

Rockhopper Penguins
A Plan for Research and Conservation
Action to Investigate and Address
Population Changes

Proceedings of an
International Workshop
Edinburgh
3–5 June 2008



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Acronyms

APF	Antarctic Polar Front
APMS	Automated Penguin Monitoring System
BAS	British Antarctic Survey
CONICET	Consejo Nacional de Investigaciones Científicas y Técnicas (Argentina)
CPUE	Catch Per Unit Effort
EAZA	European Association of Zoos and Aquaria
EEZ	Exclusive Economic Zone
EIA	Environmental Impact Assessment
ESB	European Studbook
FAO	Food and Agriculture Organisation
FC	Falklands Conservation
FICZ	Falklands Interim Conservation Zone
FIG	Falkland Islands Government
FL	Feather Link
FOCZ	Falklands Outer Conservation Zone
GBP	Great Britain Pounds
GPS	Global Positioning System
HAB	Harmful Algal Bloom
IUU	Illegal, Unreported and Unregulated (Fishing)
K	Thousand
MT	Metric tonnes
NICT	New Island Conservation Trust
NIWA	National Institute for Water and Atmospheric Research Ltd.
PIT	Passive Integrated Transponder
PSP	Paralytic Shellfish Poisoning
RFID	Radio Frequency Identification
RSPB	Royal Society for the Protection of Birds
RZSS	Royal Zoological Society of Scotland
SAP	Species Action Plan
SST	Sea Surface Temperature
TCD	Tristan Conservation Department
TDR	Time Depth Recorder
TIRIS	Texas Instruments Registration and Identification System
USD	United States Dollars
VHF	Very High Frequency
WCS	Wildlife Conservation Society

English and Spanish nomenclature

English name	Spanish name
Falkland Islands	(Malvinas)
Staten Island	(Isla de los Estados)
South Georgia	(Islas Georgias del Sur)

This document contains references to the Falkland Islands (Malvinas), which are the object of a sovereignty dispute between the Argentine Republic and the United Kingdom of Great Britain.

SECTION A: INTRODUCTION

1. Aim of the Workshop

The overarching objective for this Workshop was to develop research and conservation action for the northern and southern rockhopper penguin *Eudyptes moseleyi* and *E. chrysocome*, respectively, in particular to investigate and address, where possible, population declines, with a focus on the South Atlantic region.

- Specific aims of the Workshop were to:
- Review status and trend data and where appropriate, comment on the existing Red List assessments for the northern and southern rockhopper penguin
- Identify the key actual and potential causes of historical and current population changes
- Develop Species Action Plans that identify how the key knowledge gaps and threats should be addressed, both in the short-medium term and into the future

2. Workshop structure and process

The International Rockhopper Penguin Workshop was hosted by the Royal Zoological Society of Scotland (RZSS) and held at Edinburgh Zoo, Scotland, from 3–5 June 2008. Twenty-one delegates from nine countries attended, a remarkable effort considering the distance travelled by a number of participants (most notably from Tristan da Cunha). A full list of participants is at Appendix 7, as well as the list of invited scientists who were not able to attend but have contributed to this Report.

The Workshop was divided into three sessions as outlined in the Workshop Programme (Appendix 7). Proceedings from each session are included in the Appendices to the Workshop Report. Key conclusions and recommendations from the Workshop are outlined in Section 2.

The Workshop started with an overview of the two rockhopper penguin species and their genetic structure and distribution boundaries, regional and global population trends, demography, oceanography, foraging and diet. This was followed by regional reviews for the northern and southern rockhopper penguin, with two reviews for the northern species (Tristan and Gough, and Amsterdam and St Paul) and five for the southern species (Argentina, Chile, Falkland Islands (Malvinas), breeding sites in the Pacific Ocean and breeding sites in the Indian Ocean).

In order to guide development of the Species Action Plans, a short presentation was given about available survey and research techniques (particularly of newly developed methods) and the overall population trends and existing Red List assessments were discussed.

Session Two of the Workshop covered the possible causes of the population decline. The importance and relevance of these threats were discussed, along with the research and management that would be required to better understand and reduce their impacts.

Session Three looked at the way forward for rockhopper penguin research and management at both regional and international levels. Priorities for action in four regional areas (Tristan da Cunha, Pacific Ocean, Chile and Patagonia) were prepared by regional representatives present at the Workshop. Actions required on international issues such as impacts of marine productivity, climate change and oceanography on rockhopper penguin populations, the need for more taxonomic research and how captive populations could be better utilised for research were identified.

Finally, participants discussed how best to progress beyond the Workshop, particularly involving the wider scientific community working on rockhopper penguins, reporting on progress, implementing improving and adapting action plans, obtaining funding and as appropriate, meeting again. A Steering Group was established to co-ordinate the reporting back of progress in 2009 and to plan future meetings.

3. Introduction to the Workshop Report

The aim of this Report is to provide an assessment of research and conservation action required to investigate and address population declines in southern and northern rockhopper penguins, both at a global and a regional scale.

Action has been split into a plan for international research and co-operation, which addresses threats common to both species, and regional plans for the northern rockhopper penguin in the Tristan and Gough region and for the southern rockhopper penguin in the Patagonian region, in the Pacific Ocean and in Chile.

To develop recommended action plans, participants presented and discussed the known information about the northern and southern rockhopper penguin. This included taxonomic status, regional population estimates, global trends and conservation status, demography, oceanography and foraging location, dive behaviour and diet (Section C). Processes that have the potential to threaten both species were considered and evaluated. The identified threats included land-based activities such as tourism, human depredation, predation, natural disasters, wildlife health, pollution and fisheries interactions; the roles of bottom-up physical processes and top-down competition and predation were assessed (Section D).

The key knowledge gaps and critical threats were identified and priority areas for research to better elucidate the gaps, and priority tasks to prevent and mitigate threatening process were identified and collated in an International Species Action Plan (Section E). To address the specific key knowledge gaps and threats at particular breeding sites, Regional Action Plans were also developed (Section E). These plans identify the key issues for each region and indicate in more detail how the activities would be undertaken by the organisations that work in that region.

To assist in assessing priorities, recommended activities in the action plans have been ranked according to their perceived urgency and importance. Some attempt has been made to estimate the resources required (both financial and time) to complete the tasks, although these are only intended as a rough guide and will need considerable refinement. The feasibility of proposed projects and any perceived constraints have also been noted to help guide decision-makers.

Implementation of the two action plans is detailed in Section F. It is hoped that both the International Action Plan and the four Regional Species Action Plans will help focus the activities of decision-makers and funding bodies and ensure that the key action tasks receive the highest level of attention and available funding. Implementing the key actions identified in the International Action Plan and the four Regional Species Action Plans should improve the global and regional conservation status of northern and southern rockhopper penguins.

The appendices to the report provide more detailed information about the status of both species and the environment in which they live (Appendix 1) and the processes that potentially threaten the long-term survival of populations (Appendix 2). Specific details for northern rockhopper penguin in its two geographic regions are presented in Appendix 3 and for the southern rockhopper penguin in five geographic areas in Appendix 4.

To help inform the choice of the most appropriate research methods, details of some emerging research techniques are included in Appendix 5.

SECTION B: WORKSHOP CONCLUSIONS AND RECOMMENDATIONS

The rockhopper penguin is currently recognised as two species: the northern rockhopper penguin *Eudyptes moseleyi* breeding at the temperate islands of the Tristan da Cunha/Gough Island group in the South Atlantic Ocean and at St Paul and Amsterdam Islands in the South Indian Ocean, and the southern rockhopper penguin *E. chrysocome*, which breeds at a variety of sub-Antarctic islands in the South Atlantic (*E. c. chrysocome*), South Indian and South Pacific Oceans (*E. c. filholi*).

Both species are important in sub-Antarctic zone, being top predators in the ocean and colonial breeders on coastal areas of the islands. They are also iconic species known to people around the world. Both historical and contemporary (post 1970) population declines have been documented for the northern and southern rockhopper penguin.

Workshop Results and Conclusions

1. A population estimate was produced for all known breeding sites

However, only at a few breeding sites can the most recent counts be considered 'current' (i.e. made within the last three years). For most sites of both species the most recent population estimate was made during the 1970s or 1980s. Notwithstanding, the best estimate of the present total population for northern rockhopper penguin is 240,000 breeding pairs and just over 1.23 million pairs for southern rockhopper penguin.

2. Population modelling showed that both species have exhibited significant declines

Over the past 37 years (= 3 generations), the number of northern rockhopper penguins has declined by 57%, while the number of southern rockhopper penguins has declined by 34%. Under the 2008 IUCN Red List Category, Birdlife International (2008) lists the northern rockhopper penguin as Endangered and southern rockhopper penguin as Vulnerable. Analysis of global trends provided strong support for retention of these classifications.

3. The lack of demographic data is a significant impediment to understanding conservation status and diagnosing causes of decline

It is not (yet) clear whether the ecological and demographic drivers of the current rockhopper penguin trends are the same as those that drove trends through the 20th century.

4. Eight potential causes of decline were identified

These were: tourism and land-based predation; pandemic disease; pollution; fisheries interactions; climate change causing a drop in primary productivity that reduces prey availability; climate change causing bottom-up food web shifts that reduce prey availability; top-down changes in food web structure leading to increased inter-specific competition; and top-down changes in food web structure leading to increased secondary predation.

5. These threats were examined and the result was inconclusive, largely due to the paucity of data

Overall, there is no strong support for any of the top-down or bottom-up global causes of rockhopper decline, but none of the hypotheses has been thoroughly tested. The assessment does suggest that no single factor, acting across all sites, is strongly supported by the evidence. It seems plausible that prey availability factors are likely involved at many sites, but that other causal factors may also be operating and may differ amongst sites.

6. An International Species Action Plan was drawn up

This addresses the key knowledge gaps (particularly related to taxonomy, global population, demography, foraging and diet, and whether some potential threats are actual threats) and suggests potential action against known critical threats common to both the northern and southern rockhopper penguin.

7. Regional Action Plans were developed to address knowledge gaps and threats at particular breeding sites

Regional plans were prepared for the northern rockhopper penguin at Tristan and Gough and for the southern rockhopper penguin in Patagonia, Chile and the Pacific Ocean. Due to the focus of the workshop being centred on the populations of northern and southern rockhopper penguin in the South Atlantic Ocean, no Species Action Plan was prepared for the Indian Ocean region.

Key Recommendations

1. Taxonomy

A comprehensive investigation of southern rockhopper penguin should be conducted using samples (including of DNA) of adequate size from several different sites within each region together with a re-examination of morphological and behavioural differences between populations. Any resulting revision of taxonomic status would require a reassessment of conservation status.

- Analysis of Chilean population to determine genetic variability at inter and intra population levels
- Penguin taxonomy to be resolved particularly for crested penguins endemic to New Zealand.

2. Populations

Accurate population estimates are needed throughout the species' ranges. Obtaining these estimates would represent an important first step in addressing rockhopper penguin conservation for many sites and regions.

- Conduct a global census in the 2010/11 breeding season to reevaluate the conservation status of rockhopper penguin.
- Conduct as a matter of urgency a census for Middle Island, and as a high priority at Gough, Tristan, Inaccessible, Nightingale Islands in the Tristan da Cunha Group, and estimate breeding success.
- Undertake a population survey and monitoring at Isla de los Estados (Patagonia).
- In the Falkland Islands (Malvinas), survey the rockhopper penguin population every 5 years and monitor annually.
- Determine site locations and complete site surveys along the coast of Chile as a matter of urgency.
- Analyse existing photo-point images for Campbell Island, census Campbell, Antipodes, Auckland and Macquarie Islands and use ground truth photographs to assist this process.

3. Demography

Long-term studies of individual birds are needed for both the northern and southern species to assess survival, age at first breeding and breeding frequency. Such studies should be conducted at sites where the population is stable/increasing, and at sites where the population is declining. Such work of necessity requires long-term commitment and funding. The lack of demographic data is a significant impediment to understanding conservation status and diagnosing causes of decline. Demographic studies should use Passive Integrated Transponder (PIT) tags for individual recognition of penguins in study colonies. An automated recording system, particularly with capacity to record weight, was regarded as a key tool for any demographic studies.

- Establish transponder tagged population on Tristan and/or Gough Island.
- Conduct demographic studies at Isla de los Estados (Patagonia).
- Ensure demographic research on New Island continues, and establish second site in the northern part of Falkland Islands (Malvinas).
- Establish tracking study at Isla de los Estados (Patagonia) in winter.
- Undertake track annual movements in Chile.

4. Oceanography

It is critically important to investigate spatial and temporal links between rockhopper population trends, sea surface temperature and primary productivity. This can be done using existing data, with the best information available for the Falkland Islands (Malvinas) and Marion Island (Indian Ocean).

5. Foraging and diet

More research is required to understand the links between foraging areas and diet, especially outside the breeding season. New technological devices that measure foraging behaviour and their attachment methods should be tested in captivity wherever possible.

- Track for summer feeding locations (Gough and Tristan populations) and winter locations.
- Collect penguin diet data at Gough (Tristan Group).
- Undertake diet and stable isotope sampling at Isla de los Estados (Patagonia).

6. Pandemic disease & poisoning

Relevant governments/administrations should consider establishing regular monitoring for plankton to detect future harmful algal blooms. Contingency response plans should be in place to cope with these. Where disease is suspected, samples should be taken for analysis and effects on the population determined.

- Wildlife health monitoring to be undertaken in the Falkland Islands (Malvinas).
- Wildlife health monitoring to be set up for Isla de los Estados (Patagonia).

7. Pollution

Lobby for vessels to uphold international pollution regulations and ensure stringent Environmental Impact Assessments for offshore developments (particularly hydrocarbon exploitation).

- Update Falkland Islands (Malvinas) oil contingency plan.
- Develop oil contingency plan for Isla de los Estados (Patagonia).

8. Fisheries

Competition between fisheries and rockhopper penguins should be investigated in all regions. Ensure that seine netting does not occur in rockhopper penguin foraging areas and that the effects on rockhopper penguins are taken into account when new fisheries are established.

9. Competition/predation

An assessment of the historical impact of removing whales and seals from the ecosystem and the effect this may have had on rockhopper penguins (and the recovery of fur seal and sea lion populations) should be undertaken. Pinniped/rockhopper penguin interactions need to be studied in more detail, including analyses of census data and pinniped predation rates on penguins.

- Obtain and analyse data on fur seal populations (Tristan Group).
- Assessment of goat impact at Isla de los Estados (Patagonia).

10. Implementation

Implementation of this Report will require acquisition of long-term funding, particularly to support demographic research, and international collaboration.

It was recommended that a follow-up Workshop should be held in 2010. To aid progress a Steering Group was established, initially consisting of Helen Otley and Petra Quillfeldt.

It was identified that zoos specialising in penguins offer an opportunity to develop a public understanding of the problems facing rockhopper penguins, provide opportunities to raise awareness about rockhopper penguin research and conservation and may enable research techniques and equipment to be tested.

SECTION C: SPECIES STATUS

This section of the Report summarises the key known information about the northern and southern rockhopper penguin, including in captive populations, and discusses the potential of using a number of recently developed techniques. More detailed information about the various aspects of the status of the northern and southern rockhopper penguin are found in Appendix 1 and research methods and techniques are further expanded on in Appendix 5. Regional reports for both species are found in Appendices 3 and 4 for the northern and southern rockhopper penguin, respectively.

1. Taxonomy and distribution

Two rockhopper penguin species are recognised: the northern species breeds at Tristan da Cunha and Gough in the South Atlantic Ocean and on St Paul and Amsterdam in the Indian Ocean, whilst the southern species breeds on sub-Antarctic islands in the South Atlantic Ocean, Pacific Ocean and Indian Ocean. Some studies suggest a further split of the southern species, with an eastern species in the Pacific Ocean and Indian Ocean. The northern rockhopper penguin, excepting those at Gough, breeds north of the Subtropical Front (STF) and the southern rockhopper penguin breeds south of the STF but north of the Antarctic Polar Front, excepting at Heard Island.

2. Regional population estimates and trends

A population estimate has been produced for all known breeding sites. However, only at a minority of breeding sites can the most recent counts be considered 'current', dating to within the last three years. For the remainder and majority of sites, and for both species, the most recent population estimate was made during the 1970s or 1980s. Nevertheless, the total 'current' population for northern rockhopper penguin is 240,000 breeding pairs and just over 1.23 million pairs for southern rockhopper penguin.

Determining accurate population trends at breeding sites is difficult for several reasons. Few sites are regularly monitored and/or monitored using repeatable and robust count/estimate methods. Furthermore, rockhopper penguins tend to breed in difficult terrain and frequently in association with other penguin species, making surface counting approaches problematic. Despite these limitations, it is clear that many populations of both the northern and southern rockhopper penguin have shown major, long-term population crashes.

For example, from a population of approximately 2 million pairs of northern rockhopper penguins at Gough in the 1950s, over 95% were lost to leave 64,700 pairs in 2006. Similarly, the southern rockhopper penguin population at Campbell Island declined by 94%, from 800,000 to 51,000 pairs, between 1942 and 1986, and at the Falkland Islands (Malvinas) by 86%, from 1.5 million to 210,000 pairs between the 1930s and 2005. Several other sites appear to have suffered severe declines (>40%) between the 1970s and the 1990s.

To our knowledge, there is no information on population trends for southern rockhopper penguin at Kerguelen, Crozet, Macquarie and Heard Islands, which accounted for approximately 250,000 pairs in the 1980s (Ellis et al., 1998; BirdLife International, 2008b), nor for many of the breeding sites in Chile and for Isla de los Estados in Patagonia. There is also no trend information for Middle Island, a tiny islet in the Tristan da Cunha group, which was estimated to hold 100,000 pairs, or >70% of the Tristan da Cunha population, of northern rockhopper penguins in the early 1970s.

3. Global trends and conservation status

Population modelling has shown that both species have exhibited significant declines. Over the past 37 years (= 3 generations), the number of northern rockhopper penguins has declined by 57% from 390,000 to 168,000 pairs, while, based on breeding sites that have been accurately surveyed, the number of southern rockhopper penguins has declined by 34% from 1,792,000 to 1,177,000 pairs.

Under the 2008 IUCN Red List, Birdlife International (2008) lists the northern rockhopper penguin as Endangered and the southern rockhopper penguin as Vulnerable. Analysis of global trends provided strong support for retention of these classifications. However, the greatest declines occurred more than three generation times ago (the time frame used in the current classification system), so the current assessment system does not fully reflect the longer-term depletion of the global population.

4. Demography

Whilst the duration of breeding activities in the populations of northern and southern rockhopper penguin appear to be relatively similar, the timing of breeding differs by up to four weeks between populations in different regions. Little is known about the breeding success and juvenile and adult survival of the northern and southern rockhopper species. No long-term survival data exists for the northern or southern rockhopper penguin in the wild; they can live for up to 25 years in captivity. The median age at first breeding for the northern rockhopper penguin on Amsterdam Island was 4.7 years; no data exists for the southern species.

Breeding fidelity and frequency is not known, although some studies over 2-3 years of marked individuals suggest that some birds do not breed every year. If only a small proportion of breeding-age rockhopper penguins return to the island each year to breed, estimates of the population size may be a significant under-estimate. Breeding success in both species is highly variable, ranging between 0.2 and 0.5 chicks per breeding pair. It appears to be higher in the Falkland Islands than elsewhere, including some evidence of the ability to fledge two chicks in some seasons.

The lack of demographic data is a significant impediment to understanding conservation status and diagnosing causes of decline. Demographic studies should use Passive Integrated Transponder (PIT) tags for individual recognition of penguins in study colonies. The key issue to overcome with this method is to determine tag loss and failure as it leads to an under-estimate of survival. Double tagging some of the birds, so that the proportion retaining only a single tag can be estimated, might be one solution. Tag loss could be investigated in captive populations

An automated recording system, particularly with capacity to record weight, was also seen as a key tool for any demographic studies. Although a number of different systems are currently in use for a variety of penguin species, some key characteristics were identified for an automated recording/weigh bridge system for rockhopper penguins to work over the long term. Only one system is currently in operation for rockhopper penguins, at New Island in the Falkland Islands (Malvinas).

5. Foraging location and diet

Foraging behaviour can be studied successfully in rockhopper penguins through the use of satellite transmitters and time-depth recorders. Research has shown that inter-annual variation can occur both in the use of different foraging areas, and also in the time at which the winter migration begins.

Foraging behaviour has been investigated for southern rockhopper penguins at Isla de los Estados, Falkland Islands (Malvinas), Antipodes, Macquarie, Crozet and Kerguelen and for the northern rockhopper penguin at Amsterdam during the breeding season. Foraging ranges exceed 100km and include waters deeper than 200m, depending on the stage of the breeding season. During the non-breeding season, migration has been investigated at Isla de los Estados and at the Falkland Islands (Malvinas). The two populations forage in two distinct but very large areas.

The diving behaviour of the northern and southern rockhopper penguin is relatively similar, with 14 to 40 dives per hour for 153-193 seconds at mean depths of around 15 to 45 m. However, some aspects of the diving behaviour vary as a function of the physical and biological characteristics of the foraging areas and of the particular stage of the breeding season.

Diet can be successfully determined by collection and examination of stomach contents. However, this requires the capture and use of a potentially invasive method, and it is banned at some locations where research is currently taking place. The diet of rockhopper penguins is subject to large temporal and spatial variation. In general, rockhopper penguins are opportunistic feeders, preying on a mixture of fish, crustaceans and cephalopods. Southern rockhopper penguins in the Pacific and Indian Oceans appear to focus on crustaceans, whereas cephalopods play an important part in the diet of southern rockhopper penguins in the Chilean and Patagonian region and for northern rockhopper penguins at Amsterdam Island.

Diet has been successfully determined by analysing the levels of stable isotopes of carbon and nitrogen in feathers and other tissues. This research shows that southern rockhopper penguins in the Pacific and Indian Oceans forage in sub-Antarctic and polar waters to the south of the breeding island, although only birds from Kerguelen appeared to forage in inshore waters as well.

Isotopically, southern rockhopper penguins from Isla de los Estados and the Falkland Islands (Malvinas) show virtually no overlap with each other, although both forage pelagically and on the shelf. Birds from different sites within the Falklands, and even birds from within the same site at Isla de los Estados exploit different resources during the pre-moult exodus. Northern rockhopper penguins from Gough forage pelagically prior to moult and those at Amsterdam forage in sub-tropical waters.

A fundamental difference between isotope and gut content/stomach flushing approaches to diet studies is the time scale each method addresses. Whereas direct diet sampling yields information about the most recent meals, the isotopic signature of a given tissue is an integration of diet over a relatively protracted timescale from weeks to months. Further stable isotope analysis for some populations is possible because feather samples have been stored. Further research is also possible to determine whether abandoned eggs and toenails could be used for analysis.

DNA fingerprinting faeces is a new technique that has been successfully trialled with macaroni penguins at Heard Island. The new technique has promise, but requires access to a specialised laboratory and that the DNA signature of all potential prey is known.

6. Captive populations

Twenty-eight zoos around the world hold northern and/or southern rockhopper penguin in captivity, holding 207 males, 196 females and 67 unknown individuals. Eight institutions in Europe have rockhopper penguins on display. These captive penguins provide an opportunity to study the species in a controlled environment and despite the obvious constraints, carefully planned research with captive animals can inform, test and qualify aspects of research in the wild, including methods.

SECTION D: THREATS

It is not (yet) clear whether the ecological and demographic drivers of the current rockhopper penguin trends are the same as those that drove trends through the 20th century. A full understanding of population trends requires that both the ecological drivers and the demographic mechanisms of population decline are understood. Eight putative causes of decline were identified and these were examined using the 'multiple competing hypotheses approach'. The evaluation was inconclusive, largely due to an extreme paucity of data. There are very few good data on population trends, and demographic and ecological data are almost entirely absent.

1. Land-based threats

Land-based threats do not appear to play a major role in the recent declines of northern and southern rockhopper penguins (Ellis et al., 1998). Rockhopper penguins appear to persist in the presence of a variety of introduced animals and although tourism and recreation activities are growing in extent and intensity at many coastal sectors, these activities if appropriately managed generally appear compatible with seabird conservation. However, smaller colonies may be more significantly affected by some land-based threats than larger colonies and thus some of the threats may become more important if population sizes continue to decline.

2. Isolated mortality incidents caused by pandemic disease and poisoning

As most rockhopper penguin colonies are little visited, the frequency and the effects of pandemic disease and poisoning events are difficult to determine. No disease outbreaks have been recorded in any northern or southern rockhopper penguin populations. However, wildlife health testing suggests that the Falkland Islands (Malvinas) populations of the southern rockhopper penguin have not been exposed to common infectious agents found elsewhere and therefore may be naïve and susceptible to disease.

Isolated cases of poisoning of rockhopper penguins are not reported for any populations, except those in the Falkland Islands, where one harmful algal bloom (HAB) caused paralytic shellfish poisoning and death in a large number of seabirds. Exactly how the rockhopper penguins in the Falkland Islands (Malvinas) were affected by the HAB event was difficult to determine because not all known colonies were surveyed during the event. A similar die-off was also reported during the 1985/86 breeding season, although starvation was diagnosed as the cause, possibly related to a shortage of krill due to an unusually long period of hot weather conditions.

It is not thought that pandemic disease and poisoning events (except perhaps in the Falkland Islands (Malvinas)) are implicated in the historic and contemporary decline of the rockhopper penguin. However, with climate change and an apparent increase in the frequency and severity of HABs in the South Atlantic, this threat may be more important in coming years.

3. Pollution

Chemical pollution does not appear to be implicated in the decline in the populations of northern or southern rockhopper penguins. Although some penguins are killed by becoming entangled in plastic debris floating in the ocean and swallowing small plastic items, reports suggest this affects a very low proportion of the breeding population.

Oil should not be released at sea under international legislation but this does occur both deliberately and accidentally. There have been some serious acute oil spills around the world but none has affected northern or southern rockhopper penguins. Chronic petroleum pollution (i.e. small but frequent oil discharges) may be a more serious threat to rockhopper penguins. Although few oiled northern and southern rockhopper penguins are reported ashore at breeding colonies, because they forage offshore few oiled birds may make it ashore.

Whilst most of the colonies and foraging areas of rockhopper penguins are in the remoter parts of the world, those in Argentina and Falkland Islands (Malvinas) are likely to be affected by oil pollution associated with oil platforms and terminals and with ports involved in the international cargo shipping route along the coastal waters of Brazil, Uruguay and Argentina. The number of rockhopper penguins affected by oil pollution is currently unknown but given the estimates for Magellanic penguins *Sphenicus magellanicus* in Argentina, the number of rockhopper penguins involved may be significant.

4. Fisheries

From the research available on fisheries interactions, there is little evidence that rockhopper penguins are currently directly impacted by commercial fisheries at a significant level. Seine netting poses the most serious threat to penguins and although it occurred during the 1980s in some parts of the range of the northern and southern rockhopper penguin, does not occur presently in the known ranges of the two species. Although no direct competition has been demonstrated, a greater understanding is required of the marine food webs to determine if there might be indirect interactions between rockhopper penguins and commercial fisheries.

5. Climate change causing a drop in primary productivity that reduces prey availability

A range of potential bottom-up physical effects of increased sea surface temperature (SST) and atmospheric CO₂ on marine primary productivity has been suggested in recent literature but there is weak support for it being a cause of the decline in the rockhopper penguin. The isotopic data appears superficially to support it, but on closer examination is inconsistent. Empirical data on productivity in the relevant ocean areas do not suggest wholesale decreases in productivity. Data on comparable vertebrate predators are equivocal.

6. Climate change causing bottom-up food web shifts that reduce prey availability

There have been suggestions that warmer and more acidic seas favour different sets of producers and primary consumers, with consequent effects further up the food chain (i.e. less of the prey of rockhopper penguins). This hypothesis is poorly defined, and therefore it is difficult to test its role in the decline of the northern and southern rockhopper penguin. Nevertheless, the isotopic evidence of no major shift in rockhopper diet suggests that it is unlikely to be important. Similarly, the relatively minor shifts in oceanic pH and temperature (relative to future projections) during the period of recent rockhopper decline make it seem unlikely. However, we have limited understanding of the implications of relatively minor changes in sea surface temperature, deep ocean temperature or pH on marine systems and productivity, so cannot infer what the effects of such changes would have been on penguin populations.

7. Top-down changes in food web structure, leading to increased inter-specific competition between rockhopper penguins and other higher vertebrates (especially pinnipeds)

The 'competition with pinnipeds' hypothesis requires further examination. There is some indication that rockhopper penguins have declined at several sites where there has been major fur seal recovery. However, this does not appear to apply at all sites. The available census data on fur seals and rockhopper penguins should be examined in more detail. There is very little empirical evidence of competition between the taxa at present.

8. Top-down changes in food web structure, leading to increased secondary predation on rockhopper penguins by increasing marine mammal (especially pinniped) populations

The 'secondary predation by pinnipeds' hypothesis falls into a similar category to the competition hypothesis: there is little empirical evidence, but it cannot yet be ruled out. More detailed analyses are needed, along with some simple modelling of plausible levels of predation and their population impact.

Overall conclusions

More detailed collation and analysis of existing data would potentially help to assess each of the eight threats. Overall, there is no strong support for any of the top-down or bottom-up global causes of rockhopper decline, but none of the hypotheses has been thoroughly tested. Because of the widespread unexplained declines of the northern and southern rockhopper penguin, there is a temptation to assume that there is a common causal factor. However, this assessment does suggest that no single factor is strongly supported by the evidence across sites. It seems plausible that at-sea, prey availability factors are likely involved at some sites, but also that causal factors could differ among sites.

Recent papers describing links between population size, demography and oceanography for other seabird species in the region are a model for much needed field research on rockhopper penguins. However, a more detailed, quantitative assessment of the existing data, to test the competing hypotheses listed above, might be a worthwhile exercise in the interim.

SECTION E: INTERNATIONAL AND REGIONAL ACTION PLANS

Recommendations to address the key knowledge gaps and critical threats common to both the northern and southern rockhopper penguin as identified in Section C and D, and which require international collaboration, are collated into an International Species Action Plan (Section E). To address the specific key knowledge gaps and threats at particular breeding sites, Regional Action Plans were also developed (Section E). These plans identify the key issues for each region and indicate in more detail how the activities would be undertaken by the organisations that work in that region.

To assist in assessing priorities, recommended activities in the regional action plans have been ranked according to their perceived urgency and importance. Some attempt has been made to estimate the resources required (both financial and time) to complete the tasks, although these are only intended as a rough guide and will need considerable refinement. The feasibility of proposed projects and any perceived constraints have also been noted to help guide decision-makers.

Due to the oceanography of the South Atlantic, South Pacific, South Indian and Southern Oceans and how northern and southern rockhopper penguin breeding in these areas use different parts of these oceans, breeding islands were split into six regions.

The northern rockhopper penguin was identified as having two regions—the Tristan and Gough region in the South Atlantic Ocean and the Amsterdam/St Paul region in the South Indian Ocean. Three workshop participants representing the Tristan and Gough region prepared a regional plan for that area. No plan was prepared for the northern rockhopper penguin in the Amsterdam/St Paul region.

The southern rockhopper penguin was identified as occupying four distinct regions. One region is Patagonia, encompassing breeding colonies in Isla de los Estados, Isla Pingüino and the Falkland Islands (Malvinas). A Regional Species Action Plan was prepared by seven workshop participants who represented this region.

Chile was identified as a separate region because the limited tracking data suggests that southern rockhopper penguins breeding there do not forage in the South Atlantic Ocean, and instead go south towards Antarctica and westwards to the Pacific Ocean. Two workshop participants who conduct southern rockhopper penguin research in Chile worked with other participants to prepare a Regional Species Action Plan for Chile.

A fifth region is Pacific Ocean, encompassing sub-Antarctic islands belonging to Australia and New Zealand such as Macquarie Island, Campbell Island and the Auckland Islands. One southern rockhopper penguin researcher from New Zealand was able to attend the Workshop and a Regional Species Action Plan was prepared, effectively updating current plans that exist for both Australia and New Zealand.

The final region identified incorporated the breeding sites of the southern rockhopper penguin in the South Indian Ocean, including the Prince Edward Islands (South Africa), Kerguelen and Crozet (France) and Heard and MacDonald (Australia). Because the workshop focussed on the populations of northern and southern rockhopper penguin in the South Atlantic Ocean, no Species Action Plan was prepared for the Indian Ocean region.

INTERNATIONAL ACTION PLAN

Species status

	Action	Urgency/ importance	Feasibility/Constraints
Taxonomy	Investigation of southern species with further collection of genetic samples from different sites within regions, with analysis of both mitochondrial DNA and nuclear DNA.	High	It may take 2-3 summers to obtain samples for a wide range of breeding sites, given the geographic separation of most colonies.
	Concurrent re-examination of morphological and behavioural differences between populations.	Moderate	
	Investigation of other members of the <i>Eudyptes</i> genus, specifically the other crested penguins endemic to New Zealand (Snares penguin, erect-crested penguin and Fiordland penguin), and also macaroni and royal penguins.	Low	A New Zealand or Australian-based genetics laboratory would represent a suitable 'home' for this research.
	The reliability of DNA sampling techniques (e.g. blood versus swabs, feathers etc) should be tested using captive populations, in order to be using the least invasive method.	Moderate	
Global population	As further counts are completed, and hopefully a global census in 2010, the conservation status of rockhopper penguins needs to be reviewed.	High	
	Any revision of their taxonomic status would require a reassessment of their conservation status.	High	
Demography	Long-term study of marked individuals to assess survival, age at first breeding and breeding frequency.	High	Is required for both the northern and southern species, and at sites where the population is stable/increasing and declining. Any long-term monitoring requires long-term funding, which can be difficult to acquire. Needs to involve use of automatic monitoring systems.
	Breeding activities, including pair fidelity, of captive populations to be monitored and reported	Moderate	Would require both behavioural observations and DNA testing.
Oceanography	Investigation of spatial and temporal links between rockhopper population trends and remotely sensed sea surface temperature and primary productivity datasets should be made using the existing data.	Critical	Best available datasets exist for the Falkland Islands (Malvinas) and Marion Island.
	Investigation of spatial and temporal links between demography and oceanography need to be tested.	High	
Foraging and diet	More research to understand links between foraging areas and diet, especially outside the breeding season.	Moderate	
	Feather and other samples should be collected where possible, including at current research sites, and stored for analysis in the future.	Moderate	P. Quillfeldt to undertake stable isotope analysis of existing samples.
	The effects of diet on breeding success should be investigated using captive populations.	Low	
	New equipment, e.g. leg and flipper bands attachment of devices, automatic gateways, weighbridges, should be tested using in captivity, where necessary.	Moderate	

Threats

	Action	Feasibility/Constraints
Land-based	Ensure that there is sufficient environmental legislation and enforcement to prevent direct take by people.	Many breeding sites are remote.
	Where possible, human disturbance should be minimised and kept to areas where penguins are habituated to human visitors. Minimum distance and slow approach are recommended along with strict rules on quarantine for visitors.	Most visitors at breeding colonies are with IAATO vessels that have appropriate visitor regulations.
Pandemic disease and poisoning	At accessible sites, governments should consider establishing programmes of regularly monitoring the plankton in coastal waters to detect any future harmful algal blooms and to identify factors that lead to them.	
	In countries where HAB events have occurred previously, governments should consider establishing contingency response plans. These must be multi-agency and have an immediate response team for a successful and timely diagnosis.	
	Where disease is suspected, samples should be taken where possible, and the effects on the population determined. Visitors should be kept away from any colonies where disease is suspected.	Most samples taken for disease testing cannot be stored for long periods.
	Use molecular methods for detection of blood parasite prevalence across the distribution range.	Samples to be collected at the same time as DNA samples, using kits to be distributed by D. Oehler, analysis by P. Quillfeldt & collaborators
Pollution	Ensure that all vessels uphold international pollution regulations associated with MARPOL to prevent discharge of oil and plastic.	
	Agree standard protocols for assessing rates of mortality due to chronic and acute oil pollution.	
	Develop a simple standard protocol to measure the amount of plastics in the stomach of rockhopper penguins, and add the data to a global database.	
	Ensure stringent and wide-ranging Environmental Impact Assessment (EIA) for hydrocarbon exploitation if/when it happens in any waters where the rockhopper penguin is known to breed.	
Fisheries	Competition between fisheries and rockhopper penguins should be investigated at all regions, using the assessment used in the Falkland Islands (Malvinas), where appropriate.	
	Ensure that seine netting does not occur in any foraging areas of the rockhopper penguin.	
	Ensure that where new fisheries are developed that effects on rockhopper penguins are considered/investigated, e.g. shallow water longlining, anchovy fisheries.	
Top-down changes in food web structure leading to increased inter-specific competition	Assess in more depth the impact of removing whales and seals from the ecosystem may have had on historical rockhopper penguin populations.	
	Assess in more depth the impact of the recovery of fur seal/sea lion populations during the 1930s to 1950s may have had on rockhopper populations.	
Top-down changes in food web structure leading to increased secondary predation	The available census data on fur seals and rockhopper penguins should be examined in more detail.	It is noted that there is very little empirical evidence of competition between the taxa at present.
	More detailed analyses of predation by pinnipeds on rockhopper penguins are needed, along with some simple modelling of the plausible levels of predation and their population impact.	
Bottom-up changes in food web structure affecting zooplankton and other prey	Detailed analysis of penguin behaviour to changes in water temperature within and between seasons.	

REGIONAL SPECIES ACTION PLANS

1. Northern rockhopper penguin - Tristan and Gough

Contributors: Geoff Hilton, Richard Cuthbert, Trevor Glass and Norman Ratcliffe

Priority recommendations for Tristan and Gough:

- *Critically important to undertake a census of rockhopper penguins on Middle Island and a seal count/ mapping.*
- *High priority for repeat censuses of rockhopper penguin populations on Gough, Tristan, Inaccessible and Nightingale Islands.*
- *Tracking to establish summer feeding locations and establishing a transponder tagged population.*

TCD - Tristan Conservation Department

RSPB = Royal Society for the Protection of Birds

Action	Urgency/ importance	When/how often/ by whom	Cost (in GBP and human resources)	Feasibility/Constraints
Middle Island census & seal count/ mapping. (<i>GPS map rockhopper colony, estimate density in plots. Similar for fur seals to estimate destroyed habitat area.</i>)	Critical	Oct 2009 and every few years TCD	£2,000	Dependent on boat for TCD - RZSS supplied RIB <i>Arctic Tern</i> in December 2008 Access to Middle can be weather-dependent
Gough Rockhopper Penguin Census	High	Annually - do the simple bits (about a third), full census every few years when possible. RSPB	Can be fitted into weather station changeover if sufficient people available	Dependent on enough experienced staff available but generally feasible.
Tristan Rockhopper Penguin Census	High	Annual TCD	Part of role of Conservation Officer, boat and assistant costs, £1,500	Reasonably straightforward, landing at some colonies can be difficult and not possible every year
Inaccessible Rockhopper Penguin Census	High	Every few years TCD	Part of role of Conservation Officer, boat and assistant costs, £2,000	Reasonably straight-forward
Nightingale Rockhopper Census	High	Annual TCD	Part of role of Conservation Officer, boat and assistant costs, £1,000	Reasonably straight-forward
Tracking for summer feeding locations (both Gough and Tristan populations)	High	Use GPS, satellite transmitters & compass-loggers. One-off, soonest. RSPB and TCD	Ca.10-15K for hardware and satellite time Considerable staff time	Pretty high, established techniques
Establish transponder tagged population on Tristan and/or Gough	High	Probably not automated—use hand-held readers. RSPB and TCD Annual, but may have to live with occasional missed years	Initial hardware cost (few thousand). RSPB may have leftover Ascension kit. Time for annual checks by TCD /Gough changeover team.	Seems pretty do-able. Needs quite high commitment to get it going and iron out initial problems
Obtain and analyse existing data on fur seal diet (Marthán Bester)	Medium	Lead not identified	Not known	Not known
Opportunistically collect rockhopper penguin stomach contents	Medium	Lead not identified	Not known	Not known

Action	Urgency/ importance	When/how often/ by whom	Cost (in GBP and human resources)	Feasibility/Constraints
Collect feathers for stable isotope analysis using an annual protocol	Medium	RSPB to co-ordinate with TCD	Not known	Not known
Gather rockhopper penguin diet data if possible	Medium	RSPB to scope out possibilities	Time of conservation officer (and changeover team on Gough), possibly analytical costs	Stomach flushing extremely problematic. Hi-tech techniques need developing elsewhere & may be expensive
Estimate breeding success at Tristan (on some colonies?)	Medium	TCD. Match October incubation count to a December chick count. Should become annual	Time of Conservation Officer, Assistant, three Darwin Team members and boat running costs	Feasible (limitations are the Conservation Officer's time)
Nightingale breeding success (Find a discrete sub-colony for counts)	Medium	TCD. Could become annual, may have to live with occasional missed years	4-person team needed, £2,000 boat running costs	Access to/from Nightingale can be weather-dependent Limitations on Conservation Officer's time
Estimate body condition and growth rates + adult mass at arrival on Gough & Tristan. Need known age chicks to calibrate initially. Single measurement of mass against age (from morphometrics) on Tristan (and on Gough when opportunity arises)	Medium	RSPB and TCD Annual, but may have to live with occasional missed years. Tristan chick condition annual, Gough opportunistic. Calibration year would need repeated work in Nov-Dec (on Gough). After that, probably single visit to Tristan colonies in December	Simple equipment for morphometrics & body mass (£100) After establishing protocol, two team-days per year on Tristan	2008-9 Gough team can do the calibration

2. Southern rockhopper penguin - Patagonia

Contributors: Ann Brown, Isaac Forster, Grant Munro, Helen Otley, Klemens Pütz, Petra Quillfeldt and Andrea Raya Rey

Priority Recommendations for Argentina and the Falkland Islands (Malvinas)

- *Critically important to undertake monitoring and population surveys on Isla de los Estados and Falkland Islands (Malvinas)*
- *High importance to conduct demographic studies on Staten and the Falkland Islands (Malvinas)*
- *High-moderate importance for satellite/ geo-location tracking, diet sampling and stable isotope monitoring for both regions*
- *Moderately important to implement oil contingency plans and wildlife health monitoring*

CONICET = Consejo Nacional de Investigaciones Científicas y Técnicas (Argentina)

FC = Falklands Conservation

NICT = New Island Conservation Trust (Falklands)

FIG = Falkland Islands Government

Action	Urgency/ importance	When/how often/ by whom	Cost (in GBP and human resources)	Feasibility/Constraints
Isla de los Estados monitoring	Critical	Beginning Oct 2008 Annually CONICET	£6K	Access to Staten Is currently dependent on Argentine Navy, but reasonably straightforward
Isla de los Estados population survey	Critical	2010 Every 5 years CONICET	£12K	Access to Staten currently dependent on Argentine Navy but reasonably straightforward
Falkland Islands (Malvinas) monitoring	Critical	Ongoing Annually FC, NICT	£25K, but for four species. Funding likely to be met	Straightforward
Falkland Islands (Malvinas) population survey	Critical	2010 Every 5 years FC	£40K, but for four species. Funding likely to be met	Reasonably straightforward although methodology needs refinement
Isla de los Estados demographics	High	Ideally Oct 2008 Approximately monthly for gateway download	Capital costs ~£10K	Start up costs considerable Conditions at island very basic
Falkland Islands (Malvinas) demographics	High	New Island demographics ongoing. Establishment of a northern site preferable within 2 years Annually NICT, FC, FIG	NICT maintenance £600 per year, Student for NICT (several projects) £12K per year, northern gateway £6K Staff maintenance wage for northern gateway £20K	Start up costs considerable. FI northern site establishment and access potentially difficult
Isla de los Estados tracking	High for winter Medium for summer	Within 2 years Preferably a 3 year program to account for environmental variability CONICET	Satellite tags £25K for first year, GLS loggers £5K per year. If GLS data validated by satellite tracking, only GLS after Year 1	Winter tracking feasibility unknown due to attachment issues If high capital costs overcome fairly straightforward for summer tracking
Isla de los Estados diet sampling/ stable isotope sample collection	High for winter diet Medium for summer diet	Within 2 years Annually to assess variability CONICET	£1K for sample processing Maintenance costs (as part of monitoring/ demographics)	Diet sample collection and storing difficult because of basic facilities at Staten but samples can be stored dry (feathers, toe nails, egg membranes, dried blood)

Action	Urgency/ importance	When/how often/ by whom	Cost (in GBP and human resources)	Feasibility/Constraints
Falkland Islands (Malvinas) diet sampling/ stable isotope collection	High for winter diet Moderate for summer diet	Oct 2008 Annually to assess variability NICT for western site FC for selection of an eastern site	£1K for sample processing	Stomach contents sampling using water-offloading currently not permitted at New Island, otherwise straightforward
Falkland Islands (Malvinas) tracking	High for winter Moderate for summer	Within 2 years Preferably a 3 year program to account for environmental variability NICT for western site FC for an eastern site	Satellite tags £35K for first year, GLS loggers £10K per year. If GLS data can be validated by satellite tracking, GLS after year 1	Winter tracking feasibility unknown due to attachment issues If high capital costs overcome fairly straightforward for summer tracking
Falkland Islands (Malvinas) oil contingency plan update	High	ASAP given current events Reviewed every 5 years FIG	Negligible, capacity exists	Straightforward
Isla de los Estados oil contingency plan	Moderate	As early as practicable Reviewed every 5 years CONICET	Should be minimal	Development straightforward Implemental potentially difficult
Isla de los Estados wildlife health monitoring	Moderate	At next visit Opportunistically CONICET	Negligible	Straightforward
Falkland Islands (Malvinas) wildlife health monitoring	Moderate	Nov 2008, Annually FC	Negligible	Straightforward
Falkland Islands (Malvinas) disease contingency plan	Moderate	Within 12 months Reviewed 5 yearly FIG	Negligible, capacity exists	Reasonably straightforward to adapt an FAO plan and implement
Isla de los Estados disease contingency plan	Moderate–Low	Within 12 months Reviewed 5 yearly CONICET	Should be minimal	Reasonably straightforward to adapt an FAO plan. Implementation potentially more difficult
Isla de los Estados assessment of goat impacts	Low	Within 3 years One assessment CONICET	If built into other programs minimal	Straightforward

3. Southern rockhopper penguin - Chile

Contributors: David Oehler and Manuel Marin

Priority recommendations for the Chilean region were to:

- Determine site locations of rockhopper populations and complete site surveys along the coast
- Track annual movements of rockhopper penguins (this research began in 2007 and will be continued until 2009)

FL = Feather Link

Action	Urgency/ importance	When/how often/ by whom	Cost USD	Feasibility/Constraints
Determine site locations and complete site surveys along the coast of Chile	Critical	Continued efforts, to be completed by 2011, FL	Capital \$50,000 per year	Feasible in stages Access is weather-dependent
Tracking of annual movements	Critical	Initiated in 2007 to be completed by 2009, FL	\$16,000	Feasible during site surveys
Genetic Analysis: determine genetic variability at inter and intra populations levels	Moderate	Initiated in 2007, to be completed by 2009, Collaborative effort	\$2,000	Feasible during site surveys
Diet analysis; collection of stomach content and stable isotope	Low	Collection of contents and feathers could be completed during all site surveys	To be decided	Feasible during site surveys
Plant ecology: establish base line data of plant ecology in undisturbed colonies	Low	Initial plot surveys completed in 2005 with follow-up in 2008 and 2009	Minimal	Feasible during site surveys

4. Southern rockhopper penguin - Pacific Ocean

Contributor: David Thompson

Priority recommendations for Pacific Ocean sites around New Zealand were to:

- Increase knowledge of population sizes on key islands
- Resolve the crested penguin taxonomy

NIWA = National Institute for Water and Atmosphere

Action	Urgency/ importance	When/how often/ by whom	Cost	Feasibility/Constraints
Analyse existing photo-point images: Campbell Island	High	Collaboration: Moore–Thompson - Australian group. Immediately	Relatively low	Requires time, and truthing–see below
Census Campbell, Antipodes, Auckland and Macquarie Islands	High	From 2008-09 onwards NIWA and field teams Full census whenever possible	May require dedicated visits - expensive	Apart from Macquarie, would require dedicated island visits, and in any event would be hard for Auckland group
Ground truth photographs	High	Should be undertaken as part of census work	Embedded in action point above	Straight forward
Resolve crested penguin taxonomy	High	Sample collection to begin 2008/09 Explore options for NZ lab to lead	Unknown	Requires widespread sample collection—as many key sites as possible from at least 7 taxa

SECTION F: IMPLEMENTATION OF ACTION PLANS

1. Implementation of action plans

It is the responsibility of workshop participants, other rockhopper penguin researchers and conservation managers in each region to present the International Action Plan and their Regional Action Plan to appropriate managers and decision makers to assist in implementing the recommendations.

