Yellow-eyed penguin - review of population information

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Abstract

The yellow-eyed penguin is endemic to New Zealand and is one of two penguin species with the most fragile conservation status on the planet. It is a long-lived species and population viability analysis shows that even a small increase in adult mortality augments extinction probability dramatically. The yellow-eyed penguin population on the New Zealand mainland, including Stewart Island, is small (600-800 breeding pairs). Previous population strongholds such as on the Otago Peninsula are declining. Since the mainland population is genetically distinct from sub-Antarctic populations (inferred immigration rate 0.003 per generation) the current loss of yellow-eyed penguins along the Southeast coast of the New Zealand South

Island and in the Foveaux Strait will not be compensated by immigration. 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 that operate within foraging areas of yellow-eyed penguins in order to quantify numbers caught and document operational details affecting the likelihood of capture. Since bycatch rates are extremely uncertain, independent observer coverage needs to be high to achieve reasonable precision in bycatch estimates. Electronic Monitoring can supplement independent observers allowing better overall coverage while keeping the related costs manageable. Such data are essential for the development of mitigation measures or temporal/ spatial management to reduce Yellow-eyed penguin bycatch in the commercial fisheries.

Keywords

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

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Yellow-eyed penguin - review of population information

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

Author: Ursula Ellenberg

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. The literature database considered for the yellow-eyed penguin review of population information contains 237 publications.

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 (Figures 1.1 & 1.2).

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 1.1). The Otago Peninsula used to host nearly half of these pairs (see Section 2). 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 breeding areas (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 1.2).

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 (see 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 completed on the sub-Antarctic yellow-eyed penguin populations.

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 1.2).

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 reasonable expansion of productive continental shelf at less than 200m depth which makes it a 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 1.2).

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 satisfactory knowledge of the current distribution of yellow-eyed penguin breeding areas and are beginning to learn more about fine scale habitat requirements. 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 to improve our 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 quantity of at-sea-distribution data would greatly increase the reliability of risk assessments.

2. Population levels and trends of yellow-eyed penguins

Author: Ursula Ellenberg

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 due to starvation and disease was documented during a five year study (2003-2008) along the Anglem Coast, Northeast Stewart Island. The population has considerably declined since the initial survey suggesting recruitment failure.

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 breeding sites) over the last 20 years the number of yellow-eyed penguins breeding pairs on the Otago Peninsula has

declined considerably from a maximum of 385 breeding pairs in the late 1990s down to 184 breeding pairs during 2011-12.

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 available for sub-Antarctic Auckland and Campbell Islands, and for Stewart Island and outliers.

In addition 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 1992-2011 breeding seasons 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 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 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 interpreted 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 was historically the most important region hosting about half of the South Island breeding population. However, this has changed: 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 20^{th} 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 the penguin population 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 have triggered this outbreak remains unclear. Fortunately, such an episode of high adult mortality has not repeated to date.

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 breeding sites (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 sites yellow-eyed penguin breeding pairs in North Otago probably remain stable with extreme fluctuations and overall low numbers (6 breeding sites; 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 breeding sites, linear regression: $F_{1, 18} = 12.74$; $p = 0.002$; $r^2 = 0.41$), and the South West of the Peninsula (-38%; 4 breeding sites; linear regression: $F_{1, 18} = 8.41$; $p = 0.010$; $r^2 = 0.32$).

Catlins

The Catlins have seen the less 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 46 in 2009 and only 39 nests were found in November 2011 (Houston & Nelson 2012). While during the initial survey of Codfish Island 17 juveniles were observed during one beach count and altogether 30+ juveniles (Massaro & Blair 2003, Houston & Nelson 2012), not a single juvenile was observed in 2009 or 2011 (Houston & Nelson 2012). "Given that 44 chicks were known to have fledged in 2010 (Leseberg 2011) the absence of first-year birds in 2011 is indicative of poor first-year survival due to poor marine conditions, however other causes of mortality such as fisheries bycatch may have also contributed." (Houston & Nelson 2012).

Yellow-eyed penguins along the Anglem Coast declined steadily over a five year study (2003-2008) and in total by 37% since the survey in 1999-2001, when considering only breeding sites searched during both population surveys (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 areas had reduced nest numbers King (2009) suspects increased search effort and experience may have obscured a potential decline. King (2009) thus suggests for a more accurate estimate of trends to ignore the "new" locations that were likely active but not searched during the initial survey; resulting in a slight decrease for the remaining yellow-eyed penguin breeding areas on Stewart Island (from 73 breeding pairs in 1999-2000 to 65 pairs counted in 2008-09; King 2009). However, for reliable conclusions about trends comprehensive population surveys are required at more regular intervals.

The observed 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).

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, sub-Antarctic Yellow-eyed penguins 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 61 pair on 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, when Codfish Island the largest island outlier 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.

A subsequently initiated five year study did not confirm a single case of cat predation. Instead, starvation and disease have been found to be the main causes of chick mortality along the Anglem Coast, Northeast Stewart Island (King 2008a, b; King 2009). Veterinary research into the causes of chick mortality along the Anglem Coast found diseases such as the hemoparasite *Leucocytozoon* and *Corynebacterium amycolatum*, which causes diphtheric stomatitis in yellow-eyed penguins (King 2008a, b; McInnes et al. 2008; Hill et al. 2010). The results were summarised as follows: "2006-07 had the highest incidence of diphtheritic stomatitis, 2005-06 had *Leucocytozoon,* and 2005-07 were the worst for starvation" […] "the cause of death of young chicks in 2007 was starvation. In other years *Leucocytozoon,* diphtheritic stomatitis or trauma may have played a significant role, but it is not possible to determine which came first, starvation or disease (McInnes et al. 2008).

Corynebacterium is a secondary pathogen i.e. the outbreak of diphtheric stomatitis requires a triggering agent, for example a virus, however, despite all efforts such a virus could not be isolated so far. Another plausible trigger that weakens the immune system is starvation which has also been suspected to be at least in part responsible for major diphtheric stomatitis outbreaks in chicks in 2002 and 2004 on the Otago Peninsula.

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; compare section five for a more detailed discussion on the effects of benthic habitat degradation due to oyster fisheries). Hence, while disease may cause starvation, lower food quality and quantity 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 suggested 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 (King 2009). However, penguins breeding on neighbouring Codfish Island, previously a population stronghold that was considered stable and healthy, appear to be declining as well (Houston & Nelson 2012). Given the considerable fishing effort throughout the foraging range of Codfish Island birds and three observed deaths 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 (Rowe 2009, 2010; Ramm 2010; Houston & Nelson 2012).

Yellow-eyed penguins breeding along 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 (e.g. Alterio et al. 1997, 1998; Moller et al. 1998, 1999; Ratz & Murphy 1999; Ratz 2000), human disturbance (e.g. Ellenberg et al. 2007, 2009; Seddon et al. 2008), disease (e.g. Alley et al. 2004; Sturrock & Tompkins 2008), terrestrial habitat quality (e.g. Darby & Seddon 1988; Seddon 1988; McKay 1999; Clark 2007; Hegg et al. 2012) 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 breeding sites in North Otago). In 1984 Janice Jones started a penguin hospital at Katiki Point 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 site at Katiki Point was established by four rehabilitated and translocated penguins in 1991/92 (Jones et al. 2004). Since then the population has gradually increased to up to 30 breeding pairs in 2008/09. Breeding success was significantly higher at these two intensely managed sites (Katiki Point and Barracouta Bay; mean of 1.46 chicks fledged per pair) than at neighbouring less managed breeding areas 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 sites at Penguin Place on the Northeastern shores of the Otago Peninsula has declined.

Management of terrestrial threats alone does not appear sufficiently safeguard yellow-eyed penguin populations. In the case of Katiki Point an initially voluntary set net ban area was 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 breeding sites (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. In addition to substantial fisheries bycatch (Darby and Dawson 2000), drivers for the observed population decline are complex but probably include an increase in sea lion predation (particularly apparent in some of the breeding areas in the Northeast; Lalas et al. 2007), human disturbance impact (Sandfly Bay; McClung et al. 2004, Ellenberg et al. 2007), and a mix of factors 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 time, 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. Sea-based threats in particular are little understood and we need to rapidly increase our knowledge and understanding 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 time. 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 are beginning to realise that even intensive management on land alone is not enough to safeguard yellow-eyed penguin populations.

2.6 Recommendations

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. 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.

In the following I explore important issues in more detail.

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). In 2009, 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 to be 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, which currently contains 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 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 to be 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.

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

Authors: Aviva Stein & Ursula Ellenberg

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 survival 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 mainly 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. Disease-related mortality can affect both adults and chicks, with recent evidence that diseases occur also on the subantarctic islands (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 industry 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; Ellenberg 2010). 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; Richard et al. 2011). Although there is currently no evidence for direct competition for food resources with commercial fisheries (Taylor 2000, but compare Section 5), 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 female (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 1989, 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 1989).

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 1.1). 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 and has an inter-decadal history of being intensively monitored. It has received irregular predator trapping effort over time. This site has longest history of chick banding, and thus the majority of chicks fledged at this site have been banded.

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 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.

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 ± 5% and 94 ± 1%, excluding 1989 when survival rates were between 20 ± 6% and 59 ± 5%. Results indicated that yearly survival of experienced breeders with chicks was 94 ± 1%, and the survival rate for inexperienced breeders with chicks was 89 ± 2%. The survival rate for experienced breeders without chicks was 83 ± 3%, and inexperienced breeders that failed to hatch chicks had an estimated survival rate of 72 ± 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).

The current 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. To capture prey the penguin must swim faster than its prey, at least over short distances. Rory Wilson (1985) demonstrated that adult Jackass penguins *Spheniscus demersus* can swim significantly faster than juveniles of the same species, and recently fledged young swim slower still so that they are unable to capture any of the important yet fast moving prey species, such as anchovies, herring and mackerel. Fledging weights are an important predictor of juvenile survival in many seabird species, e.g. kittiwakes *Rissa tridactyla* (Coulson and Porter 1985), sooty shearwaters *Puffinus griseus* (Sagar and Horning 1998), grey-headed albatrosses *Diomedea chrysostoma* (Reid et al. 2000), and yellow-eyed penguins (McClung et al. 2004). A well fed chick likely has more time to build up muscles and to learn efficient foraging strategies. However, we currently have little information what factors drive yellow-eyed penguin fledgling weights in the Boulder Beach complex.

Therefore, the reason 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 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 (1989) 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.

3.3.4 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 birds of exceptionally quality producing many offspring and thus contributing most to the next generation (Clutton-Brock 1988; Newton 1989).

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.

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, as well as reduced prey abundance as a result of high fishing pressure on spawning stocks (e.g. red cod fisheries off the Otago Peninsula). It is difficult to assess to which extent fisheries bycatch might contribute to the increase in juvenile mortality as the independent observer programme reports currently do 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 Campbell and Auckland 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. Foraging ecology of yellow-eyed penguins

Author: Thomas Mattern

Summary

Yellow-eyed penguins breeding on the mainland have been found to be almost exclusive benthic foragers taking the majority of their prey at or close to the seafloor. The species exhibits consistent at-sea movement patterns where the birds tend to have individual foraging sites that they revisit on consecutive foraging trips and even between years. Foraging ranges vary between sites, however, during the breeding season the majority of breeding Yellow-eyed penguins stay within 20km from their nest sites. During incubation and post-guard stages these ranges can be extended to 50-60km. There is currently no information available on the foraging ranges of penguins outside the breeding season (or juveniles), but presumably they employ similar benthic foraging strategies. Therefore, non-breeding penguins can be expected to forage anywhere over the continental shelf, although it seems unlikely that penguins forage in waters deeper than 150m.

The penguins' individual foraging sites are characterised by diverse benthic communities such as horse mussel fields and or oyster beds with associated sponge and coral assemblages that provide food and shelter for invertebrates and fishes. Main prey species are demersal (i.e. seafloor dwelling) species such as blue cod and opalfish. Pelagic species like sprat, arrow squid and ahuru are also taken, although diving behaviour suggests that these are also caught at or near the seafloor. Benthic communities provide a spatially predictable source of food out of reach for most other seabirds, thus, reducing competition for the penguins. This specialised foraging strategy comes at the expense of behavioural flexibility if the penguins are exposed to disturbances of the benthic ecosystem. Although the birds are able to extend their foraging

ranges and effort, they still require intact benthic communities within reach. Whether the foraging behaviour observed on the mainland also applies to the sub-Antarctic populations is unsure, but a primarily benthic foraging strategy is feasible around both the Auckland Islands and Campbell Island.

4.1 Introduction

Although yellow-eyed penguins have received considerable scientific attention in the past decades, our understanding of their marine ecology is based on only a handful of studies. Access to results is furthermore limited as a good amount of the work has never been, or is yet to be published.

Since 1990 three papers were released that focussed on the foraging behaviour of the species (Seddon & van Heezik 1990, Moore 1999, Mattern et al 2007a). Additional information on the marine ecology of yellow-eyed penguins can be gleaned from Peacock et al (2000).

In the same time period, six papers dealing with the diet of yellow-eyed penguins have been published in scientific journals (van Heezik & Seddon 1989, van Heezik 1990a,b, van Heezik & Davis 1990, Moore & Wakelin 1997, Browne 2011).

Apart from scientific publishing, several theses and reports touching on the yellow-eyed penguin's marine ecology have emerged in the past three decades (van Heezik 1989, Peacock 1995, Mattern 2006a, Browne 2007). Some of these cover or expand on data published in above listed papers. A considerable amount of foraging research has been conducted between 2003 and 2007 – primarily by Thomas Mattern, University of Otago. While most of the data has been analysed, results have yet to be summarised and published. However, general outcome of the studies has been disseminated through unpublished reports as well as presentations and posters on national and international conferences (Mattern et al. 2005a, 2007b, Mattern 2006b, 2008).

4.2 Methods

This report is based on two sources – published accounts and unpublished data. Available publications relevant for the foraging ecology of yellow-eyed penguins were reviewed and are summarised in the Results section (4.3). To provide an overview of foraging parameters and diet composition, data from publications as well as unpublished material have been collated in Tables 4.1a-c. Foraging parameters cover the three breeding stages – incubation, chick-guard and post-guard. Data are grouped by site and breeding season. Definitions of foraging parameters are as follows:

- **Trip duration (h)**

  Duration of an individual foraging trip either determined from nest attendance patterns (Seddon & van Heezik 1989), via automated VHF signal data loggers in the nesting area (Moore 1995, 1999) or from the time interval between the first and last recorded dive events (all other data).

- **Foraging range (km)**

  Maximum distance a penguin reached from its nesting site during a foraging trip.

- **Distance covered (km)**

  Minimum horizontal distance a penguin covered during a foraging trip as calculated as the sum of distances between from successive position fixes. The distance does neither include the deviations from the straight line course a penguin was assumed to have followed, nor does it incorporate the vertical component (i.e. the dives) of a penguin's foraging trip.

- **Number of dives per trip (n)**

  Number of dives per trip is the sum of diving events during which the penguins reached depths >1m. Mattern et al (2007a) only considered dive events >3m due to sensor inaccuracies of some of additional Time-Depth Recorders (TDR) used during this study. No information is available as to how Moore et al (1995) distinguished surface noise from true dive events.

- **Proportion of benthic dives (%)**

  Dives were categorised as either pelagic or benthic (i.e. to the seafloor). Dives were defined as benthic when dive profiles had a trapezoidal shape (steady descent, horizontal bottom phase with little undulations, steady ascent) and dive bouts featured a constant maximum dive depth (see Fig 4.1).

- **Mean dive duration (s)**

  The time interval between onset and end of a dive event. Onset of a dive event was the exact time of the last zero value before depth sensor registered positive pressures. Accordingly, the end of a dive event was the time of the first zero value recorded after >0 bar pressures were logged.

- **Max depth reached (m)**

  The single maximum depth recorded during a foraging trip.

All foraging parameters were calculated from individual means, i.e. if individuals performed more than one foraging trip during the deployment period, means were calculated from the different trips performed by that bird.

Information about the yellow-eyed penguin's feeding ecology (i.e. diet composition) was summarised from six publications (van Heezik & Seddon 1989, van Heezik 1990a,b, van Heezik & Davis 1990, Moore & Wakelin 1997, Browne et al 2011). All publications used the same parameters to describe relative importance of prey species which are summarised in Table 4.2. Reproduced in this report are

- **Mean frequency of Occurrence (% FO)**

  %FO describes the number of samples containing the respective prey species as a percentage of the total number of samples.

- **Mean percentage of total calculated meal weight (% weight)**

  The mass contribution of an individual prey species was calculated via allometric equations using otolith (fish) or beak (squid) dimensions. % weight describes how much biomass the respective prey species contributed to the total meal size the penguins brought ashore.

