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Developing adaptation options for seabirds and marine mammals impacted by climate change

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FRDC Project No. 2010/533
February 2014

Australian Government
Bureau of Meteorology

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Australian Government
Department of Climate Change and Energy Efficiency

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The Fisheries Research and Development Corporation plans, invests in and manages fisheries research and development throughout Australia. It is a statutory authority within the portfolio of the federal Minister for Agriculture, Fisheries and Forestry, jointly funded by the Australian Government and the fishing industry.

National Library of Australia Cataloguing-in-Publication entry

Author:	Hobday, Alistair J., author.
Title:	Developing adaptation options for seabirds and marine mammals impacted by climate change : final report / A.J. Hobday ; L.E. Chambers ; J.P.Y. Arnould ; T.A. Patterson; C. Wilcox ; G.N. Tuck and R.B. Thomson.
ISBN:	978-1-922173-58-4 (ebook)
Notes:	Includes bibliographical references and index.
Dewey Number:	577.22

Suggested citation

Hobday, A. J., Chambers, L. E., Arnould, J. P. Y., Patterson, T. A., Wilcox, C., Tuck, G. N. & Thomson, R. B. 2014 Developing adaptation options for seabirds and marine mammals impacted by climate change. Final Report. FRDC-DCCEE Marine National Adaptation Research Project 2010/0533.

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1 Non-technical Summary

2010/533 Human adaptation options to increase resilience of conservation-dependent seabirds and marine mammals impacted by climate change

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OBJECTIVES:

1. Connect researchers, managers and policy makers, to focus on climate-ready monitoring and adaptation options for conservation-dependent seabirds and marine mammals.
2. Link ongoing monitoring programs around Australia for seabirds and marine mammals with relevant wildlife and conservation management agencies.
3. Extract climate signals for selected time series around Australia using cutting-edge statistical approaches.
4. Develop protocols for monitoring impacts of environmental variation on indicator species and develop an indicator suite of spatial and temporal metrics for climate change impacts.
5. Combine the indicator metrics to develop multi-species productivity indicators for Australian regions.
6. Provide practical adaptation guidelines for science and management, including on-ground monitoring protocols

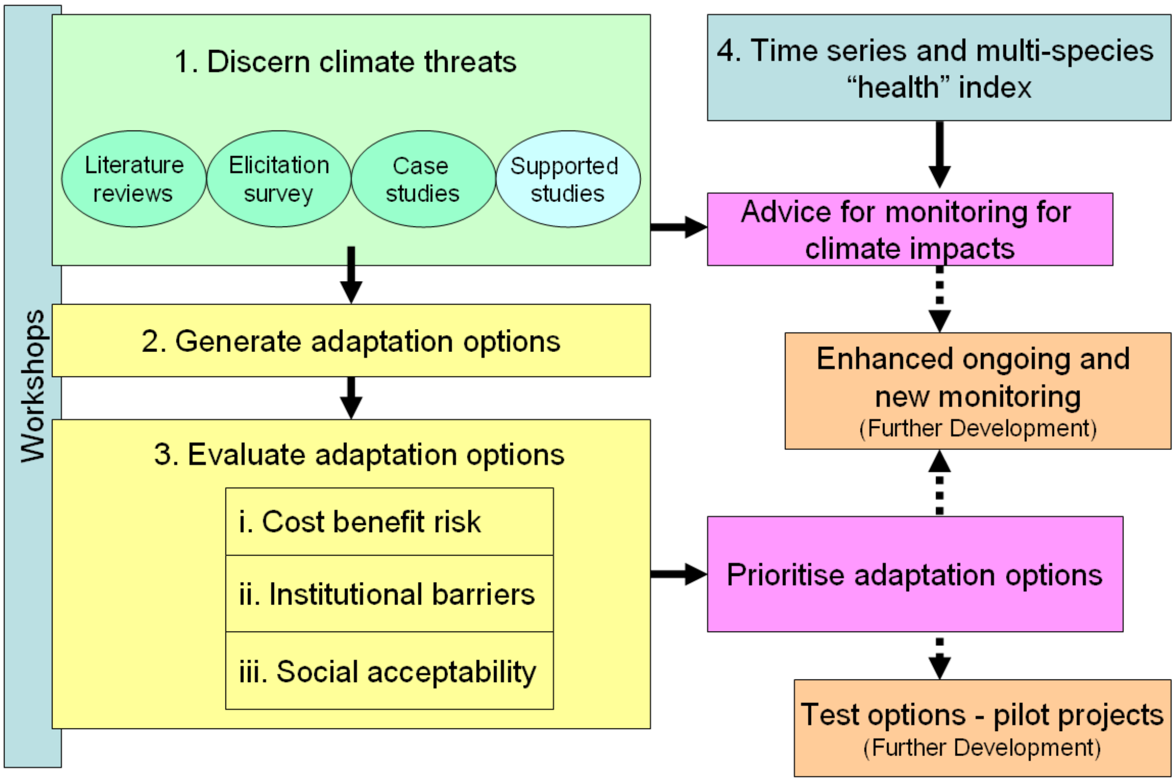
OUTCOMES ACHIEVED TO DATE

This project has increased connectedness between seabird and marine mammal researchers, managers and policy makers about the range of climate impacts that are already being experienced by these iconic taxa in Australian waters. Through workshops and collaborative analyses, we have increased the state of knowledge for Australia's iconic marine species, and demonstrated, through publications, a range of analytical approaches for discerning climate impacts, and in some cases resolving these impacts from non-climate drivers, such as bycatch in fisheries, or competition from similar species. The range of adaptation options that could be used to respond to climate-related threats to seabirds and mammals has also raised awareness amongst managers and researchers, and shifted thinking towards active intervention. Preliminary project results have been welcomed by managers at state agencies, particularly the tools developed to prioritise adaptation options. This project provides a solid foundation for testing of adaptation options, with tools to evaluate likely success, institutional barriers to success, and likely social acceptance of different adaptation options.

Climate change is already impacting marine species around Australia. Changes in distribution, abundance, physiology, and phenology have been documented at a range of lower trophic levels in Australia, including phytoplankton, seaweeds, intertidal and subtidal invertebrates, coastal and pelagic fish. For Australia's iconic higher trophic level marine taxa, such as seabirds and marine mammals, there is a knowledge gap regarding responses to climate change. These species are protected throughout Australia and in some cases are recovering from previous anthropogenic impacts. Resolution of climate change impacts from other anthropogenic threats is needed for these species, in order to implement appropriate and timely adaptive management responses. Evidence of responses to environmental variability and the functional processes driving these affects is limited for most species which is seen by managers as a major impediment to ongoing conservation management and planning in the face of climate variability and change. The project was targeted towards seabirds (rather than shorebirds) and sea lions (rather than all marine mammals) as these taxa are colony-based, particularly when breeding, such that long time series are collected on the same population in the same space, and mostly at the same time, which allowed evaluation of climate risk.

To achieve the project objectives, the project team first reviewed known climate impacts on seabirds and marine mammals by way of (i) literature reviews for climate impacts for Australian seabirds and marine mammals, (ii) case studies involving detailed investigation of representative time series to illustrate different climate signals, (iii) an expert elicitation survey of Australian researchers to determine perceived climate impacts, and (iv) additional case studies by partner scientists with the project team providing methodological, data and statistical support. Summaries of this information was presented in workshops, and led to increased awareness and connections between researchers and managers, and is presented in detail in publications associated with the project. In workshops we also generated adaptation options in response to particular climate threats for both seabirds and marine mammals. Rather than presenting a long list of options, we then developed a set of tools to evaluate the potential for a subset of all the adaptation options, and tested these in workshops with researchers and managers.

We reviewed the range of climate impacts that are already affecting marine mammals and seabirds, and improved the connectivity between researchers and managers with respect to climate adaptation thinking (**Objectives 1 and 2**). In five case studies we investigated additional impacts of climate change, using a range of analytical approaches (**Objective 3**). Using expert elicitation, we surveyed experts around Australia to generate a summary of expectations for future change in biological variables that can also be used to guide monitoring approaches (**Objective 4**). We generated multi-species indices that can be used as indicators of ocean and biodiversity "health" (**Objective 5**).



In consultation with researchers, managers and policy makers, almost 200 adaptation options were generated in response to impact scenarios for 25 scenarios, 156 for seabirds and 42 for marine mammals, representing an average of 10.4 options for each seabird scenario, and 4.2 for each marine mammal scenario (**Objective 6**). Three tools were developed to evaluate 25 of these adaptation options. These tools allow a rapid screening of (i) cost-benefit-risk, (ii) identify potential institutional barriers in implementing adaptation options, and (iii) assess likely social acceptance of these options. Together, these evaluation tools allow relative prioritization and identification of issues associated with each adaptation option that might need to be considered before implementation.

Overall, in workshops, conference presentations, popular articles, and peer-reviewed publications we have shown that as for other taxa in Australia, climate is projected to have an impact on marine mammals and seabirds. Due to variability in data on these species, we show that long time series are needed, and thus emphasise the value of ongoing monitoring. Some variables are better indicators than others, and we illustrate considerations when selecting variables for monitoring to detect impacts of climate change. Given the conservation status for the species we have studied, which include one endangered, five vulnerable, and three near-threatened species, an understanding of how these species respond to climate variability and change and determining the 'best' adaptation options is an important component in efforts to improve their population status. Policy intervention may be required to offer additional protection to species threatened under climate change, and this project has shown that the design of adaptation options can be structured and evaluated. Fortunately there are a wide range of options for reducing vulnerability of colony-nesting seabirds. Adaptation options for seabirds ranked highly by the cost-benefit tool, the barriers analysis and the social acceptability include shading burrows to reduce effects of extreme temperatures, reducing the impact of flooding of burrows during storms, habitat restoration to reduce the impacts of strong winds, and eliminating feral pests at breeding colonies. Translocating seabirds to new areas with more favourable conditions was also considered a viable strategy, and builds on existing conservation experience with this approach. At this time, however, options appear to be more limited for marine mammals. Of the 25 options we considered, the highest ranking option for marine mammals was 9th overall. The three highest options were creating set-aside areas for dugong to reduce non-climate stressors, providing some higher elevation haul-out options for seals where storm surge is an issue, and enhancing seagrass production to provide food for dugong. We emphasise that these seabird and mammal options were not selected from an exhaustive test of adaptation options but from a selection to illustrate how to assess options in more detail.

Overall, we have shown that some management responses for known climate threats can be simple, and as such are continuation of good conservation practice, while novel options are also available to reduce the impact of climate-specific threats. We highlight that monitoring to evaluate effectiveness of adaptation option is also critical, and should be a focus in any adaptation experiments. Testing some of the adaptation options in limited field trials would be a useful next step, and further build the experience of researchers and managers charged with securing the status of these iconic species into the future.

2 Acknowledgments

We greatly appreciate the support and contribution to the outcomes of this project from seabird and marine mammal researchers around Australia, for both workshop participation and/or contributing data or expert opinions for our analyses. Similarly, agency representatives charged with management of marine and terrestrial species also contributed generously in workshops and in reviewing draft reports and we are grateful for their involvement in the project. Much of the data available for analysis of climate trends has been collated by individuals and groups volunteering their time, with varying levels of financial support. The value of these data far exceed their initial collection purpose, and we hope to see greater levels of support for monitoring these indicator species and guiding adaptation responses to safeguard population viability in the face of climate change.

3 Background

The global oceans have warmed over the last 100 years by an average of ~0.6°C as a consequence of anthropogenic emission of greenhouse gases. The rate of warming accelerated in the last decades of the 20th century and is expected to accelerate further during the 21st century (IPCC 2007). Ocean temperatures are not increasing at the same rate everywhere and the rate of change varies regionally around Australia: tropical oceans are warming at close to the global average rate; west-coast waters are warming around twice as fast as the global average; while warming off south-east Australia is greatest, at around four times the global average (Lough and Hobday 2011). Changes to other physical variables include rising sea level, declining pH (ocean acidification), winds, upwelling, stratification, and ocean circulation, all of which have regional variation. Biological impacts in response to these physical changes occur in several categories, including changes in (i) distribution and abundance, (ii) physiology (e.g., growth) and phenology (timing of life-history events such as breeding), and (iii) community structure and function (including general productivity). Some species will be advantaged and others disadvantaged by these changes. In order to improve the coping ability of some species, adaptation may be required. In the context of this project, adaptation can be biological (e.g. genetic evolution in response to a changing climate), which may require only minimisation of non-climate threats, or directed adaptation efforts by humans to reduce vulnerability and improve outcomes for species (**Box 1**).

The Australian Government in December 2007 emphasised the importance of climate change as an area requiring specific policy development, forming the Department of Climate Change (DCC, now the Department of Climate Change and Energy Efficiency, DCCEE), and announcing support for the CSIRO Climate Adaptation Flagship (2008) and the National Climate Change Adaptation Research Facility (NCCARF, initiated in 2008) both to be focused on adaptation. In turn NCCARF commissioned a series of eight National Climate Change Adaptation Research Plans (NARPs) and corresponding National Climate Change Adaptation Research Networks, one of which focused on marine biodiversity and resources (Frusher et al. 2013).

The marine biodiversity and resources NARP identified priority questions that required additional attention to guide adaptation planning in Australia's marine zones (Mapstone et al.

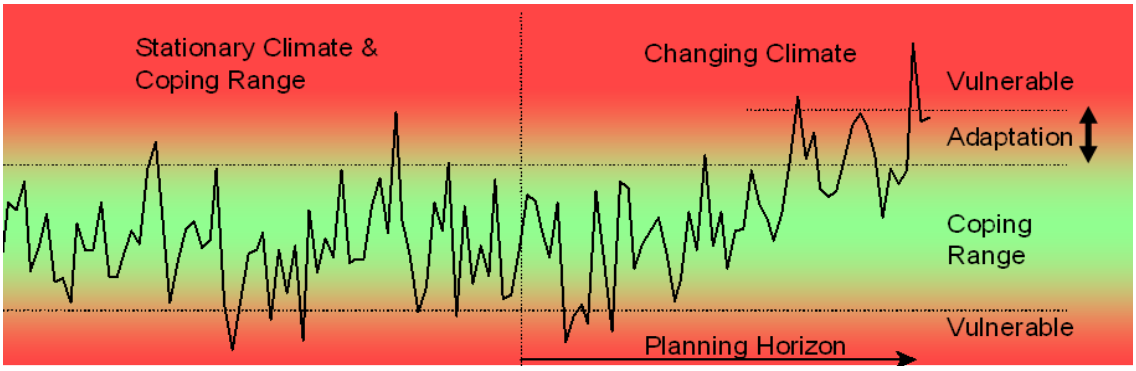
2010). This project was developed to address Research Priority 3, relevant to conservation management in the Marine NARP, which contained two elements:

- Which ecosystems and species of conservation priority most require adaptation management and supporting research, based on their status, value, vulnerability to climate change and the feasibility of adaptive responses?
- How should conservation managers and planners adapt their practices to ameliorate climate change risks and enhance adaptation options? What intervention strategies will increase system resilience and improve the time within which biological systems can adjust to a future climate?

The focal conservation species for this project, seabirds and marine mammals, were selected as previous reviews (e.g. Hobday et al. 2007; 2009 Marine Report Card, www.oceansclimatechange.org) showed that climate impacts and adaptation options were not being widely or consistently considered for the iconic marine species (e.g. Chambers et al. 2009), despite their conservation status and wide public appeal. Iconic species, such as marine birds (seabirds and shorebirds), marine mammals (whales and dolphins, seals and sea lions, dugong) and marine reptiles (turtles, crocodiles and sea snakes) are major tourism drawcards in most parts of Australia where they occur, and are also disproportionately represented in lists of threatened and endangered species. Thus, maintaining viable populations in the face of climate change is important to many Australians. We consulted with a wide range of seabird and marine mammal researchers to determine if there was interest and data available to consider climate impacts for these important marine species. The project was targeted towards seabirds (rather than shorebirds) and sea lions (rather than all marine mammals) as these taxa are colony-based, particularly when breeding, such that long time series are collected on the same population in the same space, and mostly at the same time. Marine reptiles, particularly sea turtles, are also colony-based, however, we perceived that there was initial adaptation-focused research underway (see Fuentes et al. 2010), and these species do not tend their young when breeding, such that climate impacts at the colony location are expressed in different ways to mammals and seabirds.

Box 1. Adaptation

Adaptation has been used to refer to both genetic change (evolution) by species to cope with a new environment, and to societal responses to minimise the impacts of climate change. Natural systems are likely to have limited capacity to adjust to the rate of climate change and so as the climate changes, some form of adaptation (natural or human-assisted) is needed to increase the coping range.



Source: Jones and Mearns 2005

A key question in predicting the ecological effects of climate change is whether species will be able to adapt fast enough to keep up with their changing environment. For example, the maximum rate of adaptation will set an upper limit to the rate at which temperatures can increase without leading to a decline in, say, breeding success. Research is in its infancy with respect to enhancing biological responses to climate change. Potential strategies that have been proposed seek to reduce stress and enhance resilience. These approaches are expected to increase the period of time over which biological response (e.g. evolution to increased temperature tolerance) can occur. Examples include habitat restoration, provision of shade for turtle-nesting beaches, assisted translocation of heat tolerant coral genotypes from warmer waters, inoculation of bleached corals following bleaching, disease suppression, stocking of genetically modified animals, and establishment of new populations or habitat structure. Many concepts and ideas have been borrowed from the terrestrial sphere but the scale at which these intervention strategies can be applied in the ocean is limited. The application of intervention strategies is likely to be limited to high conservation value species and locations.

4 Need

Climate change is already impacting species from a range of trophic levels around Australia. In recent years, shifts in species distribution have been documented at a range of lower trophic levels in Australia (Hobday et al. 2007), including phytoplankton (Thompson et al. 2009; McLeod et al. 2012a), intertidal and subtidal invertebrates (Ling et al. 2009; Pitt et al. 2010), and coastal fish (Last et al. 2010; McLeod et al. 2012b). For Australia's iconic higher trophic level conservation-dependent marine taxa, such as seabirds (and shorebirds) and marine mammals, a number of studies focused on the response to climate variability, particularly in north-east Australia and Bass Strait region (e.g. Cullen et al. 2009; Gibbens and Arnould 2009; Kirkwood et al. 2008; Devney et al. 2009a,b; Erwin and Congdon 2007; Peck et al. 2004; Smithers et al. 2003), but overall there is a knowledge gap regarding responses to climate change (but see Congdon et al. 2007). Australia has a large number of marine mammals and seabirds, particularly when Australian Antarctic and Southern Ocean species are included: 110 species of seabird (Chambers et al. 2011) and 52 species of marine mammal (45 of which are cetaceans; Schumann et al. 2013). These species are protected throughout Australia and in some cases are recovering from previous anthropogenic impacts. Resolution of climate change impacts from other anthropogenic threats is needed for these species, in order to implement appropriate and timely adaptive management responses. Unfortunately, for most species, evidence of responses to environmental variability and the functional processes driving these affects is limited (Chambers et al. 2011; Schumann et al. 2013). This is seen by managers as a major impediment to ongoing conservation management and planning in the face of climate variability and change.