Internationally and regionally, the action tasks in the Action Plans need to be planned into work schedules, allocated time and resources of current programmes. However, it is recognised by all workshop participants that it will be a challenge to obtain the necessary funding to implement most of the tasks and to maintain current activities. It will be important to ensure that any large funding bids are co-ordinated and that smaller bids made by regions are not directly competing with each other.

Workshop participants identified a number of issues relating to potential sources of funding. Most of the recommended actions are of a research/monitoring nature (and not directly management orientated), and this strongly affects who the donors might be. Collaborative bids might be more attractive to many donors, and would certainly generate more powerful data. It was agreed that collaboration between the Falkland Islands (Malvinas) and Argentina is very sensitive (and perhaps impossible).

It was noted that zoos offer opportunities for researchers and the general public to meet to assist with the public understanding of science and to raise awareness about research and its conservation implications.

2. Progress review

Participants agreed that this Workshop had been a good starting point for combining knowledge and research, but most of the recommended action tasks require a continuation of the collaboration and sharing of knowledge used in this Workshop.

Due to the widespread geographic location of rockhopper penguin researchers, future meetings could be timed to coincide with other conferences that a number of workshop participants are likely to attend. The possibility of holding a second Rockhopper Penguin Workshop in 2010 before or after the International Ornithological Congress in Brazil, the World Seabird Conference in Canada or at the 7th International Penguin Conference in the USA were discussed.

Before any 2010 Workshop, it will be important to ensure that the group remains together and committed to fulfilling this Workshop's recommendations. To aid progress a Steering Group was established initially consisting of Helen Otley and Petra Quillfeldt.

The possibility of establishing a species interest group for rockhopper penguins was discussed. As the primary aim of this group would be to exchange information, an email group could be an effective first step. However to ensure that the email group works effectively, at least one person would be required be the focal point of contact and operation, as well as keeping enthusiasm for the group going. As no one volunteered to run the group during the Workshop, it was not established. If such a group was to be set up, the possibility of including the crested penguin community from New Zealand should be investigated.

	Action	Feasibility/Constraints
Funding	Several of the range states of the northern and southern rockhopper penguin are European Overseas Territories. Funding opportunities offered or in the pipeline from the European Commission should be explored and appropriate approaches made. Regional programmes are applicable.	
	Apply for short term funding from the UK Government's Overseas Territories Environment Programme (OTEP).	Limited support for research projects.
	Develop co-ordinated fundraising appeal to seek support from multi-national companies and charitable trusts/institutions.	
	The very high recognition and popularity of the species might mean that public-facing donors (e.g. trust funds, companies) are a promising source.	
	Approach BirdLife International to explore applying for sponsorship from the British Birdwatching Fair.	
	Investigate fundraising possibilities with zoos by preparing appropriate materials and information on different challenges the penguins are facing and the conservation funding priorities at different levels (e.g. visitors, zoo institutional members, penguin working groups).	This might best be achieved by having one institution leading the campaign and having someone from the Workshop attending the next European penguin TAG meeting.
Progress review	This workshop was focused largely on the South Atlantic region and it was agreed that future workshops or meetings should encompass all regions, and through longer term planning with sufficient funding in place early, many representatives from different regions could participate.	
	Most participants favoured a meeting before or after the Penguin Conference (most of the 2008 Workshop participants are likely to attend this). It would also provide a good opportunity to showcase projects that are going on amongst the group to the wider penguin community and to potential sponsors.	
	In late 2009, the Steering Group will ask for regional representatives to submit a progress report for group circulation and to consult with group members about the 2010 Workshop.	

APPENDIX 1 Species status

1. Taxonomic status
2. Regional population estimates
3. Global trends and conservation status
4. Demography
5. Oceanography
6. Foraging location, dive behaviour and diet
7. Captive populations

1. Taxonomic status

Helen Otley and David Thompson

The northern rockhopper penguin is found in the South Atlantic and Indian Ocean (Figure 1.1). It has a restricted range, breeding on only seven islands that lie at 37-40°S (with total land area of 250 km²) in two oceans. In the Indian Ocean, breeding sites occur on Amsterdam and St Paul, while in the Tristan da Cunha region northern rockhopper penguins breed on Gough, Inaccessible, Middle, Nightingale and Tristan islands.

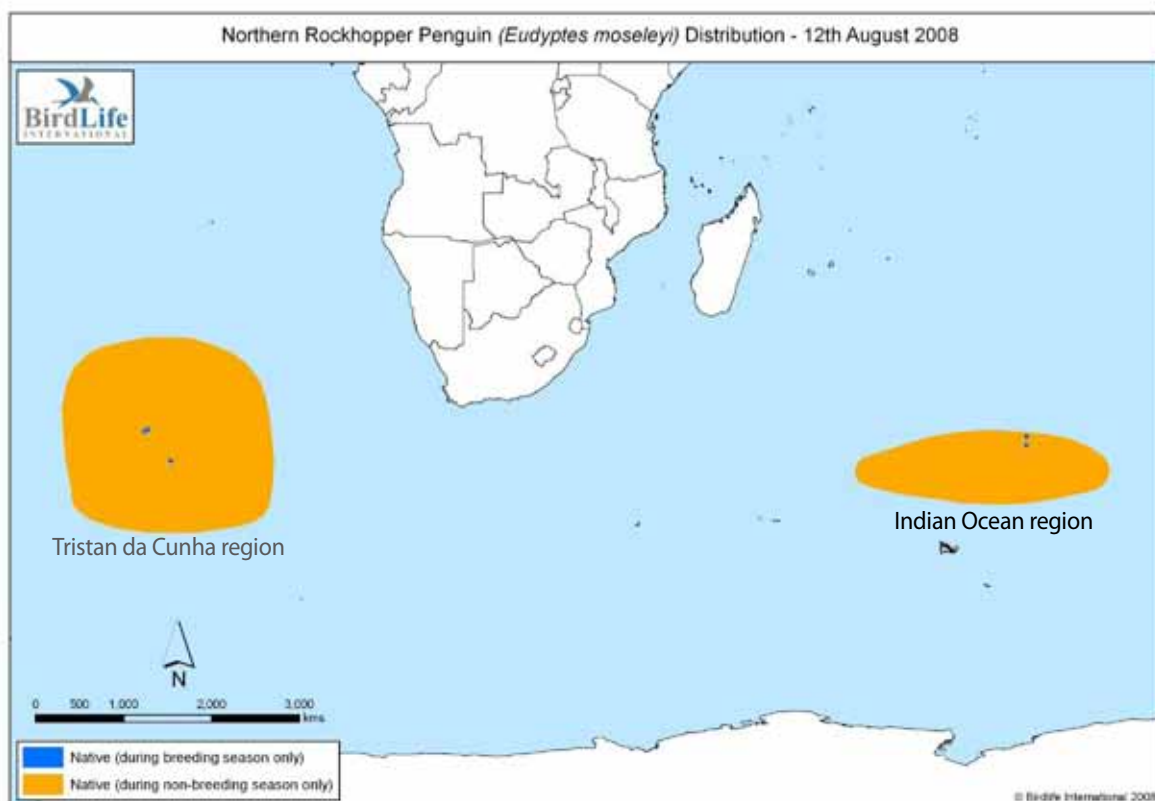


Figure 1.1. Breeding and non-breeding ranges of the northern rockhopper penguin (Source: BirdLife International).

The southern rockhopper penguin breeds on islands located in the South Atlantic, Indian and Pacific Oceans, ranging from 46° S in the South Atlantic Ocean and South Indian Oceans to Macquarie Island at 54°S in the Southern Ocean (Fig. 1.2 and Table 1.1).

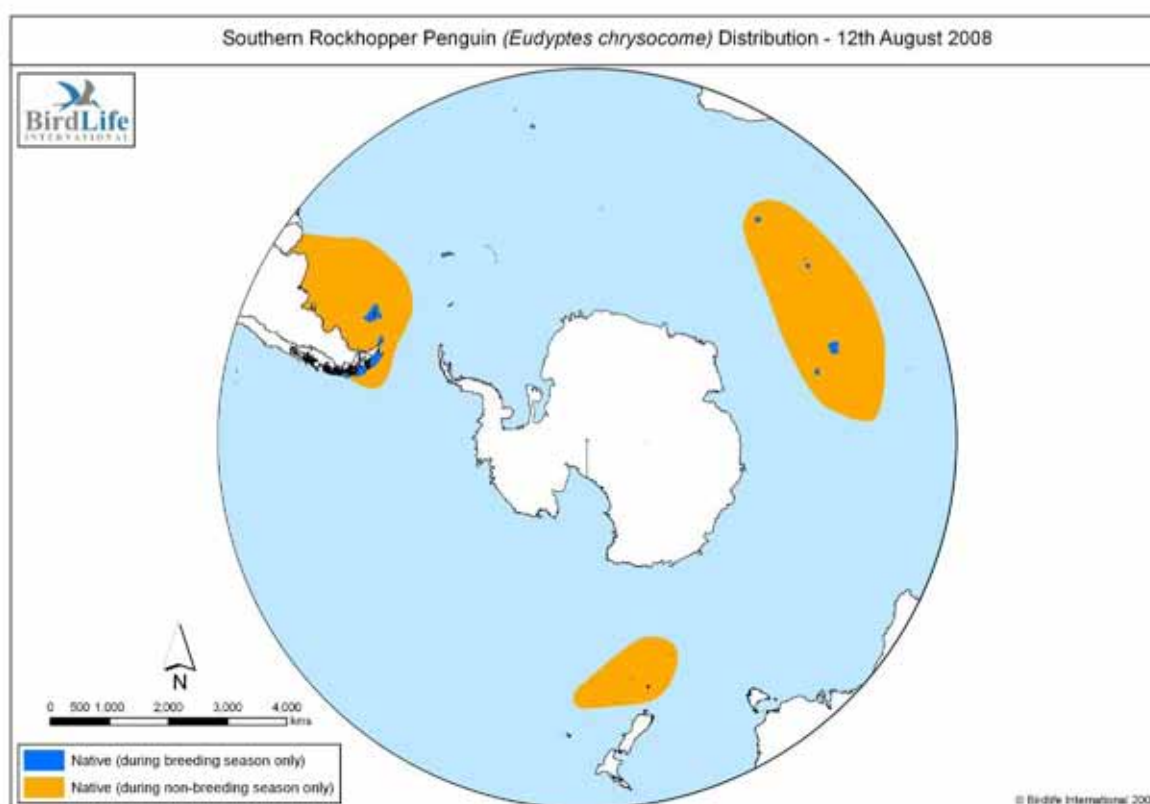


Figure 1.2 Breeding and non-breeding regions of southern rockhopper penguins.
(Source: BirdLife International)

Table 1.1 Islands where southern rockhopper penguins breed and their associated regions.

Regions	Islands
Indian Ocean	Kerguelen, Crozet, Heard and McDonald Islands, Marion and Prince Edward Islands
Pacific Ocean	Antipodes, Auckland, Campbell, Macquarie
Patagonian	- Falkland Islands (Malvinas) - Chile: Barnevelt, Isla Terhalten, Isla Buenaventura, Isla Ildefonso, Isla Recalada, Isla Diego Ramirez, Isla Noir - Argentina: Isla Pingüino and Isla de los Estados

Genetic analysis

There have been three genetic studies undertaken on rockhopper penguins all using mitochondrial DNA analysis (Banks et al., 2006; Jouventin et al., 2006; de Dinechin et al., 2009). Samples from a fourth location (a number of sites in Chile) are soon to be analysed in the USA by Feather Link Inc. Analyses undertaken in these three studies did not include any samples from southern rockhopper penguins in the Pacific sector, where contemporary populations are historically low and relatively small compared to populations in the Indian Ocean, and particularly low when compared to populations around South America.

Results

Banks et al. (2006) identified three species, being the northern, southern and eastern species, whereas Jouventin et al. (2006) found only significant genetic differentiation between the northern and southern/eastern populations. The study by de Dinechin et al. (2009) using the previously published genetic sequences plus new samples suggested that the three species existed (Table 1.2).

Banks et al. (2006) proposed a further split of *E. chrysocome* into southern (*chrysocome*) and eastern (*filholi*) 'species', but this was not adopted by BirdLife International, on the grounds of small sample sizes and limited morphological differences between the southern and eastern forms (BirdLife International 2008a, b). However, further research by de Dinechin et al. (2009) also supports the split of *chrysocome* and *filholi*, and BirdLife International have yet to consider this new evidence.

Table 1.2 The genetic outcomes of three taxonomic studies on the mitochondrial DNA of rockhopper penguins, showing the number of samples analysed from each region. In the de Dinechin et al. (2009) study, five new samples were obtained from Crozet and Kerguelen and these were compared to the samples obtained by Jouventin et al. (2006).

Site	No. of samples		
	Banks et al. (2006)	Jouventin et al. (2006)	de Dinechin et al. (2009)
Falklands (New Is.)	5	0	13
Crozet	5	17	5 + 17
Kerguelen	5	19	5 + 19
Amsterdam	0	18	18
Gough	0	16	16
Result	3 species <i>E. moseleyi</i> <i>E. filholi</i> <i>E. chrysocome</i>	2 species <i>E. moseleyi</i> <i>E. chrysocome</i>	3 species <i>E. moseleyi</i> <i>E. filholi</i> <i>E. chrysocome</i>

Defining and recognising species is a contentious issue amongst biologists and geneticists. However, in the context of the rockhopper penguin, the focus should perhaps be on management units (i.e. populations that share discrete and definable geographic areas) rather than on species.

Biogeography

The combination of radiochronological, palaeomagnetic and palaeoclimatic data enables calibration of an accurate molecular clock for rockhopper penguin sequences and de Dinechin et al. (2009) suggest the following speciation scenario:

- i) During the early Pleistocene (1.9-0.9 Myr), the Southern Atlantic Ocean was cold, so that Gough and Tristan da Cunha Islands were surrounded by temperatures equivalent to the present sub-Antarctic watermass.
- ii) The mid-Pleistocene climatic transition, around 0.9 Myr ago, was associated with major southward migration of the frontal positions, and Gough and Tristan da Cunha Islands became surrounded by the 10°C-warmer subtropical watermass. This event was followed by a split between northern and southern rockhopper penguin populations.
- iii) Numerous advance and retreat cycles of the Patagonian Icecap during the late Pleistocene may have created a barrier to gene flow between southern Pacific and Atlantic populations, and caused the split between southern and eastern rockhopper penguins.
- iv) Around 0.25 Myr, Amsterdam and St. Paul Islands emerged in the Southern Indian subtropical watermass, and were rapidly colonized by individuals from northern Atlantic populations (Gough and Tristan da Cunha) within the same watermass, following the direction of the currents.

2. Oceanography

Helen Otley and Richard Cuthbert

The northern and the southern rockhopper penguin are appear generally to be geographically separated by different water masses, with the southern species breeding and foraging in waters south of the subtropical convergence (STC) and the northern species north of this. Gough Island is marginally south of the STC and it is not known where the northern rockhopper penguins that breeds on the Tristan da Cunha and Gough group forage.

The use of the term subtropical convergence has been widely used for more than half a century, but recently the term Subtropical Front (STF) has come into use for the subtropical gyre-Antarctic Circumpolar Current boundary. In the South Atlantic, the subtropical front can be traced from 40°S offshore of the east coast of South America into the Indian Ocean. The STF separates the Subantarctic Surface Water to the south from the Subtropical Surface Water to the north.

The STF is a major oceanographic boundary and is characterised by high eddy variability and moderate surface chlorophyll-a concentrations. The surface hydrographic properties of the STF include a rapid

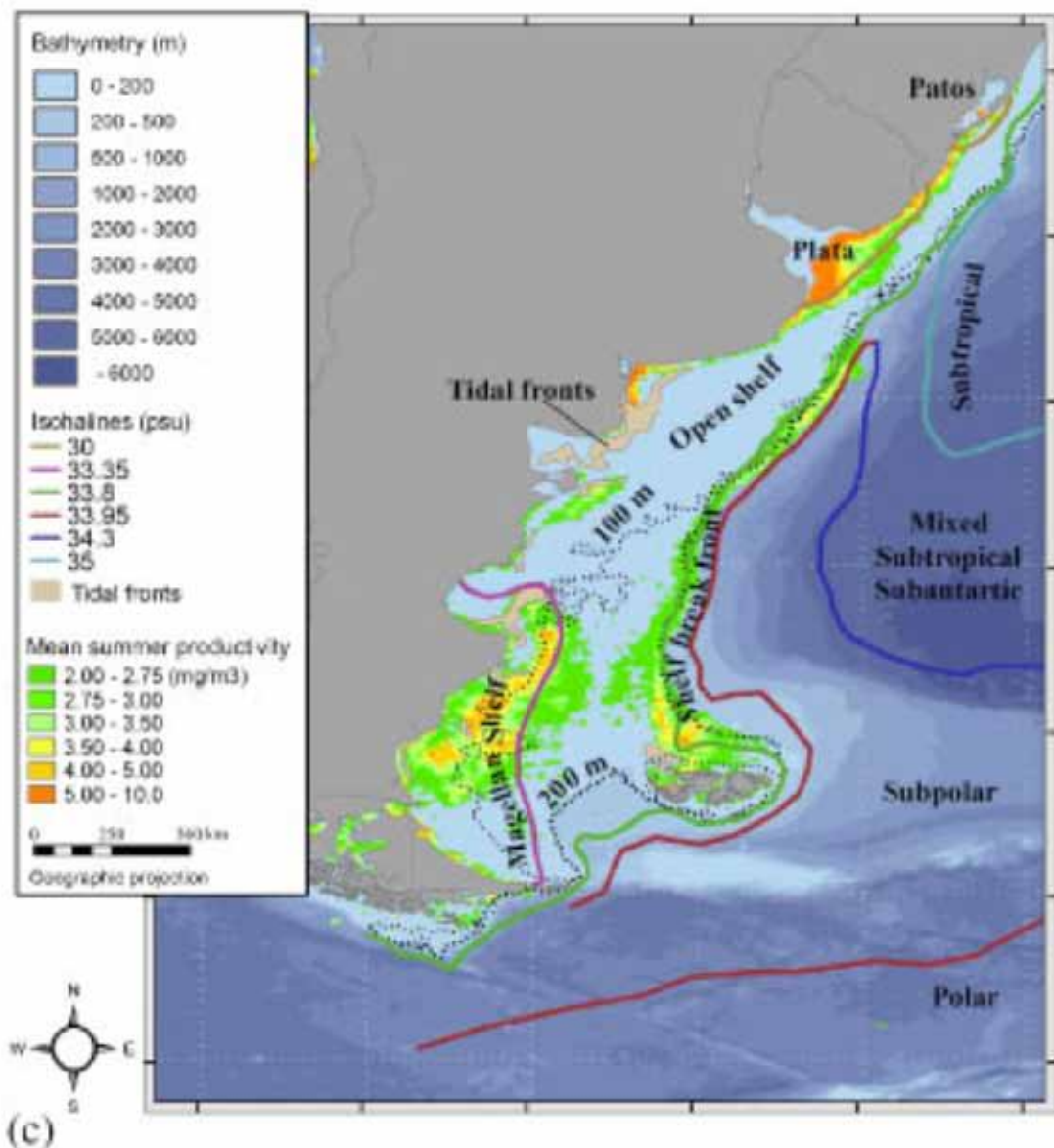


Figure 1.3 Bathymetric profile and location of currents in the south west sector of the South Atlantic Ocean, including salinity and mean summer productivity expressed as chlorophyll-a. (Source - Campagna et al., 2008). (Source: BirdLife International)

salinity change from 35.0 psu to 34.5 psu and a strong temperature gradient as one crosses from north to south (from 14 °C and 18 °C in summer and 10 °C and 14 °C in winter, respectively). At 100 m, its approximate location is within a band across which temperatures increase northward from 10 to 12 °C and salinities from 34.6 psu to 35.0 psu, with the salinity gradient usually the more reliable indicator. The position as well as the intensity of sinking or rising motion in the STF is more variable than in any other front or divergence in the Southern Ocean.

South-west Atlantic sector

The southwest sector of the South Atlantic Ocean is heavily influenced by the position of the continents and their marine shelves. The Patagonian system including the area south and east of Tierra del Fuego encompasses an extended and shallow shelf, a broad frontal area, the shelf edge and part of the deep Patagonian basin (Figure 1.3). The shelf extends some 750 km out from Argentina, including 50 km beyond East Falkland Island. However, southeast of Terra del Fuego and south of Isla de los Estados, the continental shelf edge is only the 2-20 km away. The shelf is quite large directly south of Cape Horn, about 50 km, and east of Isla de los Estados it extends via Burdwood Bank for about 500 km.

Water from the Antarctic Circumpolar Current, after passing east through the Drake Passage, generates the Falklands-Malvinas Current. This current carries cold, nutrient-rich waters northwards, meeting the warm, nutrient-poor waters of the Brazil Current travelling south, at between 40° and 47 °S, depending on the season. The Brazilian Current is relatively nutrient poor, but productivity is very high because of high turnover.

Immediately west of the western edge of the Falklands-Malvinas Current is a narrow transition region between subpolar and shelf waters, being the shelf breakfront (Figure 1.3). This area is characterised by frequent chlorophyll-a maxima in summer that extend from 50 to 40 °S, resulting from the upwelling zone created by the Falklands-Malvinas Current striking the coastal shelf break.

It is this combination of continental shelf topography causing water mixing, as well as the large-scale oceanic currents meeting that creates highly productive foraging areas for predators such as rockhopper penguins.

South-east Atlantic sector

The Tristan da Cunha archipelago and Gough Island are both volcanic islands that have arisen from the Mid-Atlantic Ridge. Both islands rise steeply from the seabed, which lies at depths of 2000m. This depth of 2000m is reached between Tristan and the two outer islands in the archipelago despite Nightingale and Inaccessible being only 38 and 40km from Tristan. The seabed is shallower (500m) between Nightingale and Inaccessible. Shallow shelf waters around Tristan generally only extend to 2km, other than on the western side of Inaccessible where they extend to 10km offshore. Shallow shelf waters are dominated by giant kelp (*Macrocystis pyrifera*), which grows around all the islands at depths up to 40m.

The water surrounding both Gough and Tristan da Cunha are oceanic and are clear of silt or any significant freshwater run off. Both islands are affected by westerly currents of the Antarctic Circumpolar Current, as well the anti-clockwise current of the South Atlantic gyre. The STF lies north of Gough Island and south of Tristan da Cunha, separating the islands into cooler sub-Antarctic and warmer subtropical zones of the South Atlantic. At Tristan da Cunha, mean sea-surface temperatures vary from 12-16°C winter and 16-20°C in summer. At Gough, sea-surface temperatures range from 10-13°C and 12-15°C in winter and summer, respectively. Around both islands, sea temperatures at 1,000m depth are at 2-3°C.

3. Regional population estimates and trends

Geoff Hilton and Helen Otley

Population estimate

A population estimate has been produced for all known breeding sites, although few are based solely on direct counts. Some are acknowledged to be 'guess-estimates' whilst other counts are based by density counts in small areas and extrapolation based on colony size determined using aerial photography.

At some breeding sites, the most recent counts were made within the last three years, but for some sites for both species, the last count was made during the 1970s and 1980s (Table 1.3).

The total known population for the northern rockhopper penguin is 238,534 breeding pairs and just over 1 million pairs for the southern rockhopper penguin (Table 1.3). Eighty-six percent of northern rockhopper penguins are found in the Tristan da Cunha/Gough group, with 100,000 breeding pairs on Middle Island.

The Falkland Islands, with 55 distinct breeding colonies, had a total of 210,418 breeding pairs in 2005 and Isla de los Estados had 173,793 in 1998. In Chile, there are two large colonies on Isla Diego Ramirez and Isla Noir, and all breeding sites represent 36% of the global population of southern rockhopper penguins (Table 1.3).

Table 1.3 Population estimates for known breeding sites for the northern and southern rockhopper penguin.

	Region	Site	Year	No. breeding pairs	% of global total	Long-term population trend
Northern rockhopper penguin	Indian Ocean	Amsterdam	1993	24,890		Decrease
		St Paul	1993	9,023	14	?
	Tristan da Cunha/Gough	Gough	2006	64,700		Decrease
		Inaccessible	2004	18,000		Decrease
		Middle	1973	100,000		?
		Nightingale	2005	19,500		Decrease
		Tristan	2005	3,421	86	Decrease
				239,534		
Southern rockhopper penguin	Indian Ocean	Heard	1987	10,000		?
		Kerguelen	1985	85,500		?
		Crozet	1982	152,800		?
		Marion	2001	67,000		Decrease
		Prince Edward	2001	45,000	29	Decrease
	Pacific Ocean	Antipodes	1995	4,000		Decrease
		Auckland	1990	3,000		Decrease
		Campbell	1986	51,000		Decrease
		Macquarie	2007	37,500	8	Decrease
	Patagonia	Falkland Islands (Malvinas)	2005	210,418		Decrease
		Pingüino	2007	501		Increase
		Estados	1998	173,793	31	?
	Chile	Barnevelt	1992	10,800		?
		Cape Horn	1992	600		?
		Terhalten	2005	1,000		?
Buenaventura		1992	500		?	
Ildefonso		2006	86,400		?	
Recalada		2005	0		?	
Diego Ramirez		2002	132,721		?	
Noir		2005	158,200	32	?	
				1,230,733		

Regional population trends

Determining the population trends at breeding sites within each region is difficult because few sites are regularly monitored and/or monitored using comparative count/estimate methods. Few robust population estimates are known before the 1970s, although some indications of population or colony size are known from memories, egg collection records kept by governments and historical photographs.

Therefore, while it is acknowledged that historically populations were much larger, the timing of the decline cannot be determined accurately for any populations prior to the 1970s.

However, it is clear that populations of both the northern and southern rockhopper penguin have shown major long-term population crashes. For the three largest population declines, the original population estimates for each of these sites is higher than the estimated total contemporary world population.

Approximately 2 million pairs of northern rockhopper penguins (98%) were lost from Gough Island between 1955 and 2006 and Tristan da Cunha is thought to have held hundreds of thousands of pairs in the 1870s, which were reduced to ~5,000 pairs by 1955 (Cuthbert et al., 2009). The breeding colonies on Amsterdam/St Paul Islands have reduced in size by 40% (Guinard et al., 1998).

Approximately 1.5 million pairs of southern rockhopper penguins are estimated to have been lost from Campbell Island (94% of the original total) between 1942 and 1986 (Cunningham and Moors, 1994), and the Falkland Islands (Malvinas) population fell by ~1.4 million pairs between 1932 and 2005 (87% of the original total) (Pütz et al., 2003a). Several other sites appear to have suffered severe declines (>40%) between the 1970s and the 1990s: Marion Island (Crawford et al., 2003b), Antipodes Islands and Auckland Islands (Ellis et al., 1998). Earlier trends at these sites are not recorded.

There are a few major populations for which expert opinion suggests no recent decline, though quantitative trend information is lacking. One example is Isla de los Estados in Argentina. To our knowledge, there is no information on population trends at Kerguelen, Crozet, Macquarie and Heard Islands, which accounted for approximately 250,000 pairs in the 1980s (Ellis et al., 1998; BirdLife International, 2008b). There is also no trend information for Middle Island, a tiny islet in the Tristan da Cunha group, which was estimated to hold 100,000 pairs of northern rockhopper penguins in the early 1970s but has not been recently surveyed.

The rate of the decline is also difficult to determine for most breeding colonies. In the Falkland Islands (Malvinas), annual monitoring of a sub-set of sites since 1987 indicates a strongly stepwise decline (Huin 2007a). There was a major decline event in 1987—the proximate cause apparently being starvation of moulting birds, followed by stability until 2002/3 when there was a further reduction (attributed to a harmful algal bloom). In between these events, there was minimal recovery. Conversely, at Marion, where a similar data set runs from 1994/5 to 2007/8, the decline has been smooth (Crawford et al., 2008).

4. Global trends and conservation status

Norman Ratcliffe and Geoff Hilton

Introduction

Assessing the global numbers, population trends and conservation status of the two rockhopper penguin species depends on synthesising the information presented on regional population estimates. This is a far from straightforward task, since the frequency and quality of counts varies enormously through time and space, such that annual variation in summed counts reflects patterns of missing values as well as real population trends. Moreover, summing counts to arrive at global population totals is problematic because the timing of the most recent counts differs substantially between sites. This approach will produce underestimates of current numbers when overall numbers are increasing and overestimates when they are declining.

This chapter infers global population size, trends since 1970 and conservation status using statistical and simulation modelling approaches, discusses the limitations of the outputs and makes recommendations for further modelling and survey work.

Methods

All available whole colony or archipelago counts of both rockhopper penguin species between 1970 and 2007 were extracted from the regional reports (Appendices 3 and 4). The 1970 cut-off point was consistent with earlier analysis of conservation status by Birdlife International. The counts were used to produce a complete site-year matrix, with missing counts adopting a value of -1.

All counts were treated as though they were free from sampling error, which is an oversimplification as many were derived from samples of density extrapolated to colony area. Ignoring this sampling error will lead to Type I errors in statistical testing and underestimation of confidence limits. Counts of sample sub-colonies that took place in between whole colony/archipelago censuses (e.g. at Marion Island, Falkland Islands (Malvinas)) were excluded from analysis, even though these could have improved temporal resolution. Data from plots within colonies can be included in trend analyses, but would require a hierarchical model design (Parsons et al., 2006) that was beyond the scope of this exercise.

Trends for each species were modelled using a log-linear model with a Poisson error distribution and log link, implemented in the freeware programme TRIM (Pannekoek and van Strien, 1996). This models time and site effects on counts, allowing prediction of missing values and estimation of rates of change with standard errors.

Model criticism was conducted using χ^2 goodness-of-fit tests and by plotting the standardised residuals (calculated by subtracting the fitted counts from those observed and dividing them by the square root of the fitted counts) against the fitted counts, time and region (Tristan da Cunha, Indian Ocean, Isla de los Estados, Falkland Islands (Malvinas) and New Zealand). These allow assessment of heteroscedasticity (i.e. increasing variance with the mean), non-linearity in trends with time and spatial variation in trends, respectively.

Conservation status was assessed from the modelled rate of population decline against the IUCN criteria A2 (since the declines may not have ceased, the causes are not understood and they may not be reversible: (Birdlife International, 2000). The metric used is the percentage decline in three generations or 10 years (whichever is greater) where generation time (T) is calculated as:

$$T = \frac{1}{(1 - Sa)} + A$$

where Sa is adult survival and A is age of first breeding. The decline thresholds used to allocate a species to threat category are:

Critical: $\geq 80\%$ over three generations/10 years	Endangered: $< 80\%$, $\geq 50\%$
Vulnerable: $< 50\%$, $\geq 30\%$	Near Threatened: decline approaches 30%
Least Concern: $\ll 30\%$	

Moreover, northern rockhopper penguins have a restricted range (occupying less than 10 sites and with an Area of Occupancy totalling $< 2,000\text{km}^2$), and so qualify as Vulnerable if a decline occurs, irrespective of the rate, according to criterion B2 a+b(v).

There are no reliable estimates of Sa or A for rockhopper penguins so uncertainty surrounding these was included in the assessment of conservation status by means of a Monte Carlo analysis, implemented in a bespoke programme written in Microsoft Visual Basic 6.0. Random values for Sa and A were drawn from a normal distribution with means of 0.85 and 5 and standard deviations of 0.025 and 0.3 respectively. These produced a range of values from 0.77 to 0.93 for Sa and 4 to 6 for A , which seems realistic given knowledge of demography of *Eudyptes* penguins.

These were substituted into Equation 1 to calculate T (average 11.7 years, range 8.3-18.5). Average population multiplication rates (l) for each species were taken from the results section. The percentage decline was calculated as $100 \cdot l^T$ and was used to determine the threat category using criteria A2 above. In the case of northern rockhopper penguins, any iterations being classed as *Not Threatened* were revised to *Vulnerable* in accordance with criteria B2 a+b(v). This procedure was repeated 10,000 times, and the likelihood of each threat category occurring for each species was calculated.

Results

Data were sparse for both species; there were no counts for northern and southern rockhopper penguins in 21 and 13 years respectively and single colony counts in 9 and 14 years, respectively (Table 1.4). This meant that the data were inadequate to support full time-dependent models, and so only models of linear trend with time were fitted.

Table 1.4 Observed counts of northern and southern rockhopper penguins between 1971 and 2007.

	Region	Site	Year	No. breeding pairs	Population change
Northern rockhopper penguin	Indian Ocean	Amsterdam	1971	58,000	57% decline over 22 years
			1982	53,000	
			1988	38,971	
			1990	31,000	
			1991	17,000	
			1992	37,000	
			1993	24,890	
		St Paul	1971	4,000	126% increase over 22 years
			1982	5,100	
			1988	5,000	
1992	8,900				
1993	9,023				
Tristan da Cunha/ Gough	Gough	1979	78,300	Considerable change	
		1984	142,800		
		2004	32,400		
		2007	64,700		
	Inaccessible	1989	22,000	18% decline over 15 years	
		1999	27,000		
		2004	18,000		
	Middle	1973	100,000	N/A	
	Nightingale	1973	25,000	22% decline over 32 years	
		2005	19,500		
	Tristan	1973	7,000	51% decline over 32 years	
		1992	3,343		
		1994	4,489		
		1995	3,185		
2004		3,861			
2005		3,421			
Southern rockhopper penguin	Indian Ocean	Kerguelen	1985	85,500	N/A
		Crozet	1982	152,800	N/A
			1987	100,000	N/A
		Marion	1973	212,000	68% decline over 28 years
			1994	173,000	
			2001	67,000	
		Prince Edward	1977	35,000	22% increase over 24 years
			2001	45,000	
Pacific Ocean		Antipodes	1973	50,000	92% decline over 22 years
		Auckland	1995	4,000	54% increase in 20 years
		Campbell	1972	50,000	N/A
		Macquarie	1992	2,700	N/A
			1986	51,500	
			2007	37,500	

Region	Site	Year	No. breeding pairs	Population change	
Patagonia	Falkland Islands (Malvinas)	1995	287,799	30% decline over 10 years	
		2000	298,496		
		2005	210,418		
	Pingüino	1994	170	295% increase over 13 years	
		1997	165		
		1998	275		
		1999	255		
		2000	365		
		2001	380		
		2002	400		
		2003	380		
		2004	414		
		2005	420		
	2007	501			
Chile	Estados	1998	173,793	N/A	
	Barnevelt	1992	10,800	N/A	
	Cape Horn	1992	600	N/A	
	Terhalten	2005	1,000	N/A	
	Buenaventura	1992	500	N/A	
	Ildefonso	2006	86,400	N/A	
		Recalada	1989		10,013
		1991	3,304		
	Recalada	2005	0	locally extinct (100% decline) in 16 years	
		Diego Ramirez	1981		112,738
Diego Ramirez	2002	132,721			
	Noir	1978	134,000	15% increase over 25 years	
2003		145,000			
2005		158,200			

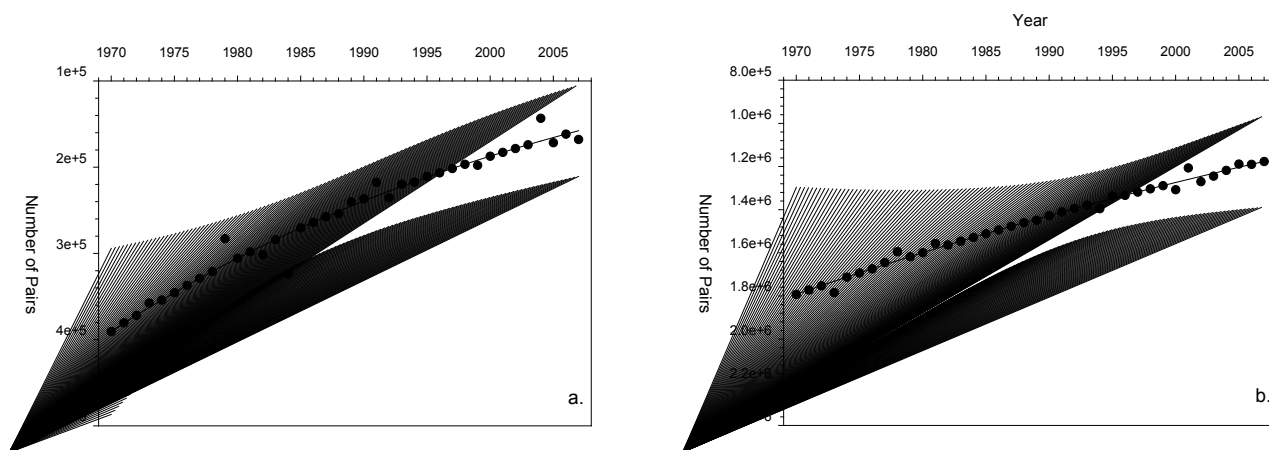


Figure 1.4 Global population trends of northern (left) and southern rockhopper (right) penguins. Y-axis values are expressed in scientific notation (i.e. 1e+5 is 100,000 and 1e+6 is 1,000,000). The solid line is the fitted trend and dotted lines are the 95% confidence interval of this. Solid black circles are imputed values, where observed counts have been substituted for fitted ones where available.

The goodness-of-fit of the linear models for both species was poor, with the predicted values being significantly different from those observed (northern: $c^2_{20} = 73,973$, $P < 0.0001$, southern: $c^2_{21} = 127,687$, $P < 0.0001$). This is indicative of rates of change being non-linear through time and/or variable among colonies. To account for this in statistical testing, the residual deviance was rescaled using an overdispersion parameter (northern: 3,698, southern: 6,080).

Both species exhibited a significant decline (Fig 1.4) (northern: $Wald_1 = 12.84$, $P < 0.0001$, southern: $Wald_1 = 4.21$, $P < 0.05$). The overall population multiplication rate (λ) was 0.976 (SE=0.007) for northern and 0.989 (SE=0.055) for southern, indicating annual decline rates of 2.4% and 1.1% respectively.

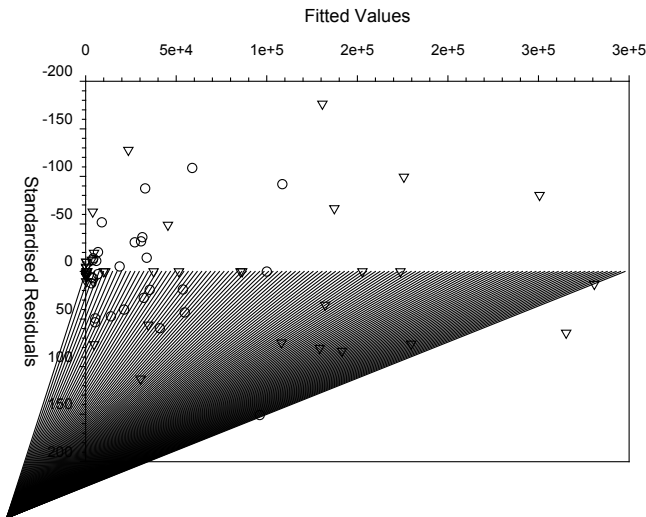


Figure 1.5 Standardised model residuals plotted against the fitted values. Open circles represent northern and open triangles southern rockhopper penguins. Note that the residuals are clustered around zero for fitted values < 10,000 pairs but tend to stabilise at higher levels.