4.3 Results

4.3.1 Foraging behaviour

Maximum dive depths of yellow-eyed penguins – Seddon and van Heezik (1990)

A first foray into the experimental examination of the species' diving capabilities was conducted by Seddon and van Heezik (1990) who used capillary depth recorders to determine maximum dive depths of yellow-eyed penguins from Boulder Beach, Otago Peninsula. The capillary depth recorders consisted of narrow PVC tubes that were sealed on one side and coated with water soluble powder on the inside. When a bird dived, water entered the capillary and washed out the powder. The distance water was able to enter the tube depended on the ambient pressure so that the length of tube clear of powder allowed the estimation of the maximum dive depth.

Of the 110 depth recorders that were deployed, 43 were recovered of which 24 allowed the determination of maximum dive depths. The average maximum dive depth was 34±8m (range: 19-56m). Dive depths were independent from sex, i.e. male and female penguins dived to comparable depths. The same study also obtained stomach samples of six penguins from the same location and found that their diet was dominated by demersal species (see also 4.3.2). Accordingly it was concluded that the dive depths recorded represented values from dives to the sea floor.

Capillary dive recorders provide only a crude measurement of the maximum depth reached during an entire foraging trip. Especially on animals that dive regularly to fixed depths – like benthic foragers – capillary dive recorders tend to overestimate the maximum dive depth (Burger and Wilson 1988). However, later studies of diving behaviour conducted at the same site (Moore et al. 1995; Mattern, unpubl. data) showed that the depths determined by Seddon and van Heezik (1990) seem to be reasonably accurate.

Foraging ranges and dive behaviour 1991-1995 – Moore et al (1995), Moore (1999)

A more sophisticated approach was used by Peter Moore and colleagues. Following the population crash in 1990 (Section 2), a comprehensive study of at-sea behaviour was conducted that involved radio telemetry and deployment of dive loggers.

Foraging ranges were determined by deploying radio transmitters on 14 individual penguins from Boulder Beach, Otago Peninsula over three consecutive seasons 1990/91-1992/93; 6 birds were repeatedly tracked in all three years while an additional 8 birds were added to the sample in 1991/92 and 1992/93. At Long Point, Catlins 23 birds were tracked during the post guard stages of the seasons 1992/92 (19 birds) and 1992/93 (4 birds). The study covered all stages of breeding (i.e. incubation, chick guard, post-guard) except for the first season which commenced in the post-guard stage (February 1991). In the Catlins, penguins were only tracked during the post-guard stage.

Radio transmitters were glued to the penguins' backs where the devices stayed for a two to three week period before they were recovered. Foraging trip durations were estimated from automated data-logging stations that recorded the presence of radio transmitter signals in the study areas at 10 minute intervals. The penguins' at-sea positions were calculated via signal triangulation from two tracking stations approximately 15km apart on land; bearings were recorded at 1 hour intervals and position accuracy varied depending on distance from the coast between 270 and 1,500m.

A summary of foraging data recorded is given in Tables 4.1a-c. At the Otago Peninsula, trip duration and foraging ranges were considerably longer during the incubation stage when compared to the chick-guard stage and the post-guard stage. Failed breeders or non-breeders stayed at sea for longer and travelled farther. It appears that the foraging trip duration during the incubation phase gives an indication for potential breeding failure later on, with failed breeders generally exhibiting longer trips during the incubation stage when compared to successful conspecifics.

Moore (1999) mentions that the foraging trip durations recorded during the post-guard stage in the Catlins were significantly shorter when compared to the Otago Peninsula. However, it seems results were biased by certain Catlins individuals in the season 1993/94 which tended to perform up to three short foraging trips per day (see Moore 1999, Table 4.1c). Mean trip durations for the years 1991/92 and 1992/93 do not indicate significant differences between the two breeding locations (Catlins v. Otago Peninsula; 1991/92: 13.5±5.4 v. 15.9±5.4, 1992/93: 13.6±6.6 v. 14.4±6.8). The foraging ranges at both sites also did not differ significantly. Judging from the presented data foraging ranges of yellow-eyed penguins from Catlins and Otago Peninsula are similar.

The penguins generally stayed over the continental shelf with the majority of birds from the Otago Peninsula foraging in water depths of 40-80m, some 5-16km to the South and South-west of their breeding sites. In the Catlins most penguins foraged in deeper waters (80-120m). The analysis of individual foraging patterns revealed that each penguin had well-defined centres of activity that were retained between trips and years. Furthermore, some individuals tended to consistently forage much closer inshore (<5km from coast) while others generally travelled further offshore than the majority of birds (>16 km from coast). Moore (1999) was unsure as to whether the habitual foraging patterns reflected "the favouring of particular areas or some other factors, such as the birds taking a similar heading each day" (this question was addressed later by Mattern et al (2007), see below). However, prey items differed depending on whether a penguin foraged closer or further from the shore. Penguins with centres of activity closer to the coast ate proportionally more blue cod and sprat, while penguins foraging further offshore brought mainly opalfish and arrow squid ashore.

To supplement the telemetry study, time-depth recorders (TDR) were deployed on a total of 11 penguins from the Otago Peninsula (n=8) and the Catlins (n=3) (Moore et al 1995). The TDRs consisted of an electronic pressure transducer that recorded ambient pressure at predefined intervals and stored data with a corresponding timestamp to a memory chip. After recovery of the device, the data could be downloaded to a computer for analysis. The report does not reveal the exact technical details of the devices nor does it elaborate on the intervals at which depth readings were recorded. Dive data was recorded for a total 74 days of foraging representing 62 foraging trips. At both locations, a bimodal distribution of dive depths was apparent. The penguins tended to either perform shallow dives ranging between 5 and 30 m, or deeper dives of 40-60m off the Otago Peninsula, and 80-110 m off the Catlins coast.

Maximum dive depths recorded were 66.2 m (Otago Peninsula) and 127.9 m (Catlins). The deeper dives almost certainly represent benthic dives as the depths reached correspond to the water depths of the continental shelf areas that the birds foraged over.

Climatic influence on population dynamics and foraging conditions – Peacock 1995, Peacock et al. 2000

Lora Peacock from the Department of Zoology at the University of Otago took a more theoretical approach to explain the strong population fluctuations observed in the early 1990s. For her MSc thesis she modelled population variables in relation to climatic parameters such as sea surface temperatures and rainfall to gain some understanding as to whether and how periodical climatic events, namely El Niño Southern Oscillation, affect the penguins' population dynamics. While not directly focussing the foraging ecology of yellow-eyed penguins the study nevertheless draws some conclusions with regard to the species at-sea biology.

The study found that long-term climate change is likely to have a stronger impact on long-term population trends when compared to periodical El Niño events. While the results did not provide enough information to isolate the mechanisms by which penguin numbers are influenced, it suggested that changes in ocean productivity may play a pivotal role. In the 1930s and 1940s population variables (e.g. breeding success) tended to decrease in years with cold and wet conditions. Such years coincided with severe south-westerly storms that were thought to affect the penguins' food availability (Richdale 1957). This pattern seemingly reversed in the latter decades of the 20th century when poor the seasons 1986, 1989 and 1990 all followed years of warmer and drier conditions. Peacock et al. (2000) hypothesised that presently yellow-eyed penguins might benefit from the fact that cooler seasons positively influence larval survival of the penguins' prey species like sprat and ahuru.

Consistent foraging routes and benthic foraging – Mattern et al (2007)

The new millennium saw the introduction of new devices based on the Global Positioning System (GPS) that not only allowed penguin tracking with unprecedented accuracy (Wilson 2004), but also incorporated high-precision pressure sensors to record fine-scaled diving behaviour with depth resolutions of 10cm (Mattern et al. 2005b). Such devices – GPS TDlogs produced by earth&Ocean Technology in Kiel, Germany – were first deployed on yellow-eyed penguins breeding at Bushy Beach in Oamaru, North Otago. In the breeding seasons 2003/04 a total of 4 penguins were fitted with GPS loggers that yielded data of 7 foraging trips. An additional 3 penguins were fitted with smaller Time-Depth Recorders (TDR; MK9, Wildlife Computers, Redmond, WA, USA) that only recorded diving behaviour at 0.5m resolutions and provided dive data of 17 foraging trips. The following season 2004/05, another four penguins were fitted with GPS dive loggers and resulting in data of five foraging trips.

The logger data provided a detailed insight into the penguins foraging habits. The penguins performed either one-day long foraging trips (mean trip duration: 11.5-12.9hrs) or shorter evening trips (4.0±0.9 hrs; see Mattern 2007)[1]. Evening trips, which were only recorded in 2003/04, were characterised by short foraging ranges (6.2±0.8km) reasonably short travel distances (15.9±1.2km) during which the birds dived 108±15 times. During full one-day trips, penguins foraged on average 17.5±2.5km from their nest sites, covered 47.5±1.8 km and performed 246±39 dives (Mattern 2007). In the following season 2004/05 only one-day trips

[1] To allow comparison with data from other sites, data for evening and one-day trips that were kept separate in Mattern et al (2007) have been combined in Table 4.1b.

were recoded. Foraging parameters recorded were comparable to those determined on one-day trips the previous season.

As a geographic position could be associated with most of the dives recorded by the GPS loggers, it was possible to quantify the benthic foraging behaviour that was suspected in the previous studies. The penguins indeed dived predominantly to the seafloor (80.3-91.5% of all dives, see Table 4.2b). Surprisingly, the penguins not only dived predominantly to the seafloor when they were actively searching for prey at their main foraging grounds, but also when they were travelling to those sites. Only on the return journey the proportion of benthic dives decreased (Mattern 2007).

All penguins foraged to designated, individual foraging sites that were revisited on subsequent trips and in subsequent seasons. This corresponded well with the findings of Moore (1999). The relatively shallow depths off Oamaru permitted a scuba survey of one of those foraging areas and found a horse mussel (*Atrina zelandica*) field in an otherwise featureless benthic environment that was dominated by sand and silt. The horse mussel shells protrude from the seafloor and thus provide substrate for epibenthic fauna such as sponges and coral, which in turn sustain a diverse benthic community of invertebrates, crustaceans and fish (Cummings 2001). It appears the penguins specifically target such horse mussel fields as they provide a stable and predictable supply of prey. This in turn raised the question how well the penguins are able to respond to disturbances within their foraging grounds.

Furthermore, this study revealed that the penguins use benthic features – e.g. reefs, shingle patches and associated flora – to precisely navigate to their foraging grounds (Mattern et al. 2007). It appears that yellow-eyed penguins not only dive to the seafloor in pursuit of prey, but also to use underwater landmarks for route finding similar to homing pigeons.

Foraging along straight lines, Otago Peninsula – Mattern et al (2005, unpubl. data)

An outbreak of diphtheritic stomatitis in yellow-eyed penguins caused significant chick mortality in November 2004 (Houston 2005). In an effort to determine whether this outbreak might have been triggered by a sea-based pathogen (e.g. water pollution from Dunedin's sewage outfall), GPS loggers (GPS-TDlog, earth&Ocean Technology, Kiel, Germany) were deployed on breeding yellow-eyed penguins. Between late November 2004 and early January 2005, nine birds from the Boulder Beach complex (Southern Otago Peninsula) and four birds from Ryan's Beach (n=3) and Pipikaretu (n=1) (Northern Otago Peninsula) were fitted with loggers. While all deployments at Boulder Beach occurred during the chick-guard stage, the penguins from Ryan's Beach/Pipikaretu had already entered the post-guard stage of breeding. In the following season, GPS loggers were deployed on four of the Boulder Beach birds. Two of the birds were still guarding chicks, the other two had chicks old enough to be left alone at the nest (post-guard).

During the 2004/05 season data for a total of 13 complete foraging trips were obtained at Boulder Beach. Of the four penguins from the Northern Otago Peninsula, only three birds left to forage during the logger deployment; yielding data for one foraging trip each. While the four birds fitted with GPS loggers in the 2005/06 season performed a total of 11 foraging trips, dive data was only recorded on one bird (band no: 14647, three trips); during the remaining deployments the dive sensor failed.

In the chick-guard stage of the 2004/05 season, the birds from Boulder Beach all undertook one-day foraging trips that lasted around 14.6 hours (see Table 4.2b), which means that trip durations were around 2-4 hours longer than what was reported by Peter Moore (1999). Foraging ranges were also considerably longer with 25.8±4.3 km. In the following season, the two birds fitted with loggers during chick guard foraged much closer to their breeding site and stayed at sea for shorter time periods. In fact, one of the two (band no: 14688) performed five evening trips (mean trip duration: 5.9±4.2, mean foraging range: 6.0±3.0 km). In the previous season it had foraged for one full day only while fitted with a logger (trip duration: 12.2hrs, foraging range 17.2km). For the other bird (band no: 14647), foraging parameters were more comparable between both seasons. In 2004/05 it left on a single one-day trip (14.2 hrs, 22.6km), and in the following season it performed three trips, one evening trip (8.4 hrs, 7.1km) and two one-day trips (16.5±2.3hrs, 15.7±2.6km). So the apparent differences between both seasons (Table 4.2b) are likely to be strongly biased by individual variation. However, observed foraging patterns differed significantly between both seasons. In 2004/05 birds from the Boulder Beach complex exhibited remarkable at-sea movements. 6 of the 8 birds foraged further than 14km from their nest site. All 10 trips recorded for these birds featured patterns that were rather unusual in that the birds foraged along straight line courses that were parallel to the coast. While the birds' movements away from the coast appeared "normal", i.e. their courses were not particularly straight, all birds at some point changed their heading from more or less South to either Northeast or Southwest. After these course changes the birds moved along straight lines that could not have been drawn straighter with a ruler on a map. Most of the birds not only followed the straight lines once but followed exactly the same line repeatedly in both directions. While on the lines, the birds did not deviate more than 50m from the straight line course which corresponds to the accuracy of the GPS unit. A total of 5 distinct lines were identifiable from the GPS data, two of which were followed by two and three birds, respectively. All five lines were parallel to each other; two of the lines appeared to be segments of a single longer line. The length of the lines ranged from 0.5-9.7km. If the birds' traveling periods from and to their nesting sites (ca. 3-4hrs both ways) are disregarded, the penguins spent an average 6.6 hours actively foraging in water depths of about 80 meter. During this time, the birds spent between 52-95% of their time on the straight line courses. 95% of their dives were bottom dives (Mattern 2005). As it was impossible to organize a drop camera or ROV at the time, it probably will be difficult to provide clear evidence for the origin of the straight line courses observed in 2004/05. In the following season, none of the four birds that had foraged along the lines in the previous year did so in 2005/06. So it can be assumed that the observed patterns were a one-off which further underlines that permanent, natural features played no role in the unusual foraging behaviour observed.

The penguins from the Northern Otago Peninsula foraged to the East (2 birds) and Northeast (1 bird) of their breeding locations (mean foraging range 15.8km, mean trip duration: 18.8hrs). The ranges and trip durations are longer than what Moore (1999) observed, but these differences might be an artefact of the small sample size of post-guard birds. It is interesting to note, however, that one of the birds foraged within the outer ranges of Blueskin Bay to the North of the Otago Harbour. This area is the designated location for the dumping of significant amounts of dredge spoil during the proposed widening of the Otago harbour, which would impact significantly on the benthic ecosystem (Willis et al 2008) and, thus, may affect the foraging success of penguins from the Northern Peninsula.

Comparison of foraging behaviour on Stewart Island and Codfish Island and potential impact of oyster fisheries on yellow-eyed penguins – Mattern et al (2006, 2007b, 2008, unpubl. data)

In the face of an on-going decline of the yellow-eyed penguin population breeding along the North-eastern coastline of Stewart Island – generally referred to as the Anglem Coast – a comprehensive study of the penguins' foraging behaviour was conducted during three consecutive seasons 2004/05 to 2006/07. While work in the first season focussed solely on Stewart Island, the two following years of the study had a comparative approach through the inclusion of penguins from Codfish Island.

At two sites on the Anglem Coast (Golden Beach & Rollers Beach), GPS loggers were deployed on a total of 13 penguins between January 2005 and December 2006, covering the post-guard stage (2004/05, 3 birds, 5 trips) and chick guard stage (2005/06, 4 birds, 9 trips; and 2006/07, 6 birds, 12 trips). The relatively small numbers of logger deployments along the Anglem Coast were primarily due to the limited numbers of nests that did not fail early on. The data yield was considerably better on Codfish Island, where a total of 18 birds were fitted with GPS dive loggers, nine birds each per season. In the 2005/06 season, six of the nine penguins were still guarding chicks and undertook a total of 11 foraging trips. The three remaining birds had entered the post guard stage and each performed one long overnight foraging trip. In 2006/07 all nine birds were in chick-guard, performing a total of 14 foraging trips. The foraging behaviour of yellow-eyed penguins from Stewart Island and Codfish Island differed significantly in almost every way.