In response to climate impacts, and particularly when these impacts are seen as negative, adaptation options can be developed and implemented. For the iconic species, and particularly regarding marine climate change, a common perception is that there is little option for adaptation, with the exception of reducing existing stressors, such as bycatch reduction in fisheries. However, a range of options currently used for conservation management of iconic species may also be appropriate for climate related responses. Overall, comprehensive development of adaptation options has not been undertaken for marine mammals and seabirds.

In addition, monitoring approaches for some of these species may need to be reassessed and modified in order to better detect the impacts of climate change. Efficient ongoing monitoring is also required to allow adaptation responses to be validated. Results from this project will support adaptation by researchers undertaking the monitoring and adaptation by managers. Furthermore, options for enhancing the adaptive capacity of species impacted by climate change will fostered as a result of this project.

5 Objectives

The six project objectives were to:

1. Connect researchers, managers and policy makers, to focus on climate-ready monitoring and adaptation options for conservation-dependent seabirds and marine mammals.
2. Link ongoing monitoring programs around Australia for seabirds and marine mammals with relevant wildlife and conservation management agencies.
3. Extract climate signals for selected time series around Australia using cutting-edge statistical approaches.
4. Develop protocols for monitoring impacts of environmental variation on indicator species and develop an indicator suite of spatial and temporal metrics for climate change impacts.
5. Combine the indicator metrics to develop multi-species productivity indicators for Australian regions.
6. Provide practical adaptation guidelines for science and management, including on-ground monitoring protocols.

6 Methods

The marine mammals considered in this study include Sirenia (dugong), Carnivora (seals and sea lions), but not cetaceans (whales and dolphins). Prominent seabird taxa include Phaethontiformes (tropicbirds); Procellariformes (petrels, prions, albatross, shearwaters); Sphenisciformes (penguins); Phalacrocoraciformes (frigatebirds, booby, cormorants) and Charadriiformes (e.g. terns, gulls, noddies). With the exception of dugong, we focused on taxa that breed in colonies. Colonial breeding enables long time-series to be collected on the same population at the same location and, generally, at single time points, which will make both intervention and monitoring of responses to adaptation actions easier compared to other taxa (e.g. whales). Around the Australian mainland a wide range of seabird species, including one species of penguin, form breeding colonies, but there are just three seal and sea lion species that are regular breeders, while dugong access predictable feeding grounds.

To achieve the project objectives, the project was organised according to the following schematic (**Figure 1**). In order to discern climate impacts on seabirds and marine mammals several approaches were used including (i) literature reviews for climate impacts for Australian seabirds and marine mammals, (ii) case studies involving detailed investigation of representative time series to illustrate different climate signals, (iii) an expert elicitation survey of Australian researchers to determine perceived climate impacts, and (iv) additional case studies by partner scientists with the project team providing methodological, data and statistical support. Summaries of this information was presented in workshops, and led to increased awareness and connections between researchers and managers, and is presented in detail in publications associated with the project (**Table 1)**. In workshops we also generated adaptation options in response to particular climate threats for both seabirds and marine mammals. Rather than just presenting a long list of adaptation options, we then developed a set of tools to evaluate the potential for a subset of all the adaptation options, and tested these in workshops with researchers and managers. This evaluation allows relative prioritization and identification of issues associated with each scenario that might need to be considered before implementation.

In parallel with the set of approaches used to discern climate impacts, we compiled a list of suitable time series from around Australia, extended these time series for a limited number of cases, and generated multi-species indices that can indicate general ocean health for seabirds and mammals. Together with the evaluation of climate impacts and generation of adaptation options, the multi-species indices suggest future monitoring priorities for these taxa. The project did not extend to on-ground testing of adaptation options, nor the instigation of monitoring, but these are recommended for future work (see **Further Development**).

In the following sections we outline briefly the methods used to achieve each objective (**Table 1**), and note that full methodological details are presented in the scientific publications arising from this project (**Appendix 3**).

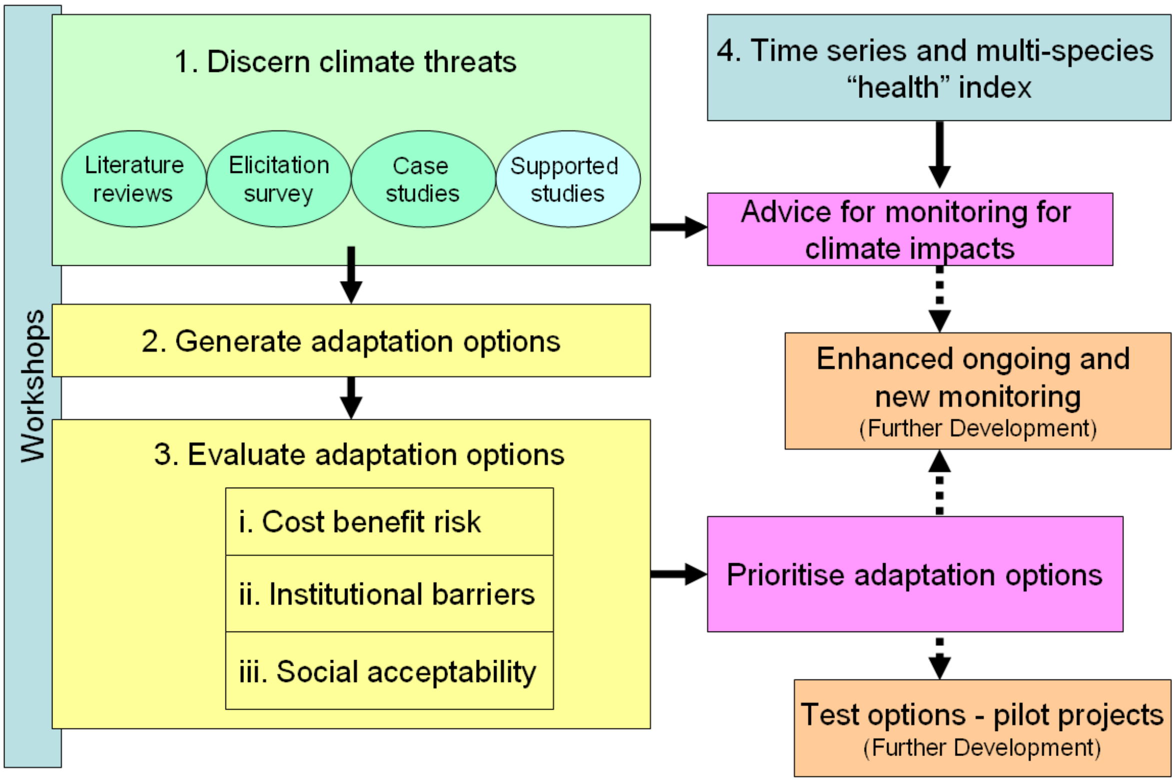


Figure 1. Overview of the project illustrating the main segments of project activity: discerning climate threats to marine mammals and seabirds (1), generating and evaluating adaptation options (2 & 3), and developing a multi-species ocean health index (4). Workshops with stakeholders provided connectivity between the segments, and were used to generate and evaluate the adaptation options. Major project outputs for managers include a way to prioritize adaptation options and advice regarding monitoring for climate impacts. This project should be followed by testing of adaptation options and enhanced monitoring.

Table 1. Methods for each objective and outputs that meet the objective

	Objective	Methods	Output
1	Connect researchers, managers and policy makers, to focus on climate-ready monitoring and adaptation options for conservation-dependent seabirds and marine mammals.	• Workshops • Review climate impacts • Review known interventions • Provide climate data for researchers	• Workshop reports • Popular articles (Appendix 3) • Report Card Papers – (i) seabirds, (ii) marine mammals • Paper 1a: Chambers et al • Paper 1b: Schumann et al • Paper 6. Hobday et al. Overview of project
2	Link ongoing monitoring programs around Australia for seabirds and	• Workshops • Identification of	• Workshop reports • Supported researcher studies

	marine mammals with relevant wildlife and conservation management agencies.	historical data and time series • Elicitation survey	• New data created/recovered • Paper 1a: Chambers et al • Paper 3: Wilcox et al.

3	Extract climate signals for selected time series around Australia using cutting-edge statistical approaches.	• Workshop on analysis methods
		• Data access for researchers
		• Partner with primary data collectors
		• Primary data analysis
		• Recovery of historical data
			• Peer-reviewed papers – listed in Table 2
			  • Paper 2a
			  • Paper 2b
			  • Paper 2c
			  • Paper 2d
			  • Paper 2e

4	Develop protocols for monitoring impacts of environmental variation on indicator species and develop an indicator suite of spatial and temporal metrics for climate change impacts.	• Extracted from analysis and review of ongoing time series	• Paper 1a: Chambers et al. • Paper 3: Wilcox et al. • Report Card papers (i) seabirds, (ii) marine mammals
5	Combine the indicator metrics to develop multi-species productivity indicators for Australian regions	• Time series analysis: Multiple imputation and PCA	• Paper 4: Hobday et al. Multi-species indicators
6	Provide practical adaptation guidelines for science and management, including on-ground monitoring protocols	• Survey literature • Select framework for generating options (E-S-AC) • Workshops - generate options with the stakeholders • Develop tools for prioritizing these options	• Paper 5: Hobday et al. Adaptation options • Paper 6. Hobday et al. Overview of project

6.1 Objectives 1 and 2 – Linking and informing managers and researchers

The methods used to achieve these two objectives are similar (**Table 1)**, so they are treated together here.

6.1.1 REVIEWS OF CLIMATE IMPACTS AND ADAPTATION OPTIONS

The project team undertook literature reviews to summarize the known and projected impacts of climate change on (i) seabirds and (ii) marine mammals. Full methodological details are provided in these reviews (**Appendix 3**; **Paper 1a, Paper 1b**).

6.1.2 WORKSHOPS

In order to connect the researchers, managers and policy makers with each other and the project team, three workshops were held over the course of the project. Leading researchers and custodians of long time series were invited to the first workshop, while attendees at the next two workshops included agency managers and policy makers from each state, together with a subset of the research group. The workshops consisted of presentations from project team and participants, surveys, statistical guidance, advice re environmental variables, discussions, and development of methods for assessment of adaptation options. Reports from each workshop were prepared and distributed to participants, and insight and results from each workshop were used by the project team to develop outputs.

6.1.3 PROVISION OF CLIMATE DATA AND ANALYTICAL SUPPORT FOR RESEARCHERS

At the first workshop and in subsequent months, we extracted environmental data from historical archives maintained at CSIRO for a number of researchers to aid their analysis of time series that were not a focus of our case studies. We also budgeted for time in the project for one of the project team to assist non-project researchers with data analyses.

6.1.3.1 Extension of existing datasets

We identified a range of data that could be created, recovered or extended and used in this project, and supported project partners in the preparation of these data. Support was evaluated based on the following criteria:

1) Be for any region of Australian coastline (not including subantarctic/Antarctic territories)
2) Cover a time series of at least 10 years, preferably longer and continuous
3) Be used either for
    a. converting existing data sets in raw formats (e.g. field note books, loose and disparate spreadsheets) into analysis-ready data for this project
    b. analysing existing biological samples that can be used to infer physiological status of animals (such as blood for stress or reproductive hormones, disease)
    c. analysing existing biological samples that can be used to infer trophic relationships (e.g. feathers, bone, teeth etc. for stable isotope analysis; scat or regurgitate samples).

These additional time series were then available for use in the project (e.g. Objective 3 and 5), and for the primary data custodian to use in their own analyses.

6.1.4 IDENTIFICATION OF TIME SERIES

Together with researchers from around Australia, we identified the time series on seabirds and marine mammals (pinnipeds and dugong) that could be examined for evidence of climate impacts. The species, geographic region, start and end year, frequency, data type, and data custodian were summarised for each time series in a metadata file. These time series were classified into five categories, including (i) population counts, (ii) breeding success measures, (iii) diet metrics, (iv) body mass indices, (v) breeding chronology, and (vi) other. These time series were used in a number of investigations, including Objective 3 and 4.

6.1.5 EXPERT ELICITATION FOR PROJECTED IMPACTS OF CLIMATE CHANGE

Biological time series of sufficient length to evaluate the impacts of climate change and to inform future adaptation are not available for all seabirds and marine mammals. In the absence of such data, the experience of researchers could be used to inform decision making. We used expert elicitation to identify ecological traits of seabirds and marine mammals that were expected to respond to climate change. To evaluate if expert judgements can be used to infer climate impacts on Australian seabird and marine mammals, we elicited from a range of experts (with varying years of field experience and climate-focus to their research), a set of expert judgements regarding observed and expected impacts of climate change for their best known study species. Through this we evaluate if experts could be reliably considered as providing early warning of climate change impacts, and if suitable monitoring priorities could be identified based on their expert judgements. The survey and analytical methods are described in Paper 3 (**Appendix 3**).

6.2 Objective 3 – investigate climate signals in existing time series

To investigate climate signals in existing time series, we selected a range of data types that represented the time series identified (**Table 2**). These case studies included non-colony (case study 1 and 5) and colony-based (case study 2, 3, and 4) time series, and limited (case study 1, 2, and 5) and multi-indicator (case study 3 and 4) time series for each species. We chose examples where the effects of competition (case study 1) and fishing (case study 3) could be resolved from climate related impacts. Detailed methods for each case study are provided in the scientific papers (**Appendix 3**), and spanned a range of statistical and model-based analytical approaches.

Table 2. Summary of case studies used to investigate climate signals in existing time series.

Case study	Style of time series	Key question	Output
1	Abundance counts of three species of gulls in south-east Tasmania – non-colony data	Does competition from other gulls obscure detection of climate signal?	Paper 2a. Woehler et al.
2	Breeding success of 3 species of shearwater in NSW – colony based data.	Do extreme events drive population responses?	Paper 2b. Patterson et al.

3	A range of demographic time series for Shy Albatross – colony based	Can fishing and climate signals be resolved in time series?	Paper 2c. Thomson et al.
4	Breeding success (5 measures) for little penguin in Western Australia – colony-based	What is the relative influence of currents and ocean temperatures, and extreme events?	Paper 2d. Cannell et al. 2012
5	Growth increments and isotope analysis from Australian fur seal teeth – non-colony based	What is the influence of large-scale climate drivers?	Paper 2e. Knox et al. 2013

6.3 Objectives 4 and 5– indicator metrics and multi-species productivity indicators

The methods used to achieve these objectives are similar, so they are treated together.

6.3.1 INDICATOR METRICS

Indicator metrics are those which can provide information on the signal of interest. We highlight appropriate indicators based on time series analysis showing the variability in different metrics (Paper 1a) and expert elicitation surveys (Paper 3).

6.3.2 MULTI-SPECIES PRODUCTIVITY INDICATORS

We selected time series for both seabirds and pinnipeds for south-east Australia, encompassing a range of data types, based on a review of available data for the region (Chambers et al. in review, **Paper 1a**). Multi-species indices were generated with principal components analysis (PCA) run on the biological time series. Missing values were first estimated using multiple imputation with Bayesian linear regression techniques. Mean principal component (PC) scores and associated standard deviation (SD) values for every year with missing time series values were estimated. We limited our analysis to no more than the first two PCs in order to concentrate on the most important modes of variability. Inclusion of additional time series from around Australia will allow development of regional indices (e.g. south-east, south-west, north-east), and once we finalise the analysis for the south-east data, we will extend the analysis to these other time series.

6.4 Objective 6 – generating adaptation options

6.4.1 DEVELOPING A FRAMEWORK FOR GENERATING ADAPTATION OPTIONS

The project team reviewed both the range of existing adaptation options and approaches to generating adaptation options, including ad-hoc and structured methods. Summaries of existing options for seabirds and marine mammals are presented in Chambers et al. 2011. There is a diverse range of adaptation options being presented in the scientific literature (e.g. Mawdsley et al. 2009; Koehn et al. 2011, Dawson et al. 2011) (**Figure 2**), and one option was to just to build on the set of existing options identified in our review and then brainstorm a larger set of options for seabirds and marine mammals.

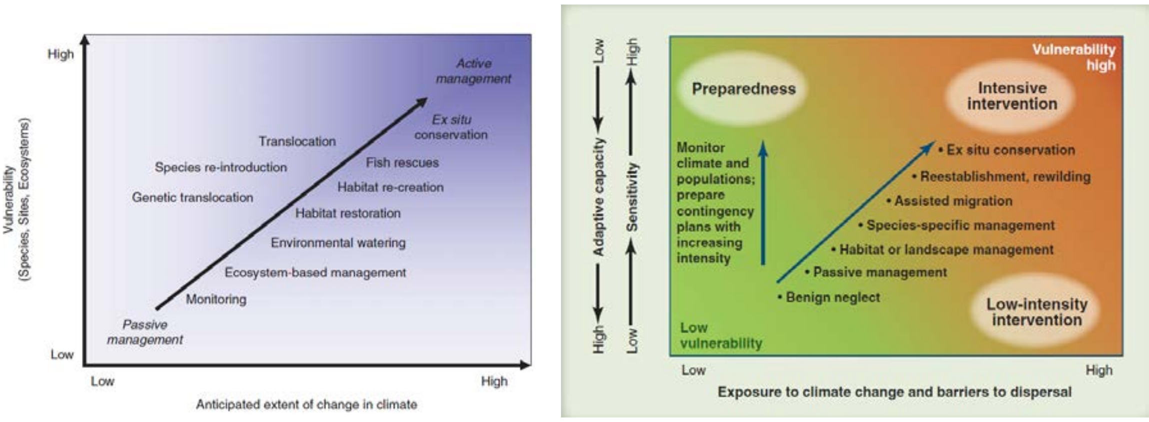


Figure 2. A range of adaptation options in response to climate change have been organised schematically, as a function of extent of climate change and species vulnerability (defined in several ways). Left: Koehn et al. (2011); right: Dawson et al. (2011).

Instead, we chose a structured approach, combining scenarios and a framework, to generate a range of adaptation options. The framework we selected was to use the IPCC model of vulnerability to climate change (**Figure 3)** to comprehensively evaluate the range of options that might be applicable to climate scenarios leading to increased vulnerability for iconic marine species.

