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Using expert elicitation to rank ecological indicators for detecting climate impacts on Australian seabirds and pinnipeds

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ABSTRACT

Designing monitoring programs to detect impending climate change effects on marine vertebrates is challenging, as data sufficient for large-scale power analysis is severely limited, yet sensitivity and response time of potential indicator variables are key uncertainties. In the absence of such data, the experience of researchers can be used to inform decision making on monitoring design to detect impacts of climate change. We used expert elicitation to identify ecological traits of seabirds and marine mammals that have or were expected to respond to climate change. We analyzed the projected biological changes for five general categories of ecological traits that have been shown elsewhere to relate to climate signals: foraging and diet, body mass, breeding phenology, breeding success, and population size. Based on analysis of 106 traits in the five categories, 29 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. Body mass related traits were projected to change almost as frequently, but with much lower variance. The timespan over which experts expected to see change also varied between trait categories. 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 106 traits. When combined with cost estimates, our results allow managers to choose ecological indicators that deliver information on system response in the most cost-effective manner.

1. Introduction

Seabirds and marine mammal populations have long been regarded as ecosystem indicators via changes observed in a number of demographic variables (Boyd and Murray, 2001; Reid et al., 2005; Parsons et al., 2008; Sydeman et al., 2012, 2015), with monitoring variously designed to detect the impacts of fishing, pollution and introduced predators (Furness and Camphuysen, 1997; Zacharias and Roff, 2001; Durant et al., 2009; Einoder, 2009). Dramatic perturbations are now occurring as a result of climate change, modifying marine environments and ecosystems (Doney et al., 2012; Poloczanska et al., 2013). Seabirds and marine mammals have already responded to climate change in a variety of ways in many regions of the world (Sydeman et al., 2012, 2015; Chambers et al., 2014). Analysis of long-term data has revealed changes in abundance (Thompson et al., 2012; Woehler et al., 2014), distribution (Weimerskirch et al., 2012), foraging (Mills et al., 2008), breeding phenology (Gibbens and Arnould, 2009; Chambers et al., 2011; Hindell et al., 2012; Chambers et al., 2013), and breeding success (Cannell et al., 2012) attributable to both long-term change and to climate-related extremes.

However, multi-decadal time series are often required to detect responses to climate change (Henson et al., 2010; Edwards et al., 2010; Hobday and Evans, 2013; Chambers et al., 2014). Climate signals are also evident to varying degrees in different aspects of a species' biology. For example, in a study of Antarctic seabirds and mammals, variability in indices differed between body mass variables (CVs < 10%) and breeding success (CVs > 50%) (Reid et al., 2005). Impacts are also expected to range from beneficial to detrimental across species (Van der Wal et al., 2013).

The ecological traits that are most informative may not be easy to measure or incorporated into existing long-term programs. For example, measurement of pup or chick survival at breeding colonies is more common than time series of juvenile survival in the period immediately after leaving the colony (Alderman et al., 2010; Chambers et al., 2014). However, while easy to measure, these variables may be relatively insensitive due to buffering by parents (Kitaysky et al., 2010; Furness and Tasker, 2000). This type of selection of existing monitoring variables due to historical precedence is a major issue in environmental

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monitoring in general, particularly in natural resource management (Nichols and Williams, 2006; Niemeijer and de Groot, 2008). Instead, monitoring systems should be designed based on a framework which targets detection of responses to climate change specifically (e.g. Newson et al., 2009; Constable et al., 2016).

Responsiveness and sensitivity have been identified as two key criteria in selecting ecological indicators for climate change impacts (Newson et al., 2009; Constable et al., 2016). However, information on responsiveness and sensitivity is much more difficult to obtain for proposed indicators than for other criteria such as policy relevance or data continuity, and there have been calls for systematic estimates (Einoder, 2009). Structured use of expert knowledge can fill this key information gap on potential ecological indicators. Conservation science has seen a growth in the use of expert knowledge to characterize complex systems where resources are limited and decision-making is urgent (Pascoe et al., 2009; Donlan et al., 2010; Kuhnert et al., 2010; Martin et al., 2012). Expert knowledge can be scrutinized to measure patterns, ensuring that uncertainty is quantified and bias is minimized (Kriegler et al., 2009; Donlan et al., 2010; Martin et al., 2012), providing significant predictive power.

We identify promising monitoring variables for detecting climate impacts using formal elicitation of expert opinion. We elicited a set of judgements from experts regarding observed and expected impacts of climate change for Australian marine birds and mammals. We evaluated the reliability of these judgements, examining variability across species and between experts. We use the data to predict the expected sensitivity to climate change and the expected response time for each of the 106 traits scored by the experts across a range of species. Based on our results we rank the potential monitoring variables, identifying those that are expected to be most sensitive and to respond quickest to climate change impacts. This ranking can also inform selection of variables to be monitored in future research.