The Stewart Island birds generally did not travel more than 12km from their nesting site, regardless of the breeding stage they were in. Similarly, trip duration did not differ considerably between years at Stewart Island although penguins in post-guard stayed at sea for longer (Table 4.1b&c). One bird from Golden Beach exhibited a very unusual foraging behaviour as it repeatedly foraged within a 3km radius from its nest site in Murray Bay. The bird could be observed from the beach patrolling up and down the bay some 50m from the shore, in very shallow waters (<10m) during as well as after the logger deployment. What kind of prey it pursued there is unclear. All other penguins foraged along more or less coast parallel courses northwards. Similar to patterns observed in Oamaru (Mattern et al 2007), individual birds tended to revisit certain areas on subsequent foraging trips. However, unlike at Oamaru centres of activity of the individual birds were located in close proximity to each other. The foraging area that the penguin utilised to search for prey was spatially very limited and did not change between breeding stages or years. The diving behaviour leaned strongly towards predominantly benthic foraging (Table 4.1b&c).

On nearby Codfish Island, the penguins stayed at sea between 17-22 hours hours during chick-guard and around 43 hours in post guard. Particularly noteworthy is the behaviour of three birds guarding chicks in the 2006/07 season that undertook long foraging trips during which they ranged more than 50km away from their nest site. In the 2005/06 season such patterns were only observed in post-guard penguins. This indicates that during the 2006/07 season, the food situation was not as good as the season before.

In comparison to Stewart Island, the Codfish Island birds, ranged considerably further, foraging trips of individual birds were distributed over wide areas Northeast to Northwest of Codfish Island, including distant Te Waewae Bay. Accordingly sea areas utilised by penguins from both islands differ significantly. While the Stewart Island birds remained in all years in an area of approximately 97.3km², the home range of Codfish Island birds was larger by an order of magnitude – 989.4km² (see Fig 4.2).

The diving behaviour also differed greatly between both sites. Linked to the longer foraging trip times, penguins form Codfish Island performed far more dives per trip than their Stewart Island counterparts. The dive time of penguins from Stewart Island was on average 10s longer when compared to Codfish Island. At the same time, Stewart Island birds did only dive at depths <50m whereas their Codfish Island conspecifics regularly dived to 60+m. All this indicates that the Stewart Island penguins have to compensate their much smaller home range by increasing their diving effort. The post-guard data underpin this hypothesis further.

During the post guard stage, Stewart Island penguins performed more dives per trip which is to be expected considering the longer foraging trip times. However, since the in post-guard penguins performed more benthic dives when compared to chick guard (see Tables 4.1b&c) it appears as if the penguins must increase their diving effort in order to meet the growing demands of their chicks.

In summary, yellow-eyed penguins from both sites exhibit two different strategies – vertical v. horizontal foraging. The Stewart Island birds increase their dive effort (more, longer dives); Codfish Island penguins travel farther afield.

Considering the higher breeding success on Codfish Island (King 2008), the question arises why Stewart Island penguins do not follow the example of their counterparts from the neighbouring island. The most likely explanation is that for them Te Waewae Bay is too far to reach, especially since the birds from the Anglem coast would have to travel against the strong tidal current in Foveaux Strait while travelling East to West (and vice versa) around the Northern part of Stewart Island; the Codfish Island penguins only have to cross the tidal flow in northerly and southerly directions.

In theory birds from the Anglem Coast should be able to forage farther towards eastern Foveaux Strait. However, this region is subject to substantial fishing activities, principally oyster extraction. Dredging has a significant negative impact on the benthic environment. The past decades saw a large scale removal of biogenic reefs of Foveaux Strait resulting in a reduction of the benthic biodiversity and productivity (e,g, Cranfield et al. 1999, Jiang & Carbines 2002, Cranfield et al. 2003). The foraging data suggests that sea areas utilised by the oyster fisheries do not produce enough prey for yellow-eyed penguins. Only a small area off the North-to-Northeastern coast of Stewart Island appears to offer somewhat suitable foraging habitat. The greatly reduced foraging area available leads to increased intraspecific competition for the limited prey resources. As a result prey available for chick provisioning is very limited which subsequently facilitates chick starvation and mortality. This hypothesis received substantial support from a diet study that was carried out at both sites in 2006/07 (Browne et al 2012, see below).

4.3.2 Diet

Erosion of otoliths and squid beaks – van Heezik and Seddon (1989)

The first paper touching the subject of yellow-eyed penguin diet to be published in a scientific journal was principally of a technical nature. It focussed on the rate of erosion of otoliths (i.e. ear-bones of fish that can be used for species identification and size/mass estimation) and squid beaks (used similarly to otoliths to determine species and size) in the stomachs of yellow-eyed penguins and the analytical consequences thereof. In essence the study found that otoliths are digested usually within 24 hours, whereas squid beaks are retained in the stomach for much longer periods. This is an important fact to consider when dealing with stomach samples as the analysis of hard-part remains potentially biases the results towards squid. Additionally, the paper lists the main prey species of which otoliths and beaks were used: red cod (*Pseudyphycis bacchus*), opal fish (*Hemerocoetes monopterygius*), sprat (*Sprattus antipodum*) and arrow squid (*Nototodarus sloani*).

Seasonal, geographical and age-related diet variations – van Heezik (1990b)

The first comprehensive study of the yellow-eyed penguin's diet was conducted by Yolanda van Heezik. Between 1984 and 1986, she obtained stomach samples from a total of 512 adult yellow-eyed penguins breeding at eight different locations ranging from Moeraki, Shag Point and Bobbys Head in North Otago, to Boulder Beach on the Otago Peninsula and Nugget Point, Hina Hina Cove, Penguin Bay and Falls Creek in the Catlins. Stomach samples were obtained via the water-offloading method (Wilson 1994) during which water is pumped into a penguin's stomach to induce vomiting. Two flushes were sufficient to remove entire stomach contents.

Overall, 26 prey species were identified during the study, with fish comprising 87% of the weight. Sprat was the most commonly taken prey species (frequency of occurrence: 67%) although it contributed only 12% of the calculated meal weight (see Table 2). Less frequent but contributing more mass were red cod (FO: 47%; weight: 36%) and opalfish (FO: 44%, weight: 22%). Inshore species that are commonly taken by shags were absent in the penguin diet which led to the conclusion that penguins forage further away from the coast.
Interestingly it was concluded that the majority of the prey species were pelagic rather than bottom-dwelling ("demersal") species. This stands in contrast to the findings of subsequent foraging studies and diet studies. However, all of the species listed as pelagic also occur at or close to the sea floor. Particularly the distribution of arrow squid is discussed ("arrow squid are most abundant towards the surface […] where they have found to represent 47% of the total commercial catch"). Yet the diel vertical migration in which squid migrates to the surface at night (when commercial fishing occurs) but stay at greater depths and, thus, closer to the seafloor during the day (when yellow-eyed penguins forage) was not considered (Roper & Young 1975).
The study found geographic variations in prey composition. For example, penguins from Bobbys Head caught a reasonably large amount of sprat (weight: 20%) while at Shag Point only 10 km to the North, opalfish, red cod and silversides dominated the diet. Interestingly, penguins form Bobbys Head brought less food ashore but had higher body weights when compared to the birds from Shag Point. Van Heezik hypothesised that sprat had a higher caloric value when compared the species found in the Shag Point penguin diet.
Overall, the study concluded that yellow-eyed penguins appeared to be selective rather than opportunistic foragers that target certain species which makes them vulnerable to decreased availability of its principal prey species. This vulnerability was further substantiated when the effect of diet changes on growth rates, fledgling sizes and reproductive success were analysed.

Effects of food variability on growth and survival– van Heezik and Davis (1990)

Simultaneously to the diet study summarised above, the growth rates and fledging success of yellow-eyed penguins was recorded by Yolanda van Heezik and Lloyd Davis. The study focussed on two sites, Boulder Beach on the Otago Peninsula and Nugget Point in the Catlins. In the breeding seasons 1984/85 and 1985/86 chicks were weighed and measured at weekly intervals. An adverse change in diet occurred in the second season which resulted in reduced weight gains, higher chick mortality and increased adult mortality during moult.

Compared to 1984/85, the 1985/86 season meal sizes were larger (1984/85 v. 1985/86: 249.2g v. 711.8g) and there was a change in absolute quantities of certain species, some appeared less frequent while others were more abundant. At Nugget Point sprat (mean % weight: 75g) and red cod (137.7g) dominated the diet in 1984/85 (arrow squid: 30.7g), while it was primarily arrow squid (420.6g) that was taken in the following season (sprat: 10.6g; red cod: 84.6g; van Heezik 1990b, Table 1). Similarly, penguins from Boulder Beach fed primarily on opalfish (401.8g), red cod (102.2g) and arrow squid (162.9g) in the first season. In the following season, the amount of arrow squid brought shore almost tripled (424.6g), while the mass of opal fish (228.2g) and red cod (32.8g) was halved. These differences in prey composition reflected particularly in lower growth rates, lower fledging weights and higher mortality rates at Nugget Point.

Van Heezik & Davis (1990) argued that the different growth rates observed in both seasons are linked to the caloric value of the prey species taken. Sprat, which played an important part in the diet of Nugget Point birds, has high oil content when compared to other prey such as red cod and arrow squid. Since sprat was all but absent from the penguins' diet in 1985/86 it seems that even though arrow squid was taken in much larger quantities, it could not compensate for the lack of prey with higher energy content. At Boulder Beach, opal fish seemed to have played the role of "quality food" as it is firm-fleshed and likely to have a high oil-content. While the amount of opalfish was reduced in the 1985/86, it still contributed significantly to the penguins' diet so that the impact of prey changes was less pronounced when compared to the Catlins.

Regardless of site the fledgling survival was significantly lower during the second season. None of the fledglings were resighted as juveniles and as such presumably died in their first year at sea. Juveniles eat predominantly arrow squid probably because the species is easier to catch when compared to other fish species. As such the prevalence of low quality food (i.e. squid) in 1985/86 was believed to negatively affect the young penguins' likelihood for survival.

Prey composition on Codfish Island – van Heezik (1990a)

In the season 1984/85, Yolanda van Heezik sampled the diet of yellow-eyed penguins, Fiordland penguins (*Eudyptes pachyrhynchus*) and little blue penguins (*Eudyptula minor*) breeding sympatrically on Codfish Island. 22 yellow-eyed penguins, 21 Fiordland penguins and 28 little penguins were stomach flushed and their prey composition analysed and compared. The two single most important prey species for yellow-eyed penguins were blue cod and opalfish both species that only occur at the sea floor. Other species present in the diet were arrow squid, Ahuru and red cod, but neither of these species contributed significantly to the calculated weight of the samples. Instead these species were the primary prey species for Fiordland and little blue penguins. Overall there was only small overlap in diet composition of yellow-eyed penguins and the other two species. 7 out of the 16 species eaten by yellow-eyed penguins were not present in the diet of Fiordland or little blue penguins. The majority of the species taken exclusively by yellow-eyed penguins were demersal species; whereas the other two penguin species primarily took pelagic prey.

Diet of yellow-eyed penguins from Otago Peninsula & Catlins – Moore & Wakelin (1997)

In conjunction with the radio telemetry study that occurred between 1991 and 1993, stomach samples were taken from a total of 86 individuals covering four breeding seasons. The study focussed on the Boulder Beach complex on the Otago Peninsula and Long Point in the Catlins (Fig 4.2). A total of 43 types of prey were identified, 37 of which were fish, four cephalopod and two crustacean species. Opalfish, blue cod and arrow squid again turned out to be the most important prey species (Table 4.2). When compared between both sites, opalfish was equally important, while blue cod and arrow squid contributed relatively more to the penguins' diet at Boulder Beach when compared to Long Point. Here, the pelagic ahuru (*Auchenoceros punctatus*) was the second most important prey species. However, this might be a biased representation as the samples containing the majority of ahuru were all taken on a single day at Long Point.

Just as observed in previous studies, prey composition differed between sites. However, more interestingly the study found individual preferences for prey, and thus causing variability of diet composition between individuals from a site. The paper provides the feeding preferences of five birds as an example, where one bird preferably fed on blue cod, another took more arrow squid, while two other birds had comparable prey species in their stomachs consisting of opalfish, blue cod and red cod. The fifth bird was sampled five times and was responsible for bringing 79% of the total number of krill *Nyctiphanes australis* ashore. These differences underpin the findings of the tracking studies summarised above, where individuals tend to revisit distinct locations to forage and do so not only between foraging trips but also between years. Hence, the individual differences in prey composition probably reflect the individual foraging patterns, e.g. individuals eating predominantly blue cod forage on rocky habitat closer to the coast.

The paper also challenges van Heezik's (1990) conclusions about the relative quality of prey. The argument that sprat provides a richer energy source than opalfish or red cod was questioned as the size of sprat taken by the penguins has only intermediate oil and energy levels. Likewise the assumption that blue cod and arrow squid are low quality prey was refuted as blue cod has low oil content but nevertheless high energy values, while arrow squid has oil content and energy levels that are comparable to most of the yellow-eyed penguin's fish prey. "It may be that digestibility of protein is more important than the oil content or energy value." Overall "the relationship between prey species and nutrition is likely to be complex, and our assumptions are hindered by the paucity of data on chemical composition of prey" (Moore & Wakelin 1997).

At any rate, similar to van Heezik (1990b) it was apparent that breeding success was improved in years where opalfish, red cod and sprat were the preferred prey over arrow squid and blue cod.

Diet quality differences between Stewart and Codfish Island – Browne et al. (2011)

The significantly different foraging patterns observed on Stewart and Codfish Islands raised the question whether these differences would reflect in the diet composition of penguins from both sites. In pursuit of an answer to this question, Tiffany Browne and colleagues conducted a diet study on both islands in the season 2006/07. A total of 12 breeding penguins from Anglem Coast, Northeast Stewart Island, were stomach flushed during the chick guard stage, followed by stomach flushing of 15 penguins from Codfish Island (see Fig 4.2). The low sample sizes resulted from permitting constraints (only one penguin per breeding pair was allowed to be sampled) and the low numbers of breeding pairs along the Anglem Coast. The stomach contents were not only quantitatively analysed but also energetic contents of the meals were determined via bomb calorimetry.

For stable isotope ratio analyses feather and blood samples were taken from adult penguins and chicks. Stable isotope ratios reflect those of the penguins' prey in a predictable manner. The nitrogen isotope ratio of $^{14}N/^{15}N$ provides information about the trophic level of the consumer, while the carbon $^{12}C/^{13}C$ ratio gives an indication about the food sources. Dependent on the tissue type, stable isotope ratios reflect diet of a variety of durations. Stable isotopes in feathers provide an indication of diet at the time of the feather synthesis, i.e. the weeks prior to the moult, whereas isotope ratios in blood integrate diet over a period from a few days up to four weeks.

It needs to be pointed out that in the year the stomach samples were taken, with the exception of one chick none of the yellow-eyed penguin chicks from Stewart Island survived until fledging. Because of that, feather samples taken in the previous season were used in the analysis and as such reflect the diet composition in 2005/06.

Of the 12 birds sampled on Stewart Island, five birds returned with an empty stomach. Of the remaining 7 samples, only three contained identifiable remains (i.e. entire fish or otoliths). On Codfish Island only two of the 15 birds returned with empty stomachs, 10 birds brought diagnostic remains ashore. The proportion of empty stomachs was considerably higher than in previous studies. At the same time the body mass of the adult birds sampled during this study was significantly higher than in previous studies, perhaps an indication that the adults focussed on self-sustenance rather than offspring survival.

The principle prey species at both locations was blue cod, which occurred in all three of the Stewart Island samples and in seven of the 10 samples from Codfish Island. Apart from one bird that returned with Tarakihi (*Nemadactylus macropterus*) in its stomach, no other prey was identified from Stewart Island stomach samples. The stable isotope analysis revealed that in the previous year (when the feather samples for the analysis were taken) opalfish must also have been an important part of the Stewart Island penguins' diet. Especially in fledglings isotope signatures indicated a greater importance of opalfish over blue cod.

On Codfish Island, prey taken by the penguins was more diverse. In addition to blue cod,, opalfish, jock stewart (*Helicolenus percoides*), sprat and arrow squid were found in the samples. However, compared to previous studies (particularly van Heezik 1990b) prey diversity was low. The blue cod taken by birds from both sites were rather large ranging from 13-28cm, whereas the opalfish found in penguins from Codfish Island was smaller (around 14cm). The prey size could potentially be a problem for the provisioning of chicks as it is probably difficult for the offspring to swallow large prey items like blue cod. And indeed, undigested blue cod remains were found frequently around nests along the Anglem Coast (Thomas Mattern personal observation).

Lastly, the analysis of the energetic values showed that the meals brought ashore by Codfish Island birds was significantly higher in energy (mean: 18.4kJ g^{-1}) than on Stewart Island (mean 14.2kJ g^{-1}). Interestingly, the energetic content determined for blue cod (19.8kJ g^{-1}) and opalfish (19.59kJ g^{-1}) were similar, so that the preference for one over the other species is most likely determined by availability and not as much a result of quality related selectiveness by the penguins as suggested by van Heezik (1990b). At the same time, stable isotopes provide an indication that the adult penguins selectively provision their offspring by preferably feeding (smaller, easier to swallow) opalfish to their young while using (larger) blue cod for self-sustenance. It appears that the overall energetic content of the penguins' diet depended more on the diversity of available prey rather than the nutritional value of single prey species. As such, the low prey diversity observed and the high proportion of birds returning with empty stomachs is a clear indication that the foraging situation is poor for penguins breeding along the Anglem Coast. A logical conclusion is that high starvation rates of Stewart Island penguin chicks are largely a result of reduced prey availability in the spatially very limited foraging ranges of the Stewart Island penguins (see 4.3.1).