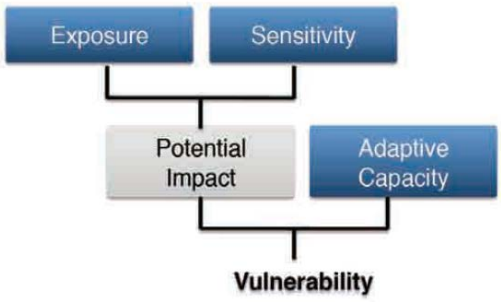


Figure 3. Vulnerability framework used in IPCC assessments to generate adaptation options.

The project team first generated a range of species-specific climate impact scenarios linked to a physical change in the ocean based on our reviews of known impacts, and then in workshops challenged the participants to come up with multiple adaptation options for each of the scenarios. Options in each of the three categories of the vulnerability framework were encouraged and recorded. Under this framework, vulnerability to climate change can be reduced by adaptation options that (i) reduce exposure of the individuals/populations/species to the physical effects of climate change, (ii) reduce the sensitivity of the organisms to the physical effects of climate change, and (iii) increase the adaptive capacity of the individual/species to cope with the physical effects of climate change, such as decreasing the impact of other stressors.

6.4.2 EVALUATING OPTIONS

Having generated a range of adaptation options, we then evaluated a subset of options in each of the vulnerability categories (reduce exposure, reduce sensitivity, increase adaptive capacity) with three tools developed or modified in this project. These tools were designed to evaluate the technical aspects (cost-benefit-risk), the institutional barriers, and the potential social acceptability.

6.4.2.1 Cost-benefit-risk scoring

The first tool, “cost-benefit-risk”, was developed in this project and evaluated each scenario-specific adaptation option against a number of semi-quantitative criteria. Criteria for scoring each adaptation option in three categories were developed: cost, benefit, and risk (**Box 2**). The cutoffs for each category were developed and tested within the project team prior to used. Each criteria was scored as low (1), medium (2) or high (3). This approach was conceptually similar to other scoring systems developed by members of the project team (e.g. Hobday et al. 2011).

Box 2. Criteria used to score the adaptation scenarios (low=1, medium =2, high =3) in three categories (cost, benefit, risk)

Cost

1. Implementation cost
   <$10K = L, 10K-1M =2, > 1M$ = H
2. Ongoing cost
   <5 years=L, 5-10 years=M, >10 years=H
3. Time to implement – lead time till action can begin
   Now=L, 1-5 years=M, >5 years=H

Benefit

4. Persistence of action
   1 season, <5 seasons, >5 seasons
5. Scale of benefit
   Individual/colony/population
6. Benefit of action to target group
   Minimal improvement, partial solution, solve problem
7. Benefit of action to wider ecosystem
   Low, medium, high

Risk

8. Risk of action failing
   <33%, 33-66%, >66%
9. Risk of mal-adaptation - negative outcome on another strategy for target group
   Low, medium, high
10. Risk of adverse impacts to wider (eco)system
    Low, medium, high

In this project, scoring was carried out during workshops using *Turning Point*© software, which is embedded within a PowerPoint presentation, and allows scoring using hand-held devices (like TV remote controls). Each adaptation scenario was presented to the whole group along with the proposed adaptation option. The group then individually scored each of the criteria using the hand-held devices, and the results were displayed to the group at the conclusion of the scoring for each criteria. Each adaptation option thus required scoring of 10 criteria. Each adaptation option score for all participants was converted to a mean cost (average of the three cost attribute scores) and benefit (average of the three benefit attribute scores) score, and plotted with risk criteria averaged and represented on a plot as relative size of the symbol (large symbols representing high risk) **(Figure 4)**.

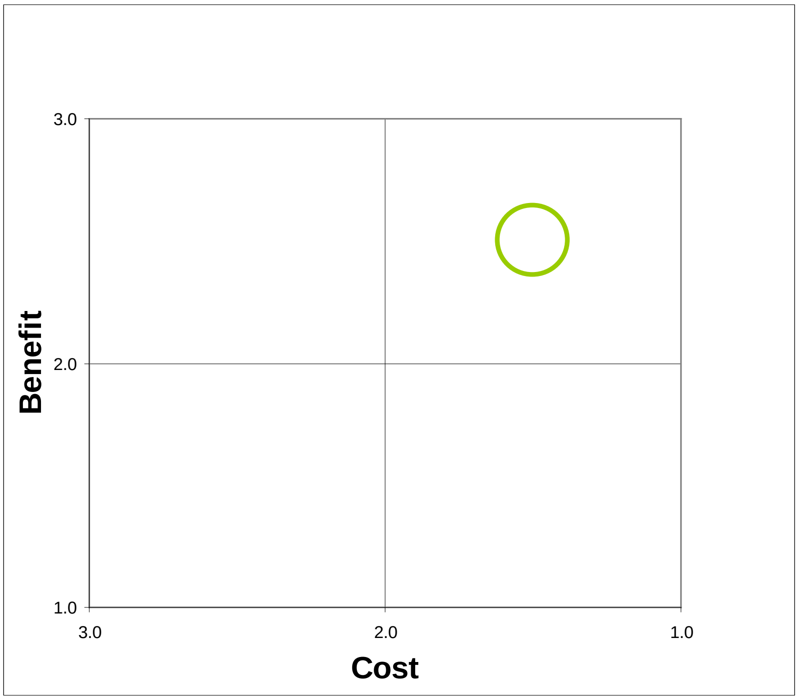


Figure 4. The cost-benefit-risk plot. In this example, an option has been scored as relatively low cost and high benefit, thus falling in the upper right quarter, with the relative risk indicated by the size of the symbol.

This scoring identifies which adaptation options are high cost and low benefit (lower left) and so might be discarded, and which are high benefit and low cost (upper right) and might be rapidly implemented (depending on risk). Options which are low cost and low benefit might not be pursued, while those that are high cost, but high benefit (upper right) deserve more detailed attention.

6.4.2.2 Barriers analysis

Even with technical merit, adaptation options can fail because of institutional problems with implementing options. Thus, a second evaluation tool was based on the conceptual framework on barriers to effective climate adaptation developed by Moser and Ekstrom (2010). The potential barriers can be divided into three stages (understanding, planning and managing), each with three elements (**Figure 5**). For each scenario-adaptation option combination, the nine elements in the framework were scored on a likert scale from 1-5, where 5 represented a likely barrier for the option, and 1 represented no barrier. These questions were answered by workshop participants from the perspective of the likely agency charged with implementing the adaptation strategy. The specific questions were:

1). Detecting a signal will be a barrier for this adaptation strategy?

2) Gathering/using information will be a barrier for this adaptation strategy?

3) Defining the problem will be a barrier for this adaptation strategy?

4) Developing options will be a barrier for this adaptation strategy?

5) Managing the process will be a barrier for this adaptation strategy?

6) Selecting options will be a barrier for this adaptation strategy?

7) Implementation will be a barrier for this adaptation strategy?

8) Monitoring the outcomes will be a barrier for this adaptation strategy?

9) Evaluating effectiveness will be a barrier for this adaptation strategy?

Additional descriptions of each element were provided to participants and discussed prior to scoring the scenarios. The scores for each element were then averaged for each of the three stages, and compared across scenarios.

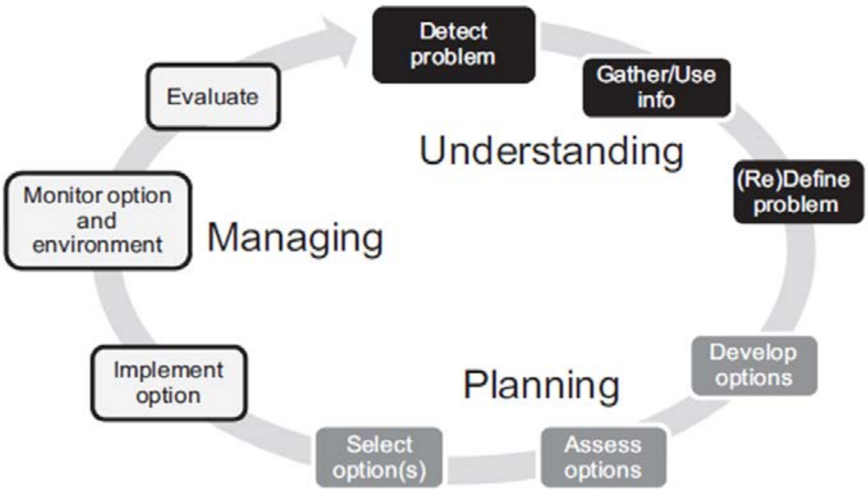


Figure 5. Barriers framework used to evaluate adaptation options. Source: Moser and Ekstrom (2010).

6.4.2.3 Developing a measure of social acceptability

Even with technical merit, and an understanding of the institutional barriers, adaptation options may not be acceptable to society at large, or may be resisted by vocal opponents or groups. Awareness and identification of potentially contested options would be useful to managers charged with implementing adaptation options. Assessing social licence after the event is a difficult task, and attempts to assess it before the action has occurred is even more problematic (**Box 3)**, and is discussed in more detail in Hobday et al. (in prep – **Paper 5**).

Box 3. Social licence.

The term "social licence to operate" was developed as a response to a United Nations initiative that requires industries to operate in the territories of indigenous people to secure free, prior and informed consent from those indigenous people. Social licence is a term that has been applied to the mining industry and has recently become part of the business environment. It is generally defined as the level of acceptance or approval given to an organisation, project, or industry by the local community and other stakeholders.

Issues around social licence also impact on wildlife management and exploitation, and noteworthy examples in Australia include the culling of kangaroos, sterilization of koalas, beach closures during breeding seasons, pest removal programs, and plans to use a "supertrawler" to fish for small pelagic fishes.

A social licence is referred to as 'ongoing' to reflect that it is a dynamic approval that must be continually renegotiated as beliefs, opinions and perceptions can change when new information is acquired. Thus, a social licence is like a having an account of good-will and trust that has been deposited by the community/stakeholders. It takes time to build a relationship with the local community and stakeholders, and once social licence is lost it is difficult to regain.

There are two aspects to social licence, the perceived impact of the activity, and the relationship between the proponent and the community. The first is more easily evaluated, while the second is considered difficult.

Social licence is usually measured after the fact, but there are other research attempts to evaluate community acceptance ahead of time, and we follow that approach in this project.

Thus, the final element in the evaluating of the adaptation options was designed to assess the social acceptability of each option. Each scenario was first scored on a Likert scale [1 7] in response to two questions:

1. What do you think? (expert opinion)
2. What do you think the general public will think?

The project team presented a short-list of issues that may be a concern when implementing that particular adaptation scenario. This was designed to draw out the details of attributes to inform a more detailed assessment of social acceptability. After discussion, the group selected a set of 10 attributes to judge acceptability, in two categories: perceived impact and relationships, and nominated all attributes (i.e. between 0 and 10 attributes) that might be associated with each scenario.

- Perceived "impact" attributes
    1. Is the species threatened or protected?
    2. Is the impacted animal iconic, dangerous or cute?
    3. Will other animals be killed or harmed, or habitat modified? Ethical treatment of animals
    4. Contested action – is there a need for action, evidence for need, benefits clear

5. Will it impact on lifestyle, livelihood or recreation (closures, cat ownership, dogs on beaches)

- Relationship attributes

6. Distrust for the proposing individual/organisation (e.g. government)
7. Are community groups already engaged with a good history of engagements?
8. Is there a powerful or divergent interest groups involved?
9. Is it "crazy" from public point of view. (will it engage radio-jocks), e.g. cost of use of public moneys (value for money)
10. Is the location for the activity in proximity to human settlement/recreation area? (e.g. wind-farm)

The scores for each scenario and the set of issues identified were then analysed to allow a ranking of "preferred" and "non-preferred" scenarios, from both an expert and the assumed perspective of the general public.

6.4.2.4 Overall ranking

The scores from these three tools for each selected scenario-adaptation option were then used to each generate a "ranking" where a rank of 1 is more desirable than a rank of 25.

7 Results/Discussion

In the following sections, we summarize the results relevant to each Objective.

7.1 Objectives 1 and 2 – linking researchers, managers, policy makers

As stated in Table 2, the approaches to achieve these two objectives were similar, and so the results are also presented together.

7.1.1 REVIEWS OF CLIMATE IMPACTS AND ADAPTATION OPTIONS

Two reviews were completed, one for marine mammals and one for seabirds, and both were included as chapters in the 2012 Marine Report Card. The marine mammals review has now also been submitted to Australian Journal of Zoology (**Paper 1b**), while an overall integrating paper has also been prepared (see **Appendix 3, Paper 1a**). Impacts for a range of variables have been documented (**Table 3**), as have a number of adaptation option (**Table 4**). These reviews and examples were critical to generating a wider set of scenarios and adaptation options under Objective 6.

Table 3. Expected and observed responses to climate-related change in Australian marine mammals and seabirds. Based on reviews by Chambers et al. (2011) and Schumann et al. (2013) and taken from Chambers et al. (in review) (**Paper 1a)**.

Climate variable	*Climate Response*	*Expected Species Response*	*Observed Species Response*
Air temperature	↑	Increased heat stress & mortality	Physiological limits known for some species but no clear signal observed
		Reduced breeding success	Limited evidence
		Altered breeding timing	Some evidence
		Poleward range expansion	Limited evidence
Sea surface temperature	↑	Reduced breeding participation & success	Some evidence for but also some contradictory
		Altered breeding timing	Some evidence but direction of effect varies by location and species
		Poleward range expansion	Some evidence in WA seabirds
Ocean currents (including mixed layer depth & stratification)	Strengthen (at least in short term)	Altered foraging & breeding success	Some evidence
Sea level	↑	Breeding sites move with changing coastline	No quantitative link observed
Ocean Acidification	↑	Change in prey	No quantitative link observed
Winds, storms,	↑ (freq. & intensity)	Increased mortality	Some evidence
Cyclones	↑ (intensity)	Reduced breeding success	Some evidence
		Altered breeding timing	Some evidence
Precipitation, streamflow	↓ (southern regions)	Impact on prey species recruitment	No direct link observed
Fire	↑	Colonies at risk of extreme mortality events	Unexpected response for burrow nesting species (stay & burn)

Table 4: Result of literature review of anticipated or observed climate threats and adaptation options implemented or proposed to directly combat these threats (i.e. not including adaptation options which increase resilience through reducing/eliminating non-climatic threats).

Climate 'threat'	Adaptation option (proposed – P or implemented - I)	Species	Location	Outcome
Fire	I: Reduce fire risk by placing powerlines near penguin colonies underground[1]	Little Penguin	Phillip Island	Powerlines placed underground eliminating this source of fire risk
	I: Training of personal to provide rapid response to fires[1]	Little Penguin	Phillip Island	Staff trained – evidence risk reduced
	I: Manage vegetation appropriately to reduce fire risk (as well as providing suitable habitat) [1]	Little Penguin	Phillip Island	Control burns, planted vegetation – evidence of risk reduction?
Heat events – temperature increase	I: Reduce exposure by shading natural and artificial burrows[1]	Little Penguin	Phillip Island	Artificial boxes covered in soil and planted with ground covers; shrubs planted to provide shade in some locations[1] – shade provided by vegetation reduces burrow temperature[2]
	I: Raised boardwalks provide shade and protection from weather[1]	Little Penguin	Phillip Island	Shade reduces artificial boxes temperature[2] as well as temperature for birds outside their burrows
Sea level rise	P: Use of artificial nesting sites, adjusted to take into account sea level rise and storm surge, by seabirds[3]			Species such as Australasian Gannets readily nest on artificial structures such as wooden platforms (e.g. in Port Phillip Bay, Victoria) and Little Penguins in rocks of breakwaters (e.g. St Kilda, Victoria)

[1] Dann and Chambers in review, [2] Ropert-Coudert et al. 2004, [3] Chambers et al. 2011.

7.1.2 WORKSHOPS

A total of three workshops were held during the project (**Table 5**) involving, in addition to the project team, a total of 34 researchers, managers and policy makers from around Australia (**Appendix 2**). Each workshop involved between 18 and 25 people. Across all workshops, participants self-identified themselves as experts in marine mammals (n=6), seabirds (n=14), both seabirds and mammals (n=7), or generalists (n=6). In a second classification, a total of 15 participants classified themselves as "science" focused only, while the remainder (n=19) identified themselves as involved in two or more of "science", "management" and "policy".

Workshop reports (available on request) that summarised the goals, agenda, activities and outcomes from each workshop were prepared and distributed to all participants, along with PowerPoint slides from most presentations. Participants indicated a desire to use materials from the workshop to discuss with colleagues, or use in subsequent work.

Table 5: Summary of project workshops.

Date	Main focus	Main outcome
Workshop 1. March 28-29, 2011, BoM, Melbourne	Researcher focused • Project introduction to partner researchers • Identification of available time series • Overview of available environmental data	• Awareness of project amongst research community • Project team and partner researchers identified additional data sets • Generated meta-data listing for Australia
Workshop 2. March 19-20, 2012, Deakin, Melbourne	Manager and policy focused • Generating adaptation options for a range of climate scenarios • Scoring these scenarios	• Selection of a conceptual framework to generate adaptation options • List of adaptation options based on conceptual framework
Workshop 3. Nov 19-20, 2012, CSIRO, Hobart	Researcher, Manager, policy focused • Project summary of case studies • Evaluation of additional scenarios using cost-benefit-risk tool, and institutional barriers analyse • Refinement and testing of social acceptability methodology	• Summary of project findings • Recognition of the different elements that impact on adaptation (scientific merit, institutional, societal acceptance) • Final ranking of adaptation options

In workshops 2 and 3 we used *Turning Po*int software, which is embedded within PowerPoint, and allows scoring of options presented in each PowerPoint slide using hand-held devices (like simple TV remote controls). For example, as discussed under Objective 6, different adaptation scenarios were presented to the whole group along with the proposed adaptation option. The group then individually scored each of the criteria using the hand-held devices, and the results displayed to the group at the conclusion of the scoring for that criteria. The results are saved both graphically in PowerPoint, and can be exported into Excel for subsequent quantitative analysis. This tool was very effective in allowing large numbers of scenarios to be evaluated by the group at each workshop, and focused discussion when clarity in scenarios was insufficient. The approach also allowed "unusual" scoring to be identified, and discussion sometimes led to re-scoring based on additional information presented by one or more participants.