2. Materials and methods

2.1. Survey

We designed a survey to elicit from experts observed and potential responses to climate change by seabirds and marine mammals (pinnipeds) using a scheme for ecological traits that follows the general categories of Reid et al. (2005), and draws on recent literature reviews (Chambers et al., 2011; Schumann et al., 2013). The questionnaire separated the traits into five broad categories, including breeding chronology, foraging and diet, body mass, population size, and breeding success. In each category we specified a wide range of possible traits that could be affected by climate change in discussion with an independent set of experts and review of the literature. In each case we structured the description of the trait in terms of a quantity that could be measured in the field. Subsequently, we refined these questions based on testing with a preliminary group of experts. We eliminated any traits that were composites of other variables. The five response categories ultimately contained 106 possible traits that could be affected by climate change and could be measured in the field (Appendix A).

As part of the survey, each expert was provided with a short background description of the expected changes in climate and the physical aspects of the marine environment in four marine regions (described as northwest, northeast, southeast, and southwest) offshore of the Australian continent (Table S1 in Supporting Information) to ensure each expert had a minimum level of common information on the expected environmental changes in their geographic region of expertise. We intentionally did not provide any estimates of effects on species, as our goal was for the experts to evaluate these based on changes in the environment.

For each ecological trait we asked experts three questions. First, given a brief description of how the climate is expected to change in the future in their region and their knowledge of the species for which they are responding, would they expect climate change to increase, decrease, or result in no change in the trait. Second, if a change were expected to occur, how long would it take between the change occurring and it becoming detectable in measurements of the trait. Time spans were divided into four categories: < 1 year, 1–5 years, 5–10 years, and > 10 years. Finally, for traits that the experts had formally measured or for which they had anecdotal evidence, we asked them if, or in what direction, the species trait had been observed to change, although we did not ask them to attribute this solely to climate change. We allowed five options for the expert's response to this third question: (i) was there an increase, (ii) decrease or (iii) no change in the variable, (iv) no data, or (v) the trait was unmeasurable.

The final survey was distributed to a group of experts participating in a project on climate change impacts on Australian seabirds and marine mammals, who were identified as part of a national search for researchers working on long term population dynamics of marine species in Australia (Hobday et al., 2014). Experts nominated the species for which they would complete the survey. An expert could complete a survey for more than one species, and these were treated as independent. Surveys were distributed both in person at a preliminary project workshop, with follow-up via email, and via direct email contact with other known seabird and marine mammal researchers, identified by referral from colleagues or other experts. A final meeting was held, with follow-up to ensure completion of surveys and clarification of any ambiguities. Surveys were conducted under CSIRO ethics permit 002/12, and informed consent was obtained from each survey participant.

The survey used multiple-choice responses for each question to ensure structured and comparable responses. For the first and third questions, responses were coded into ordinal categories of -1 for decrease, 0 for no change, and $+1$ for increase. Additional categories of no data or not measureable were used to exclude questions from the analysis. For the second question, related to time-to-detect-effect, we coded data as described in the following section.

2.2. Analysis

All analysis was conducted in the R statistical language (R Core Team 2012, http://www.R-project.org/). We estimated the responsiveness of the ecological traits to climate change by calculating the proportion of responses for which a given trait was expected to change, out of the total number of responses (i.e. species and experts) for which that trait was scored.

In order to measure consistency across experts we considered scores for each ecological trait, comparing scores across experts responding for the same species. For each ecological trait we calculated the variance in the expert scores. We then calculated the mean of these variances across the 106 traits, excluding missing values where experts did not provide responses. Since scores only range from -1 to $+1$ on our ordinal scale, the largest possible difference between observations is 2. On such bounded scales the variance of the sample of responses is affected by the number of possible responses, thus we calculated the probability distribution of the possible variances for each of the species given the number of experts using simulation. We report the proportion of possible variances smaller than the observed mean of the variances.

We analyzed which ecological traits would be most valuable to measure as indicators for climate change effects by considering both the reported time for a trait to change and the proportion of traits that were expected to change. Time values were treated as intervals, and analyzed using formal interval statistics (Ferson et al., 2007). We coded traits that were not expected to change as having times of $[\infty,\infty]$, yielding interval measures of time in years [0,1), [1,5), [5,10), $[10,\infty]$ and $[\infty,\infty]$, with square brackets indicating an inclusive set boundary, and round brackets a noninclusive boundary. We calculated the median predicted time to a response, and the quantiles of the predicted time