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ORIGINAL PAPER

Prioritizing climate change adaptation options for iconic marine species

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Abstract Adaptation options in response to climate impact scenarios for marine mammals and seabirds were developed based on the IPCC vulnerability framework. Under this framework, vulnerability to the physical effects of climate change can be reduced by adaptation options that reduce exposure of individuals, reduce the sensitivity of individuals, and increase the adaptive capacity of individual/species to cope with climate change. We evaluated options in each vulnerability category with three screening tools collectively forming an approach we term sequential adaptation prioritization for species. These tools were designed to evaluate (i) technical aspects (cost-benefit-risk, CBR), (ii) institutional barriers, and (iii) potential social acceptability. The CBR tool identified which adaptation options were high cost and low benefit, might be discarded, and which were high benefit and low cost, might be rapidly implemented (depending on risk). Low cost and low benefit options might not be pursued, while those that are high cost, but high benefit deserve further attention. Even with technical merit, adaptation options can fail because of institutional problems with implementation. The second evaluation tool, based on the conceptual framework on barriers to effective climate adaptation, identifies where barriers may exist, and leads to strategies for overcoming them. Finally, adaptation options may not be acceptable to society at large, or resisted by vocal opponents or groups. The social acceptability tool identifies potentially contested options, which may be useful to managers charged with implementing adaptation options. Social acceptability, as scored by experts, differed from acceptability scored by the public, indicating the need to involve the public in assessing this aspect. Scores from each tool for each scenario can be combined to rank

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the suite of adaptation options. This approach provides useful tools to assist conservation managers in selecting from a wide range of adaptation strategies; the methodology is also applicable to other conservation sectors.

Keywords Climate change · Marine mammals · Seabirds · Conservation · Social license · Prioritization

Introduction

Impacts of climate change are now widely reported for many taxa and regions (Chen et al. 2011; Poloczanska et al. 2013; Chambers et al. 2013; IPCC 2014). Given the pace of change and projected novel environments (Williams et al. 2007) many conservation scientists and practitioners posit that new conservation objectives are needed (Dunlop and Brown 2008; Hagerman et al. 2010; Stein et al. 2013). There is now widespread acceptance that objectives focusing on preserving ecosystem processes rather than structure (species composition) should be added to conventional species- and place-based conservation objectives (Hagerman et al. 2010; Stein et al. 2013). Many practitioners, however, including major conservation organizations, are unwilling to relinquish species preservation objectives, particularly as anthropogenic climate change is a result of human activities, and concomitant species declines are morally no different to declines caused by historical habitat destruction, over-harvesting, and pollution (Hagerman and Satterfield 2014). Even if new objectives are established, some species will remain focal conservation targets, due to societal preference (e.g. pandas, tigers), legal mandates (e.g. endangered species legislation), or because of their role as ecosystem engineers (e.g. wolves, beavers).

Thus, development of adaptation options for individual species threatened by climate change remains important, even as conservation objectives broaden (Mawdsley 2011; Dunlop and Brown 2008). Adaptation can be autonomous, whereby species respond to climate change without human intervention, such as by changing migration routes, moving to new regions, or modifying vital rates in situ. In such cases, the best approach for conservation managers may be to reduce other stressors that reduce survival. In other cases, particularly where barriers to autonomous adaptation exist, direct options, such as translocation, may be considered (Hoegh-Guldberg et al. 2008). These directed adaptation approaches, where humans are active in the process of change, are the focus of this paper.

Directed adaptation strategies may be needed for species, particularly in areas where rates of autonomous adaptation are insufficient to cope with ongoing environmental change (Mawdsley 2011). Some proposed adaptation options will be novel (Bowman 2012), while other efforts will continue long standing conservation practice, such as habitat restoration, translocation, pest removal, or captive breeding programs (Dawson et al. 2011; Koehn et al. 2011). Just as for conservation intervention in general, there are a range of techniques for generating climate adaptation options, including ad-hoc and structured methods. Ad hoc approaches can be successful, and are often implemented based on the expertise of the management personnel responsible (e.g. Mawdsley et al. 2009; Dawson et al. 2011; Koehn et al. 2011). Several interventions, also applicable under climate change, have been implemented for seabirds in Australasia (Chambers et al. 2014), including placing powerlines underground to reduce bushfire risk to a little penguin colony (Chambers et al. 2011), species management through translocation (e.g. Priddel et al. 2006), threat/stressor reduction via pest species eradication (Donlan and Wilcox 2008) and reduction of bycatch (e.g. Reid et al. 2012). These examples demonstrate that human interventions are possible and successful, and counter fears that scientists cannot intervene in ecosystems without undesirable and unexpected outcomes (IUCN 2001).

Given the climate-related changes that are anticipated in the future will move systems to new states (Williams et al. 2007), the historical experience of conservation practitioners may become less valuable, and so more structured frameworks may be suitable, particularly in novel situations. These structured approaches can be generally classified as model-based, scenario-based, or typology-based, although the classification is not mutually exclusive. Model-based approaches can be quantitative or qualitative. Some adaptation options may result from detailed quantitative demographic analysis of species-specific threats, which can provide specific or general guidance on timing to implement appropriate adaptation efforts to reverse, for example, declining reproduction, or loss of critical habitat (e.g. McDonald-Madden et al. 2011). Qualitative or conceptual models can be used to guide a reproducible approach from a group of experts. Scenario-based approaches can provide insight into the nature of a climate risk for a particular species or habitat. For example, climate change has the potential to reduce average recurrence intervals of 1-in-100 year storm tide levels along the northern Bass Strait coast to between 1 and 2 years by 2070 (McInnes et al. 2009), which may remove breeding habitat for a range of species. Typological frameworks emerge from an analysis of existing approaches, for example, Mawdsley et al. (2009) assigned adaptation strategies from scientific literature and public policy documents into four broad categories: land and water (habitat) protection and management; direct species management; monitoring and planning; and law and policy. These typological approaches can inform a checklist which can be used to guide development of specific species adaptation options within each category (Mawdsley et al. 2009).