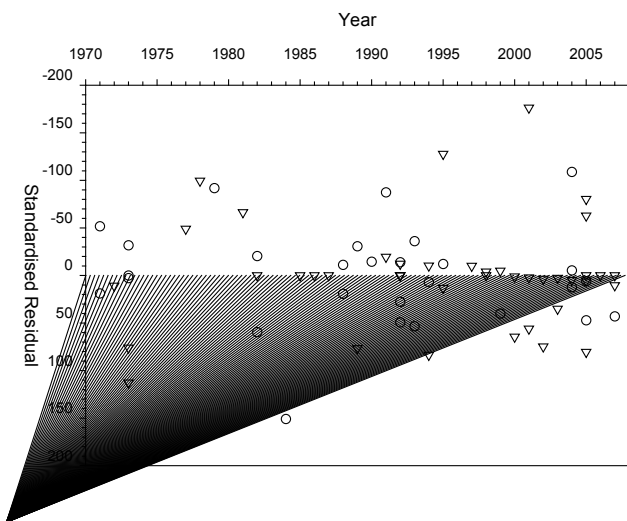


Figure 1.6 Standardised model residuals plotted against time. Symbols are as for Figure 1.5.

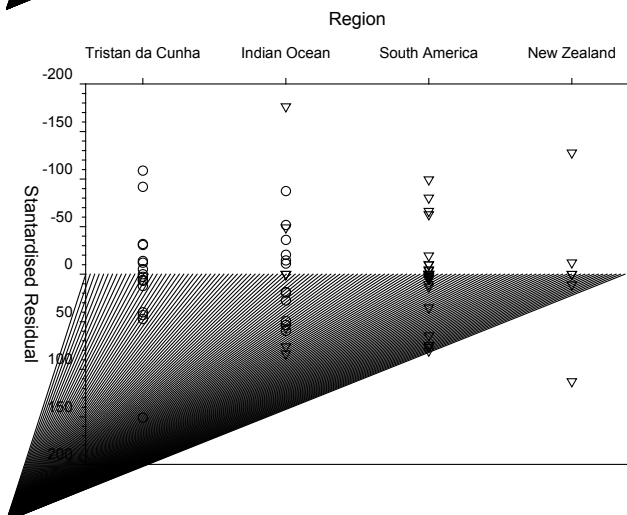


Figure 1.7 Standardised model residuals plotted against region. Symbols are as for Figure 1.5.

The number of northern rockhopper penguins has declined from 390,000 to 168,000 pairs over the past 37 years, and southern from 1,792,000 to 1,177,000 pairs; reductions of 57% and 34%, respectively. Note that the confidence intervals are wide for both species, but that precision improves through time, reflecting the increased count effort in the last decade.

Model criticism suggested some degree of heteroscedasticity, since variance was lower for those colonies with the smallest fitted values (Figure 1.5), though this stabilised above a threshold level of 10,000 pairs. This suggests that colonies of over 10,000 pairs have greater variance in counts, and most likely reflects size-dependent count or sampling errors. There was no clear pattern in the standardised residuals with time (Figure 1.6) or among regions (Figure 1.7), and so the poor fit seems to be largely due to a lack of synchronicity in rates of change across colonies and years at relatively fine spatial and temporal scales.

The Monte Carlo analysis of threatened status classed 99.4% of simulations for both northern as endangered and southern as vulnerable (these being identical coincidentally). The classification was therefore robust to plausible variation in generation times, with only 0.6% of simulations falling into alternative categories.

Discussion

The models fitted during this exercise assume that trends were linear and synchronous across sites, with errors being Poisson distributed. The poor fit of the model to the data indicated that these assumptions were not upheld. Examination of the residuals indicated that this was largely due to numbers at colonies varying independently at relatively fine spatial and temporal scales rather than non-linearity of trends across sites or variation in trends within regions. Common causes of colony-specific variation in rates of seabird population change at local scales are large-scale movements between colonies, asynchronous non-breeding events and density-dependence (Parsons et al., 2006). This variation resulted in wide confidence intervals around estimates of λ , but the decline remained significant despite this. Hence, we can have high confidence that an overall decline has occurred in both species, but there is high uncertainty in the magnitude of the decline and in the numbers predicted by the model for a given colony-year.

Improving the model fit would demand incorporation of time-dependent variation in population change within sites. This can be achieved using the Bayesian analyses described in Parsons et al. (2006) but these are unlikely to achieve convergence with the sparse data sets available for the two species of rockhopper penguin (A. Butler, pers. comm.). Alternatively, specification of covariates that explain the site-dependent variation in trends in the TRIM model could improve the fit, and also offer insights into the causes of population change (Pannekoek and van Strien, 1996). However, discussions at the workshop failed to identify a plausible set of explanatory variables that could be fitted as model covariates.

The accuracy of global population estimates rely on the assumption that all colonies in the world have been counted on at least one occasion. Following discussion at the workshop, this seems reasonable for the northern rockhopper penguins, and for southern rockhopper penguins except for a few colonies along the coast of Chile. However, it seems unlikely that these sites will host a large proportion of the global population however, and thus this negative bias will be minor and certainly within the large confidence intervals of the southern rockhopper penguin estimates.

While it is not possible to improve the quality of past data, workshop participants should make efforts to improve them in the future. A complete count of all sites in a single year would be highly desirable to obtain a global population estimate that is not biased by time effects. It would be sensible to time this to coincide with the next full census of the Falkland Islands (Malvinas) in 2010 given that this represents a large proportion of the task. More frequent counts of whole archipelagos or islands would also be desirable at intervals of five years. Annual variation in numbers between such censuses can be inferred from counts of a sample of representative sub-colonies, as is done for Marion Island and the Falkland Islands (Malvinas).

Birdlife International (2008b) lists northern rockhopper penguins as *Endangered* and southern as *Vulnerable*. The Monte Carlo analysis provided strong support for retention of this classification. Participants at the workshop noted, however, that the greatest declines of both species of rockhopper penguin occurred during a period greater than three generations ago, and so the current classification does not fully reflect the longer-term depletion of the global population.

5. Demography

Helen Otley, Sue Woodgate, Jo Elliott and Sarah Robinson

Breeding biology

Southern rockhopper penguins return to their breeding colonies in October, which range from sea level sites to cliff-tops, and sometimes inland. At some sites, such as in the Falkland Islands (Malvinas), rockhopper penguins nest amongst black-browed albatrosses *Thalassarche melanophrys* and king shags *Phalacrocorax atriceps*. Timing amongst the southern rockhopper penguin colonies varies by up to 6 weeks, being earlier at sites that are further from the Antarctic Polar Front. For example, the colonies at Ildefonso and Diego Ramírez Islands (Chile) commence breeding the earliest, one week ahead of the populations on Isla de los Estados and Isla Noir and three weeks ahead of the colonies on the Falklands (Malvinas) (Raya Rey et al., 2009).

They incubate eggs during November and December for 32-34 days (Table 1.5). When both eggs have been laid, the male leaves for a period of between two and four weeks to forage at sea while the female incubates the eggs. After the male has returned to the nest and taken over incubation duties, the female departs to sea, sometimes for a period of between 10 and 14 days to restore their energy reserves until the chicks hatch. However, the length of foraging trips can vary depending on food availability and foraging success.

Once the chicks have hatched, the female alone is responsible for provisioning the offspring regularly with food while the male takes over brooding duties. Mostly females make daily trips, with few staying away from the colony overnight. Only after the chicks have entered the crèches at 24-26 days of age will both parents engage in chick provisioning.

During February, the chicks fledge and depart the colony. At this point, the adults depart to sea to fatten up before returning to their breeding localities to moult. During moulting, they are ashore for several weeks, and do not feed. Thereafter (by mid May at the latest), they leave again to the sea to regain condition during the winter months.

The breeding cycle of the northern rockhopper penguin is similar to that of the southern species but the northern species begins some 6 weeks earlier (Table 1.5). Breeding at Tristan da Cunha is around 3-4 weeks earlier than at Gough Island (T. Glass pers. obs).

Table 1.5 A comparison of breeding chronology for the northern and southern rockhopper penguin at different sites.

		Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun
Tristan da Cunha	Male	W	W/A	I	B	B/C	C	PM/M	M	W	W	W	
	Female	W	W/A	I	B	B/C	C	PM/M	M	W	W	W	
Gough	Male	W	W	A	I	B	B/C	C	PM/M	M	W	W	W
	Female	W	W	A	I	B	B/C	C	PM/M	M	W	W	W
Chile	Male	W	W	W	A	I	I/B	B	C	PM	M	W	W
	Female	W	W	W	A	I	I/B	B	C	PM	M	W	W
Argentina	Male	W	W	W	A	I/B	B/C	C	PM	M	W	W	W
	Female	W	W	W	A	I/B	B/C	C	PM	M	W	W	W
Falklands (Malvinas)	Male	W	W	W	A	I	B	C	PM	M	M	W	W
	Female	W	W	W	W/A	I	B	C	PM	M	M	W	W
Marion	Male	W	W	W	W	A	I	B/C	C	PM	M	M/W	W
	Female	W	W	W	W	A/I	I	B/C	C	PM	M	M/W	W
Crozet/Kerguelen	Male	W	W	W	W	A	I	B	C	PM	M	M/W	W
	Female	W	W	W	W	A	I	B	C	PM	M	M/W	W
Macquarie	Male	W	W	W	A	A/I	I/B	B/C	C/PM	M	M/W	W	W
	Female	W	W	W	A	A/I	I/B	B/C	C/PM	M	M/W	W	W

Campbell	Male	W	W	W	A	I	I/B	C	C/PM	PM	M	M	W
	Female	W	W	W	A	I	I/B	C	C/PM	PM	M	M	W

(Key: Wintering=W; Arrive=A; Incubation=I; Brood=B; Crèche=C; Pre-moult trip=PM; Moulting=M).

Breeding success

Little is known about the breeding success and juvenile and adult survival of the northern and southern rockhopper species, as there are yet to be long-term monitoring programmes that follow the life history of individual rockhopper penguins. More is known about the southern than the northern species.

Breeding success of the northern rockhopper penguin at Amsterdam Island is highly variable, at 0.28, 0.35 and 0.52 chicks per pairs during the period 1993–1995 (Guinard et al., 1998). At Marion Island, Macquarie Island and Isla de los Estados, the breeding success of southern rockhopper penguins was 0.20 and 0.50, but in the Falkland Islands (Malvinas), it was much higher at 0.35–0.61 (Table 1.6). At most breeding sites, rockhopper penguins usually rear only one chick to fledging. However, there is some evidence that it is not unusual for rockhopper penguins in the Falkland Islands (Malvinas) to raise two chicks (Clausen and Pütz, 2002).

Table 1.6 Breeding success (fledged chicks per pair) for southern rockhopper penguin at four sites.

Island	Chicks per pair, min. & max. value reported	No. colonies	Period	Source
Marion	0.33 - 0.49	3	1985/86 to 2006/07	Crawford et al., 2008
Macquarie	0.47	1	1993/94 to 1995/96	Hull et al., 2004
Staten	0.23–0.31	1	2002/03 and 2004/05	Raya Rey et al., 2007b
Falklands (Malvinas)	0.35 - 0.61	8	1992/93–2006/07	Clausen and Pütz, 2002
	0.69	1	2006/07	Poisbleau et al., 2008

Survival

On Amsterdam Island, over a three year study, first year survival of northern rockhopper penguin chicks was estimated at 39%, and immature and adult survival at ~84%, although it is very important to note that these birds were flipper-banded, which may have negatively affected their survival probability. The authors did take steps to adjust for this (Guinard et al., 1998).

No long-term survival data exists for the northern or southern rockhopper penguin in the wild. The information for known age birds in the captive population is improving but is limited mainly due to the lack of long-term data on known age birds. However, in captivity, rockhopper penguins that survive to fledging live for up to 25 years (European studbook records) (Fig. 1.8). The mortality rate for 144 captive

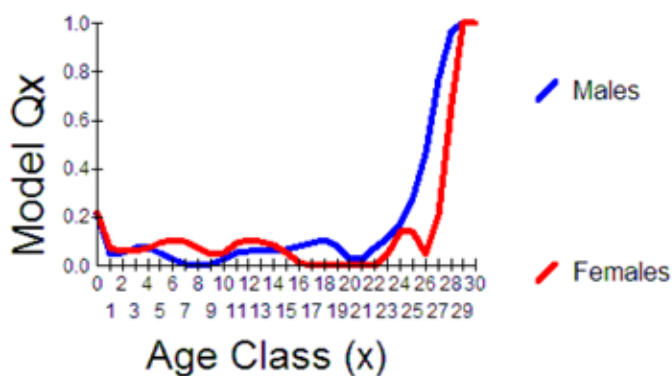


Figure 1.8 Age (year) specific mortality, i.e. the probability that an animal will reach the next age class, for northern and southern rockhopper penguins held in captivity in European zoos (data from European Association of Zoos and Aquaria).

chicks at 30 days old is 20%.

Breeding frequency

Captive breeding data from an unknown number of captive populations of both northern and southern rockhopper penguins held in European zoos shows that most males and females begin to breed at age four years and will continue to do so into their 20s. On Amsterdam Island, the youngest northern rockhopper penguin to recruit into the breeding population was 2 years, with a mean of 4.7 years (Guinard et al., 1998).

Based on the last 10 years of data for known age parents living in captivity in European zoos (17 events), halfway point between first breeding and dying (i.e. generation time) is 13.4 years of age for males and 18.2 years for females. However, data obtained of captive animals may not be representative of animals in the wild.

At Isla de los Estados, 76 adult birds were micro-chipped and monitored with a gate system for three breeding seasons. The return rate of the micro-chipped adults was 72 and 63% in the two years studied (Raya Rey et al., 2007b). On Macquarie Island, of approximately 200 banded birds in a study area, over three breeding seasons only 3% of males and 8% of females attempted to breed during all years (Hull et al., 2004). The authors did suggest that the low rate of annual breeding may be partly explained by the fact that not all birds in the study colony were banded permanently during the first season and that some banded penguins were disturbed by investigators, either through handling or through the attachment of flipper bands. However, Hull et al. (2004) concluded that the actual percentage of birds attempting to breed each year may still be low.

Skipping breeding seasons is not a very well studied phenomenon in penguins but has been studied in other long-lived seabirds. Breeding deferral in adult seabirds is a strategy to minimise the risk of mortality and is related to food shortage and large-scale environmental perturbations, which is taken to minimise the risk of mortality, mediated by body condition (Hull et al., 2004). If only a small proportion of breeding-age rockhopper penguins return to the island each year to breed, estimates of the population size may be a significant under-estimate.

Conclusions

Whilst the duration of breeding activities in the populations of northern and southern rockhopper penguin appear to be relatively similar, the timing of breeding differs by up to four weeks between populations in different regions. Little is known about the breeding success and juvenile and adult survival of the northern and southern rockhopper species.

No long-term survival data exists for the northern or southern rockhopper penguin in the wild and they can live for up to 25 years in captivity. The median age at first breeding for the northern rockhopper penguin on Amsterdam Island was 4.7 years and no data exists for the southern species. Breeding success in both species is highly variable, ranging between 0.2 and 0.5 chicks per breeding pair. It appears to be higher in the Falkland Islands than elsewhere, including some evidence of the ability to fledge two chicks in some seasons.

Breeding frequency is not known, although some studies over 2-3 years of marked individuals suggest that some birds do not breed every year. If only a small proportion of breeding-age rockhopper penguins return to the island each year to breed, estimates of the population size may be a significant under-estimate. The lack of demographic data is a significant impediment to understanding conservation status and diagnosing causes of decline.

6. Foraging location, dive behaviour and diet

Klemens Pütz, Petra Quillfeldt, David Thompson and Geoff Hilton

Foraging location during the breeding season

Foraging habitats of southern rockhopper penguins have been investigated during the breeding season at Isla Noir in the Chilean region (Raya Rey et al., 2009), Isla de los Estados (Pütz et al., 2006a), Falkland Islands (Malvinas) (Boersma et al., 2002; Pütz et al., 2003b, 2006a), Antipodes Island (Sagar et al., 2005) and Macquarie Island (Hull, 1999b).

During the incubation period, male rockhopper penguins from Isla de los Estados forage in deep waters extending south and east from the breeding site (Figure 1.9; Pütz et al., 2006a). Male rockhopper penguins from northern colonies in the Falkland Islands (Malvinas) foraged to the north of the islands while travelling in an anti-clockwise direction (Figure 1.9; Pütz et al., 2003b). Contrary to this, breeding birds from New Island in the southwest of the Falkland Islands (Malvinas) foraged to the west, sometimes as far as the eastern entrance of the Magellan Strait (Boersma et al., 2002). The same area was used by birds from Bird

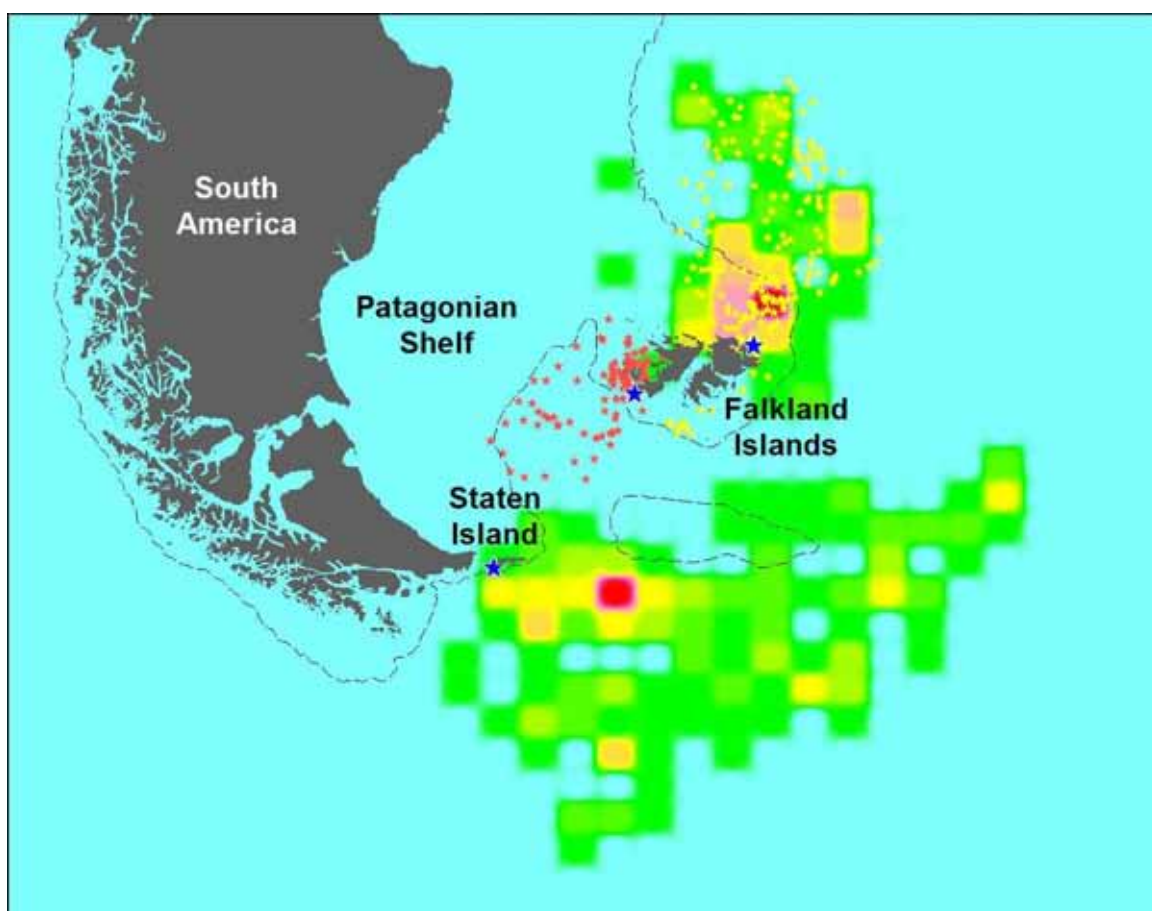


Figure 1.9 Foraging habitats of male southern rockhopper penguins during the incubation period from the Falkland Islands (Malvinas) and Isla de los Estados. Frequency distribution patterns are derived from GLS-locations (Mount Low colony, Falklands, $n=9$ birds in 2000; Isla de los Estados, $n=10$ birds in 2001), whereas symbols indicate positions obtained by satellite telemetry from penguins at the Seal Bay (Falklands) colony during incubation ($n=10$ birds in 1998 and 1999) and from birds at Bird Island (Falklands) during the pre-moult period ($n=4$ birds in 1999; Pütz et al., 2006a).

Island in the south of the Falkland Islands (Malvinas) during the premoult period (Pütz et al., unpubl. data). Breeding rockhopper penguins from Macquarie Island foraged to the east (Hull, 1999) and those from Antipodes Islands to the northeast (Sagar et al., 2005). In all cases, foraging range exceeded 100 km and included waters deeper than 200 m.

Foraging location during the non-breeding season

Migration of rockhopper penguins was studied at Isla de los Estados (Pütz et al., 2006b; Raya Rey et al., 2007a) and the Falkland Islands (Malvinas) (Pütz et al., 2002). Whereas breeding in Isla de los Estados is largely concentrated at one site, different breeding sites occur around the coast and islands in the Falkland

Islands (Malvinas). Research has shown that birds from the northern coast of the Falkland Islands (Malvinas) migrate mainly westwards towards the Argentine coast and northwards along the shelf break, whereas birds from a southerly breeding site also frequent the Burdwood Bank, an isolated extension of the Patagonian Shelf ca. 250 km to the south of East Falkland (Figure 1.10).

Only few rockhopper penguins from Isla de los Estados migrated to the Burdwood Bank, with the vast majority frequenting the northeastern coast of Tierra del Fuego and/or the Drake Passage as far south as the South Shetland Islands (Figure 1.10). One out of 24 satellite tracked birds also headed on a

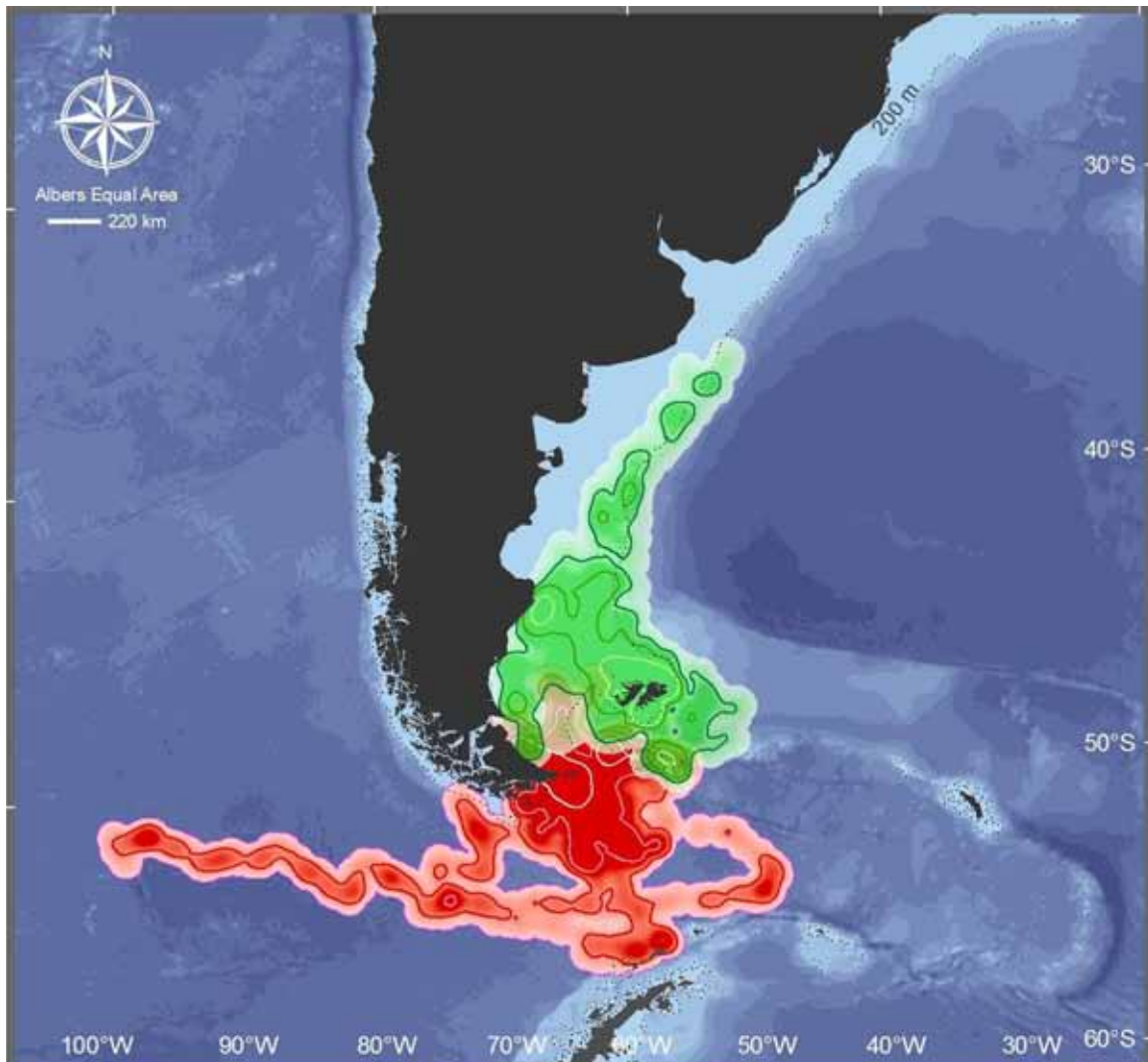


Figure 1.10 Kernel distribution of southern rockhopper penguin locations obtained from birds in the Falkland Islands (Malvinas)(green) and Isla de los Estados (red) during the initial part of the winter period (Data source - Pütz et al., 2002, 2006b; Raya Rey et al., 2007).

northwesterly course far into the Pacific. Only marginal overlap existed between the wintering areas of the two subpopulations on Isla de los Estados and the Falkland Islands (Malvinas), the division zone extending eastwards from the entrance of the Magellanic Strait.

Dive behaviour

The diving behaviour of incubating and brooding southern rockhopper penguins at the Falkland Islands (Malvinas), Isla de los Estados and Isla Noir is similar to that of conspecifics from the Indian and Pacific Oceans (Table 1.7; Raya Rey et al., 2009). However, comparatively, male and female birds from Isla de los Estados dived deeper, covered a greater vertical distance per hour and had higher ascent rates, but spent

Table 1.7 A comparison of selected dive parameters obtained from southern rockhopper penguins at a range of sites and from northern rockhopper penguins from Amsterdam Island (Source - Pütz et al., 2006a).

Location	Table 4 Comparison of selected dive parameters obtained from Rockhopper Penguins throughout their breeding range											
	Macquarie [Hull (2000)]	Staten (this study)	Falklands (this study)	Staten (this study)	Staten [Schiaivini and Raya Rey (2004)]	Falklands (this study)	Kerguelen [Tremblay and Cherel (2003)]	Crozet [Tremblay and Cherel (2003)]	Amsterdam [Tremblay and Cherel (2003)]	Amsterdam [Cherel et al (1999)]		
Subspecies	<i>Filbohi</i>	<i>Chrysolome</i>					<i>Filbohi</i>		<i>Moseleyi</i>			
Sex investigated	M & F	M	M	F	F ^a	F	F	F	F	F	F	
Study period	Breeding ^b	Incub	Incub	Incub	Brood	Brood	Brood	Brood	Brood	Brood	Brood	
Dives analysed (m)	≥6m	23	23	23	23	23	25	25	25	22	22	
Number of dives analysed	57,130	99,263	59,638	16,480	520	108,440	1,622	1,632	1,632	16,572	16,572	
Foraging trip duration (d)	c	22.2	13.3	12.3	0.65	0.61	0.50	0.47	0.51	0.51	0.51	
Foraging dives (%)	NR	87	91	84	90 ^d	83	84	83	79	NR	NR	
Time spent underwater (%)	37	38	40	32	69	63	64	64	62	68 ^d	68 ^d	
Dives per hour (n/h)	14.8	18.8	20.7	18.6	32.7	39.4	29.6	27.1	37.2	44.4	44.4	
Mean dive depth (m)	27.3	27.1	21.4	25.1	28.9	14.0	29.1	40.4	22.5	18.4	18.4	
Maximum dive depth (m)	104	101	93	79	113	66.5	85	104	9.3	109	109	
Vertical distance (m/h submerged) ^e	2,340	2,691	2,157	2,909	2,634	1,716	2,397	2,880	2,066	2,324	2,324	
Mean dive duration (s)	84.0	71.7	70.3	62.0	79.0	58.6	87.4	101.0	78.4	57.0	57.0	
Maximum dive duration (s)	660 (?)	184	153	140	164	189	177	190	193	168	168	
Mean bottom time (s)	27.6	19.6	26.6	21.2	35.0	23.1	54.7	57.4	41.8	28.4	28.4	
Bottom time (mins/h underwater) ^f	19.7	16.3	22.7	20.4	26.6	23.6	37.6	34.1	32.0	29.9	29.9	
Diving efficiency	NR	0.18	0.26	0.23	0.34	0.26	0.45	0.42	0.40	0.34	0.34	
Mean descent rate (m/s)	1.2	0.9	1.1	1.1	1.2	0.9	1.6	1.7	1.1	1.2	1.2	
Mean ascent rate (m/s)	1.0	0.8	0.8	1.0	0.8	0.8	1.3	1.3	0.9	1.0	1.0	

NR Not recorded
^aData only for daily trips^bData pooled over sexes and breeding stages
^cFor details on trip duration of both sexes during incubation and brooding see the text
^dCalculated from parameters provided in the respective study
^eCalculated for other studies from mean dive depth × 2 × no of dives/(mean dive dur × no of dives/3,600)
^fCalculated for other studies from mean bottom time × no of dives/(mean dive dur × no of dives/3,600)

less time underwater and at the bottom of a dive than birds from the Falkland Islands (Malvinas). The diving behaviour varies as a function of the physical and biological characteristics of the foraging areas and of the particular stage of the breeding season.

Diet determined by stomach contents

The diet of rockhopper penguins is subject to large temporal and spatial variation. In general, rockhopper penguins are opportunistic feeders, preying on a mixture of fish, crustaceans and cephalopods (Table 1.8). Southern rockhopper penguins in the Pacific and Indian Ocean sectors appear to focus on crustaceans, whereas cephalopods play an important part in the diet of southern rockhopper penguins in the Chilean and Patagonian region and for northern rockhopper penguins at Amsterdam Island.

However, in the 2003/04 breeding seasons in the Falkland Islands (Malvinas), incubating rockhopper penguins from Sea Lion Island in the south of the archipelago preyed exclusively on fish while their conspecifics from Steeple Jason in the northwest concentrated on crustaceans (Huin, 2005). This clearly demonstrates the large variation in their diet and makes it difficult to link their diet to any changes in their environment or human activities.

Table 1.8 Summarising diet data (by wet mass) collected over the entire breeding range of southern and northern rockhopper penguins.

Species	Site	Diet composition by wet mass	Source
Southern rockhopper penguin	Falklands (Malvinas)	53% cephalopods, 45% crustaceans, 2 % fish	Croxall et al.,(1985)
		50% cephalopods, 49% crustaceans, 1% fish	Cooper et al. (1990)
		53% crustaceans, 29 % cephalopod and 18% fish, large temporal & spatial variation	Pütz et al. (2001)
		mixture of fish, crustaceans and cephalopods, large temporal & spatial variation, ranging from 100% fish at Sea Lion Island to 98% crustaceans at Steeple Jason	Huin (2005)
		Incubation: 61% crustaceans, 39 % cephalopod and <1% fish, Chick-rearing: 51% crustaceans, 46 % cephalopod and 2% fish, Post-fledging: 8% crustaceans, 73 % cephalopod and 14% fish,	Thompson (1989)
	Estados	Mixture of cephalopods, fish and crustaceans: 74%, 87% & 67% cephalopods, 26%, 14% & 33% crustaceans (1999, 2000 & 2001), fish not estimated by mass	Raya Rey and Schiavini (2005)
		Mixture of cephalopods, fish and crustaceans (no % by mass given)	Raya Rey et al. (2007a)
	Noir	Fish (<i>Sprattus fuegensis</i>), crustacean (<i>Thysanoessa</i> spp.) and unidentified cephalopods	Venegas 1998
	Campbell	mainly fish, but also cephalopods and crustaceans	Marchant and Higgins (1990)
	Macquarie	70% euphausiids, 17% fish (myctophids)	Horne (1985)
Heard	69% euphausiids (<i>E. vallentini</i>), 17% fish (<i>K. anderssoni</i>)	Hindell (1988)	
	60% euphausiids, 29% fish (myctophids), 1% cephalopods	Hull (1999a)	
	91% crustaceans, 8% fish, 1% cephalopods	Klages et al. (1989)	
Crozet	71% crustaceans, 17% cephalopods, 11% fish	Ridou (1994)	
Kerguelen	95% crustaceans (<i>E. vallentini</i>), 4% fish, 1% squid	Tremblay and Cherel (2003)	
	97% crustaceans (<i>E. vallentini</i>), 3% fish	Tremblay and Cherel (2003)	
Northern rockhopper penguin	Marion	100% & 91% euphausiids, 0% & 6% fish, 0% & 3% cephalopods	Brown and Klages (1987)
	Amsterdam	50% cephalopods, 40% crustaceans, 10% fish	Duroselle and Tollu (1977)
		44% & 15% cephalopods, 25% & 64% fish, 31% & 21% crustaceans	Tremblay et al. (1997)
		44% crustaceans (<i>T. gregaria</i>), 44% cephalopods, 12 % fish	Tremblay and Cherel (2003)
Gough	94%, 92% & 90% crustaceans, 2%, 6% & 9% fish, 4%, 1% & 1% cephalopods	Klages et al. (1988)	

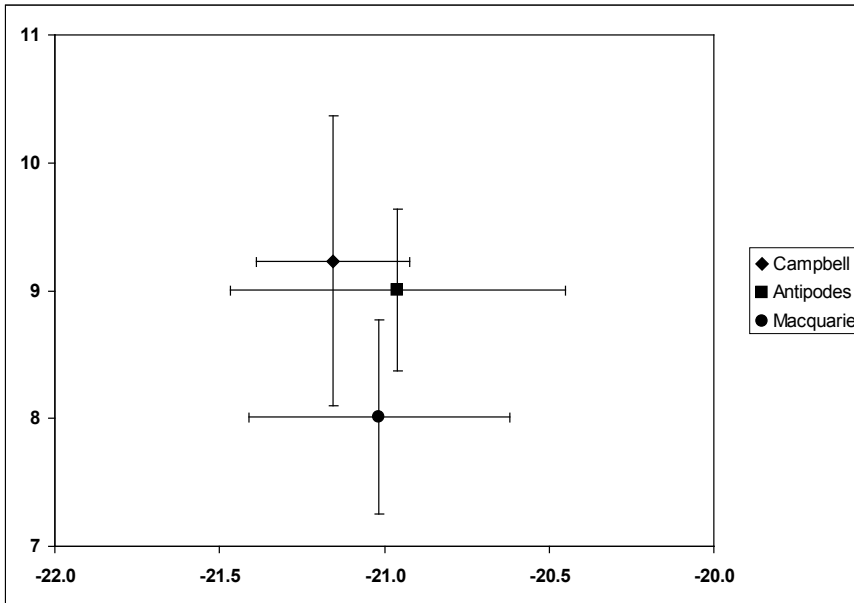


Figure 1.11 Summary contemporary isotope data for southern rockhopper penguins from three Pacific Ocean breeding locations.

Isotope data is expressed as mean isotope signature for each site (with error bars as plus/minus 1 s.d.), $\delta^{13}\text{C}$ values (as ‰) along the X axis and $\delta^{15}\text{N}$ (‰) values along the Y axis, using combined data for sites where samples were analysed for more than one year.

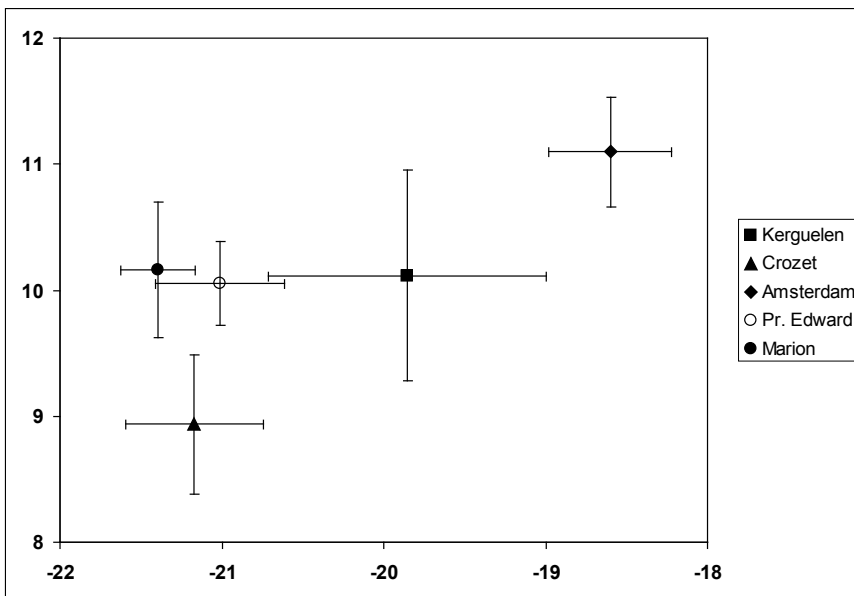


Figure 1.12 Summary contemporary isotope data for four sites of the southern rockhopper penguin and for one site for the northern rockhopper penguin in the Indian Ocean.

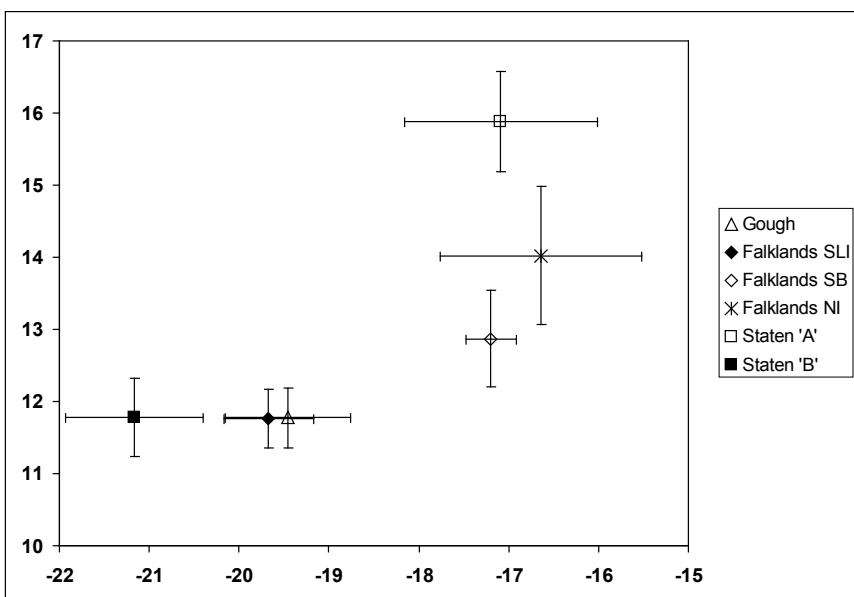


Figure 1.13 Summary contemporary isotope data for rockhopper penguins from three South Atlantic Ocean breeding locations. 'SLI' = Sea Lion Island,

'SB' = Seal bay,

'NI' = New Island.

Note that the separation of Staten samples into two groups was done post-hoc, based on the bi-modal nature of the data, and not on any prior known differences between the two groups of individuals.

Diet/foraging location determined by stable isotope analysis

Four studies of diet/foraging location determined by stable isotope analysis of northern and southern rockhopper penguins have been completed: historic and recent feather samples (Hilton et al., 2006), chick blood and nail data of southern rockhopper penguins from Crozet and of northern rockhopper penguins from Amsterdam (Cherel and Hobson, 2007; Cherel et al., 2007) and a dataset of contemporary feather samples from nearly all breeding sites of the northern and southern species (D. Thompson et al., in prep.) and a study on the feasibility of using egg membranes as a non-invasive sample for diet during egg production (Quillfeldt et al., submitted). Rockhopper penguin stable isotope data are also included in a comparative analysis of foraging ecology of seabirds breeding at New Island (Weiss et al., in press).

The feather data primarily represent feeding during the pre-moult exodus period, although there may be some integration of diet beyond this into the chick-rearing phase of the breeding season. In keeping with recent work confirming the broad latitudinal component encapsulated in the $\delta^{13}\text{C}$ signature (Cherel and Hobson, 2007), these data illustrate the wide range of foraging zones utilized by northern and southern rockhopper penguins prior to moult.

Southern rockhopper penguins from the three Pacific Ocean sites show much dietary overlap, and mean $\delta^{13}\text{C}$ signatures consistent with a sub-Antarctic/polar front foraging zone to the south of the breeding islands (Figure 3.11). Similarly, birds from the Indian Ocean appear to use polar frontal waters (Crozet, Marion and Prince Edward) (Figure 3.12). Birds from Kerguelen exhibited $\delta^{13}\text{C}$ isotope values over a wide range, probably indicative of both the polar frontal zone and inshore foraging, as opposed to sub-tropical foraging.

Birds from the Chilean and Patagonian sites exhibit the most interesting isotope signatures: birds from Staten and the Falklands Islands (Malvinas) have a bimodal distribution in $\delta^{13}\text{C}$ signatures, with relatively enriched values indicative of feeding over the Patagonian Shelf, and relatively depleted values typical of pelagic feeding (Figure 3.13). Isotopically, southern rockhopper penguins from Isla de los Estados and the Falkland Islands (Malvinas) show virtually no overlap with each other, which indicate that they use separate feeding zones based on $\delta^{13}\text{C}$ signatures (Hilton et al., 2006).

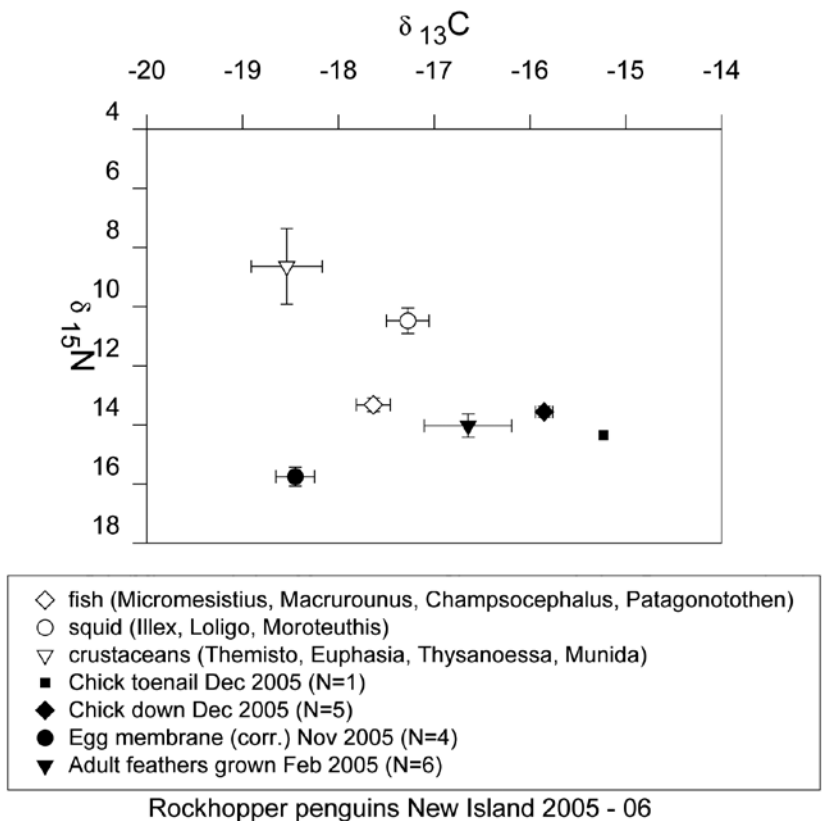


Figure 1.14 Southern rockhopper penguin data from New Island 2005–06 (Quillfeldt unpubl. data).

