here (e.g. Richdale 1941, 1951, 1957). In the late 1970s John Darby initiated extensive nest searches on the Otago Peninsula and selected sites in North Otago and the Catlins (Darby 1985; Darby & Seddon 1990). Since 1992 Yellow-eyed population monitoring is coordinated by the Department of Conservation.

Historic population accounts

Anecdotal evidence suggests considerably higher population numbers at the beginning of the 20th century. "John Darby (pers. comm.) believes there were once 2000-3000 pairs of yellow-eyed penguins on the mainland, breeding in the traditional South Island coastal podocarp/hardwood forests. With the gradual clearance of the coastal forest breeding habitat, predation by feral cats, ferrets and dogs, disturbance by stock and people, and occasional crashes of the food supply, there has been a population decline" (Moore & Moffat 1990).

Lance Richdale himself believed that "within quite recent years *Megadyptes antipodes* occupied probably in their thousands the one time bush clad slopes of the Otago Peninsula. The destruction of the vegetation which formed his natural habitat has been no doubt the chief agent in the decimation of his numbers from thousands to hundreds" (Richdale 1942, cited from Moore 2001). Lance Richdale (1942) further attributes the apparent dramatic decline of the yellow-eyed penguin population to commercial collectors and even after passing the

Animals Protection Games Act in 1921-1922 "nests have been continually robbed by the thoughtless; in the 1939-40 season, a whole colony was deprived of its eggs". Additionally, "a series of devastating massacres by youths with pearifles" took its toll, "and it was reported that as many as forty were slaughtered in one afternoon" (Richdale 1942).

During the years of depression at the end of the II World War penguin colonies could recover to some extend: "in those years, the nations were at war, petrol was scarce, and man's destructive agencies were practically negligible. The forces of nature were able to work unimpeded" (Richdale 1957). "After the low point of 25 nests in 1940-41, the population of Richdale's study areas increased to 82 nests in 1952" (Moore 2001). Following World War II, "human disturbance resumed and episodes of shootings of penguins and burning of breeding habitat by youths hunting rabbits gave Richdale cause to urge the authorities to appoint a ranger for the peninsula, which occurred in 1948" (Moore 2001).

In 1985-86 a record of 276 active yellow-eyed penguin nest were counted on the Otago Peninsula (New Zealand Wildlife Service 1986). Only a few years later, in December – February 1989-90 a mysterious episode of adult mortality occurred causing the death of an estimated 50% of the breeding population in the monitored Boulder Beach complex on the Otago Peninsula (Effort et al. 1996). While dead birds were slightly lighter than surviving adults, the difference was too small to suggest starvation as cause of death, and no pathogens or toxins were isolated (Gill & Darby 1993, Effort et al. 1996, Figure 2.1). Graczyk colleagues (1995) suggested these deaths may have been caused by an outbreak of avian malaria; however, what factors triggered the high adult mortality remains unclear. Fortunately, such an episode of high adult mortality has not repeated to date, yet this event illustrates the fragility of yellow-eyed penguin populations.

The highest number ever recorded on the Otago Peninsula was 385 breeding pairs in 1996-97. This may be in part attributed to the increased search effort after the major population crash in

1989-1990 that prompted more regular monitoring of virtually all known South Island breeding areas (Figure 2.2). Currently more than half (~34) of the 53 known breeding areas are assessed each year, with particular efforts to cover all known breeding areas in the Catlins at five year intervals. Following an initial rapid increase in breeding pairs in 1991 when previously known breeders returned the subsequent season, the following six years of low adult mortality and good recruitment allowed full recovery (Figure 2.1, Efford et al. 1994, 1996). However, factors driving such dramatic population changes still remain little understood.

Regional trends 1992-2011:

Banks Peninsula

The few Yellow-eyed penguins on the Banks Peninsula (i.e. 26 adult birds and 3 active nests found in 2008/09; 18 adult birds and 5 active nests confirmed in 2009/10) breed with little success and recruitment appears to come from mainland breeding areas further south (Parker 2009, 2010). During last breeding season (2011/12) a record of 6 nests were found on the Banks Peninsula with the help from enthusiastic and experienced Otago nest searchers (Melanie Young pers. comm.). Available data is insufficient to analyse any population trends.

North Otago

All 8 known breeding areas in North Otago have received comparable nest search efforts over the last 20+ years by the same persons most importantly: Dave Houston and Kevin Pearce, Department of Conservation, North Otago Area Office. Annual surveys began during the breeding season 1984/85 with peaks in 1985/86 (43 nests) and 2001/02 (51 nests; Jones et al. 2004, the nest data spreadsheet maintained by DOC states 48 nests in North Otago for the

same season). The highest number observed so far was 77 nests in 2008/09. In 1984/85, three locations accounted for 68% of the nest numbers. By 2001/02 the same three areas contributed only 22% to the total nest count (Jones et al. 2004). Two new breeding areas have gained importance and now host most breeding pairs in North Otago.

Numbers of breeding pairs have significantly increased since 1992 (linear regression: $F_{1, 18}$ = 43.35; $p < 0.001$; $r^2 = 0.71$; Figure 2.3a). This positive trend is solely driven by two intensely managed colonies (Katiki Point and Barracouta Bay) that have seen a considerable increase in the number of breeding pairs ($F_{1, 18} = 119.84$; $p < 0.001$; $r^2 = 0.87$; Figure 2.3b). Without these two colonies yellow-eyed penguin breeding pairs in North Otago probably remain stable with extreme fluctuations and overall low numbers (6 colonies; linear regression: $F_{1, 18} = 0.001$; $p = 0.975$; $r^2 = 0.00$, Figure 2.3c).

Otago Peninsula

The number of breeding pairs on the Otago Peninsula has significantly declined since 1992 (linear regression: $F_{1, 18} = 7.00$; $p = 0.016$; $r^2 = 0.28$; Figure 2.4). This is despite one of the 10 breeding areas included into the analysis saw a considerable increase in nest numbers over the same time period (+225%; linear regression: $F_{1, 18} = 31.10$; $p < 0.001$; $r^2 = 0.63$).

The strongest decline, about -60%, has been observed in Sandfly Bay (linear regression: $F_{1, 18} = 16.10$; $p = 0.001$; $r^2 = 0.47$), followed by breeding areas in the Northeast (-51%; 4 colonies, linear regression: $F_{1, 18} = 12.74$; $p = 0.002$; $r^2 = 0.41$), and the South West of the Peninsula (-38%; 4 colonies; linear regression: $F_{1, 18} = 8.41$; $p = 0.010$; $r^2 = 0.32$).

Catlins

The Catlins have seen the least consistent penguin monitoring in the past. Five breeding areas that were visited most regularly have been included into this analysis (linear regression: ns. $F_{1,\,18} = 2.00$; $p = 0.174$; $r^2 = 0.10$; Figure 2.7). However, issues with nest count reliability and accuracy (see methods section) may explain part of the fluctuations even at more regularly visited sites. The complete Catlins survey that has been established in 1997 to take place about every 5 years provides additional data (a complete census took place in 1997/98; 2001/02; 2007/08; 2011/12; Figure 2.5). From the data available, the nest numbers in the Catlins appear stable since 1992; however, the increased search effort with more experienced personnel in recent years may conceal a potential decline.

Stewart Island and outliers

During the first comprehensive survey in 1999/2001 a total of 178 active nests were found: 79 pairs on Stewart Island and 99 pairs on the smaller adjacent islands (Massaro and Blair 2003). The most recent survey (2008/09) found 77 pairs on Stewart Island and 30 pairs on smaller outliers; however, larger islands such as Bench and Codfish were not included (King 2009). While Bench Island has not been searched in recent years (Sandy King pers. comm.), Yellow-eyed penguins breeding on Codfish Island were down from 61 nests in 2001/02 (Massaro & Blair 2003) to 39 nests in November 2011 (Dave Houston pers. comm. – get report once completed!).

Yellow-eyed penguins along the Anglem Coast declined steadily over a five year study (2003-2008) and in total by 50% since the survey in 1999-2001 (King 2008a, b). The dramatic decline of Yellow-eyed penguins breeding along the Anglem Coast appears to be independent of population trends at other breeding areas on Stewart Island (King 2009). The number of known breeding areas increased from 24 (1999/2000 survey) to 29 (2008/09; King 2009).

However, since some of the previously know breeding sites had reduced nest numbers King (2009) suspects increased search effort and experience may have obscured a potential decline.

2.3.2 Population levels and trends in the New Zealand sub-Antarctic

The sub-Antarctic Yellow-eyed penguin population has received very little attention so far and current population levels and trends remain unknown.

Campbell Island group

During the two sub-Antarctic winter surveys of 1988 and 1992 Peter Moore and colleagues found 172 and 140 landing sites, respectively. The Campbell Island population was estimated around 2277 ± 122 individuals in 1988. When the census was repeated four years later in 1992 the total population (estimated from mark-recapture analysis) had declined by 41% to 1347 ± 91 birds (Moore et al. 2001). Counts at 11 selected landing sites between 1987 and 1998 showed some signs of recovery after 1994 (Moore et al. 2001).

The Yellow-eyed penguin population on the New Zealand mainland crashed during the same time the Campbell Island population declined dramatically; reasons for this crash remain unclear (Gill and Darby 1993, Efford et al. 1996). While the struggling population on the mainland prompted more regular monitoring of breeding areas, Yellow-eyed penguins breeding in the sub-Antarctic received very little attention.

In November 2008 index counts were repeated at a selection of landing sites. Numbers at Northwest Bay (on average 131 birds) were higher than the previous count in November 1996, but have not yet reached previous peak records. At Southeast Harbour only 21.5 birds were observed (average from two counts per landing site), the lowest record ever and considerably lower than the previous count in 1997 (Hiscock 2008). Whether this is caused by

lower adult survival or merely a shift in use of landing sites potentially to avoid sea lion predation remains unclear (Hiscock 2008, see also Moore et al. 2001).

The last comprehensive population census in 1992 has not been repeated to date.

Auckland Island group

In 1989 a single population census of the northern part of the Auckland Island group was carried out (Moore 1992b). Moore himself describes this census as "brief and incomplete" and "provisional" (Beer 2010) and concluded that further surveys are needed.

Recent efforts have been made to survey Yellow-eyed penguin landing sites along the extensive but more sparsely populated eastern and southern shores (Beer 2010). Some spare time allowed re-visiting the northern part of the Auckland island group and could confirm the presence of Yellow-eyed penguins at the sites previously surveyed by Moore and colleagues in 1989. They found a total of 100 landing sites along the North coast/Port Ross and outlying islands a number that is comparable to what Moore found 20 years earlier (Moore 1992a, Beer 2010). However, since there is no general understanding how landing sites are defined, which close-by sites are considered one (i.e. likely providing access to the same breeding area), and what defines a site as new, any comparisons remain extremely vague. Furthermore, the presence of landing sites means only that penguins are still there but provides no information of abundance – i.e. how many individuals are using a landing site or the number of breeding pairs.

There are no recent estimates of population size.

2.4   Discussion

The first objective stated in the yellow-eyed penguin recovery plan is "to obtain accurate population census and trend data from all parts of the hoiho range using approved survey and monitoring techniques" (McKinlay 2001). This task had been already stated in preceding species conservation plan (Department of Conservation 1991, McKinlay 2001). Today, more than 30 years later, this primary objective has still not been achieved. Although monitoring effort has increased in recent years, accurate population census data is lacking for most yellow-eyed penguin breeding areas.

Despite being considered the population stronghold information about yellow-eyed penguins breeding on the **sub-Antarctic Campbell and Auckland Islands** is scarce and outdated. Campbell Island has been surveyed twice, in 1988 and 1992, and this latest population census has not been repeated to date. For the Auckland Island Group the information is even sketchier and a first population census is urgently needed.

The first comprehensive population census on **Stewart Island** and neighbouring islands during 1999-2001 found 178 breeding pairs. Previous estimates of 470-705 (New Zealand Wildlife Service 1986), 350-450 (Darby & Seddon 1990), and 470-600 (McKinlay 2001 – stating "these figures should be treated with a great deal of scepticism" since "only a partial survey was completed in the early 1990's") have greatly overestimated the actual population size. Darby (2003) realised that partial ground searches between1984-1994 suggested lower numbers than expected and revised earlier estimates to 220-400 breeding pairs.