Not all proposed adaptation options can be implemented, due to technological or scientific barriers, institutional barriers, or a lack of social acceptability. Technical barriers can exist due to logistical difficulties, lack of technology, or to prohibitive costs associated with an option. Institutional barriers can arise where there is no clear mandate for intervention, or where clear process and responsibility is absent. The last potential barrier, social acceptability is seldom considered ahead of implementing a particular adaptation option. Social acceptance for adaption options is related to “social license to operate”, developed as a response to a United Nations initiative that required industries operating in the territories of indigenous people to secure free, prior and informed consent from those people (United Nations 2014). Social license has been widely applied to the mining industry and recently to the business environment (Thomson and Boutilier 2011). 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 license also impact on wildlife management and exploitation (Ng et al. 2014)—noteworthy examples in Australia include social conflicts around the culling of kangaroos (Lunney 2010), culling or sterilization of koalas (Ross and Pollett 2007), culling or relocation of flying foxes (Roberts et al. 2011), beach closures for recreational users during shorebird breeding seasons (Dodge et al. 2003), pest and cat removal programs (Wilkinson and Priddel 2011), and plans to use a “supertrawler” to fish for small pelagic fishes (Tracey et al. 2013). Without adequate consideration of social acceptability, some species adaptation options may be initiated but remain unsuccessful (Ng et al. 2014).

Here, we illustrate a linked set of methods that can be used to develop and prioritize adaptation options for a wide range of species. Adaptation options are first generated based on the widely used IPCC vulnerability model (exposure-sensitivity-adaptive capacity), and then assessed for technological barriers, institutional barriers, and social acceptability, to generate an overall priority. These tools reflect implicit conservation objectives: to optimise cost-benefit-risk ratios, optimise options that are practical for implementation, and maximise the social license associated with the selected options. We demonstrate these approaches using the iconic large marine animals of coastal Australia—a group already impacted by climate change and variability (Fuentes et al. 2010; Chambers et al. 2011; Schumann et al. 2013). Given the imperiled status of many of these species (Fuentes et al. 2010; Croxall et al. 2012; Lascelles et al. 2014) and the expected increase in novel situations and habitats, providing additional options for population management may reduce the risk associated with a historical preserve and protect approach. These methods can be applied to a wide range of species and habitats, and the co-generation approach to these options strengthens institutional acceptance.

Methods

We describe (i) the development of a four stage assessment of adaptation options to reduce the impact of climate change, termed the sequential adaptation prioritization for species (SAPS), (ii) demonstrate the SAPS system using climate impact scenarios for a range of marine mammals and seabirds, and finally (iii) the expert groups that developed options and evaluated them using SAPS.

Generating and evaluating adaption options

Our four stage sequential process to develop and prioritize adaptation options for seabirds and marine mammals (Table 1) is based around semi-quantitative scoring by specialist groups of stakeholders. Semi-quantitative methods as a form of risk-based assessment have been widely used to quickly screen and assess impacts in a range of fields, including fisheries management (Hobday et al. 2011), conservation prioritisation (Donlan et al. 2010; Small et al. 2012) and climate change (Chin et al. 2010; Foden et al. 2013). An advantage of these approaches is relatively rapid scoring, allowing screening of a large number of risks or options (Hobday et al. 2011). The involvement of appropriate stakeholders in such processes is critical, as elements of scoring rely on expert knowledge (Burgman 2005; Martin et al. 2012; Foden et al. 2013). In SAPS, species experts are important in the first and second stages, policy and management and policy practitioners in the second and third stages, and representative members of the general public in the final stage. While each stage could be used independently, sequential consideration of each stage is likely to yield more useful results with regard to successfully implementing an adaptation option.

Table 1 Stages in the prioritization of adaptation options in the SAPS

Stage	Responsible group	Assessment tool	Illustration
1. Generate options	System or species experts	Vulnerability framework	Figure 1
2. Technical assessment	System or species experts	Cost-benefit-risk	Figure 2
3. Institutional assessment	Policy and management	Barriers analysis (Moser and Ekstrom 2010)	Appendix 1
4. Social assessment	Public	Social acceptability	Figure 3

In response to the known climate threats to Australian seabirds and marine mammals, and potential population impacts (Chambers et al. 2011; Schumann et al. 2013), we developed a set of 25 climate impact scenarios, to span a range of Australian seabirds (n = 15 options) and marine mammals (n = 10 options) (Table 2). Both direct (e.g. temperature-related mortality) and indirect impacts (e.g. mediated through the food chain) were considered, with climate drivers and biological responses specified to guide development of adaptation options. In a targeted assessment of adaptation options, a single taxa might be the focus (Alderman and Hobday, in review; Thresher et al. 2015), but here our goal is to illustrate the methods across a broad range of taxa, rather than specifying priorities for a single species.