These data support the idea that birds from different sites within the Falklands (Malvinas), and even birds from within the same site at Isla de los Estados exploit different resources during the pre-moult exodus. Whether these diverse foraging strategies are reflected in life history characteristics of these different sub-populations remains to be determined.

Northern rockhopper penguins from Gough exhibit isotope signatures very similar to those from Sea Lion Island in the Falkland Islands (Malvinas) and reflect pelagic feeding prior to moult (Figure 3.13) and those at Amsterdam in the Indian Ocean forage in sub-tropical waters (Figure 1.12).

A number of other historical feather samples were collected and analysed at a number of sites (e.g. Macquarie, Heard and Marion/Prince Edward), but these were not included in Hilton et al. (2006) because sample sizes were insufficient. In addition, 21 historical samples from the Falkland Islands (Malvinas) and other sites from continental South America were collected and analysed. But it was not possible to include these in the global analyses, since collection data were not robust enough to enable an analysis that accounted for the highly spatial component of the Falkland Islands (Malvinas) and Isla de los Estados diet.

Some stable isotope analysis has also been carried out at New Island, Falkland Islands (Malvinas), using samples obtained during 2005-2008 (e.g. Weiss et al., in press) and the study is on going. Preliminary results suggest that the egg membrane can be used to determine stable analysis levels (using a correction factor) (Quillfeldt et al., submitted). For southern rockhopper penguins from New Island, during the egg formation period, more southern (or offshore) feeding grounds were used and higher trophic level prey (i.e. fish) was taken than during chick-rearing and moult periods (P. Quillfeldt, unpublished data, see Fig. 1.14).

Further stable isotope analysis of South American populations is possible because feather samples have been collected over different years from different colonies in the islands in Chile. There is also the opportunity to use eggs abandoned in captivity for correctional analysis to investigate individual differences. The use of toenails for stable isotope analysis could also be investigated rockhopper penguins held in captivity, which would be an ideal situation to determine toenail growth rates.

7. Captive populations

Sarah Robinson and Miguel Bueno

Twenty-eight zoos around the world hold northern and/or southern rockhopper penguin in captivity, holding 207 males, 196 females and 67 unknown individuals (International Species Information System website). Eight institutions in Europe have rockhopper penguins on display. These captive penguins provide an opportunity to study the species in a controlled environment and despite the obvious constraints, carefully planned research with captive animals can inform, test and qualify aspects of research in the wild. Colonies and the individuals within them can be closely monitored to reveal demographic and behavioural information. Tools used to monitor wild colonies can be tested and the effect of diet and non-intrusive methods for assessing diet can be experimentally measured.

New knowledge needs to flow between *in situ* and *ex situ* research programmes. Zoological societies, parks and gardens strive to maintain healthy populations of animals and constructive comments are welcomed from informed researchers.

APPENDIX 2 Threats

Introduction

It is not (yet) clear whether the ecological and demographic drivers of the current rockhopper penguin trends are the same as those that drove trends through the 20th century. Are current declines—for example in the Falkland Islands (Malvinas)—a continuation of the collapse of populations that numbered in the millions in the 1930-50s, or are new factors coming into play?

If the latter is the case, then diagnosing the cause of historic population crashes is largely an academic exercise (albeit a useful one for our understanding of marine food webs). If the former is the case, then understanding historic declines is critical to assessing current status and conservation options. Of course, a conservation assessment for the rockhopper penguin should also take account of potential future threats, of which the most obvious are global environmental changes, such as ocean warming and acidification.

A full understanding of population trends requires that both the ecological drivers and the demographic mechanisms of population decline are understood. In any attempt to diagnose causes of decline, it is important to be explicit about whether these are ecological or demographic, and about how the former influences the latter to drive population trends.

Putative causes of decline

1. Land-based - invasive alien predators, over-harvesting by humans, and anthropogenic disturbance at breeding/moulting sites
2. Isolated mortality incidents caused by pandemic disease and poisoning
3. Pollution
4. Fisheries interactions—bycatch and competition for marine prey
5. Climate change causing a drop in primary productivity that reduces prey availability
6. Climate change causing bottom-up food web shifts that reduce prey availability
7. Top-down changes in food web structure, leading to increased inter-specific competition between rockhopper penguins and other higher vertebrates (especially pinnipeds)
8. Top-down changes in food web structure, leading to increased secondary predation on rockhopper penguins by increasing marine mammal (especially pinnipeds) populations

Threat 1. Land-based threats

Petra Quillfeldt

A number of land-based threats have been identified for the northern and southern rockhopper penguins. These are tourism and research, human depredation, competitive interaction with native species, predation by native species, predation by invasive alien predators, habitat changes and natural disasters.

Tourism and research

Due to their relative isolation or difficult access, most northern and southern rockhopper penguin colonies have experienced very little direct disturbance from human visitors. Colonies in the Falkland Islands (Malvinas) receive the most visitors, although only some colonies such as New Island and West Point Island receive large numbers (e.g. 5-10,000 cruise ship passengers). The southern rockhopper penguin breeding sites in Argentina (Isla de los Estados and Isla Pingüino) have only small-scale tourism. In Chile, there is a suggestion that the Government plans to rent Isla Diego Ramirez for tourism, and this development may have to be evaluated regarding the potential disturbance.

All cruise ship companies that visit rockhopper penguin colonies operate to International Antarctic Association of Tourism Operators (or similar) standards, which has a maximum approach distance of 5 metres for all wildlife. On New Island, the breeding success of sub-colonies of southern rockhopper

penguins with either close, distant or no tourism was monitored. Each category of tourism level showed highly variable breeding success and it was concluded that tourism did not influence the breeding success of the rockhopper penguin (Catry et al., 2007).

Studies at New Island and Macquarie Island found no influence of disturbance and handling by researchers on the breeding success and chick growth of rockhopper penguins (Hull and Wilson, 1996; Poisbleau et al., 2008). These studies of tourism and research on rockhopper penguins and those of other penguin species suggest that individual penguins are more physiologically stressed in the presence of tourists or researchers when they are not accustomed to seeing humans (Fowler, 1999). Thus, where possible, tourism should focus on delimited areas (spatial zoning), such that birds in visited areas can habituate to the presence of people. Furthermore, a minimum distance and a slow approach are also recommended.

Tourists and researchers could be potential "vectors" for pathogens. Tourists visiting colonies should go through an appropriate footwash (on the ship or upon arrival on the islands). Researchers should follow specific biosafety guidelines for all activities, including visits to colonies and handling individual birds.

Human depredation

Egg collection was common in some northern and southern rockhopper penguin colonies until the 1950s, such as in the Falkland Islands (Malvinas) and on Tristan da Cunha, but is now prohibited at both territories. Rockhopper penguins were taken historically as bait for use in crab pots at a number of sites, including at St Paul (Indian Ocean), Tristan da Cunha and some Chilean islands. The case of the disappeared rockhopper penguin colony of Isla Recalada in Chile indicates that human depredation, in this case the collection of zoological specimens and as bait for crab pots (Oehler et al., 2007), is still a serious threat to colonies where sites are not well protected and are accessible. The number of birds taken in recent years from other Chilean colonies is less than 500 individuals per year (M. Marin pers. comm.).

Competitive interaction with native species

Competition for nest sites may occur, for example at some Chilean islands with Macaroni penguins (Oehler et al., 2008), and at sites in the Falkland Islands (Malvinas) with king shags and black-browed albatrosses. However, competition for nest sites is unlikely to account for significant population declines.

Predation by native species

A number of predators like skuas (*Catharacta* spp.), striated caracaras (*Phalco boenus australis*), giant petrels (*Macronectes* spp.), fur seals (*Arctocephalus* spp.) and sea lions (*Otaris* spp.), prey on rockhopper penguins. In the case of skuas, caracaras and giant petrels, the shape of the colony, the proportion of nests on edges and presence of vegetation determines the relative impact of the predation (Jackson et al., 2005; Liljeström et al., 2008). These aerial predators could accelerate the fragmentation of rockhopper penguin colonies, leading to more 'edges' and thus greater predation by birds. It is clear that a relatively stable but small population of skuas, caracaras or giant petrels would have relatively limited impact on a large penguin population, but that the same bird population would have a far greater impact on a small penguin population, such that a much-reduced penguin population would then be impacted. The breeding success and population trajectory of small and fragmented colonies are more likely to be effected by avian predation, and increasingly so as the colonies shrink in size.

Giant petrels, fur seals and sea lions mainly prey on rockhopper penguins in the waters adjacent to colony areas. Their predation on penguins can be intense (e.g. Guinard et al., 1998; see Argentina regional report). Observations of predation of macaroni penguins by fur seals at South Georgia suggest that the intensity of predation is often related to the number of specialized individual seals (J. Croxall pers. obs.), and that predation rates decreases when the number of penguins declines. However, specific studies on predation rates of rockhopper penguins are necessary to elucidate the degree of the effect.

Predation by invasive alien predators

The only reported cases of major predation by invasive mammals on rockhopper penguins are feral pigs on Tristan and Inaccessible (where pigs were eradicated in 1873 and 1930, respectively) and at Auckland Islands where plans for eradication await funding. Domestic and feral dogs were also reported to be a problem on Tristan da Cunha.

Feral cats are found at some sites where northern and southern rockhopper penguins breed, but they appear to rarely prey on penguins. On Campbell Island, Dilks (1979) found no rockhopper remains in the diet of feral cats and at New Island in the Falkland Islands (Malvinas), penguin remains were found in only 3 of 370 cat scats examined during two years (Matias and Catry 2008) .

There is none or very little indication that feral mice, which are found on some islands in the Falklands (Malvinas) and Antipodes and Auckland Island, black/ship rats (e.g. found on one island in the Falklands (Malvinas)) and Norway rats (e.g. islands in the Falklands (Malvinas), Macquarie, Crozet, Kerguelen) prey on rockhopper penguins (Quillfeldt et al., 2008b). Although given the predatory nature of house mice on other seabird chicks on Gough, investigation into potential impacts on chick survival of northern rockhopper penguins may be warranted. Cunningham and Moors (1994) carried out cage trials with Norway rats and large seabird eggs (i.e. size of rockhopper egg) and showed that they were only able to break into eggs that were already cracked or damaged. The authors mentioned disease transmission by rats (e.g. avian cholera), as a possible indirect influence of the presence of rats.

Habitat issues

Both the northern and southern rockhopper penguin appear to prefer colony areas with some vegetation, which probably provides both ground stability and protection from aerial predators. At some sites, introduced grazing animals have caused significant vegetation loss and at Macquarie Island, overgrazing by rabbits has led to serious landslips. On the Falkland Islands (Malvinas) and on some islands in the Indian Ocean, southern rockhopper penguins do not appear to be effected by the presence of livestock such as sheep, cattle and horses. Rabbits on Macquarie Island cause significant landslips, which may lead to the loss of some nesting habitat. The effect of grazing of tussock grass by goats and deer on southern rockhopper penguins at Isla de los Estados is not known and should be investigated.

When ashore, fur seals and sea lions can destroy the vegetation, and the size of damaged sites will increase with the expanding fur seal populations at many islands where northern and southern rockhopper penguins breed. Some concern about the amount of destruction of penguin breeding habitat has been expressed for Gough Island and at Middle Island in Tristan da Cunha Group.

Natural disasters

Fire, landslips following heavy rain and volcanic eruptions (on Tristan da Cunha only) are the only natural disaster type events that are recognised as having the potential to affect the northern and southern rockhopper penguin. Wildlife disease is covered separately as Threat 2. However, any effects are likely to be localised and the fire history on islands in the Falkland Islands (Malvinas) suggest that rockhopper penguins are not affected in the medium and long-term by fires.

Summary

Land-based threats do not appear to play a major role in the recent declines of northern and southern rockhopper penguins (Ellis et al., 1998). Rockhopper penguins appear to persist in the presence of a variety of introduced animals and although tourism and recreation activities are growing in extent and intensity at many coastal sectors, these activities if appropriately managed generally appear compatible with seabird conservation. However, smaller colonies may be more significantly affected by some land-based threats than larger colonies and thus some of the threats may become more important if population sizes continue to decline.

Threat 2. Isolated mortality incidents caused by disease and poisoning

Marcela Uhart, William Karesh and Helen Otley

Introduction

Disease is defined as any impairment that interferes with or modifies the performance of normal functions, including responses to environmental factors such as nutrition, toxicants, and climate, infectious agents, inherent or congenital defects or combinations of these factors (Wobeser, 1981).

Penguins may be a good sentinel of marine environmental health because they are dependant of marine resources. They are particularly susceptible to catastrophic events and disease epidemics because of their colonial nature and their annual migration exposes them to a variety of threats in areas that can be difficult to manage and monitor (Uhart et al., 2002).

Long-term health monitoring is instrumental in the interpretation of the present status of seabird populations and the prediction of future trends (Uhart et al., 2007). The south west sector of the South Atlantic Ocean is subject to significant human modifications both on land and at sea, including fishing, tourism, oil exploration and drilling, mining, industrial establishment and urban development. A thorough understanding of wildlife health is useful in helping to develop appropriate tourism and research visitation procedures that should reduce the risk of introducing and/or spreading infectious diseases (see section on impact on colonies above).

Infectious disease outbreaks

There needs to be an appropriate interaction between the host, the pathogen and the environment for a disease outbreak to occur. Triggers of disease include changes such as increased host density and/or susceptibility (i.e. poor condition), the introduction of a new pathogen, and a change in the environment. The overall disease process must be considered in ecological terms.

Epidemics of particular diseases such as avian pox and avian flu have caused death of significant proportions of populations of seabirds worldwide. There are few records of disease outbreaks in rockhopper penguins, although very few colonies are visited regularly. Avian cholera has caused deaths of a small number of adults and chicks at Campbell Island in 1985/86 (de Lisle et al., 1990). Several hundred macaroni penguins (*Eudyptes chrysolophus*) died of avian cholera at one colony at Marion Island in 2005 (B. Dyer pers. comm.). Avian cholera is probably the major cause of the decrease on Amsterdam Island of the yellow-nosed albatross (*Thalassarche chlororhynchos*) (Weimerskirch, 2004).

In the Falkland Islands (Malvinas), gentoo penguins at five colonies in the south-west region were affected by avian pox; a previous outbreak occurred in the 1960s in black-browed albatrosses at one colony (Munro, 2007). Avian pox was detected in two Magellanic penguin colonies in Argentina during 2007/08, with at least 40 chicks severely affected (Uhart et al., 2008d). Phylogenetic analysis of the avian pox strains from the 2006 Falkland Islands (Malvinas) and 2008 Argentina outbreaks are underway, but the Argentinean strain is closely related to a strain isolated from black-browed albatrosses from the Falkland Islands (Malvinas) in 2003 (Uhart et al., unpublished data).

Disease exposure

Some penguins from the Antarctic and sub Antarctic regions have been tested for the presence of antibodies for a variety of bacteria and viruses. Antibodies to three types of avian viruses have been detected: Newcastle disease virus (paramyxovirus type 1), other paramyxovirus avian influenza viruses and infectious bursal disease virus. However, isolations have been limited to only a few pathogens and no clinical signs of disease have been observed or reported.

There has been some limited antibody testing of penguins from Campbell Island, with avian malaria antibodies present in yellow-eyed penguins but absent from rockhopper penguins (de Lisle et al., 1990). Infectious disease in rockhopper penguins in the Falkland Islands (Malvinas) was investigated and considered in depth during the investigation of the mortality event of 1985/86 in the Falkland Islands (Malvinas). The following were eliminated without reasonable doubt: bacterial infections (including chlamydiosis), mycoses (protozoan infections including haematozoa), helminthiasis and viral infections (Keymer et al., 2001). Specific examinations for some unlikely pathogens such as Rickettsiae or *Mycoplasma* spp. were not carried out in 1986. Haematology tests (e.g. haemoglobin, red cell counts, lymphocytes, etc) of rockhopper, gentoo and Magellanic penguins from the Falkland Islands (Malvinas) in 1986/87 were not different from specimens held captive in the UK (Hawkey et al., 1989).

Vets from the Wildlife Conservation Society (WCS) have collected samples from a variety of seabirds in the Falkland Islands (Malvinas) and Patagonia, including rockhopper penguins (Karesh et al., 1999). Sampling occurred in the Falkland Islands (Malvinas) in 2003 of black-browed albatrosses, gentoo penguins

(*Pygoscelis papua*), rockhopper penguins and Magellanic penguins, in 2007 of rockhopper and Magellanic penguins and in 2008 of black-browed albatross and rockhopper penguins. The 2008 Falklands (Malvinas) samples are currently being analysed at specialized labs in the USA. The 2003 Falklands (Malvinas) samples indicated that generally the seabird populations are remarkably free of exposure to infectious diseases when compared to populations on mainland South America (M. Uhart, unpublished data). It suggests that the Falkland (Malvinas) populations to date have not been exposed to common infectious agents found elsewhere and therefore may be naïve and susceptible to disease. However, more specifically, the rockhopper penguins sampled on East Falkland had similar pathogen exposure, with some variation, to rockhopper penguins breeding on Isla Pingüino, Argentina (Karesh et al., 1999; Karesh et al., unpublished data). Exposure to Newcastle disease virus (paramyxovirus type 1) was found at both localities, although the prevalence was higher in Patagonia. In addition, an undescribed serotype of paramyxovirus was found in samples taken from East Falkland in 2007, and this is currently being identified (D. Swayne, personal communication).

A significant finding in 2003 was the presence of antibodies to avian influenza viruses in rockhopper penguins from East Falkland because exposure to this virus has not been detected in any other species of bird tested in the Falkland Islands (Malvinas) and it is not commonly found in wild penguins from Argentina (Uhart et al., 2003; Pereda et al., 2008; Uhart et al., 2008b). However, low pathogenicity strains of avian influenza viruses are not uncommon in wild waterfowl from the northern hemisphere, while very little is known for the southern hemisphere. In February 2007, the WCS vets collected further swabs from the rockhopper penguins in an attempt to isolate the virus that produced the previous test results. Results to date are negative for avian influenza viruses. Overall, rockhopper penguins breeding near to Magellanic penguins on East Falkland had an overall higher prevalence of antibodies to infectious agents (Uhart et al., unpublished data). The main differences were the presence of antibodies to avian influenza and Newcastle disease viruses in rockhopper penguins and a higher aspergillosis and *Chlamydomphila* spp. exposure in Magellanic penguins, which could be related to their burrowing nature (Uhart et al., 2007).

The significance of the presence of these disease antibodies remains uncertain, especially as the viruses themselves have been only rarely isolated. It is important to note that serological studies (antibodies in blood) suffer from inadequate reagents for precise diagnosis in wild birds, and from insufficient knowledge of the immune responses of penguins to viral and bacterial antigens, which makes the interpretation of results difficult. As well, some of the viruses in these groups occur in a number of serotypes that vary in pathogenicity. Thus, it is possible that birds infected with viruses of low pathogenicity may develop resistance to related but more dangerous serotypes (i.e. non-PVM1 paramyxoviruses could protect against infection with PMV1).

It should also be considered how penguins and other seabirds due to their movements could potentially transmit these viruses at sea and winter migrations.

Harmful algal blooms

A rockhopper penguin die-off event was recorded late in the 1985/86 breeding season. Starvation was diagnosed as the primary cause of death, possibly related to a shortage of krill due to an unusually long period of hot weather conditions (Keymer et al., 2001). The authors ruled out red tide toxins but without explanation. However, the histopathology results were very similar to those from animals poisoned by a harmful algal bloom that occurred in 2002/03 (see below). A number of factors can drive animals to starvation, including diarrhoea. Collecting samples that are suitable for harmful algal bloom (HAB) poisoning needs rapid response and appropriate storage means, which may not have been available in 1985/86.

A large-scale seabird mortality occurred in the Falkland Islands (Malvinas) from December 2002 through January 2003, involving large numbers of many seabird species, including gentoo penguins, rockhopper penguins and Magellanic penguins, black-browed albatrosses, thin-billed prions (*Pachyptila belcheri*), common diving petrels (*Pelecanoides urinatrix*), rock shags (*Phalacrocorax magellanicus*), king shags and Falkland steamer ducks (*Tachyeres brachypterus*). Birds were reported at colony areas sick or dead, particularly in the north and west sectors of the Falkland Islands (Malvinas) and colonies were reduced to 10% of their usual size in some areas and in other areas entire breeding

sites were abandoned even though eggs had been laid (Huin, 2003). Exactly how the rockhopper penguins in the Falkland Islands (Malvinas) were affected by the HAB event is difficult to determine because not all known colonies were surveyed during the event.

Water samples were collected at the time from between West Point and New Island, south of Falklands Sound, Beaver Island, New Island, Queen Charlotte Bay and Goose Green/Darwin area and although dinoflagellate algae capable of producing toxin were found in two of the samples taken, the levels were not quantitatively large enough to qualify as an algae bloom (Huin, 2003). Samples from healthy, clinically ill and dead seabirds from both affected and non-affected colonies were collected and some severely affected gentoo penguins were euthanized and necropsies conducted. Based on the signs observed in clinically ill penguins and the overall characteristics of the event, paralytic shellfish poisoning (PSP) was suspected. Five of eleven penguins tested positive for component chemicals of PSP, with one or more tissues having levels above those considered unsafe for humans. They also had low or trace levels of other PSP toxins. Samples collected from euthanized or dying animals proved to be better for toxin isolation, compared to those from animals found dead, even if they were fresh. There was no gross necropsy finding of significance and bacteriology was negative. Infectious disease serology on the euthanized penguins and on a sample of apparently healthy animals at various locations revealed no positive animals, except for avian adenovirus, which was found in both clinically ill and healthy individuals. The exact mechanism for the PSP in 2002/03 was not identified because the prey of the seabirds could not be collected at the time.

PSP toxins have been previously reported in sardines and in higher trophic level feeders such as mackerel and anchovy in the South Atlantic and 'red tide' organisms of the genus *Alexandrium* have been reported in the waters of Argentina and Chile since the early 1980s. HABs are thought to occur during periods of warmer water, less wind and/or water mixing and shallower, coastal waters are more likely to experience these conditions than more pelagic waters. This makes coastal foragers such as gentoo penguins more susceptible to HABs than rockhopper penguins, although because how the toxins are accumulated up the food web is not known, relative risks to different species are still not clear. The Falklands (Malvinas) HAB of 2002/03 is the first report of PSP affecting and/or killing large numbers of seabirds in the South Atlantic Ocean. Although it is highly possible that similar events have occurred before in this area (e.g. in Patagonia in 2000, (Quintana et al., 2001), the identification of toxins in tissues of affected or dead animals had not previously been successful. The frequency and severity of HABs in the South Atlantic also appears to be increasing (Shumway et al., 2003). In 2006, PSP toxins were diagnosed as the cause of a mortality of kelp gulls and terns at two breeding colonies in northern Chubut (Uhart et al., 2008a).

In order to diagnose future toxin-related mortality events, regular monitoring of plankton in coastal waters as well as an immediate response team to investigate wildlife mortalities as they are reported must be established in the area. The experience gained during the investigation of the 2002/3 event has shown that there must be an organized, joint multi-agency effort with governmental support for successful and timely diagnosis.

Summary

It is not thought that disease and poisoning events (except perhaps in the Falkland Islands (Malvinas) are implicated in the historic and contemporary decline of the rockhopper penguin. However, with climate change and an apparent increase in the frequency and severity of HABs in the South Atlantic, this threat may be more important in coming years.

Threat 3. Pollution

Helen Otley

Chemical pollution

During the late 1970s, the levels of organochlorine (e.g. DDT pesticides) and polychlorinated biphenyls (PCBs) in the eggs of sea, coastal and inland birds of the Falkland Islands (Malvinas) were measured. The levels of these persistent organic pollutants in the Falkland Islands (Malvinas) were of a magnitude less than that reported for comparable northern Germany species (Hoerschelmann et al., 1979).

The levels of heavy metals and radio-activity were determined for a number of rockhopper penguins from the Falkland Islands (Malvinas) that died in 1986 and healthy individuals in 1987 (Keymer et al., 2001). Levels of heavy metals and radioactivity were below levels that induce toxic effects or were not different between dead and healthy specimens. Low levels of lead and organochlorines were reported in Magellanic penguins in the central-southern part of Patagonia (Schiavini et al., 2005).

Plastics pollution

The amount of marine debris in all ocean systems has at least doubled in the last decade, particularly in the form of plastics. In the Falkland Islands (Malvinas), monthly beach surveys during the 2001/02 summer at Volunteer Beach (East Falkland) showed an accumulation rate that was about that expected for its location and degree of fishing vessel activity (Otley and Ingham, 2003). Most debris found on beaches is fishing equipment and household waste that appears also to have come from fishing vessels.

Most vessels that work around the South Atlantic Ocean are flagged to countries that are signatories to MARPOL, which prohibits the disposal of plastics at sea. However, an unofficial report based on Falkland Islands Fisheries Department Fisheries Observer reports from 2001 - 2002 found that observers on 35 trips reported no waste disposal system in operation on 20 vessels, particularly in Asian jigging fleet and finfish trawlers. The current state of affairs has not been recently reviewed and it is an area that the Falkland Islands (Malvinas) should attempt to improve.

A handful of penguins have been found dead on Falkland Islands (Malvinas) beaches entangled in fishing nets (H. Otley pers. comm.). Of 40 dead first year Magellanic penguins washed ashore in Brazil, 42% had plastics in their stomach, mostly likely bits of plastic bag (Pinto et al., 2007). However, it was unclear whether this caused or was a contributory factor to death.

Monitoring the rates and effects of marine debris ingestion by rockhopper penguin is identified as a priority action in the Australian Species Action Plan (Garnett and Crowley, 2000), although the presence of plastics in the stomachs of southern rockhopper penguins from the islands of Macquarie, Heard and MacDonald has not been documented (Hull, 1999a).

Oil pollution

Under MARPOL 73/78 regulations, no oily wastes should be disposed of at sea but oil-contaminated ballast water and tank washing at sea seem to occur as well as the accidental release of oil by spills or shipwrecks.

Argentina has an Oil Spill Contingency Plan for the Patagonia/Tierra del Fuego area. Currently, no plan exists for management of a major oil spill at Tristan da Cunha and given the isolation of all the islands and limited resources, the ability to handle such disasters is limited. The Falkland Islands Government adopted an Oil Spill Contingency Plan in 1998 and it is due for revision in 2008. Some failings have been identified in two recent incidents where vessels have gone aground or sunk.

Within Falkland Island (Malvinas) waters, there has been a number of small acute light fuel (i.e. marine gas oil) spills from vessels unknown, ones with mechanical problems and vessels that have run aground. More recently, a fishing vessel sunk in Berkeley Sound, a sheltered bunkering area close to Stanley, which has released an amount of both light and heavy fuel oil. At the time of the spill, rockhopper penguins were absent from the colony having finished breeding and dispersed from the colony. If the spill had occurred during the breeding season, there could have been significant mortality.

Rock shags and king shags were present in the area at the time of the oil spill and over 30% of the shags seen in the week after the vessel sunk were recorded with oil (Falklands Conservation, unpublished data). Penguins as flightless birds would have been more susceptible to surface oil and the heavy oil trapped in the kelp would have affected all birds accessing or departing the colonies. Overall, the annual number of oiled seabirds reported in the Falkland Islands (Malvinas) is relatively low and few long lasting effects on the inshore or offshore environment have been documented associated with acute oil spill events.

Although oil extraction is yet to occur in the Falkland Islands (Malvinas), one Environmental Impact Assessment (EIA) for exploratory drilling to the north of the islands has been accepted and one is in preparation for the southern region. The EIA includes details to prevent oil pollution and response to any accidental spills.

The coasts of Brazil, Uruguay and Argentina have extensive maritime activities that may result in petroleum discharge. From Salvador down to the border with Uruguay, Brazil has 21 maritime main harbours, 43 oil terminals and 96 active oil platforms and Uruguay has one important port at Montevideo and an oil terminal nearby at Punta del Este. In Argentina, there are 11 main oil terminals and 17 harbours (Ruoppolo et al., no date). There is also extensive international cargo shipping to and from the Atlantic and Pacific Oceans.

It has been estimated that 40,000 Magellanic penguins in Argentina alone die annually as a result of contamination with oil (Gandini et al., 1994) and the number of reported oiled penguins has greatly increased since the early 1990s and is strongly correlated with petroleum exports from Argentina (Garcia-Borboroglu et al., 2006). More adult Magellanic penguins are found oiled than juveniles and even small amounts of petroleum reduced reproductive success in Magellanic penguins.

It is thought that chronic petroleum pollution (i.e. small but frequent oil discharges) account for most long-term environmental damage. In 1997, tanker routes were moved further offshore in Argentina by law and north and south tanker routes were separated to reduce the probability of accidents resulting from boat collisions. However, whilst this may have been of benefit to the more coastal foraging Magellanic penguin, the routes may now be in the foraging areas of the rockhopper penguin.

Although fewer penguins are now oiled along the coast of Argentina, many are still being oiled along the coasts of Uruguay and Brazil (Ruoppolo et al., no date). Garcia-Borboroglu et al. (2006) estimated that petroleum-covered Magellanic penguins could travel up to 1500 km before their fat reserves forced them to retreat to land to remain warm and therefore they are likely poor indicators of the exact location of chronic oil pollution. Oiled rockhopper penguins may not make it to land as they forage further offshore than Magellanic penguins. Thus, where this oil is coming from is not known, but the problem seems to be major, as annually there are several rescue centres cleaning oiled penguins along their distribution range.

Less is known about the movement of vessels in the south-eastern sector of the South Atlantic Ocean, where rockhopper penguins from Tristan da Cunha and Gough Island may forage. Few oiled birds are sighted. An oilrig drifted and eventually wrecked on Tristan da Cunha after being released by a tug during a storm. Whilst the oilrig did not contain oil, biosecurity issues were raised.

Summary

Chemical pollution does not appear to be implicated in the decline in the populations of northern or southern rockhopper penguins. Although some penguins are killed by becoming entangled in plastic debris floating in the ocean and swallowing small plastic items, reports represent a very low proportion of the breeding population.

Oil should not be released at sea under international legislation but it does occur both deliberately and accidentally. There have been some serious acute oil spills around the world but none has effected northern or southern rockhopper penguins. Chronic petroleum pollution (i.e. small but frequent oil discharges) may be a more serious threat to rockhopper penguins. Although few oiled northern and southern rockhopper penguins are reported ashore at breeding colonies because they forage offshore, oiled birds may not make it ashore.

Whilst most of the colonies and foraging areas of rockhopper penguins are in the remoter parts of the world, those in Argentina and Falkland Islands (Malvinas) are likely to be effected albeit to a small degree to oil pollution due to the oil platforms, terminals and harbours in the international cargo shipping route along the coastal waters of Brazil, Uruguay and Argentina. The number of rockhopper penguins affected by oil pollution is currently unknown but given the estimates for Magellanic penguins in Argentina, the number of rockhopper penguins affected may be significant.

Threat 4. Fisheries interactions

Grant Munro

Types of fisheries

Due to the number of sites where the northern and southern rockhopper penguins breed and their large foraging areas, they encounter a range of artisanal and industrial fishing fleets that use a variety of methods to target specific fish, cephalopods and elasmobranchs. However, except for a few Exclusive Economic Zones (EEZ) belong to specific countries, type and effort of fishing is not always known. The waters of the Falkland Islands (Malvinas), Australia and New Zealand have well regulated fisheries, whereas fishing activities within the EEZ of the Tristan da Cunha–Gough group and in international waters are poorly known.

Direct interactions

A range of potential interactions can occur between fisheries and seabirds of either a direct or indirect nature and most are generally negative but in the case of discards can be positive. The rockhopper penguin is not particularly susceptible to incidental mortality. Drift-net fishing in the 1980s around Tristan da Cunha was thought to present a significant threat but this type of fishing has ceased. All the breeding populations within New Zealand waters are outside the range of set-net fisheries. In waters where rockhopper penguins are known to forage, the seabird bycatch monitoring systems do not or very rarely report mortality of rockhopper penguins.

The diet of the northern and southern rockhopper penguin has been investigated to some degree at most breeding sites, and the degree of overlap in the prey species and prey size targeted by rockhopper penguins and fishing vessel is limited. More information is required about the diet of the northern rockhopper penguin in the Tristan da Cunha–Gough group and the fisheries before such an assessment could be made for that region. Existing stable isotope data could provide some information, but is very limited because of lack of 'source values' available for prey items and information about foraging location.

Some degree of competition and/or potential for conflict has been identified in the Falkland Islands (Malvinas). However, this is also the breeding site where the most detailed prey competition studies have been completed. The diet research in the Falkland Islands (Malvinas) has revealed some evidence that squid is of greater importance in the diet of the southern rockhopper penguin there than elsewhere (Clausen and Pütz, 2002; Raya Rey and Schiavini, 2005).

However, over the sampled period (1995–2000), the reliance on squid has declined with an increase in fish as a component of the diet (Clausen and Pütz, 2002). This was mirrored in the squid fishery with declining catches of squid and declining catch per unit effort and increasing bycatch of nototheniids, which are discarded. It could be implied that rockhopper penguins have been forced to target fish due to the reduced availability of the preferred squid or it may be that fish is being targeted because it has a higher nutritional value. Management regulations have closed some fishing areas close to shore where juvenile and undersized squid are known to occur and this may also be of benefit to the rockhopper penguin (Arkhipkin et al., 2008).

At present, the main bycatch species for the finfish trawlers in the Falkland Islands (Malvinas) is rockcod (*Patagonotothen ramsayi*), which is taken by rockhopper penguins. As there is an increasing interest in utilising and marketing this species (Brickle et al., 2005; Laptikhovskiy et al., 2006), there may be potential direct effects on the rockhopper penguin.

Indirect interactions

Indirect effects are much harder to investigate and assess. On the Patagonian Shelf, there is concern over the over-exploitation of some fish and squid stocks, including the accidental take of juvenile fish, and of the high levels of bycatch of non-target crustaceans and fish. How targeted and non-targeted fishery catch affects marine ecosystems and apex predators like rockhopper penguin is not known in any of the areas where they forage.

Possible effects could include:

- Modification of food web relationships due to removal of biomass of predatory fish
- Fishing of upper trophic levels resulting in the depression of average trophic level
- Reduction in size-at-age and age-at-maturation of target species
- Increased rate of nutrient turnover due to offal discharge and non-commercial bycatch
- Food web competition where apex predators may not compete with fisheries directly but could compete indirectly through the primary production required to sustain their respective prey populations
- Cascade effects of change at one food level to another through interconnectivity of trophic levels

CHANGES IN CLIMATE AND ECOSYSTEMS

Geoff Hilton

Threat 5. Climate change causing a drop in primary productivity that reduces prey availability

A range of potential bottom-up physical effects of increased SST and atmospheric CO₂ on marine primary productivity has been suggested in recent literature. Perhaps most attention has focused on the hypothesis that warmer waters become more thermally stratified, causing consequent reduction in nutrient upwelling. Where such nutrients are limiting, the consequence is a decline in primary production. Such a phenomenon has been inferred in the Bering Sea, where a major regime shift has occurred (Hirons et al., 2001; Schell, 2000) and in Lake Tanganyika (O'Reilly et al., 2003).

However, there are several other potential chains of cause and effect, some of which may have positive effects on primary productivity (Figure 2.1). It is the net outcome of these processes that will determine the direction and magnitude of change for any given location and time frame.

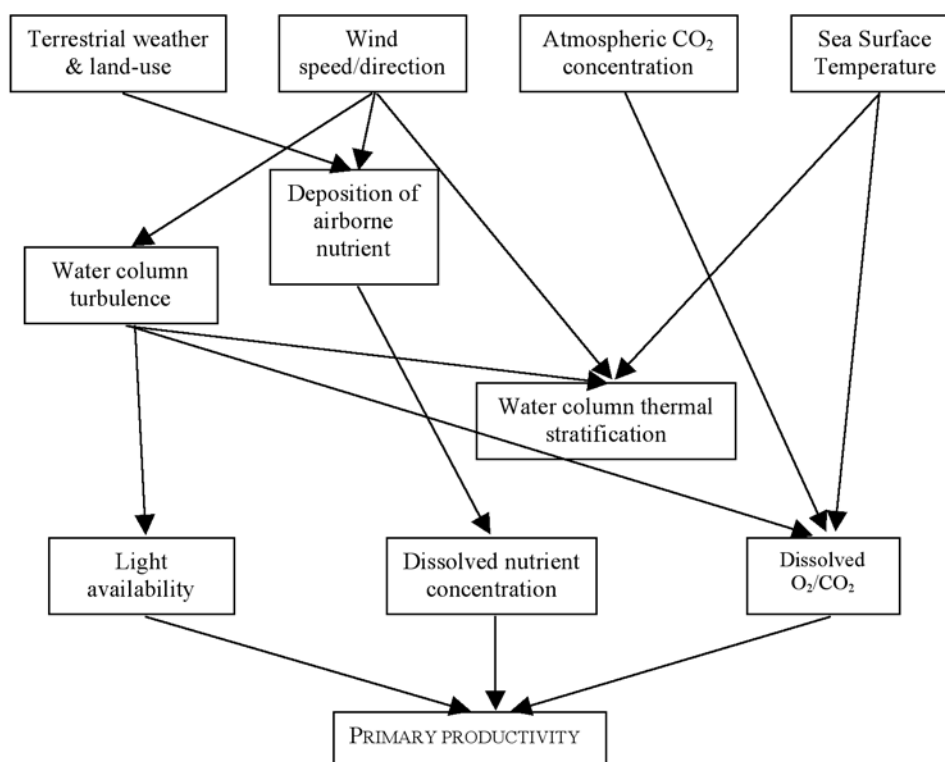


Figure 2.1 Simplified diagram of links between climate and marine primary productivity.

Threat 6. Climate change causing bottom-up food web shifts that reduce prey availability

Climate related shifts in the food web are less well documented than the climate related shifts in productivity as discussed above. However, there have been suggestions that warmer and more acidic (more dissolved CO₂) seas favour different sets of producers and primary consumers, with consequent effects further up the food chain. In short, there may be as much primary productivity, but less of it is converted into potential prey species of rockhopper penguins (and perhaps other vertebrate predators).

Diatoms are a dominant phytoplankton group in temperate and polar oceans, and are in turn a major food source for zooplankton and ultimately vertebrate consumers (fish, pinnipeds, cetaceans, seabirds). In warming and acidifying oceans, some researchers have predicted shifts away from diatoms towards smaller nanophytoplankton (e.g. coccolithophores) -dominated communities, which do not support a vertebrate-dominated food chain in the same way (Hare et al., 2007; Iglesias-Rodriguez et al., 2008; Moline et al., 2004) (Fig. 2.1). However, other authors have predicted a shift in the opposite direction (Martin-Jézéquel et al., 2004; Tortell et al., 2002).

There is very little empirical evidence of impacts on actual food webs hitherto, although (Moline et al., 2004) report a shift from diatoms towards smaller phytoplankton cells under warming conditions in the Antarctic Peninsula, which was predicted to reduce krill abundance and hence food availability for vertebrate predators. In general, therefore, there is not a clear hypothesis for climate/CO₂ impacts on food webs, but there are some indications that marine food webs might be sensitive, albeit in unpredictable ways, to the changes that are occurring.

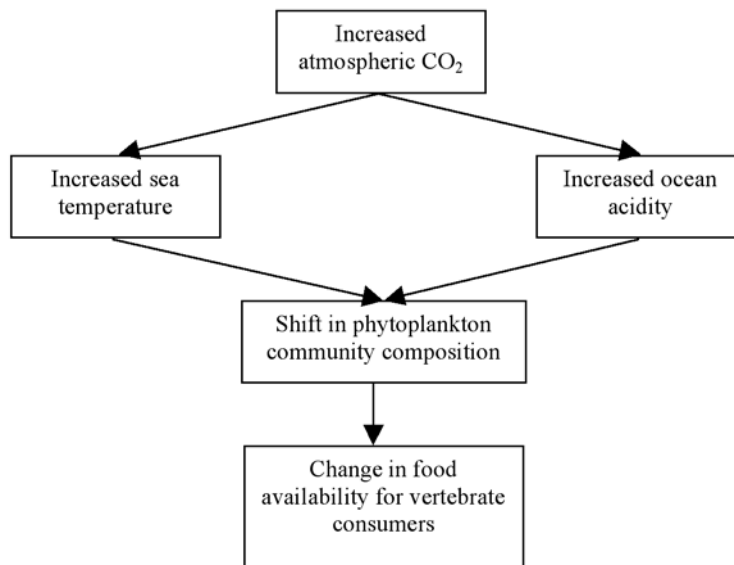


Figure 2.2 Simplified diagram of links between climate and marine food webs.

Threat 7. Top-down changes in food web structure, leading to increased inter-specific competition between rockhopper penguins and other higher vertebrates

One possible 'top-down' effect on the eudyptid penguins that has been hypothesised is competition with rapidly increasing pinnipeds—especially fur seal populations (Barlow et al., 2002). Fur seals were hunted to near extinction during the 19th century, and since then have staged massive recoveries at many sites (Bester, 1980; Bester et al., 2003; Bester et al., 2006; Hofmeyr et al., 1997; Page et al., 2003). For example at Gough, sub-Antarctic fur seals (*Arctocephalus tropicalis*) have increased dramatically from relative scarcity (~2,750 pups in 1955) to abundance (44,230 pups in 1977/8 (Bester 1980), with 60,000 pups recently (Ryan, 2007).

Their diet overlaps, at least in broad terms, with that of eudyptid penguins (Barlow et al., 2002; Beuplet et al., 2004; Casaux et al., 2004; Daneri et al., 2005; Makhado et al., 2008; Reid et al., 2006), indicating potential for competition. However, focused studies of sympatric eudyptids and fur seals by Chérel et al. (2007) and Goldsworthy et al. (2001) suggested that there was a clear segregation in feeding niche.

Notwithstanding the latter result, if there is dietary overlap, then the virtual disappearance of fur seals, and subsequent recovery, might be expected to cause historic (nineteenth century?) increases in rockhopper penguins, with subsequent declines. This does not appear to be the case for both the northern and southern rockhopper penguin species. The population declines date back longer than the very strong population increase in seals that has occurred during the last 15-20 years, and at some places, like the Falkland Islands (Malvinas) and Campbell Island, sea lions and seals have not experienced population increases after commercial sealing ended in the early 1900s.

Among sites where more recent rockhopper declines have been noted, the fur seal population (both sub-Antarctic and Antarctic *A. gazella*) at Marion/Prince Edward was very low in the 1950s, but numbers in the tens of thousands today (Bester et al., 2003; Hofmeyr et al., 2006). At Amsterdam/St Paul, sub-Antarctic fur seals increased very rapidly simultaneously with the rockhopper decline, from hundreds in the 1960s to several thousand by the 1980s. Similar fur seal increases have taken place at the Antipodes Islands.

Threat 8. Top-down changes in food web structure, leading to increased secondary predation on rockhopper penguins by increasing marine mammal populations

There are widespread reports that penguins form a small part of the diet of several fur seal and sea lion species (e.g. Casaux et al., 2004; du Toit et al., 2004; Lalas et al., 2007; Makhado et al., 2008). This may take the form of a small proportion of individual seals specialising on penguins (du Toit et al., 2004), or opportunistic foraging by a larger proportion of seals (Casaux et al., 2004; Makhado et al., 2008). It seems conceivable that, as fur seal populations have increased, a relatively low rate of additive mortality due to predation on adult penguins has reached levels sufficient to drive population decline. An alternative hypothesis is that other predators, in particular killer whales (*Orcinus orca*), might have switched towards preying on rockhopper penguins, as a result of the loss of other favoured prey species, such as whales.

Such an impact on seal and otter species has been hypothesised in Bering Sea following the collapse of whale populations (Springer et al., 2003) although this was subsequently refuted (Wade et al., 2007). However, with pinnipeds being a favoured prey of killer whales, and rapid increases in fur seal populations having taken place in the sub-Antarctic, it would seem unlikely that a major shift towards preying on penguins would have taken place.

ASSESSMENT OF THREATS - *Testing the hypotheses*

Geoff Hilton

There are a number of approaches to diagnosing declines in animal populations (Peery et al., 2004). For rockhopper penguins, three approaches are likely to be most appropriate. Firstly, the '*population comparisons approach*', in which spatial variation in population trends is used to identify environmental correlates of decline. For example, are sites with declining populations those in the warmest water bodies?