4.4 Discussion

4.4.1 Foraging behaviour and diet

From the information available it can be concluded that yellow-eyed penguins on the mainland are almost exclusively benthic foragers. Consistent individual foraging patterns that are characterised by re-visitation of foraging sites (Moore 1999, Mattern et al. 2007) suggest that a specialisation on benthic prey species provides yellow-eyed penguin with a spatially predictable, stable source of food. The individuality of foraging patterns is further emphasised by the consistent diet composition of single yellow-eyed penguins (Moore & Wakelin 1997). Although suggested by van Heezik (1990b) subsequent studies did not support the hypothesis that yellow-eyed penguins selectively target energy rich prey species.

Blue cod, opalfish and arrow squid appear to be the universal staple food of yellow-eyed penguins across their entire mainland range, although red cod used to be more important in the early 1980s. Whether or not yellow-eyed penguins are obligate benthic feeders is unclear, although the principally benthic diving behaviour would suggest as such. Even the penguins from Codfish Island that showed a high proportion of non-benthic dives performed most of these during the linear travelling trip phases. Yet, it seems unlikely that yellow-eyed penguins which encounter a patch of pelagic prey would not pursue this opportunity. Conversely, the presence of pelagic species in the diet of yellow-eyed penguins does not necessarily mean that the prey was caught in the upper ranges of the water column.

Penguins from Oamaru, the Otago Peninsula and Stewart Island all show a great affinity for benthic foraging along consistent – in some cases predictable – routes (Mattern et al. 2007).

The results highlight reasons for this foraging strategy other than searching for benthic prey, i.e. navigation along bottom features. The accuracy with which penguins from the Otago Peninsula swam along straight line courses (Mattern 2008) further enforces this hypothesis. The individual centres of activity observed during both the radio tracking (Moore 1999) and GPS logger studies (Mattern et al. 2007) even suggest that the penguins may be able to memorise seafloor features and locations over time and develop individual "seascape maps" of their foraging habitat similar to homing pigeons (e.g. Meade et al. 2005). The individual capabilities to do so would certainly represent a selection factor of great importance and as such warrants further investigation.

Overall, the yellow-eyed penguins' behavioural patterns point towards a species which has developed a specialised foraging strategy that provides them a competitive advantage over other seabird species (e.g. O'Driscoll et al 1998) but comes at the cost of reduced ability to react to changes in their marine environment. The foraging patterns observed on Stewart Island clearly demonstrate this restrain.

4.4.2 Variables affecting foraging ecology

At-sea movements, diving behaviour and diet composition all suggest that yellow-eyed penguins are highly specialised foragers. Such behaviour is unique amongst penguins, which usually inhabit highly variable marine environments. Yellow-eyed penguins breeding around the New Zealand mainland live in a stable environment where the availability of prey is not dictated by seasonality like in the Polar Regions or the dynamics of the pelagic environment (e.g. Davis & Renner 2003).

The benthic prey species of yellow-eyed penguins such as opalfish and blue cod are available throughout the year, which allows yellow-eyed penguins to be sedentary rather than migratory like Fiordland penguins (Mattern, in press). But it also means that the birds rely on functioning benthic ecosystems within their range. In situations where the benthic habitat has been degraded penguins struggle to survive on the little food they can find.

The Foveaux Strait historically featured expansive biogenic reefs that were greatly reduced in size as a result of increasing efforts of the local oyster fishery (Cranfield et al. 1999, Cranfield et al 2003). While traditionally oyster beds of the eastern and central region of the Foveaux Strait were fished, the effort moved westwards in the 1970s and 1980s (Cranfield et al. 1999) – towards Stewart Island and into areas of potential yellow-eyed penguin foraging habitat. Today the birds only forage over the fringes of the formerly expansive Foveaux reef systems. The areas dredged for oysters have markedly lower prey diversity than undredged regions; fish species like blue cod show significantly reduced growth rates in areas where reefs have been removed or disrupted as a result of oyster dredging (Jiang & Carbines 2002). Te Waewae Bay is likely to be out of reach for the Stewart Island birds so that the penguins in theory could only try to switch to pelagic prey to compensate for the reduced availability of benthic species. However, none of the studies summarised here suggests that yellow-eyed penguins are able to adjust to a pelagic foraging strategy.

It is not known how exactly penguins that forage in a pelagic environment are able detect their prey. Olfactory capabilities have been suggested (Culik et al 2000), but it seems that pelagic foragers generally use an "inspired guess" approach in which they forage towards known sea regions with higher productivity (e.g. frontal systems) and travel until encountering prey patches (e.g. Wilson 1995, Mattern 2006b) . Yellow-eyed penguins on the other hand seem to use benthic features to travel precisely to locations that are then revisited over days and years to obtain prey (Mattern et al. 2007). This is a perfect strategy in an environment like the continental shelf off Oamaru, where patchily distributed horse mussel fields offer areas of high prey abundance and underwater landmarks help the penguins to navigate to such fields quickly. However, what if these horse mussel fields disappear, for example as a result of anthropogenic influences (e.g. fisheries activities, sedimentation)? How will the penguins be able to find new patches – if there are any around? The example of yellow-eyed penguins from Stewart Island suggests that the species will not be able to adjust to changes that occur over short time periods but affect the benthic environment for many years. Cranfield (2004) found that it takes at least 12 years or longer for benthic communities in Foveaux Strait to regenerate to stage III (of V regeneration stages) after disturbance by oyster fisheries. During such a period resident yellow-eyed penguins experience significantly reduced reproductive success and recruitment probabilities – a situation that applies to the Anglem coast population (King 2008).

With regard to the Southern Oscillation, the results from Peacock et al. (2000) imply that foraging conditions for yellow-eyed penguin improve following El Niño events. Such events are characterised by predominantly south-westerly winds, increased rainfall and reduced temperatures in the species mainland breeding range. Accordingly in the years following La Niña events, north-easterly winds usually result in reduced rainfall and warmer than normal temperatures, detrimental foraging conditions result in lower than normal breeding success (see also Perrimen et al. 2000). However, in the context of long-term population dynamics SOI events seem to play a negligible role. The apparent reversal of the relationship of climatic conditions and breeding success – i.e. higher success after warm conditions in the first half of the 20th century (Richdale 1957), versus higher success after warm conditions in recent years (Peacock 1995, Peacock et al. 2000) – suggest that on-going long-term changes might give yellow-eyed penguins the time to adjust. In this light, the influence of acceleration of alterations as a result of global climate change must be a focus of future research endeavours.

4.4.3 Research implications

Clearly the survival of yellow-eyed penguin – or any other type of seabird for that matter – depends to a very large degree on their marine environment. In the face of climate change and increasing anthropogenic factors ranging from fisheries impacts to pollution, changes in the yellow-eyed penguins' marine habitat are likely to occur at rates that will make it difficult for the species to adjust. It is apparent that the future of the species is determined at sea. Considering this, the marine ecology of yellow-eyed penguins requires stronger consideration during the prioritisation of conservation measures. Nest monitoring, population censuses and rehabilitation are important observational tools that tell us something about the current status of the population, but provide little information as to how the situation for the species can be improved. Terrestrial management measures such as habitat restoration and predator trapping in important breeding areas are only effective as long as the penguins survive their foraging trips and find enough food in the vicinity. Monitoring the yellow-eyed penguin's foraging ecology – i.e. diet, foraging ranges and at-sea behaviour – will provide the data needed to analyse important factors driving population dynamics and to determine appropriate conservation actions.

In comparison to seriously scientifically neglected New Zealand penguin species like the Fiordland penguin or erect-crested penguin, we have at least baseline information on the foraging behaviour of yellow-eyed species. However, compared to the wealth of data available for penguin species breeding within the Ross Dependency, Antarctica our understanding of the yellow-eyed penguins' marine ecology is minute. This is primarily due to the absence of continuous research activities. With regard to yellow-eyed penguins, most of the research projects of the past three decades had a short term focus and were principally part of Masters or PhD research programmes. Coherent, long-term research activities can only be achieved by a dedicated research group that provides scientific guidelines on which future research projects are based. With regard to studies of penguin foraging ecology, a logistic and scientific framework that provides materials, analysis protocols and tools would be invaluable.

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

Authors: Ursula Ellenberg & Thomas Mattern

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 foraging areas. There is strong evidence that commercial oyster dredging in the Foveaux Strait significantly reduces the abundance, diversity and quality of penguin prey by modification of epifaunal reefs, 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. Furthermore, potential **indirect fisheries competition** via the reduction of spawning stocks (e.g. red cod fisheries) warrants further investigation.

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 important yellow-eyed penguin breeding areas. Electronic monitoring can

supplement independent observers allowing better overall coverage while keeping the related costs manageable. Such data are 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. Since bycatch rates are extremely uncertain, high independent observer coverage is required to achieve reasonable precision in bycatch estimates.

To assess the impact of benthic habitat degradation on yellow-eyed penguins better, 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 (600-800 breeding pairs) and fragile. Previous population strongholds such as on the Otago Peninsula are declining. Since the mainland population is genetically distinct from sub-Antarctic populations (inferred immigration rate 0.003 per generation) the current loss of yellow-eyed penguins along the Southeast coast of the New Zealand South Island and in the Foveaux Strait will not be compensated.

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 can 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 we have assembled and circulated a discussion paper which has been considerably 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.

We have prepared a PowerPoint presentation and led 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 responses.

The updated version was circulated to colleagues from the International Penguin Expert Group of the World Conservation Union (IUCN) Species Survival Commission (SSC). Particularly, Pablo Garcia Borboroglu, CONICET, University of Washington & Global Penguin Society, and Peter Dann, Research Manager at the Phillip Island Nature Park & University of Melbourne, provided valuable feedback and have greatly improved this section.

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

5.2.2 Fisheries competition via reduction of spawning stocks

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). Of 42 carcasses available for autopsy 28 were adults. Gillnet effort peaks in summer between November and March which coincides with the yellow-eyed penguin breeding season. Loss of one parent usually results in reproductive failure (Darby & Dawson 2000) and the remaining bird will generally skip at least one breeding season following the loss of its partner (Setiawan et al. 2005).

The presented bycatch figure likely underestimates true bycatch substantially, since the majority of incidents remain unreported and there is little incentive for fisherman to report entanglements (Darby & Dawson 2000, discussion at the CSP meeting 28 May 2012).

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, fisheries effort, 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). However, 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 suggest 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 placed further offshore by commercial operators.

Anecdotal evidence suggests that yellow-eyed penguin bycatch is considerably higher than what is being reported. We decided to not include unreferenced anecdotal data into this report. Hence, we urgently need a representative independent observer programme for reliable bycatch estimates.

Research approach

A substantial increase in independent observer coverage is required 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)[2].

Numbers of yellow-eyed penguin breeding pairs on Northeast Stewart and Codfish Islands and on the Otago Peninsula are declining. Hence particular effort needs to be placed on fishing vessels that operate around these areas. For highest data return rates independent observer effort should initially focus on setnets deployed during January – March since this is the time when we expect the a concentration of birds in the water in proximity of their breeding sites. Growing chicks have the highest energy demands January - February forcing parents to spend a lot of time at sea in order to provide sufficient food. February – March onwards recently fledged chicks will add to the numbers of yellow-eyed penguins at sea.

[2] 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.

Records need to distinguish between juvenile and adult yellow-eyed penguins. Ideally drowned individuals are sexed, and checked for band numbers or transponder ID. While yearly reports are imperative for immediate feedback we strongly suggest a comprehensive review of all 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 obtained 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, when 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.

During the CSP meeting on 28 May 2012 it has been suggested by the Seafood Industry Council (SeaFIC) to consider “gathering information directly from fishermen” and the example of the rock lobster fisheries was given which is being managed on self reporting. In the subsequent discussion the consensus was that the incentive for reporting fish catch is different to that for reporting bycatch. Since the main measure currently available for bycatch mitigation in set nets is fishing closure a negative incentive to reporting should be expected. Hence, a questionnaire will unlikely yield reliable information on bycatch and thus can not replace the urgently needed independent observer coverage on set netters operating in yellow-eyed penguin foraging areas.

We believe it is very important to engage with the fishing communities as early as possible in the process to make the development and implementation of mitigation measures more effective. We need to articulate economic incentives either in the form of marketing opportunities or by avoiding costly damage to gear or catch as well as pointing out the inconvenience of bycatch (e.g. taking away time form landing catches, legal obligations etc.). For these and other reasons most fishermen will be genuinely interested in bycatch reduction.

A voluntary (and anonymous?) reporting scheme asking fishermen to report yellow-eyed penguin (and other rare seabirds/ marine mammals?) sightings at sea using a questionnaire that includes a gridded map for easier reference will be a valuable resource. Additionally this would offer the opportunity to engage with the fishing community in a non-threatening way. We need to create opportunities for information exchange between fishermen, NGOs and governmental agencies. A monetary award for smart ideas reducing setnet bycatch would make such an involvement for fishermen more attractive. Fishermen know their gear and will be aware when and where bycatch occurs. Hence, they are the best pool of knowledge and the most productive inventers when it comes to develop mitigation techniques for the New Zealand situation.

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 and co-operative effort will allow development of effective mitigation measures or temporal/spatial management in order to reduce yellow-eyed penguin bycatch in the 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 are 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 particularly for the mainland management unit. 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

A substantial increase in independent observer coverage is required on 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 are 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 in 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). The Foveaux Strait historically featured expansive biogenic reefs where oyster banks provided the substrate for extensive benthic communities featuring sponges, corals and bryozoans which in turn provided habitat for a variety of invertebrates and fish species.

During the extraction of oysters, these epifaunal assemblages are removed as bycatch (e.g. Cranfield et al. 1999, Cranfield 2003). As oyster fishing efforts increased from the 1960s onwards the biogenic reefs were greatly reduced in size (Cranfield et al. 1999, Cranfield et al

2003). Over the past four decades the number of vessels grew and fishers developed more efficient dredging methods, resulting substantially increased disturbance and removal of biogenic reefs. Traditionally oyster beds of the eastern and central region of the Foveaux Strait were targeted. However, after these areas were fished to commercial extinction, the effort moved westwards closer to Stewart Island and yellow-eyed penguin breeding areas (Cranfield et al. 1999). By 1990 there were few unfished epifaunal reefs left which were confined to the southern and north-western parts of Foveaux Strait (see Figure 6d in Cranfield 1999). Yet fisheries continued to target the oyster beds adjacent to Yellow-eyed penguin breeding areas (Figure 2; Cranfield et al. 2001; compare also section 4).

The removal of biogenic reefs results in less diverse fish populations and smaller fish sizes (Cranfield et al. 2001; Jiang & Carbines 2002: Carbines et al. 2004). Fish species like blue cod show significantly reduced growth rates in areas where reefs have been removed or disrupted as a result of oyster dredging (Jiang & Carbines 2002).

Under favourable conditions habitat regeneration to Stage III (of V stages, with V being the most diverse) may be achieved within 12 years post fishing disturbance (Cranfield et al. 2004). However, the ability and time to regenerate appears to depend greatly on the proximity of intact biogenic reefs that could act as a source of propagules on habitat regeneration and macrofauna assemblage succession (Cranfield et al. 2004). Some areas need considerably longer to recover: One area had not been disturbed by dredging since 20 years but the level of regeneration conformed only to stage II; another area had not been fished for oysters for 50 years but still showed no sign of recovery, the habitat was classified as Stage I i.e. the stage observed in areas that are being still disturbed by dredging likely because the nearest habitats that could act as a source for settling organisms were 13-21 km away (Cranfield et al. 2004).

In 2004/05 to 2006/07 penguins breeding along the Anglem Coast only foraged along the fringes of the formerly expansive Foveaux epifaunal reef systems and did not forage in areas that had been commercially targeted in the previous decade (Mattern et al. 2007b; Mattern 2008; section 4). Hence foraging grounds of yellow-eyed penguins have become spatially very limited much to the detriment of the species. This clearly reflects in low prey diversity, quality and quantities observed in penguins from the Anglem Coast (Browne et al 2011). Poor foraging success causes chick starvation, and subsequently poor recruitment and declining population numbers.

"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, which 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 and patchily 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 foraging radius of yellow-eyed penguins during the crucial early chick rearing stage (i.e. 20km from breeding sites)[3].

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.