In the first SAPS stage, a range of adaptation options related to specific climate impact scenarios, are generated using a structured approach based on a combination of climate change scenarios and the IPCC model of vulnerability to climate change (IPCC 2007; Fig. 1). A starting point for generating adaptation options is a realistic set of physical changes expected over the time period of interest, in our case the next 30–100 years. Previous work in Australia provided a strong base for these scenarios (e.g. Poloczanska et al. 2007; Hobday and Lough 2011). Under this framework, vulnerability to the physical effects of climate change can be reduced by adaptation options that (i) reduce exposure of the individuals/populations/species, (ii) reduce the sensitivity of the organisms, and (iii) increase the adaptive capacity of the individual/species to cope with the effects, such as decreasing the impact of other stressors (Fig. 1). At this stage, experts should consider a wide range of options in each category, informed by checklists, experience, available literature, and discussion, to generate list of options in response to specific climate threats. Having generated a range of adaptation options in each vulnerability category (reduce exposure, reduce sensitivity, increase adaptive capacity), each option is assessed with the three tools designed to evaluate the technical aspects (Stage 2), institutional barriers (Stage 3), and potential social acceptability (Stage 4) (Table 1).

The second stage, uses a tool based on estimating “cost-benefit-risk” to evaluate each scenario-specific adaptation option against a number of semi-quantitative criteria reflecting cost (n = 3 attributes), benefit (4 attributes), and risk (3 attributes) (Table 3). Each criterion is scored as low (1), medium (2) or high (3) by the taxonomic experts. Each adaptation option requires scoring of these 10 criteria, with each adaptation option score for all participants converted to a mean cost score (average of the three cost attribute scores) and benefit (average of the four benefit attribute scores), and represented on a scatter plot with the relative size of the symbol indicating averaged risk attribute scores (large symbols representing high risk). This scoring identifies which adaptation options are high cost and low benefit and might be discarded, and which are high benefit and low cost and be might be prioritized. Options which are low cost and low benefit might not be pursued, while those that are high cost and high benefit might receive more detailed attention.

The Stage 3 tool was developed based on the conceptual framework on barriers to effective climate adaptation developed by Moser and Ekstrom (2010). Even with technical merit (Stage 2), adaptation options can fail because institutional barriers can impede implementation of particular options. Potential barriers may occur in three phases (understanding, planning and managing), each with three elements (Appendix 1). For each scenario-adaptation option combination, these nine elements in the Moser and Ekstrom (2010) framework were scored on a Likert scale from 1–5, where 5 represented a likely barrier for the option under evaluation and 1 represented no barrier. Scores for each

Table 2 Summary of climate scenario adaptation option combinations evaluated for seabirds (B) or marine mammals (M), with several adaptation options considered for some of the scenarios

#	Taxa	Climate scenario	Resulting impact	Adaptation option	Vulnerability category[a]
1	B	Increased air temperatures	Decreased chick survival in burrow nesting birds	Decrease exposure via shade cloth over burrows	E
2	B	Increased air temperatures	Decreased chick survival in burrow nesting birds	Shade burrows with re-vegetation to shrubby foliage	E
3	B	Increased air temperatures	Decreased chick survival in burrow nesting birds	Construct longer deeper burrows that are cooler	E
4	B	Increased air temperatures	Decreased chick survival in burrow nesting birds	Eliminate feral pest (e.g. foxes) on an island of approximately 10,000 ha (e.g. Phillip is size)	AC
5	M	Increased air temperature	Mortality in females pupping at isolated colonies, by increasing their time in water (exposure to predators), disease increase, and disturbance to mother–pup bond	Build artificial rock pools to provide safe cooling areas	S
6	M	Increased air temperature	Mortality in females pupping at isolated colonies by increasing their time in water (exposure to predators), disease increase, and disturbance to mother–pup bond	Install shark deterrents (acoustic) off seal colonies	AC
7	B	Increased intensity of rainfall	Flooding of burrows and chick mortality	Improve drainage around colony with agricultural drain	E
8	B	Increased intensity of rainfall	Flooding of burrows and chick mortality	Remove chicks during extreme event and replace after event	S
9	M	Increased sea level and storm surge	Overtopping of seal breeding colony and mortality of pups—overall population decline	Initiate island raising with dumping of very big rocks or concrete	E
10	B	Wind speed increases	Nesting failure of tree nesting birds	Transition wind breaks from artificial structures to vegetation planting to replace artificial structures in time	E
11	M	Declining ocean productivity	Declining participation of female seals in breeding	Artificial feeding of female seals during gestation period (when likely to be at the colony)	S
12	M	Declining ocean productivity	Declining participation of female seals in breeding	Temporary closures of fisheries operating in the foraging range of the species	AC