The population census found 79 pairs on Stewart Island and 99 pairs on islands outliers including Codfish Island (Massaro & Blair 2003). Judging from the apparently abundant and comparably little modified terrestrial habitat the actual number of nests found was considerably lower than expected. In the absence of mustelids, important introduced predators of penguin eggs and chicks on the New Zealand South Island, feral cats were suspected to be

responsible for the overall low numbers of breeding pairs on mainland Stewart Island and for the low breeding success observed (0-33% of chicks fledged) compared to predator free island outliers (27-76%; Massaro and Blair 2003; King 2008a, b). However, a subsequently initiated five year study did not confirm a single case of cat predation. Instead, starvation and disease have been found the main causes of chick mortality along the Anglem Coast, Northeast Stewart Island (King 2008a, b; King 2009).

Predator free Codfish Island, the largest island outlier, which is situated 4 km to the East of Stewart Island contributed 61 breeding pairs to the overall count (Massaro & Blair 2003). When Codfish Island is removed as a special case from the dataset, the argued differences between mainland Stewart Island and cat free outliers cease to exist. Hence, the problem needs to be addressed in a more holistic manner.

Darby (2003) suggested apart from the potential impact of feral cat predation on chicks and adults that other factors such as "habitat degradation by grazing mammals, accidental capture of birds in fishing nets, disease, and changes in the marine environment" may be limiting yellow-eyed penguins on Stewart Island.

Degradation of the marine foraging habitat due to oyster dredging in the Foveaux Strait appears to affect prey availability and quality (Browne 2007; Mattern et al. 2007; Mattern 2008, Browne et al. 2011). Fisheries bycatch may also play a role (Rowe 2009, 2010; Ramm 2010; Rose Grindley, Dave Houston pers. comm.). Additionally, disease, such as the hemoparasite *Leucocytozoon*, has been observed (King 2008a, b; Hill et al. 2010).

However, while disease may cause starvation, lower quality of food found along the Anglem Coast strongly suggests that depletion of foraging habitat makes the chicks more vulnerable to disease (Browne et al. 2011).

The subsequent census in 2008/09 suggests that other breeding areas in Stewart Island are less affected and decline in number of breeding pairs is localised to the Anglem Coast, Northeast

Stewart Island. However, penguins breeding on neighbouring Codfish Island, previously a population stronghold that was considered stable and healthy, appear to be declining as well (Dave Houston pers. comm. – get report once available). Given the considerable fishing effort throughout the foraging range of Codfish Island birds and three observed death in commercial set nets in this area over the last few years it is conceivable that bycatch may play an important role in the demise of yellow-eyed penguins in this area.

Yellow-eyed penguins breeding of the **New Zealand South Island** have received considerably more scientific attention (e.g. Richdale 1941, 1951, 1957; Darby 1985; Darby & Seddon 1988, 1990; van Heezik 1990; Gill & Darby 1993; Alterio et al. 1998; Efford & Edge 1998; Wright 1998; Edge et al. 1999; Moore 1999; Ratz & Murphy 1999; Moore 2001; Massaro 2002, 2004, 2006, 2007; Ellenberg et al. 2007; Lalas et al. 2007; Mattern et al. 2007; Setiawan et al. 2007; Sturrock & Tompkins 2008; Ellenberg et al. 2009; Boessenkool et al. 2009, 2010; Hegg et al. 2012).

We now have a reasonable idea about the terrestrial drivers of reproductive success, survival and recruitment on the New Zealand mainland (such as introduced predators, human disturbance, disease, terrestrial habitat quality etc.) and appropriate management measures. However, we know very little about sea-based factors affecting population parameters, such as oceanographic conditions and food supply or fisheries interaction and bycatch.

The current population on the New Zealand mainland is small, 400-600 breeding pairs, and has experienced extreme fluctuations over the last 30 years. Since only a small number of pioneering individuals have established the mainland Yellow-eyed penguin population, genetic variability is low (compare section 1). Hence, reduced adaptive potential may compromise the long term viability of this population (Boessenkool et al. 2010). This is particularly concerning in face of environmental change, and multiple other threats this

population has to face; refer to Seddon et al. (*in press*) for a comprehensive summary of threats.

While some breeding areas appear stable despite considerable fluctuations, others show a significant decline (most areas on the Otago Peninsula) or an increase (two colonies in North Otago). In 1984 Janice Jones started a penguin hospital at Katiki Point, near Moreaki in **North Otago**, and in 2000 she initiated the Katiki Point Penguin Charitable Trust to obtain better funding for the penguin hospital and habitat restoration, intense predator trapping and visitor management programmes. Following the retirement of the founders in 2003 the intensive habitat management and rehabilitation programmes have been continued by Rosalie Goldsworthy.

After changing rehabilitation techniques from hard to soft release the breeding colony at Katiki Point was established by four rehabilitated and translocated penguins in 1991/92 (Jones et al. 2004). Since then the colony has gradually increased to up to 30 breeding pairs in 2008/09. Breeding success was significantly higher at these two intensely managed colonies (Katiki Point and Barracouta Bay; mean of 1.46 chicks fledged per pair) than at neighbouring less managed colonies in North Otago (0.96; 1997-2002; Jones et al. 2004).

A recent evaluation of rehabilitation outcomes found that although rehabilitation of resident breeders did not generate a significant increase in mean annual survival, it can increase the local number of nesting attempts at sites where anthropogenic threats to the species are adequately managed (Ratz and Lalas 2010). Chris Lalas (pers. comm.) believes that the increase of breeding pairs at Katiki Point is driven by "a mixture of good management and good luck". While the two colonies at Katiki Point have significantly increased in size, the number of breeding pairs at similarly intensely managed colonies at Penguin Place on the Northeastern shores of the Otago Peninsula has declined.

Management of terrestrial threats alone appears not sufficient to safeguard yellow-eyed penguin populations. In the case of Katiki Point an initially voluntary set net ban area has been established decades ago (Rosalie Goldsworthy pers. comm.) which may have improved reproductive success, juvenile and adult survival. Analysing the factors that drive population parameters in relation to management regimes in greater detail has been recommended (e.g. Busch & Cullen 2009; Seddon et al. *in press*) and would be an important and worthwhile exercise.

While 1 of the 10 colonies (selected for data consistency and reliability) on **Otago Peninsula** has shown an increase in breeding pairs, the remaining 9 breeding sites experienced considerable reduction in nest numbers. Drivers for the observed population decline are complex but probably include on top of the substantial fisheries bycatch (Darby and Dawson 2000) an increase in sea lion predation (particularly apparent on some of the colonies in the Northeast; Lalas et al. 2007), human disturbance impact (Sandfly Bay; Clung et al. 2004, Ellenberg et al. 2007), and a mix of factors, probably including human disturbance, varying intensity of predator control, and further fisheries interaction at the South-western Peninsula breeding areas.

Overall, marine based effects likely play an important role affecting population trends. The factors driving population changes on the Otago Peninsula and throughout the range of the yellow-eyed penguin need to be teased apart carefully comparing well designed explanatory models using validated nest count data and breeding parameters.

While the general appreciation of yellow-eyed penguins has considerably improved since Richdale's times, they still face a wide range of challenges in their battle for survival. In addition to long recognised dangers new threats are emerging such as increasing human disturbance, novel disease outbreaks, marine pollution, changes in oceanographic conditions and food supply, and marine habitat degradation due to fisheries activities, which are acting

on top of the bycatch observed in the commercial set net and trawl fisheries. Particularly, sea-based threats are little understood and we need to learn a lot very quickly in order to make informed anticipatory management decisions to safeguard yellow-eyed penguin populations.

2.5   Conclusions

There is insufficient knowledge of population levels and trends for most yellow-eyed penguin breeding areas. We know particularly little about the suspected "population stronghold" in the sub-Antarctic. The Auckland Island group is still awaiting its first comprehensive population census. For Campbell Island the last population census in 1992 is now 20 years back. Following the Stewart Island census we had to learn that previous estimates may considerably exceed actual (unexpectedly low) population numbers. Numbers of breeding pairs on the New Zealand South Island are low and have seen dramatic fluctuations over the last ~30 years.

We have come a long way since Richdale's times. Yellow-eyed penguins are now valued by the general public as well as international visitors and commercial tourism operators. Conservation efforts (including habitat restoration, effective predator control, and visitor management) have greatly improved the situation for penguins at many breeding areas on the New Zealand mainland. However, previously unrecognised threats are beginning to emerge and we start to realise that even intensive management on land alone is not enough to safeguard yellow-eyed penguin populations. Threats occurring in their marine environment need to be better understood and addressed urgently.

2.6   Recommendations

2.6.1   Increase nest count reliability and comparability between years

To assess the reliability of yellow-eyed penguin nest counts we recently used double counts by two independent teams on consecutive days at a range of breeding sites (Hegg et al. 2012). We employed teams of three searchers each with one experienced team leader and aimed to keep nest search area and effort comparable. We estimated the detection rate of single nest counts at around 88% (with some variability depending on steepness of terrain). Double counts provide the precision to detect annual variations in yellow-eyed penguin breeding populations as small as 3.3%. Consistent nest search protocols and small teams with an experienced leader are imperative to conduct both count methods adequately. Since yellow-eyed penguins are sensitive to human disturbance (Ellenberg et al. 2007, 2009; Ellenberg 2010) we recommend repeating double counts every five years to obtain precise estimates for the purpose of long-term population monitoring (Hegg et al. 2012). In order to evaluate the reliability of nest count data search effort, experience, area, and search conditions need to be recorded and stored with the data.

2.6.2   Maintain and improve annual population monitoring on the mainland

The Yellow-eyed Penguin Research Advisory Group has affirmed that the annual recording of the reproductive performance of marked individuals at selected sites must be sustained so as to contribute to an electronic relational database maintained by DOC and currently containing over 30 years of data (DOC, unpublished data). Maunders et al. (2007) who attempted to assess potential fisheries impact had to conclude that "estimates of recruitment are very uncertain. This could be improved by including information about the age-structure and/or the number of individuals each year that are first time breeders. However, due to some individuals not being marked, this may be problematic." It is concerning that there is currently

no funding in place to secure the future of detailed monitoring of important breeding areas, such as the Boulder Beach complex, for which we have more than 30 years of monitoring data. It should be a primary objective at least to keep such populations marked. A key approach for future research will entail the interrogation of long-term population data collated in the yellow-eyed penguin database (Seddon et al. *in press*).

2.6.3   Improve data quality, accessibility and maintenance

Currently, the electronic yellow-eyed penguin database comprises "banding records, nesting records, necropsy reports and other ancillary tables and reports. The electronic database has a companion set of paper records which contain original data and material not yet entered into the electronic database. As well there are paper files which cover many more years and study sites which are held separately" (McKinlay 2012). The draft memorandum of understanding, intended to provide a basis for future ownership and management of the electronic database, needs to be completed to allow easier access to database records for research and management purposes. Furthermore, we need to work up an ability to improve and maintain the yellow-eyed penguin database. The database suffers from a large degree of data inaccuracy and inconsistency and requires substantial cross-validation with paper records to perform scientifically sound analyses. Over the last year Aviva Stein and Melanie Young have put considerable effort into correcting database records for the Boulder Beach complex on the Otago Peninsula. Conclusions from these improved records of one well documented yellow-eyed penguin breeding area are presented in section 3. Unless similar effort is put into correcting the entire database, it will not be suitable for detailed analysis or reliable conclusions on the drivers of population changes.

2.6.4   Sub-Antarctic population census

The yellow-eyed penguin survey on Campbell Island needs to be repeated following the methods established by Peter Moore (Moore & Moffat 1990; Moore 1992; Moore et al. 2001). Since beach counts appear the most feasible approach to obtain a population census for remote and logistically difficult areas such as the sub-Antarctic islands, we suggest extending this approach to the Auckland Island group. However, methods previously established on Campbell Island will need to be adapted, refined, and enhanced.

A recent survey of yellow-eyed penguin landing sites around Auckland Island group found the search for landing sites alone not very reliable (Beer 2010). Of 22 landing sites found via searches for penguin sign by teams of experienced observers walking the coast the previous day only 15 were seen to be used by penguins during beach counts the next morning (meaning that during the incubation period not every landing that showed clear sign of recent penguin use will be actually be frequented every day). Additionally, these beach counts revealed that a further 27 sites in the same area had penguins departing without leaving sufficient sign to be picked up while walking the coast. Hence, more than half of the actual landings may have been missed by the survey (Beer 2010).

Therefore, any survey that relies on beach counts needs to cover every site more than once and ideally often enough to account for the sometimes considerable fluctuations in numbers departing or landing even between days. Here modern technologies can be of considerable help. Surveillance cameras can be employed at important landing sites for several days or even weeks producing more representative and reliable data while keeping the logistics manageable and observer bias low. Such cameras need to be installed by experienced personnel after establishing important landing sites following initial beach counts in a particular area. This will also allow validation of camera recordings.