Secondly, the '*timing of decline approach*' in which temporal variations in decline rates is related to environmental factors. For example, did the species decline fastest during periods of high sea surface temperature (SST)? Thirdly, the '*species life-history comparisons approach*' involves identifying environmental factors that differ among declining and stable species within relevant guilds or taxa. For example, is a particular dietary guild of marine predators declining in the areas occupied by

rockhopper penguins? The '*multiple competing hypotheses approach*' combines these three methods by identifying a series of competing predictions about the effects of potential ecological drivers on the ecology and demography of the species, and then evaluating them against the data available.

Eight processes were identified as potentially threatening populations of northern and southern rockhopper penguins. In Table 2.1, we list some predictions that follow from the proposed eight ecological drivers of decline. In theory, the plausibility of each driver can be evaluated by testing these hypotheses. In this report, we do not attempt to test all predictions, since to do so would require extensive data collation. Instead, we make some initial comments, and point out useful future analyses.

Table 2.1 *Multiple competing hypotheses for the putative causes of rockhopper penguin decline.*

Ecological driver	Spatial pattern of decline	Temporal pattern of decline	Species comparisons
1. Land-based threats	Declines where invasive alien predators, human disturbance and persecution greatest	Decline gradual	
2. Disease and/or poisoning	? Declines where colonies heavily visited, where eutrophication most severe and more warm/calm conditions	Decline step-wise	?
3. Pollution	? Declines where pollution most severe	Decline step-wise	
4. Fisheries interactions	Declines at colonies near to fisheries where penguins are bycaught and/or take favoured prey of penguins	Decline gradual	
5. Climate change: reduced primary productivity	Declines where most rapid warming Declines in sites with high SST Declines in sites where primary productivity has fallen	Decline gradual, perhaps reversing in cool periods Declines during periods when primary productivity was falling	Widespread declines in high trophic level predators at affected sites
6. Climate change: food web shifts	Declines where most rapid warming Declines in sites with high SST	Decline gradual, perhaps reversing in cool periods Decline associated with change in diet (?)	No clear prediction
7. Top-down: competition with pinnipeds	Declines where pinnipeds most abundant/most rapidly increasing	Decline gradual Decline associated with diet shift away from favoured prey of fur seals	Declines among other species in the foraging guild except fur seals
8. Top-down: predation	Declines where pinnipeds most abundant/most rapidly increasing	Decline gradual	Declines in other species that are secondary prey of pinnipeds

Trajectory of declines

Declines caused by competition, predation or oceanographic factors might be expected to be relatively gradual in a long-lived species. By contrast, if mass-mortality due to disease or poisoning is involved, then it might be expected to be more step-wise. Very few data sets are available with which to assess this, since it requires frequent, preferably annual, census data, and these are rare. At the Falklands (Malvinas), annual monitoring of a sub-set of sites since 1987 indicates a strongly step-wise decline. There was a major decline event in 1987—the proximate cause apparently being starvation of moulting birds, followed by stability until 2002/3 when there was a further reduction (attributed to a harmful algal bloom). In between these events, there was minimal recovery. Conversely, at Marion, where a similar data set runs from 1994/5 to 2007/8, the decline has been smooth (Crawford et al., 2008).

Declines where most rapid warming and/or in sites with high SST

Northern and southern rockhopper penguins occupy breeding islands that differ in mean annual SST by $>10\text{ }^{\circ}\text{C}$, with $\sim 15\text{ }^{\circ}\text{C}$ at Tristan da Cunha and $\sim 4\text{ }^{\circ}\text{C}$ at Heard Island. The within-site increases in SST during recent anthropogenic warming are much smaller than the between-site variation: breeding sites have shown non-linear temperature increases of $\sim 0.5\text{--}1.0\text{ }^{\circ}\text{C}$ since the 1920s. In general, predictions (based on theory, palaeoecological evidence and current observations) are that populations affected by climatic warming would undertake poleward range-shifts, and hence would decrease at low latitudes and increase at high latitudes.

Although we have not formally tested the hypothesis that declines are associated with warm or rapidly warming waters, extremely large rockhopper penguin declines are known to have occurred at both the northern (Gough Island) and southern (Falkland Islands (Malvinas)) ends of the range. It is possible that SST has a strong impact on carrying capacity, and that relatively small increases in SST could have almost universally negative consequences for populations.

Declines when warming most rapid, or during warmest periods

Temperature changes during the twentieth century at northern and southern rockhopper breeding sites have been non-linear (Figure 2.3). Patterns vary geographically, but in summary SST tended to be lowest in the 1920s, with an increasing trend at most sites until the mid-late 1950s. There was a relatively cool period in the early 1960s, but another warming period began in the mid-late 1960s, with stability again from the late 1980s. This non-linearity ostensibly gives some opportunity to relate the timing of rockhopper declines to decadal SST changes. However, there are almost no long-term datasets with which to accurately assess the timing of the declines (but see Cunningham and Moors, 1994).

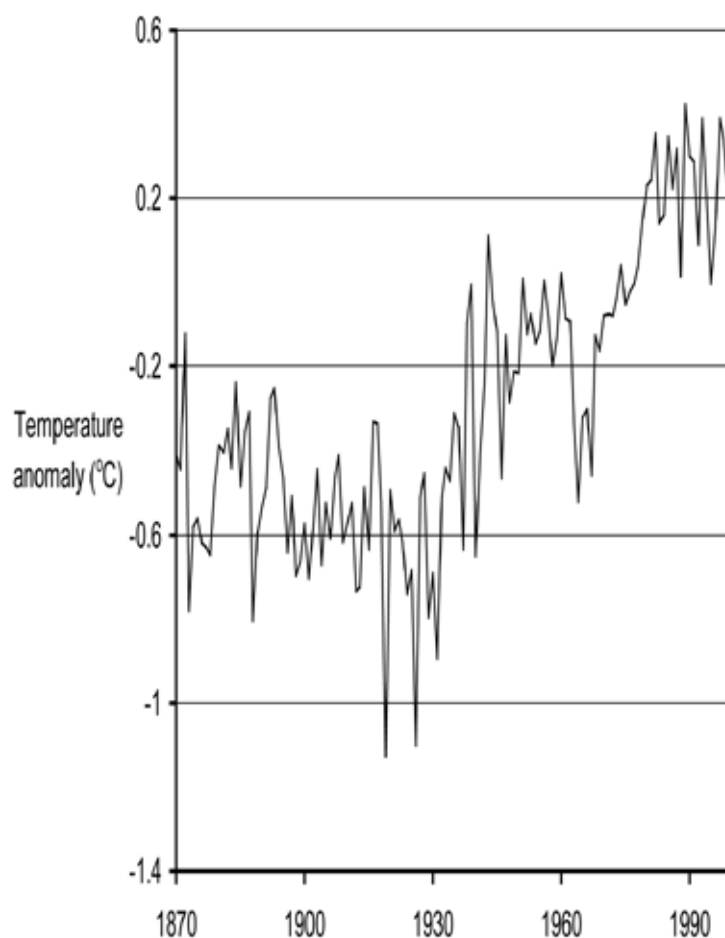


Figure 2.3 Mean twentieth century SST anomaly for main rockhopper penguin breeding sites. (Source - Hilton et al., 2006).

For some penguin species, demographic studies have shown clear links between SST and population dynamics (e.g. Le Bohec et al., 2008). However, to our knowledge, no studies have attempted to link annual variation in northern or southern rockhopper penguin fecundity to SST. Such studies might be possible using data sets from the Falkland Islands (Malvinas) (annual monitoring from 1987 until present) and Marion Island (R. Crawford in Crawford et al., 2006). However, there are no long-term studies that would permit an evaluation of the effect of SST on adult survival or recruitment rates in northern and southern rockhopper penguins.

Declines in sites or times where primary productivity has fallen

Turning to empirical data, Gregg et al. (2003) report net changes in oceanic primary productivity between 1980 and 2000. Their Figure 3 indicates that areas of the Southern Ocean south of approximately 45-50°S tended to increase primary productivity during this period, while areas immediately to the north of this tended to decrease. Both northern and southern rockhopper penguin breeding populations tend to cluster around the boundary between increasing and decreasing productivity. There is certainly no clear evidence of systematic primary productivity declines around rockhopper sites.

Large increases in primary productivity were indicated for the Patagonian Shelf, and the Pacific coast of Chile, where very large southern rockhopper populations breed. The Falkland Island (Malvinas) population suffered large declines during 1980 - 2000, while the Argentinean and Chilean populations are tentatively believed to have been stable. It is important to note that the time-window of this analysis is short relative to the overall time-scale of rockhopper declines, and for many rockhopper sites there is no clear evidence of decline during that specific period. Furthermore, the SST rises that characterised most of the period from the 1920s to the 1980s were modest or non-existent from the mid 1980s onwards in most sites (see Figure 2.4).

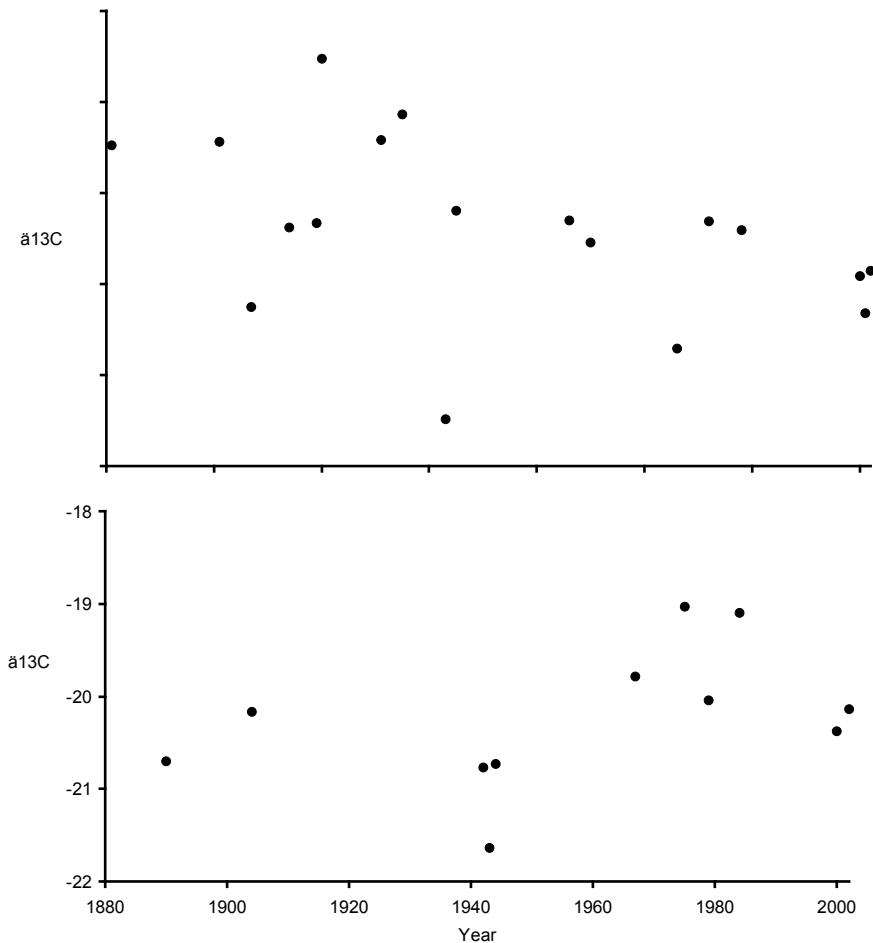


Figure 2.4 Temporal trends in carbon isotope ratios of southern rockhopper penguins at two sites in the Pacific Ocean, (a) Campbell Island and (b) Antipodes Islands. (Source - Hilton et al., 2006).

Hilton et al. (2006) used stable isotope ratios to test whether longer-term rockhopper penguin declines were associated with declining primary productivity. Their work was based on the idea that carbon isotope ratios ($\delta^{13}\text{C}$) increase as algal growth rate, and hence primary production, increases. They examined $\delta^{13}\text{C}$ in the feathers of rockhopper museum skins going back to the 19th century, and tested for significant temporal trends, within sites, and among all sites combined. Overall, there was a significant decrease in $\delta^{13}\text{C}$, indicating that the waters in which rockhopper penguins obtained the protein used for feather-moult had experienced a drop in primary productivity.

However, several important caveats mean that this is only weak evidence that climate-driven decreases in primary productivity are implicated in the decline of the northern and southern rockhopper penguin. Firstly, anthropogenic influences on background $\delta^{13}\text{C}$ need to be accounted for and it is difficult to do this with precision: the uncertainty around the estimated correction factors is quite large relative to the overall modelled trend in $\delta^{13}\text{C}$. Secondly, there were radical differences between sites in the $\delta^{13}\text{C}$ trend, even where the rockhopper penguin population trends were similar (e.g. between Campbell Island and the nearby Auckland Islands, Figure 2.4), suggesting that the $\delta^{13}\text{C}$ trends were not necessarily important drivers of the population trend.

Thirdly, the $\delta^{13}\text{C}$ pattern in the period after 1940 was rather different to the overall trend. During the post-1940 period, $\delta^{13}\text{C}$ in rockhopper penguins was positively related to SST, indicating that primary productivity was tending to increase as the surface of the sea warms (Figure 2.5).

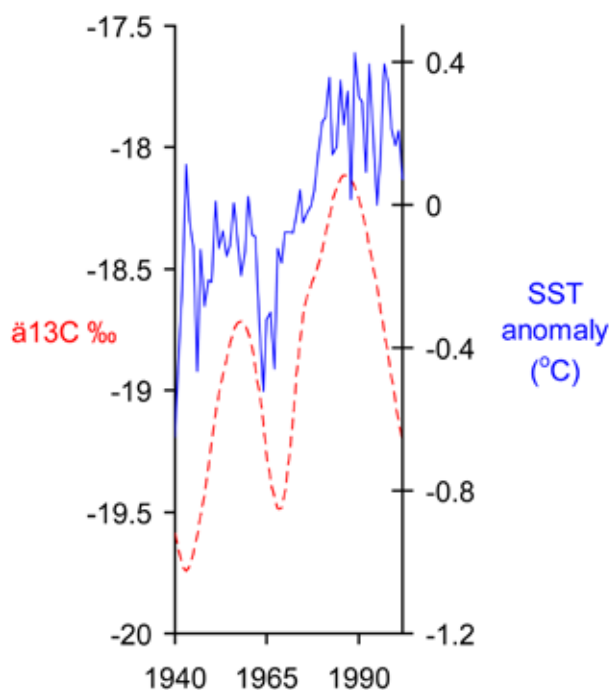


Figure 2.5 Sea surface temperature anomaly (dark line) and rockhopper penguin $\delta^{13}\text{C}$ (dashed line) during the period 1940-2000.

Recent papers have ascribed the declines at different sites to sea surface warming (Amsterdam and St Paul Islands, Guinard et al., 1998) and sea surface cooling (Campbell Island, Cunningham and Moors, 1994) respectively, but both papers simply report temporal correlations between decline periods and temperature changes, without discussing causal mechanisms in detail, either in demographic or ecological terms.

Weimerskirch et al. (2003) reported declines among a wide range of vertebrate marine predators in the Southern Indian Ocean during a period of rising temperatures between the mid-1960s and mid-1980s, including data for northern rockhopper penguins from Amsterdam/St Paul. This was tentatively attributed to declining primary production and consequent reductions in food supply, perhaps affecting fecundity.

However, in the specific case of rockhopper penguins, the data-set used by Weimerskirch et al. (2003) appears in fact to be the same as that used by Guinard et al. (1998), which ascribed the decline to the temperature decrease in the Amsterdam/St Paul area which took place between the early 1980s and early 1990s. Clearly, the exact timing of declines in relation to temperature, and/or a clearer understanding of demographic mechanisms, is needed.

Decline associated with change in diet

Rockhopper penguins eat crustaceans, fish and squid in variable proportions. If food webs have shifted as a result of climate change (or other factors), it is possible, though not inevitable, that a shift in diet would occur among these items. If competition with fur seals is intense, then a diet shift away from favoured prey of fur seals might be expected. In the krill-dominated ecosystems south of the Antarctic Polar Front (APF), there are indications that the removal of baleen whales from the system created a 'krill surplus' for other vertebrate predators, and that this might cause diet shifts (as well as potentially greater food resources). New evidence suggests that such a shift has occurred in Adelie penguins (*Pygoscelis adeliae*) (Emslie and Patterson, 2007). While northern and southern rockhopper penguins are largely found north of the APF, the removal of baleen whales might be expected to have similar effects on other planktonic crustacean in the sub-Antarctic region.

There are few studies of northern rockhopper diet (e.g. Tremblay and Cherel, 2003) and a few more papers on the diet of the southern species (Pütz et al., 2001; Hull et al., 2004). But there are few that document the changes in diet across multiple years. Falkland Conservation's Falkland Island (Malvinas) Seabird Monitoring Programme has developed a data set on diet over the period 1987 - 2003. During the 1990s, there was a decrease in the importance of squid in the diet, and a concomitant increase in the importance of crustacean, while fish varied greatly between years (Clausen and Pütz, 2002). Although a valuable result, this is not yet indicative of a long-term trend that can be linked to population decline.

Hilton et al. (2006) conducted a stable isotopic investigation into historic diet shifts in rockhopper penguins, using $\delta^{15}\text{N}$ as a marker of diet. There was no strong evidence of a large or systematic diet shift over the last ~130 years, either overall, or at individual sites. There was a strong tendency for rockhopper penguins to feed at a lower trophic level—presumably on crustacean—in years when SST was high. This might indicate a climate-driven impact on food webs, but there is no evidence to link it to the population dynamics of rockhopper penguins.

Trends in sympatric vertebrate predators

Many species of fish, seabird, pinniped and cetacean might be expected to show similar population trends to rockhopper penguins, if large-scale declines in productivity or food web shifts were taking place. For some relatively well-monitored taxa, such as albatrosses, pinnipeds and whales, direct anthropogenic impacts (e.g. fisheries and persecution) have had overwhelming impacts on population trends in recent decades, possibly swamping any bottom-up effects. For the extremely abundant smaller seabird species, especially petrels, data on trends are mostly non-existent at relevant sites.

If primary productivity decreases are a cause of rockhopper declines, then one would expect widespread reductions in other vertebrate predators, independent of foraging niche, except insofar as productivity reductions might have affected some habitats more than others (e.g. offshore vs. inshore). Conversely, if competition with or predation by increasing fur seals is the problem, then declines might be expected in species with most similar foraging niches to rockhopper penguins/fur seals and/or which are known to be secondary prey of fur seals.

However, forming testable hypotheses in this area is certainly difficult, since food web interactions are complex and poorly understood: it is not obvious which taxa give relevant comparisons. Similarly, it is likely that species make non-linear responses to environmental change, such that rockhopper penguins may have declined first and fastest of their guild to the suggested environmental pressures.

In the krill-dominated ecosystems further south than the rockhopper range, there have been recent reports of widespread declines in predator numbers or demographic performance (Reid and Croxall, 2001), which have been linked to climatic effects on krill recruitment. However, northern and southern rockhopper

penguins breed north of the krill-dominated systems, and data for rockhopper penguin species are less clear. Weimerskirch et al. (2003) suggested that declines in vertebrate predators were widespread in the southern Indian Ocean during the period 1965-1985. They specifically related this to temperature increases during the same period, causing a 'regime shift'. Furthermore, Delord et al. (2008) recently reported declines in large Procellariiformes in the sub-Antarctic and sub-tropical sectors of the Indian Ocean, and suggested that these were linked to oceanography and climate. Similarly, the grey-headed albatross (*Thalassarche chrysostoma*) at Campbell Island has crashed by ~80% since the 1940s (Waugh et al., 1999), and bottom-up physical factors have been invoked as a major cause.

Rockhopper penguins are sympatric with other eudyptid penguin species on several of the islands on which they occur. These sympatric species are likely to occupy similar (though presumably segregated in important ways) foraging niches to rockhopper penguins, so might be expected to show similar responses to both oceanographic change and competition. They are also very likely to be similarly vulnerable to predation by fur seals, unlike, for example procellariiform seabirds or marine mammal species.

Among sites where rockhopper penguins have declined, the taxon is sympatric with erect-crested penguin (*E. sclateri*) at Antipodes and Campbell Islands. At the former site, the erect-crested penguin has declined rapidly since at least the late 1970s, and the tiny population on Campbell Island appears to have been extirpated since the 1940s. The erect-crested penguin population at Bounty Islands, also on New Zealand's southern continental shelf, has also declined since the late 1970s. Similarly, at Marion/Prince Edward, where rapid declines in rockhopper penguins were noted from the 1970s onwards, the relatively small population of macaroni penguin (4,000 pairs) has also declined.

On Macquarie Island, possibly declining rockhopper penguin population estimated at 37,500 pairs (Tasmanian Parks and Wildlife Service, 2006) co-exists with an estimated 850,000 pairs of the endemic, closely related royal penguin (*E. schlegeli*). The royal penguin is believed to have shown long-term recovery from persecution in the 19th century, and currently has a stable population (BirdLife International, 2008b). Similarly the macaroni penguin population in Chile, like the sympatric rockhopper penguin population, is thought—though with very limited data—to be stable or increasing (BirdLife International 2008).

At Crozet, Kerguelen and Heard Islands in the Indian Ocean, where rockhopper penguin trends are largely unknown, there are also very large macaroni penguin populations (1 million, 1.8 million and 1 million pairs, respectively) whose trends are poorly understood, though the Kerguelen macaroni population increased between 1962 and 1998. The small macaroni penguin population on Isla Noir (Chile) is also thought to have declined.

Elsewhere in the Southern Ocean, macaroni penguins tend to replace rockhopper penguins on more southerly islands, such as South Georgia, South Sandwich Islands and South Shetland Islands. The South Georgia population, which is the world's largest at several million pairs, is thought to have increased in the 1960s and 1970s, but to have decreased rapidly from the late 1980s onwards, although trends information is sparse (BirdLife International, 2008b).

Snares penguin (*E. robustus*) is endemic to the Snares Islands on the New Zealand southern continental shelf, which has no rockhopper penguins, and the population is believed to be stable. Fiordland penguin (*E. pachyrhynchus*) is found on and around the southern coast of New Zealand, and its small population is declining, though perhaps due largely to localised problems with invasive alien predators (BirdLife International, 2008b).

While distinctly different in many rather obvious respects, it has been suggested that there are parallels between population trends in the southern elephant seal (*Mirounga leonina*) and the northern and southern rockhopper penguins. The southern elephant seal has an extremely similar breeding range to rockhopper penguins, breeding north to Amsterdam/St Paul and Gough, and through almost all of the Atlantic, Indian Ocean and Pacific nesting sites of the rockhopper. The range of the southern elephant seal however extends further south into areas where the macaroni penguin replaces the rockhopper, such as South Georgia, South Orkney and South Shetland Islands.

Southern elephant seals are absent from the Pacific coast of Chile and Tierra del Fuego. Major, poorly explained declines in southern elephant seals have taken place over several decades at many sites

(McMahon et al., 2005). Between the 1970s and about 1990, severe declines were noted at Campbell, Marion and Gough—where rockhopper penguins have also declined, but also at Macquarie, Crozet and Heard, where rockhopper trends are poorly known. The population in the Falkland Islands (Malvinas) always appears to have been small and has been stable in recent times.

In parallel with the growing southern rockhopper population at Isla Pingüino in Argentina, there has also been an increase in elephant seals throughout the same period at nearby Peninsula Valdés. Although clearly occupying very different foraging niches—elephant seals being deep-diving squid specialists—further examination of links between the species in population trends might be worthwhile.

Another parallel decline in a pinniped population is that of the southern sea lion (*Otaria flavescens*) in the Falklands (Malvinas), which have only currently reached 2.5% of their 1930s level (Thompson et al., 2005). They claim that the first 30 years of the decline can be explained by hunting pressure, but the subsequent decline is not understood.

Conclusions

This limited evaluation of the competing hypotheses is inconclusive. In large part, this is due to an extreme paucity of data. There are very few good data on population trends, and demographic and ecological data are almost entirely absent. A second reason is that this is a preliminary evaluation only: more detailed collation and analysis of existing data would potentially help to some degree.

Because of the widespread unexplained declines of the northern and southern rockhopper penguin, there is a temptation to assume that there is a common causal factor. However, this assessment does suggest that no single factor is strongly supported by the evidence across sites. It seems plausible that causal factors differ among sites.

The 'reduced primary productivity hypothesis' has relatively weak support. The isotopic data appears superficially to support it, but on closer examination is inconsistent. Empirical data on productivity in the relevant ocean areas does not suggest wholesale decreases in productivity. Data on comparable vertebrate predators are equivocal.

The 'shift in food web hypothesis' is poorly defined, and therefore difficult to test. Nevertheless, the isotopic evidence of no major shift in rockhopper diet suggests that it is unlikely to be important. Similarly, the relatively minor shifts in oceanic pH and temperature (relative to future projections) during the period of recent rockhopper decline make it seem inherently unlikely.

The 'competition with pinnipeds' hypothesis requires further examination. There is some indication that rockhopper penguins have declined at several sites where there has been major fur seal recovery. Conversely, it does not appear to apply at all sites. The available census data on fur seals and rockhopper penguins should be examined in more detail. It should be noted that there is very little empirical evidence of competition between the taxa at present.

The 'secondary predation by pinnipeds' hypothesis falls into a similar category to the competition hypothesis: there is little empirical evidence, but it cannot yet be ruled out. More detailed analyses are needed, along with some simple modelling of the plausible levels of predation and their population impact.

Recent papers describing links between population size, demography and oceanography for other seabird species in the region (Quillfeldt et al., 2007; Delord et al., 2008; Rolland et al., 2008) are a model for much needed field research on rockhopper penguins. However, a more detailed, quantitative assessment of the existing data, to test the competing hypotheses listed above, might be a worthwhile exercise in the interim (see McMahon et al., 2005 for a similar attempt).

APPENDIX 3 Northern rockhopper penguin: Regional reports

1. Tristan and Gough Island
2. Indian Ocean sites

1. Northern rockhopper penguin - Tristan and Gough Island

Geoff Hilton, Richard Cuthbert, Trevor Glass, Peter Ryan and John Cooper

1. Populations

Around 200,000 pairs are estimated for the Territory, based on most recent counts on each island (Table 3.1). However, it should be noted that the count for Middle Island, which accounts for 50% of the total, is 35 years old. Given apparent declines on other islands in the Territory over the intervening period, 200,000 pairs may be optimistic. Further details of trends, population size and threats are collated in Cuthbert et al. (2009), along with a collation of historical information in greater detail.

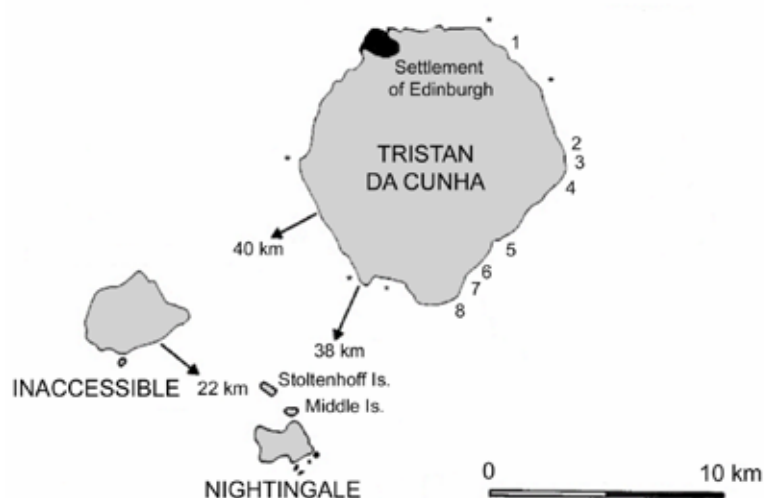


Figure 3.1 Map of the Tristan da Cunha group (consisting of the main island of Tristan, and satellite islands of Inaccessible, Nightingale, Stoltenhoff and Middle). For Tristan numerals 1 to 8 indicate the position of the extant penguin colonies at West Jew's Point (1), Big Gulch (2), Phoenix Beach (3), East End (4), Trypot Bay (5), Goat Road Gulch (6), Stony Beach (7), and Stony Hill (8). Asterisks indicate the position of colonies that are known to have become extinct. Arrows and kilometres on the Tristan da Cunha map mark the direction and distance between Tristan, Inaccessible and Nightingale Islands. Gough Island is 350 km to the south-east of Tristan.

Table 3.1 Population estimates and trends for the Tristan da Cunha group.

Site	Population	Data quality	Year of estimate	Trend	Source
Gough	64,700	Estimate	2006	95% decline from 1956-2006	Cuthbert et al. (2009)
Tristan da Cunha	3,421	Counts	2005	50% decline from 1970 to 2006	Cuthbert et al. (2009)
Inaccessible	18,000	Estimate	2004	Unclear	Cuthbert et al. (2009)
Nightingale	19,500	Counts	2007	Unclear	Cuthbert et al. (2009)
Middle	100,000	Estimate	1973	One count only	Cuthbert et al. (2009)

Gough Island

Probably in the region of 1-2 million pairs from the late 19th century up until the mid-1950s. A massive decline had taken place by the late 1970s/early 1980s, to something in the region of 100,000-150,000 pairs (Figure 3.2). A further decline to approximately 65,000 pairs took place between the early 1980s and 2004-06. The overall decline at Gough over 50 years (1956-2006) is probably in the region of 95%, with the most rapid decrease apparently being in the late 1950s to the end of the 1970s (Figure 3.2). There is high confidence in the assertion of a population crash, but insufficient information to determine the timing or nature of the crash (e.g. step-wise or gradual), or to be precise about its magnitude.

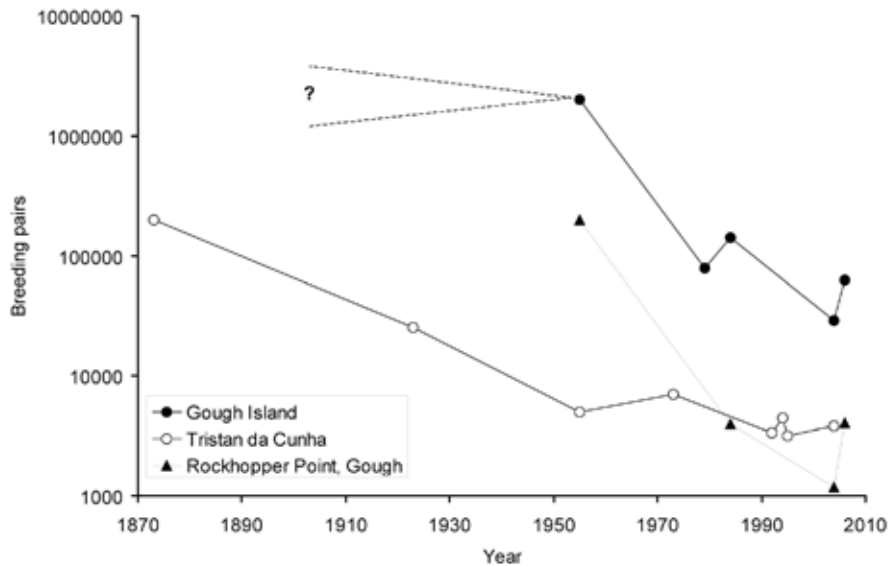


Figure 3.2 Long-term trends in northern rockhopper penguin counts at Tristan-Gough (on a log-scale).

Tristan da Cunha

Estimates from the 19th century appear to lie in the low hundreds of thousands of pairs, with very low precision. By the late 1930s, massive declines were noted and by the 1950 - 1970s the population was in the region of 5,000 pairs. A further decline to around 3,000-4,000 pairs seems to have taken place between the early 1970s and the 1990s, with population stability between then and at least 2005 (Figure 3.3).

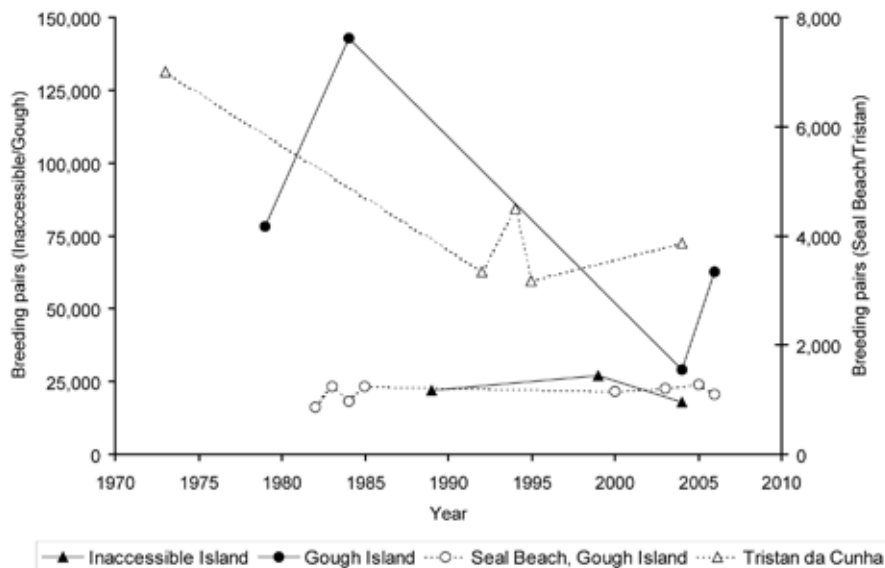


Figure 3.3 Modern trends in northern rockhopper penguin counts in Tristan-Gough.

The overall decline is probably in the order of 90-99% since the 19th century, but there is very low precision on the early estimates. A decline of approximately 50% seems to have taken place since the early 1970s (again, low precision).

Tristan outer islands

In 1950-2, the population of Inaccessible, Nightingale and Middle was put at 250,000, with no information on how these were distributed. Most recent estimates (Middle from 1973, Inaccessible from 2004, Nightingale from 2007) put the total population at approximately 137,500 pairs, a 50% decline.

On Inaccessible Island, there were no real estimates prior to 1955, since when several population estimates have put the number of breeding pairs at 18,000-27,000, with no clear evidence of trend, although very little power to detect such a trend. There was an apparent reduction on Nightingale Island from 25,000 pairs in 1973 to 19,500 pairs in 2007, a decrease of approximately 25%, although given inter-annual fluctuations and methods that are not strictly comparable, this is not strong evidence of decline.

On Middle Island, there is only one estimate available, of 100,000 pairs in 1973.

2. Breeding, post-breeding, diet and foraging

Very little known on breeding, diet and foraging of northern rockhopper penguins in the Tristan-Gough group. Existing stable isotope data could provide some information, but is very limited because of lack of 'source values' available for putative prey items and information about foraging location. The timing of breeding of penguins at Tristan da Cunha is around 3-4 weeks earlier than at Gough Island (T. Glass pers. obs.).

3. Land and Sea Management

There is a very high level of site protection at the breeding colonies. Gough Island and Inaccessible Islands are a World Heritage Site and strict nature reserves. Penguin colonies on Tristan da Cunha are protected under the 2006 conservation ordinance. Management Plans are in place at Gough (Cooper and Ryan, 1994), Inaccessible (Ryan and Glass, 2001) and there is a Biodiversity Action Plan for Tristan (including Nightingale and Middle) (Tristan Natural Resources Department and The Royal Society for the Protection of Birds, 2006).

Currently, no plans exist for management of "disasters" such as a major oil spill or large-scale outbreak of disease. Given the isolation of all the islands and limited resources, the ability to handle such disasters is limited, although provision should be made to enable sample collection from sick and/or diseased animals.

A 200 nm Exclusive Economic Zone (EEZ) is in place, with fishing subject to license. However, enforcement is minimal, and illegal and unregulated fishing takes place with unknown consequences. Previously, both drift net fisheries and the rock lobster industry (through use of penguins to bait pots) were threats to rockhopper penguins on Tristan and Gough (Ryan and Cooper, 1991; Cuthbert et al., 2009). However, this is no longer likely to be the case. Smaller scale threats on land include entanglement in nets and other marine debris. Where such cases have been found (e.g. at Gough Island) penguins have been freed, but in most instances, entangled birds are unlikely to be found.

4. Threats

Very little specific research has been undertaken, and suggestions are largely based on plausible hypothesis, evidence from other sites etc.

4.1 On land

Introduced species

Feral pigs present on Tristan between 1811 and 1873 may have caused major predation at colonies during that time, although there is no direct evidence. The pigs were extirpated in 1873. Pigs were also present on

Inaccessible from 1820 to about 1930, and were reported to be major predators. Feral and domestic dogs have been reported killing large numbers of penguins on Inaccessible in the 19th century and on Tristan in the 1960s.

Feral cats were present on Tristan until the 1970s, but have been extirpated. There are no reports of predation on penguins (it is thought that chicks are most vulnerable), though it seems likely to have occurred (with unknown severity), based on evidence from other eudyptids.

Black rats are present on Tristan da Cunha but there have been no reports of rat predation on penguins. Predation on small chicks has not been studied but is thought it may occur on occasion. However, all evidence suggests that this is not a big conservation concern. Mice are present on Gough Island and whilst predation on albatross chicks has been documented, predation rates and effects on the rockhopper penguin population are not known but considered unlikely.

Interactions with native species

There are few reports of predation by native predators on penguins, but this reflects a lack of research, not evidence for the absence of the behaviour. There are some recent reports of penguins being taken by southern giant petrels (*Macronectes giganteus*) in the water at landing sites on Nightingale Island (Ryan et al., 2008). It is also possible, though entirely unstudied, that the large fur seal populations are significant predators of or competitors with rockhopper penguins at Tristan-Gough.

Habitat issues

The expanding number of fur seals at Gough Island (Bester, 1990; Bester et al., 2006) and increasing numbers at Tristan da Cunha (James Glass pers. com.) may be directly competing with breeding penguins for space on land, with evidence for seals displacing breeding penguins at Nightingale (James Glass pers. com.).

Tourism

There is very occasionally a cruise ship visit to the Tristan da Cunha group (perhaps 1-3 per year when Antarctic vessels are on re-positioning trips northwards). Visitors primarily go ashore at Tristan and Nightingale, very rarely at Inaccessible and never to Middle or Gough.

Human depredation

There was very large-scale persecution of penguins (eggs and adults) on Tristan da Cunha and Nightingale during the 19th century and the first half of the 20th century. Take of eggs declined from the 1950s onwards, and though it still occurs to a small degree at Nightingale under a formalised conservation ordinance of 2006, it is considered to be insignificant.

Penguins were also killed by sealers on Gough in the 19th century, although the lack of permanent habitation on Gough means this practise was likely to be more limited in comparison to Tristan. Penguins were also formerly used as bait in the rock lobster fishery, but this practice has now ceased, and probably never accounted for large numbers of birds, perhaps hundreds.

Persecution may account for much or all of the historic decline on Tristan—and the location of remaining colonies on the island in areas well away from the Settlement may reflect this—but it can not account for the Gough decline, and probably not for the more recent declines on the Tristan group.

Natural disasters

Given the volcanic nature of Tristan, eruption is a potential major threat to breeding colonies, although there is no evidence that the 1961 eruption affected breeding birds. Landslips following heavy rain have been observed to fall upon penguin rookeries on all islands in the group, but such events are a natural feature of the islands and are usually very localised. Wildfire could also present a major threat to rockhopper penguins, and in the past, the Settlement Plain on Tristan was burned, with the likely destruction of any breeding colonies in this area.

Disease

There is currently no evidence of disease on any of the islands.

4.2 At Sea

Fisheries bycatch

Very little is known about fisheries bycatch. Large-scale commercial fisheries (as opposed to sealing and whaling) have rarely operated in Tristan waters. However, drift-net fishing in the 1980s was thought to present a significant bycatch threat to rockhopper penguins; it has since ceased (Ryan and Cooper, 1991; Cooper, 1994). There is no information on bycatch or entanglement mortality, but again, the relatively low fishing effort in Tristan waters suggests that this is likely to be relatively minor, at least within the EEZ.

Depending on migration routes and wintering areas of Tristan-Gough rockhopper penguins, it is conceivable, but entirely unknown, that they are bycatch victims of in parts of their range that lie outside the EEZ.

Fisheries competition

Fisheries competition in Tristan waters is not thought to be of major concern. As their foraging areas are not known, over-exploitation of fish stocks in other waters could conceivably be an issue.

Competition with native species

Broadly, speaking fur seals have similar diets to rockhopper penguins in at least some parts of their range, although detailed studies of foraging niche overlap are few. There are no data on fur seal diet at Gough, but British Antarctic Survey studies at South Georgia implied considerable competition between macaroni penguins and Antarctic fur seals, although it is difficult to find really direct evidence (Barlow et al., 2002). There is a possibility therefore that increasing fur seal numbers at Tristan-Gough (Bester et al., 2006) has increased competition and reduced carrying capacity for rockhopper penguins.

Pollution

The incidence of oiling or entanglement and ingestion of manmade debris is not known but is likely to be relatively minor.

Harmful algal blooms

No harmful algal blooms have been documented at any of the islands.

Oceanographic changes

This section is largely based on Hilton et al. (2006) and unpublished material gathered under the same project. Stable isotope data for the Gough population go back only as far as the late 1940s/early 1950s (with a single exception in 1921). However, it is believed that the main population crash on Gough occurred after then, so a comparison of the early data with contemporary samples might be instructive.

There is no strong evidence of a systematic change in the level of $\delta^{13}\text{C}$ among the Gough population between the samples collected in 1921-1956 ($n=8$ samples collected in 4 years) and 2000-2001 ($n=60$ samples collected in 2 years) (Figure 3.4). Nor is there very strong evidence of a link between $\delta^{13}\text{C}$ and the sea surface temperature (SST) anomaly, although the spread of SST anomalies is very small (no feather samples obtained from cold years). However modelling does indicate a slight upward trend in $\delta^{13}\text{C}$ (equivalent to increasing primary productivity, if that is the source of the variation) at Gough in response to 'year' and SST.

Data for the Tristan group are available for 1873 to 1973, and again, show no evidence of systematic trend in the level of $\delta^{13}\text{C}$ in relation to 'temperature' or 'year'. There is no evidence of temporal shifts in diet, as indicated by $\delta^{15}\text{N}$ for either Tristan or Gough rockhopper penguins (Figure 3.5). Neither is there any evidence of a strong link between diet and SST anomaly.

Overall, the evidence suggests that rockhopper penguins at Tristan-Gough, at least during the pre-moult exodus, have been operating in a fairly constant marine food web in recent decades, although limited sample sizes makes this conclusion rather tentative.

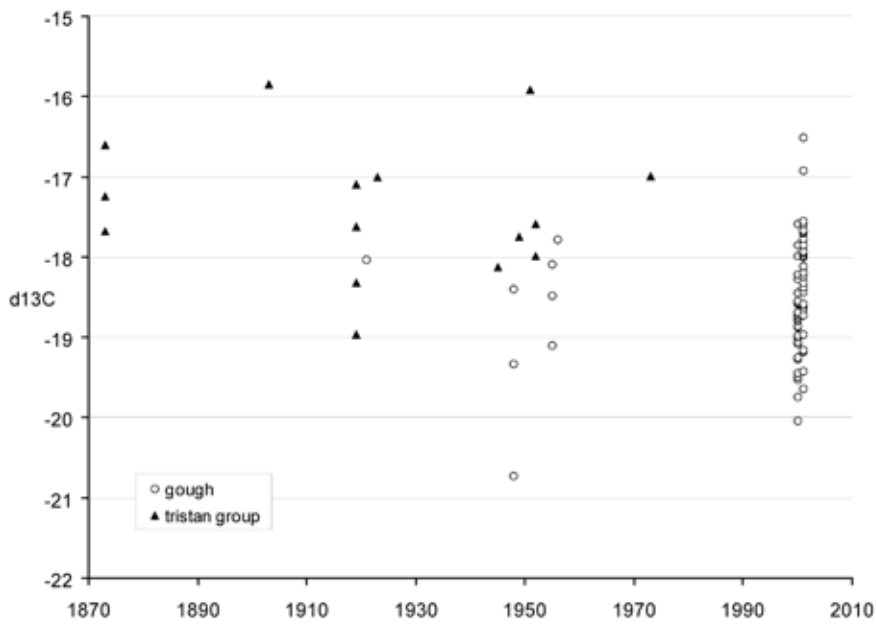


Figure 3.4 Temporal trends in carbon isotope ratios of northern rockhopper penguins at Tristan-Gough.