Table 2 continued

#	Taxa	Climate scenario	Resulting impact	Adaptation option	Vulnerability category[a]
13	M	Cyclone frequency increases and destruction of seagrass beds	Starvation and death of dugongs following each cyclone	Relocate animals in affected areas to other locations	E
14	M	Increasing water temperatures	Declines in dugong feeding areas (seagrass declines in some parts of the range)	Create strategic set aside areas that reduce other stressors	AC
15	M	Declining productivity of seagrass beds	Starvation and mortality in some parts (~25 %) of the dugong range	Initiate seagrass nurseries and outplanting to enhance natural production in these regions	S
16	B	A competitive bird species (e.g. silver gull or gannet) is favoured by climate change	Arrives at the colony of a threatened species and begins to take over nesting sites	Cull competitor (e.g. firearms)	AC
17	B	Decreased foraging success of adults	Chicks (e.g. n = 2) fledging at lower weights and first year survival declines	Reduce brood size (e.g. from 2 to 1) to increase condition and survival of remaining chick	S
18	B	Warmer weather	Increased vegetation growth around burrows, leading to both a fire risk, and preventing birds from accessing the burrows	Burning of habitat in non-breeding season (i.e. when birds absent) to reduce vegetation overgrowth and fire risk during breeding season	S
19	B	Warmer weather	Increased vegetation growth around burrows, leading to both a fire risk, and preventing birds from accessing the burrows	Introduce a grazing species to control vegetation (e.g. rabbit)	S
20	B	Decreased foraging success of adult birds (due to decreasing ocean productivity)	Chicks fledging at lower weights and first year survival declines	Decrease parasite loads in chicks via drenching	AC
21	B	A competitive bird species (e.g. silver gull or gannet) is favoured by climate change)	Arrives at the colony of a threatened species and begins to take over nesting sites. (space competition)	Provide alternative habitat for competitor, e.g. floating platform for gannets	S
22	B	Declining ocean productivity	Declining fledging success of birds	Initiate fish farming to produce feed for marine species	AC
23	B	Warmer weather	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, little penguin)	Reduce public access (manage human access) to reduce fire risk	S

Table 2 continued

#	Taxa	Climate scenario	Resulting impact	Adaptation option	Vulnerability category[a]
24	B	Warming waters and a deepening thermocline	Reduced foraging success and loss of northern colonies of seabirds (suitable areas elsewhere)	Translocate chicks to new location (assuming site fidelity)	E
25	B	Increased intensity of rainfall events	Direct mortality of eggs and chicks of surface nesting seabirds (e.g. albatross, terns, gannets)	Corral chicks from crèche to under “shelters” (e.g. crested tern)	S

[a] Each option could reduce vulnerability by reducing exposure (E), reducing sensitivity (S), or increasing adaptive capacity (AC)

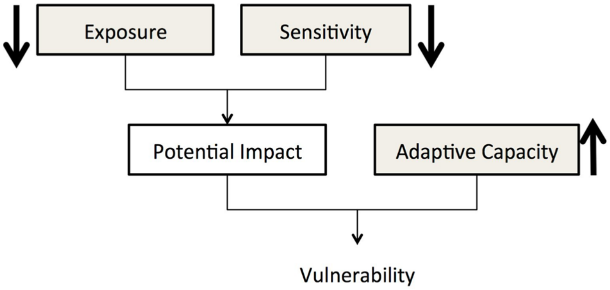

Fig. 1 IPCC vulnerability framework (IPCC 2007) used to guide experts in the generation of adaptation options for iconic marine species that could reduce their exposure, reduce their sensitivity, and increase their adaptive capacity

element can be considered individually, and averaged for each of the three steps for ease of comparison across scenarios.

Finally, following evaluation of technical merit, and potential institutional barriers, adaptation options may not be acceptable to society at large, or may be resisted by vocal opponents or groups. In cases where societal acceptance is important, awareness and identification of potentially contested options is useful to conservation managers charged with implementing adaptation options. Assessing social license after an event has occurred is a difficult task and attempts to assess it before the action has occurred are even more problematic. However, attention to social issues may reveal important issues that prevent conservation action. Thus, the final SAPS stage, aimed at detecting issues regarding social acceptability, may not be the final attempt to measure social acceptability, which may include significant outreach and engagement with society at large. Each adaptation-scenario was given a single score based on a Likert scale [1–7], where 1 indicates high acceptability and 7 is high disagreement with an option. Note, as the assessments become more subjective and based on fewer attributes, the scoring scale increased at each stage of SAPS ([1–3], [1–5], [1–7]) to provide more resolution.

Table 3 Cost-benefit-risk scoring criteria used in Stage 2 of SAPS to score attributes to assess each adaptation scenario

Category	Attribute	Low (1)	Medium (2)	High (3)
Cost	Implementation cost[a]	<\$10,000	>\$10,000–< M\$1	>M\$1
	Ongoing cost—how many years is action needed	<5 years	5–10 years	>10 years
	Time to implement—lead time till action can begin	Now	1–5 years	>5 years
Benefit	Persistence of action	1 season	<5 seasons	>5 seasons
	Scale of benefit (at the scale action is applied)	Few individuals	Most of colony	Most of the population
	Benefit of action to target group	Minimal improvement	Partial solution	Solve problem
	Benefit of action to wider ecosystem	Low	Medium	High
Risk	Risk of action failing	<33 %	33–66 %	>66 %
	Risk of mal-adaptation—negative outcome on another strategy for target group	<33 %	33–66 %	>66 %
	Risk of adverse impacts to wider (eco)system	<33 %	33–66 %	>66 %

[a] In this case, costs are in Australian dollars

The scores from these three tools for each scenario were used to generate a prioritization table where a rank of 1 is more desirable than a rank of 25, with analysis and visualization conducted in Excel ® and Matlab®.

Testing SAPS

Stages 1–3

We evaluated adaptation options for seabirds and marine mammals using SAPS with a range of experts, managers, and policy makers from around Australia, at two workshops. We selected these experts based on geographic representation and domain knowledge. The first workshop covered Stages 1 and 2, while Stages 3 and 4 were assessed at the second workshop. Membership overlapped between the workshops, with 20 participants at the first and 18 at the second; comprising 34 unique experts. Across both workshops, participants self-identified as experts in marine mammals ($n = 6$), seabirds ($n = 14$), both ($n = 7$), or generalists ($n = 6$). In a second classification, 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”.