For a reliable population estimate a known and marked population is needed for mark-recapture analysis and interpretation of beach count data. This should be accompanied by nest searches to establish the proportion of breeders during a particular season. Nest searches proved to be difficult in areas of low penguin abundance with sea lion and feral pig activity (Beer 2010). Thus, it will be most efficient to focus on predator free outliers with plenty of penguin activity for establishing such baseline data. Using double counts by two independent teams will provide a more accurate estimate of actual nest numbers (Hegg et al. 2012; compare 2.6.1). For better representation I suggest a minimum of two such control areas e.g. on Enderby Island, which is a population stronghold and ideal for logistical reasons, and on Adams Island covering the entire range of the Auckland Island group. Ideally, comprehensive information on breeding parameters, foraging ecology and reproductive output would be gathered during such an effort. Beer (2010) recommends repeating sub-Antarctic surveys of yellow-eyed penguin numbers every 5-10 years as an index for population trends. Sub-sample surveys at more frequent intervals will provide additional information essential for the interpretation of full survey results.

2.6.5   Repeat population census on Stewart Island

The population census on Stewart Island needs to be repeated at regular intervals to establish the extent of the previously observed decline along the Anglem Coast and if this decline indeed remains localised and independent of other breeding areas around Stewart Island. For a more reliable outcome I suggest using double counts of selected areas by independent teams as a measure of nest count accuracy (Hegg et al. 2012; compare 2.6.1). Since the last comprehensive population census was in 2008/09 it will need to be repeated in 2013/14 if aiming at financially and logistically manageable 5 year intervals between surveys for the purpose of monitoring population trends. However, considering the significant rate of decline

along the Anglem Coast (50% between 1999 and 2007; King 2008) an on-going annual monitoring programme would be desirable for sample areas.

2.6.6   Sustain appropriate management of terrestrial threats

➢ Ensure adequate predator control at important yellow-eyed penguin breeding sites

➢ Improve understanding and management of human disturbance effects

➢ Improve visitor education and management

➢ Endorse dog control

➢ Continue research into epidemiology of YEP diseases

➢ Develop protocols of minimum YEP habitat standards

2.6.7   Increase understanding of marine threats

➢ Improve understanding of fisheries impact (direct & indirect effects) on yellow-eyed penguins and their marine habitat.

➢ Analyse the effects of changes in the marine environment (habitat alterations, oceanographic & climatic changes) on yellow-eyed penguin marine ecology, foraging success, reproductive output and survival.

➢ Study potential effects of increasing sea lion population on yellow-eyed penguins breeding along the Otago Peninsula.

➢ Initiate the monitoring of marine pollutants in yellow-eyed penguin tissue as part of the post mortem protocol.

Overall, I encourage the maintenance and further improvement of yellow-eyed penguin monitoring data via standardized monitoring and data acquisition protocols (e.g. employing electronic aids for data recording) to reduce inconsistencies and improve data quality and robustness. A functioning database containing long-term population data along with the monitoring of key ecosystem parameters will not only provide better understanding of terrestrial and marine drivers of population change but will also allow investigation of secondary effects via complex ecological networks and multiple stressor interactions and will ultimately provide the basis for adaptive management strategies.

3.   Adult survival, juvenile survival, age of first breeding and fecundity of yellow-eyed penguins

Executive Summary

Adult survival and breeding parameters are fundamental when aiming to assess the risk of extinction for a species. Threats known to affect the survival of yellow-eyed penguins include habitat loss, predation, disease, human disturbance, and impacts from fisheries. This chapter is a summary of existing information relating to adult survival, juvenile survival, age at first breeding and fecundity of yellow-eyed penguins.

Existing studies report that yellow-eyed penguins have generally a relatively high adult survival (>85%). Current juvenile recovery rates are relatively low, with only 18.8% to 20.8% surviving to adulthood (1981-2003), compared to 32% in 1936-1954.

Age of first breeding is usually 2-3 years in females and 3-4 years in males. Age-specific reproduction followed a similar curve to most seabirds, with smaller clutch sizes, hatching success, and fledgling success in the adolescent and senescent years. The distribution of lifetime reproductive success (LRS) is highly negatively skewed, with only a small proportion of the population producing many offspring and subsequent recruits.

Data on adult survival, juvenile survival, age at first breeding and fecundity is either insufficient or lacking entirely for the majority of yellow-eyed penguin breeding areas (with some sites on the Otago Peninsula being a notable exception).

Population viability analysis has shown that small changes in yellow-eyed penguin adult survival can have dramatic effects on the overall risk of extinction. Thus losses of yellow-eyed penguins due to commercial fisheries activities need to be quantified for a sound risk assessment.

3.1   Introduction

3.1.1 Factors affecting survival of yellow-eyed penguins

According to life-history theory, adult survival is the single most important life history parameter for seabirds (Stearns 1992), and is fundamental to consider when assessing a species risk of extinction. There are several identified threats affecting the survival of yellow-eyed penguins, including habitat loss, predation, disease, human disturbance, and fisheries bycatch (e.g. McKinlay 2001, Darby and Dawson 2000). The disappearance of mature coastal forest is likely responsible for requiring yellow-eyed penguins to nest in sub-optimal habitat (Richdale 1957; Roberts & Roberts 1973), exposing them to greater risk of heat stress (Seddon & Davis 1989; Darby & Seddon 1990; Clark 2007). Predation is known to affect the survival of yellow-eyed penguin chicks, with the possibility of up to 88% of chicks being killed before fledging at sites lacking predator control programs (Darby & Seddon 1990). Although adult yellow-eyed penguins are not as susceptible to predation as chicks, feral pigs *Sus scrofa* may kill chicks and adults on the mainland and the Auckland Islands (Taylor 2000), and dogs are a serious threat to mainland populations (Hocken 2005). At sea, yellow-eyed penguins are at risk for predation by sharks, barracouta *Thyrsites atun*, and fur seals *Arctocephalus forsteri* (Hocken 2005; Schweigman & Darby 1997). Predation by female New Zealand sea lions *Phocarctos hookeri*, has been recorded, however these events are rare and recorded events were likely to be attributed to one individual (Lalas et al. 2007). Disease outbreaks have been known to affect yellow-eyed penguins on the mainland and the sub-Antarctic. The population crash in the 1990-91 breeding season is not well understood, suggested reasons include toxic diatom bloom or avian malaria (Gill & Darby 1993; Sturrock & Tompkins 2007, 2008). In recent years diseases such as leucocytozoonosis (*Leucocytozoon spp)* and diphtheritic stomatitis (*Corynebacterium amycolatum*) have been found to infect and reduce survival in yellow-eyed penguin chicks. Recent research has shown disease-related

mortality of adults, including evidence of disease in the subantarctic islands affecting both adults and chicks (Argilla et al. 2010, in Seddon et al. *in press*).

The yellow-eyed penguin is one of the flagships of New Zealand's wildlife tourism and concern has been raised that tourism related pressures may be becoming too high. Exposure to frequent unregulated visitor disturbance was associated with reduced breeding success and lower chick weights at fledging, leading to lower first year survival and recruitment probabilities (McClung et al. 2004; Ellenberg et al. 2007). Birds that continue to breed at frequently disturbed sites have not habituated to human proximity, on the contrary, they showed stronger heart rate and hormonal stress responses to human disturbance compared to penguins at neighbouring less disturbed sites (Ellenberg et al. 2007, 2009). Hence, yellow-eyed penguins exposed to unregulated tourism are not only disturbed more often, each disturbance event is more costly for the affected birds and disturbance effects accumulate.

Yellow-eyed penguins are at risk of entanglement in fishing gear (Darby and Dawson 2000; McKinlay 2001). Yellow-eyed penguins have been recorded as bycatch in inshore nets (Rowe 2009, 2010; Ramm 2010, 2012), however the observer coverage of inshore fishing vessels has been extremely low (~2%), making an accurate threat level assessment with the available information impossible (Maunder et al. 2007). Although there is currently no evidence for direct competition for food resources with commercial fisheries (Taylor 2000), benthic habitat degradation caused by commercial fishing activities results in fewer and lower quality prey with implications for population viability (e.g. Cranfield et al. 2001; Jiang & Carbines 2002; Mattern et al. 2007a, b; Mattern 2008; Browne et al. 2011).

3.1.2 Age at first breeding

Life-history theory (e.g. Caswell 1982) predicts that individuals attempt breeding as early as possible in order to maximise reproductive output during their lifetimes. However, under the

assumption that reproduction occurs at a cost of subsequent reduced survival (Williams 1966) evolutionary theory predicts there will be a single optimal age at first breeding which will maximise fitness (Stearns 1992). Variation in age at first breeding can be caused by constraints in the external environment, such as resource availability (e.g. Newton 1985; Korpimäki 1992), or if the cost of reproduction outweighs survival benefits, in which case a bird may skip breeding in order to increase the chance of future reproductive success (Curio 1983). Female yellow-eyed penguins have an earlier age at first breeding than males, with female yellow-eyed penguins mainly breeding between two to three years of age, and males beginning breeding mostly three and four years of age (Richdale 1957; Darby & Seddon 1990; Stein 2012).

3.1.3 Fecundity

The yellow-eyed penguin is a solitary breeder, contrasting with the majority of other penguin species and seabirds that breed colonially (Richdale 1957; Darby & Seddon 1990). Courtship and nest site selection commences in late August and September, and in September to October single clutches of up to two eggs are laid approximately three to five days apart (Richdale 1957; Seddon & Darby 1989). In some rare cases three eggs are found in one nest bowl, although it is unknown whether the third egg is laid by an additional attending adult (Darby & Seddon 1990; Seddon et al. *in press*). Incubation is shared by both parents, and chicks hatch synchronously in November (Seddon & Darby 1989; van Heezik & Davis 1989). Parents continue to share chick feeding duties until the guard stage from November to December, and post guard phases until fledging, which occurs in late January to March (Darby & Seddon 1990).

Yellow-eyed penguins that begin breeding at two to three years of age are more likely to lay single egg clutches (34% of clutches laid by two year old females were single egg clutches,

whereas single egg clutches were laid by less than 1% by three year old and older; Seddon et al. *in press*). Lay date varies for individual females, and egg size usually increases with female age (Massaro et al. 2002). Young birds also have significantly lower breeding success (63%) than older birds (89%) during their first breeding attempt (Darby & Seddon 1990). These younger and less experienced birds may also have shorter pair bonds, and pairs are four times more likely to separate if the breeding attempt is unsuccessful (Setiawan et al. 2005).

There is often a link between age-specific reproduction and breeding performance. In most instances for seabirds, reproductive success improves from the first breeding attempt, steadily increases to a plateau, and eventually declines with senescence (Newton 1989a, Partridge 1988). These age-specific increases in fecundity are likely a consequence of a lack of breeding and foraging practice in less experienced breeders, as well as increased reproductive effort in older birds to offset the decline in opportunities to reproduce. Low survival and poor breeding success in young breeders is common among many species of birds, and could be the product of underdeveloped foraging strategies, and inexperience with predators (Partridge 1989), while the increasing success could be due to physical maturation, increased foraging, mate finding and breeding experience, and improvement in breeding site selection (Newton 1989a).

3.1.4 Objective

There have been several studies on adult survival, juvenile survival, age at first breeding and fecundity, beginning with Lance Richdale's long-term study between 1936-1954 (Richdale 1957). Considerable monitoring and research effort at certain sites on the Otago Peninsula resulted in some 30 years of population data. However, population data and observations from yellow-eyed penguin breeding sites on the mainland (the Catlins, North Otago and Banks Peninsula) are less consistent and we know little about offshore island populations including

Codfish Island, Stewart Island, and the Auckland and Campbell Islands. The aim of this chapter is to summarise existing information on adult survival, juvenile survival, and fecundity of yellow-eyed penguins.

3.2   Methods

3.2.1. Study site

The majority of existing data is from the Otago Peninsula population of yellow-eyed penguins has been collected from the Boulder Beach Complex on the Otago Peninsula (45°500 S and 170°300 E, Figure 3.1). Boulder Beach is approximately three kilometres in length, and is divided into four sections: Double Bay; Midsection; Highcliff A1; and Highcliff. This complex was regularly chosen as a study site as it supports a large population of yellow-eyed penguins; has an inter-decadal history of being intensively monitored; and has been trapped for predators haphazardly over time. This site also has longest history of chick banding, and thus the majority of chicks fledged at this site have been banded (Figure 3.1).

3.2.2 Existing adult survival data

Existing data on adult survival was gathered and summarised from the following sources:

1.) Richdale (1957) measured age specific survival (recovery) rates for 30 male and 21 female yellow-eyed penguins that began breeding on the Otago Peninsula between 1936 and 1953.