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

5.2.2 Fisheries competition

Rationale

Moore and Wakelin (1997) suggest that a direct competition between commercial fisheries and yellow-eyed penguins seems unlikely, as the penguins target smaller size classes of commercially exploited species. An example given is red cod (*Pseudophycis bachus*) where yellow-eyed penguins take principally juvenile red cod whereas fisheries focus on adult red cod. At the same time, the authors point out that the occurrence of red cod in the diet of the penguins peaked in the same years of high red cod landing by commercial fisheries. Yet "a lag would be expected between a year of high penguin consumption (<2 year old fish) and one of high catch in the fishery (3-4 year old fish)" (Moore and Wakelin 1997). Unless the simultaneous peaks in red cod occurrence in the yellow-eyed penguin diet and red cod landings is purely coincidental, it seems plausible that the abundance of juvenile and adult red cod is determined by the same factors.

A fact sheet published by the Ministry of Fisheries published online (MFish 2007) concludes that "red cod abundance is naturally variable [in response to environmental parameters] but the length and magnitude of the decline in commercial landings […] indicates fishing pressure may have significantly reduced spawning stock abundance" (page 273, point 27). Therefore it appears that the availability of red cod is not only a product of environmental variables, but is also determined by fishing pressure.

To which degree this fishing pressure may either directly or indirectly affect juvenile red cod is unclear. However, "there are no distinct red cod juvenile grounds and distribution is similar to that of red cod general distribution except for a few areas where they are more abundant between about 250 and 450m." (Nabis 2012). Furthermore, the majority of juvenile red cod reside close to the species' spawning hotspots before moving to the main commercial fishing grounds (Nabis 2012). For Southern New Zealand these spawning hot spots are Canterbury Bight, Puysegur and the Snares Shelf. Hence, it appears that red cod caught by yellow-eyed penguins along the Otago coastline are probably sub-adults that intermingle with the adult population.

The potential competition effects may therefore be of an indirect nature, e.g. via affecting juvenile red cod during fishing operations and reducing the spawning population (MFish 2007). While red cod continues to be an important food source found in about half of all diet samples the average contribution to total meal size has declined from 36% in the mid 1980s to 7.4% in the 1990s (van Heezik 1990; Moore & Wakelin 1997; Section 4). At any rate, a more detailed examination of the potential impact of fisheries competition is warranted particularly in areas where red cod fisheries and yellow-eyed penguin foraging grounds overlap.

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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 4.1a Foraging parameters of yellow-eyed penguins determined during the **incubation stage** of breeding.

	Otago Peninsula				
	1988/89	1991/92	1992/93	1993/94	1994/95
Foraging Parameters					
No of Birds (n)	130	13	14	17	11
Trip duration (h)	33.6±9.6	64.9±41.2	27.3±23.3	42.0±31.1	57.8±40.5
Foraging range (km)	-	26.3±11.3	16.9±9.8	-	-
Distance travelled (km)	-	-	-	-	-
Diving Parameters					
No of Birds (n)	24	-	-	-	-
Number of dives per trip	-	-	-	-	-
Proportion of benthic dives (%)	-	-	-	-	-
Mean dive duration (s)	-	-	-	-	-
Mean dive distance (m)	-	-	-	-	-
Max depth reached (m)	34±8	-	-	-	-
Foraging effort	-	-	-	-	-
Reference	(1)	(2)	(2)	(2)	(2)

Table 4.1c Foraging parameters of yellow-eyed penguins determined during the **post-guard stage** of breeding.

	Otago Peninsula						Catlins			Stewart Island	Codfish Island
	1990/91	1991/92	1992/93	1993/94	2004/05*	2005/06	1991/92	1992/93	1993/94	2004/05	2005/06
Foraging Parameters											
No of Birds (n)	6	10	10	3	3	2	9	10	3	3	3
Trip duration (h)	16.4±9.0 (5)	15.9±5.4 (5)	14.4±6.8 (9)	16.0±8.5	18.9±7.3	10.6±0.6	13.5±5.4 (5)	13.6±6.6	8.1±4.8	12.5±0.7	43.0±11.7
Foraging range (km)	14.4±7.2	15.5±8.7	12.4±6.1	-	15.8±4.9	12.0±1.2	13.3±8.1	10.2±6.6	-	11.7±4.8	55.4±6.2
Distance travelled (km)	-	-	-	-	51.5±18.8	27.9±2.4	-	-	-	37.0±5.1	139.9±26.3
Diving Parameters											
No of Birds (n)	-	-	8	?***	3	**	-	3	?	3	3
Number of dives per trip	-	-	254*	?	355±172	-	-	-	-	246±39	890±330
Proportion of benthic dives (%)	-	-	-	-	67.2±11.1	-	-	-	-	88.6±0.6	33.8±20.5
Mean dive duration (s)	-	-	-	-	107.7±30.1	-	-	-	-	120.2±0.8	95.6±14.2
Max depth reached (m)	-	-	66.2	?	75.9±15.0	-	-	127.9	-	43.4±6.4	62.7±4.9
Reference	(1) (2)	(1) (2)	(1) (2)	(1)	(3)	-	(1) (2)	(1) (2)	(1)	(4)	(4)

* Data recorded at Ryan's Beach & Pipikaretu, Northern Otago Peninsula

** Dive sensor failed during both deployments

*** Moore et al. (1995) do not distinguish between the two seasons and only provide pooled results of TDR deployments.

(1) Moore (1999), (2) Moore et al (1995), (3) Mattern, unpublished data, (4) Mattern (2006)

Table 4.1b Foraging parameters of yellow-eyed penguins determined during the **chick-guard stage** of breeding.

	Otago Peninsula					North Otago		Stewart Island		Codfish Island	
	1991/92	1992/93	1993/94	2004/05	2005/06	2003/04**	2004/05	2005/06	2006/07	2005/06	2006/07
Foraging Parameters											
No of Birds (n)	52	53	26	8	2	4	4	4	6	6	9
Trip duration (h)	14.4±17.0	13.3±5.9	12.8±7.9	16.9±5.5	9.4±6.4	8.0±4.5 (7)	12.9±1.2	8.9±2.3	8.7±2.5	17.1±2.4	22.2±12.0
Foraging range (km)	-	15.4±6.9	15.6±6.3	25.8±4.3	9.9±6.9	12.2±6.9	18.2±1.1	9.1±5.1	10.9±1.6	24.3±4.8	34.2±18.3
Distance travelled (km)	-	-	-	63.0±10.6	31.1±23.1	31.5±18.0	46.0±3.0	29.5±1.0	31.4±9.5	66.9±9.5	87.4±47.3
Diving Parameters											
No of Birds (n)	-	-	-	9	1*	7	5	4	6	6	9
Number of dives per trip	-	-	-	282±86	*218±116.3*	180.9±79.4	286±66	187±72	180±74	351±77	520±365
Proportion of benthic dives (%)	-	-	-	57.8±7.8	*40.2±13.1*	80.3±11.1	91.5±2.1	75.0±3.7	78.1±8.7	63.4±14.7	47.8±16.1
Mean dive duration (s)	-	-	-	110±13	*71.9±12.0*	100.0±14.4	112.6±13.5	128.1±7.2	103.3±6.8	114.9	95.0±18.3
Max depth reached (m)	-	-	-	71.4±12.4	*71.9±12.0*	20.3±4.4	38.4±8.2	37.6±20.9	45.8±8.6	63.4±2.7	64.3±3.5
Reference	(1)	(1)	(1)	(3)	(3)	(2) (3)	(2) (3)	(3) (4)	(3)	(3) (4)	(3)

* Dive sensor failed during second deployment; dive parameters represent the individual means for bird 14647 which undertook threeforaging trips while fitted with GPS logger. The bird's trips were reasonably short (mean foraging range: 13.0±4.2km, distance travelled: 38.4±21.6km, trip duration: 7.9±4.2 hrs).

** Combined data of evening (trip duration <5 hrs) and full one-day trips (>9 hours) of yellow-eyed penguins equipped with GPS Logger (n=4 birds) and TDR deployments (n=3 birds). See Mattern et al (2007) for details on trip types. No evening trips were observed in 2004/05.

(1) Moore (1999) , (2) Mattern et al (2007), (3) Mattern, unpublished data, (4) Mattern (2006)

Table 4.2 Diet composition of yellow-eyed penguins. %FO describes the frequency of occurrence of prey species in all samples. % Weight gives the calculated average mass contribution of a prey species to the mean meal size.

Prey species	Habitat	Otago				Codfish Island				Stewart Island	
		1984-1986 n=512		1991-1993 n=198		1988 n=22		2006/07 n=17		2006/07 n=8	
		% FO	% Weight	% FO	% Weight	% FO	% Weight	% FO	% Weight	% FO	% Weight
Red cod *Pseudophycis bachus*	demersal*	47	36	45.5	7.4	86	<1	-	-	-	-
Opalfish *Hemerocoetes spp.*	demersal	44	22	78.3	27.6	45	20	50	27.5	-	-
Arrow squid *Nototodarus sloani*	pelagic-oceanic**	47	9	59.6	14.4	36	<1	20	0.9	-	-
Sprat *Sprattus antipodum*	pelagic-neritic	67	12	34.8	2.2	<1	<1	10	1.5	-	-
Ahuru *Auchenoceros punctatus*	pelagic-oceanic	17	7	13.6	4.8	100	<1	-	-	-	-
Blue cod *Parapercis colias*	demersal	6	2	54.5	18.3	50	77	70	70	100	99.2
Silverside *Argentinas elongata*	demersal	15	6	40.9	10.0	<1	<1	-	-	-	-
Jock Stewart *Helicolenus percoides*	demersal	-	-	-	-	-	-	10	<1	-	-
Tarakihi *Nemadactylus macropterus*	demersal	39.4	2.3			-	-	-	-	33	0.8
Reference		(1)		(2)		(3)		(4)		(4)	

* juvenile stages are also pelagic

** Often overlooked is the diel vertical migration of squid in which the animals descend to greater depths during the day. Over the continental shelf this brings them into the demersal zone (Roper & Young 1975)

(1) van Heezik (1990), (2) Moore & Wakelin (1997), (3) van Heezik (1990b), (4) Browne et al (2011)

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**	

Figure captions

Figure 1.1 Map of the current global distribution of yellow-eyed penguins *Megadyptes antipodes*. Inserts show in more detail the distribution of the mainland population in four distinct breeding regions on the New Zealand South Island (Banks Peninsula, North Otago, Otago Peninsula, and the Catlins).

Figure 1.2 Map of the current global distribution of yellow-eyed penguins *Megadyptes antipodes*. Inserts show in more detail the distribution of the mainland population on Stewart Island and outliers, as well as the sub-Antarctic populations on Campbell Island, based on landing sites found in 1988 and 1992 (adapted from Moore et al. 2001), and 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).

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 (adapted from Seddon et al. *in press* – and updated).

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).

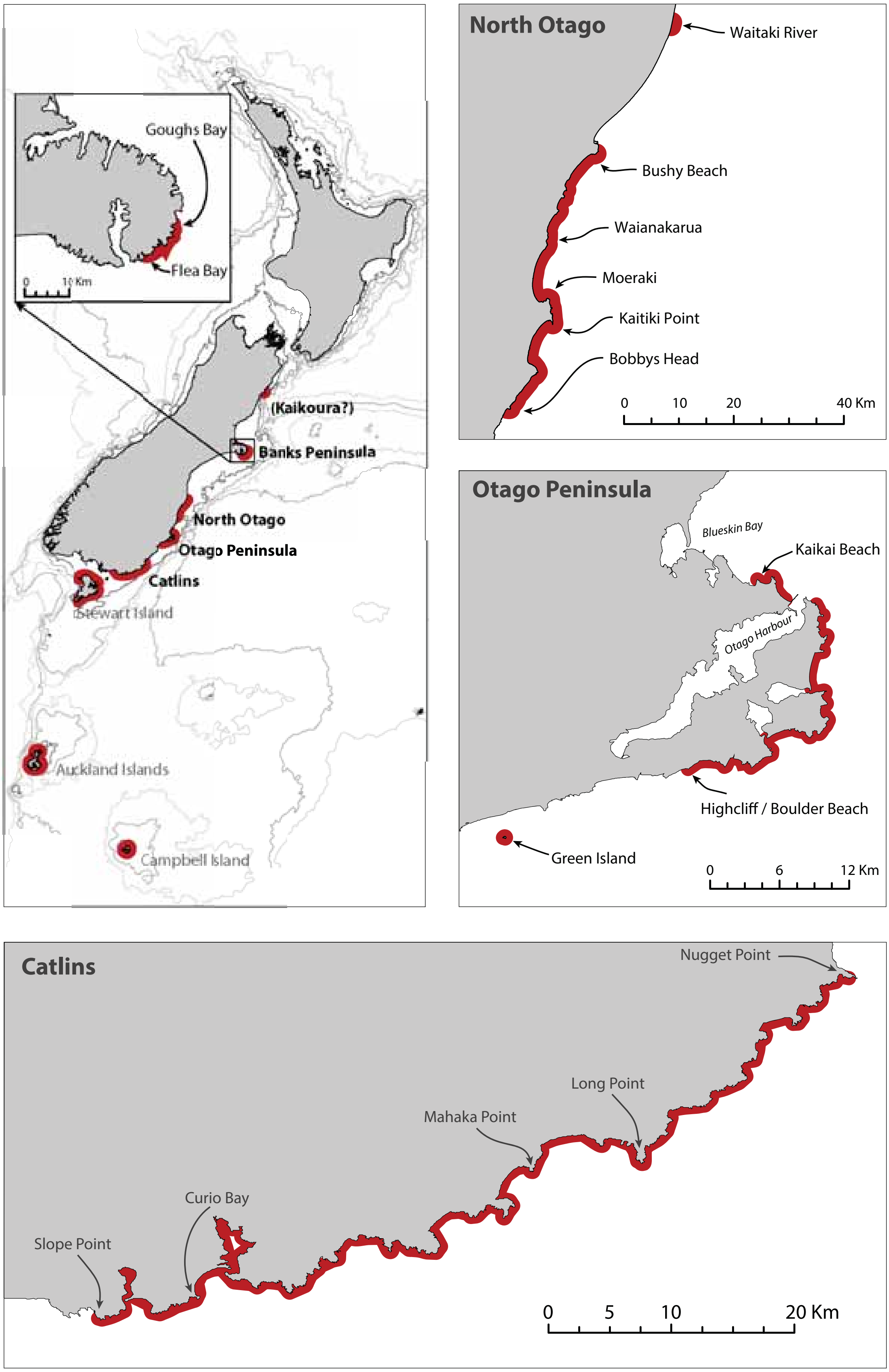
Figure 2.5 Number of yellow-eyed penguin breeding pairs observed 1992-2011 in the Catlins, New Zealand South Island, in five breeding areas that were considered to provide the most reliable and consistent nest count data; solid line depicts linear regression analysis of population trends, dashed lines are 95% confidence intervals. Additionally, the results of the complete Catlins census established in 1997 to take place about every five years has been included into the figure. (Data provided by the Department of Conservation, Coastal Otago Area Office; Appendix I).

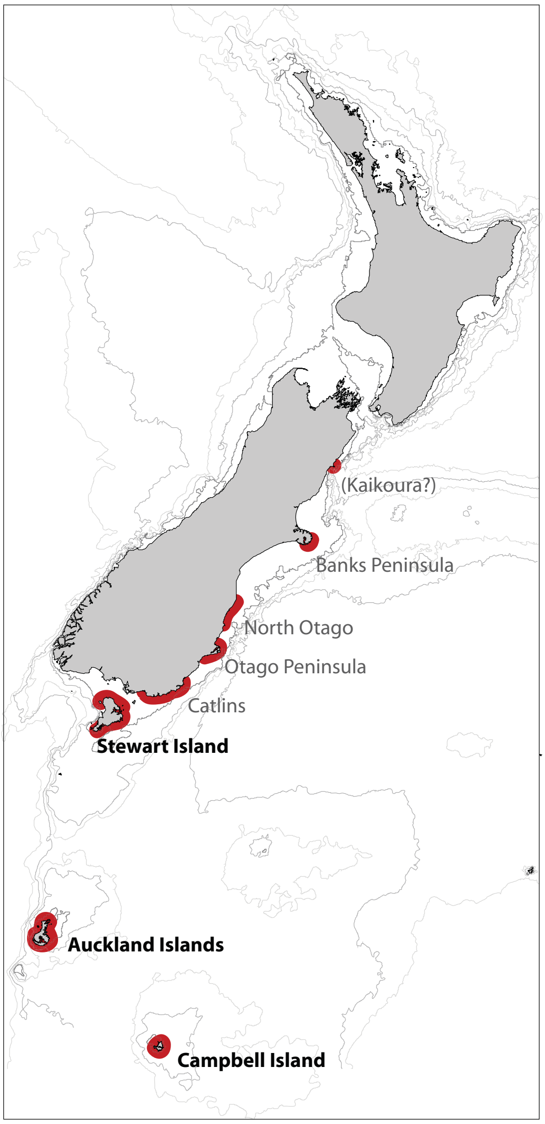
Figure 3.1 Bar plot displaying frequencies of the number of chicks fledged in their lifetime (LRS) by female (n = 107) and male (n = 102) yellow-eyed penguins breeding at Boulder Beach, Otago Peninsula, New Zealand, from Stein (2012).