We generated a range of species-specific climate impact scenarios linked to a physical change in the ocean based on our reviews of known impacts (Chambers et al. 2011; Schumann et al. 2013), and used the first workshop to challenge expert participants to develop multiple adaptation options for each climate impact scenario. A large number of options relevant to each of the three categories (reduce exposure, reduce sensitivity, increase adaptive capacity) of the IPCC vulnerability framework were encouraged and recorded. A subset of the options was selected for evaluation in Stage 2 (technical merit) and Stage 3 (barriers). In the examples presented here, Stage 3 elements were answered by workshop participants (scientists, managers and policy practitioners) from the perspective of the likely agency charged with implementing the adaptation strategy.

Because of the large number of scores (25 scenarios × 10 Stage 2 scores, 9 Stage 3 scores, and 1 Stage 4 score = 500 scores), we used the interactive software Turning Point® in workshops, allowing efficient recording of expert responses to scoring options using handheld devices registered to each participant (Hobday et al. 2014). Rapid compilation of scores allowed discussion between experts in the workshops—which was important for developing adaptation planning skills amongst participants.

Stage 4: social acceptability

To illustrate the importance of evaluating adaptation options by the appropriate group in the final SAPS stage (Table 1), at a second workshop we scored, using Turning Point®, social acceptability for each of the 25 options using (i) a technical experts group ($n = 18$), and (ii) the same technical experts instructed to score based on their assumed views of the general public. A third group (iii) was a sample of the general public ($n = 69$). For the general public, we distributed a paper copy of social acceptability score sheets to people following face-to-face requests for participation, first checking that respondents were not involved in science or conservation management. Anonymous responses were returned to the authors.

To evaluate where our two groups, experts and the public, fell with respect to environmental attitudes and if these attitudes were related to views on social acceptability of adaptation options, we also surveyed both groups using the revised new environmental paradigm (NEP) survey (Dunlap et al. 2000). This widely used method consists of 15 questions that rate the respondent's world view with regard to the environment and human impact. High scores indicate a more ecocentric belief system in which humans are seen as part of natural systems, while lower scores suggest a more anthropocentric belief system in which humans are seen as independent from, and superior, to other organisms in nature (Hawcroft and Milfont 2010).

Results

Stage 1: Generating adaption options

Adaptation options for 25 climate impact scenarios were generated by seabird and mammal scientific, management and policy experts in the first workshop. Initially, 269 adaptation options (222 for seabirds, 47 for marine mammals) were generated. After combining similar options within each scenario, 198 adaptation options remained across the 25 scenarios, 156 for seabirds and 42 for marine mammals (see Hobday et al. 2014), representing an average of 10.4 options for each seabird scenario, and 4.2 for each marine mammal scenario. These options were applicable to the three elements of the vulnerability framework: reduce exposure ($n = 63$ options), reduce sensitivity ($n = 64$) and increase adaptive capacity ($n = 71$).

A subset of 25 of the scenario-adaptation option combinations was selected for detailed evaluation at Stages 2–4 of SAPS to test the methodology. These examples were selected to provide representative coverage across each vulnerability category (8 Exposure, 10 Sensitivity, 7 Adaptive Capacity options), to represent a range of climate threats and

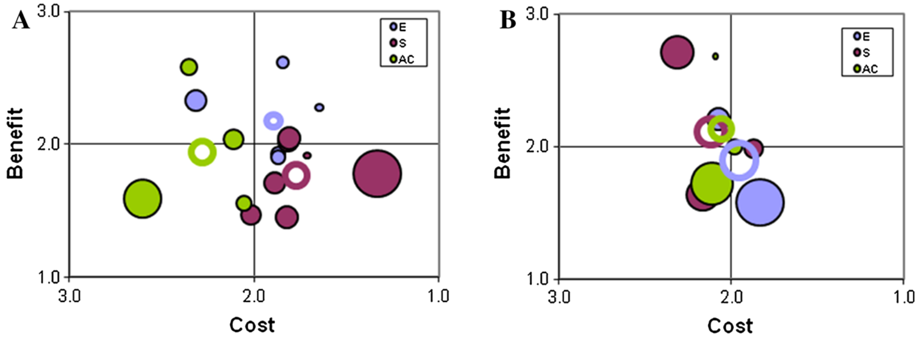

Fig. 2 Average adaptation scores for Stage 2 assessment for **a** Seabirds and **b** Marine mammals. *Open circles* represent the mean value for exposure (E), sensitivity (S) and adaptive capacity (AC) options. The size of the bubbles represents the risk score (small represents low risk, large is higher risk)

population responses (more than one response could be included for each scenario), and a variety of species (17 seabird, 8 marine mammal options). Not all 25 original climate scenarios were evaluated, with multiple adaptation options to the same climate-response scenarios considered in some cases.

Stage 2: Technical assessment

The 25 adaptation options (Table 2) were scored for the 10 cost-benefit-risk criteria (Table 3) by workshop participants. Each adaptation option attribute score was converted to a mean cost, benefit and risk score, and average scores calculated across all participants. The mean of the exposure options was slightly better with regard to higher benefit and lower cost than sensitivity or adaptive capacity options. 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).