2.) Efford et al. (1994) calculated Jolly-Seber survival rates for 339 birds breeding at Boulder Beach, Otago Peninsula, between 1981 and 1992. Survival rates represent the probability of a bird remaining alive and in the local population until the following breeding season.

3.) Edge et al. (1996) studied how reproduction and parental quality may affect adult survival of yellow-eyed penguins, and whether or not breeding experience may be used to predict

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adult survival. This study analysed data from 260 birds breeding on the Otago Peninsula between 1982-1994, and included survival data from the 1989 breeding season when there was a mass mortality event during which 150 juvenile and adult yellow-eyed penguins on the Otago Peninsula died over a two-month period (Efford et al. 1994).

4.) Edge et al. (1999) analysed recovery rates from 58 birds in 1992, and 62 birds in 1993, breeding at Boulder Beach on the Otago Peninsula. A sample of these birds was subjected to a brood manipulation experiment.

5.) Ratz et al. (2004) compared overall survival rates between Ryans Beach and Pipikaretu on the Otago Peninsula over six breeding seasons between 1991 and 1996.

6.) McKinlay (1997) performed a population viability analysis (PVA) to estimate the extinction probability for yellow-eyed penguins breeding on the Otago Peninsula, the Catlins, North Otago and the Auckland and Campbell Islands. The issues examined were: mortality across all age classes, migration and movement, impact of El Niño Southern Oscillation events, minimum breeding area, habitat size, usage of new habitat and predation. Adult survival estimates were calculated from a base figure of 17% from Efford et al. (1994)

3.2.3 Existing juvenile survival data

1.) Richdale (1957) calculated a juvenile mortality rate by assuming age at first breeding to be three years for males and females, and the mortality rate was the same for two year olds and juveniles. Richdale (1957) also studied juvenile return rates from 399 birds banded as chicks between 1939 and 1949 on the Otago Peninsula.

2.) Efford et al. (1994) analysed recovery data from 587 birds banded at the Boulder Beach Complex on the Otago Peninsula between 1981 and 1990.

3.) Stein (2012) analysed recovery data from 2032 birds banded between 1981 and 2003 at the Boulder Beach complex.

3.2.4 Existing age at first breeding data

1.) Richdale (1957) documented the age at first breeding for 304 yellow-eyed penguins between 1936 and 1947 on the Otago Peninsula.

2.) Stein (2012) calculated age at first breeding from a sample of 209 yellow-eyed penguins (107 females, and 102 males) banded as fledglings between 1981 and 1998 at the Boulder Beach complex, Otago Peninsula.

3.2.5 Existing fecundity data

1.) Stein (2012) calculated updated age-specific breeding information from a sample of 199 female yellow-eyed penguins banded as fledglings between 1981 and 2005, breeding between 1983 and 2010 at the Boulder Beach Complex. This study also analysed factors affecting the lifetime reproductive success (LRS) of a sample of 209 yellow-eyed penguins breeding at Boulder Beach between 1984 and 1998.

3.3   Results and Discussion

3.3.1 Adult survival Estimates

There are several published estimates of adult survival of yellow-eyed penguins (Table 3.1). Studies by Richdale (1957), Efford et al. (1994), Edge (1996), Edge et al. (1999) and Ratz et al. (2000) estimated adult survival to be >80% on the Otago Peninsula, except for an isolated

population crash in the 1989-90 breeding season (c. 50%) reasons for this crash remain little understood (Table 3.1).

Richdale (1957) estimated yearly survival to be 85.4% between 1936-1954, and concluded that there is little reduction in adult survival rates once birds reach maturity. Richdale also noted a slightly lower survival rate for females of 85.7% compared with 87.4% for males (Richdale 1957).

Efford et al. (1994) estimated adult survival to be 80% or higher in every year excluding 1989-90, when it fell to 50%, due to the unidentified mortality event (Gill & Darby 1993, Efford et al. 1994). These numbers are similar to those reported by Richdale (1957), and no significant differences were found when compared. Emigration was low and therefore a negligible factor for survival analysis, with only 5.9% (20 of 339) of birds found breeding at sites other than their natal colonies (Efford et al. 1994).

Edge et al. (1996) estimated survival for adult yellow-eyed penguins breeding at Boulder Beach 1982-1994 to range between $72 \pm 5\%$ and $94 \pm 1\%$, excluding 1989 when survival rates were between $20 \pm 6\%$ and $59 \pm 5\%$. Results indicated that yearly survival of experienced breeders with chicks was $94 \pm 1\%$, and the survival rate for inexperienced breeders with chicks was $89 \pm 2\%$. The survival rate for experienced breeders without chicks was $83 \pm 3\%$, and inexperienced breeders that failed to hatch chicks had an estimated survival rate of $72 \pm 5\%$. Edge (1996) found a link between reproductive success and probability of survival to the next breeding season, and that age and breeding experience were important predictors for adult survival in the following season.

Edge et al. (1999) found that in 1992, survival rates were 14/14 (100%) and 14/15 (93%) for parents of manipulated and natural single-chick broods respectively. This was compared to recovery rates of parents of two-chick nests which were 25/29 (86%), with an overall adult recovery rate of 91.3%. In 1993 survival rates were 11/12 (92%) and 16/18 (89%) for parents

of manipulated and non-manipulated single-chick broods respectively, and 29/32 (91%) for parents of two-chick nests, with an overall recovery rate of 90.3%. Differences between years, brood sizes and whether or not broods were manipulated were not significant. Overall survival from the two years was >86%.

Ratz et al. (1994) found that the average annual survival was 90% for two study sites on the Otago Peninsula combined over four seasons. This study also found no significant difference between survival of males (93%) and females (90%).

Population Viability Analysis (PVA) by McKinlay (1997) showed that the entire species is unlikely to go extinct within the next 1000 years; however sub-populations are significantly more vulnerable. For example, the Otago Peninsula population may go extinct within a few hundred years; increased adult mortality would accelerate this process considerably (McKinlay 1997). PVA showed that even small fluctuations (~1%) in adult survival had dramatic effects on the probability of extinction (McKinlay 1997). While existing extinction risks were reported to be sufficiently close to zero, populations were found to be barely maintaining themselves.

In long-lived species like yellow-eyed penguins, changes in mortality rates of adults have the most dramatic effects for the population. Natural variations in adult survival are likely to be driven by food availability (Efford et al. 1994). However, it is important to understand any additional threats affecting adult survival, since even small changes in mortality can significantly affect the overall risk of extinction (McKinlay 1997).

3.3.2 Juvenile Survival

Richdale (1957) found that of 399 fledged chicks 152 (38%) were re-sighted in the four months after fledging, 129 (32%) were re-sighted as two year olds, and 108 were re-sighted as three year olds (i.e. 27% survived from fledging until three years of age; Table 3.2).

Low juvenile survival from fledgling to sexual maturity is likely to be accountable for the sparse numbers of breeders recruiting to breeding populations (13.8%; Stein 2012). Stein (2012) found that only 18.8% of yellow-eyed penguin fledglings survived to maturity, a similar proportion to the 20.8% (122/587) of juvenile yellow-eyed penguins re-sighted as adults at the Boulder Beach complex between 1981 and 1990 calculated by Efford et al. (1994).

The most common hypothesis for the high rate of mortality in young birds is their inability to feed themselves (Orians 1969; Dunn 1972), and this is most likely the case for yellow-eyed penguins. However why the juvenile survival is currently so much lower than during Richdale's times remains a matter of speculation. Factors affecting the food availability particularly along around the Otago Peninsula need to be determined.

3.3.3 Age at first breeding

Between 1936 and 1947 about half of the yellow-eyed penguin females started breeding at two years of age (48%), compared to only 8% of males of the same sage (Richdale 1957). Another 48% of females began breeding at three years, and the remaining 4% began breeding at age four. 47% of the males started breeding when 3 years old, and 33% did not breed before their fourth year (Richdale 1957).

Stein et al. (2012) analysed complete life history data from a sample of 209 birds (107 females, and 102 males) banded as fledglings between 1981 and 1998 and found similar trends to Richdale (1957), except for the significantly higher numbers of females beginning breeding at age two (Table 3.3). This could be attributed to differences in monitoring effort and detection.

Stein (2012) found that, although success for first time breeders is often relatively low, age at first breeding was a significant predictor of lifetime reproductive success (LRS, number of

banded offspring fledged during an individual bird's lifetime) for yellow-eyed penguins. This corresponds with the conclusions of Newton (1989a) who reports that in many long-lived seabirds, individuals that start breeding later will produce fewer lifetime offspring as a result of a decrease in total breeding opportunities throughout the bird's life.

4.4 Fecundity

Age-specific reproduction followed a similar curve to most seabirds, with smaller clutch sizes and success rates in the adolescent and senescent years. Yellow-eyed penguins lay smaller clutches at ages two and three, with fecundity increasing and reaching a plateau between ages four to 13. Breeding peaked between ages 13 and 17, and declined thereafter (Stein 2012, Table 3.4).

Stein (2012) found that the mean lifetime number of offspring produced was 5.00 for females, and 4.31 for males (Table 3.5). Longevity was the strongest correlate of LRS, with the number of offspring produced increasing significantly with increased lifespan. There was high individual variance in LRS calculated for both males and females, with females demonstrating a higher range of observations among individuals than males (Figure 3.2).

For yellow-eyed penguins, the maximum number of fledged offspring for both males (20 chicks, Bird ID: J2165; Table 3.5) and females (22 chicks, Bird ID: J2377) is high compared to the mean LRS of 4.31 and 5.00, respectively. The distribution of LRS was highly negatively skewed, being consistent with other studies that have found that most individuals produce small numbers of young, with only a few "super birds" producing many offspring (Clutton-Brock 1988; Newton 1989a).

3.4   Conclusions

Since yellow-eyed penguins are a long-lived species and lifetime reproductive success depends on lifespan, adult survival is a paramount concern for this species.

Furthermore, the juvenile survival (~20%) on the Otago Peninsula in the past 20 years was lower than what was observed by Lance Richdale some 60 years ago (32%). Reasons for the increased juvenile mortality are unclear. Starvation i.e. inexperience to find food is thought to be the main cause of juvenile mortality. Hence, factors affecting the availability and quality of yellow-eyed penguin prey need to be analysed. This includes benthic habitat degradation as a result of anthropogenic factors, such as commercial bottom fisheries (e.g. bottom trawls, oyster dredging) or increased sedimentation. It is difficult to assess to which extent fisheries bycatch might contribute to the increase in juvenile mortality as the independent observer programme currently does not distinguish between juvenile and adult birds.

The majority of existing studies have utilised the long-term data collected from yellow-eyed penguins on the Otago Peninsula to produce sufficient evidence regarding survival rates, age at first breeding and fecundity of yellow-eyed penguins. However, data is either insufficient or non-existent for other sites, including the assumed population stronghold on the sub-Antarctic Auckland and Campbell Islands. The birds breeding in the sub-Antarctic are genetically distinct from the mainland population; as migration is negligible these populations need to be managed separately. Until there are even baseline measures available for sub-Antarctic populations, it will be impossible to identify any relevant trends or changes on a population level.

Since even small fluctuations in adult survival can greatly increase the risk of extinction for yellow-eyed penguins, it is important to analyse factors that affect adult survival. Particularly the extent of mortality via entanglement in fishing gear is poorly understood and needs to be quantified urgently.

4.   Yellow-eyed penguin marine ecology

This section is being prepared under a different contract but will be included into the final

report to keep important information in one place.

5.   Research priorities to assess the impact of commercial fisheries on yellow-eyed penguins

Executive Summary

The endemic, endangered yellow-eyed penguin is at risk from bycatch as well as affected by benthic foraging habitat degradation due to commercial fisheries activities.

Particularly, **bycatch** in gillnets (set nets) poses a significant threat to yellow-eyed penguin populations. Additionally, bycatch in the commercial inshore trawl fisheries (i.e. flatfish trawl, small inshore trawl, large fresher trawl) and bottom longline fisheries pose risk to yellow-eyed penguins.

Since yellow-eyed penguins are primarily bottom foragers that take benthic prey they can be affected by **benthic habitat degradation** in their traditional foraging areas. There is strong evidence that commercial oyster dredging in the Foveaux Strait by modification of epifaunal reefs significantly reduces the abundance, diversity and quality of penguin prey, ultimately leading to a population decline of yellow-eyed penguins along the Anglem Coast, Stewart Island. The effects of benthic habitat degradation e.g. via bottom trawls in other penguin foraging areas still need to be quantified.