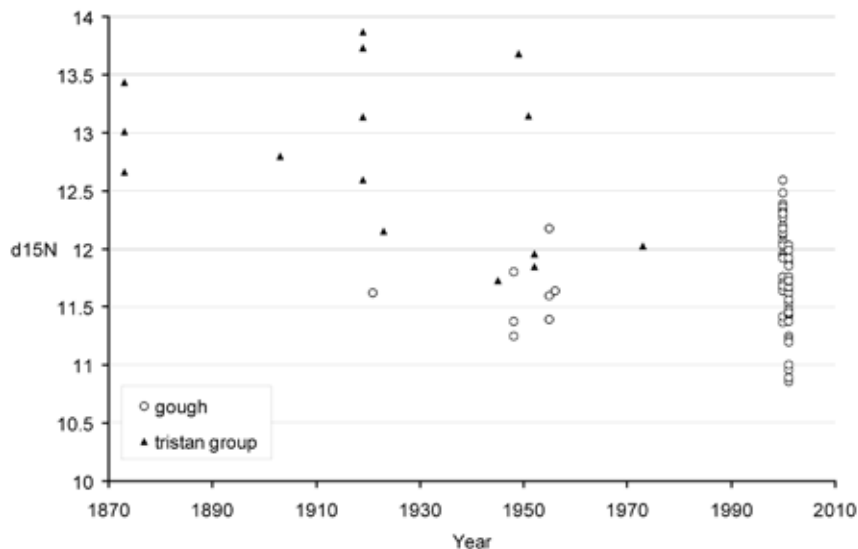


Figure 3.5 Temporal trends in nitrogen isotope ratios of northern rockhopper penguins at Tristan-Gough.

5. Current research and monitoring

There is little current research and monitoring. There are (more or less) annual scan-counts of incubating pairs on Tristan in recent years. Breeding pair censuses on other islands have only taken place on an ad-hoc basis. Protocols have been developed for monitoring breeding numbers at Gough, Tristan, Nightingale and Inaccessible islands (Cuthbert and Sommer, 2004; Ryan, 2006), with counts occurring annually on Tristan and every 3-5 years at other sites. Plans are underway to obtain a population estimate for Middle (Alex) Island where very large numbers (100,000 pairs) were recorded at the one and only count of this site from 1973 (Richardson, 1984). Additional research includes limited information on breeding success (Cuthbert and Sommer, 2004) and the collection of feathers for stable-isotope studies (Hilton et al., 2006).

2. Northern rockhopper penguin - Indian Ocean sites

Geoff Hilton

Introduction

Amsterdam (55 km²) and St Paul Islands (6 km²) are part of the French Southern and Antarctic Territory, and support the only population of the northern species away from Tristan-Gough. The islands lie marginally north of the sub-tropical convergence in the Indian Ocean and are 95 km apart.

1. Populations

All information reported here is summarised from Guinard et al. (1998), which presents population size and trends for the period 1971-1993 (Table 3.2). During this period, rockhopper penguins at the site as a whole decreased by ~45% from approximately 60,000 pairs to ~35,000 pairs. There were contrasting trends at the two islands, with the far smaller St Paul population increasing from ~4,000 to ~9,000 pairs, whilst the Amsterdam population decreased from ~58,000 to ~25,000 pairs (Fig. 3.6). The data are notable for considerable inter-annual fluctuations at Amsterdam during 1988-1993, when counts varied (up and down) by a factor of more than two indicating a considerable degree of deferred breeding. Guinard et al. (1998) did not present any data for the period before the 1970s or after 1993, although some unanalysed data on trends since 1993 apparently exists.

Based on the most recent counts from Amsterdam, St Paul and the Tristan da Cunha Group, the two islands in the Indian Ocean support in the region of 20% of the global population of the northern rockhopper penguin.

Table 3.2 Population estimates and trends for Indian Ocean sites

Site	Population	Data quality	Year of estimate	Trend	Source
Amsterdam	24,890	Estimate	1993	57% decline over 22 years	Guinard et al. (1998)
St Paul	9,023	Estimate	1993	126% increase over 22 years	Guinard et al. (1998)

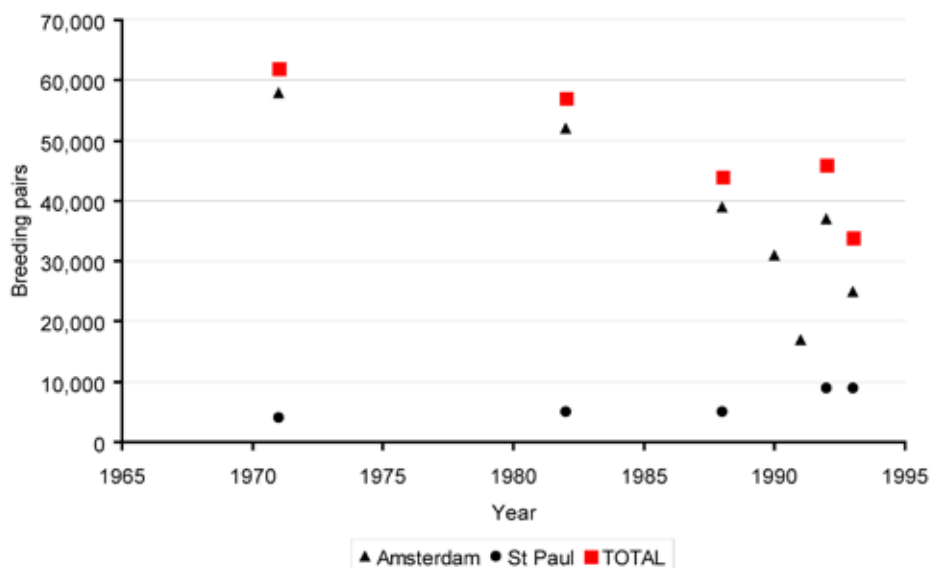


Figure 3.6 Population trends of northern rockhopper penguin at Amsterdam and St Paul, 1971-1993. (Source: Guinard et al., 1998).

2. Breeding, post-breeding, diet and foraging

Compared to Crozet and Kerguelen islands, rockhopper penguins at Amsterdam Island live in a low productivity sea, and have low chick provisioning and chick growth rates. However, chicks from Amsterdam Island partially compensate for a lower provisioning rate by having a 10% high crude growth efficiency, either by having a higher digestive efficiency or by the fact that warmer air temperatures reduce thermoregulation costs (Tremblay and Cherel, 2005).

Northern rockhopper penguins at Amsterdam feed mainly on the euphausiid *Thysanoessa gregaria* and on juvenile squid, and, at least during the brood period, tend to be inshore foragers, mainly within 6km of shore (Cherel et al, 1999; Tremblay and Cherel, 2003; Tremblay and Cherel, 2005).

3. Land and Sea Management

Both islands are managed as nature reserves.

4. Threats

4.1 On Land

Introduced species - Amsterdam Island has introduced rats, mice, cats and cattle, whilst St Paul has mice only.

Interactions with native species - None documented

Habitat issues - None documented.

Tourism - There is little tourism on either island, though some visitors arrive on the research supply vessel and from occasional yachts.

Human depredation - The rockhopper penguin population on St Paul was used as a source of bait for crab fishing during the early part of the 20th century.

Natural disasters - None documented.

Disease - There is currently no evidence of disease on either island, although avian cholera is thought to have had a major impact on Indian yellow-nosed albatrosses (*Thalassarche carteri*) and perhaps two other albatross species on Amsterdam Island (Weimerskirch, 2004).

4.2 At Sea

Fisheries bycatch - Not known.

Fisheries competition - Not known.

Competition with native species - Guinard et al. (1998) observed that the decline coincided with an increase in the sub-Antarctic fur seal population from 5,000 in 1971 to 35,000 in 1982 and 1993, and that fur seals may use penguins as secondary prey.

Pollution - The incidence of oiling or entanglement and ingestion of manmade debris is not known, but likely to be relatively minor.

Harmful algal blooms - No harmful algal blooms have been documented at either island.

Oceanographic changes - Guinard et al. (1998) reported two possible causes for the decline at Amsterdam Island. Firstly, they noted that the sharp decrease during the 1980s was correlated with a decrease in SST, and found a particularly strong relationship between February SST and breeding numbers the subsequent spring.

5. Current Research and Monitoring

Some ad hoc population estimates have been made, where there are researchers on-site and able to conduct surveys. There is a permanent scientific base on Amsterdam Island.

APPENDIX 4 Southern rockhopper penguin: Regional reports

1. Argentina
2. Falkland Islands (Malvinas)
3. Chile
4. Pacific Ocean Sites
5. Indian Ocean Sites

1. Southern rockhopper penguin - Argentina

Andrea Raya Rey, Patricia Gandini, Esteban Frere, Klemens Pütz and Adrian Schiavini

1. Populations

Population size for Isla de los Estados was evaluated through an assessment of nest density and then extrapolation to the minimum occupied area as determined by aerial photographs (Schiavini 2000). Southern rockhopper penguins breed at two locations at Isla de los Estados: Bahía Franklin had 166,762 breeding pairs in 1998/99 and Cabo San Juan had 7,031 breeding pairs (Figure 4.1, Table 4.1). There have not been any subsequent surveys at either colony.

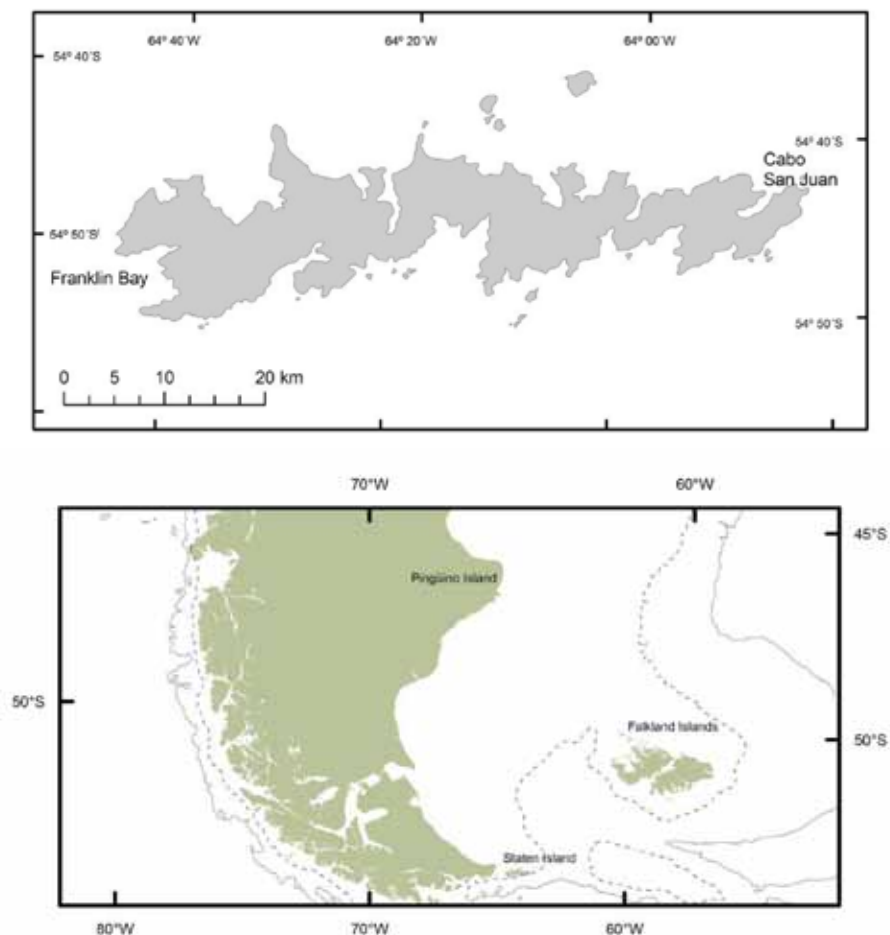


Figure 4.1 Map showing the location of the southern rockhopper colonies in Argentina: Isla Pingüino and Isla de los Estados and a detail on the two colonies on Isla de los Estados.

At Isla Pingüino, Santa Cruz province, various direct counts have been made since 1985. The colony has increased greatly since 1985 when 300 pairs were counted (Frere et al., 1993). The population increased at 27% pa on average between 1991 and 2007, reaching a total of 501 pairs in 2007/08 (Schiavini et al., 2005; E. Frere pers. comm.). An increase of this rate implies that immigration, as well as intrinsic increase, was responsible.

Table 4.1 Population estimates and trends for Argentina

Site	Population	Method	Year of estimate	Trend	Source
Isla de los Estados Bahía Franklin Cabo San Juan	166,762 7,031	Extrapolation from sample counts	1998/99		Schiavini 2000
Isla Pingüino	501	Direct count	2007/08	Increase 27%, 1991-2007	E. Frere pers. comm.

2. Breeding, post-breeding, diet and foraging

At Isla de los Estados, females during the guard phase and both sexes during the crèche period feed on a mixture of crustaceans, cephalopods and fish; frequency of occurrence of these three main food types, and percentage by numbers, varied between years and sexes (Raya Rey and Schiavini 2005; Raya Rey et al., 2007b). Isotopic analysis of feathers of rockhopper penguins from the Bahía Franklin colony on Isla de los Estados showed that the population foraged in two discrete areas during the pre-moult period (Hilton et al., 2006).

At Isla Pingüino, 31 stomach contents were obtained during the guard and crèche periods of 2004/05 through the stomach pumping technique and data is being analysed. From a preliminary study of the samples, it is known that penguins consumed a mixture of (in order of importance) fish, euphausiids and cephalopods (E. Frere pers. comm.).

The provisioning behaviour of females and males during the breeding period was studied at Isla de los Estados through the use of an automated penguin monitoring system, which logged the arrival and departure times of 76 micro-chipped individuals (Raya Rey et al., 2007b). They performed longer trips throughout the breeding season than do other species of *Eudyptes* at several other locations (Schiavini and Raya Rey 2004; Pütz et al., 2006a). Males only provisioned chicks during the crèche stage and at a slightly lower rate than females. Female parental investment was different between years and was related to chick survival. Return rates or survival of the micro-chipped adults was 72 and 63% in the two years studied, whilst breeding success during the same period was 31 and 23% (Raya Rey et al., 2007b).

The foraging area of incubating males and females from Isla de los Estados comprised 350,000 km² of oceanic waters to the southeast of the breeding site and female during the guard period travelled as much as 20 km to their foraging waters, either in shelf waters and/or in waters of the nearby shelf-break and slope (Schiavini and Raya Rey, 2004).

During the winter, the penguins dispersed over an area totalling about 1.3 million km², ranging from 50 to 62°S and from 49°W in the Atlantic to 92°W in the Pacific, and covering polar, sub-polar and temperate waters in oceanic regions as well as Shelf waters (Pütz et al., 2006b). However, two important wintering grounds for rockhopper penguins from Isla de los Estados could be identified, both located over shelf regions. One extended from Isla de los Estados to the north along the coast of Tierra del Fuego up to the Magellan Strait and the other was located over the Burdwood Bank, an isolated extension of the Patagonian Shelf to the south of the Falkland Islands (Malvinas). The Drake Passage also appeared to be an important area for wintering penguins, with birds ranging widely rather than concentrating effort in particular areas.

Oceanography conditions were overlaid on foraging areas during two consecutive years (Raya Rey et al., 2007a). In both years, penguins concentrated their activities in shallow and highly productive waters with temperatures ranging from 5 to 8°C. The two years were characterised by different oceanographic conditions; sea surface temperatures in 2002 were colder than the long-term average, while temperatures

in 2003 were not significantly different from the long-term average. The southern rockhopper penguins migrated to the same general locations in both years but used a larger number of foraging areas in 2002 and they spent less time travelling than in 2003. After the colder winter with more heterogeneous oceanographic conditions, more micro-chipped rockhopper penguins returned to the colony to breed than during the winter that was warmer than usual (Raya Rey et al., 2007a).

3. Land and sea management

In 1991, the Province of Tierra del Fuego, Antarctica and Islands of the South Atlantic was created, which included declaring Isla de los Estados, Isla Año Nuevo and the adjacent islets as an ecological, historical and tourist reserve. Isla de los Estados has a base document but no management plan.

Close to Isla de los Estados, 200 km of mainland coastline and 3 miles out from the shoreline from Cape Nombre up to the mouth of the Ewan River is the Atlantic Coast Reserve. It is intended to extend the reserve to 12 miles and whilst a management plan has been adopted, it is yet to be fully implemented.

Oil companies, and the Coast Guard and the Argentine Navy to a lesser extent, are charged with the implementation of the oil contingency plan for the region. The Province does not have an implementation plan for marine debris management, but occasionally there are some organised campaigns to clean beaches on the mainland and islands of the area.

Isla Pingüino and the adjacent Isla Chata has been a marine protected area of about 2,000 ha since 1992. There is a management plan for the island, which focuses primarily on tourism usage. Around 300 people visit Isla Pingüino each year; its inaccessible location represents the primary form of protection for the island.

4. Threats and mitigation

4.1 On land

Introduced species

There are no introduced predators on Isla Pingüino, while red deer, goats, black rats and Norway rats are present on Isla de los Estados. Predation of eggs and chicks by the two rat species has not been detected, but there have not been any specific studies.

Interactions with native species

Avian predation at the Bahía Franklin colony on Isla de los Estados is low and comparable to that experienced at other penguin colonies (Liljeström et al., 2008). Sea lion predation—on penguins in the water at landing sites is intense at the Bahía Franklin colony (A. Raya Rey, personal observations). This interaction needs to be quantified, as well as collecting information on population trends on seals and sea lions. No such information exists for the Isla Pingüino population.

Habitat issues

The deer and goats on Isla de los Estados are affecting the extent of tussock grass (*Poa flabellata*), the main nesting habitat for the rockhopper penguins.

Tourism issues

Four people live at a navy base on Isla de los Estados but it is not close to the rockhopper penguin colonies. There are some guidelines for tourism and some limited tourism is allowed, although no trips have been made in recent years. Occasionally small yachts with 4–8 people visit unofficially; this is not regulated or quantified.

Isla Pingüino is close to the town of Puerto Deseado (25 km by sea), where ecotourism is a growing sector. The island has a management plan, which allows regulated tourism. There are around 300 tourists per season, with no more than 12 tourists per trip.

Human depredation

No human depredation has been detected.

Natural disasters

No natural disasters have been detected.

Disease

No disease outbreaks have been detected, although the Isla de los Estados colonies are not often visited.

4.2 At Sea

Fishery bycatch

It is possible that rockhopper penguins are accidentally caught by fishing vessels. But if it occurs, it is infrequent, with only one mortality recorded in 10 years of fisheries observers' data in the central and northern Patagonia area (E. Frere and P. Gandini, pers. comm.). Less is known about fisheries activities and seabird bycatch records around Tierra del Fuego; this information is currently being sought. No rockhopper penguins were recorded caught by Chilean demersal longliners fishing working around southern Chile, including south of Tierra del Fuego (Moreno et al., 2003).

Fisheries competition

Within the foraging range of rockhopper penguins from Isla de los Estados, there are at least five trawlers operating to the north, west and southeast of the island. There is no competition in terms of target prey but there is an overlap in location. Target species for the fishing boats are hoki, Patagonian toothfish, kingclip and southern blue whiting, with an incidental catch of rock cod, grenadier and other species. All vessels operate at least 4 miles away from the shoreline.

Competition with native species

Approximately 150,000 pairs of Magellanic penguins breed in three different colonies on Isla de los Estados. The diet of this species comprises squid (mainly *Moroteuthis ingens* and *Loligo gahi*) and fish species, particularly *Sprattus fuegensis*. Although there is an overlap in prey items with the rockhopper penguin, sizes are slightly different, such that there appears to be little competition between the two species.

The diet of other potential competitors (e.g. fur seals, sea lions or shags) is not known at Isla de los Estados or Isla Pingüino.

Pollution

The incidence of rockhopper penguins with oil, entangled in debris or with stomach samples containing manmade objects is not known but is likely to be relatively minor. A few oiled rockhopper penguins are found along the coast of Chubut and Buenos Aires, but the annual numbers are decreasing year to year.

Harmful algal blooms

No harmful algal blooms have been documented at any of the islands.

Oceanographic changes

There is slight evidence that sea water temperature during the non-breeding season affect movements and foraging areas of rockhopper penguins from Isla de los Estados, which then influences breeding success and return rates to the colony the following season (Raya Rey et al., 2007a).

5. Current research and monitoring projects

On Isla Pingüino, E. Frere and co-workers are planning to go on with the annual monitoring of breeding pairs to establish trends in population and breeding success and further studies of reproductive biology. There has not been any monitoring or research at Isla de los Estados since January 2005, although it is the intention once sufficient funds are obtained.

2. Southern rockhopper penguin - Falkland Islands (Malvinas)

Paulo Catry, Nic Huin, Grant Munro, Petra Quillfeldt, Maud Poisbleau, Helen Otley and Klemens Pütz

1. Populations

Southern rockhopper penguins breed at a total of 35 sites in the Falkland Islands (Malvinas), comprising approximately 55 separate colonies. Colony distribution is predominantly to the west and north of the islands, with only three sites to the east and south. Most are located on rocky cliffs and platforms, often in association with black-browed albatross and/or king shags (Huin, 2007b).

Falklands Conservation undertakes a programme of annual monitoring of nine colonies at four sites, which commenced in 1987 (Huin, 2007b) and 5-yearly census of the entire population (1995, 2000, and 2005) (Huin, 2007a). Annual monitoring is undertaken by direct count of the colonies. Initial breeding pair counts are undertaken in November and fledging chick counts are undertaken at the end of January.

Island-wide census of breeding pairs is undertaken in November and three separate survey methods are employed (Huin, 2007a). Direct counts are undertaken of small colonies that are visible from a vantage point or where there is access around the colony. Boat-based photographic counts are undertaken where access is limited due to the steep nature of the terrain.

A system of colony area measurement and nest density transects through the colony is undertaken for the two largest colonies of mixed southern rockhopper penguin and black-browed albatross. This method may need to be reviewed in the future as with the reductions in population, there is an increasing tendency for rockhopper penguins to congregate in pockets rather than be distributed throughout the colony, which leads to a high level of variability in the recorded nest density between transects (Huin, 2007a).

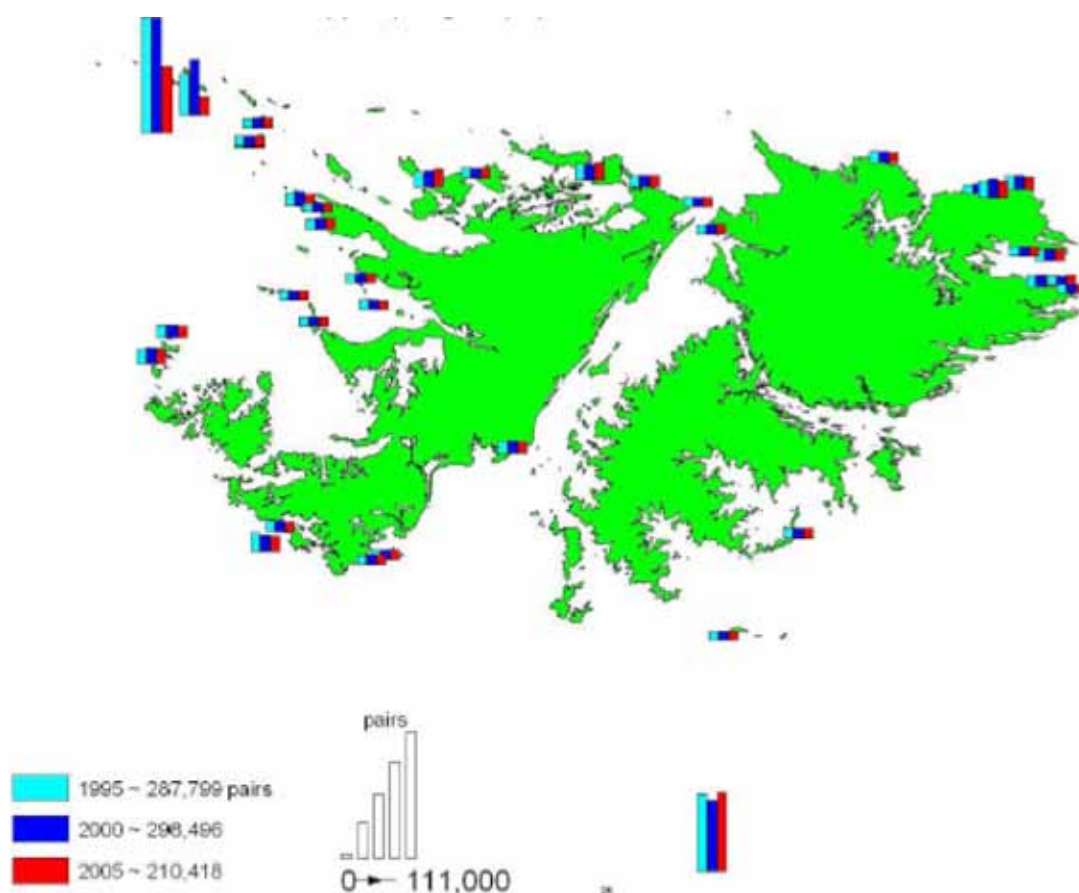


Figure 4.2 Changes in southern rockhopper penguin population in the Falkland Islands (Malvinas) between 1995 and 2005. (Source - Huin 2007a.)

At New Island, rockhopper penguins nest in four localities and due to the difficulties in counting due to the terrain and habitat, various census techniques have been developed and evaluated (NICT 2007). An estimate of 30-40,000 pairs was made of the largest colony, the Settlement Rookery, in the mid to late 1970s (I. Strange, unpublished data).

During October 2001, an infrared beam coupled to an electronic counter was used to census males and females returning to a section of the main Settlement Rookery known as The Bowl, which contains about one quarter of the Settlement Colony. The counts of males and females were comparable, with a total breeding population of 2,593 pairs (Strange, 2001).

Standardised whole-day counts of rockhopper penguins coming ashore on 11-13 Dec (brooding stage) at the landing place of the Settlement Rookery were initiated by Paulo Catry in 2003 and carried out in subsequent years by 6-8 researchers and helpers. This methodology is further discussed in Appendix 5.

At the most recent census in 2005/6, the total Falkland Islands (Malvinas) population was estimated to be 211,000 breeding pairs (Huin, 2007a, Table 4.2). This represents a decline of 88,000 breeding pairs over the 5 years since 2000. The three most important colonies are on Beauchêne Island (71,343 pairs, 31% of the total), Steeple Jason (59,033 pairs, 28%) and Grand Jason (10,496 pairs, 5%) (Figure 4.2).

Trends over the three conducted censuses from 1995–2005 show that there was a population increase of 0.74% per annum (p.a.) from 1995 to 2000 and a population decrease of 5.9% p.a. from 2000–2005 (Figure 4.3). Over the last 10 years, this represents a loss of 77,381 pairs or a rate of decline of 2.7% p.a.

A partial survey conducted in 1932/33 by A.G. Bennet provides the earliest estimate of population at approximately 3 million breeding pairs (Bennet 1933). Following review of this historic data, and corrections to over-estimates of colony area, a more accurate 1933 estimate of 1.5 million breeding pairs has been proposed (Pütz et al., 2003a). Thus since 1933 the population has declined by 86% (Figure 4.3). However, various Falklands (Malvinas) bird experts suggest that the Bennet 'guesstimates' are extremely unreliable and place significant weight on the fact that the report was never published.

Table 4.2 Population estimates and trends for the Falkland Islands (Malvinas).

Site	Population	Data quality	Year of estimate	Trend	Source
Falkland Islands (Malvinas)	210,418	Counts	2005	Decline 86% from 1933 - 2005	Huin 2007a

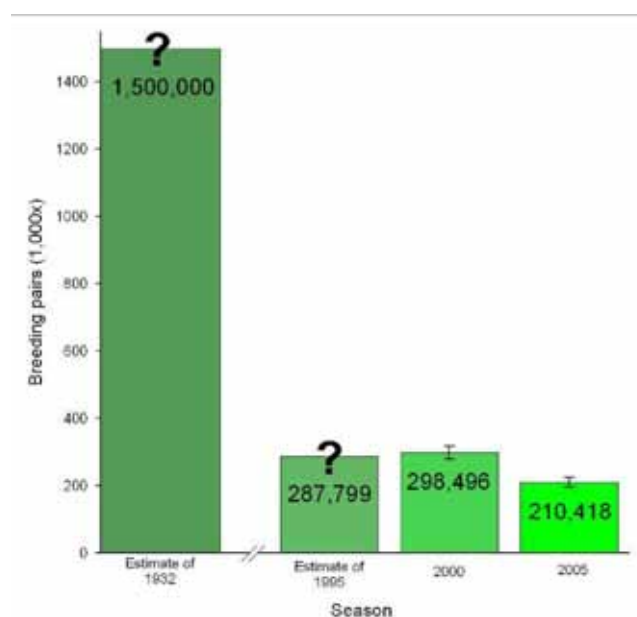


Figure 4.3 Reconstructed trends in the Falkland Islands (Malvinas) southern rockhopper penguin population. (Source - Huin 2007a).

Annual monitoring shows that the changes in population and breeding success have not been constant either over time or between colonies (Pütz et al., 2001; Huin, 2007a) (Figure 4.4).

Population decline appears to occur due to periodic mortality events caused for example by harmful algal blooms (HABs), as occurred in 2002/03, and starvation prior to moult as occurred in 1985/86 and to a lesser extent in 2001/02 (Boersma et al., 2002; Boersma et al., 2004; Pütz et al., 2002; Pütz et al., 2003b). Starvation during the 2002/03 moult may possibly be attributed to atypical oceanographic events and low sea-surface temperatures (Huin, 2007a). The starvation in the 1986/87 mortality event was possibly caused by a shortage of euphausiid crustaceans due to unusual oceanographic conditions and overexploitation of some forms of prey species (Keymer et al., 2001). Mortalities during moult in the Falkland Islands (Malvinas) were not found at the same time at nearby Isla de los Estados.

The HAB of 2002/03 caused paralytic shellfish poisoning in a number of seabird species, not only rockhopper penguins. High levels of adult mortality and breeding failure in rockhopper penguins were recorded (Huin, 2003). Whilst the subsequent decline in gentoo penguin numbers clearly matched the geographical extent of the HAB, there were greater inter-colony variation declines in the rockhopper penguin colonies suspected to have been affected by the HAB (Huin, 2007a).

In intervening years, the population appears stable, with breeding success varying between 0.63–0.80 chicks per breeding pair (Figure 4.4 right), but the colonies seem unable to recover to levels prior to crashes associated with HABs and starvation events. The factors determining the inability of the species to recover from such episodic events has not been ascertained (Huin, 2007a).

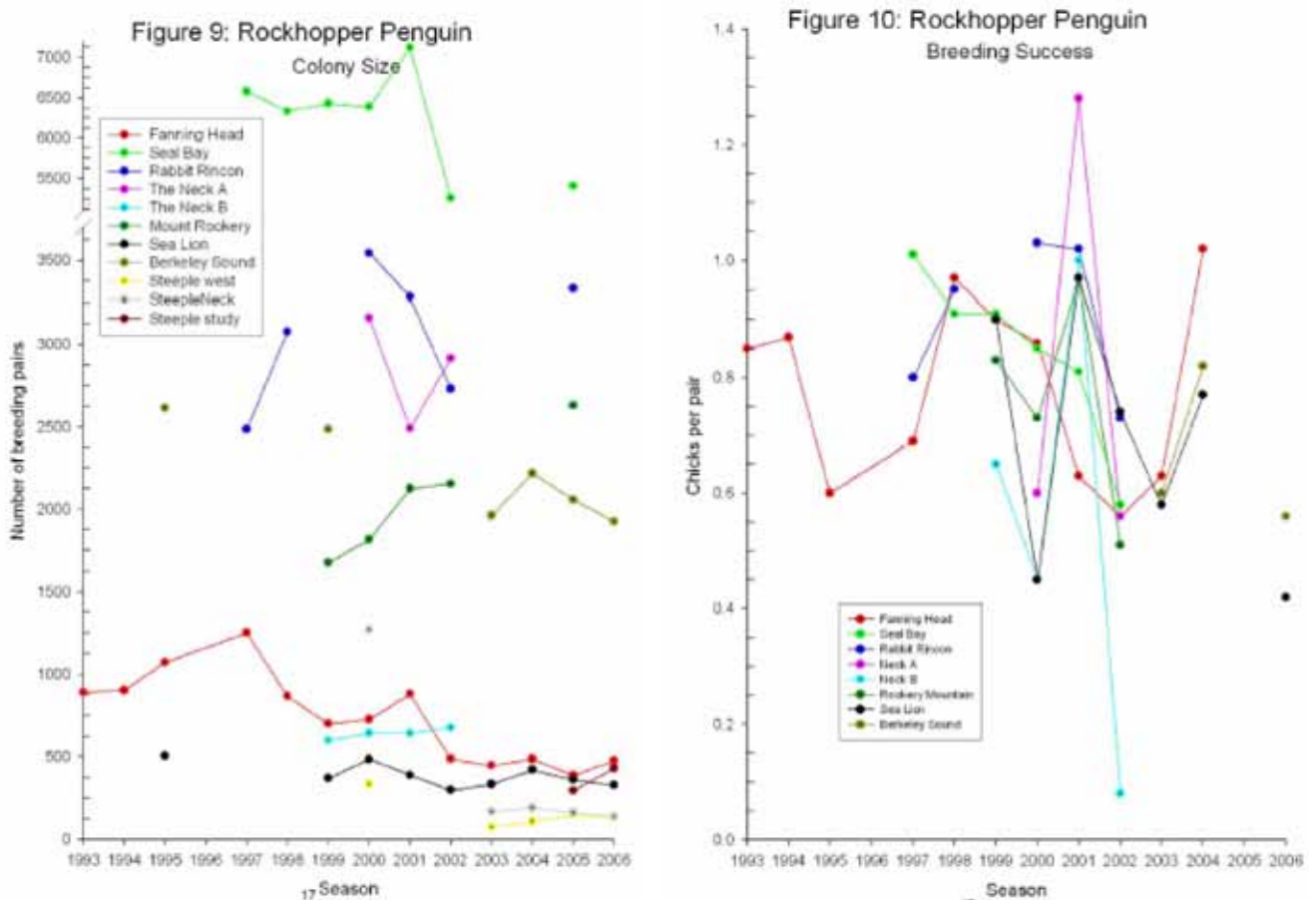


Figure 4.4 Population sizes (left) and breeding success (right) of annually monitored southern rockhopper penguin colonies during 1993–2006 in the Falkland Islands (Malvinas). (Source - Huin, 2007b).

2. Breeding, post-breeding, diet and foraging

Strange (1982) documented the breeding biology of the rockhopper penguin at New Island. Poisbleau et al. (2008) have completed two years of long-term monitoring programme (see Section 4 below).

One discovery is that when alone, the A-egg (first, smaller egg) has the same theoretical intrinsic potential to lead to a fledged chick as the B-egg (second, larger egg), but the hatching success and survival of the B-chick was not significantly different when alone or in a two-egg clutch.

Diet sampling was conducted as part of the Falkland Islands (Malvinas) Seabird Monitoring Programme (FISMP) from 1987/88 until 2003/04. The diet is predominantly crustacean prey with varying proportions of *Euphausia lucens*, *Euphausia vallentini*, *Thysanoessa gregaria*, *Themisto gaudichaudi* and *Munida gregaria*. Cephalopods and fish are also taken to a lesser degree, including the commercial species *Loligo gahi* (Pütz et al., 2001; Clausen and Pütz, 2002). The diet varies geographically. There is some evidence that squid is of greater importance in the diet around the Falklands (Malvinas) than elsewhere (Clausen and Pütz, 2002; Raya Rey and Schiavini, 2005). However, over the sampled period, the reliance on squid has declined with an increase in fish (Clausen and Pütz, 2002).

Adult, fledging and first year rockhopper penguins in the Falkland Islands (Malvinas) have been tracked from a total of six sites around the Falkland Islands (Malvinas) during incubation, brood, pre-moult and winter dispersal phases of the breeding cycle (Boersma et al., 2002, 2004; Pütz et al., 2002; Pütz et al., 2003b).

Foraging is conducted across the Patagonian shelf waters. During the breeding season, birds from the northern colonies utilised the predominant current patterns travelling in an anti-clockwise manner, travelling first north, then west before returning south on a counter eddy having reached as far north as 49°S. Birds tracked from southern colonies and New Island showed greater variation in tracks, some travelling in a westerly direction across the shelf, but others remaining in more coastal waters.

During the winter dispersal period, birds used an area extending from Falklands (Malvinas) coastal waters to the Magellan Strait and as far north as 49°S along the coast of South America, up to 1,500 km from the Falklands (Malvinas). At-sea surveys conducted through the year match these foraging patterns (White et al., 1999).

The separation in the foraging areas of northern and southern/western birds is reflected in the stable isotope analysis of feathers, with very different values for birds from Sea Lion Island (south) and Seal Bay (north) (Hilton et al., 2006).

To date there has been no detailed demographic study or research into the breeding biology of the southern rockhopper penguin in the Falkland Islands (Malvinas). However, P. Quillfeldt has initiated a study at the Settlement Rookery on New Island and this is detailed separately within the current research section below.

3. Land and sea management

The 35 breeding sites have varied ownership and management, from national nature reserve status and very limited access permitted to privately owned sheep/cattle farms. No sites are under Falkland Islands Government adopted site managed plans, although some are designated national nature reserves. However, all landowners (more or less) actively protect breeding sites from detrimental effects of livestock grazing and tourism (see Section 4 below).

FIG adopted an Oil Spill Contingency Plan in 1998 and it is due for revision in 2008. Some failings have been identified in two recent incidences where vessels have gone aground or sunk. There is no Wildlife Disease Contingency Plan in the Falkland Islands (Malvinas).

A 200 nautical mile economic exclusion zone is in place around the Falkland Islands (Malvinas), with fishing subject to licence, and this is enforced by fisheries patrol vessels and aircraft. There is no fishing within 3 nm of the coast. FIG enforces marine debris pollution legislation but it only extends to all locally registered vessels and all other vessels within 12 nm of coastlines (i.e. territorial waters).

4. Threats and mitigation

4.1 On land

Due to the large number of breeding sites and their geographical separation, any catastrophic land-based disasters would tend to be site-specific.

Introduced species

The South Atlantic Invasive Species programme is currently coordinating action and response to invasive species and biosecurity issues in the Falkland Islands (Malvinas). There is no documented evidence of significant predation of rockhopper penguins by rats, cats or mice on New Island or elsewhere (Matias and Catry, 2008; Quillfeldt et al., 2008b).

Interactions with native species

The rockhopper penguin interacts with skuas, giant petrels, gull species, turkey vultures (*Cathartes aura*) and striated caracaras (St Clair and St Clair, 1996). A study of the diet of striated caracaras showed that that 15% of striated caracara pellets contained penguins (mostly rockhopper penguins and Magellanic penguins) (Catry et al., 2008) although these are probably carrion and caracaras are not a significant predator (P. Catry, pers. comm.).

The rates and success of predation by birds may be increasing as the colonies become smaller and fragmented, increasing the proportion of birds on the edge of colonies (Huin 2007a). There is no evidence of seals and sea lions amongst colony areas creating significant problems. Depending on the timing of breeding, in some years king shags out compete southern rockhopper penguins for breeding sites at New Island (M. Poisbleau unpublished data).

Habitat issues

An 80% reduction in the extent of tussac grass cover has occurred in the Falkland Island due to sheep, cattle and horse grazing. The effects of site characteristics, e.g. tussac grass and rock cover, has been studied on New Island; no clear effects were found (Matias, 2005; Poisbleau et al., 2008).

Tourism

Tourism continues to increase in the Falkland Islands (Malvinas) and the 2007/08 season witnessed a 21% growth in the cruise industry sector and 18% growth in the land-based sector (Falkland Islands Tourist Board data). However, given the relatively inaccessible location of most rockhopper colonies, particularly the largest ones, disturbance effects associated with tourism are low. The Falkland Islands Countryside Code recommends a maximum viewing distance of 6 m.

A tourism impact study has been conducted on New Island and there was no significant difference in the colony breeding success of sites where there was close, distant and no tourism (Catry et al., 2007).

A specific study into the impact of visitor activity on king and gentoo penguins to visitor activity showed that these penguin species were relatively robust to managed tourism sites (Otley, 2006).

Drivers are requested not to drive vehicles within 200 m of breeding seabirds and it is not permitted to overfly colonies at heights of less than 500 feet (150 m) or 1,500 feet (460 m) (depending on the presence of other seabird species).

Human depredation

Rockhopper penguins are fully protected under the Conservation of Wildlife and Nature Ordinance 1999 and it is prohibited to collect eggs from the species. However, prior to this, large numbers of eggs were taken, particularly from colonies close to settlement areas, and this activity was thought to have been a factor in population declines up until the 1950s. Sealers also took penguins during the late 1800s and early 1900s, although gentoo penguins were thought to be the primary target species due to their more accessible colony areas (Woods and Woods, 1997).

Natural disasters

Lightning strike wildfires are a threat in the Falkland Islands (Malvinas) and fires started accidentally by visitors are an increasing risk. Landowners at many visitor sites have a no smoking policy.

Disease

Vets from the Wildlife Conservation Society (WCS) conducted disease monitoring on black-browed albatrosses, gentoo penguins, rockhopper penguins and Magellanic penguins in 2003. The results showed that these populations are remarkably free of exposure to infectious diseases when compared to populations on mainland South America (M. Uhart, unpublished data). It suggests that the Falkland (Malvinas) populations to date have not been exposed to common infectious agents found elsewhere and therefore may be naïve and susceptible to disease.

Another remarkable finding from 2003 was the high prevalence of antibodies (indicative of previous exposure/infection) to low pathogenic avian influenza virus in the rockhopper penguins on East Falkland. This was not detected in any other species of bird tested in the Falklands (Malvinas) nor is it commonly found in wild waterbirds of mainland South America (M. Uhart, unpublished data). Low pathological strains are not uncommon in wild waterfowl of the northern hemisphere but very little is known of them in the southern hemisphere.

In February 2007, the WCS vets collected further swabs from the rockhopper penguins in an attempt to isolate the virus that produced those previous test results. Results to date are negative for low path avian influenza viruses, while a paramyxovirus of an unidentified serotype has been isolated from one individual. Work is still in progress. Additional black-browed albatross and rockhopper penguin samples were collected in 2008 and these are currently being analyzed at specialized labs in the USA (M. Uhart unpublished data).

An outbreak of avian pox occurred at one colony of black-browed albatrosses in the 1960s, with the most recent outbreak (2006) occurring only in gentoo penguins (Munro, 2007).

4.2 At sea

Fisheries bycatch

Both Falklands Conservation and FIG currently operate fisheries observer programmes. Incidental capture of rockhopper penguins has only occasionally been recorded within Falklands (Malvinas) waters (Falkland Islands Fisheries Department, unpublished records). However, satellite tracking has shown that birds forage across the Patagonian shelf where they may be at risk from fisheries.

Fisheries competition

The rockhopper penguin does not compete directly with the commercial fishery, with only a slight overlap for *L. gahi* (Clausen and Pütz, 2002). Rockhopper penguins have not been observed taking discards. Whilst no direct overlap with the commercial fisheries has been identified, indirect effects cannot be excluded. Future research should focus on the potential interactions between the target species of the fishing fleet and the prey species taken by seabirds. Before potential impacts can be fully elucidated, food web interactions involving the multiple trophic levels would have to be identified (Clausen and Pütz, 2002).

Some areas around to the Falkland Islands (Malvinas) are closed to fishing, including a 3 nm limit around all coastlines and an area east of Stanley (the 'Loligo' box) (Figure 4.5).