Low cost high benefit options for seabirds included Scenario 2, while high cost low benefit options, with high risk included Scenario 22 (Fig. 2a; Table 2). Low cost low benefit options included Scenario 19, and there were also some high benefit high cost options. For marine mammals, there was a general relationship between cost and benefit, with low cost low benefit, or high cost high benefit options identified (Fig. 2b), including Scenarios 13 and 15, respectively. The average risk estimated for the marine mammal options (1.53) was similar to that for seabirds (1.59).

Stage 3: Bbarriers analysis

The expert group evaluated the same 25 scenarios with regard to institutional barriers. Scores by individuals ranged between 1 (barriers considered weak) and 5 (barriers considered strong), with average scores closer to middle of the range. Overall, across all taxa, 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). Seabird scenarios considered to have low barriers to implementation included Scenarios 17 and 22, while for marine mammals, Scenarios 6 and 5 were considered more tractable (Table 4). Within each barriers analysis stage, the understanding phase was seen as the greatest barrier (mean 3.39) while the planning stage

Table 4 Stage 3 barrier scoring in each of the three phases and overall average for the 25 adaptation options, ordered by vulnerability category

Scenario	Taxa	Vulnerability category	Understanding average	Planning average	Managing average	Overall average
1	B	E	3.42	3.44	3.16	3.34
2	B	E	3.47	3.82	3.07	3.46
3	B	E	3.60	3.60	2.44	3.21
7	B	E	3.58	3.36	3.04	3.33
10	B	E	3.64	3.19	3.36	3.40
24	B	E	3.86	3.10	3.43	3.46
9	M	E	3.83	2.98	3.02	3.28
13	M	E	3.48	2.29	2.79	2.85
8	B	S	3.31	3.33	2.83	3.17
17	B	S	2.12	2.14	2.45	2.24
18	B	S	3.52	3.10	3.64	3.42
19	B	S	3.76	2.14	2.95	2.95
21	B	S	3.88	2.74	3.26	3.29
23	B	S	3.95	2.79	3.26	3.33
25	B	S	3.69	2.50	3.33	3.17
5	M	S	2.14	2.96	2.05	2.39
11	M	S	3.36	2.13	2.71	2.73
15	M	S	3.48	2.50	2.69	2.89
4	B	AC	3.75	3.61	2.79	3.39
16	B	AC	3.93	2.71	3.29	3.31
20	B	AC	2.38	2.69	2.86	2.64
22	B	AC	3.52	1.83	2.14	2.51
6	M	AC	2.26	2.85	2.04	2.38
12	M	AC	3.36	2.33	2.05	2.58
14	M	AC	3.40	2.64	2.74	2.93
		Average	3.39	2.83	2.86	3.03
		SD	0.55	0.53	0.46	0.39

E reducing exposure, *S* reducing sensitivity, *AC* increasing adaptive capacity and taxa (*B* seabird, *M* marine mammal)

Scores in each phase were averaged for each expert then averaged across all experts

was seen as the least problematic (mean 2.83) (Table 4), a result consistent across taxa (mean scores for understanding, planning and managing for seabirds were 3.49, 2.95, 3.15, respectively, and for marine mammals 3.16, 2.59 and 2.75). 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 (Table 4). Overall, seabird options were considered to have higher barriers to implementation than marine mammals (mean scores 3.15 and 2.75, respectively).

The specific set of scores for each of the nine elements of Stage 3 can be inspected in detail for each scenario to plan how to overcome barriers associated with a particular option. We do not present these scores here, as results are intended to be illustrative, rather than instructive for any option, as barriers are likely to be agency and species specific.

Stage 4: social acceptability

Social acceptability scores varied for the 25 scenarios, ranging from acceptable to unacceptable (Fig. 3). For ease of reporting, we arbitrarily define preferred options as those with average scores <2.5. Expert group scoring showed variation between the social acceptability of some adaptation options, ranging from high to low. Overall, experts preferred options 2, 1, 23, 24, 14, and 4 (Fig. 3).

A total of 69 responses from the general public were suitable for analysis and, as for the expert group, there was a wide range of acceptability scores for the 25 adaptation options considered. Overall, the public preferred options 2, 14, 15, 12 (Fig. 3). There were similarities between preferred options for experts and the public (e.g. options 2 and 14—shading seabird burrows with revegetation and set-aside areas), and also some differences–the public scored lower than experts for translocation of chicks (option 24) and the use of shade cloth (option 1), while experts were less likely to consider establishment of seagrass nurseries for dugong (option 15), introducing grazing species, such as rabbits (option 19), and relocating dugongs (option 13) to be socially acceptable. Differences in scoring of options by experts and the public, defined as differences that were less than −0.5 (options in order of decreasing difference: 24, 1, 9, 23, 8, 10, 21) and greater than 0.5 (options 13, 15, 19, 22, 5, 11, 18, 6, 12, 25) did not appear to have common factors (such as vulnerability category, level of interference, or taxa).

Social acceptability scores from the public compared to how the experts perceive the public's views saw some major differences. Experts involved in this study tended to find options more acceptable (mean score across all options = 3.64) than the public (mean score 3.61) and the experts thought the public would like options more than they actually did (mean score 3.53).