To improve the quality of risk assessment, **observer coverage needs to be substantially increased** on commercial set netters and inshore trawlers/bottom-longline fisheries operating within 50 km of yellow-eyed penguin breeding areas. Electronic monitoring can supplement independent observers allowing better overall coverage while keeping the related costs manageable. Such data is essential not only to derive reliable estimates of total penguin bycatch but also to understand operational details affecting the likelihood of capture so that mitigation measures can be developed.

To better assess the impact of benthic habitat degradation on yellow-eyed penguins a **comprehensive analysis of foraging ecology and at sea distribution** needs to be carried out covering at least 5 breeding seasons to account for variable oceanographic and climatic conditions. This needs to be accompanied by the monitoring of **population parameters** to quantify the link between foraging parameters such as effort, success and the breeding outcome. **Independent seafloor surveys** will provide the required information on the extent of benthic habitat degradation from oyster dredging and bottom trawls.

The yellow-eyed penguin population on the New Zealand mainland is small and fragile. Previous population strongholds such as on the Otago Peninsula are declining. We need to find effective ways to reduce the pressure of commercial fisheries on yellow-eyed penguins in the near future. Effective mitigation of the impact of commercial fisheries will arise only from detailed management guidelines derived from rigorous research.

Background

The endemic yellow-eyed penguin is internationally classified as endangered (B2b(iii)c(iv), IUCN 2011) and as threatened (nationally vulnerable) following the New Zealand internal threat classification system (Miskelly et al. 2008). This species may live to more than 25 years (own observations, John Darby unpublished data) and adult mortality is generally low (0.09-0.17; Richdale 1957; Efford et al. 1996; Edge et al. 1999; Ratz et al. 2004). Population Viability Analysis shows that even a small increase in adult mortality rate leads to a dramatic increase in extinction probability of the yellow-eyed penguin (McKinlay 1997).

Methods

After thorough review of the little available published data and unpublished reports I have assembled and circulated a discussion paper which has been improved by feedback from the Yellow-eyed Penguin Research Advisory Group (which is a subgroup of the Yellow-eyed penguin Recovery Group) during a meeting on 24 February 2012.

I have prepared a PowerPoint presentation and lead a session on the "Impact of commercial fisheries on yellow-eyed penguins - what we know and what we need to know" with the Seabird Research Group (SRG) at the University of Otago on 17 May 2012 and received substantial response.

This is the updated version and I currently seek input from international experts. I plan to incorporate all feedback from the International Penguin Expert Group of the World Conservation Union (IUCN) Species Survival Commission (SSC) into the final version of this report.

Overview of research priorities in order of importance:

5.1   Quantify the direct effects of commercial fisheries

  5.1.1   Yellow-eyed penguin bycatch in commercial set net fisheries

  5.1.2   Yellow-eyed penguin bycatch in commercial trawl fisheries

5.2   Document the indirect effects of commercial fisheries

  5.2.1   Fisheries induced benthic habitat degradation

5.1   Quantify the direct effects of commercial fisheries

5.1.1 Yellow-eyed penguin bycatch in commercial set net fisheries

Rationale

Bycatch in gillnets, especially set nets, pose a significant threat to yellow-eyed penguin populations. The "Level 1 Risk Assessment for Incidental Seabird Mortality" categorises the risk of yellow-eyed penguin entanglement in set nets as "extreme" (Rowe 2010). Between 1979 and 1997 a total of 72 confirmed deaths of yellow-eyed penguins in gillnet entanglements were recorded, most at or near Otago Peninsula (Darby & Dawson 2000). This figure likely underestimates true bycatch substantially, since the majority of incidents remain unreported (Darby & Dawson 2000).

The *National Plan of Action to Reduce Incidental Catch of Seabirds in New Zealand Fisheries* (MFish and DOC 2004) lists yellow-eyed penguins as bycatch in inshore set nets. Historically observer coverage of the inshore fishing fleet has been low (~2%) and erratic (Ramm 2010; Seddon et al. 2012). Although observer coverage has increased in recent years (Rowe 2008, 2009, 2010; Ramm 2010, 2012), there is still little information available on the numbers of yellow-eyed penguins killed each year. The absence of these data makes reliable assessment of likely impacts of commercial fisheries operations impossible (Maunder et al. 2007). In a recent attempt to "assess the risk to seabird populations from New Zealand commercial fisheries" Richard and colleagues (2011) had to exclude set net and purse seine commercial fisheries from the analysis, because "they were poorly observed and quite heterogeneous" (Richard et al. 2011).

Table 5.1 provides an overview of observer coverage and the number of yellow-eyed penguins caught in recent years. Despite an overall low observer coverage over five breeding seasons a total of 9 yellow-eyed penguins were found drowned in set nets by independent

observers (Table 5.1). Five of these deaths occurred along the east-coast of the South Island (FMA 3, SEC, ranging from Clarence Point, North Canterbury, to Slope Point, Southland). A further four penguins were found dead in set nets in the Foveaux Strait region (FMA 5, SOU, covering the southern coast of mainland, Stewart Island and the Snares Islands). These figures can be extrapolated and indicate that annual penguin deaths in inshore set nets along the New Zealand mainland may be around 20 birds annually in each of the two Fisheries Management Areas (FMA 5 and FMA 3). However, the true numbers of penguins caught in set nets each year remain a matter of conjecture. Ramm (2012) points out that observer coverage for set netting operations is "highly spatially focussed" so that the detection rate of penguin bycatch depends largely on whether observed vessels operated in marine areas frequented by yellow-eyed penguins (e.g. within a 50km radius of penguin breeding sites during the breeding season and included yellow-eyed penguin foraging hotspots, compare section 4 of the report).

Of the seabirds captured in set nets, over half were released alive as they were caught at the surface after being attracted by offal discharge (Ramm 2010). All of the yellow-eyed penguins recovered from set nets were dead (Rowe 2009, 2010, Ramm 2010, 2012), most likely because they got caught in the net and drowned while diving. In this light, suggested mitigation measures such as reducing attractants for birds (e.g. offal discharge; Ramm 2010) during hauling will not affect the numbers of penguin casualties.

The few data we have on the impact of set net fisheries suggests that penguins are taken over a wide range of habitats from shallow coastal waters to depths exceeding 140m and 20km offshore (Darby & Dawson 2000). The recently introduced set net ban within 4 nautical miles off shore along most of the East coast of the South Island (NZ Ministry of Fisheries 2008) may reduce bycatch of penguins travelling to their foraging grounds (Mattern et al 2007). But considering that the main foraging grounds of penguins along the New Zealand South Island

are about 15-20 km offshore the ban will have no effect on the impact of set nets brought out by commercial operators further offshore.

Anecdotal evidence suggests that yellow-eyed penguin bycatch is considerably higher than what is being reported. For example, more than 30 yellow-eyed penguins were caught over one season by a single set netter operating around the Otago Peninsula. None of these deaths were reported and the crew member doesn't wish to be named. Hence, we urgently need a representative independent observer programme.

Research approach

Substantially increase independent observer coverage on commercial set net fisheries for at least 5 years to account for variable oceanographic conditions and fishing effort in foraging areas of yellow-eyed penguins. Independent observer effort needs to focus on high risk areas where set netters operate within 50km of important yellow-eyed penguin breeding areas and within 25km off the Southeast coast of the New Zealand South Island (i.e. over the continental shelf)[1].

Numbers of yellow-eyed penguin breeding pairs on Northeast Stewart and Codfish Islands and on the Otago Peninsula are declining. Hence particular effort should be placed on fishing vessels that operate around these areas. Records need to distinguish between juvenile and adult yellow-eyed penguins and ideally drowned individuals are sexed. While yearly reports are imperative for immediate feedback we strongly suggest a comprehensive review of all

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[1] The recommended distances derive from foraging studies at selected sites that found chick-rearing Yellow-eyed penguins may travel up to 50km away from their breeding sites to obtain food (e.g. penguins from Codfish Island, see section 4. Marine Ecology). The foraging radius is limited by the extent of the continental shelf since Yellow-eyed penguins are benthic foragers that generally do not forage at water depths >150m. The continental shelf edge off the Southeast coast is situated ca. 25km offshore. Currently, we have no information about the foraging ranges of Yellow-eyed penguins outside the breeding season. However, it is likely that the birds continue to forage in reasonably shallow waters (<150m) and therefore penguins can be assumed to stay over the continental shelf area.

data acquired after 5 years. This will provide a robust estimate of total numbers caught in conjunction with operational details affecting the likelihood of capture.

At-sea distribution and foraging effort of yellow-eyed penguins need to be analysed using GPS dive loggers in order to document foraging hotspots and thus identify areas where penguins are at high risk from bycatch. There is particularly little information of yellow-eyed penguin movement and at-sea distribution during the non-breeding season. Then penguins do not need to return to their breeding areas on a daily basis, hence, they can potentially cover considerably longer distances to reach productive foraging areas. A comprehensive study should encompass not only adults but also juveniles in both breeding and non-breeding seasons. Since at-sea distribution and foraging ecology varies with oceanographic and climatic conditions a comprehensive study needs to encompass a minimum of 5 consecutive seasons.

For a better risk assessment detailed information on fishing gear, effort, timing, location, total time and depth of gear deployment is essential. Ideally, GPS tracks of every vessel operating in the SEC and SOU areas will be provided in addition to operational details so temporal and spatial overlap with foraging penguins can be extrapolated.

Since inshore vessels are small and often struggle to accommodate an independent observer we strongly encourage to explore the suitability and potential of electronic monitoring systems (EM; e.g. McElderry 2008; McElderry et al. 2011) in set net fisheries (compare also 5.1.2). A trial of EM in conjunction with an independent observer on the same vessels will enable validating observations and advance necessary adjustments for a permanent installation of EM on set netters. Only a robust set of data will allow development of effective mitigation measures or temporal/spatial management in order to reduce yellow-eyed penguin bycatch in commercial set net fisheries.

5.1.2 Yellow-eyed penguin bycatch in commercial trawl fisheries

Rationale

The extent to which inshore trawl fisheries interact with protected species is poorly known. "In terms of number of tows, the effort in inshore trawl exceeds that in all of the offshore fisheries combined. Though the trawl nets used are considerably smaller it still demonstrates that inshore trawl is a significant fishery in New Zealand. Inshore trawl is also one of the few remaining fisheries in New Zealand with no regulated mitigation measures. Data is not currently available to allow the quantification of interactions with protected species, but the substantial fishing effort and lack of mitigation creates potential for significant levels" (Ramm 2010).

"Monitoring of the inshore trawl fishery using government observers began only relatively recently (2006/07), with a focus on monitoring seabird and dolphin interactions. Due to the high levels of fishing effort and difficulty of placing observers on these small vessels, historic coverage levels have generally been low and coverage has been limited to specific areas and times of interest" (Ramm 2010). Even the increased observer coverage from 2006-2009 amounts to a total of only 0.92% of flatfish trawls, 1.74% in small inshore trawls, 5.59% in large fresher trawls and 2.89% in small bottom longline fisheries (Richard et al. 2011). These are the commercial fisheries (given in order of importance) that, apart from set net fisheries, have the potential to affect yellow-eyed penguins most (Richard et al. 2011).

"In 2008/09 in total over 1900 tows were observed over 634 observer sea days which represented 3.45% of the year's inshore fishing effort. The highest level of coverage was achieved along the South East coast of the South Island (SEC) with 7.13% observer coverage; this area also had the highest rate of seabird captures. While 31 of these captures can be

attributed to a single event [a group of spotted shags being caught], even if this was excluded SEC would still have shown the highest capture rate" (Ramm 2010).

Richard and colleagues (2011) attempted to assess the potential annual fatalities of yellow-eyed penguins in commercial inshore trawl fisheries (including small inshore trawl, large fresher trawl, and flatfish trawl fisheries), and estimated 2-55 individuals ("mean 16") dead per year. Additionally, 1-11 individuals ("mean 4") are estimated to die in commercial bottom longline fisheries each year (Richard et al. 2011). These numbers add to the already substantial threat posed by set net fisheries.

When calculating the "potential biological removal" (PBR), Richard et al. (2011) neglect the fact that sub-Antarctic and mainland populations need to be assessed and managed separately (see section 1), which will lead to smaller PBR and increased extinction probabilities for both management units. The already struggling yellow-eyed penguin populations on the New Zealand South Island and around Stewart Island appear to suffer significantly from bycatch. With regard to the species' sub-Antarctic strongholds, we have no information about yellow-eyed penguin at sea distribution and consequently no information on the potential overlap of feeding grounds and intensive commercial fishing operations in the sub-Antarctic.