7.1.3 PROVISION OF CLIMATE DATA AND ANALYTICAL SUPPORT FOR RESEARCHERS

The project team provided advice on appropriate environmental data, and spatio-temporal scales, for use by a range of researchers who we met as part of the project (e.g. Workshop 1) and subsequently extracted and provided a range of data to a subset of researchers (**Table 6**). We anticipate that these researchers are independently analysing their data, and the base of knowledge regarding climate impacts on Australia's iconic marine mammals and seabirds will increase.

Table 6: Summary of data supplied to researchers to aid their analyses for climate impacts on species of interest.

Date	Researcher	Data supplied
January 2011	Leesa Sidhu/Billie Ganendran/Ted Catchpole/Peter Dann	Historical SST data for Bass Strait
April 2011	Marcus Salton/Peter Dann	Daily wind speed and direction data; sea state
May 2011	Andre Chiaradia	Surface and 50m temperature data for Bass Strait
May 2011	Mariana Fuentes	Windspeed, rainfall, temperature for NE Australia
July 2011	Leesa Sidhu/Billie Ganendran/Ted Catchpole/Peter Dann	Daily wind speed and direction data
November 2011	Belinda Cannell	High resolution SST data for Western Australia
November 2012	Billie Ganendran/Peter Dann	Chlorophyll-a (ocean productivity) for Bass Strait

7.1.3.1 Extension of existing datasets

Interaction with researchers around Australia and workshop 1 led to identification of a number of time series that could be updated or generated without requiring additional fieldwork. These time series were evaluated by the project team, and a small amount of project funding was provided to facilitate updates to these time series (**Table 7).**

Table 7: Summary of existing datasets that were extended or new data sets created as a result of this project, and subsequently used in project analyses.

Researcher	Dataset	Main outcome
John Arnould	Victoria: Generate a time series based on seal teeth	Data included in project Time series created, used in multi-species index Research paper generated (Paper 1e- Knox et al. in press – **Appendix 3**)
Roger Kirkwood	Victoria: Extend existing Australian fur seal diet time series by sorting and analysing existing samples for two most recent years	Data included in project
Nic Dunlop	Western Australia: Generate a survival time series from monitoring data on seabirds in WA	Time series could not be generated from the data, as MARK program would not converge to solution
Belinda Cannell	Western Australia: Extend an existing time series for Little penguin breeding success by digitizing last two years of data	Data included in project Research paper generated (Paper 1d - Cannell et al. 2012 – **Appendix 3**)
John Arnould	Victoria: Generate a new time series for little penguin data population size from paper records	Data included in project
John Arnould	Victoria: Generate a new time series for short-tailed shearwater population size from paper records	Data included in project

7.1.4 IDENTIFICATION OF TIME SERIES

In collaboration with researchers from around Australia, we identified 171 time series on seabirds (n=132) and marine mammals (n=39), representing some 40 species. In terms of geographic coverage, 94 time series are for south-east Australia, 41 for south-west, 15 for the north-east, 14 for the northwest, with 3 slipping in for sub-Antarctic colonies (this was not a focus, and so the compilation for sub-Antarctic is not even close to complete). A total of 30 time series were greater than 30 years in length, while 46 were less than 10 years (**Figure 6**).

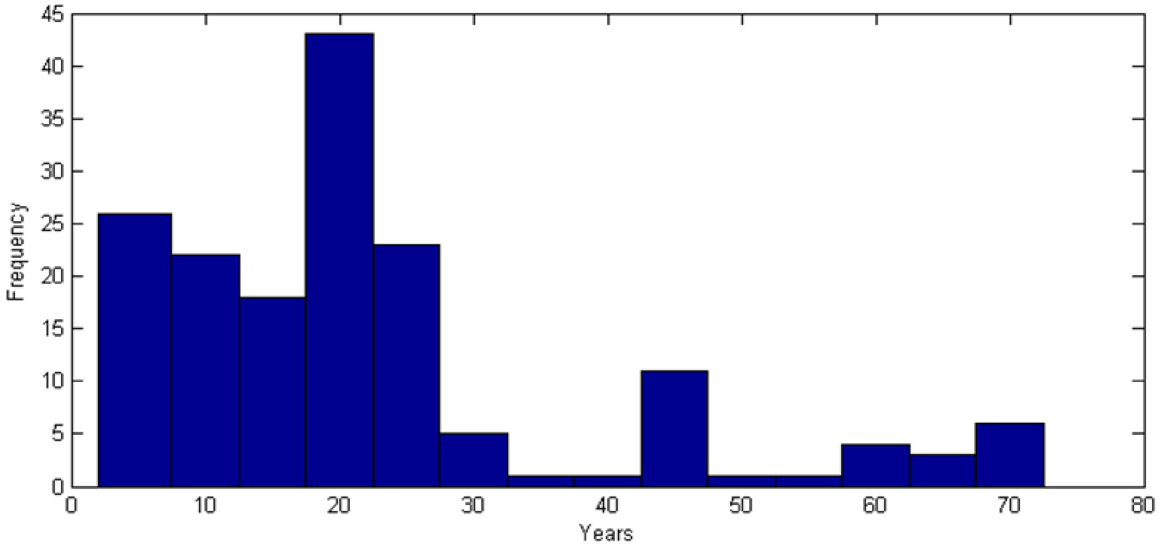


Figure 6. Frequency distribution of the length of time series available to this project.

With regard to the five categories for data type, there were 74 population counts, 34 breeding success measures, 21 diet metrics, 13 body mass indices, 19 breeding chronology measures, and 10 “other”. Time series that were considered suitable for detailed analysis were requested from the data custodians, and used in a number of analyses in this report. A complete listing of the time series is available on request from the report authors.

7.1.5 EXPERT ELICITATION FOR PROJECTED IMPACTS OF CLIMATE CHANGE – WILCOX ET AL. IN REVIEW

Results from the expert elicitation are presented in **Appendix 3** (Wilcox et al. in review). In summary, we surveyed 29 experts, who provided 41 survey responses covering 19 species (17 seabirds, 2 pinnipeds). There were four species which were evaluated by multiple experts: Australian fur seals (4), little penguins (14), crested terns (2), and sooty terns (2). We sought out survey responses on little penguins in particular due to known long-term studies on this species by numerous experts and over a wide geographic region. We analysed the observed and projected biological changes for five general classes of ecological traits: foraging and diet, body mass, breeding phenology, breeding success, and population size.

Based on analysis of 107 traits, experts rated foraging and diet-related traits to be the most responsive to climate change, although predictions for traits in this category were also the most variable across experts (**Table 8**). Body mass was projected to change almost as frequently, but with much lower variance between experts. The timespan over which experts expected to see change also varied between trait classes. Foraging success was expected to respond most quickly. Considering sensitivity and response rate, we predict that the duration of foraging trips will be the best climate change indicator among the 107 traits.

Table 8. Summary statistics for the probability of change for the set of response variables within each response category. Probabilities for each response variable are based on a relative proportion of responses predicting a change.

Response category	**Median Probability**	**Mean Probability**	**Variance**
Breeding Chronology	0.60	0.59	0.014
Foraging/Diet	0.69	0.62	0.028
Body Mass	0.61	0.62	0.008
Population Size	0.55	0.56	0.011
Breeding Success	0.59	0.58	0.010

This approach and evidence suggests that while there may be some bias in responses, expert predictions are relatively reliable and can be used to design climate change monitoring and response plans in the absence of alternative data. Additional information is presented in **Appendix 3** (Wilcox et al. in review).

7.2 Objective 3 – investigate climate signals in existing time series

A total of five case studies investigating different aspects of climate on seabirds and pinnipeds (see **Table 2**) have been completed, and manuscripts have been published (Cannell et al. 2012), are in press (Knox et al. in press), or in final stages of preparation (see **Appendix 3**). Specific details are provided in each of these papers, but in brief, the following results were obtained.

7.2.1 CASE STUDY 1 – GULLS IN SOUTH-EAST TASMANIA – WOEHLER ET AL. IN REVIEW

Figure 7. Kelp, Pacific and silver gulls in south-east Tasmania were the subjects of case study 1.

We examined time series of counts of three species of co-occuring gull in south eastern Tasmania. Two species (the silver gull *Chroicocephalus novaehollandiae* and the Pacific gull *Larus pacificus*) are native to the region while the third (the kelp gull, *Larus domincanus*) is a self-introduced species which colonized in the 1950s from New Zealand populations. Our analysis focuses on examining evidence for the role of climate in mediating abundance trends and also on examining evidence of inter-specific competition. We present simple log-linear models of population change whereby juvenile recruitment is a function of various climate data for the region and consider both large scale climate variables and local conditions as explanatory variables. For the invasive species a null model of simple population growth was selected which is consistent with a population establishing and increasing in a novel environment. For the native species, climate-driven models were selected and for both, average wind speed was important, while for pacific gulls ENSO and SST were also included in the selected candidate model (**Figure 8**).

These results are broadly consistent with other studies of bottom-up forcing in the south-east Tasmanian marine ecosystem; increased wind forcing encourages mixing and increased productivity which leads to increased abundance in *Nyctiphanes australis* an important Euphausid prey species for gulls. Conversely, in years with lower wind speed, warmer waters and higher water column stability, *N. australis* production is reduced. Models implying competition effects by the self-introduced *L. dominacanus* on the two native species were also fitted to the data but performed poorly relative to models with climate covariates. These results indicate that competition alone is not a sufficient explanatory factor in the observed changes of the native species, and future management strategies to maintain populations of the endemic Pacific gull should seek to reduce other stressors, such as climate change impacts.

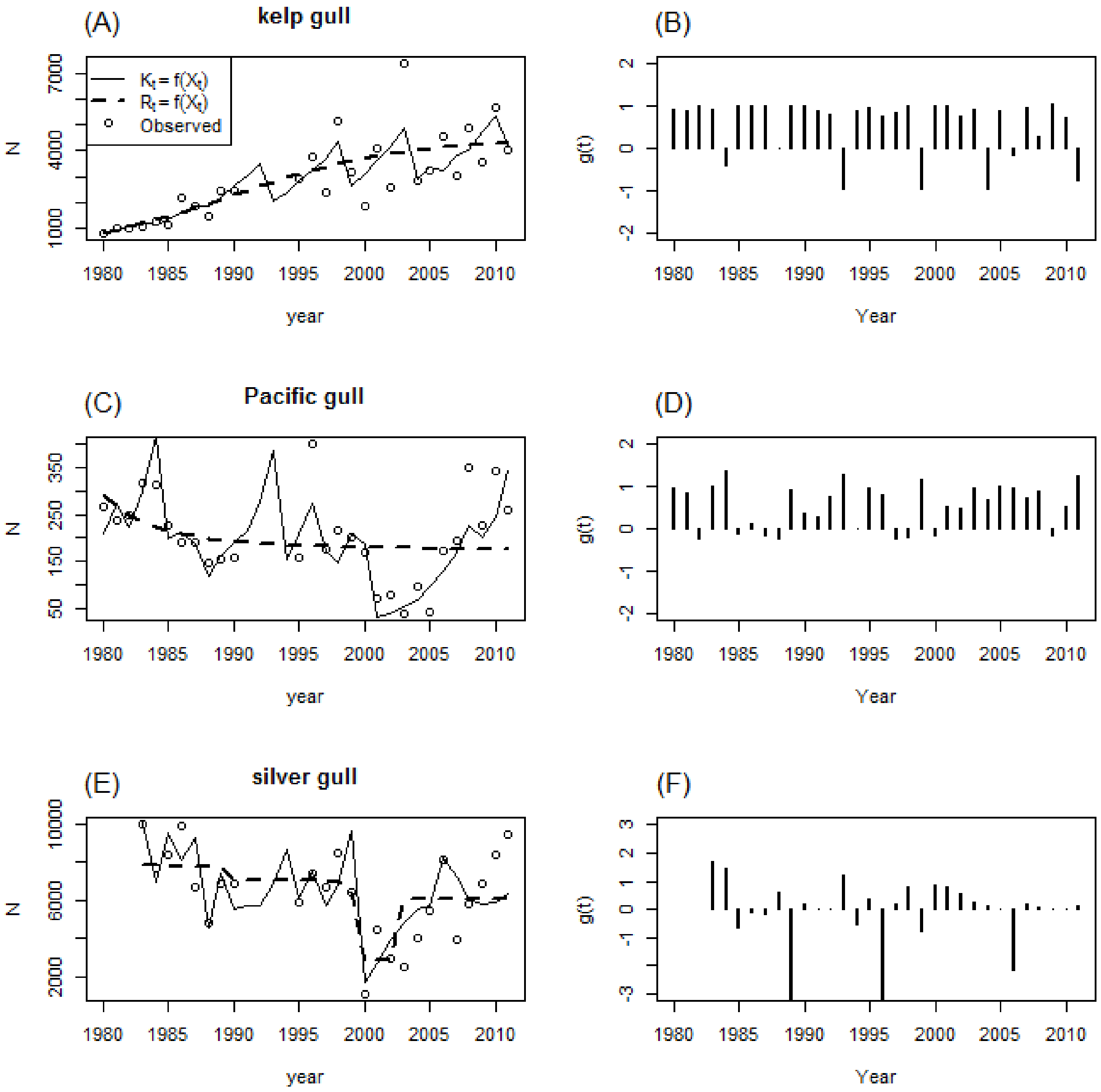


Figure 8. Model fits to the three gull time series. (A,C,E) Model fits to raw count data (dots) from the best fitting time-varying K (solid lines) and r (dashed lines) models. (B,D,F) Estimated time series of annual growth (see equation 3). For ease of comparison between species the vertical axis of (F) is truncated at the lower value of -3 despite some values being substantially less than this limit.

7.2.2 CASE STUDY 2 – SHEARWATERS ON MONTAGUE ISLAND – PATTERSON ET AL. IN PREP

Figure 9. Wedge-tailed and short-tailed shearwaters were the subjects of case study 2.

Long term monitoring data are invaluable in determining the role of climate variability on the performance of marine predator populations and to projecting future impacts. South-east Australia exhibits one of the most rapid rates of warming observed in the global ocean and impacts on many marine species have already been reported in this region. The relative importance of long-term gradual change versus extreme events has rarely been considered for marine species, yet may be critical for understanding population responses to climate variability and change. Here, we examine a 44 year monitoring series of chick production from three shearwater species; wedge-tailed shearwater *(Ardenna pacifica),* short tailed shearwater *(Ardenna tenuirostris),* sooty shearwater *(Ardenna grisea)* at Montague Island in eastern New South Wales (NSW), Australia, where both extremes and long-term trends may be important. For all three species, extreme rainfall events have been observed to cause breeding failures through burrow inundation, while long term sea surface temperature (SST) warming may be impacting at-sea foraging habitat. Analysis of monthly rainfall records from 1955-present indicate that breeding failures are likely when rainfall events during the November-February breeding period exceed the 90th percentile of the observed rainfall distribution. We built statistical models of chick production which can include climate and ocean data as explanatory variables and putative oceanic regime switches. A model with three regimes fit the time series well and predicted declining productivity with three rainfall-related drops in breeding success (**Figure 10**).

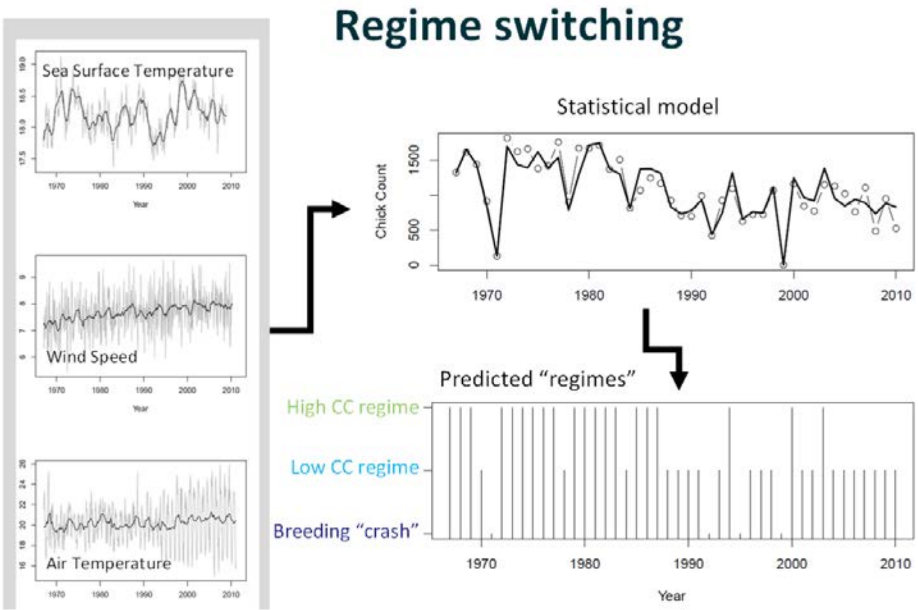


Figure 10. Environmental variables were used to generate a statistical 3-state model for shearwater chick production.

Explanatory variables included in the final models were SST, wind speed, the Nino3.4 index and Nov-Feb total rainfall. Future projections from these models were interpreted in light of extreme rainfall predictions using generalized extreme value analysis of output from Coupled Model Intercomparison Project phase 3 (CMIP3) Global climate models (GCMs) and downscaled Cubic Conformal Atmospheric Model 805 (CCAM). Both the CCAM and GCM downscaled predictions for eastern NSW suggest the possibility of moderate increases in the occurrence of extreme rainfall events. These future patterns may negatively impact on these shearwater populations, however, a range of adaptation options may reduce potential impacts and should be considered for these and similar populations.

7.2.3 CASE STUDY 3 – ALBATROSS, FISHING AND CLIMATE VARIABILITY – THOMSON ET AL. IN PREP.

Figure 11. Shy albatross was the focal species of case study 3. Photo: Alistair Hobday

Long lived, central place foragers such as albatross offer an opportunity to investigate the integrated effects of climate change on the marine biota. Shy albatross (*Thalassarche cauta*) breeding on Albatross Island, Tasmania, show an unusually restricted foraging range year-round, allowing the effects of non-climate stressors, in particular fisheries bycatch, and the influence of environmental variation on key demographic parameters, to be more easily resolved. For this population, local environmental variables - rainfall, air temperature, and sea-surface height (an indicator of upwelling) during the vulnerable chick-rearing stage of the breeding cycle, have been correlated with breeding success. Here we use an age-, stage- and sex-structured population model for shy albatross to explore potential relationships between local environmental factors and albatross breeding success while accounting for fisheries bycatch by trawl and longline fisheries. The model used time-series of observed breeding population counts, breeding success and adult and juvenile survival rates, a bycatch mortality observation for trawl fishing to estimate fisheries catchability and population parameters such as the natural mortality rate, density dependence, and productivity. At-sea distribution data for adult and juvenile birds were coupled with reported fishing effort from pelagic and demersal longline and trawl vessels to estimate vulnerability to incidental bycatch. The model attributed almost all fishing mortality to trawl rather than longline fisheries. Observed demographic time-series are well reproduced, except for adult survival rate for which estimates are consistently lower than those derived frommark-recapture estimates. Global climate models do not predict a substantial change in the local average rainfall therefore this factor had little influence on breeding success, however, temperatures are predicted to increase, with detrimental effects on breeding success. Upwelling is predicted to increase, resulting in a beneficial effect. Complete eradication of bycatch of shy albatross in fisheries cannot entirely offset losses due to future temperatures, even if upwelling increases substantially. Our results highlight the benefits of using an integrated modeling approach, which uses available demographic as well as environmental data within a single estimation framework, to provide future predictions to inform development of management options in the face of climate change.