When the experts scored social acceptability as they expected the general public to respond, they tended to score adaptation options as less acceptable than when scoring as "experts" (Fig. 3). For some options, there was agreement between the social acceptability

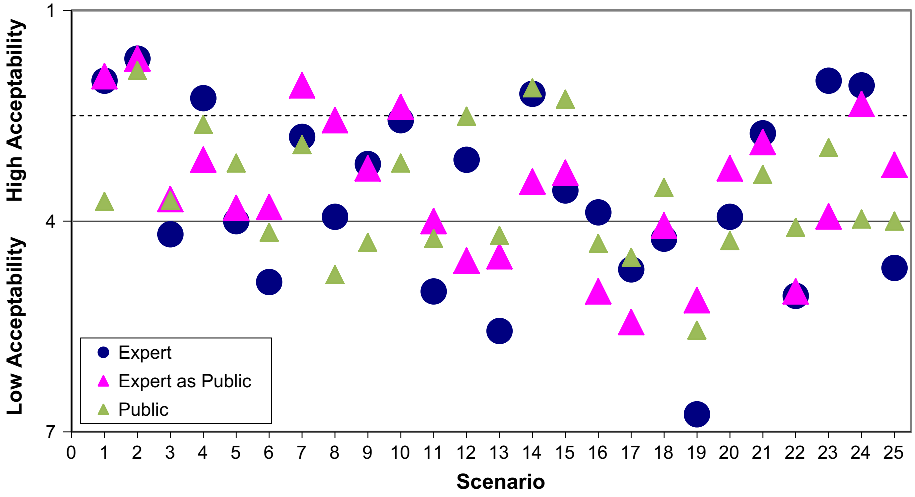

Fig. 3 Mean social acceptance scoring for 25 adaptation options by experts, experts judging public acceptance, and the public. The *dashed line* at 2.5 is a reference line to identify options with high acceptability discussed in the text. Scenario numbers and descriptions are provided in Table 2

scoring of experts and how they judged society at large might feel (Fig. 3) (e.g. options 1, 2, 9). In other cases, the average acceptability as judged by the experts was higher than they rated how general public might feel (e.g. options 4, 12, 14). The third possibility, higher public acceptance than expert acceptance, was also noted in a number of scenarios (e.g. scenarios 3, 6, 7). For some options (options 8, 1, 24, 9, 20), the public was less likely to find the option acceptable than the experts thought they would be, including options related to moving species (Fig. 3). There were also options that the public appeared to like more than the experts expected, e.g. options 12, 14, 15, 17, 23 and 21, which included set aside areas and mammal related options.

Overall ranking of adaptation options

The overall ranking of adaptation options based on Stages 2–4 reflects a "prioritization" for the evaluated set of scenarios (Table 5); a rank of 1 being more desirable than a rank of 25. The leading option overall, Scenario 2 (re-vegetation to offset warming burrow temperatures) was ranked 3rd for the cost-benefit-risk (Stage 2), 2nd with regard to barriers (Stage 3), and 1st for social acceptability rated by the public. In contrast, the leading option based on Stage 2 and 3 was rated 14th overall by the public with regard to acceptability.

Table 5 Ranks for each of the 25 scenarios evaluated with the three evaluation tools, sorted from most to least preferred (rank) across all stages for seabirds (B) or marine mammals (M)

Rank	Scenario	Taxa	Average rank	Stage 2 technical	Stage 3 barriers	Stage 4 acceptability	Vulnerability category
1	2	B	2.00	3	2	1	E
2	4	B	5.33	6	5	5	AC
2	24	B	5.33	1	1	14	E
4	14	B	6.67	2	16	2	AC
5	23	M	7.33	8	7	7	S
6	18	M	7.67	9	3	11	S
7	7	B	8.00	10	8	6	E
8	10	B	8.33	13	4	8	E
8	15	M	8.33	5	17	3	S
10	21	B	9.00	7	10	10	S
11	1	M	11.00	14	6	13	E
12	3	M	13.00	15	12	12	E
13	12	M	13.67	16	21	4	AC
14	5	M	14.33	12	23	8	S
14	9	M	14.33	11	11	21	E
16	19	B	14.67	4	15	25	S
17	16	B	16.00	17	9	22	AC
17	25	B	16.00	20	13	15	S
19	13	B	18.33	19	18	18	E
20	8	B	20.33	23	14	24	S
21	6	B	20.67	21	24	17	AC
21	11	B	20.67	24	19	19	S
21	20	B	20.67	22	20	20	AC
24	22	B	21.00	25	22	16	AC
25	17	B	22.00	18	25	23	S

Green shading indicates the option was in the upper third for the stage, orange indicates it was in the lower third, and yellow indicates the middle third

Similarly, option 19 was rated highly for technical merit (Stage 2), but with considerable barriers (Stage 3) and lack of public acceptance (Stage 4). In this case, it was an undesirable option (introduce rabbits to an island to control weed growth), but illustrates the different outcomes when all aspects of an adaptation option are evaluated.

The rank correlation between results from each of the three stages is only moderate, as expected, as each stage involved evaluating a different aspect of each scenario (Stage 1 and Stage 2 $r = 0.58$; Stage 1 and Stage 3 $r = 0.56$; Stage 2 and Stage 3 $r = 0.32$). Thus, combining the three measures into a single score may not be useful, and considering each of the scores will be valuable in considering issues that may need to be overcome with each adaptation option.

The average NEP score for the experts group was 64.33 (range 51–75) while the score for the general public was 59.28 (range 42–74), indicating that the expert group had a more ecocentric belief system, while the public tended more to the anthropocentric system of beliefs (Hawcroft and Milfont 2010). Despite these differences, there was no significant correlation between the average acceptability scores (Stage 4) by each public respondent and their NEP score ($R^2 = 0.0002$), or for the experts, although experts showed a slight negative non-significant correlation with average acceptability scores ($R^2 = 0.15$), suggesting a more ecocentric set of beliefs was associated with lower support for adaptation options.