Similarly to Maunders and colleagues (2007) Richard et al. (2011) had to conclude that low confidence levels due to deficient data made it impossible to draw reliable conclusions about the actual impact of commercial trawl fisheries operations on yellow-eyed penguins.

Research approach

Substantially increase independent observer coverage for commercial trawl fisheries to quantify numbers caught as well as operational details affecting the likelihood of capture. Such effort needs to focus on areas where trawlers operate within 50km of important

mainland breeding areas and within 25km off the south east coast of the New Zealand South Island (compare section 5.1.1).

For a better risk assessment detailed information on fishing gear, effort, timing, location, total time and depth of gear deployment is essential. Ideally, GPS tracks of every vessel operating in the SEC and SOU areas are being provided in addition to operational details so temporal and spatial overlap with foraging penguins can be extrapolated.

Detailed knowledge of foraging hotspots and at-sea distribution of yellow-eyed penguins both during the breeding and non-breeding season will greatly improve bycatch risk assessment (compare section 5.1.1).

A recent pilot study on inshore trawl vessels operating off the New Zealand North Island showed electronic monitoring (EM) can supplement independent observers allowing better overall coverage while keeping related costs manageable (McElderry 2008; McElderry et al. 2011). We strongly encourage exploring this promising monitoring method further and engage with fisheries to assure their cooperation and support. The quality and effectiveness of any monitoring effort will depend on good working relationships with the fishing industry. A robust set of data will allow assessment of the numbers of yellow-eyed penguins (and other protected species) being caught in commercial trawl fisheries. Such data is essential for the development of effective mitigation methods.

5.2   Document the indirect effects of commercial fisheries

5.2.1 Fisheries induced benthic habitat degradation

Rationale

Yellow-eyed penguins have declined considerably along the Anglem Coast, Northeast Stewart Island (King 2008, 2009). High chick mortality observed 2003-2008 suggests that recruitment is insufficient to sustain the population (Mattern 2008; King 2009). Chick deaths were mainly attributed to starvation and disease (McInnes et al. 2008; King 2009). A study of foraging ecology and penguin diet during chick rearing found strong evidence for a localised sea-based problem with low prey diversity, availability and quality affecting the colonies along the Anglem Coast (Mattern et al. 2007b; Mattern 2008; Browne et al. 2011).

As a primarily benthic forager, the yellow-eyed penguin depends on an intact benthic ecosystem (Mattern et al. 2007a; Mattern 2008). Oyster dredging has been found to have detrimental effects on benthic communities resulting in reduction of benthic biodiversity, which also reflects in less diverse fish populations and smaller fish sizes (Cranfield et al. 2001; Jiang & Carbines 2002). It appears that penguins breeding along the Anglem Coast do not forage in areas that are commercially dredged for oysters; hence suitable foraging grounds of these birds have become spatially very limited.

"In this light, it seems likely that the degradation of the benthic habitat associated with dredging is limiting viable foraging habitat and prey diversity for Stewart Island penguins. Since yellow-eyed penguins are at the top of the benthic food web, their rapid decline in the past few years suggest that far more is at stake than the fate of a single species of penguin. The unique biogenic reefs of Foveaux Strait off Stewart Island must also be disappearing at an alarming rate" (Mattern 2008).

While there is already strong evidence for the impact of commercial oyster dredging in the Foveaux Strait on benthic communities and ultimately yellow-eyed penguins on Stewart Island, other such potential interactions have yet to be quantified. For example, yellow-eyed penguins from Oamaru were found to forage at a few discrete, spatially limited areas that were defined by the presence of horse mussels that provide substrate for benthic communities in an otherwise featureless sea floor environment dominated by sand and silt (Mattern et al. 2007). Such horse mussel fields are scarcely distributed and penguins foraged at the same locations not only on different days but in different years (Mattern et al. 2007). Disturbance or destruction of even one of such horse mussel fields may have severe consequences for the foraging success of local penguin populations.

Beyond the degradation of the benthic foraging habitat of yellow-eyed penguins, there are indications for other interactions between the penguins and bottom fishing operations. A pilot study examining the marine ecology of yellow-eyed penguins from the Otago Peninsula with GPS dive loggers observed highly unusual foraging patterns (Mattern et al. 2005; compare section 4): "On their trips, the penguins spent up to 94% of their foraging time swimming along straight lines for up to 9.6 km (mean 3.3 km). These lines were not only parallel to the coast but also parallel to each other. Astoundingly, the penguins navigated along the lines with extreme accuracy, having a mean horizontal deviation from an ideal straight line course of 37 m. In order to maintain such accurate navigation in open water, the penguins need cues. Considering the scale of the lines and the accuracy of navigation, it seems unlikely that the birds used natural features but rather used man-made cues. These could be fishing vessels but it seems more likely that dredge marks from bottom trawls are used as linear guides" (Mattern et al. 2005). To which extent such interactions affect the foraging success of yellow-eyed penguins in the short as well as the long term is unclear and warrants further investigation.

Research approach

The at sea distribution, foraging effort and success of yellow-eyed penguins needs to be documented by deployment of GPS dive loggers on breeding adults. In order to determine to which extent the penguins' foraging grounds are limited by degradation of the benthic habitat as a result of commercial oyster extraction independent surveys of the sea floor (e.g. scuba surveys or drop camera/ROV deployment) are required. Such surveys need to compare the state of the benthic habitat (i.e. level of disruption, benthic diversity) within the penguins' current foraging regions as well as within the natural foraging radius of yellow-eyed penguins during the crucial early chick rearing stage (i.e. 20km from breeding sites)[2].

Food supplied to the chicks needs to be examined (e.g. meal frequencies & sizes, prey diversity & quality, chick growth rates). Furthermore, the current population status and yellow-eyed penguin population parameters (i.e. numbers of breeding pairs, reproductive success, fledgling weights, adult & juvenile survival, recruitment) on Northeast Stewart Island needs to be re-assessed. Since population parameters and foraging ecology vary with oceanographic and climatic conditions as well as fishing effort a comprehensive study needs to encompass a minimum of 5 consecutive seasons.

Along the Otago coastline, it is essential to analyse the potential for fisheries induced benthic habitat degradation. The vulnerability of yellow-eyed penguins to the degradation of patchy distributed benthic communities and the species' behavioural flexibility to compensate for such disturbances needs to be quantified. This requires the analysis of foraging patterns and diving behaviour of yellow-eyed penguins using GPS dive loggers in order to identify important foraging hot spots i.e. areas of high benthic biodiversity and productivity that should receive special attention with regard to potential fisheries impact.

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[2] During the chick guard stage, penguin chicks need to be fed frequently which limits the foraging radius of adult penguins. Under normal conditions adults seldom travel further than 20km from their breeding site when rearing chicks (see section 4. Marine Ecology)

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Figure captions

Figure 1.1   Map showing the current global distribution of yellow-eyed penguins.

Figure 1.2   Yellow-eyed penguins breed in four regions on the New Zealand mainland.

Figure 1.3   Distribution of yellow-eyed penguins on Stewart Island and adjacent island outliers (adapted from Massaro and Blair 2000).

Figure 1.4   Distribution of Yellow-eyed penguins on Campbell Island, based on landing sites found in 1988 and 1992 (adapted from Moore et al. 2001).

Figure 1.5   Distribution of Yellow-eyed penguins on the Auckland Island group (adapted from Moore 1992 and Beer 2010).

Figure 2.1   Estimated number of yellow-eyed penguin breeding pairs in Otago, including all known breeding locations in North Otago, Otago Peninsula and the Catlins, southeast coast of the New Zealand South Island 1980-2010; numbers contain best guesses for breeding areas that have not been searched during a particular season (data provided by the Department of Conservation, Coastal Otago Area Office; Appendix 1).

Figure 2.2   Mean number of Yellow-eyed penguin nests per mainland breeding location searched (Otago, New Zealand South Island, black dots) and number of locations searched each breeding season (grey bars). A linear trend line including 95% Confidence Intervals illustrates large fluctuations of breeding pairs between seasons. The data has been extracted from the Yellow-eyed penguin database managed by the Department of Conservation, NZ (from Seddon et al. *in press* – permission pending).

Figure 2.3   Number of yellow-eyed penguin breeding pairs observed 1992-2011 in (a) all eight breeding areas in North Otago, New Zealand South Island (b) two

intensely managed colonies in North Otago, New Zealand South Island (c) six

remaining less intensely managed colonies in North Otago, New Zealand

South Island; solid line depicts linear regression analysis of population trends,

dashed lines are 95% confidence intervals (data provided by the Department of

Conservation, Coastal Otago Area Office; Appendix I).

Figure 2.4   Number of yellow-eyed penguin breeding pairs observed 1992-2011 on the

Otago Peninsula, New Zealand South Island, in ten breeding areas that were

considered to provide the most reliable and consistent nest count data; solid

line depicts linear regression analysis of population trends, dashed lines are

95% confidence intervals (data provided by the Department of Conservation,

Coastal Otago Area Office; Appendix I).

Figure 2.5   Number of yellow-eyed penguin breeding pairs observed 1992-2011 in the

Catlins, New Zealand South Island, in five breeding areas that were considered

to provide the most reliable and consistent nest count data; solid line depicts

linear regression analysis of population trends, dashed lines are 95%

confidence intervals. Additionally, the results of the complete Catlins census

established in 1997 to take place every five years has been included into the

figure. (Data provided by the Department of Conservation, Coastal Otago Area

Office; Appendix I).

Figure 3.1   Map showing the location of Boulder Beach on the Otago Peninsula, Dunedin,

New Zealand (adapted from McClung et al. 2004).

Figure 3.2   Bar plot displaying frequencies of the number of chicks fledged in their

lifetime (LRS) by female (n = 107) and male (n = 102) yellow-eyed penguins

breeding at Boulder Beach, Otago Peninsula, New Zealand, from Stein (2012).

Table 3.1

Published sources and estimates of adult survival in yellow-eyed penguins on the Otago Peninsula, South Island, New Zealand.

Source	Dataset	Survival Rate (%)	Range (%)	Method
Richdale 1957	1936-1954	85.4	72-94	Recovery rate
Edge 1996	1982-1994	-	83-94	JS model
Efford et al. 1994	1981/82-1991/92	83.2	49-100	JS estimate
Efford et al. 1994	1981/82-1991/92*	87	80-100	JS estimate
Efford et al. 1994	1989/90	50.0	-	JS estimate
Edge 1996	1989/90	-	20-59	Recovery rate
Edge 1999	1992	91.3	-	Recovery rate
Edge 1999	1993	90.3	-	Recovery rate
Ratz et al. 2004	1991/92-1996/97	90	86-95	Recovery rate

*Excluding 89/90

Table 3.2

Published sources of survival to adulthood for yellow-eyed penguins, for the Otago Peninsula, South Island, New Zealand.

Source	Dataset	Age survived	Number banded	Sighted as adult	Yearly Range (%)	Method
Richdale 1957	1939-1949	2	399	129 (32%)	-	Recovery rate
Richdale1957	1939-1949	3	399	108 (27%)	-	Recovery rate
Richdale 1957	1939-1954	4	491	411 (84%)	-	Recovery rate
Efford et al. 1994	1981/82-1991/92	2	587	122 (20.8%)	1.1-37.5%	Recovery rate
Stein et al. 2012	1981-2003	2	2032	382 (18.8%)	-	Recovery rate

Table 3.3

Numbers and percentages of the age at first breeding in female and male yellow-eyed penguins from Richdale (1957) and Stein (2012).

Age at first breeding	Richdale (1957)	Stein et al. (2012)
Females		
2	48%	19% (20)
3	48%	59% (63)
4	4%	13% (14)
5-7	-	9% (10)
Males		
2	8%	8% (8)
3	47%	49% (50)
4	13%	19% (20)
5	-	24% (24)
6-9	-	13% (13)

Table 3.4

Age-specific fecundity of female yellow-eyed penguins breeding between 1983 and 2010, at Boulder Beach, Dunedin, New Zealand (n = 199), from Stein (2012).