7.2.4 CASE STUDY 4 – LITTLE PENGUINS, OCEAN TEMPERATURES AND THE LEEUWIN CURRENT – CANNELL ET AL. 2012

Figure 12. Little penguin was the focal species of case study 4.

Using 20 years of data (1986 to 2008), we examined relationships between oceanographic variables (Fremantle sea level (FSL) – a proxy for the strength of the Leeuwin Current – and sea surface temperature (SST)) and five measures of little penguin, *Eudyptula minor*, breeding performance near Perth, Western Australia: namely (1) the laying date, (2) the number of chicks produced per pair, (3) the proportion of eggs that hatched, (4) the overall breeding success, defined as the proportion of total eggs laid that resulted in successful fledglings and (5) chick mass at fledging. The next three years of data (2009 to 2011) were used to test the performance of our statistical predictive models. FSL provided more accurate predictions of timing of laying, whereas SST provided more accurate predictions of breeding success. A later end to laying was associated with a high FSL during the summer (December to February) before breeding. Higher SSTs in the pre-breeding period from April to May corresponded to reduced breeding success, with lower fledgling success, fewer chicks per pair and generally a lower mean mass of chicks at fledging. The models predict that future oceanographic warming is expected to reduce the breeding success of this colony of little penguins.

7.2.5 CASE STUDY 5 – AUSTRALIAN FUR SEALS, TEETH AND CLIMATE DRIVERS – KNOX ET AL. 2013

Figure 13. Australian fur seal was the focal species of case study 5.

The widths of the dentine growth layer groups of teeth from 67 male Australian fur seal (*Arctocephalus pusillus doriferus*) collected at Seal Rocks, in Bass Strait, south-eastern Australia between 1967-73 were examined to assess relative growth. Fluctuations in relative growth were apparent between 1956-71 suggesting inter-annual variations in food availability within Bass Strait, and were found to be significantly correlated to winter Bass Strait sea surface temperature, wind-speed, and the Southern Oscillation Index (SOI) on a 2 year lag. The delay between the measured environmental variables and relative growth may reflect the time required for the nutrient cascade to filter through to the predominantly benthic prey of Australian fur seals. Stable isotope analysis of carbon and nitrogen were used to investigate whether fluctuations in growth were associated with different prey resources. Inter-individual variation in $\delta^{15}N$ and $\delta^{13}C$ was high and did not correlate with relative growth. However, inter-annual variations in $\delta^{13}C$ were found, suggesting changes in the influence of oceanographic currents into Bass Strait and the prey transported into the region. Variations were correlated to SOI on a 2 year lag, which is consistent with previous studies showing correlations between SOI and prey assemblages in the diet of the Australian fur seal in the region.

7.3 Objectives 4 and 5– indicator metrics and multi-species productivity indicators

7.3.1 INDICATOR METRICS

As part of the review by Chambers et al. (in review), we considered a variety of data types to examine whether particular types of data are expected to be more robust for the detection of climate change. We anticipated that the most sensitive indicators of climate-related change would be biological time-series with higher year-to-year variability. Alternatively, phenological and mass-based measures, may be more sensitive indicators than those based on abundance due to the time-scales they generally operate over, particularly as measures of abundance may also be influenced by non-climatic factors, including harvesting, competition and management actions. We found that time-series with lower year-to-year variability, i.e. those based on chronology or mass, were more likely to detect trends, including those related to climate, than other commonly measured biological variables (**Table 9**).

Table 9. Variability (CV) of south-eastern Australian seabird and marine mammal time-series data by response category.

Response category	*N*	*Mean*	*Quartile 1*	*Quartile 3*
Mass	5	6.76	4.02	8.65
Chronology	8	11.23	6.58	15.86
Breeding Success	4	33.53	18.70	46.10
Population	14	35.52	17.20	41.80
OVERALL	31	24.36	8.49	39.75

Variability in the data influences detection of trends – climatic or otherwise. The length of time needed to detect a significant change in 50 % of 10,000 time series for range of CV's (1 % to 100 %), given an underlying trend of 0.1, 0.5, 1 and 5 % per time period. As the strength of the underlying trend increases (e.g. to 1 % or 5 % per year) shorter time-series can show significant trends (**Figure 14**).

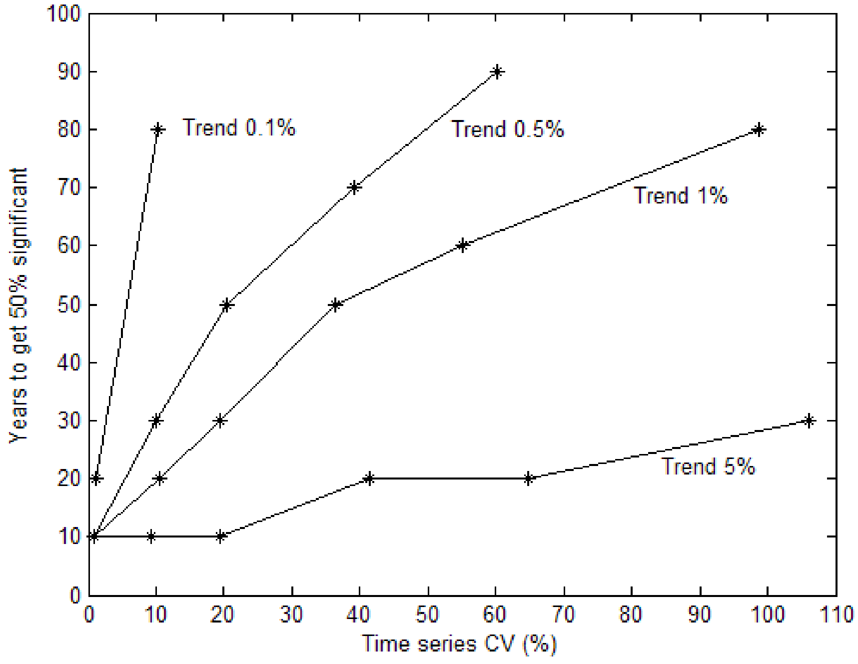


Figure 14. Simulated number of years required to detect a linear trend in a time-series according to the level of variability present (CV).

As the CV increases, the number of years required to detect the trend also increases and fewer documented datasets have the length of data required to be able to detect even a linear trend. However, as shown above in **Table 9**, the CV also varies by the type of data. In general fewer years of data are required to detect a temporal trend for measures of chronology or mass than those for breeding success or population size. Therefore, if a manager's main aim is to monitor a population for temporal changes the choice of the biological information monitored can impact on how soon a change may be observed.

Based on the meta-analyses presented here, recording biological variables such as mass and chronology should result in a greater chance of detecting temporal trends in a time-series with fewer years than do observations on breeding success and population size. This is related to the generally lower year-to-year variability in the former time-series. However, there are limits to the usefulness of time-series with very low CVs for detecting change, be it over time or in relation to climate, as there may be no response to environmental forcing at all; for example, phenological measurements on species with life-cycles driven primarily by photoperiod where little year-to-year variability exists. In initiating new or refining existing monitoring programmes, these results should guide researchers and managers in selecting critical variables with respect to assessing environment-driven trends.

The expert elicitation analysis (Wilcox et al. in review) also showed that measures of foraging success where most likely to show a climate related signal, and could be a focus for future data collection.

7.3.2 MULTI-SPECIES PRODUCTIVITY INDICATORS – HOBDAY ET AL. IN PREP

The multi-species index will be useful for assessing short-term trends or single year events for species that are not part of regular monitoring. To generate this index, a total of 27 potential data sets were investigated for south-east Australia, with a temporal coverage of between 6 and 43 years. Of these, 14 were included in the final index calculation. Datasets were excluded for two main reasons. First, the correlation matrix was not complete if at least one variable does not have an associated observation in all the other time series, as the singular value decomposition of this matrix then cannot be computed. Data could not be missing for long runs in candidate time series; however, the same amount of missing data was not a problem if the missing years were more randomly distributed. Insufficient data in the raw time series meant the process of imputation would not work. There is not a clear limit on how many years of data were needed, as this depended on what other time series were included. The PCA analysis resulted in 14 principal components (as there were 14 time series) with the first principal component representing 27% of the variance, while the second, third and fourth represented 15%, 14% and 12%, respectively.

The multi-species indices are represented by the first four principal components (PC) (**Figure 15**). These time series show variation over time, and the pattern in this variation differs between each PC time series. The uncertainty in the imputed values (vertical error bars) are highest when the overlap between all the time series is lowest (start of the time period). The loading of individual species onto these components is still to be evaluated, but will show which species and data types are associated with each PC-index.

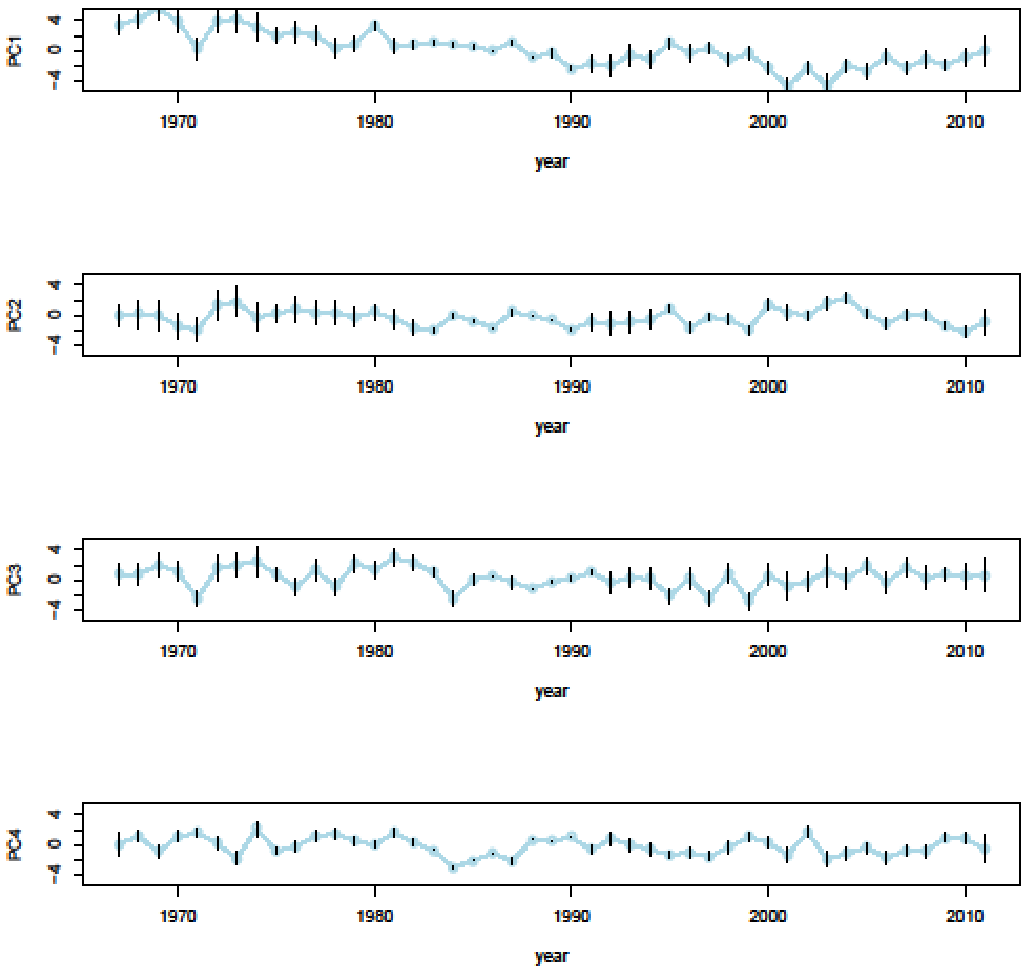


Figure 15. Imputed multi-species time series from PCA analysis

7.4 Objective 6 – Generating adaptation options

Review of existing options from the published literature, expert consultation and our own experience showed a wide range of options were being used around the world for management of seabirds. In response to the known threats, we also generated a list of potential response options where none were currently reported. A subsample of these is presented in **Table 10.**

Table 10: Examples of threats and adaptation options for marine mammals and seabirds

Species/Location	Threat	Adaptation options
Pinnipeds: Low elevation breeding or haul-out site (e.g. Seals on Dangerous Reef, SA)	Rising sea level submerges breeding or haulout site, or storm surges wash over these more frequently	Elevate habitat (e.g. concrete added to platforms); break water added
Tropical island seabird colonies on low elevation islands (e.g. Elizabeth-Middleton)	Rising sea level submerges breeding site, floods burrows, or storm surges wash over these more frequently	Translocation (e.g. Carlise et al. 2012) Elevate habitat
Burrow-nesting seabirds	Increased rainfall floods burrows more regularly/intensely	Drainage on islands Rescue
Burrow or ground nesting seabirds	Increased rainfall and warming air temperatures promote growth of weeds choking nesting habitat	Management of weeds (e.g. Chambers et al. 2011)
Little penguin	Increased fire risk from bushfires started from power lines	Bury power lines underground (Chambers et al. 2011)
Little penguin	Increased air temperature reducing breeding success and increasing heat-stress related mortality	Design of artificial nesting habitats (e.g. nest boxes) to minimize heat load; managing vegetation for provision of shade in nesting habitats – improved microclimates (also design to increase ventilation – Ropert-Coudert et al. 2004)
Seabird colonies	Erosion of colonies, or access to them, by waves, storms or rainfall	Protect or increase appropriate vegetation and reduce inappropriate vegetation to stabilise habitat
Seabirds and marine mammals	Warming ocean, lower productivity, less food	1. Translocate colonies (e.g. Priddel et al. 2006) 2. Supplemental feeding (e.g. Gummer 2003) 3. Provide man-made structures and/or decoys to encourage breeding at new

		locations (e.g. Gummer 2003) 4. appropriately manage competing fisheries (e.g. Baker and Wise 2005); 5. establish no-take areas or Marine Protected Areas to enhance recruitment of prey stocks and maintain sub-surface predator levels (e.g. Louzao et al. 2006)

Based on this review, the project team developed a set of 25 climate impact scenarios. Seabirds and marine mammals were the focus of 15 and 10 scenarios, respectively (**Table 11)**. Both direct and indirect impacts (e.g. mediated through the food chain) were considered, and the climate drivers and biological responses specified to guide thinking.

Table 11: Scenarios for generating adaptation options for seabirds and marine mammals. For each scenario, the climate driver(s), pathway for the impact (direct or indirect) and the biological variables that could be impacted are noted to guide adaptation thinking.

Scenario	Climate driver	Direct or Indirect impact	Biological variable impacted
Seabirds			
1. Increased air temperatures lead to decreased chick survival in burrow nesting birds (Little penguin, shearwaters, ~100 bird colony).	Air temperature	Direct	Breeding success, Population size
2. Declining ocean productivity lead to declining fledging success of seabirds (e.g. shy albatross, little penguin, sooty terns, black and common noddy, wedge-tailed shearwater, boobies)	Ocean temperature Productivity	Indirect	Foraging/Diet, Breeding success, Population size, Body mass
3. Increased intensity of rainfall events leads to flooding of burrow nesting birds and chick mortality (e.g. shearwaters) - after parents have left	Rainfall	Direct	Breeding success, Population size
4. Increased intensity of rainfall events leads to direct mortality of eggs and chicks of ground nesting birds (e.g. albatross).	Rainfall	Direct	Breeding success, Population size
5. Wind speed increases lead to nesting failure of tree nesting birds on Heron island (e.g. Black noddy).	Wind/Storms/Cyclones	Direct	Breeding success, Population size
6. Storm surge coupled with sea level rise reduces available breeding habitat of low island nesting species (e.g. fairy terns, black swans, Thomas Cay)	Wind/Storms/Cyclones Sea level	Indirect	Population size

7. Warmer weather leads to increased vegetation growth around burrows, leading to both a fire risk, and preventing birds from accessing the burrows. (e.g. kikuyu grass (binds burrows))	Air temperature Fire	Indirect	Breeding success, Population size
8. A competitive bird species (e.g. silver gull or gannet) is favoured by climate change, and arrives at the colony of a threatened species and begins to take over nesting sites. (space competition)	Other	Indirect	Breeding success, Population size
9. Warming waters and a deepening thermocline lead to reduced foraging success and loss of northern colonies of seabirds. (Colonies can move south)	Ocean temperature Currents/MLD/Stratification	Indirect	Foraging/Diet, Body mass, Breeding success, Population size
10. Increased abundance of bony fish which can be captured by the parent lead to choking and gut blockage for chicks close to fledging. e.g. pipefish and terns in Nth Sea	Other	Indirect	Foraging/Diet, Body mass, Breeding success, Population size
11. Decreased foraging success of adults leads to chicks (n=2) fledging at lower weights and first year survival declines.	Productivity	Indirect	Foraging/Diet, Population size
12. A 20-30% decrease in the number of nesting shearwaters in SE Australia over the last 10-20 years – cause unknown. Could be Bering Sea changes, Southern Ocean changes or local productivity.	Other	Indirect	Population size
13. Groundwater rise to flood burrows	Rainfall	Direct	Breeding success, Population size, Breeding chronology
14. Increase disease outbreaks b/c more frequent over time e.g. flea-borne, ticks	Air temperature Rainfall	Indirect	Breeding success, Body mass, Population size
15. Warmer, drier and drought conditions – loss of nesting habitat	Air temperature Rainfall	Indirect	Breeding success, Population size
Mammals			
1. Increased sea level and storm surges lead to overtopping of a seal breeding colony and mortality of seal pups increases, leading to overall population decline.	Sea Level, Wind/Storms/Cyclones	Direct	Breeding success, Population size Breeding Chronology
2. Declining ocean productivity lead to declining participation of females seals in breeding (ie not pupping).	Productivity	Indirect	Foraging/Diet, Breeding success, Body mass, Population size
3. Increased intensity of rainfall events leads to disease outbreak at isolated colonies of seals.	Rainfall	Indirect	Population size, Breeding success
4. Cyclone frequency increases and destruction of sea grass beds leads to starvation and deaths of dugong	Wind/Storms/Cyclones	Indirect	Body mass, Population size, Foraging/diet

5. Shifts in the wind direction lead to reduced upwelling, foraging success declines, and reduced pup survival results from extended time at sea for females.	Wind/Storms/Cyclones	Indirect	Foraging/Diet, Breeding success, Body mass, Population size
6. Aggregation of sharks populations favoured by climate change at seal colonies leads to reduced survival of weaned pups.	Other	Indirect	Body mass, breeding success, population size
7. Rising air temperatures leads to mortality in females pupping on isolated colonies (shark attack, disease, mother-pup bond disturbance).	Air temperature	Direct	Breeding success, Population size
8. Sea lions and fur seals have many colonies with low lying rocky islets etc. Sea level change will impact breeding colonies (mortality of young pups) as will increase in storm surges	Sea Level, Wind/Storms/Cyclones	Direct	Breeding success, Population size
9. Increase in ambient temp will potentially impact infection with hookwork/lungworm in pinnipeds leading to reduced survivorship (many other diseases may also increase)	Air temperature	Indirect	Breeding success, Population size, Body mass
10. Increasing water temperatures leading to declines in dugong feeding areas (seagrass declines in some parts of the range) leading to starvation and mortality in some parts (~25%) of the species range	Ocean temperature	Indirect	Body mass, Population size

Adaptation options for these scenarios were generated by the project team and experts at Workshop 2. Initially, 269 adaptation options were generated for these 25 scenarios, categorized as exposure/sensitivity/adaptive capacity options. There were 222 options for seabirds and 47 for marine mammals. After combining similar options within each scenario, there were 198 options across the 25 scenarios, 156 for seabirds and 42 for marine mammals, representing an average of 10.4 options for each seabird scenario, and 4.2 for each marine mammal. These options were relatively evenly distributed between the three elements of the vulnerability framework: reduce exposure (n=63), reduce sensitivity (n=64) and increase adaptive capacity (n=71). Example adaption options in each category are provided in **Table 12**.