Discussion

Intervention in natural ecosystems is widespread and successful manipulation of the distribution of plants and animals, and the selection of desired traits in these species supports agriculture and human food security around the planet. Intervention often takes two main forms that are not mutually independent, pest species management and conservation of species. Pest management involves dramatic intervention to reduce habitat quality for the undesired species through to direct removal of unwanted species (Thresher and Kuris 2004). Conservation has always involved some intervention, from reduction of stressors, to ex situ conservation as a last resort (Dawson et al. 2011). Reintroduction of captive bred animals and the development of new viable populations is evidence of ultimate success of this approach. In this context, climate change is just the latest challenge for which some intervention for species conservation may be considered. However, generating adaptation options to threats such as climate change and selecting the most appropriate options for the species in question can be a significant challenge for conservation managers (Hagerman and Satterfield 2014).

The success of interventions depends on the technical merit, the ability to overcome institutional barriers, and potentially the social acceptability of any intervention. The use of the SAPS approach present here allows relatively rapid and transparent prioritization of options, a feature of many semi-quantitative risk based tools (Hobday et al. 2011; Foden et al. 2013). The outcome of such assessments may lead to implementation, or to a more detailed examination of a particular option (Thresher et al. 2015). The advantages of this approach is that it is semi-quantitative and can allow a participatory approach, through incorporation of views of the conservation managers, institutional representatives and the general public. Challenges can, however, arise when implementing SAPS. In our testing during workshops with experts, we found that scoring barriers was often difficult, as the interpretation of barriers was contextual and specific. Experts were asked to score each option based on their institutional experience (e.g. was this option likely to face a set of barriers in their agency). Some experts expressed ambiguity with regard to the possible responses, however, by using interactive polling software, we were quickly able to identify when issues arose and further discussion was needed, for example, when participants had vastly different scores for the same barrier. This suggests that discussion of barriers might be best done in group settings, while for the other stages, respondents reported greater certainty and personal confidence in their scoring. These tools could also be implemented for on-line use, although expert discussion is often a valuable part of semi-quantitative scoring systems (Hobday et al. 2011). They are also suitable for use at a range of scales, from national to local.

Social acceptability is an important consideration of any proposed adaptation option, yet is often neglected by conservation planners. Our results indicate that experts cannot act as proxies for the general community—although experts generally agree with the public in some cases, in others some important differences resulted. These differences included experts over-estimating the lack of acceptability by the public for some options. If decisions were made on the basis of experts scoring social acceptability, this might lead to spending too much on education and outreach when support already exists or underestimating the acceptability and failing to consider appropriate engagement. This result emphasizes the need to have public assessment if public endorsement of an adaptation option is ultimately needed. Assessment of Stage 4 with a focus group may reveal why options are not favored, and may need more detailed attention. The lack of any relationship between environmental views as measured by the NEP and the acceptability of adaptation options suggests that each case must be considered for acceptability, and there are no “shortcuts”. While social acceptability of adaptation options may be an ultimate barrier, it can also change over time (Hagerman and Satterfield 2014). As climate impacts become more widespread, society may grow more comfortable with interventions. However, there are some interventions that may always face opposition, such as culling of species, despite overwhelming evidence that such approaches will be technically successful. However, if public opinion is not a concern, a decision-making process could potentially proceed without considering Stage 4. Likewise, if there is a clear agency mandate to act, then Stage 3 may not be needed (Alderman & Hobday, in review). Thus, depending on the situation a decision can be made to use these tools in isolation or in combination.

Once favored options are implemented, it is important to continue monitoring to evaluate if the intervention was successful (Stein et al. 2013). Monitoring is often the neglected part of adaptive management, as it is often expensive and long term. New technologies for data collection and analysis are being developed, and help to lower some of the costs (e.g. Lynch et al. 2015). An important consideration for any intervention will be the ongoing need for action. Options that can be implemented once, or infrequently may be desirable (Stage 2 scoring), and as such transformation adaptation options (e.g. translocation) may be cost-effective compared to incremental adaptation options (such as supplemental feeding).

Given projections for continued environmental change over the coming century (IPCC 2014) conservation managers may need to act more like engineers for some systems (Roe and van Eeten 2001; Stafford-Smith et al. 2011). Adaptive adaptation management may become widespread, with the need to rapidly test and evaluate tools. Given the number of iconic species and the range of potential intervention options, detailed assessment may not always be possible or appropriate. Semi-quantitative tools as described here can help with the scale of the problem, and lead to more comprehensive responses to the conservations threats that climate change poses.

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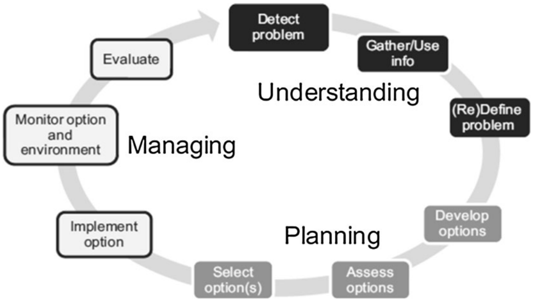
Appendix 1

Phases and elements scored in SAPS Stage 3, Barriers to implementation. Each statement is scored from 1–5, where 1 indicates disagreement (low barriers), and 5 indicates agreement (high barriers). Adapted from Moser and Ekstrom (2010).



Phase 1: Knowledge

(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?

Phase 2: Planning

(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?

Phase 3: Implementation

(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?

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