Age	N	Laid	se	Hatched	se	Fledged	se
2	27	1.63	0.09	0.63	0.16	0.41	0.13
3	104	1.88	0.03	1.88	0.07	0.92	0.08
4	102	1.92	0.03	1.92	0.06	1.24	0.08
5	88	1.97	0.03	1.97	0.07	1.11	0.09
6	79	1.91	0.03	1.91	0.07	1.06	0.10
7	63	1.95	0.03	1.95	0.07	1.14	0.10
8	58	1.98	0.02	1.98	0.09	1.02	0.10
9	52	1.94	0.03	1.94	0.07	1.19	0.10
10	42	1.98	0.02	1.98	0.10	1.14	0.13
11	36	1.97	0.03	1.97	0.11	1.03	0.15
12	34	1.97	0.03	1.97	0.08	1.18	0.16
13	32	2.00	0	2.00	0.07	1.23	0.15
14	26	2.00	0	2.00	0.91	1.35	0.16
15	22	2.00	0	2.00	0.10	1.09	0.20
16	15	2.00	0	2.00	0.15	0.87	0.25
17	12	1.92	0.80	1.92	0.11	1.60	0.23
18-24	19	2.00	0	2.00	0.16	0.74	0.18

Table 3.5

Overview of survivorship, lifetime reproductive success (LRS), lifespan and age at first breeding, breeding lifespan, and number of breeding between female (n = 107) and male (n = 102) yellow-eyed penguins breeding at Boulder Beach, Otago Peninsula, New Zealand, from Stein (2012).

Variable	mean	var	se	min	med	max
Females						
LRS	5.00	20.84	0.44	0	4	22
Recruits	1.25	2.91	0.16	0	1	9
Successful recruits	0.95	1.61	0.13	0	0	6
Lifespan (years)	7.98	21.68	0.45	2	7	24
Age at first breeding	3.20	1.04	0.10	2	3	7
Breeding lifespan (years)	4.74	18.67	0.41	0	4	17
Breeding attempts	4.99	13.52	0.35	1	4	16
Males						
LRS	4.31	16.00	0.40	1	3	20
Recruits	0.84	1.48	0.12	1	0	5
Successful recruits	0.68	1.13	0.10	1	0	5
Lifespan (years)	8.62	21.42	0.46	2	8	21
Age at first breeding	3.78	1.81	0.13	2	3	9
Breeding lifespan (years)	4.56	19.79	0.44	0	4	19
Breeding attempts	4.60	11.61	0.33	1	4	14

Table 5.1

Yellow-eyed penguin bycatch observed during 2005-2010 in the inshore fishing fleet observer programme along the Southeast coast (SEC, Fisheries Management Area FMA 3) and the South coast (SOU, FMA 5) of the New Zealand South Island. Observer coverage refers to the entire FMA and reports do not specify as to how frequently vessels operated within 50km of important penguin breeding areas. However, observer coverage has been reported as "spatially limited" (Ramm 2012). For the last two years 2010/11 and 2011/12 data from the inshore fishing fleet observer programme are not yet available.

FMA / Season	Observer Coverage	Observed penguin bycatch	Reference
SEC, FMA 3			
2005/2006	0.43%	0	Rowe (2009)
2006/2007	0.88%	0	Rowe (2009)
2007/2008	6.84%	0	Rowe (2010)
2008/2009	21.48%	4	Ramm (2010)
2009/2010	18.14%	1	Ramm (2012)
Total	**9.55%**	**5**	
SOU, FMA 5			
2005/2006	5.20%	0	Rowe (2009)
2006/2007	10.87%	2	Rowe (2009)
2007/2008	25.04%	1	Rowe (2010)
2008/2009	23.96%	1	Ramm (2010)
2009/2010	18.14%	0	Ramm (2012)
Total	**18.55%**	**4**	

(Kaikoura?)

Banks Peninsula

North Otago

Otago Peninsula

Catlins

Stewart Island

Auckland Islands

Campbell Island
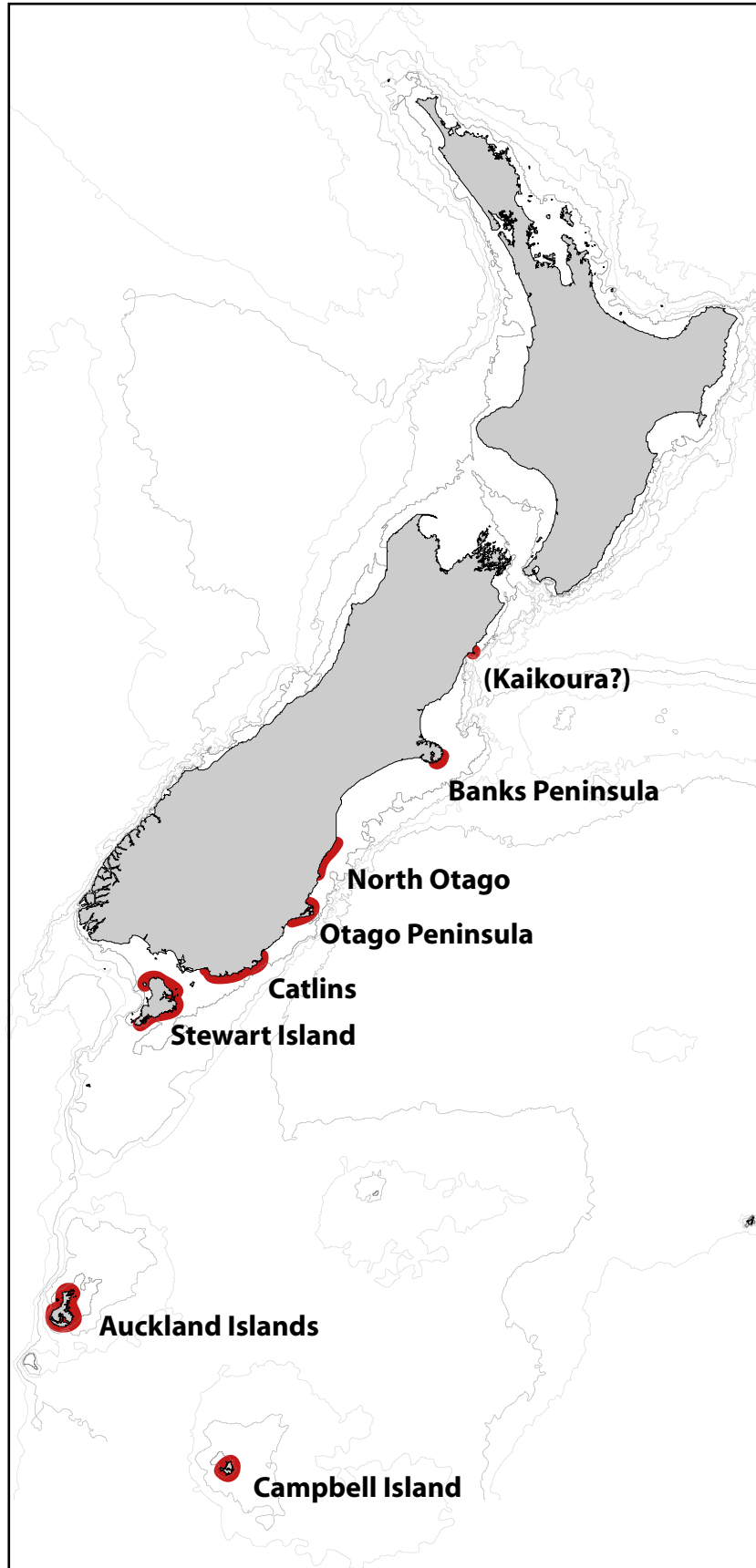
Figure 2.1

Figure 2.2

Figure 2.3a

$y = 2.2x + 26.3$
$r^2 = 0.71$

Figure 2.3b
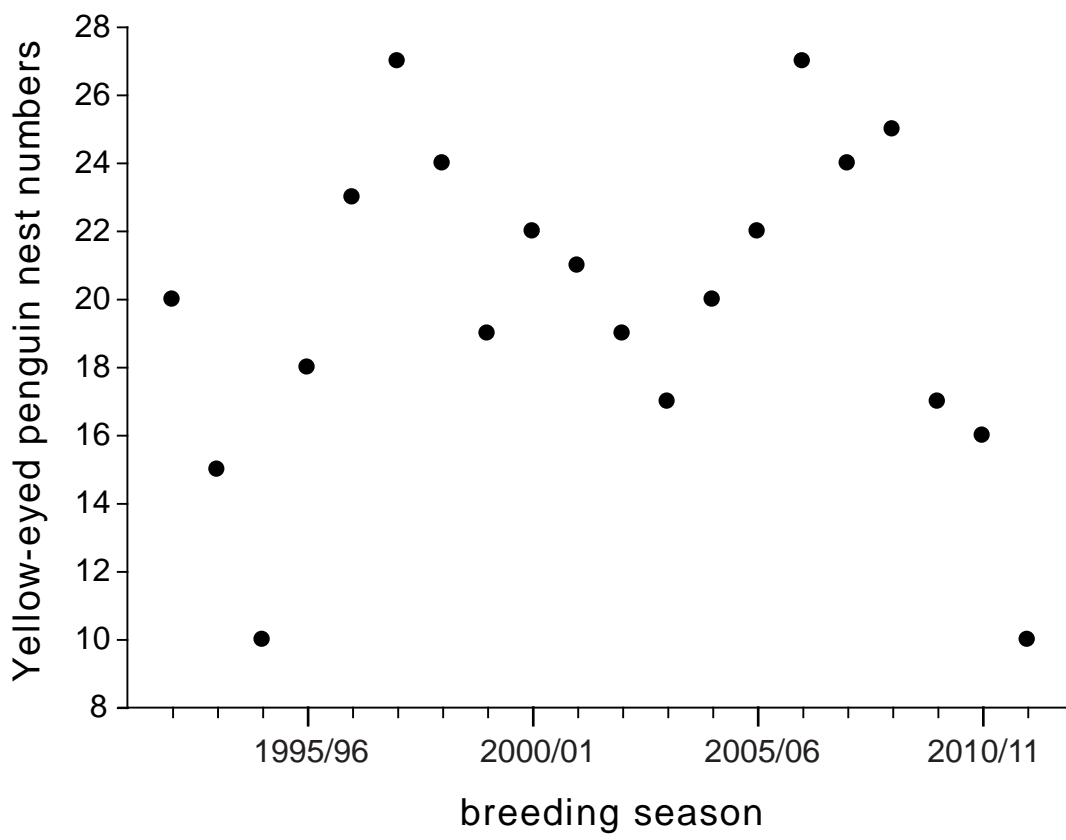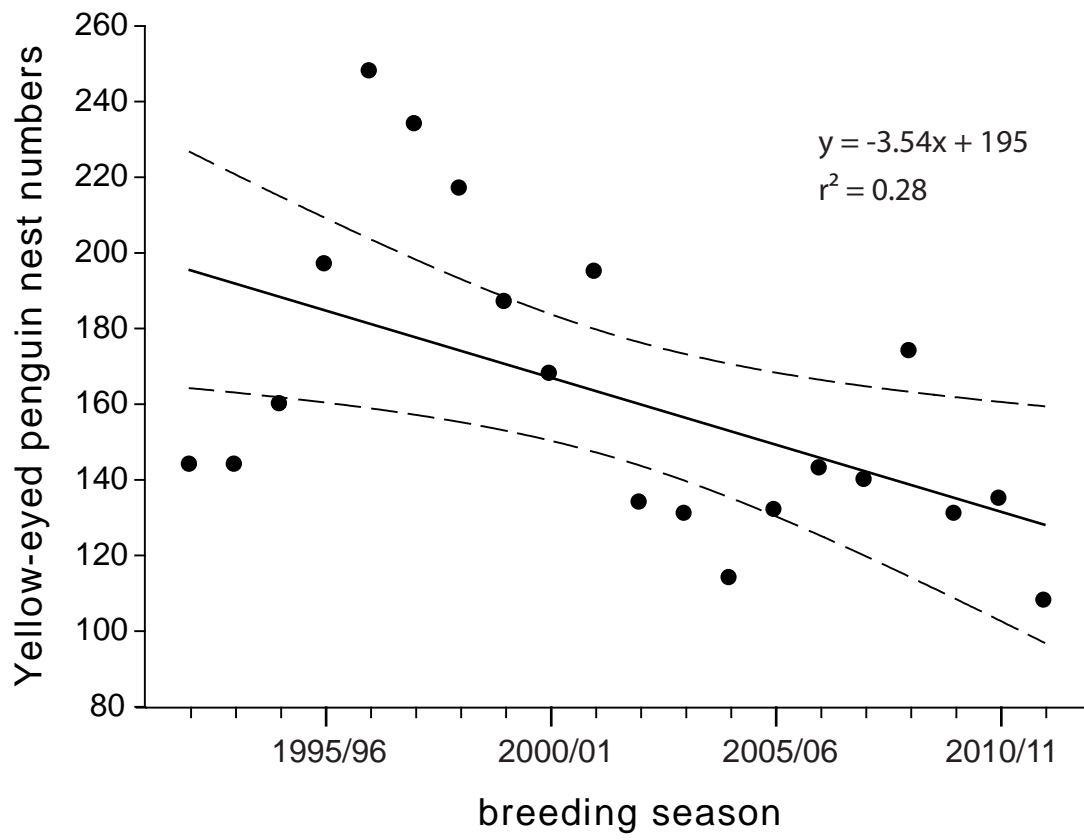