Table 12. Examples of different adaptation options in each of the vulnerability categories. Without additional information on the climate threat, these options are illustrative only. (Photos: upper and lower L. Chambers, middle – internet - unattributed).

Class of adaptation option	Example adaptation option

Class of adaptation option	Example adaptation option	
Decrease exposure	Shading of burrows (see photo) Artificial nest boxes Translocation Modify habitat Artificial haulouts Create rockpools for cooling Shade cloth for ground nesting birds	
Decrease sensitivity	Supplemental feeding of chicks (photo) Removal of extra egg Chick rescue during extreme events Construct barriers to environment Vaccinate chicks Provide cooling	
Increase adaptive capacity	Boardwalks to reduce human impact on colony nesting burrowing species (photo) Cull competitors Reduce fishing effort (bycatch reduction) Reduce feral predators Reduce competitor species	

7.4.1 EVALUATING A SUBSET OF OPTIONS

A subset of 25 scenario-adaptation option combinations was selected for detailed evaluation. These examples were selected to provide representative coverage across each vulnerability category (8 Exposure, 10 Sensitivity, 7 Adaptive Capacity), represent a range of climate threats and population responses (more than one could be included for each scenario), and a variety of species (17 seabird, 8 marine mammals). Not all 25 original scenarios listed in **Table 11** were included, and some scenarios had up to four adaptation options evaluated (**Table 13**).

Table 13. Selected scenario-adaptation options for evaluation. These scenario numbers do not correspond to previous numbering. Note that some scenarios were included more than once to compare different adaptation options. Options are noted as reducing exposure (E), reducing sensitivity (S) or increasing adaptive capacity (AC).

Number	Scenario Description	Adaptation option
1	Increased air temperatures lead to decreased chick survival in burrow nesting birds	(E) decrease exposure via shade cloth over burrows
2	Increased air temperatures lead to decreased chick survival in burrow nesting birds	(E) shade burrows with revegetation to shrubby
3	Increased air temperatures lead to decreased chick survival in burrow nesting birds	(E) construct longer deeper burrows that are cooler
4	Increased air temperatures lead to decreased chick survival in burrow nesting birds	(AC) Eliminate feral pest (e.g. foxes) on the island (e.g. Phillip Is size)

Number	Scenario Description	Adaptation option
5	Rising air temperature leads to mortality in females pupping at isolated colonies by increasing their time in water (exposure to predators) and disease increase, and disturbance to mother-pup bond	(S) building artificial rock pools
6	Rising air temperature leads to mortality in females pupping at isolated colonies by increasing their time in water (exposure to predators) and disease increase, and disturbance to mother-pup bond	(AC) shark deterrents (acoustic)
7	Increased intensity of rainfall leads to flooding of burrows and chick mortality	(E) improve drainage around colony with agricultural drain
8	Increased intensity of rainfall leads to flooding of burrows and chick mortality	(S) remove chicks during extreme event and relocate
9	Increased sea level and storm surge leads to overtopping of seal breeding colony and mortality of pups – overall population decline	(E) island raising with dumping of very big rocks or concrete
10	Wind speed increases lead to nesting failure of tree nesting birds	(E) wind breaks from artificial with vegetation planting to replace in time
11	Declining ocean productivity leads to declining participation of female seals in breeding	(S) artificial feeding of females during gestation period (likely to be at the island)
12	Declining participation of female seals in breeding	(AC) temporary closures of fisheries operating in the foraging range of the species
13	Cyclone frequency increases and destruction of seagrass beds leads to starvation and death of dugongs following each cyclone	(E) relocate animals in affected areas to other locations
14	Increasing water temperatures leading to declines in dugong feeding areas (seagrass declines in some parts of the range)	(AC) Create strategic set aside areas that reduce other stressors
15	Declining productivity of seagrass beds lead to starvation and mortality in some parts (~25%) of the species range	(S) Initiate seagrass nurseries and outplanting to enhance natural production in these regions
16	A competitive bird species (e.g. silver gull or gannet) is favoured by climate change, and arrives at the colony of a threatened species and begins to take over nesting sites.	(AC) Cull competitor (lethal) firearms
17	Decreased foraging success of adults leads to chicks (n=2) fledging at lower weights and first year survival declines.	(S) reduce brood size (n=1)
18	Warmer weather leads to increased vegetation growth around burrows, leading to both a fire risk, and preventing birds from accessing the burrows.	(S) burning habitat in non-breeding season (ie birds absent)
19	Warmer weather leads to increased vegetation growth around burrows, leading to both a fire risk, and preventing birds from accessing the burrows.	(S) introduce a grazing species (rabbit)
20	Decreased foraging success of adults leads to chicks fledging at lower weights and first year survival declines.	(AC) decrease parasite loads in chicks via drenching

Number	Scenario Description	Adaptation option
21	A competitive bird species (e.g. silver gull or gannet) is favoured by climate change, and arrives at the colony of a threatened species and begins to take over nesting sites. (space competition)	(S) provide alternative habitat for competitor, e.g. floating platform for gannets
22	Declining ocean productivity lead to declining fledging success of birds	(AC) fish farming for marine species to feed on
23	Warmer weather leads to increased vegetation growth around burrows, leading to both a fire risk, and preventing birds from accessing the burrows. (e.g. kikuyu grass (binds burrows) – shearwaters, LP),	(S) Reduce public access (manage human access) to reduce fire risk
24	Warming waters and a deepening thermocline lead to reduced foraging success and loss of northern colonies of seabirds (suitable areas elsewhere),	(E) Translocate chicks to new location (site fidelity)
25	Increased intensity of rainfall events leads to direct mortality of eggs and chicks of ground nesting birds (e.g. albatross, terns, gannets).	(S) corral chicks from crèche under "shelters" (e.g. crested tern)

7.4.1.1 Cost-benefit-risk scoring (CBR)

These 25 adaptation options (**Table 13)** were scored for the 10 criteria by between 17 and 20 workshop participants. Each adaptation option attribute score was converted to a mean cost, benefit and risk score, and plotted (**Figure 16).** This scoring identifies which options are high cost and low benefit (lower left) and so might be discarded, and which are high benefit and low cost (upper right) and might be rapidly implemented (depending on risk). Options which are low cost and low benefit might not be pursued, while those that are high cost, but high benefit (upper right) deserve more detailed attention. The mean of the exposure options was slightly higher benefit and lower cost than sensitivity or adaptive capacity. In general, adaptation options to reduce exposure were lower risk (mean 1.48) than adaptive capacity (mean 1.57), while sensitivity options were considered highest risk (mean 1.65) (**Table 14)**.

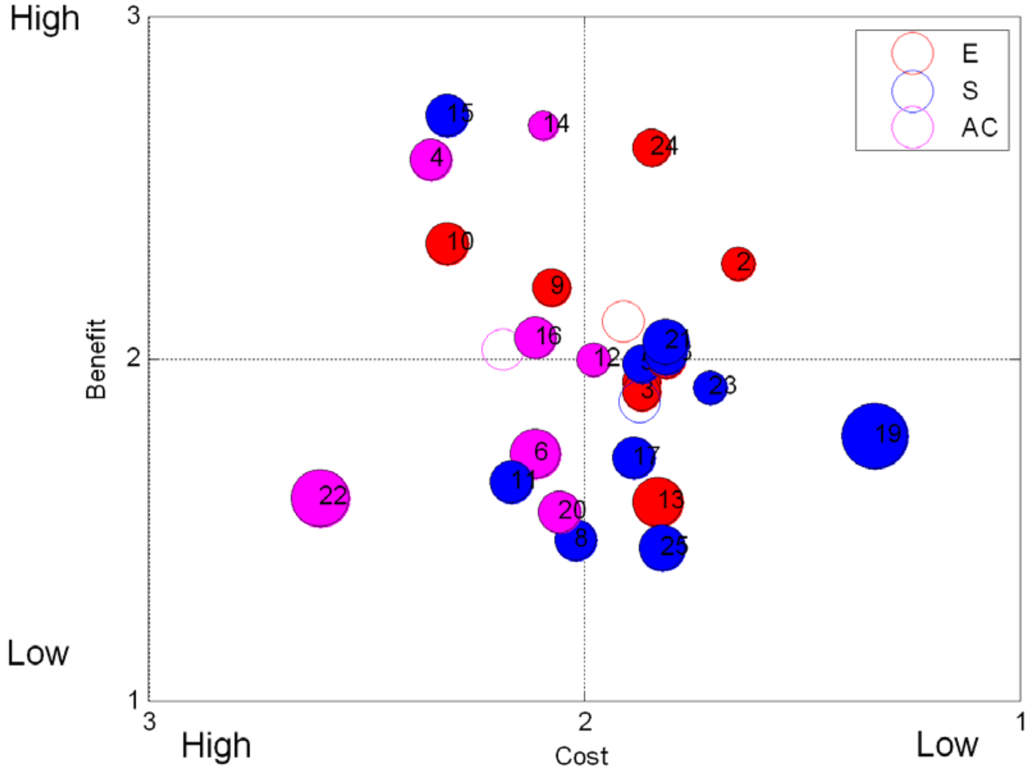


Figure 16. Summary cost-benefit-risk plot for 25 adaptation options evaluated in the project, (numbered, as in **Table 13**). Open circles represent the mean value for the exposure (E), sensitivity (S) and adaptive capacity (AC) options. The size of the bubbles represents the risk score (small represent low risk, large is higher risk).

Table 14. Results of cost-benefit-risk scoring for the 25 adaptation options evaluated in the project, ordered by category. E= exposure, S = sensitivity, AC = adaptive capacity. Average scores are the average of each participant, then averaged across all participants.

Scenario	Category	Cost average	Benefit average	Risk average
1	E	1.87	1.93	1.43
2	E	1.65	2.28	1.24
3	E	1.87	1.90	1.43
7	E	1.81	2.00	1.39
9	E	2.07	2.21	1.43
10	E	2.31	2.33	1.65
13	E	1.83	1.58	1.93
24	E	1.84	2.62	1.36
5	S	1.87	1.99	1.37
8	S	2.02	1.47	1.61
11	S	2.17	1.64	1.63
15	S	2.31	2.71	1.65
17	S	1.89	1.71	1.65
18	S	1.81	2.01	1.59
19	S	1.33	1.78	2.44

21	S	1.81	2.05	1.69
23	S	1.71	1.92	1.20
25	S	1.82	1.45	1.67
4	AC	2.35	2.58	1.50
6	AC	2.11	1.72	1.83
12	AC	1.98	2.00	1.30
14	AC	2.09	2.68	1.11
16	AC	2.11	2.04	1.61
20	AC	2.06	1.56	1.48
22	AC	2.60	1.59	2.17
Average	**Total**	**1.97**	**1.99**	**1.57**
N=8	E	1.91	2.11	1.48
N=10	S	1.88	1.87	1.65
N=7	AC	2.19	2.02	1.57

7.4.1.2 Barriers analysis

The group attending workshops 2 and 3 evaluated the same 25 scenarios with regard to barriers as was considered for CBR. In both workshops, this scoring was difficult, as the interpretation of barriers was contextual – we asked participants to score each option based on their institutional experience (i.e. would this be a barrier in my agency). The Turning Point software allowed some identification of when this discussion was needed, for example, when participants had different scores for the same barrier. Scores were between 1 (barriers considered strong) and 5 (barriers considered weak). Results show variation between scenarios (**Figure 17)**. Overall, barriers were considered to be the greatest issue for scenarios that would decrease exposure (mean score 3.29), followed by those that would decrease sensitivity (mean 2.96) and increase adaptive capacity (mean 2.82). Within each stage of the barriers analysis, the understanding phase was seen as the greatest barrier (mean 3.39) while the planning stage the least problematic (mean 2.83) (**Table 15)**. Within scenarios, there were examples where attributes associated with understanding phase was seen as the greatest barrier, while for others the planning or managing phase attributes were seen as most problematic. The specific set of attributes scores can be inspected in detail for each scenario to plan how to overcome barriers associated with a particular option, but we do not present these scores here.

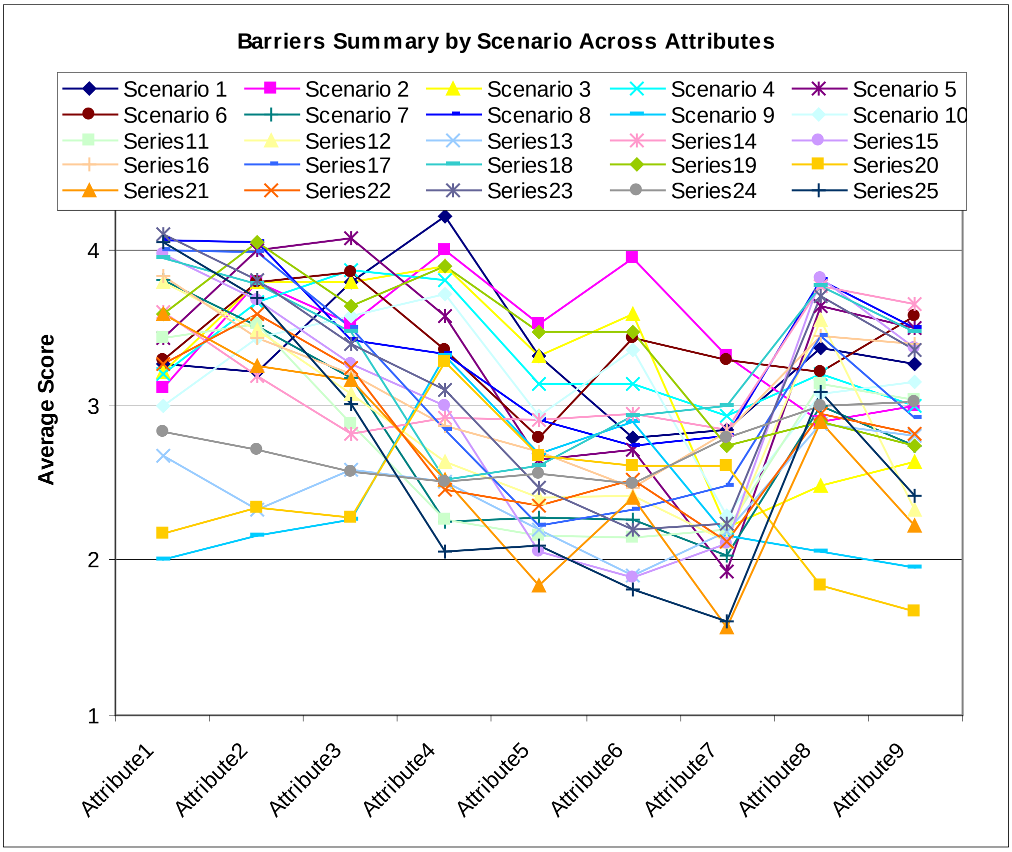


Figure 17. Summary of barriers analysis for 25 adaptation options evaluated in the project.

Table 15. Results of barriers scoring for the 25 adaptation options evaluated in the project, ordered by category. E= exposure, S = sensitivity, AC = adaptive capacity. Average scores are the average of each participant, then averaged across all participants.

Scenario	Category	Understanding average	Planning average	Managing average	Total average
1	E	3.42	3.44	3.16	3.34
2	E	3.47	3.82	3.07	3.46
3	E	3.60	3.60	2.44	3.21
7	E	3.58	3.36	3.04	3.33
9	E	3.83	2.98	3.02	3.28
10	E	3.64	3.19	3.36	3.40
13	E	3.48	2.29	2.79	2.85
24	E	3.86	3.10	3.43	3.46
5	S	2.14	2.96	2.05	2.39
8	S	3.31	3.33	2.83	3.17
11	S	3.36	2.13	2.71	2.73
15	S	3.48	2.50	2.69	2.89
17	S	2.12	2.14	2.45	2.24
18	S	3.52	3.10	3.64	3.42
19	S	3.76	2.14	2.95	2.95

21	S	3.88	2.74	3.26	3.29
23	S	3.95	2.79	3.26	3.33
25	S	3.69	2.50	3.33	3.17
4	AC	3.75	3.61	2.79	3.39
6	AC	2.26	2.85	2.04	2.38
12	AC	3.36	2.33	2.05	2.58
14	AC	3.40	2.64	2.74	2.93
16	AC	3.93	2.71	3.29	3.31
20	AC	2.38	2.69	2.86	2.64
22	AC	3.52	1.83	2.14	2.51
	Average	3.39	2.83	2.86	3.03
	SD	0.55	0.53	0.46	0.39

7.4.1.3 Evaluating social acceptability

The scoring of social acceptability showed that variation between the "social acceptability" of some of the adaptation options, ranging from very high to very low. For some scenarios, there was agreement between workshops participants "expert" opinion on the acceptability and how they judged society at large might feel (**Figure 18)** (e.g. scenario 1, 2, 9 etc). In other cases, the average acceptability as judged by the expert team was higher than they rates how general public might feel (e.g. scenario 4, 12, 14). The third possibility, higher public acceptance than expert acceptance, was also noted in a number of scenarios (e.g. scenario 3, 6, 7 etc).