Competition with native species

There is some overlap in the diet of rockhopper, gentoo and Magellanic penguins, but the diet overlap may vary temporary and spatially (Pütz et al., 2001). Fur seals and sea lions take some prey species that are also consumed by rockhopper penguins (Thompson et al., 1998; Thompson and Moss, 2001), but it is suspected that sea lion and fur seal populations are too small to create any significant interspecific competition.

In certain years, sea lions eat many rockhopper penguins on New Island; although there are no quantitative studies this may be a significant factor affecting the breeding population (P. Catry, pers. comm.).

Pollution

The incidence of oiled penguins is low in the Falkland Islands (Malvinas) due to low shipping activity and rough open seas, which leads to dispersal of any spilled oil (Smith, 1998; Nicholson and Harrison, 2001). However, studies from adjacent waters in Argentina have shown that chronic oil pollution can be a

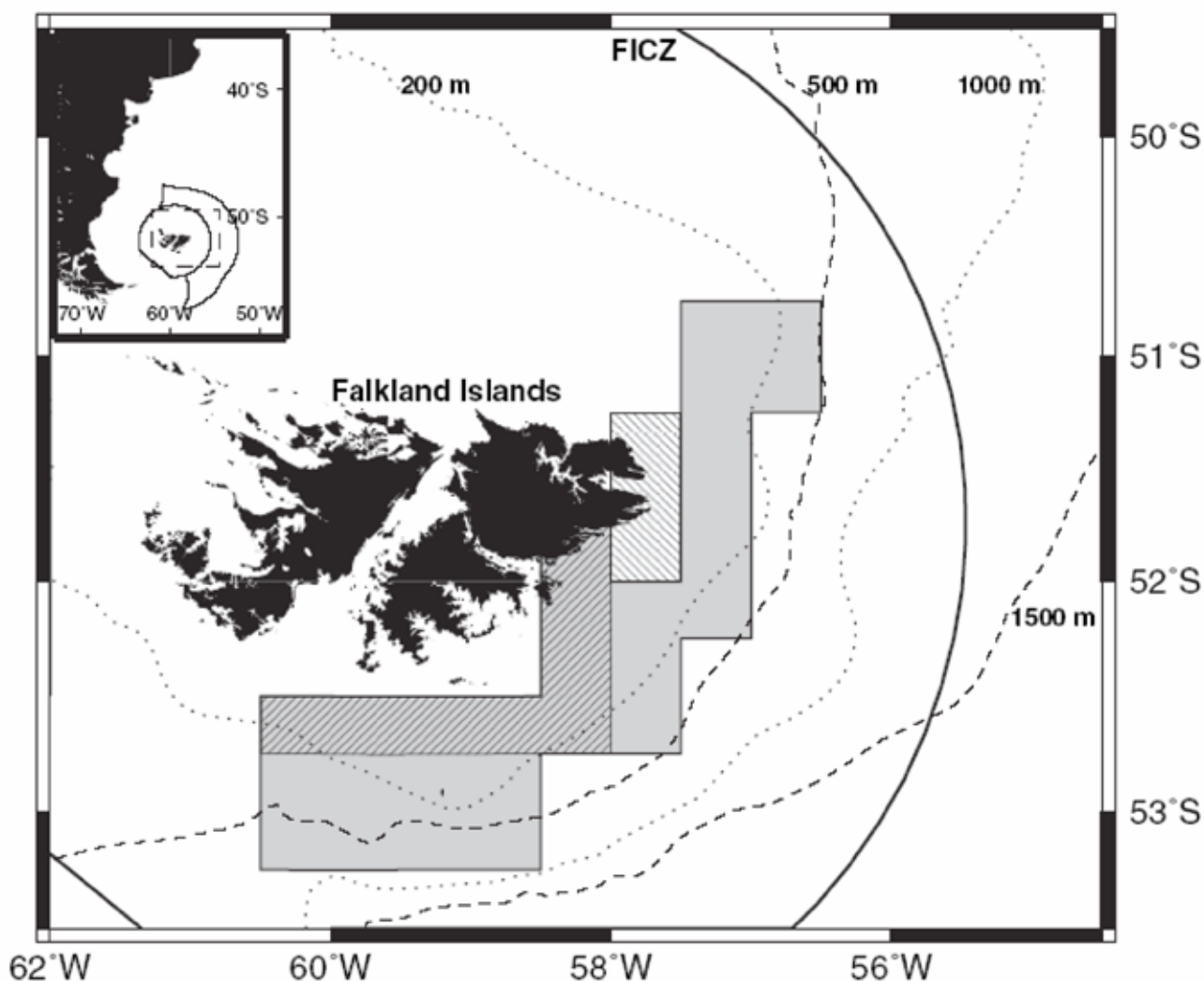


Figure 4.5 The licensed area for *L. gahi* (gray area), including the closed area (hatched area).
(Source - Arkhipkin et al., 2008).

significant risk to seabirds (Garcia-Borboroglu et al., 2006). Vulnerability of seabirds to oil pollution in the Falkland Islands (Malvinas) has been mapped and February is the most critical month because seabirds such as southern rockhopper penguins are foraging in more coastal waters (White et al., 2001). The development of an offshore oil industry may increase the risk in the future.

During the late 1970s, the levels of organochlorine and polychlorinated biphenyls in the eggs of sea, coastal and inland birds of the Falkland Islands (Malvinas) were measured. The levels of these persistent organic pollutants in the Falkland Islands (Malvinas) were a magnitude less than that reported for comparable northern Germany seabird species (Hoerschelmann et al., 1979).

The levels of heavy metals and radioactivity were determined for a number of rockhopper penguins from the Falkland Islands (Malvinas) that died in 1986 and healthy individuals in 1987 (Keymer et al., 2001). Levels of heavy metals and radioactivity were below levels that induce toxic effects and were not different between dead and healthy rockhopper penguins. Both healthy and dead rockhopper penguins had high tissue cadmium concentrations, although this is unlikely to be of pathological significance.

In the Falkland Islands (Malvinas), monthly beach surveys during the 2001/02 summer at Volunteer Beach (East Falkland) showed a litter accumulation rate that was about that expected for its location and degree of fishing vessel activity (Otley and Ingham, 2003). An unofficial report based on Falkland Islands Fisheries Department Fisheries Observer reports from 2001/02 found that observers on 35 trips reported no waste disposal system in operation on 20 vessels, predominantly those of the Asian jigging fleet and

finfish trawlers. The current state of affairs has not been reviewed recently. A handful of penguins have been found dead on Falkland Islands (Malvinas) beaches entangled in fishing nets (H. Otley personal communication).

Harmful algal blooms

There has been at least one harmful algal bloom (HAB) in the Falkland Islands (Malvinas), occurring during November and December 2002. The Falklands (Malvinas) HAB of 2002/03 is the first report of paralytic shellfish poisoning affecting and/or killing large numbers of seabirds in the South Atlantic Ocean. Although it is highly possible that similar events have occurred before in this area (See Appendix 2), the identification of toxins in tissues of affected or dead animals had not been previously successful. The frequency and severity of HABs in the South Atlantic also appears to be increasing.

Oceanographic changes

Considerable remotely sensed and real time ocean data exists for waters around the Falkland Islands (Malvinas). However, the oceanographic data has not been related to the penguin biology or ecology.

5. Current research and monitoring projects

A detailed study following the complete breeding cycle of southern rockhopper penguins has been started in 2006/07, with funding from the Deutsche Forschungsgemeinschaft, Germany (Emmy Noether Programme, Grant to P. Quillfeldt) and New Island Conservation Trust, and with small grants from the FIG Environmental Studies Budget.

During the first three seasons, work was carried out in the framework of a project called "Parent-offspring and sibling conflicts in rockhopper penguins breeding at New Island". Although the immediate output of this project will be publications in the field of behavioural ecology, it also serves as a start-up phase for a long-term monitoring programme, including monitoring of ecophysiological parameters. First publications describe breeding success parameters in 2006/07 (Poisbleau et al., 2008), as well as baseline ecophysiological data (Poisbleau et al., 2009, Poisbleau et al., in press).

Nests and individuals in a study sector at New Island are marked and eggs and chicks weighed. In addition, we have installed, and are currently making improvements on, a Radio Frequency Identification weighbridge, for automated monitoring. Starting with the season 2006/07, we have marked 407 adults and fledglings with Passive Integrated Transponder (PIT) tags. We expect that the detailed data on attendance and body condition of marked individuals will contribute to understanding how oceanographic conditions affect this species.

Further foraging area research using GPS tracking is planned for the 2008/09 season, with the funding for the devices to be supplied by the Max Planck Institute for Ornithology (Project co-ordinators: Prof. Martin Wikelski, Dr Juan F. Masello and Dr Petra Quillfeldt). This will be on-going in 2009/10 and 2010/11 as part of the OTEP-funded project "Ocean climate and rockhopper penguin foraging strategies".

Analysis of stable isotopes has been carried out of a variety of seabirds, including rockhopper penguins, at New Island using samples obtained during 2004–2007. Initial analysis has been carried out, although there were too few samples for any conclusive results for rockhopper penguins (Weiss et al., in press) and further analysis will be occurring during 2008/09.

3. Southern rockhopper penguin - Chile

Manuel Marin, David Oehler and Andrea Raya Rey

1. Populations

The southern rockhopper penguin is known to breed in Chile at a minimum of 15 sites from Isla Diego Ramirez at 56°S to Isla Solitario at 47°S (Figure 4.6, Table 4.3). However, only 11 of the known breeding sites have been surveyed properly and surveys have been conducted using a variety of methods. The estimated total population of rockhopper penguins in Chile is 396,786 pairs.

Isla Recalada had 10,000 pairs in 1993 but none by 2005, a decline that has been attributed to human depredation for crab pot bait and zoological collection (Oehler et al., 2007). It is the only known breeding site with an accessible landing.



Figure 4.6 The extent of the coastline of Chile where southern rockhopper penguins are known to breed. The place names are used to indicate geographic locations and are not breeding sites. It should be noted that in Chile, unlike at other localities, there are potentially undiscovered breeding colonies.

2. Breeding, post-breeding, diet and foraging

In late December, rockhopper penguins at Isla Noir fed on *Sprattus fuegensis*, *Thysanoessa* spp. and unidentified cephalopods (Venegas, 1998). The diving behaviour of female rockhopper penguins was studied during the late brooding/crèche period at Isla Noir during 2005/2006 using time-depth recorders. These birds mostly undertook overnight trips (60% of all trips), lasting on average 40–42 h. The dive depth and duration combined with the diet data suggests that the females were mostly foraging over the continental shelf in the southeast Pacific Ocean because the colony is located only 60 km away from the shelf slope (Raya Rey et al., 2009).

Feather Link researchers attached ten satellite transmitters to southern rockhopper penguins at Isla Noir on 12 November 2003. Problems were encountered with the underwater housings for these devices, although several units continued to transmit data for several weeks. The most distant known locations for two units on 25 November and 8 December are shown in Figure 4.7.

Table 4.3 Population estimates and trends for Chile

Site	Breeding Pairs (95% confidence limit)	Data quality	Year of estimate	Trend	Source
Diego Ramirez Arch. (56°30'S/68°52'W)	132,721 (88,860 - 185,665)	Quadrat and distance sampling	2002	Unknown	Kirkwood et al., 2007
Hall (55°52'S/67°24'W)	500	Yacht based	1984	Unknown	Clark et al., 1992
Hornos (55°50'S/67°15'W)	600	Yacht based	1984	Unknown	Clark et al., 1992
Ildefonso Arch (55°50'S/69°15'W)	5,660 (2,280 - 11,900)	Quadrat and distance sampling	2002	Unknown	Kirkwood et al., 2007
Barnevelt (55°49'S/66°46'W)	10,800	Yacht based	1984	Unknown	Woehler, 1993
Terhalten (55°26'S/67°04'W)	3,000	Direct ground count	2007	Unknown	Oehler & Marin, unpub. data
Carolina (55°25'S/69°31'W)	?	Yacht based	1913	Unknown	Murphy, 1936
Noir (54°20'S/73°01'W)	158,200 (139,716 - 176,700)	Quadrat sampling	2005	Possible increase	Oehler et al., 2008
Recalada (53°17'S/74°20'W)	0	Direct ground count	2005	Decline	Oehler et al., 2007
Desolación, Cabo Pilar (52°44'S/74°41'W)	3,000	Yacht based	1978	Unknown	Venegas, 1979
Buenaventura (50°45'S/75°09'W)	500	Yacht based	1984	Unknown	Woehler, 1993
Vorposten Group (49°22'S/75°42'W)	?	Yacht based	1977	Unknown	Venegas, 1978
Golfo Ladrillero (49°19'S/75°37'W)	300	Yacht based	1977	Unknown	Venegas, 1978
Notables Group (48°54'S/75°09'W)	?	Yacht based	1977	Unknown	Venegas, 1978
Solitario (47°42'S/75°42'W)	35	Yacht based	1978	Possible increase	Venegas and Jory, 1979

Feather Link Inc. researchers deployed geo-locator devices attached to wing bands on 15 rockhopper penguins at Isla Terhalten in December 2007 to determine annual foraging routes. They will be recovered in 12 months time. Geo-locator devices were deemed to be most appropriate, due to the difficulty of accessing sites in March, when satellite transmitters (the alternative tracking method for determining winter migration) could be attached. Feathers and blood samples were also been collected for stable isotope analysis to determine diet.

3. Land and sea management

There is little documentation about the management of the areas where the rockhopper penguins breed and most likely forage.

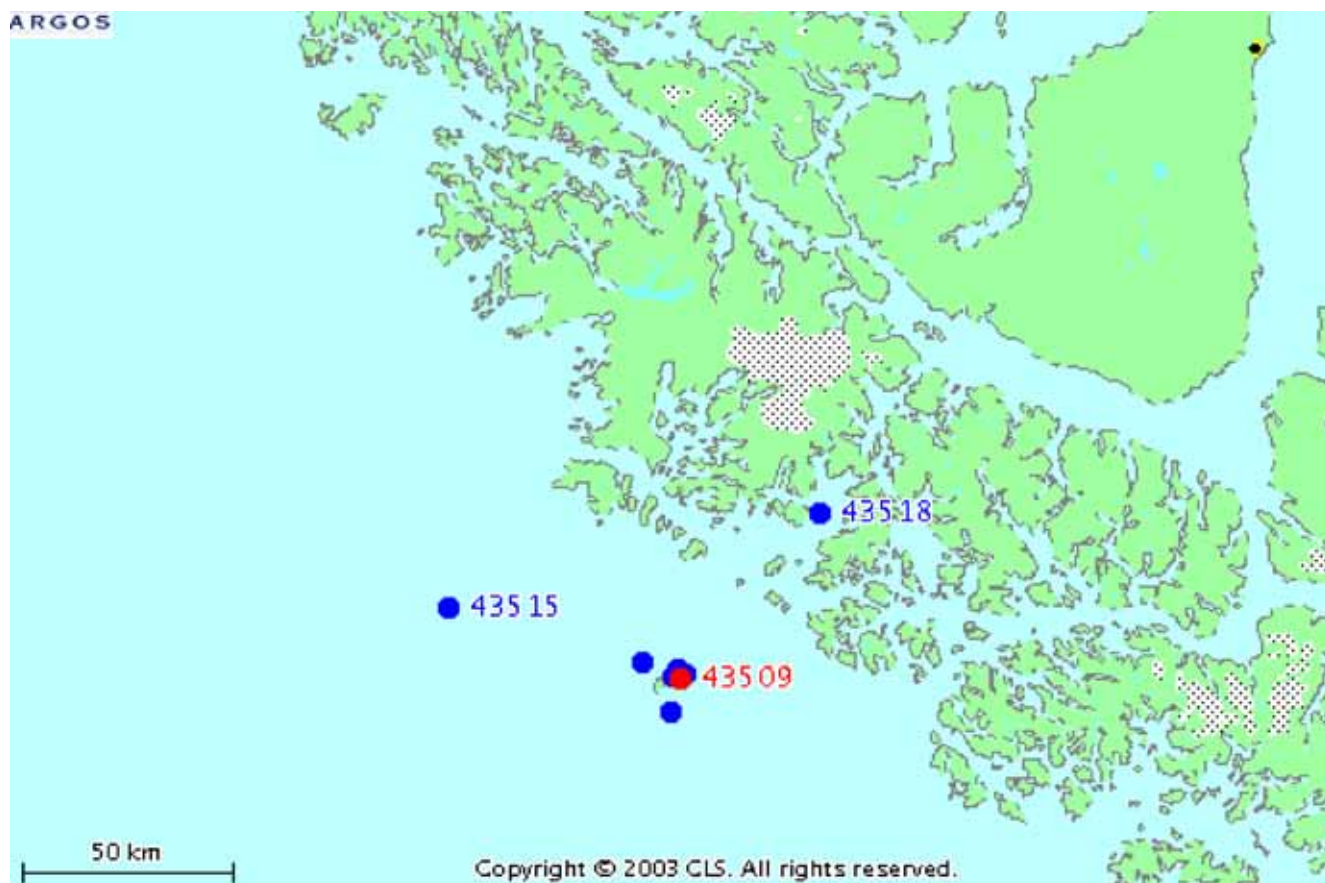


Figure 4.7 Location of the most distant locations for two satellite-tracked southern rockhopper penguins (435 15 and 435 18) from Isla Noir (435 09) during November–December 2003.

4. Threats and Mitigation

4.1 On land

Introduced species

The few limited surveys have not documented introduced species such as cats and rats at the 15 known breeding sites.

Interactions with native species

Potential predators of rockhopper penguin chicks in Chile are skuas, giant petrels, gull species, turkey vultures and striated caracaras. Some competition for nest sites with macaroni penguins has been documented (Oehler et al., 2008).

Habitat issues

No habitat issues are documented at any breeding sites.

Tourism issues

All known breeding sites are very inaccessible; therefore, they are visited very infrequently and most visits are by researchers and permission must be sought from the Chilean authorities. An ecotourism venture is tentatively proposed for Isla Diego Ramirez, which could affect the rockhopper penguins breeding there. To date, no management plan for or an environmental impact assessment of the proposed construction and tourism activities has been produced.

Human depredation

Collection of zoological specimens and bait for crab pots (Oehler et al., 2007). There is relatively little current depredation; it is suggested to be less than 500 birds per year.

Natural disasters

No natural disasters have been documented.

Disease

There have been few investigations of disease; on Isla Noir, birds had normal parasite and pathogen loads (D. Oehler unpublished data).

4.2 At sea

Fishery bycatch

It is not clear if any governmental agencies have investigated seabird bycatch issues in all fisheries in southern Chile. No rockhopper penguins were recorded caught by Chilean demersal longliners fishing working around southern Chile, including south of Tierra del Fuego (Moreno et al., 2003).

Fisheries competition

Fisheries activity in southern Chile is not known. There has been recent suggestion that salmon aquaculture ventures could be set up in the Chilean channels near to where rockhopper penguins breed; how this might effect the marine ecosystem is not known.

Competition with native species

Fur seals have been documented at several locations, including Isla Noir and further monitoring efforts should include determining if these or other mammal taxa are having an adverse affect on the rockhopper penguins.

Pollution

The chemical pollution loads have not been investigated and no birds entangled in marine debris have been observed. Some oiled birds have been seen at Isla Noir.

Harmful algal blooms

No harmful algal blooms have been documented at breeding sites, although they have been very infrequently visited.

Oceanographic changes

No details are known about this potential threat.

5. Current research and monitoring projects

Surveys by Feather Link will continue along the coast of southern Chile in 2008/09, with the recovery of geo-locators deployed in 2007 on rockhopper penguins on Isla Terhalten and the deployment of additional devices on birds on Isla Noir.

Development of known penguin micro-satellite primers for amplification via polymerase chain reaction is presently underway using feather and blood samples obtained from sites on Isla Noir and Isla Terhalten. Genetic samples could be obtained from the Isla Recalada population, which is extinct in situ but still exists ex situ in captivity in a number of zoos in the USA.

4. Southern rockhopper penguin - Pacific Ocean Sites

Rosie Gales, Cindy Hull, Helen Otley, David Thompson and Eric Woehler

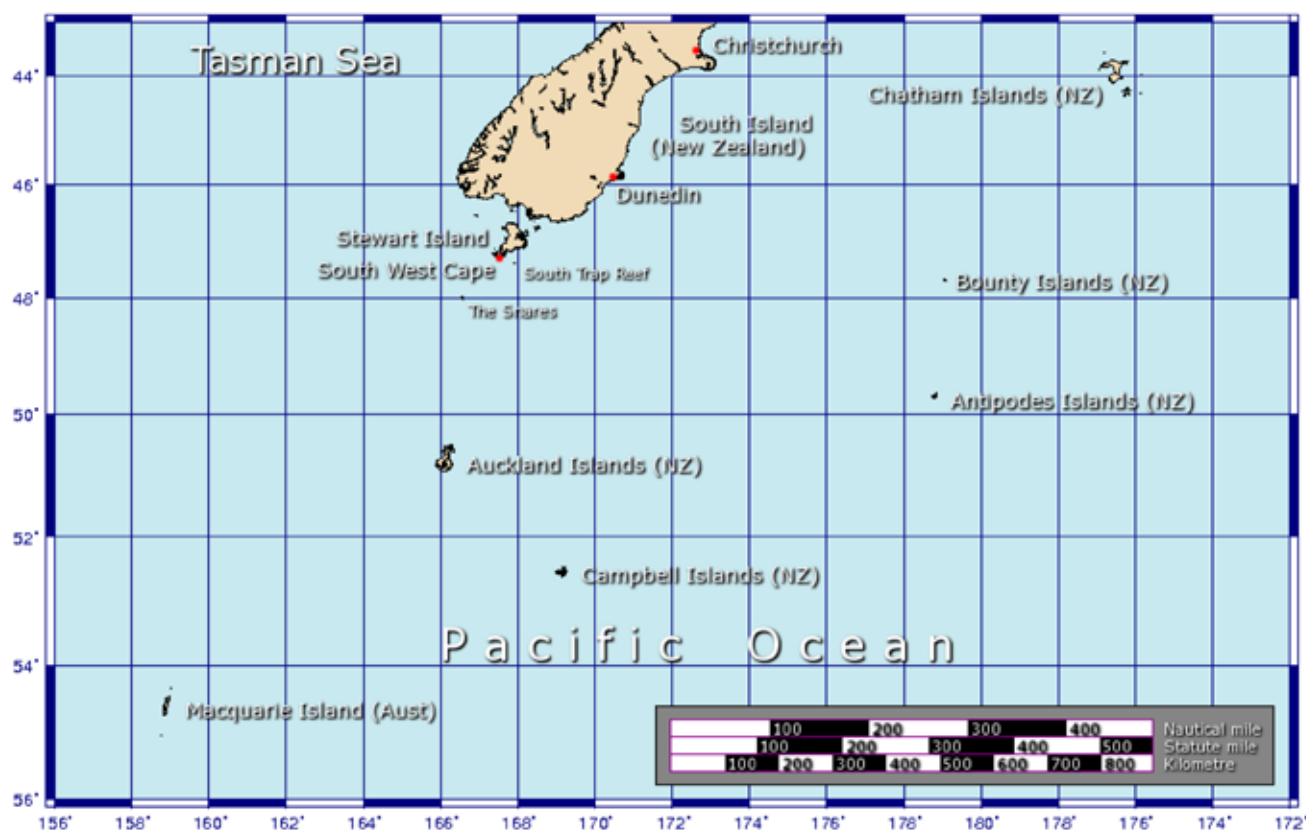


Figure 4.8 Location of breeding sites for the southern rockhopper penguin in the Pacific Ocean.

1. Populations

Auckland Islands

The southern rockhopper penguin breeds at Adams, Disappointment and main Auckland islands. In 1973, the Auckland Islands population was estimated to be 5,000 - 10,000 pairs in 12 colonies (Bell, 1975), but by 1990, based on mainly boat-based counts and some shore-based counts, this had fallen to 2,700–3,600 pairs in 10 colonies, including five sites not reported in 1973 (Cooper, 1992, Table 4.4). There are no recent estimates.

Antipodes Islands

The southern rockhopper penguin breeds at main Antipodes and Bollons islands. The population was estimated at 50,000 pairs in 1973 (Marchant and Higgins, 1990) although this value should be considered approximate as it was based on the number of moulting birds in March. In 1995, Tennyson et al. (2002) reported a total population of 4,000 pairs at the archipelago. That the population at Antipodes is in decline is supported by Ellis et al. (1998) who noted a decrease in the number of rockhopper penguin colonies from 86 in 1972/73 to about 76 in 1989/90. During their 1995 visit, Tennyson et al. (2002) compared numbers of rockhopper penguins at Ringdove Bay, Antipodes Island with those in a photograph taken of the same area in 1950 (Department of Conservation 1998), noting a decline from tens of thousands in 1950 to a few individuals in 1995 (Table 4.4). There are no recent estimates.

Campbell Island

Between the 1940s and the 1980s, and based on a photographic record, estimates of nesting density and colony area, Cunningham and Moors (1994) calculated that the breeding population at Campbell Island had declined by 94%, from a total breeding population of over 1.6 million birds to about 103,000 birds (approximately 50,000 pairs). It is likely that the rockhopper penguin population at Campbell Island

continued to decline at least into the 1990s, and perhaps beyond (Taylor, 2000). Photo-point photographs taken in 1996 (Peter Moore), in 2000 (David Thompson) and in 2007 (Peter Moore) are yet to be examined.

Macquarie Island

Tasmanian Wildlife Service (Rosie Gales) indicates that the population is possibly of concern but lack robust estimates. Reports from 1963 and 1984 record over 100,000 pairs, and 500,000 in a 2004 report but the basis for these estimates is not known. In 2006/07, the population is estimated at between 32,000 and 43,000 pairs. All data are unpublished and have not been peer-reviewed. There are no reliable data on trends.

Much of the concern about rockhopper penguins is related to anecdotal accounts that suggest substantial decreases occurred during the 1990s, based on changes in the observed distributions and abundances around the island. There are no baseline data (from systematic surveys, although there are many descriptions about colonies), so it will be difficult to establish what the populations are doing/have done. Census challenges include the large size of colonies, their remote location on steep cliffs and amongst tussac grasses and rockhopper penguins being interspersed with royal penguins.

Table 4.4 Population estimates and trends for sites in the Pacific Ocean sites.

Site	Population	Data quality	Year(s) of estimate	Trend	Source
Auckland Islands	2,700 -3,600	Estimate	1990	Decline based on anecdotal observations	Cooper, 1992
Antipodes Islands	4,000	Estimate	1995	Decline based on anecdotal observations	Tennyson et al., 2002
Campbell Island	50,000	Count	1985	Decline	Cunningham and Moors, 1994
Macquarie Island	32,000–43,000	Estimate	2006/07	Decrease based on anecdotal observations	R. Gales personal communication

2. Breeding, post-breeding, diet and foraging

Auckland Islands

Nothing known for Auckland Islands, except that egg-laying may be approximately 10 days later than at Campbell, i.e. around mid-late November (Marchant and Higgins, 1990).

Antipodes Islands

Birds return about 3 October, with egg-laying approx 7 days earlier than at Campbell (Marchant and Higgins, 1990). Satellite tracking of eight birds during the guard stage, and of two of these during the post-guard stage, showed that birds foraged up to 100 km from Antipodes, over deep, sub-Antarctic slope waters (Sagar et al., 2005). However, some evidence of deleterious device effects was noted.

Campbell Island

Birds return about 10 October, with egg-laying occurring during the two weeks of November (Marchant and Higgins, 1990). Based on 58 water-offloaded samples of adults, the diet is dominated numerically by dwarf cod *Austrophycis marginata* (59% by number), southern blue whiting *Micromesistius australis* (15%) and hake *Merluccius australis* (10%) (Marchant and Higgins, 1990). The stomach contents of 24 autopsied chicks were mainly southern blue whiting and some cephalopods and crustaceans, which does not entirely match the diet of the adults.

Some dive data from 2003 and 2004 (Thompson et al., unpublished) during post-guard stage suggests that the birds at Campbell work harder compared to other sites (although timing not consistent with all other dive studies)—for example, dive time as a percentage of trip time for Campbell Island birds was about 80% compared to 60-70% for other locations. There is no tracking information.

Macquarie Island

The breeding biology of the species was studied at Macquarie Island during 1993/94 to 1995/96 (Hull et al., 2004). Mean arrival masses of adults, growth rates of chicks and fledging masses exhibited inter-annual

variability, while egg morphometrics, hatching success ($68.0 \pm 6.0\%$) and reproductive success ($47.3 \pm 8.3\%$) were constant between years. Reproductive failures occurred primarily during incubation, with the majority of eggs lost to great skuas. Logistic regressions revealed that no variable significantly explained hatching success.

Rockhopper penguins exhibited inter-annual differences in arrival masses during these 3 years. This suggests variable foraging success during the winter or the period just prior to breeding, with prey possibly more abundant or accessible during these periods in 1995 compared to those during 1993.

Rockhopper penguins conform to the characteristics of an income breeder, by relying less on reserves built up prior to the start of the breeding season, and instead continually replacing lost body condition throughout the season. This is evident in the mass data from 1993/1994 where individuals attained masses similar to other years, although they began the season with lower body masses.

Various studies of foraging and diet were conducted on the royal and rockhopper penguins during 1993–1996 (Hull, 1999b; Hull, 2000; Hull et al., 1997). Rockhopper penguins fed on the euphausiid *Euphausia vallentini* and the myctophid fish *Krefflichthys anderssoni* at water depths of less than 60 m and the high proportion of benthic inshore fish suggested a greater degree of foraging closer inshore.

Rockhopper penguins had a more restricted foraging range than royal penguins during the breeding season, and hence potentially less flexibility in the areas they can access for foraging. The southern rockhopper penguins at Macquarie Island may not be able to endure fasting for long as royal penguins can (although this is not based on specific data on different fasting capabilities, just speculation based on their smaller size and faster turn around times in foraging trips). So if prey move further offshore (i.e. due to sea level temperature rise or prey moving further south), the southern rockhopper penguins may lose access to their prey, which will affect breeding success and possibly adult survival.

3. Land and sea management

There is a very high level of site protection at all islands. Many islands are listed World Heritage sites and/or have marine reserves in place for territorial seas. All New Zealand sub-Antarctic island groups are afforded National Nature Reserve status, and collectively (Auckland Islands, Campbell Island plus outliers, Antipodes Islands plus the Snares and Bounty Islands) constitute a World Heritage Area.

New Zealand's sub-Antarctic islands fall under the Department of Conservation's Management Strategy (Department of Conservation, 1998) and Research Strategy (West, 2005).

A 200 nautical mile Exclusive Economic Zone is in place around all islands, with fishing subject to license and this is enforced by fisheries patrol vessels and aircraft. Additionally, the Auckland Islands support a Marine Reserve extending to 12 nautical miles.

4. Threats and mitigation

4.1 On land

Introduced species

On main Auckland Island, feral pigs restrict penguins to inaccessible slopes and ledges. Feral cats are also present but their impact is likely to be small compared to pigs. Feral mice are present but effects are thought to be negligible. The Department of Conservation have plans drawn up for pig and cat eradication, and are awaiting funding. No introduced mammals are present on Disappointment and Adams islands.

On main Antipodes Island, there are introduced mice, but the effect is negligible. All mammalian vermin are now eradicated from Campbell Island. On Macquarie Island, cats have been eradicated and there is a plan to eradicate rabbits and black rats in the near future. How these species interact with the rockhopper penguin is not well understood, but rabbits are now causing significant landslips due to overgrazing resulting in erosion.

Interactions with native species

The rockhopper penguins are probably preyed by skuas, giant petrels and New Zealand sea lions (*Phocarctos hookeri*) and potentially also with New Zealand fur seals (*Arctocephalus forsteri*), whose population is recovering. There is some suggestion that these predators may contribute to colony fragmentation on Campbell Island (Jackson et al., 2005).

Habitat issues

None documented. In only one of three years in a study on Macquarie Island was fledging success significantly higher for breeders in the centre of colonies compared to peripheral breeders (Hull et al., 2004).

Tourism

There is limited cruise ship tourism at Campbell Island and Macquarie Island but these IAATO vessels are well managed. The numbers at Macquarie Island now approach 1,000 visitors annually.

Human depredation

No rockhopper penguins and their eggs are consumed at any of the islands.

Natural disasters

The effects of potential natural disasters are not thought to be an issue.

Disease

Little evidence of disease. Avian cholera has caused deaths of a small number of adults and chicks at Campbell Island in 1985/86 (de Lisle et al., 1990) and may be a problem in some seasons at other rockhopper penguin colonies. Avian malaria antibodies were absent from rockhopper penguins sampled on Campbell Island but were present in yellow-eyed penguins on the same island.

4.2 At sea*Fisheries bycatch*

No commercial fishery bycatch issues, and outside the range of set-net fisheries.

Fisheries competition

Not known.

Competition with native species

On Macquarie Island, there is a high level (>60%) of dietary overlap between royal and rockhopper penguins and between rockhopper penguins and Antarctic prions (*Pachyptila desolata*) (>60%), but no overlap with the Patagonian toothfish fishery (Goldsworthy et al., 2001). For the New Zealand sub-Antarctic islands, competition between rockhopper penguins and other native species is not known.

Pollution

A few oiled rockhopper penguins were observed at Macquarie Island (Ellis et al., 1998). The incidence of rockhopper penguins entangled in debris or stomach samples containing manmade objects is not known but is likely to be relatively minor. Ingestion of marine debris is a potential issue (Hull in litt.) but rates of ingestion and effects have not been documented.

Harmful algal blooms

No harmful algal blooms have been documented at any of the islands.

Oceanographic changes

There is some evidence of at-sea changes being linked to populations declines, with Cunningham and Moors (1994) suggesting that rises in sea surface temperature were associated with the decline, with a slight cooling period in the 1960s resulted in a temporary increase in rockhopper penguin populations in the early 1970s.

Hilton et al. (2006) using stable isotopes, concluded that levels of marine productivity had declined over time, over wide spatial scales. However, the data from the New Zealand region showed conflicting trends: a decline in marine productivity was inferred from rockhopper penguins at Antipodes Island, but not so for birds at Campbell Island, possibly confounded by the relatively small number of samples from Campbell (Hilton et al., 2006).

5. Current research and monitoring

A species action plan for rockhopper penguins in New Zealand was produced in 2000, which has a number of management, monitoring and research priorities (Taylor, 2000). Similarly, an action plan was also produced in Australia in 2000 for southern rockhopper penguins as part of a national action plan for all threatened bird species (Garnett and Crowley, 2000).

5. Southern rockhopper penguin - Indian Ocean sites

Charles-André Bost, Yves ChereI, Robert Crawford, Bruce Dyer, Pierre Jouventin, Azwianewi Makhado, Helen Otley, Henri Weimerskirch, Eric Woehler and Anton Wolvaardt

1. Populations

Prince Edward Island

In 1977, a count of 35,000 pairs was made and in 2001, 45,000 pairs were recorded, suggesting a stable population (Ryan et al., 2003).

Marion Island

The total population on Marion Island dropped from 173,000 pairs in 1994/95 to 67,000 pairs in 2001/02, a decrease of 61% (Crawford et al., 2003).

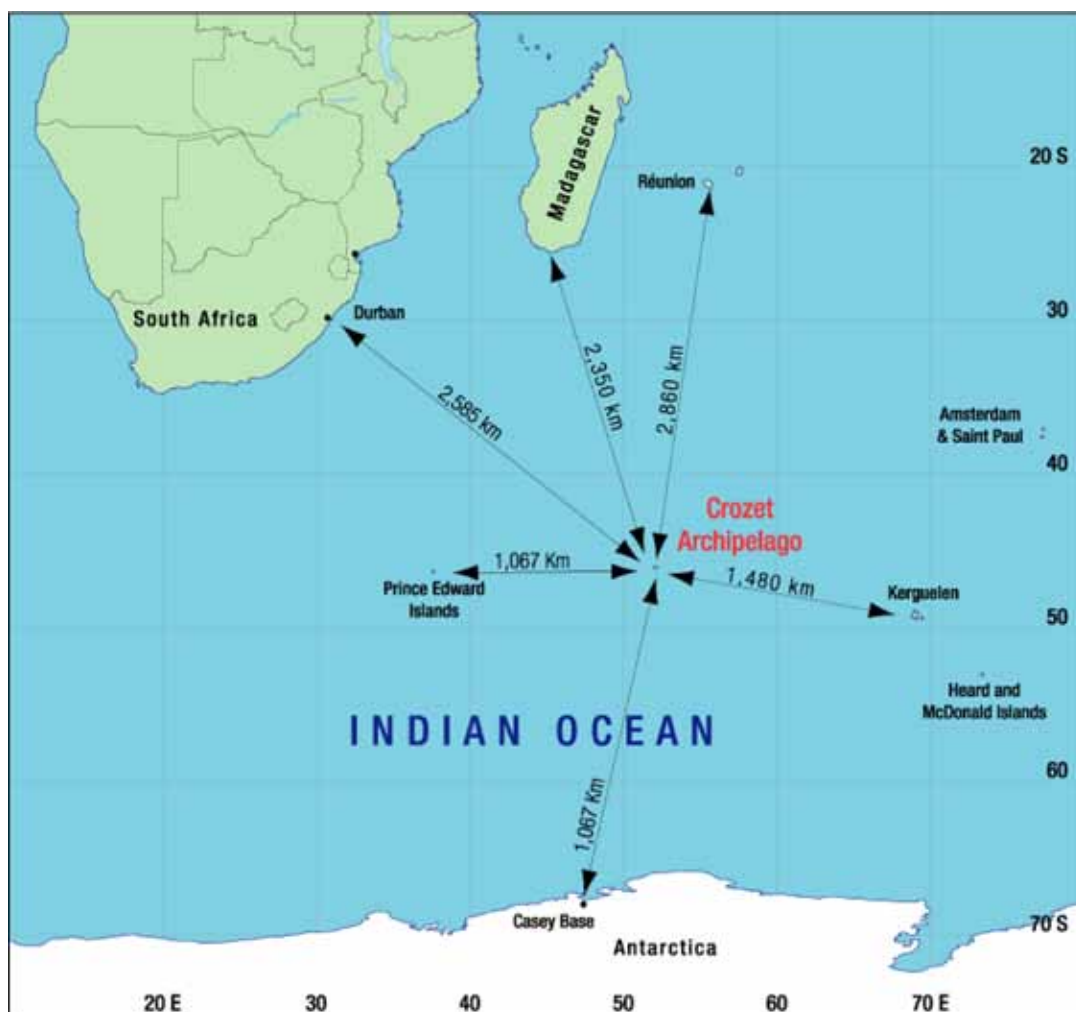


Figure 4.9 The location of the southern rockhopper penguin breeding sites in the Indian Ocean—Prince Edward Islands, Illes Crozet, Illes Kerguelen and Heard and McDonald Islands.

Most of the work on rockhopper penguins at Marion contributes to the CCAMLR Ecosystem Monitoring Programme (Crawford et al., 2006). This is a long-term monitoring programme where arrival dates at three colonies are recorded, arrival masses of a sample of male and female rockhopper penguins are taken on arrival (to gauge body condition at the beginning of the breeding season), rate of colony occupancy is measured, breeding success and fledging masses recorded/measured and diet samples collected through the breeding season.

From 1985/86-2006/07 the number of breeding pairs, hatched chicks per pair and chicks in crèches (fledged chicks per pair) at the three intensively monitored colonies has decreased (Figure 4.10). However, the trend for the three monitored colonies was different, with smaller colonies decreasing when larger ones were stable. The average fledging rate for this period was 0.33 - 0.49 chicks per pair in three colonies, whilst it has been calculated that the breeding success rate needs to be above 0.64 for the long-term survival of the population at Marion Island.

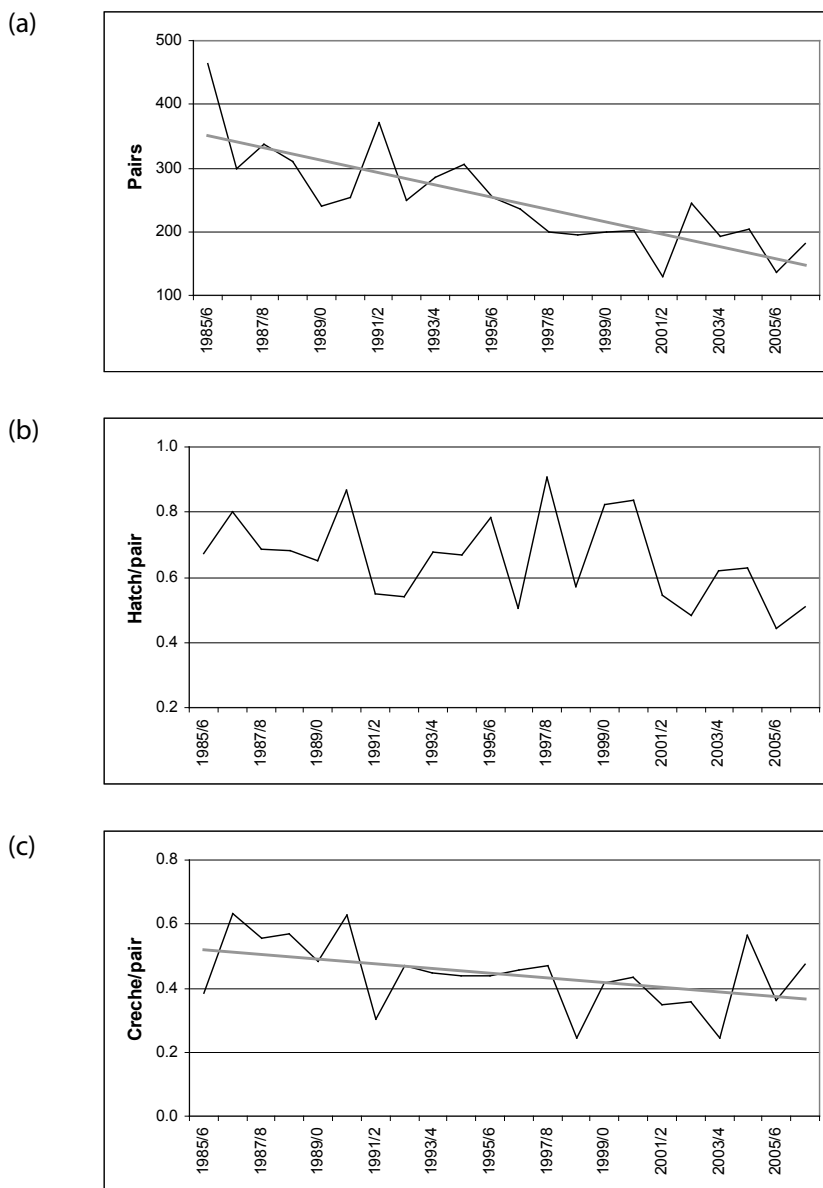


Figure 4.10 Overall trends for the three monitored colonies of southern rockhopper penguins at Marion Island in (a) number of pairs breeding, (b) number of chicks hatched per pair breeding, and (c) number of chicks in crèche per pair breeding, 1985/86–2006/07. For pairs breeding and chicks in crèche per pair breeding, the best-fitting linear regressions are shown. (Source - Crawford et al., 2008)

Iles Crozet

There is no accurate count for rockhopper penguins on Iles Crozet. A total of 152,800 pairs is a rough estimate from a compilation of old French papers (see Woehler, 1993), all rough estimates made in 1971, 1972, 1974 and 1982. There have not been more recent estimates of rockhopper penguins from Iles Crozet.

Ile de la Possession	60,000 pairs
Ile de l'Est	46,500 pairs
Ile aux Cochons	46,000 pairs
Ile des Pingouins	300 pairs

Iles Kerguelen

The total island population was very roughly estimated at 85,480 pairs in 1985 (Weimerskirch et al., 1989) and no recent counts have been made.

Heard Island

The only estimated count for the entire island was 10,000 pairs in 1987 (Woehler, 1993). Attempts were made in 2000/01 and 2003/04 to obtain contemporary data on distribution and abundance (Woehler, 2006). However, surveying southern rockhopper penguins on Heard Island will always be very difficult because there are many small colonies scattered along much of the coast and on the fringes of numerous macaroni penguin colonies. Low numbers of pairs also breed under large coastal boulders, and some colonies were located above 100 m below cliffs on the northern face of the Laurens Peninsula. The total breeding population will remain indeterminate because birds make use of lava tunnels in Azorella Peninsula for breeding.