y = 2.2x + 6.6
r² = 0.87
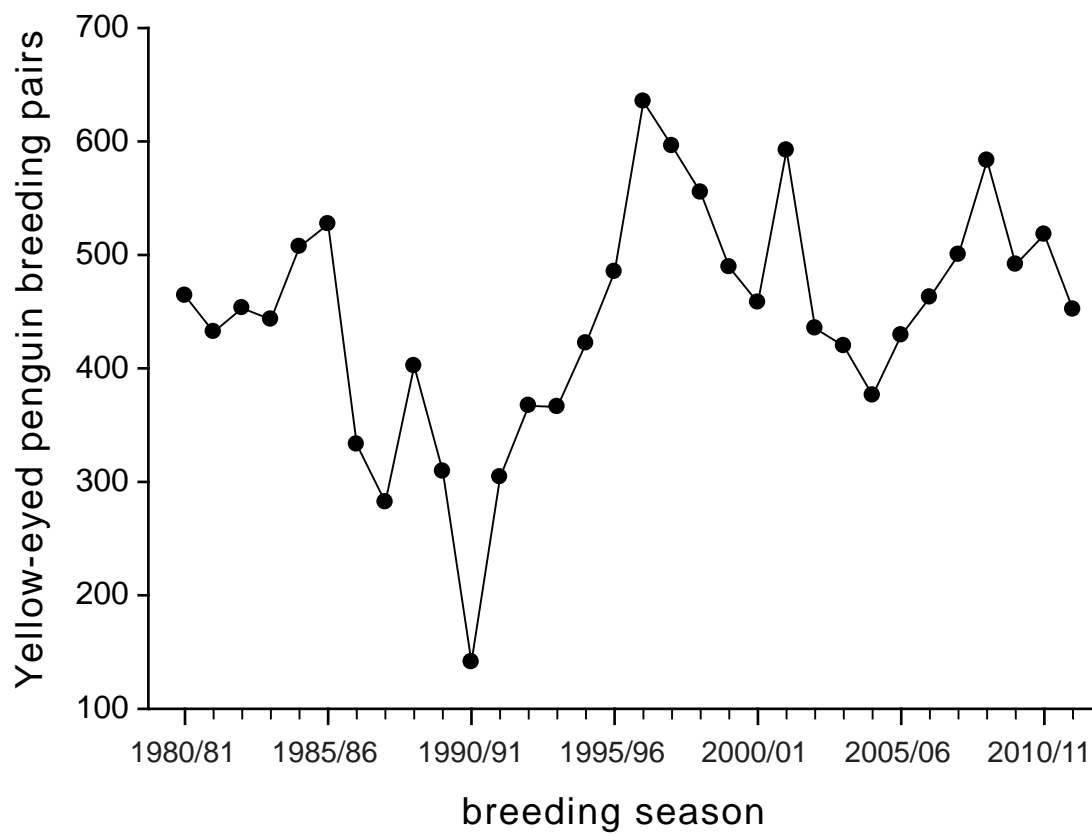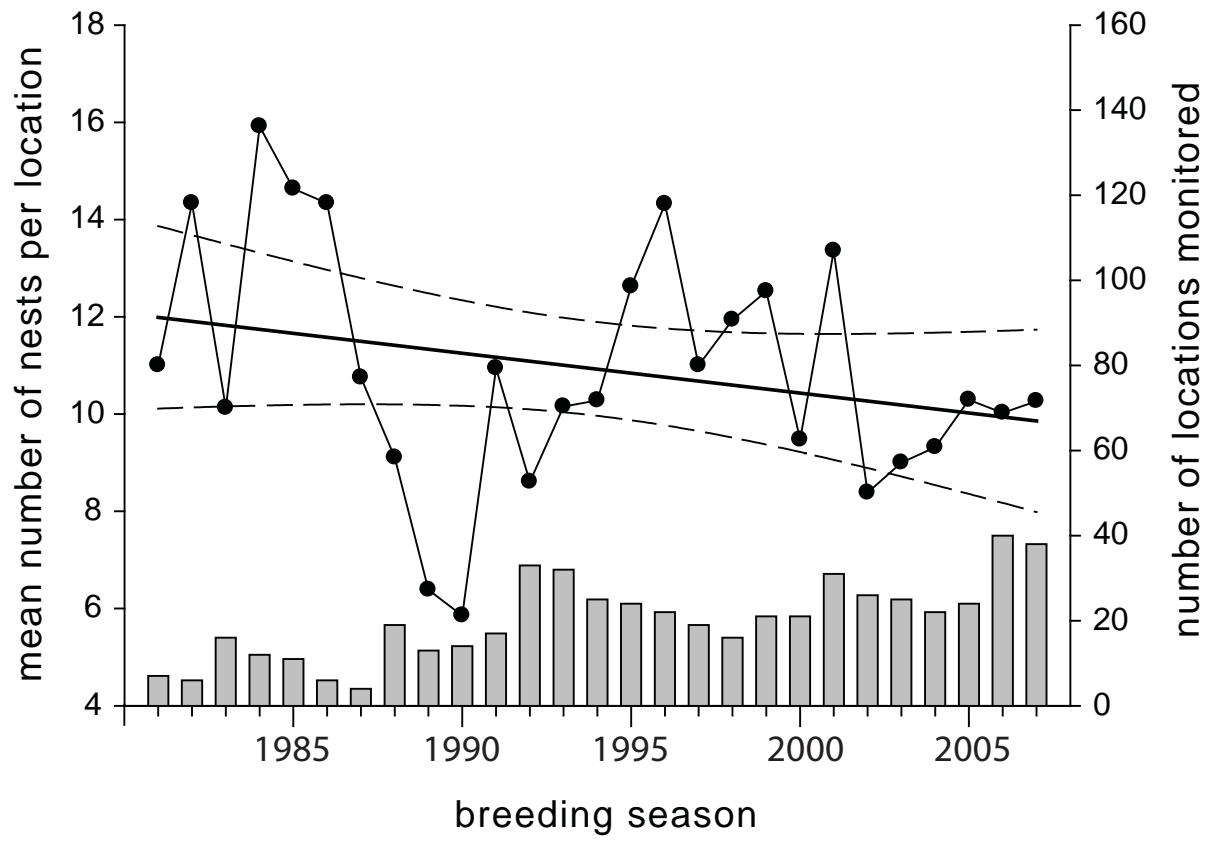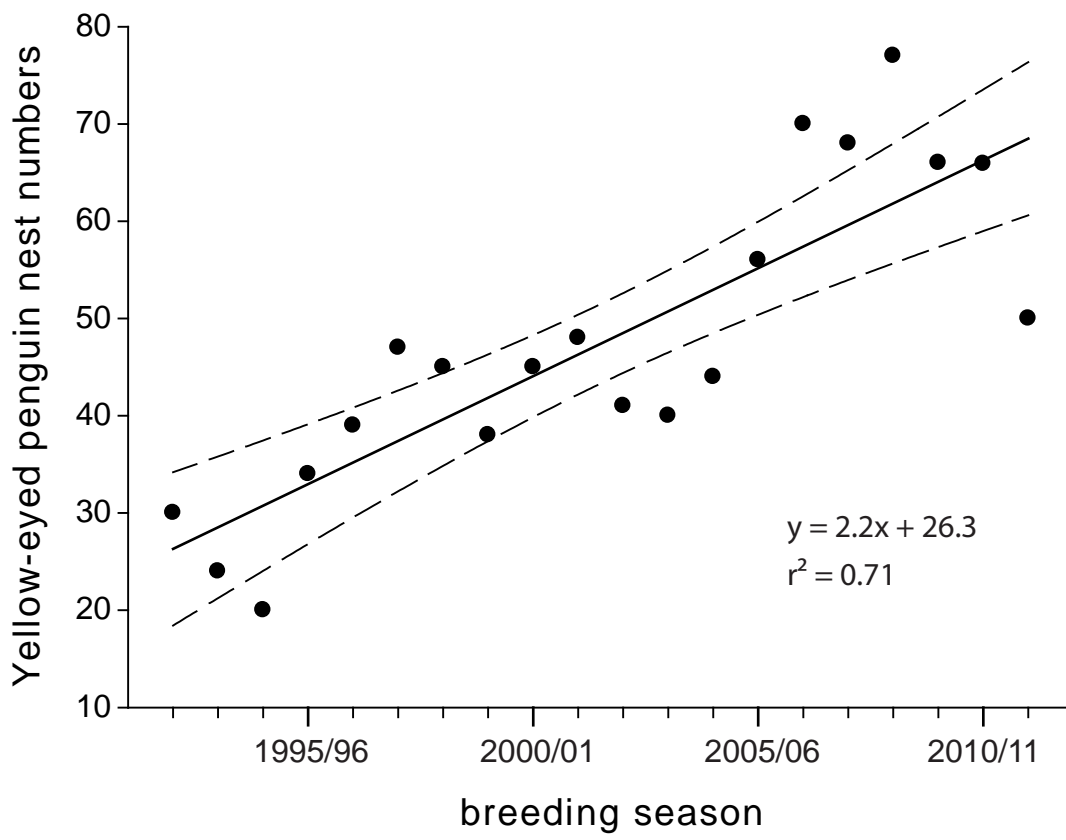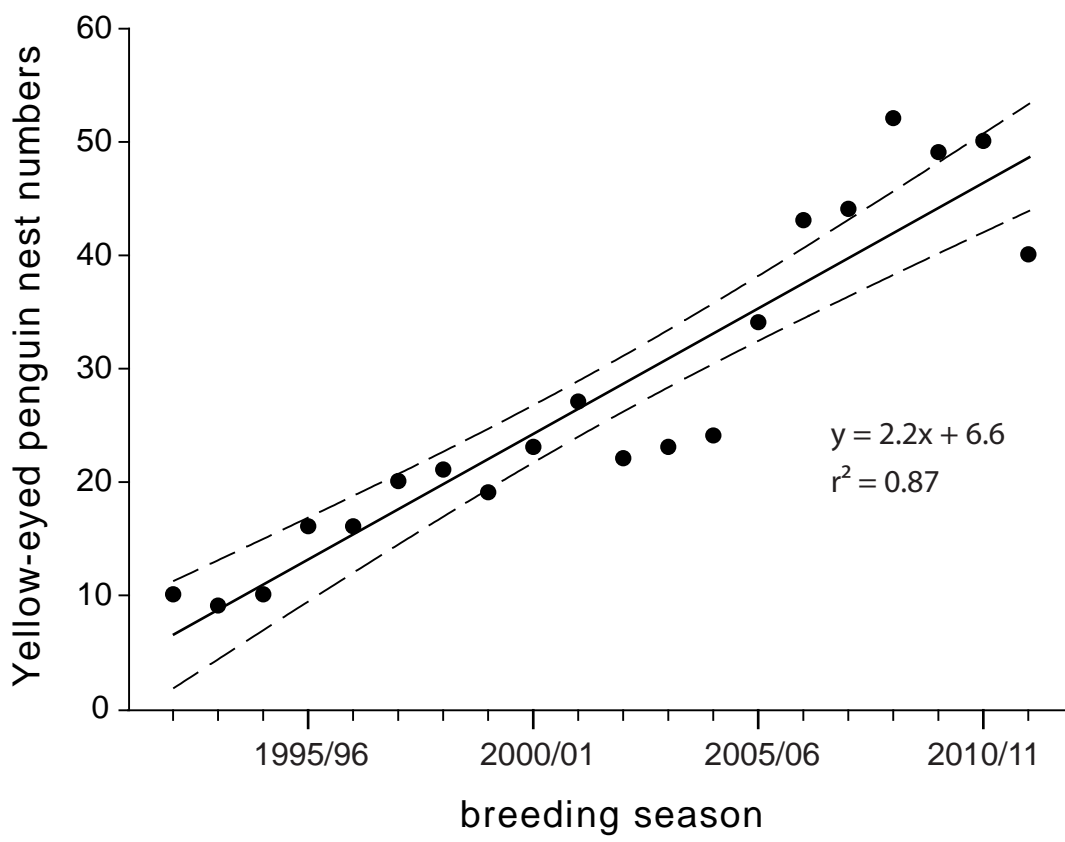
Figure 2.3c

Figure 2.4

$y = -3.54x + 195$
$r^2 = 0.28$

Figure 2.5

Figure 3.1

Figure 3.2