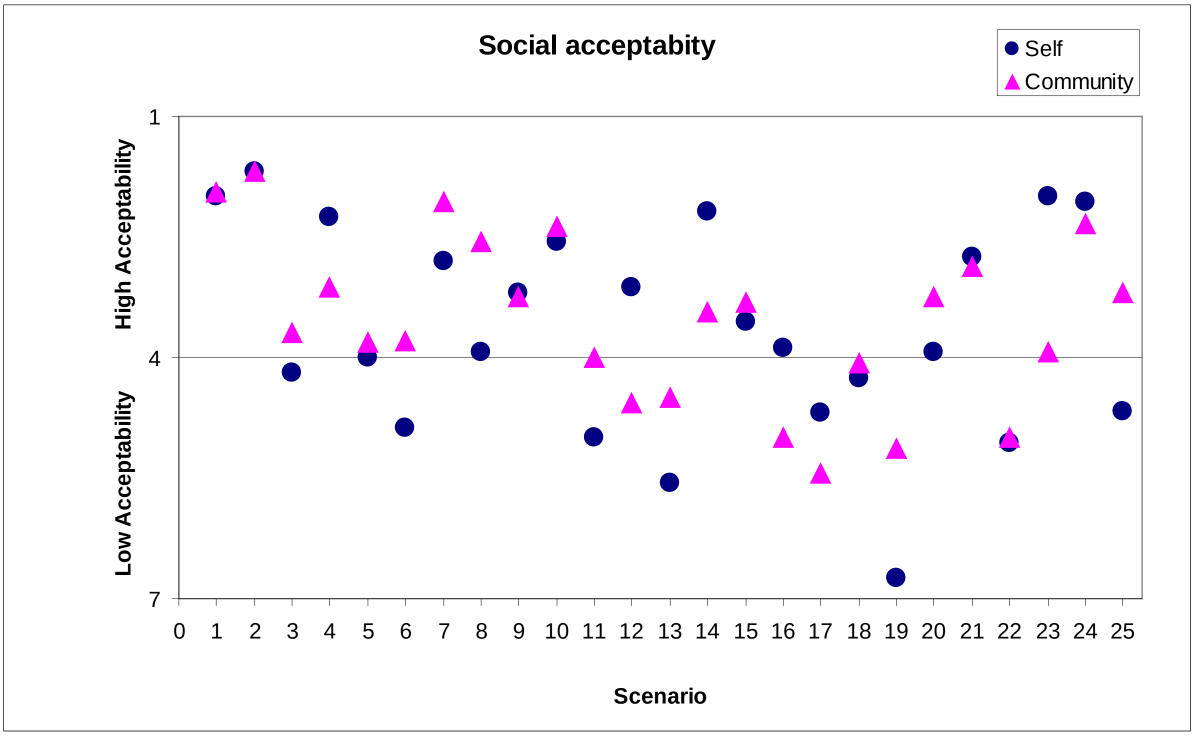
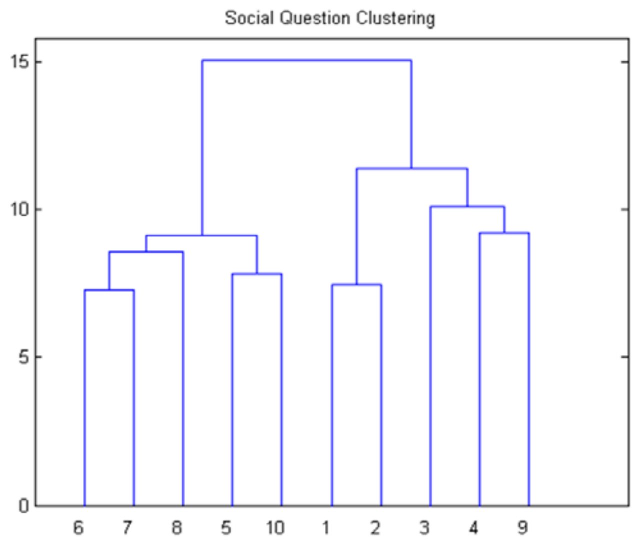


Figure 18. Summary of social acceptance scoring for 25 adaptation options evaluated in the project.

Overall, the issues that were identified as pertinent for each scenario clustered into two main groups (**Figure 19**). This result shows that “impacts” attributes were commonly nominated together, while “relationship” attributes were nominated in groups for other scenarios. The closest branches of the tree at the bottom of the figure (e.g. attributes 6 & 7, attributes 1&2) were selected together more often than say, attributes 10 and 1. The specific set of issues could be inspected in detail for each scenario to plan publicity or an education campaign around a particular option.



Perceived “impact” attributes

1. Is the species threatened or protected?
2. Is the impacted animal iconic, dangerous or cute?
3. Will other animals be killed or harmed, or habitat modified? Ethical treatment of animals
4. Contested action – is there a need for action, evidence for need, benefits clear
5. Will it impact on lifestyle, livelihood or recreation (closures, cat ownership, dogs on beaches)

Relationship attributes

6. Distrust for the proposing individual/organisation (e.g. government)
7. Are community groups already engaged with a good history of engagements?
8. Is there a powerful or divergent interest groups involved?
9. Is it “crazy” from public point of view. (will it engage radio-jocks), e.g. cost of use of public moneys (value for money)
10. Is the location for the activity in proximity to human settlement/recreation area? (e.g. wind-farm)

Figure 19. Clustering of issues identified in the social acceptance scoring for 25 adaptation scenarios.

7.4.1.4 Overall ranking

These three tools are then used to each generate a “ranking” for the evaluated set of 25 scenarios (**Table 16**), where a rank of 1 is more desirable than a rank of 25. For example, Scenario 1 was ranked 14th best for the cost-benefit-risk, 6th for the barriers, and 2nd for the social acceptability, for an overall average rank of 4th.

Table 16. Summary ranks for each of the 25 scenarios evaluated with the three evaluation tools, cost benefit and risk (CBR) barriers, and social acceptability tools, and sorted by average rank across all three tools. The highest scores for each tool are shown in green, the lowest in red, and intermediate in yellow.

Rank	Scenario	Average	CBR	Barriers	Social	Category
1	24	1.7	1	1	3	E
2	2	2.0	3	2	1	E
3	4	5.7	6	5	6	AC
4	1	7.3	14	6	2	E
4	7	7.3	10	8	4	E
4	10	7.3	13	4	5	E

7	21	8.0	7	10	7	S
7	23	8.0	8	7	9	S
9	14	8.3	2	16	7	AC
10	18	10.0	9	3	18	S
11	9	10.7	11	11	10	E
12	15	11.3	5	17	12	S
13	3	14.7	15	12	17	E
13	19	14.7	4	15	25	S
15	16	15.3	17	9	20	AC
16	8	16.0	23	14	11	S
17	25	16.3	20	13	16	S
18	5	16.7	12	23	15	S
19	12	17.0	16	21	14	AC
20	20	18.3	22	20	13	AC
21	13	19.7	19	18	22	E
22	6	21.3	21	24	19	AC
22	11	21.3	24	19	21	S
24	17	22.3	18	25	24	S
25	22	23.0	25	22	22	AC

Overall, these tools showed that for seabirds and marine mammals, adaptation options that reduced exposure had a higher average rank (8.8) than did options to reduce sensitivity (14.5) or increase adaptive capacity (15.6). Overall, the options for seabirds (average rank 10.8) rated more favourably than those for marine mammals (average rank 16.8). That said, within the range of options presented here, examples of favoured and poor choices existed within each one of the vulnerability categories and for each taxa group. Adaptation options for seabirds ranked highly by the cost-benefit tool, the barriers analysis and the social acceptability include shading burrows to reduce effects of extreme temperatures (option 1 and 2), reducing the impact of flooding of burrows during storms (option 7), habitat restoration to reduce the impacts of strong winds (option 10), and eliminating feral pests at breeding colonies (option 4). Translocating seabirds to new areas with more favourable conditions was also considered a viable strategy (option 24), and builds on existing conservation experience with this approach. At this time, however, options appear to be more limited for marine mammals. Of the 25 options we considered, the highest ranking option for marine mammals was only 9th overall. The three highest options were creating set-aside areas for dugong to reduce non-climate stressors (option 14), providing some higher elevation haul-out options for seals where storm surge is an issue (option 9), and enhancing seagrass production to provide food for dugong (option 15). We emphasise that these seabird and mammal options were not selected from an exhaustive test of adaptation options but from a selection to illustrate how to assess options in more detail.

Given the correlation (r) between each of the three measures is only moderate (as expected, as we are measuring different aspects of each scenario; **Table 17**), combining the three measures into a single score as we have above may not be useful, and we suggest that considering each of the scores will be most valuable in considering the range of issues associated with a particular adaptation strategy.

Table 17. Correlation (r) between ranks for each of the 25 scenarios evaluated with the three evaluation tools.

	CBR	*Barriers*	*Social*
CBR	1		
Barriers	0.57538	1	
Social	0.543246	0.6698	1

Overall, these three evaluation tools show how adaptation scenarios might be screened for more detailed analysis, plans to overcome institutional barriers made, or community engagement to increase awareness around the importance of apparently undesirable options. All tools can be used and results analysed with an excel workbook.

8 Benefits and adoption

The benefits of this research have already begun to flow to several groups

Researchers – among seabird and marine mammal researchers there is now greater awareness of adaptation options and new value has been identified for ongoing research and monitoring. We expect to see additional research papers that consider climate adaptation options in response to observed or projected climate impacts for marine mammals and seabirds. Some of these researchers will have been assisted by data provided by the project team, as described in previous sections, or by using some of the analytical approaches we demonstrated in the case studies.

Managers and policy makers– involvement in the project by a number of managers from state and conservation agencies has allowed sharing of existing and new information, and illustrated the range of options for generating and evaluating adaptation options for marine mammals and seabirds. The project analyses have also highlighted the value of the existing data sets and generated support for continued and coordinated monitoring of populations around Australia.

Adaptation community in other research areas

Through presentations and participation in other project meetings, we have described the novel tools we developed, and there has been interest in application to terrestrial and freshwater systems by other researchers. Following publication of these methods, we expect additional uptake nationally and internationally. Members of the project team have also reviewed and supplied expert knowledge to other NARP projects, including Marine, terrestrial, and freshwater sectors.

9 Further Development

There are a number of obvious steps that could be taken to extend and improve the work presented here, including (i) evaluating a wider set of adaptation options with the three screening tools, (ii) developing more detailed costing for a set of adaptation options, (iii) testing the three screening tools with other taxa, and (iv) evaluating social acceptance of the adaptation options with members of the general public. While we have compiled and completed desktop screening of adaptation options (v) testing some adaptation options in the field would be valuable as demonstration projects. The multi-species indices could also be continued and updated (vi). We outline each of these suggestions in the following paragraphs.

I. We have evaluated only a limited number (25) of the adaptation options generated by the project team and in workshops. It would be useful to evaluate a wider selection of options, such that the spread in the cost-benefit-risk plots might be increased, and thus more generality regarding efficient options elucidated (if it exists).

II. This project did not attempt detailed costing of any options, which will be context-specific, but several detailed case studies with costing would be very useful, and allow validation of the screening tools.

III. These methods could also be tested on other taxa in addition to seabirds and marine mammals – we anticipate they will be equally applicable.

IV. The social acceptance tool was also tested by a group of experts (scientists and managers). Evaluating more general community responses to climate change adaptation options would be useful, and again allow validation of the screening tool. This could be achieved with a wider survey or with focus groups. In a similar way, we could extend the elicitation survey across a larger group to allow more taxa comparisons and refine the conclusions about potential indicators that should be monitored to detect impacts of climate change.

V. Some of the adaptation options that were favourably rated as part of the evaluation step could be the focus of pilot trials in field studies. This would involve a manipulation that could be monitored before and after, to evaluate the success of the adaptation options with regard to reducing vulnerability to a specific or general climate change threat. Organisations or agencies that are already undertaking some of these adaptation options (and not all are specific to climate change) could share their knowledge more widely, and maintaining some records and a summary of adaptation "experiments" would be extremely valuable.

VI. The multi-species indices developed in this project could continue to be updated each year, and hosted on a website to allow general access to these indicators. These would also be of potential interest to agencies charged with reporting the state of the marine environment, or specifically on seabirds and marine mammals. This ongoing maintenance would also allow identification of likely demographic changes for similar and additional species currently without ongoing monitoring. The seabird and pinniped research community has indicated a willingness to continue to share their time series for such a purpose. Updating the indicator time series is a simple task now the method is established.

Finally, although not strictly further development, we have shown that long, continuous time series are critical to detecting impacts of climate change. Many of the time series we identified in the meta-analysis have ceased. Some of these could be reinitiated. Existing time series are not secure either. A number of researchers indicated to the project team that securing funding for ongoing monitoring was difficult, and that some time series would lapse in future, as current projects concluded. Thus, establishment of a national monitoring program, perhaps under the Integrated Marine Observing System (IMOS) - if IMOS itself is refunded - could result in long-term funding and ongoing monitoring to detect the impacts of climate change and evaluate adaptation options that will be implemented in future.

10 Planned outcomes

The main outputs of this project are the tools developed to assess adaptation options and the publications describing the project findings. Some of the publications have already been published or submitted, and the remainder are close (**Appendix 3**). We have prepared scientific papers, some of which have been submitted and considered by the lead authors responsible for the IPCC 5th assessment report.

The adaptation guidelines for managers and scientists will influence the design of ongoing monitoring of protected species in Australia, and enhance the management of current and future impacts for these species. The multi-species indices could be web-hosted and used as an ongoing indicator of marine productivity, e.g. by managers interpreting changes in other similar species that are not currently monitored. Such outputs would be useful for State of Environment reporting. If the project demonstrates that ocean conditions, such as regional productivity and climate change, can be monitored using these approaches, then securing long-term funding for monitoring marine mammals and seabirds might be prioritized, perhaps as part of ongoing IMOS initiatives. The project has also delivered information on the implications of climate change for each of the species we considered, and described a range of adaptation options for these species. These could be further developed in consultation with research partners and conservation agencies.

Knowledge building will lead to an improvement in analytical skills of mammal and seabird researchers, particularly with regard to use of the many available environmental datasets. Involvement by a wide range of researchers in the adaptation end of the research spectrum will also improve Australia's capacity to manage species in the face of climate change.

Our research partners in this project (**Appendix 2)** represented a number of state-based conservation agencies, including DPIPWE (Tasmania), DSE (Victoria), Conservation Council of WA, Department of Environment and Climate Change (NSW) and the Great Barrier Reef Marine Park Authority (GBRMPA). This close link to management should result in awareness of the project outputs and facilitate uptake where desired.

Overall, we expect to see these project approaches and recommendations used in further management and policy responses, for both marine and terrestrial species.

11 Conclusion

This project has met the six objectives. We reviewed the range of climate impacts that are already impacting on marine mammals and seabirds, and improved the connectivity between researchers and managers with respect to climate adaptation thinking, with workshops, collaborations and outreach (**Objectives 1 and 2**). In five case studies we investigated additional impacts of climate change, using a range of analytical approaches (**Objective 3**). Using expert elicitation, we surveyed experts around Australia to generate a summary of expectations for future change in biological variables that can also be used to guide monitoring approaches (**Objective 4**). We generated multi-species indices that can be used as indicators of ocean and biodiversity "health" (**Objective 5**). In consultation with researchers, managers and policy makers, a range of adaptation options were generated in response to impact scenarios (**Objective 6**). Three tools were developed to evaluate 25 of these adaptation options. These tools allow a rapid screening of (i) cost-benefit-risk, (ii) identify potential institutional barriers in implementing adaptation options, and (iii) assess likely social acceptance of these options. Together, these evaluation tools allow relative prioritization and identification of issues associated with each scenario that might need to be considered before implementation. Overall, in workshops, conference presentations (n=4), popular articles (n=3), and peer-reviewed publications (n=13) we have shown that as for other taxa in Australia, climate is projected to have an impact on marine mammals and seabirds. We show that long time series are needed to detect climate impacts, and thus emphasise the value of ongoing monitoring. Some population variables are better indicators than others, and we illustrate considerations when selecting variables for monitoring to detect impacts of climate change. Given the conservation status for these species, which include one endangered, five vulnerable, and three near-threatened species, an understanding of how these species respond to climate variability and change and determining the 'best' adaptation options is an important component in efforts to improve their population status. Policy intervention may be required to offer additional protection to species threatened under climate change, and this project has shown that the design of adaptation options can be structured and evaluated. Fortunately a wide range of options exist for reducing vulnerability of colony-nesting seabirds, however, options appear to be more limited for marine mammals. Some management responses for climate threats can be simple and follow existing conservation management approaches. We highlight that monitoring to evaluate effectiveness of adaptation option is also critical, and should be a focus in any future adaptation experiments. Testing adaptation options in limited field trials would be a useful next step, and further build the experience of researchers and managers charged with securing the status of these iconic species into the future.

12 References

Baker, G. B. & Wise, B. S. 2005 The impact of pelagic longline fishing on the flesh-footed shearwater Puffinus carnipes in Eastern Australia. *Biological Conservation* 126, 306-316.

Chambers L.E., Congdon B.C., Dunlop N., Dann P. and Devney C. (2009) Seabirds. In A Marine Climate Change Impacts and Adaptation Report Card for Australia 2009 (Eds. E.S. Poloczanska, A.J. Hobday and A.J. Richardson), NCCARF Publication 05/09, ISBN 978-1-921609-03-9.

Chambers, L. E., Devney, C. A., Congdon, B. C., Dunlop, N., Woehler, E. J. & Dann, P. 2011 Observed and predicted effects of climate on Australian seabirds. *Emu* 111, 235-253.

Carlisle, N., Priddel, D. & Madeiros, J. 2012 Establishment of a new, secure colony of Endangered Bermuda Petrel Pterodroma cahow by translocation of near-fledged nestlings. *Bird Conservation International* 22, 46-58.