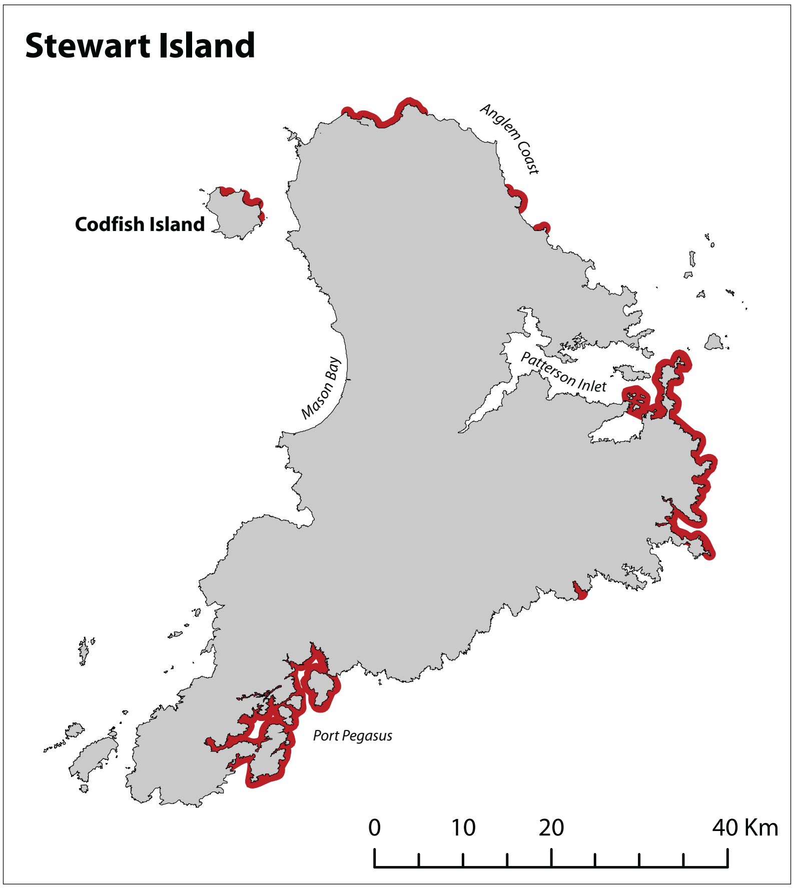
Figure 4.1 Benthic diving behaviour in Yellow-eyed penguins. The three graphs show the dive profiles of all dives performed during a single foraging trip (upper graph), a section of about 30 minutes (centre graph), and the profile of an individual dive (lower graph). The red shaded areas in the upper and centre graph indicate temporal position of the lower graph's dive. Note the single mid-water dive (fourth dive) in the centre graph.

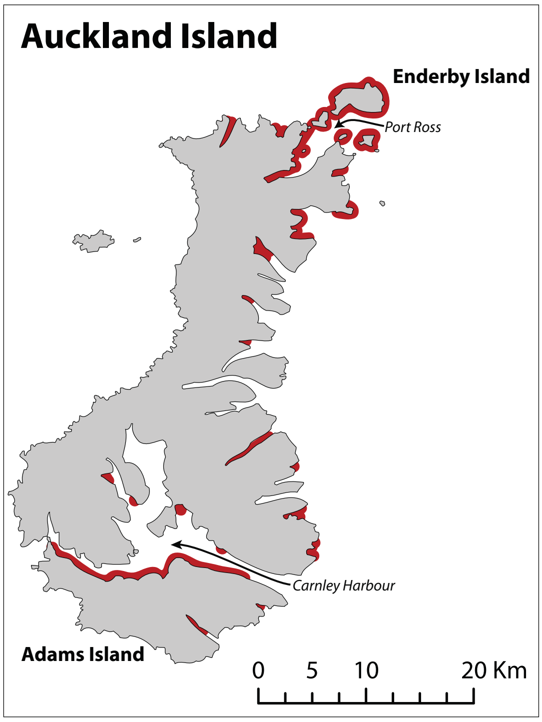
Figure 4.2 Foraging ranges of Yellow-eyed penguins determined via VHF telemetry (blue polygons; Moore et al. 1995, Moore 1999) and GPS logger deployments (green polygons, Mattern et al. 2007, Mattern unpublished data).

Figure 4.3 Estimated foraging ranges of Yellow-eyed penguins.


Goughs Bay
Flea Bay
(Kaikoura?)
Banks Peninsula
North Otago
Otago Peninsula
Catlins
Stewart Island
Auckland Islands
Campbell Island
North Otago
Waitaki River
Bushy Beach
Waianakarua
Moeraki
Kaitiki Point
Bobbys Head
0 10 20 40 Km
Otago Peninsula
Blueskin Bay
Kaikai Beach
Otago Harbour
Highcliff / Boulder Beach
Green Island
0 6 12 Km
Catlins
Nugget Point
Long Point
Mahaka Point
Curio Bay
Slope Point
0 5 10 20 Km


(Kaikoura?)
Banks Peninsula
North Otago
Otago Peninsula
Catlins
Stewart Island
Auckland Islands
Campbell Island


Stewart Island
Anglem Coast
Codfish Island
Mason Bay
Patterson Inlet
Port Pegasus
0
10
20
40 Km


Auckland Island
Enderby Island
Port Ross
Carnley Harbour
Adams Island
0
5
10
20 Km

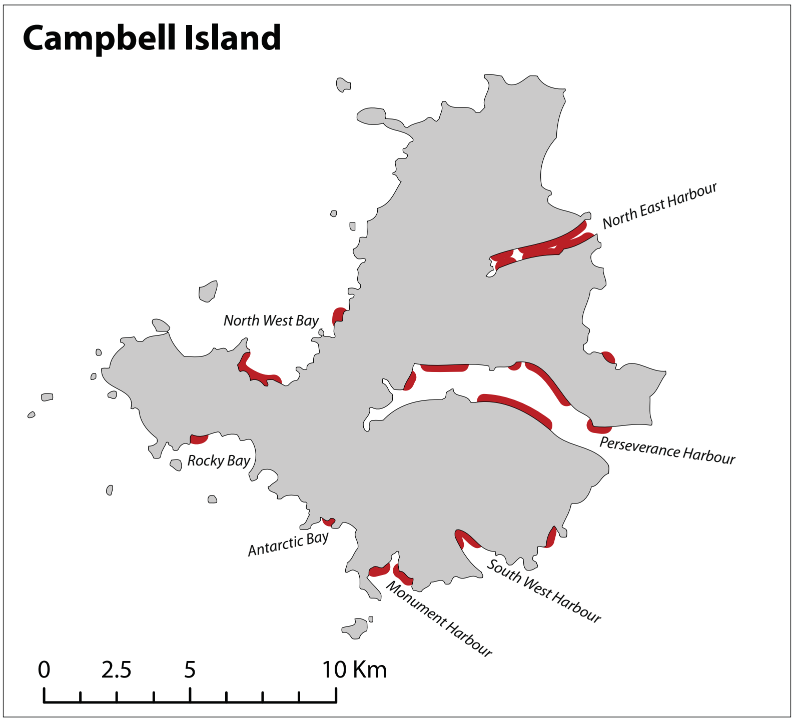
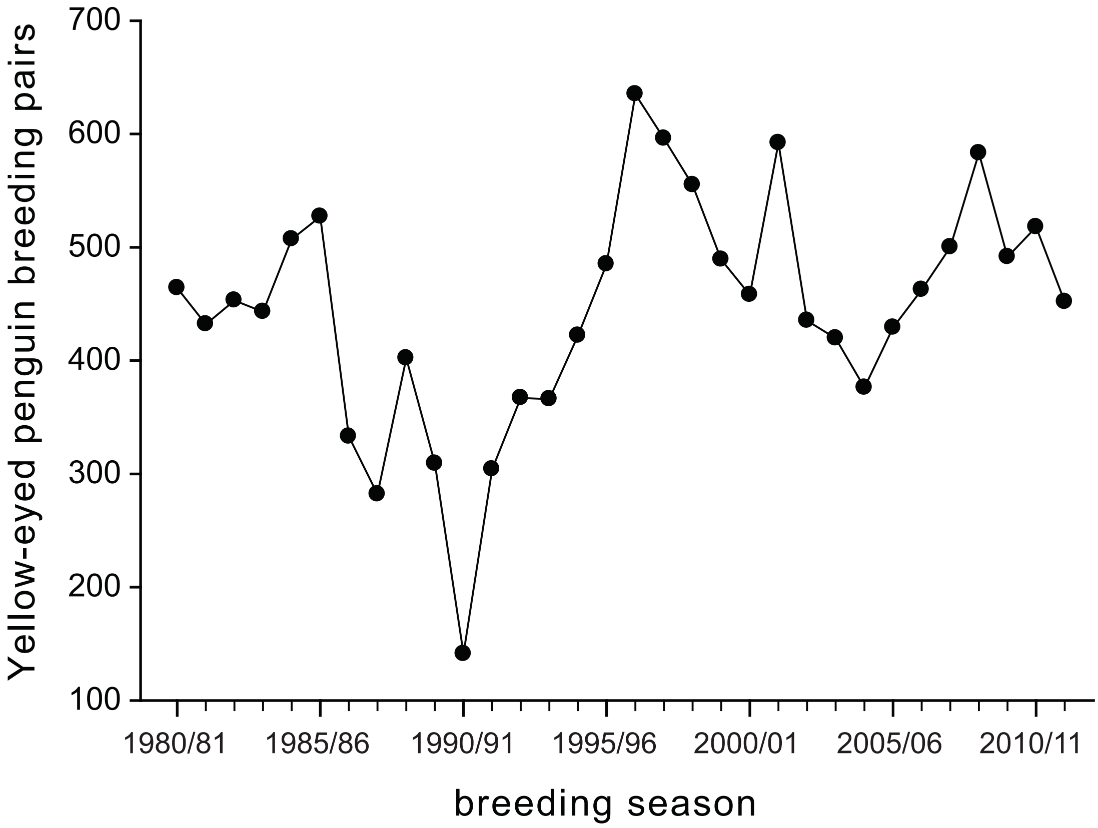
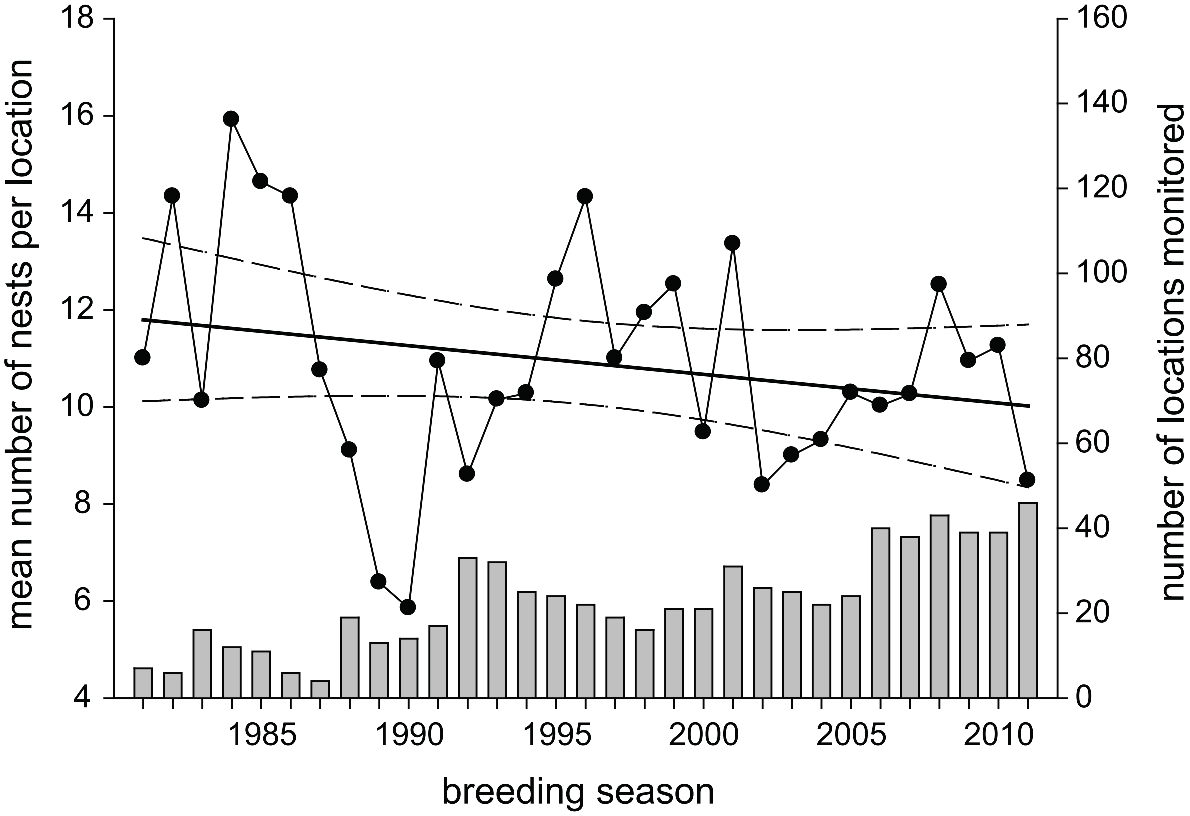

Campbell Island
North East Harbour
North West Bay
Rocky Bay
Perseverance Harbour
Antarctic Bay
South West Harbour
Monument Harbour
0
2.5
5
10 Km

Figure 2.1



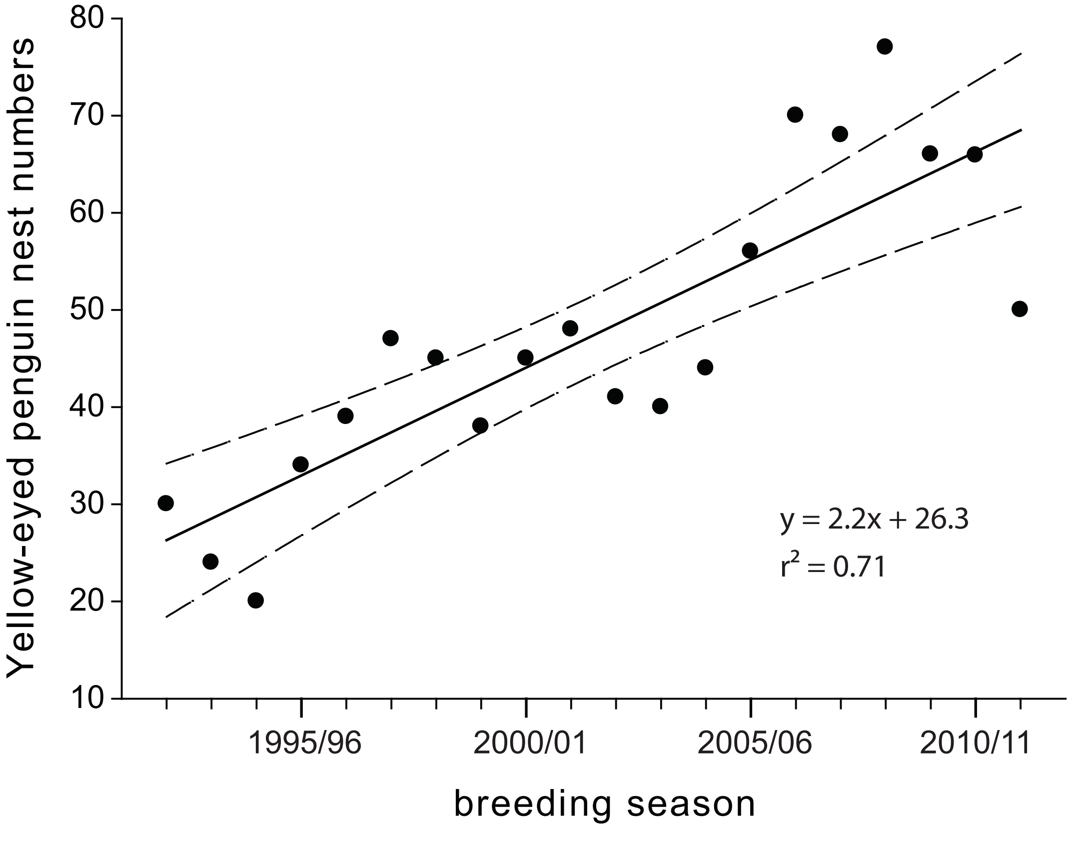
700
600
500
400
300
200
100
Yellow-eyed penguin breeding pairs
1980/81
1985/86
1990/91
1995/96
2000/01
2005/06
2010/11
breeding season