As with macaroni penguin colonies at Heard Island, there is anecdotal evidence that some colonies contracted or disappeared between the late 1980s and 2000/01 (E. Woehler unpubl. data). In the absence of quantitative data, and because of a poor 2000/01 breeding season at Heard Island when a survey was going to be attempted, an assessment of the population is also not presently possible.

Table 4.5 Population estimates and trends for sites in the Indian Ocean.

Island	Population	Data quality	Year(s) of estimate	Trend	Source
Prince Edward	45,000	Estimate	2001	Stable 1977 to 2001	Ryan et al., 2003
Marion	67,000	Estimate	2001	42% decline 1994 to 2001	Crawford et al., 2003
Crozet Possession Est Cochons Pingouins	152,800 60,000 46,500 46,000 300	Estimate	1971, 1972, 1974, 1982	No repeatable counts	Woehler, 1993
Kerguelen	85,480	Estimate	1985	No repeatable counts	Weimerskirch et al., 1989
Heard	10,000	Estimate, low confidence	1987, more recent data from 2000/01 and 2003/04	No repeatable counts, subjective assessment is of a decrease	Woehler, 1993; Woehler, 2006

2. Breeding, post-breeding, diet and foraging

Prince Edward Island

No studies.

Marion Island

There has been a decrease in body mass at arrival from 1994/95 to 2006/07, with males decreasing 21% and females 25% (Figure 4.11). Comparatively, the mass on arrival of macaroni penguins remained constant. Breeding success was related to the mass of returned males and females but the mass of chicks at fledging was not related to breeding success.

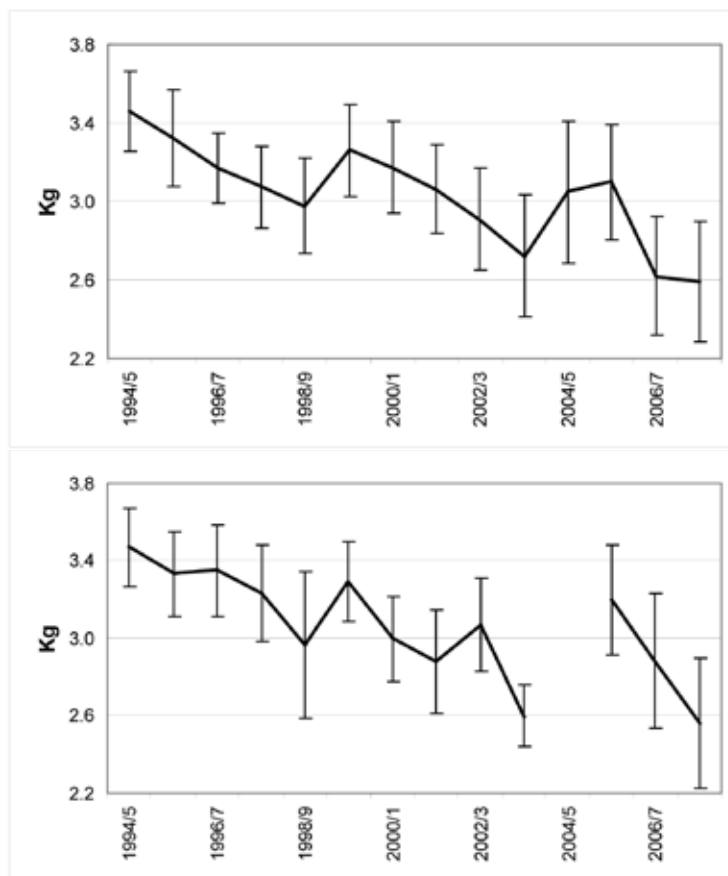


Figure 4.11 Trends in mass on arrival for breeding at Marion Island of male (left) and female (right) southern rockhopper penguins, 1994/95–2007/08. Means ± 1 SD are shown. (Source - Crawford et al., 2008).

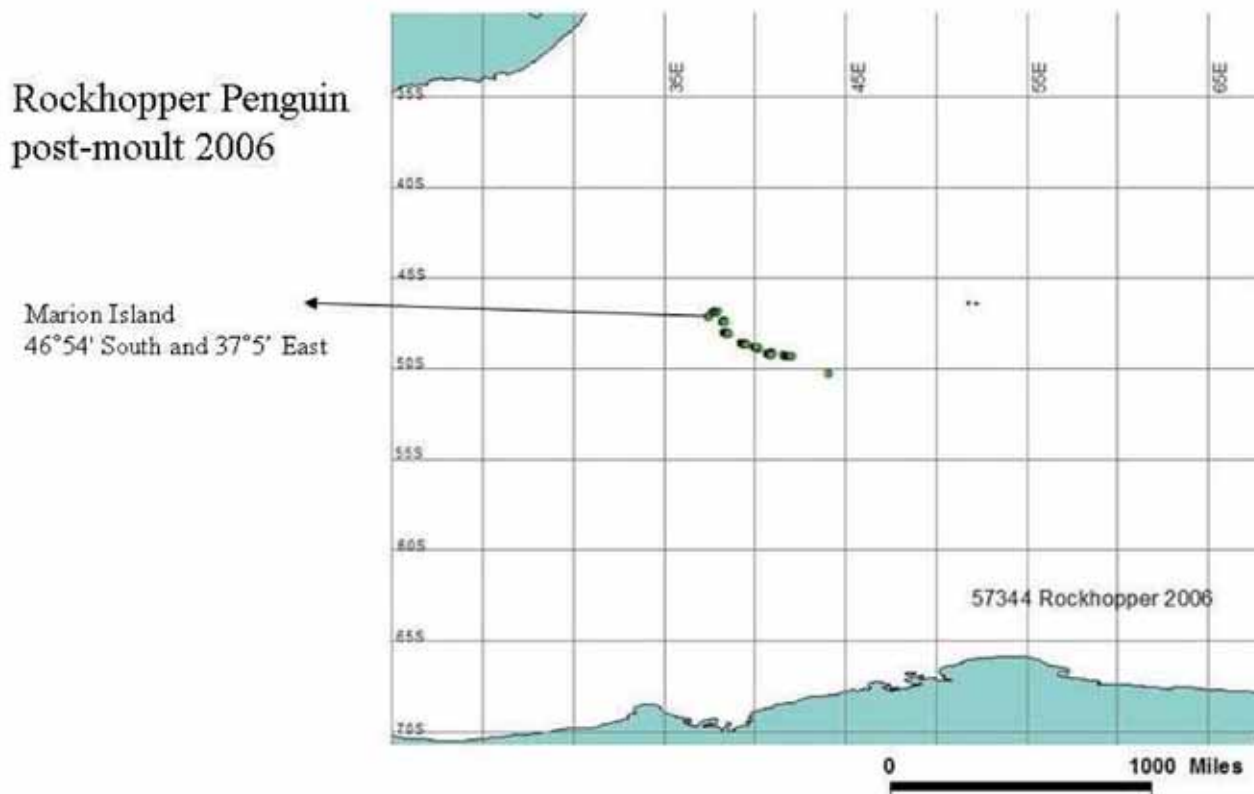


Figure 4.12 The track of one southern rockhopper penguin post moult in 2006 from Marion Island.

The diet is dominated by mass by crustaceans (*Thysanoessa vicina* and *Euphausia vallentini*), then by fish (myctophid fish notably *Krefflichthys andersoni* and *Protomyctophum tenisoni*), which does increase in proportion in some years (B. Dyer personal communication). They eat small amounts of unidentifiable cephalopods.

The ongoing decrease in mass on arrival (and body condition of parents at the beginning of the breeding season) is thought to be due to changes in the feeding conditions at over-wintering grounds. It does seem that local (inshore) factors could be contributing, rather than wider level factors only, because there is variation among colonies in many of the parameters that are measured (Crawford et al., 2008). But a similar (and persistent) trend at other localities seems to suggest the impact of wide-scale impacts (such as climate forcing), which may be affecting the quantity and/or quality of food available and/or location of food for rockhopper penguins before breeding.

Satellite tracking was conducted post-moult in 2006 (R. Crawford and A. Makhado, unpublished data). The track of one bird for a period of a few weeks is shown in Figure 4.12. No other over-winter location is known but the species is seen very occasionally on South Africa's coastline during winter months.

Iles Crozet and Iles Kerguelen

A comparative study of foraging behaviour was conducted on northern rockhopper penguins at Amsterdam in 1995 and 1996 and on southern rockhopper penguins in 1999 and 1998 in Crozet and Kerguelen Islands, respectively (Cherel et al., 1999; Tremblay and Cherel, 2003; Tremblay and Cherel, 2005). The studied birds from Kerguelen foraged in shallow and sheltered coastal waters in the Golfe du Morbihan, those from Crozet foraged in more open and deeper waters over the shelf surrounding the archipelago, and those from Amsterdam in oceanic waters.

During the study periods, chlorophyll concentrations were higher at Kerguelen than at Crozet. Accordingly, a detailed analysis of diving behaviour of rockhopper penguins showed that females from Kerguelen dived shallower, used a smaller proportion of time at sea to access to foraging grounds, and brought a heavier mass of food to their chick. Foraging pattern of female southern rockhopper penguins changed with chick age at both Crozet and Kerguelen but in different ways between sites. The local foraging environment therefore seems to influence foraging pattern of rockhopper penguins.

Dietary analysis at Kerguelen showed that southern rockhopper penguins fed upon a few benthic prey (a few fish and the mysid *Mysidetes morbihanensis*) and mostly on pelagic crustaceans, including *Euphausia vallentini*. There was a positive linear relationship between the mass of food brought ashore and an index of the proportion of benthic dives during the daily trips, thus emphasizing the importance for southern rockhopper penguins living in a coastal marine environment of feeding on pelagic migrators trapped at or near the sea floor during the day. Food loads, and accordingly chick growth, were lower for northern rockhopper penguins at Amsterdam, medium for southern rockhopper penguins at Crozet and highest for southern rockhopper penguins at Kerguelen, while indices of foraging effort presented little variation.

The study shows the complexity of foraging behaviour of penguins, illustrates the importance of behavioural plasticity and suggests that it is a fundamental trait of the life history of seabirds living in highly variable environments.

The stable isotopic ratios of carbon ($\delta^{13}\text{C}$) and nitrogen ($\delta^{15}\text{N}$) for whole blood, nails and food were measured for penguins at Crozet during breeding in summer and at their arrival in the colonies in spring, hereafter late winter, since the temporal integration of blood amounting to several months (Cherel et al., 2007). Macaroni and southern rockhopper penguins had identical isotopic signatures, indicating feeding on crustaceans near the archipelago in the summer.

Isotopic ratios were almost identical in summer and winter suggesting no major changes in the species niches, and hence in the trophic structure of the penguin community during the non-breeding period. A seasonal difference, however, was the higher $\delta^{13}\text{C}$ values of southern rockhopper penguins in winter, suggesting foraging at lower latitudes at that time.

Heard Island

Minimal studies conducted on the island. However, there was a recent study of diet and foraging behaviour of macaroni penguins during 2003/04 (Deagle et al., 2008). They foraged to northeast of Heard

Island on the shelf in water depths of 1,000 m, taking two species of euphausiids and the myctophid *Krefflichthys anderssoni*. Numerous records of rockhopper penguins are known from Australia, especially Tasmania (Woehler, 1993), but there are fewer than 10 sightings in the waters around Heard Island, all being during the spring months to the southwest of Heard Island (Woehler, 2006).

3. Land and sea management

There is a very high level of site protection at all islands. Many islands are listed World Heritage sites and/or have marine reserves in place for territorial seas. Prince Edward Islands is a Special Nature Reserve and both Prince Edward and Marion islands have a strict management plan. Some longline fishing takes place around the Prince Edward Islands for Patagonian toothfish, which is subject to license and is enforced by fisheries patrol vessels and aircraft.

Under the Terres Australes Françaises (Southern French Territories) 2006 decree, the islands of Saint-Paul and Amsterdam (including their domestic and territorial waters), Crozet archipelago territorial waters (excluding Possession Island territorial waters), and three zones of the Kerguelen Islands: Zone 1 from Cape d'Estaing to Cape Cotter, Zone 2 which includes the Nuageuses Islands and Zone 3 which includes the Railler du Baty Peninsula were designated as national nature reserves. The decree also sets out the mechanisms for the management of this nature reserve and the regulations governing the terrestrial and marine areas as well as the strict protection zones.

4. Threats and mitigation

4.1 On land

Introduced species

Prince Edward - no vertebrate species introduced.

Marion - cats were removed during 1990s, mice remain present.

Crozet - mice, black/ship rat, brown/Norway rat, cats and rabbits.

Kerguelen - mice, cats, rabbit, black/ship rat, brown/Norway rat, sheep, mouflon and reindeer.

Heard - no vertebrate species introduced.

Interactions with native species

At Possession Island (Crozet archipelago), sub-Antarctic fur seal and Antarctic fur seal, with respective annual growth rates of 19.2 and 17.4%, are reaching the maximum growth rate for the genus *Arctocephalus*. There are no reports of interaction between rockhopper penguins and fur seals, but this may reflect a lack of research, not an absence of the behaviour. Many colonies at Marion and Heard are on rocky cliffs and in lava fields, which seals do not use.

Habitat issues

None documented.

Tourism

There are minimal numbers of commercial tourists visiting Kerguelen, Crozet and Heard; Amsterdam is visited occasionally by the scientific research vessel, which carries some tourist passengers.

Human depredation

No rockhopper penguins or their eggs are consumed at any of the islands.

Natural disasters

The effects of potential natural disasters are not thought to be a serious threat.

Disease

No diseases are reported at any of the islands, except at Marion Island where avian cholera broke out at one site (Kildalkey) in about 2005, killing several hundred macaroni penguins (B. Dyer personal communication).

4.2 At Sea

Fisheries bycatch

Little is known. Rockhopper penguins have been seen at longline vessels working near Marion Island and there is at least one record of a macaroni penguin as bycatch (B. Dyer personal observation).

Fisheries competition

Not known.

Competition with native species

Not known. There is one record of rockhopper and macaroni penguin remains in the stomach of a Patagonian toothfish (B. Dyer personal observation). The trophic and isotopic niches of rockhopper and macaroni penguins are roughly similar during the breeding period, but more information is needed about the winter biology of these two species of crested penguins.

Pollution

The incidence of rockhopper penguins with oil or entangled in debris or stomach samples containing manmade objects has not been formally reported at any island, except at Heard, where survey reports state that no oiled penguins have been sighted. There has been at least one record of oil pollution at Marion Island, which occurred in the 1980s when some diesel drums came adrift at the scientific base and diesel was spilt at the scientific base, causing some bird casualties (B. Dyer personal communication).

Harmful algal blooms

No harmful algal blooms have been documented at any of the islands.

Oceanographic changes

Little is known about oceanographic conditions and effects on rockhopper penguins. At Crozet, there was a linear temporal decrease in $\delta^{13}\text{C}$ until the 1950s and subsequently, a slight increase and a linear decrease in $\delta^{15}\text{N}$ (Hilton et al., 2006).

5. Current research and monitoring

Prince Edward Island - Surveys and research occur every 5-10 years.

Marion Island - On-going CCAMLR monitoring programme.

Crozet - None.

Kerguelen - None.

Heard - None, however opportunistic visits to the island may allow research.

APPENDIX 5 Research methods and techniques

1. Population estimates using landing counts
2. Marking and monitoring systems
3. Assessing diet
4. Sources of remotely-sensed data
5. Opportunities with captive populations

The following sections provide information on a number of survey and research techniques that are currently in trial and/or are used by other seabird researchers. The techniques were highlighted at the Workshop as potential methods that could be incorporated into new programmes of research on rockhopper penguins.

1. Population estimates using landing counts

Paulo Catry and Helen Otley

Introduction

A number of northern and southern rockhopper penguin colonies are difficult to count due to the terrain and/or vegetation. The possibility of doing landing counts was discussed at the Workshop. The only known current site where this technique is being trialled is in the Falkland Islands (Malvinas).

At New Island, Falkland Islands (Malvinas), the largest rockhopper penguin colonies on the main Settlement Rookery are hidden inside dense stands of tussac grass, making it impossible to carry out direct counts of nests. The only way to get a relatively accurate idea of numbers present without causing major disturbance is by counting penguins coming ashore (Catry et al., 2005).

Method

During 2003/04, Catry et al. (2005) trialled some methods of censusing the colony by counting birds at various landing sites and along access routes. The counts of landing birds appeared most promising and a first completed trial was completed in the 2004/05 season. The count was conducted on 11 December, starting at first light and continuing until night fell (at which time the movement of penguins coming ashore had virtually stopped).

Mid December is during the brooding stage of the breeding cycle in the Falkland Islands (Malvinas). Male rockhopper penguins stay at the colony to guard the chick, while females do daily foraging trips, leaving early in the morning and coming back during the afternoon and early evening. Few birds stay at sea overnight (Tremblay and Cherel, 2003).

To allow a population estimate to be made (rather than just recording landed birds), counts in one nesting area were also made at 0800 h (after virtually all birds had left to the sea), and again in the evening (at 2000 h). By comparing the difference between these counts with known nesting numbers, we could work out the relationship between the number of arriving birds during that day and the actual number of nests in that particular sub-colony of 140 pairs.

We also counted non-breeders resting and roosting on the boulders by the sea, both in the morning and in the evening, to exclude from further analyses all the arriving birds that joined those flocks. From these two counts, a correction factor was calculated, estimating how many birds came ashore per active and per failed nest.

Results

Since 2003, counts have been conducted every year between 11–13 December (Strange et al., 2007). Only one count per year has been conducted. The number of birds counted coming ashore in the five seasons has varied between approx. 4,500 and 6,500 birds (Fig. 5.1).

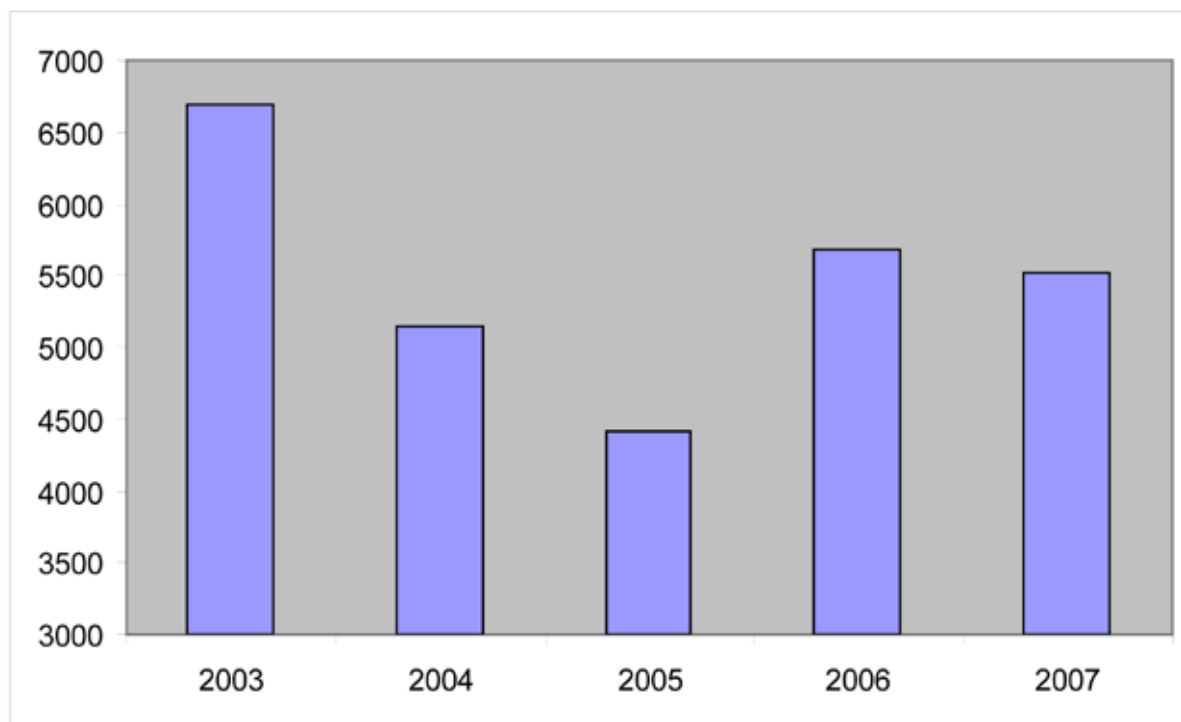


Figure 5.1 The number of southern rockhopper penguins counted coming ashore to the Settlement Rookery, New Island, during one mid-December day from 2003 to 2007.

In 2004/05, the landing count was converted to an estimate of colony size. A total of 5,150 penguins was counted landing, of which 5,018 did so between the morning and the evening count at the control sub-colony. After excluding 200 individuals that joined the non-breeder flocks roosting by the sea, an estimate of 4,818 birds that joined the nesting colonies during the relevant time interval was obtained. Multiplying this by the calculated correction factor (= 1.0672), we estimated that the breeding population at the rookery comprised 5,142 pairs. However, there is no land-based at-colony count with which to confirm the accuracy of the landing count method.

Conclusion

More research is needed to assess the repeatability of such counts and the correction factors used to derive estimates of colony size. On the other hand, given that many rockhopper penguins on New Island nest in dense stands of tussock grass, it is clear that direct counts of nests are impossible without major disturbance to the birds. Landing counts are easy to do on an annual basis and the information is better than no data at all. It will detect long-term trends, but it is possible that the method has low power, and this aspect requires further research.

2. Marking and monitoring systems

Petra Quillfeldt, Maud Poisbleau, Klemens Pütz and Andrea Raya Rey

Individual Marking

Two kinds of tagging were discussed at the Workshop: long-term marking of birds with flipper bands or Passive Integrated Transponder (PIT) tags for individual recognition (for demographic studies), and, temporary attachment of external devices (for tracking purposes). For all methods, a great variety of publications exists, far too many to be listed individually. However, for a review on flipper banding see Petersen et al. (2007) and references therein.

Pros and cons of the different marking techniques were discussed. Recent research has shown that flipper banding is quite critical and may result in an increased mortality, especially in the first year after banding.

Thus, in recent years PIT tags have been used where possible.

The advantages of the transponder system are that it does not carry the high energy cost to the birds that stainless steel flipper-bands do, and that it can automatically log the movements and body masses of large numbers of birds. Transponders can be easily be read with a hand reader when penguins are handled or without catching them using an antenna stick connected to a reader.

However, transponders are not without their problems. Migration of transponders away from the injection site has been demonstrated and this may compromise the survival of some individuals, and reduce the readability of the tag, biasing survival estimates. To reduce the introduction of bacteria under the skin, a careful injection technique is required and instruments and skin should be cleaned with iodine or alcohol (Clarke and Kerry, 1998)

Some transponder loss is also found (Clarke and Kerry, 1998). This can be minimised by injecting the transponder pointing downwards and sealing the wound with medical glue. Checks should also be made during the first few weeks after implantation. The loss rate can be lower than 5% if properly injected.

The rate of transponder loss and failure still needs verification in penguins. On New Island (Falkland Islands (Malvinas)), 180 adult rockhopper penguins were marked with temporary flipper bands and a transponder, and of 175 birds recapture at the end of the crèche period (up to 10 weeks later), only one had lost its transponder (0.6%) (M. Poisbleau, pers. comm.). P. Becker and his group have been studying common terns (*Sterna hirundo*) using injected transponders for 15 years, with 160 individuals having had their transponder working for 10 years, 11 for 14 years, and 10 for 15 years (P. Becker, personal communication). Transponder loss or failure rate during the 15 year period was 2.2% (Becker et al., 2008).

The key issue for PIT tag loss and failure is that it leads to an under-estimate of survival because tagged birds are assumed dead, when they have in fact lost their tags). If a robust estimate of tag loss can be obtained, and survival estimates adjusted accordingly, the problem is minimised. Double tagging some of the birds, so that the proportion retaining only a single tag can be estimated, might be one solution. This would give slight extra risk to the bird, and requires the assumption that in a double-tagged bird, the probability of losing one tag is independent of the probability of losing the other.

Comparison with results obtained in zoos was initiated during the workshop and may help to clarify this problem. In any case, long-term identification of individuals, which is paramount for understanding population demography, remains problematic.

Attachment of external devices

Attachment of external devices to penguins has also been viewed critically in the past, as it may alter the behaviour of the animals studied. A number of methodological issues such as size and shape of the device, but also area and method of attachment, have been extensively discussed in literature. To date, attachment of external devices with tape to the back feathers of penguins has largely been considered acceptable for recording behavioural data with acceptable impact, depending on the parameters mentioned above.

In light of the above, the attachment of external devices on flipper bands was debated at the workshop. On one hand, it may provide a suitable alternative for the long-term attachment of external devices, but on the other side the impact on the southern rockhopper penguin may be significant. Mounting devices on leg bands may provide an alternative, but initial tests were less successful.

Automatic gateway systems

The benefits of using an automated recording system to study the biology of penguins have long been recognised (Kerry et al., 1993; Clarke et al., 2002). A study of the reliability of the system in South Georgia with macaroni penguins, showed that the probability of the gateway missing a penguin that passed through was around 4% compared with between 8-16% using radio telemetry (Green et al., 2006). An automated recording system, particularly with capacity to record weight, reduces the necessity for the repeated handling of individuals during long-term demographic studies.

Often transponder detection systems include a weight bridge. These systems consist of a monitor connected to a scale, a gate antenna and two infrared sensors placed at the two sides of the scale platform.

As soon as one of the two sensors is triggered, the antenna looks for a transponder and simultaneously the bird is weighed. Current systems in place are designed such that a completely independent new weighing process starts as soon as a sensor is triggered anew, even if the previous one was not entirely finished.

Early weigh stations had a single detection antenna (30 cm x 30 cm) placed vertically on a gate, and detection area was limited (about 80 cm x 80 cm) (Clarke and Kerry, 1998; Gendner et al., 1992; Gauthier-Clerc et al., 2004). A new antenna method was developed by Gendner et al. (2005), with two 8 m long antennas separated by 1 m buried permanently on each pathway, allowing for survey of a pathway up to 8 m wide via an electromagnetic field 40 cm high. However, the range of the antenna has to be small enough to read only the transponders on the platform, thus avoiding attributing the wrong transponder number to a bird on the scale. For that, the best option seems to be to put the antenna at the middle of the scale and to limit its range.

A number of factors should be considered when deciding on the location of the gateway:

- Finding a narrow site away from the nesting site that the birds use ordinarily on their way to/from a nesting area;
- Catching penguins en route to a small colony in order to limit the number of (unmarked) birds crossing the system and thus triggering the recording system for no data;
- Far enough from the sea to limit sea sprays and away from flood-prone areas, which damages the equipment;
- In a sheltered place in order to avoid the wind, which disturbs the weighing process;
- In a sunny place to maximise the effectiveness of the solar panels providing electricity;
- In an easily accessible place so that the system can be checked several times a day without disturbing the colony.

The size of the memory in the computer is an important issue to consider, given the required frequency of the downloading, the number of birds crossing the weighbridge and budgets. Two options are available: either to record for all the birds crossing the weighbridge or to record only the birds equipped with transponders. The second option uses less computer memory, whereas the first one obtains more general data on times and weights.

Although a longer weighbridge platform allows a higher accuracy of weight determination, it is important to minimise the probability on having more than one bird on the platform at the same time. A small size seems the best option for rockhopper penguins, which form long and dense files when they are travelling from and to the sea.

It is important to weigh birds in a minimum of time. Some weighbridges continuously record the weights on the scale (for example 200 masses recorded per second) and afterwards cross-referencing is done with the transponder database to determine the weight of specific birds. With the New Island's southern rockhopper penguin automatic gateway system, mass is recorded only when birds are on the centre of the platform, to save memory and power. As soon as a sensor is triggered and the mass on the platform is above a certain threshold, the scale starts to weigh and records six consecutive masses (themselves the average of 6 weighings done in 0.1 s).

Infrared sensor cells are often used for automatic systems to detect the PIT tags. They are always exposed to mud and other dirt, and thus need to be cleaned very often (i.e. at each visitation of the weighbridge). As they are expensive, sensors should be put in a waterproof transparent box to protect them and to allow easier cleaning without the risk of scratching the surface of the sensor.

In the environment of penguins, it is always difficult to provide enough power for this sort of equipment near to a penguin colony. Therefore, it is necessary to minimise the power consumption of the system (e.g. turn off the most energy-costly parts when possible and use low consumption components, etc). Solar panels connected to car batteries seem to be the best option for providing energy without disturbing the birds.

The salty, muddy, wet and windy environment very quickly destroys all kinds of components. Therefore, it is better to install the weighbridge in an appropriate location and to protect all its parts in airtight boxes.

Worldwide, there are a number of groups and automated reading system (Table 5.1).

Table 5.1 Automatic gateway stations in use for penguins

Species	Site	Scientists
King penguin	Crozet Island	Y. Le Maho and colleagues
King penguin	South Georgia	C.O. Olsson and colleagues
Adélie penguin	Mawson, Antarctica	K. Kerry and J. Clarke
Adélie and gentoo penguin	King George Island, Antarctica	S.G. and W.Z. Trivelpiece
Little penguin	Taronga Zoo, Sydney	
Little penguin	Phillip Island, Australia	Chiaradia et al., 2006
Humboldt penguin	Algarrobo, Chile	R. Wallace
African penguin	Robben Island, South Africa	R.J.M. Crawford
Adélie penguin	Ross Island, Antarctica	Ballard et al., 2001
Macaroni penguin	Bird Island, South Georgia	Green et al., 2006
Rockhopper penguin	Isla de los Estados, Argentina	Raya Rey et al., 2007
Rockhopper penguin	New Island, Falkland Islands (Malvinas)	P Quillfeldt and colleagues

3. Assessing diet

Petra Quillfeldt and Helen Otley

Analyses of diet by killing birds or flushing stomachs using the water off-loading method are controversial scientific techniques. This has led to the development of a variety of less invasive methods, including measuring stable isotope ratios in tissue and feather samples and DNA-based faecal analysis.

Stable isotope analysis

Stable isotopes are used to monitor diet and foraging areas at broad resolutions. Measurement of nitrogen and carbon stable isotope ratios in consumer tissues can provide good information on feeding relationships if the potential prey types are well elucidated and defined isotopically. If there are few types of potential prey, mixing models can be applied as recently shown in Adélie penguins (Tierney et al., 2008).

Mixing models that are freely accessible include ISOSOURCE (Phillips et al., 2005) and the recently developed SIAR (Stable Isotope Analysis in R). The latter is especially recommended because of its greater speed and flexibility, based on Bayesian statistics, offering to address more detailed ecological questions than previously possible.

Animal tissues are enriched in $\delta^{15}\text{N}$ compared to their diet (i.e. they have more positive $\delta^{15}\text{N}$ values) than their diet by relatively large and reasonably predictable amounts. Therefore, $\delta^{15}\text{N}$ ratios are good indicators of an animal's trophic level. This effect has been found in many different species, representing a wide selection of animal classes, in marine, terrestrial and freshwater habitats and can also be reproduced in laboratory experiments with a controlled diet. The enrichment seems to be relatively constant even among distantly related groups and independent of the form in which nitrogen is excreted. Individual age also seems to have no effect on the enrichment, unless the animal changes its diet.

The enrichment factor may though vary considerably among different tissues. Therefore, different tissue types (e.g. blood vs. feathers, see below) can only be compared if the different enrichment factors are known. Nitrogen fractionation can also vary as a function of diet type, specifically protein quality, and the $\delta^{15}\text{N}$ value itself (Caut et al., 2008; Robbins et al., 2005).

Several studies have also found a slight enrichment in $\delta^{13}\text{C}$ with trophic level, while others have not found such an effect. $\delta^{13}\text{C}$ enrichment seems to occur only for certain tissues especially those rich in proteins, while lipid rich tissues may even be depleted compared to the diet. Because it is relatively unaffected by

trophic level, $\delta^{13}\text{C}$ is a good tracer of the food web. Therefore, it is commonly used when the contributions of several primary producers to the food web are studied (e.g. benthic macro-algae versus phytoplankton) and it can trace latitudinal variation in foraging distributions.

Several studies of data showed a marked decrease in carbon stable isotope ratios in Southern Ocean predators with latitude (Quillfeldt et al., 2005; Cherel and Hobson, 2007). This geographic gradient was found despite the potentially confounding effects of pelagic and coastal feeders and using different tissues (e.g. whole blood, blood cells and feathers) for the analysis (Fig. 1 in Quillfeldt et al., 2005). There is also an onshore-offshore (benthic-pelagic) gradient for $\delta^{13}\text{C}$ values in primary consumers (herbivores) in the Weddell Sea ranging from -16.8‰ for benthic algal herbivores (limpets) to -29.8‰ for krill (Dunton, 2001).

Following on from studies of general patterns of movement and foraging of seabird species, stable isotope ratios can now be used to explore other variables that influence ecological and behavioural patterns. For example, stable isotope ratios can help to explore differences in foraging between the sexes (e.g. Forero et al., 2005; Bearhop et al., 2006), between individuals (e.g. Nisbet et al., 2002; Cherel et al., 2006) and under different environmental conditions (e.g. Cherel et al., 2005a; Gladbach et al., 2007).

A fundamental difference between isotope and gut content/stomach flushing approaches to diet studies is the time scale each method addresses. Whereas direct diet sampling yields information about the most recent meal(s), the isotopic signature of a given tissue is an integration of diet over a relatively protracted timescale, the length of which is dependent on the turnover rate of the sampled tissue, but which is typically weeks to months. This can be used to test whether there are significant changes in feeding strategies over time. Stable isotope data has other advantages or are a useful addition to conventional diet analyses because it is not biased by differential digestion rates, is less invasive than stomach flushing and is inherently quantitative and easy to handle statistically, thus allowing differences in means and variances to be tested for among sample groups. However, to interpret stable isotope data correctly, it is necessary to have quite a good understanding of the ecosystem, and its isotopic properties and the data cannot normally allow species level identification.

A variety of samples can be used for stable isotope analysis:

1. Feathers

Feathers are stored dry for stable analyses. A single rockhopper penguin body feather has enough material for a sample (0.6 - 1 mg). It is important to have in mind when the feathers were grown, as the stable isotope ratios in an inert tissue like a feather do not change once it is grown. In adult rockhopper penguins, naturally moulted feathers will have grown during the preceding autumn (i.e. February–March in most places). They can be collected non-invasively during the molting period, by picking up feathers around the colonies, or can be collected at any time by plucking some feathers from animals, although this requires handling. During the breeding season, chick down and juvenile feathers are grown, and thus represent (chick) breeding season diet.

2. Down feathers

In two studies of petrels, down feathers of chicks had an intermediate stable isotope ratio between albumen and chick feathers, indicating that down is grown from a mixture of maternal resources from the egg and nutrients in the post-hatching diet (Gladbach et al., 2007; Quillfeldt et al., 2008c).

3. Differences between feathers and blood

Due to different fractionation, feathers are more enriched in $\delta^{15}\text{N}$ and $\delta^{13}\text{C}$ than blood. This has been shown in wild seabirds in their natural habitat (Quillfeldt et al., 2008a). The differences here ranged between 0.4 and 1.5‰ for $\delta^{15}\text{N}$ and between 0.9 and 1.6‰ for $\delta^{13}\text{C}$. This is in line with population-level studies (Bearhop et al., 2000a; Cherel et al., 2005b) and studies with simultaneous sampling in captive birds (Hobson and Clark, 1992b; Cherel et al., 2005a).

4. Blood

Blood can be taken throughout the breeding season from chicks and adults, thus enabling comparison within seasons. It may be especially useful to sample birds first arriving from the wintering grounds, birds with known foraging tracks, known demography, foraging locations etc. Blood can be used in different ways, and it is important to note this when interpreting and comparing data. Plasma has faster turnover (days) than blood cells (weeks), whole blood is intermediate. Blood samples are best frozen if possible, air-dried or freeze-dried. The second best option is storage in ethanol, though different ethanol brands have different isotopic signatures themselves, which can have some influence on measured isotope ratios (e.g. Bugoni et al., 2008).

5. Eggs

Abandoned eggs (for albumen, embryo tissue or egg membrane) and hatched eggs (for egg membrane pieces) can be used. Eggshells are not suitable due to high carbonation. Egg membranes can be interesting as they give a signature that reflects the female diet/location in the period leading up to breeding, and this might be quite a critical period in the annual cycle. A validation of this has been carried out (Quillfeldt et al., submitted).

6. Toenails

Collecting toenails is non-invasive and could be useful as a medium-term signal (months). However, the time-scale with toenail growth rates needs to be confirmed (Y. Cherel, pers. comm.).

7. Other tissues

Tissue of dead animals can be collected (e.g. liver for fast-turnover tissue, muscle slower, bone much slower), although it is best always to compare within the same tissue type to exclude variable fractionation effects. The best storage method is freezing. Before analysis, lipid extraction is required for muscle and liver samples.

8. Diet samples

Items may be kept from stomach analyses, or from dissected freshly dead chicks, or from spilt prey around the colony, etc. If available, the whole animal is probably better than hard parts, as these more precisely represent what the seabird is actually eating. Whole crustaceans and dried squid beaks should undergo lipid extraction for $d^{13}C$ analysis and acidification for $d^{15}N$ analysis. For squid, lipid extraction can be used for $d^{13}C$ analysis of whole animals. The best storage method is frozen or dried.

DNA-based faecal analysis

DNA fingerprinting faeces is a new technique that has been successfully trialled with macaroni penguins at Heard Island (Deagle, 2006; Deagle et al., 2007). Of the 88 faecal samples collected, 39 contained detectable DNA from one or more of the prey groups targeted with PCR tests. Group-specific PCR and sequencing, such as carried out with the euphausiid primer set, improved taxonomic resolution of prey identification compared with morphological analysis of stomach contents.

Currently the key limitation of the method is identifying the DNA sequences found in faeces because there is little reference sequence data of the prey species potential taken by macaroni penguins. Deagle *et al.* (2007) concluded that, because the ability of the DNA-based approach to detect temporal variation in the diet of macaroni penguins, the non-invasive method of DNA analysis of faeces will be useful in the future for monitoring population-level dietary trends in seabirds.

The Workshop participants also suggested that the new technique had promise but required scientists to have access to a specialised laboratory.

4. Sources of remotely-sensed data

David Thompson

There is a wide array of remotely-sensed data sources. Below are listed some commonly used data sources for marine productivity (typically as Chlorophyll-a from ocean colour data), sea surface temperature and wind data, together with typical data formats and temporal scales. This is obviously not an exhaustive list but aimed as a starting point.

Also listed are some approaches to data management and analysis.

Productivity images

MODIS–Level 3 Aqua MODIS

<http://oceancolor.gsfc.nasa.gov/>

4 km resolution (larger scale available too)

Monthly composites (larger scale available too)

SST images

MODIS

http://podaac.jpl.nasa.gov/DATA_CATALOG/modis.html

4 km resolution (larger scale available too)

Available in daily, 8-day, monthly and annual composites.

MODIS data downloaded from FTP sites in HDF format (hierarchical data format). These datasets then need to be decompressed and read. <http://nsidc.org/data/hdfeos/>

Can use HDF tools to decompress and access data:

<http://hdfeos.org/software.php#HEG>

If using GIS, recommend MGET:

<http://code.env.duke.edu/projects/mget/>

MGET = Marine Geospatial Ecology Tools, an open source programming library developed by researchers at Duke University designed for coastal and marine researchers and GIS analysts who work with spatially-explicit ecological and oceanographic data.

Wind data

QuickSCAT from <http://www.remss.com/>

25km resolution; 2 per day–morning and evening

Data downloaded from FTP sites in HDF format (hierarchical data format). Depending on which software the user is familiar with, can 'decompress' data in different ways: Fortran, IDL, Matlab

ftp://ftp.ssmi.com/qscat/scatterometer_bmap_support

APPENDIX 6 References

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APPENDIX 7 Workshop participants and programme

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Workshop Programme

DAY 1: Tuesday 3 June

8.30 am	Registration	Salvesen Room, Mansion House, Edinburgh Zoo	
9.30am	Introduction & Welcome	John Croxall, BirdLife International	
SESSION 1	Overview	Presenter	Supporting Documents
9.45 am	(i) Oceanographics of the Southern Ocean	Norman Radcliffe/ John Croxall	Will be discussed at workshop
10.00 am	(ii) Foraging and Migration	Klemens Pütz	
10.20 am	(iii) Genetic and Distribution Boundaries	Helen Otley	Session1_Genetics_HOtle.pdf
10.40 am	<i>Tea/Coffee break</i>		
	Regional Review: Current research, status and population trends		
	(a) Northern Species		
11.00 am	(i) Tristan & Gough	Trevor Glass/ Richard Cuthbert	Northern_Tristan-Gough Regional Report.pdf
11.20 am	(ii) Indian Ocean sites	Geoff Hilton	
	(b) Southern Species		
11.40 am	(i) Argentina	Andrea Raya Rey	Southern_Argentina_ Regional Report.pdf
12 noon	(ii) Chile	Manuel Marion/ David Oehler	Southern_Chile_Regional Report.pdf
12.20 pm	(iii) Falkland Islands	Grant Munro	Southern_Falkland Islands_ Regional Report.pdf
12.40pm	(iv) Pacific Ocean sites	David Thompson	Southern_Pacific Ocean_ Regional Report.pdf
1.00 pm	<i>Lunch</i>		
2.00 pm	(v) Indian Ocean sites	Helen Otley	Southern_Indian Ocean_ Regional Report.pdf
2.20 pm	Discussion		
	Survey and research techniques	Led by: Klemens Pütz	
3pm	<i>Tea/Coffee break</i>		
	Overall trends and analysis of data presented	Led by: Norman Radcliffe	
	Revisions to existing Red List assessments for Northern and Southern Rockhoppers	May split to sub group led by: Geoff Hilton	Latest Fact Sheets and supporting information from BirdLife of the 2008 IUCN Red List for Birds

DAY 2: Wednesday 4 June

SESSION 2	Causes of Population Decline	Presenter	Supporting Documents
	Presentations		
9.00 am	(i) Disease, harmful algal blooms and virus	Andrea Raya Rey	ARaya Rey_Session2_Disease_Health Paper.pdf & ARaya Rey_Session2_Disease_Shellfish Poisoning Paper.pdf
9.30 am	(ii) Fisheries interaction including diet and bycatch	Grant Munro	GMunro_Session2_Fisheries Interactions.pdf
10.00 am	(iii) Climate change, marine productivity and changes in type/ location of key food types	Geoff Hilton	
10.30 am	<i>Tea/Coffee break</i>		
11.00 am	(v) Land-based threats–tourism, predation, disturbance,	Petra Quillfeldt	
11.45 am	(vi) Chemical, oil, plastics pollution	Helen Otley	HOTley_Session2_Pollution.pdf
12.30 pm	<i>Lunch</i>		
	Discussion	Chairman John Croxall	
2.00 pm	The importance and relevance of each threat		
3.00 pm	<i>Tea/Coffee break</i>		
3.30 pm	Defining priorities for further research and action		
4.30 pm	Developing research recommendations and plans		
6pm	Visit to Edinburgh Zoo penguins with talk by Iain Valentine (RZSS Head of Animals, Education and Conservation) , <i>Workshop Reception and buffet supper</i>		

DAY 3: Thursday 5 June 2008

SESSION 3	The Way Forward	Supporting Documents
9.00am	Conclude Research Plans	
10.00am	Identify Management Actions for implementation in the short/medium term and changes in Government policy regarding sustainable land-use and marine-use activities	
11.00 am	<i>Tea/Coffee break</i>	
11.30 am	Develop Species Action Plans on a regional and national basis	Example SAPs to be provided by participants
1.00 pm	<i>Lunch</i>	
2.00 pm	Define specific projects, (particularly collaborative), and potential funding sources.	
3.00 pm	<i>Tea/Coffee break</i>	
3.30 pm	Set up Rockhopper Penguin Group to continue this initiative	
4.00 pm	Agree next steps, recommendations and Workshop conclusions	