Congdon B.C., C.A. Erwin, D.R Peck, G.B. Baker, M.C. Double, P. O'Neill (2007) Vulnerability of seabirds on the Great Barrier Reef to climate change In: Johnson J. & Marshall P. (eds) *Climate change and the Great Barrier Reef*. Great Barrier Reef Marine Park Authority, Canberra

Cullen, J.M., Chambers, L.E., Coutin, P.C., Dann, P. 2009. Predicting onset and success of breeding in little penguins *Eudyptula minor* from ocean temperatures. Marine Ecology Progress Series 378, 269-278.

Dann, P. and Chambers, L. E. (in review). Ecological effects of climate change on Little Penguins *Eudyptula minor* and the potential economic impact on tourism. Climate Research

Dawson, T. P., Jackson, S. T., House, J. I., Prentice, I. C. & Mace, G. M. 2011 Beyond Predictions: Biodiversity Conservation in a Changing Climate. *Science* 332, 53-58.

Devney C.A., M. Short & B.C. Congdon (2009a) Cyclonic and anthropogenic influences on terns breeding at Michaelmas Cay, Great Barrier Reef, Australia *Wildlife Research* 36: 368-378

Devney C.A., M. Short & B.C. Congdon (2009b) Sensitivity of tropical seabirds to El Niño precursors *Ecology* 90: 1175-1183

Erwin, C.A. & B.C. Congdon (2007) Day-to-day variation in sea-surface temperature reduces sooty tern (*Sterna fuscata*) foraging success on the Great Barrier Reef, Australia. *Marine Ecology Progress Series* 331: 255-266

Frusher, S. D., Hobday, A. J., Jennings, S. M., Crighton, C., D'Silva, D., Pecl, G. T., Haward, M., Holbrook, N. J., Nursey-Bray, M., Pecl, G. T. & van Putten, E. I. (2013) A short history of a marine hotspot - from anecdote to adaptation in south-east Australia. *Reviews in Fish Biology and Fisheries*, DOI 10.1007/s11160-013-9325-7.

Fuentes, M. M., Limpus, C. & Hamann, M. 2010 Vulnerability of sea turtle nesting grounds to climate change. *Global Change Biology*, doi: 10.1111/j.1365-2486.2010.02192.x.

Gibbens, J. and Arnould, J.P.Y. (2009). Interannual variation in pup production and the timing of breeding in benthic foraging Australian fur seals. *Mar. Mamm. Sci.* 25: 573-587

Gummer, H. 2003 Chick translocation as a method for establishing new surface-nesting seabird colonies: a review. In *DOC Science Internal Series150*, pp. 40. Wellington, NZ: Department of Conservation.

Hobday, A. J., T. A. Okey, E. S. Poloczanska, T. J. Kunz and A. J. Richardson (2007). Impacts of climate change on Australian marine life, CSIRO Marine and Atmospheric Research. Report to the Australian Greenhouse Office, Canberra, Australia. September 2006. http://www.greenhouse.gov.au/impacts/publications/marinelife.html.

Hobday, A. J., Smith, A. D. M., Stobutzki, I., Bulman, C., Daley, R., Dambacher, J., Deng, R., Dowdney, J., Fuller, M., Furlani, D., Griffiths, S. P., Johnson, D., Kenyon, R., Knuckey, I. A., Ling, S. D., Pitcher, R., Sainsbury, K. J., Sporcic, M., Smith, T., Walker, T., Wayte, S., Webb, H., Williams, A., Wise, B. S. & Zhou, S. 2011 Ecological Risk Assessment for the Effects of Fishing. *Fisheries Research* 108, 372–384.

IPCC. 2007 Summary for Policymakers. In: Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M.Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Jones, R.N. and L. O. Mearns, 2005:Assessing future climate risks. *Adaptation Policy Frameworks for Climate Change: Developing Strategies, Policies andMeasures*, B. Lim, E. Spanger-Siegfried, I. Burton, E. Malone and S. Huq, Eds., Cambridge University Press, Cambridge and New York, 119-143. http://www.preventionweb.net/files/7995_APF.pdf#page=124

Kirkwood, R., Hume, F. and Hindell, M. (2008). Sea temperature variations mediate annual changes in the diet of Australian fur seals in Bass Strait. *Marine Ecology-Progress Series* 369, 297-309.

Koehn, J. D., Hobday, A. J., Pratchett, M. S. & Gillanders, B. M. 2011 Climate change and Australian marine and freshwater environments, fishes and fisheries: synthesis and options for adaptation. *Marine and Freshwater Research* 62, 1148-1164.

Last, P. R., W. T. White, D. C. Gledhill, A. J. Hobday, R. Brown, G. J. Edgar and G. T. Pecl (2010). Long-term shifts in abundance and distribution of a temperate fish fauna: a response to climate change and fishing practices. Global Ecology and Biogeography: DOI: 10.1111/j.1466-8238.2010.00575.x.

Ling, S. D., C. R. Johnson, K. Ridgway, A. J. Hobday and M. Haddon (2009). Climate driven range extension of a sea urchin: inferring future trends by analysis of recent population dynamics. Global Change Biology 15(3): 719 - 731.

Lough, J. M. & Hobday, A. J. 2011 Observed climate change in Australian marine and freshwater environments. *Marine and Freshwater Research* 62, 984-999.

Louzao, M., Hyrenbach, K. D., Arcos, J. M., Abello , P., Gil De Sola, L. & Oro, D. 2006 Oceanographic Habitat Of An Endangered Mediterranean Procellariiform: Implications For Marine Protected Areas. *Ecological Applications* 16, 1683-1695.

Mapstone, B. D., Appleford, P., Broderick, K., Connolly, R., Higgins, J., Hobday, A., Hughes, T. P., Marshall, P. A., McDonald, J. & Waschka, M. 2010 National Climate Change Adaptation Research Plan for Marine Biodiversity and Resources, National Climate Change Adaptation Research Facility, Gold Coast, 68pp.

Mawdsley, J. R., O'Malley, R. & Ojima, D. S. 2009 A Review of Climate-Change Adaptation Strategies for Wildlife Management and Biodiversity Conservation. *Conservation Biology* 23, 1080-1089.

McLeod, D. J., Hallegraeff, G. M., Hosie, G. W. & Richardson, A. J. 2012a Climate-driven range expansion of the red-tide dinoflagellate Noctiluca scintillans into the Southern Ocean. *Journal of Plankton Research* 34, 332–337.

McLeod, D. J., Hobday, A. J., Lyle, J. M. & Welsford, D. C. 2012b A prey-related shift in abundance of small pelagic fish in eastern Tasmania? *ICES Journal of Marine Science*, doi: 10.1093/icesjms/fss069.

Moser, S. C. & Ekstrom, J. 2010 A framework to diagnose barriers to climate change adaptation. *Proceedings of the National Academy of Sciences* 107, 22026-22031.

Peck D.R., B.V. Smithers, A.K. Krockenberger, & B.C. Congdon (2004). Sea-surface temperature constrains wedge-tailed shearwater foraging success within breeding seasons *Marine Ecology Progress Series* 281: 259-266

Pitt, N. R., Poloczanska, E. S. & Hobday, A. J. 2010 Climate-driven range changes in Tasmanian intertidal fauna. *Marine and Freshwater Research* 61, 963–970.

Priddel, D., Carlisle, N. & Wheeler, R. 2006 Establishment of a new breeding colony of Gould's petrel (Pterodroma leucoptera leucoptera) through the creation of artificial nesting habitat and the translocation of nestlings. *Biological Conservation* 128, 553-563.

Ropert-Coudert, Y., Cannell, B. & Kato, A. 2004 Temperature inside nest boxes of little penguins. *Wildlife Society Bulletin* 32, 177-182.

Schumann, N. et al. (2012) Marine Mammals. In Marine Climate Change Impacts and Adaptation Report Card for Australia 2012 (Eds. E.S. Poloczanska, A.J. Hobday and A.J. Richardson) http://www.oceanclimatechange.org.au

Schumann, N., Gales, N. J., Harcourt, R. G. & Arnould, J. P. Y. 2013 Impacts of climate change on Australian marine mammals. *Australian Journal of Zoology*, http://dx.doi.org/10.1071/ZO12131.

Smithers, B.V., D.R. Peck, A.K. Krockenberger & B.C. Congdon (2003). Elevated sea-surface temperature reduced provisioning and reproductive failure of wedge-tailed shearwaters (*Puffinus pacificus*) in the Southern Great Barrier Reef. *Marine and Freshwater Research* 55: 973-977

Thompson, P. A., M. E. Baird, T. Ingleton and M. A. Doblin (2009). Long-term changes in temperate Australian coastal waters: implications for phytoplankton. Marine Ecology Progress Series 394: 1-19.

13 Appendix 1: Intellectual property

Primary time series used in this project remain the property of the data custodians responsible for their collection or maintenance prior to this project. These data were made available to the project under single use agreement conditions, as in this report.

14 Appendix 2: Staff engaged on the project

Principal investigators

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Project Partners and Workshop participants

Workshop Participants	Organisation	Science/management/policy expertise	Biological expertise: Seabirds, Mammals, Both, General	Workshop 1	Workshop 2	Workshop 3
Barry Baker	Latitute 42 Environmental Consultants	S/M/P	S	Yes	Yes	Yes
Peter Dann	Phillip Island Nature Parks	S/M/P	B	Yes	Yes	Yes
Simon Goldsworthy	SARDI	S	M	Yes	No	Yes
Belinda Cannell	Murdoch University	S	S	Yes	No	Yes

Mariana Fuentes	JCU	S	M	Yes	No	No
Roger Kirkwood	Phillip Island Nature Parks	S	M	Yes	No	No
Helene Marsh	JCU	S	M	Yes	No	No
Marcus Salton	Phillip Island Nature Parks	S	S	Yes	No	No
Cath Meathrel	LaTrobe University	S	S	Yes	No	No
Rob Harcourt	Macquarie University	S	M	Yes	No	No
Andre Chiaradia	Phillip Island Nature Parks	S	S	Yes	No	No
Bruce Robertson	LaTrobe University	S	S	Yes	No	No
Mark Hindell	University of Tasmania	S	B	Yes	No	No
Brad Congdon	JCU	S	S	Yes	No	No
Carol Devney	AIMS	S	S	Yes	No	No
Eric Woehler	University of Tasmania	S/P	S	Yes	No	No
Ian Mansergh	DSE - Victoria	M/P	B	No	Yes	Yes
Louise Gilfedder	DPIPWE - Tasmania	P	G	No	Yes	Yes
Rosemary Gales	DPIPWE - Tasmania	S/M	B	No	Yes	Yes
Graham Hemson	DERM - Queensland	S/M/P	S	No	Yes	Yes
David Priddell	DPAC -NSW	S/M/P	S	No	Yes	Yes
Andrew McDougall	DERM - Queensland	M	B	No	Yes	No
Tamara van Polnen Petel	DERM - Queensland	M	M	No	Yes	No
Malcom Turner	GBRMPA/QPWS	M	S	No	Yes	No
Steffan Howe	Parks Vic	M	B	No	Yes	No
Jo Klemke	DSE - Victoria	M/P	G	No	Yes	No
Patricia von Baumgarten	DEH - SA	M/P	B	No	Yes	No
Kelly Waples	DEC - WA	M/P	B	No	Yes	No
Ashley Bunce	DERM - Queensland	M/P	S	No	Yes	No
Gina Newton	SeWPac	P	G	No	Yes	No
Chris Marshall	SeWPac	P	G	No	Yes	No
Jennie Whinam	DPIPWE - Tasmania	P	G	No	No	Yes
Denise Hardesty	CSIRO	S	S	No	No	Yes
Chris Surman	HalfMoon Consulting, WA	S	S	No	No	Yes
	Total			16	17	12

Project partners - not able to attend a workshop, but contributing time series data or completing elicitation survey						
Nic Dunlop	CCWA – WA	S/P	S	No	No	No
Rachael Alderman	DPIPWE – Tasmania	S	S	No	No	No
Zoe Hogg	Earthcare St Kilda Inc. – Vic	S/M	S	No	No	No
Kim Williams	DEC - WA	S/M	S	No	No	No

Spencer Unthank	Penguin Study Group – Vic	S	S	No	No	No
Mary-Ellen Talmage	Penguin Study Group – Vic	S	S	No	No	No
Linda Moon	Penguin Study Group – Vic	S	S	No	No	No
Barbara Sharp	Penguin Study Group – Vic	S	S	No	No	No
Austin McLaughlin	Penguin Study Group – Vic	S	S	No	No	No
Billie Ganendran	UNSW at the Australian Defence Force Academy (ACT)	S	S	No	No	No
Ted Catchpole	UNSW at the Australian Defence Force Academy (ACT)	S	S	No	No	No
Leesa Sidhu	UNSW at the Australian Defence Force Academy (ACT)	S	S	No	No	No
Ray Chatto	Parks and Wildlife Service - NT	S	S	No	No	No

15 Appendix 3: Papers, presentations, and popular articles

The project publication output includes 13 published, submitted or planned peer-reviewed papers, three popular articles, a fact sheet, and four conference presentations.

15.1Peer-reviewed papers

15.1.1 PUBLISHED

1. Seabirds: Marine Report Card. Chambers L.E. et al. (2012) Seabirds. In Marine Climate Change Impacts and Adaptation Report Card for Australia 2012 (Eds. E.S. Poloczanska, A.J. Hobday and A.J. Richardson). Available at www.oceanclimatechange.org.au. ISBN: 978-0-643-10928-5
2. Marine Mammals: Marine Report Card. Schumann, N. Gales, N. J., Harcourt, R. G. & Arnould, J. P. Y. (2012) Marine Mammals. In Marine Climate Change Impacts and Adaptation Report Card for Australia 2012 (Eds. E.S. Poloczanska, A.J. Hobday and A.J. Richardson). Available at www.oceanclimatechange.org.au. ISBN: 978-0-643-10928-5
3. Cannell, B., Chambers, L. E., Wooller, R. D. & Bradley, J. S. (2012) Poorer breeding by little penguins near Perth, Western Australia is correlated with above average sea surface temperatures and a stronger Leeuwin Current. *Marine and Freshwater Research*, 63: 914-925. http://dx.doi.org/10.1071/MF12139. (**Paper 2d)**
4. Schumann, N., Gales, N. J., Harcourt, R. G. & Arnould, J. P. Y. (2013) Impacts of climate change on Australian marine mammals. *Australian Journal of Zoology*. http://dx.doi.org/10.1071/ZO12131 (**Paper 1b)**
5. Knox, T., Stuart-Williams, H., Warneke, R. M., Hoskins, A. J. & Arnould, J. P. Y. (2013) Analysis of growth and stable isotopes in teeth of male Australian fur seals reveals inter-annual variability in prey resources. *Marine Mammal Science*, DOI: 10.1111/mms.12078. (**Paper 2e)**

15.1.2 SUBMITTED

6. Chambers, L. E., Patterson, T. A., Hobday, A. J., Arnould, J. P. Y., Tuck, G. N., Wilcox, C. & Dann, P. in review Analysis methods for long-term marine predator data: determining trends and environmental drivers. *Global Environmental Change*. Submitted April 26, 2013 (**Paper 1a)**
7. Woehler, E. J., Patterson, T. A. & Hobday, A. J. in review Climate or competition? Environmental variability and abundance trends in Tasmanian native and invasive gull species. Marine Ecology Progress Series (**Paper 2a).** Submitted May 2013
8. Wilcox, C., Hobday, A. J. & Chambers, L. E. in review Using elicitation to rank monitoring targets for climate impacts on Australian seabirds and pinnipeds. *Global Change Biology*. (**Paper 3).** Submitted October 2, 2013

9. Hobday, A. J., Chambers, L. E. & Arnould, J. P. Y. in review Methods to prioritise adaptation options for iconic seabirds and marine mammals impacted by climate change. In *NCCARF Adaptation* (ed. J. Palutikof, J. Barnett, S. L. Boulter & D. Rissik). (**Paper 6**). Submitted October 22, 2013

15.1.3 IN PREPARATION

10. Patterson, T. A., Chambers, L. E., Hobday, A. J. & Priddel, D. in preparation Examining trends in demographic time series with respect to climate for shearwaters on Montague Island. (**Paper 2b)**

11. Thomson, R., Alderman, R., Tuck, G. & Hobday, A. J. in preparation Effects of climate change and fisheries bycatch on shy albatross (*Thalassarche cauta*). (**Paper 2c)**

12. Hobday, A. J., Patterson, T. A., Chambers, L. E., Arnould, J. P. Y., Litzow, M. A. & et al. in preparation Multi-species marine mammal and seabird indices for Australia. (**Paper 4**)

13. Hobday, A. J. Chambers, L. E., Arnould, J. P. Y., Patterson, T. A. in preparation. An evaluation of adaptation options for seabirds and marine mammals impacted by climate change (**Paper 5)**

15.2 Popular articles

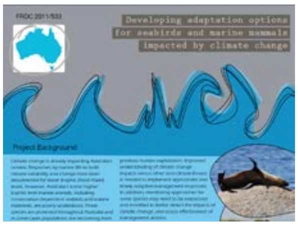
A total of three popular articles and one project fact sheet were completed.

14. **Marine Adaptation Bulletin** – MAB_v3_i1_Winter2011 - available at - http://arnmbr.org/content/index.php/site/resources_extended/category/bulletin

15. **Australasian Seabird Bulletin –** Autumn issue, May 2011, volume 53.

16. **Radio Marinara Interview** - John Arnould was interviewed on Radio Marinara hosted by radio station RRR (Melbourne) on 23 October, 2011. A podcast of the interview can be provided on request and is held by the project team.

17. **Project fact sheet** (produced as part of Jenny Shaw-led NARP project).



15.3 Conference presentations

A total of 4 conference presentations have been completed.

18. Ecological Society of Australia conference. Hobart, Dec 3-5 2011.
    - Hobday, A.J., Chambers, L., Arnould, J., Patterson, T., Tuck, G., Wilcox, C. 2011. Adaptation options for seabirds and marine mammals impacted by climate change.
19. NCCARF Adaptation in Action Conference. Melbourne June 26-29, 2012.
    - Chambers, L., Hobday, A.J., Arnould, J., Patterson, T., Tuck, G., Wilcox, C. 2012. Seabird and marine mammal management options in the face of climate change
20. Australian Marine Scientists Association. Hobart, July 1-5, 2012.
    - Hobday, A.J., Chambers, L., Arnould, J., Patterson, T., Tuck, G., Wilcox, C. 2012. Seabird and marine mammal management options in the face of climate change
21. NCCARF Adaptation Conference. Sydney June, 2013.
    - Hobday, A.J., Chambers, L., Arnould, J., Patterson, T. Prioritization tools for evaluating adaptation options for seabirds and marine mammals

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FOR FURTHER INFORMATION

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