Figure 2.2



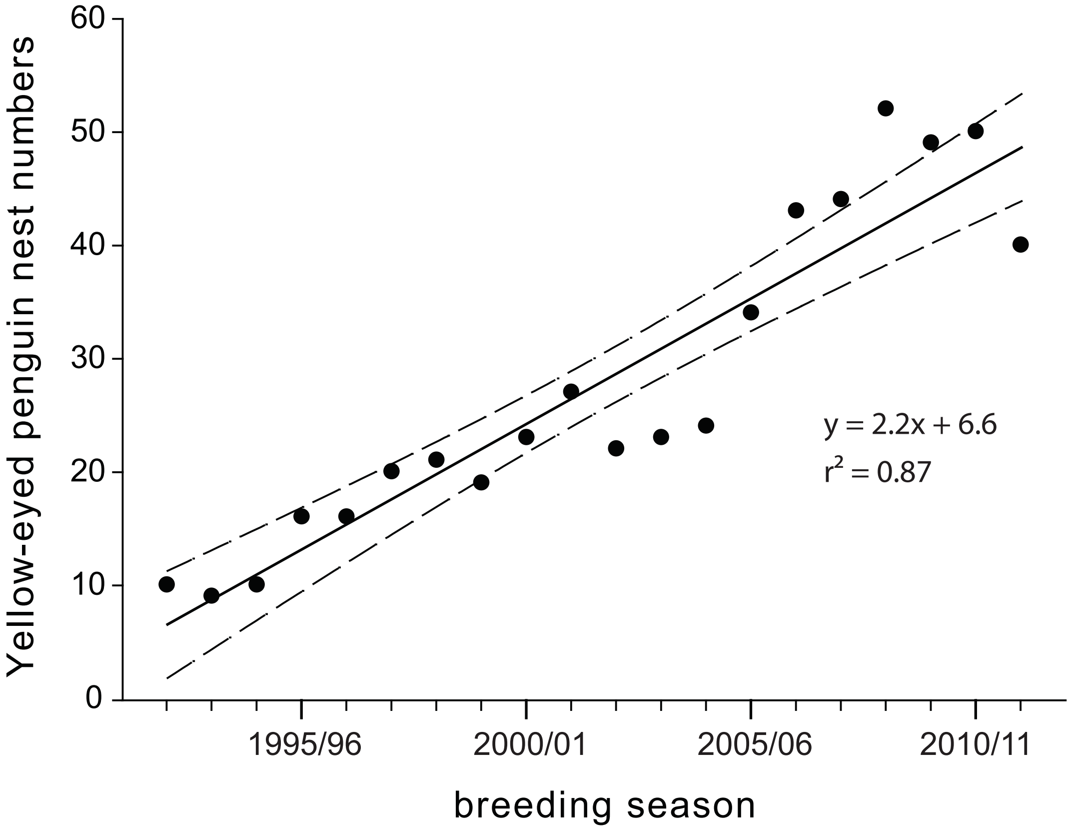
18
16
14
12
10
8
6
4
160
140
120
100
80
60
40
20
0
mean number of nests per location
number of locations monitored
1985
1990
1995
2000
2005
2010
breeding season

Figure 2.3a



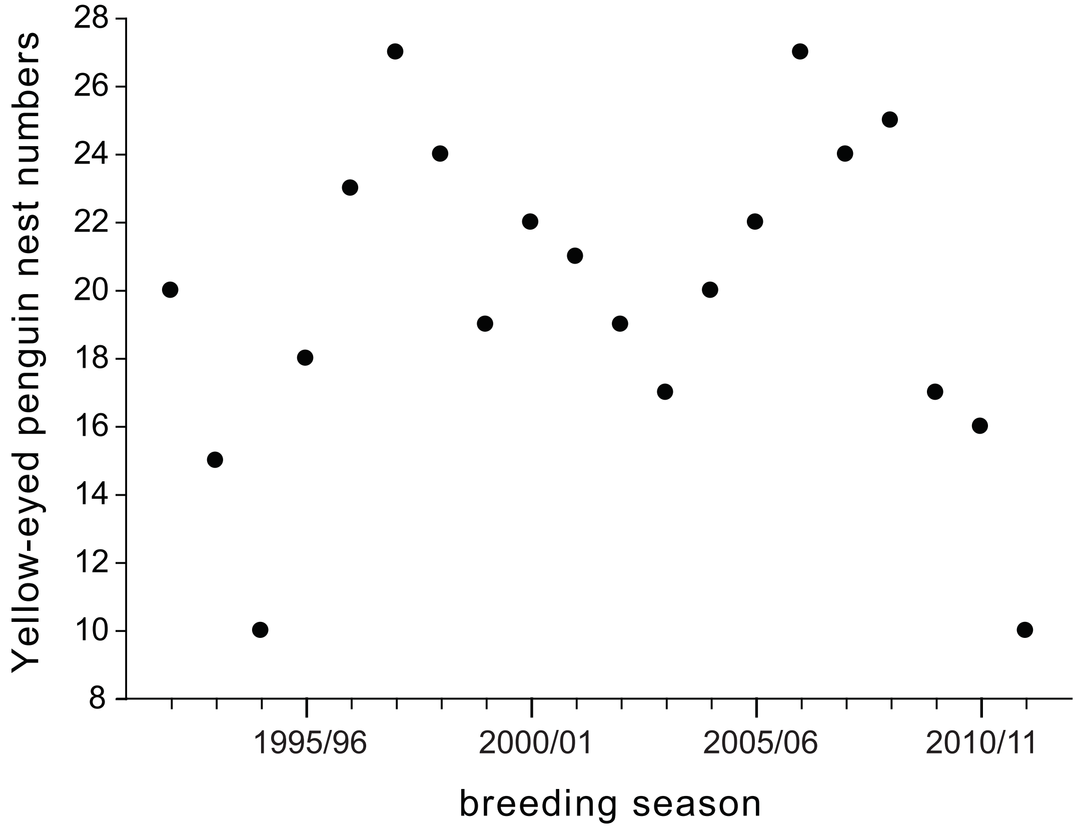
80
70
60
50
40
30
20
10
Yellow-eyed penguin nest numbers
y = 2.2x + 26.3
r² = 0.71
1995/96
2000/01
2005/06
2010/11
breeding season

Figure 2.3b



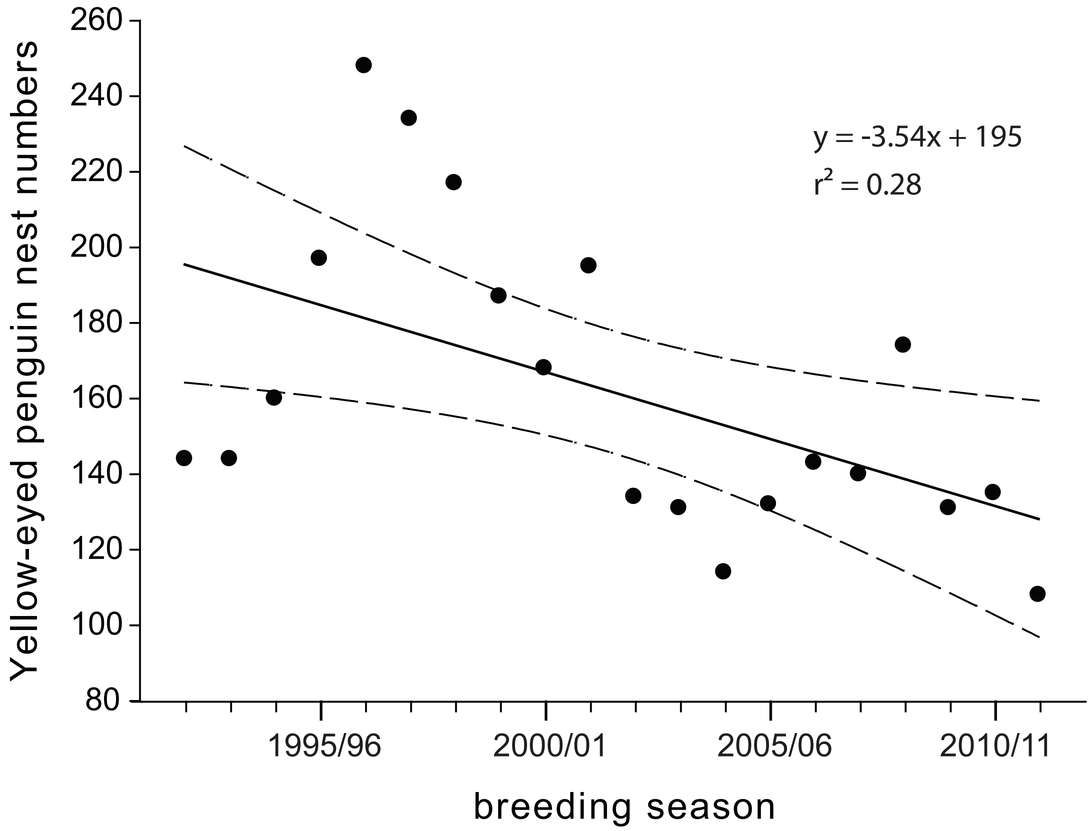
60
50
40
30
20
10
0
Yellow-eyed penguin nest numbers
y = 2.2x + 6.6
r2 = 0.87
1995/96
2000/01
2005/06
2010/11
breeding season

Figure 2.3c



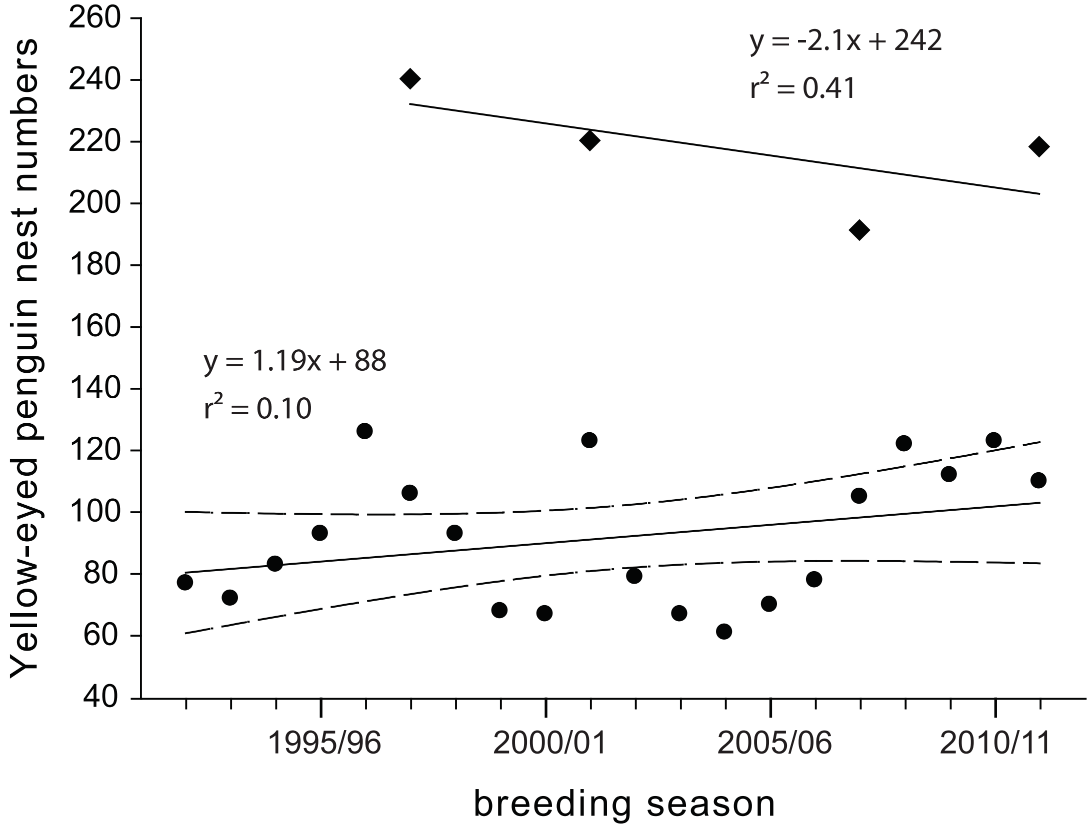
Yellow-eyed penguin nest numbers
28
26
24
22
20
18
16
14
12
10
8
1995/96
2000/01
2005/06
2010/11
breeding season

Figure 2.4



Yellow-eyed penguin nest numbers
260
240
220
200
180
160
140
120
100
80
y = -3.54x + 195
r² = 0.28
1995/96
2000/01
2005/06
2010/11
breeding season

Figure 2.5



Yellow-eyed penguin nest numbers
260
240
220
200
180
160
140
120
100
80
60
40
y = -2.1x + 242
r² = 0.41
y = 1.19x + 88
r² = 0.10
1995/96
2000/01
2005/06
2010/11
breeding season

Figure 3.2

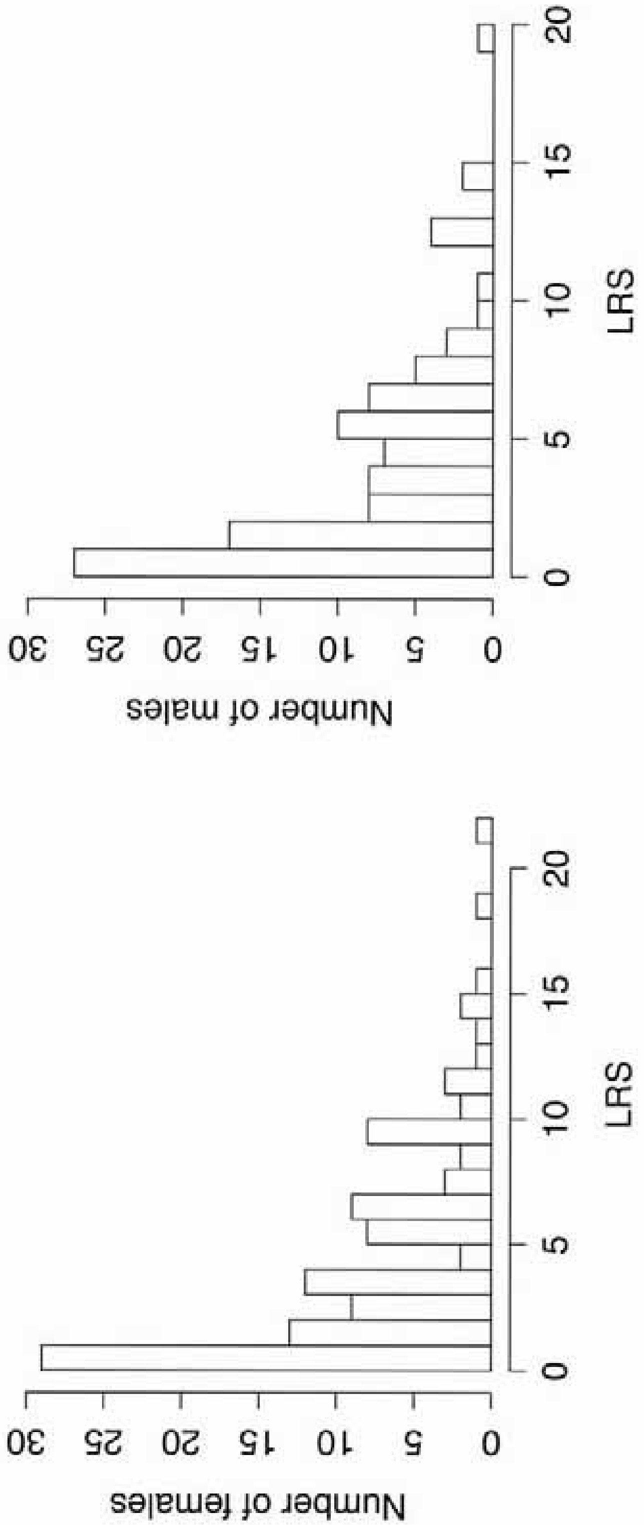
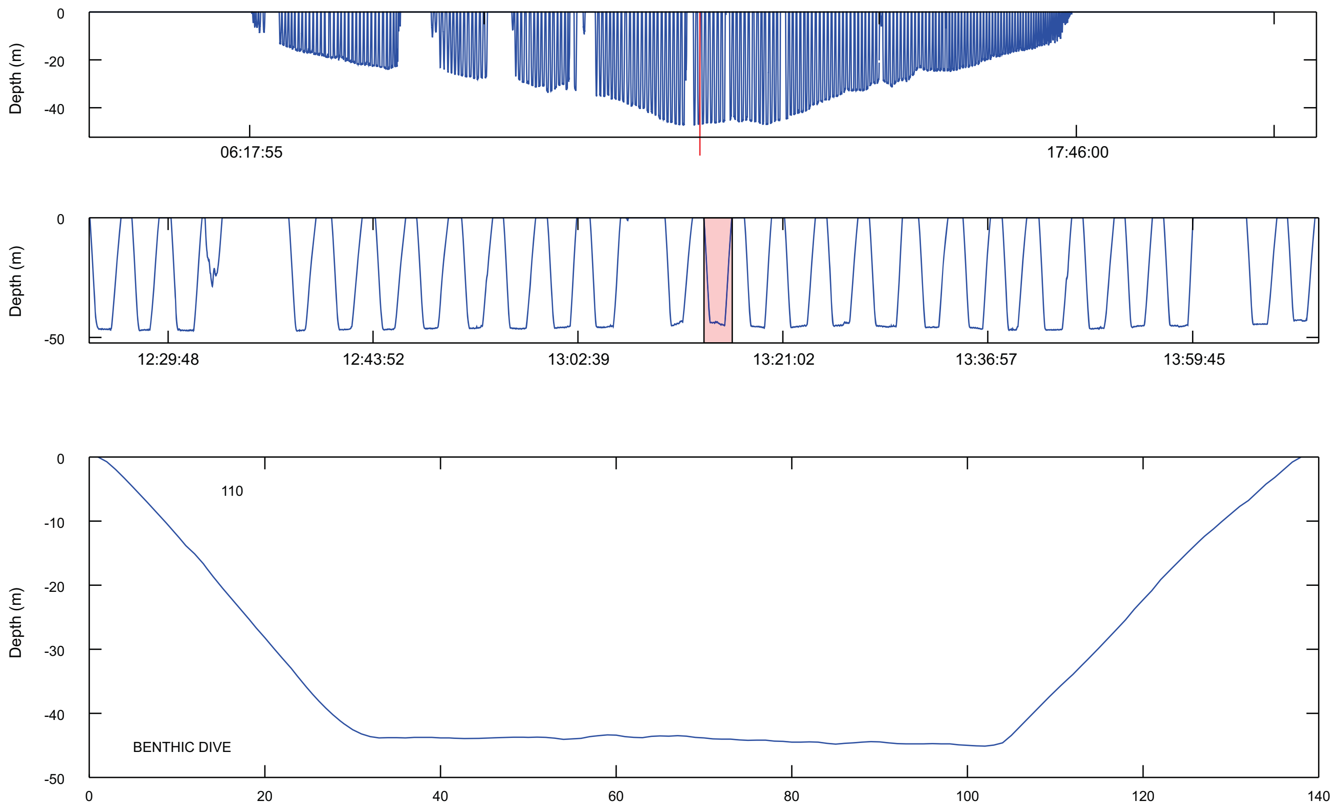
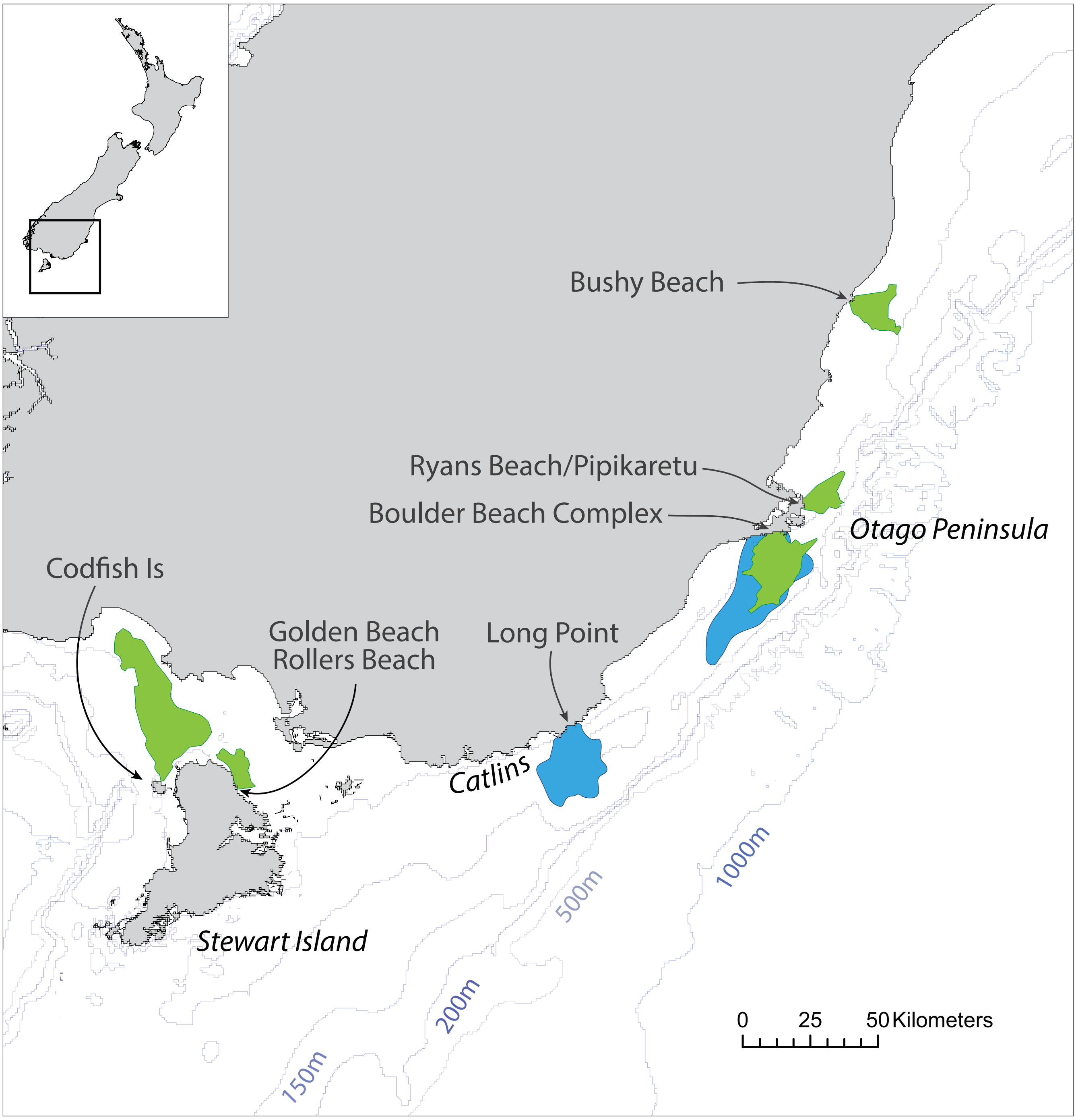


Figure 4.1



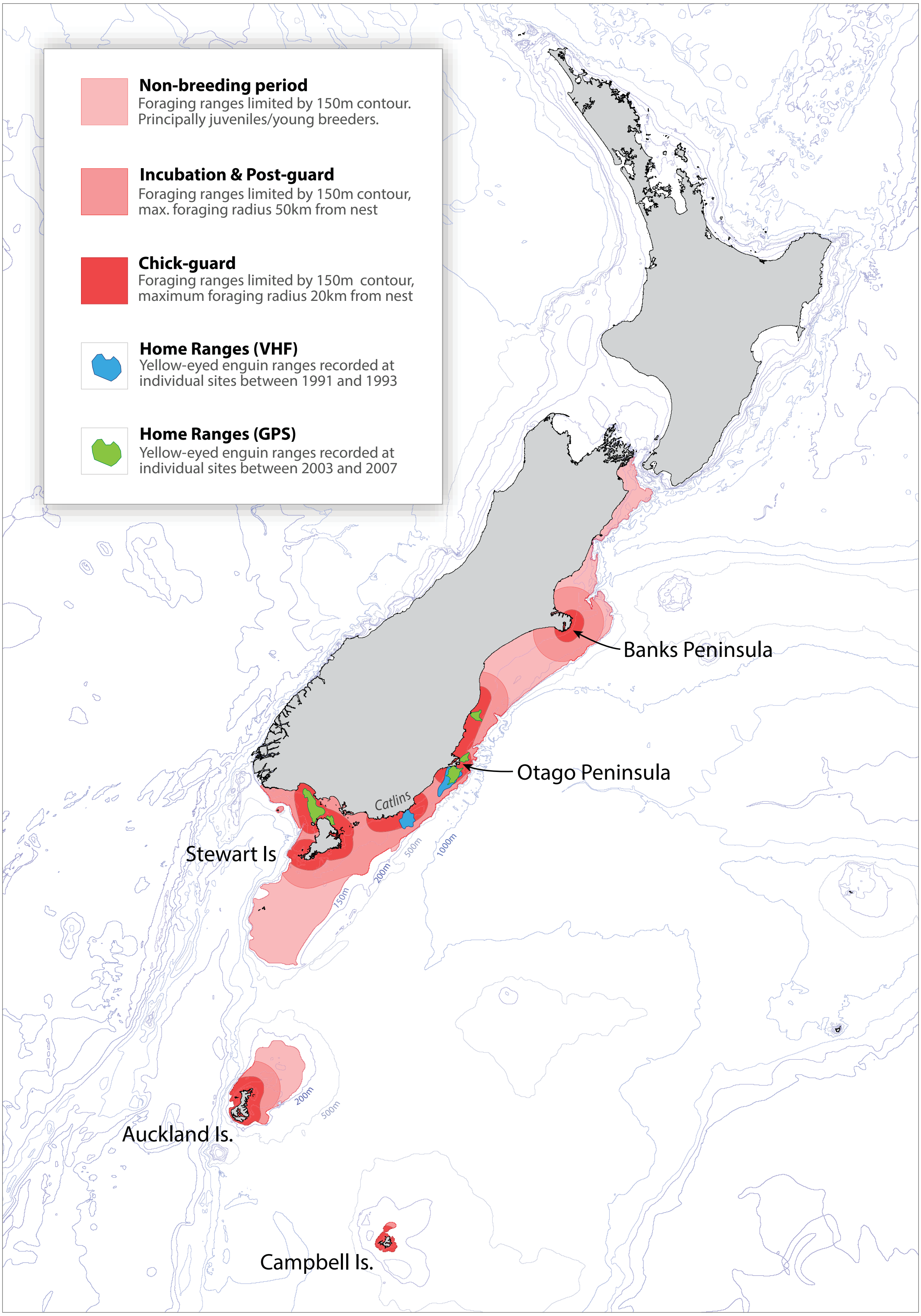
Depth (m)
0
-20
-40
06:17:55
17:46:00
Depth (m)
0
-50
12:29:48
12:43:52
13:02:39
13:21:02
13:36:57
13:59:45
Depth (m)
0
-10
-20
-30
-40
-50
110
BENTHIC DIVE
0
20
40
60
80
100
120
140

Figure 4.2



Bushy Beach
Ryans Beach/Pipikaretu
Boulder Beach Complex
Otago Peninsula
Codfish Is
Golden Beach
Rollers Beach
Long Point
Catlins
Stewart Island
1000m
500m
200m
150m
0 25 50 Kilometers

Figure 4.3



Non-breeding period
Foraging ranges limited by 150m contour. Principally juveniles/young breeders.
Incubation & Post-guard
Foraging ranges limited by 150m contour, max. foraging radius 50km from nest
Chick-guard
Foraging ranges limited by 150m contour, maximum foraging radius 20km from nest
Home Ranges (VHF)
Yellow-eyed enguin ranges recorded at individual sites between 1991 and 1993
Home Ranges (GPS)
Yellow-eyed enguin ranges recorded at individual sites between 2003 and 2007
Banks Peninsula
Otago Peninsula
Catlins
Stewart Is
150m
200m
500m
1000m
Auckland Is.
Campbell Is.

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Yellow-eyed penguin nest numbers in Otago, New Zealand South Island, during the breeding seasons 1992/93-2011/12
at a selection of breeding sites that have been monitored with reasonably comparable effort and nest search experience consistently over 20 years
(This nest summary spreadsheet is maintained by the Department of Conservation Coastal Otago Area Office)

		Breeding Area	1992/93	1993/94	1994/95	1995/96	1996/97	1997/98	1998/99	1999/00
North Otago	(all breeding areas)	Bushy Beach	3	4	3	6	7	8	8	5
		Beach Road	2	1	0	0	1	1	2	0
		Waianakarua Bluff	2	3	1	3	4	5	3	5
		Barracouta Bay	9	8	9	12	13	13	14	12
		Katiki Point	1	1	1	4	3	7	7	7
		Katiki Beach	7	2	1	3	3	3	3	2
		Shag Point	1	2	2	2	2	4	5	4
		Tavora (Bobbys Head)	5	3	3	4	6	6	3	3
Otago Peninsula	(10 of 21 considered reliable)	Omihi	4	4	4	4	4	5	4	4
		Pipikaretu Beach	26	25	26	32	37	36	35	22
		Ryans Beach	20	16	21	25	34	34	27	21
		Okia	12	7	11	12	17	15	15	8
		Otapahi	5	6	8	5	11	18	17	19
		Sandfly Bay	15	13	16	23	24	22	19	19
		Double Bay	14	18	19	25	28	17	17	15
		Mid-section	21	24	26	37	43	39	40	35
		A1	11	13	12	14	25	22	19	22
		Highcliff	16	18	17	20	25	26	24	22
Catlins	(5 of 24)	Nugget Point	10	8	10	10	25	13	14	7
		Owaka Heads	7	7	8	11	11	17	8	15
		Penguin Bay	14	16	15	17	22	16	22	19
		Hinahina Cove	14	5	12	13	21	12	10	9
		Long Point	32	36	38	42	47	48	39	18

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Yellow-eyed penguin nest numbers in Otago, New Zealand South Island, during the breeding seasons 1992/93-2011/12
at a selection of breeding sites that have been monitored with reasonably comparable effort and nest search experience consistently over 20 years
(This nest summary spreadsheet is maintained by the Department of Conservation Coastal Otago Area Office)

	Breeding Area	2000/01	2001/02	2002/03	2003/04	2004/05	2005/06	2006/07	2007/08
North Otago (all breeding areas)	Bushy Beach	6	6	7	7	7	10	11	12
	Beach Road	1	1	1	1	1	1	1	1
	Waianakarua Bluff	4	3	5	4	5	4	2	3
	Barracouta Bay	12	15	12	11	10	13	18	18
	Katiki Point	11	12	10	12	14	21	25	26
	Katiki Beach	3	1	2	2	4	3	3	1
	Shag Point	3	7	1	0	2	1	7	5
	Tavora (Bobbys Head)	5	3	3	3	1	3	3	2
Otago Peninsula (10 of 21 considered reliable)	Omihi	4	5	4	1	2	3	2	4
	Pipikaretu Beach	27	32	19	18	15	22	19	20
	Ryans Beach	20	26	22	11	3	8	7	7
	Okia	4	10	8	10	6	9	14	17
	Otapahi	19	24	20	21	20	22	18	22
	Sandfly Bay	12	16	9	10	10	12	9	8
	Double Bay	14	16	13	18	16	14	19	14
	Mid-section	31	31	15	13	13	16	21	16
	A1	15	15	9	13	14	12	18	16
	Highcliff	22	20	15	16	15	14	16	16
Catlins (5 of 24)	Nugget Point	9	23	13	14	10	9.5	12	15
	Owaka Heads	8	13	9	4	4	8	5	7
	Penguin Bay	23	24	17	16	14	18	20	26
	Hinahina Cove	9	12	9	7	8	9	14	18
	Long Point	18	51	31	26	25	25	27	39

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Yellow-eyed penguin nest numbers in Otago, New Zealand South Island, during the breeding seasons 1992/93-2011/12
at a selection of breeding sites that have been monitored with reasonably comparable effort and nest search experience consistently over 20 years
(This nest summary spreadsheet is maintained by the Department of Conservation Coastal Otago Area Office)

Region		Breeding Area	2008/09	2009/10	2010/11	2011/12	data reliability?
North Otago	(all breeding areas)	Bushy Beach	9	6	7	5	data trustworthy - include into analysis
		Beach Road	2	1	0	0	data trustworthy - include into analysis
		Waianakarua Bluff	6	4	3	2	data trustworthy - include into analysis
		Barracouta Bay	22	23	23	22	data trustworthy - include into analysis
		Katiki Point	30	26	27	18	data trustworthy - include into analysis
		Katiki Beach	2	1	1	1	data trustworthy - include into analysis
		Shag Point	5	2	1.9	0	data trustworthy - include into analysis
		Tavora (Bobbys Head)	1	3	3	2	data trustworthy - include into analysis
Otago Peninsula	(10 of 21 considered reliable)	Omihi	6	5	6	4	data trustworthy - include into analysis
		Pipikaretu Beach	26	12	15	10	data trustworthy - include into analysis
		Ryans Beach	10	9	6	4	data trustworthy - include into analysis
		Okia	17	14	16	12	data trustworthy - include into analysis
		Otapahi	31	22	23	18	data trustworthy - include into analysis
		Sandfly Bay	15	8	10	8	data trustworthy - include into analysis
		Double Bay	17	12	11	10	data trustworthy - include into analysis
		Mid-section	18	16	19	16	data trustworthy - include into analysis
		A1	16	12	10	9	data trustworthy - include into analysis
		Highcliff	18	21	19	17	data trustworthy - include into analysis
Catlins	(5 of 24)	Nugget Point	21	24	16	22	data +- (some issues) trustworthy - include into analysis
		Owaka Heads	9	6	8	8	data +- (some issues) trustworthy - include into analysis
		Penguin Bay	29	30	32	19	data +- (some issues) trustworthy - include into analysis
		Hinahina Cove	16	13	18	12	data +- (some issues) trustworthy - include into analysis
		Long Point	47	39	49	49	data +- (some issues) trustworthy - include into analysis