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Climate adaptation interventions for iconic fauna

Claire Mason¹

| Alistair J. Hobday² | Rachael Alderman³ | Mary-Anne Lea¹

¹Institute for Marine and Antarctic Studies, Hobart, Tasmania, Australia ²CSIRO Oceans and Atmosphere, Hobart, Tasmania, Australia ³DPIPWE, Hobart, Tasmania, Australia

Correspondence

Claire Mason, Institute for Marine and Antarctic Studies, 20 Castray Esplanade, Battery Point TAS 7004, Australia. Email: claire.mason@utas.edu.au

Abstract

Climate adaptation is an emerging practice in biodiversity conservation, but little is known about the scope, scale, and effectiveness of implemented actions. Here, we review and synthesize published reports of climate adaptation interventions for iconic fauna. We present a systematic map of peerreviewed literature databases (Web of Science and Scopus); however, only nine climate adaptation actions targeting iconic fauna were returned. In the grey and informal literature, there were many instances of practical intervention within our scope, that were not uncovered during traditional systematic search methods. The richness of actions reported in commercial news, government and non-government organization media outlets and other online sources vastly outweighs the limited studies that have been robustly evaluated and reported in the scientific literature. From our investigation of this emerging field of conservation practice, we draw insights and pen a series of recommendations for the field moving forward. Key recommendations for future adaptation interventions include: the sharing and publishing of climate-related conservation interventions, the use of standardized metrics for reporting outcomes, the implementation of experimental controls for any actions undertaken, and reporting and evaluation of both failures and successes.

KEYWORDS

adaptive management, biodiversity conservation, climate change, ecological renovation, environmental change, proactive conservation, resilience, threatened species, wildlife

1 **INTRODUCTION**

Evidence of climate change impacts on species, habitats and ecosystems has been widely reported from around the world (Poloczanska et al., 2013). These impacts include shifts in species' distributions (Chen, Hill, Ohlemüller, Roy, & Thomas, 2011; Lenoir & Svenning, 2015; Pecl et al., 2017), abundance (Sturm, Racine, & Tape, 2001), physiology (Munday et al., 2009), phenology (Cohen, Lajeunesse, & Rohr, 2018; Forrest, 2016; Radchuk et al., 2019), and species interactions (Putten, Macel, & Visser, 2010). In 2019, the

Bramble Cay melomys (Melomys rubicola) became the first documented mammal extinction as a direct result of climate change (Department of the Environment, 2019; Waller, Gynther, Freeman, Lavery, & Leung, 2017). Many more species are projected to decline or become extinct in the future. extinction projections can be controversial While (e.g., Thomas et al., 2004), changes in distribution have already been widely observed. Many species are moving toward the poles and mountain tops to escape increasing temperatures (Chen et al., 2011; Lenoir & Svenning, 2015; Pecl et al., 2017) or seeking refugia in the landscape (Keppel

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et al., 2012; Reside et al., 2014). For species that rely on specific habitats, changes over this century are expected to have dire consequences for populations, such as species dependent on ice environments, such asemperor penguins (*Aptenodytes forsteri*), Adelie penguins (*Pygoscelis adeliae*), and polar bears (*Ursus maritimus*; Kovacs, Lydersen, Overland, & Moore, 2011; Jenouvrier et al., 2014; Cimino, Lynch, Saba, & Oliver, 2016; Jenouvrier et al., 2020). However, species responses to climate change have been varied and complex, with some thriving in new environments (Ling, Barrett, & Edgar, 2018), or demonstrating unexpected redistribution (Archaux, 2004; Fei et al., 2017; Lenoir et al., 2019).

Climate change mitigation (i.e., reducing greenhouse gas concentrations in the atmosphere) may not relieve the projected stresses of climate change on the environment, especially if positive feedbacks emerge, such as release of carbon dioxide from ocean sinks and of methane from melting permafrost (Lenton et al., 2019). Other human activities compound climate pressures, such as habitat fragmentation and the subsequent patchy landscapes often containing hostile habitats, humans competing for food sources, introduced species, and the spread of disease (Maxwell, Fuller, Brooks, & Watson, 2016). Many species are struggling, and will struggle, to persist in the face of these cumulative impacts. Alongside mitigation of climate change, actions to facilitate adaptation to the changing climate is required to maintain current ecosystem function (McDonald et al., 2019).

1.1 | Adaptation as a response to climate impacts

Adaptation was a term historically associated with evolution-the process over many generations by which species genetically adjust to new environments. Subsequently, the term has been broadly used to include human intervention to adjust systems (human and natural) to cope with current and future climate (IPCC, 2018). Henceforth, our use of the term "climate adaptation" refers to the latter definition. Such directed adaptation involves reducing species vulnerability to climate change, as well as exploiting any potential benefits of new environments (Morecroft et al., 2019). For biodiversity conservation, especially regarding the conservation of iconic fauna, there has been some reluctance to embrace the principles of climate adaptation as opposed to more traditional conservation methods (Colloff et al., 2017; Hagerman, Dowlatabadi, Satterfield, & McDaniels, 2010; Tam & McDaniels, 2013). As a new and emerging field, theory and practice is not yet well-established or widely accepted. Traditional conservation methods, such as protected areas, captive breeding, and invasive species control, can all be framed as climate adaptation actions, as they contribute to the species resilience under current or future climate vulnerabilities. Furthermore, innovative and emergency actions such as artificial nests or wind barriers that have a direct link to the climate threat are emerging as new tools to conserve species under climate change. However, when in unchartered territory and with limited resources allocated to conservation efforts, well-established traditional approaches are often favored (Prober, Doerr, Broadhurst, Williams, & Dickson, 2019).

Many climate adaptation actions are seen as an extreme approach by some leading conservation scientists and practitioners (e.g., Ricciardi & Simberloff, 2009), as well as by some members of the general public (Taylor, Dessai, & Bruine de Bruin, 2014). A range of perceptions and attitudes, and therefore barriers exist for climate adaptation as a management strategy both generally (Jantarasami, Lawler, & Thomas, 2010), and in the conservation sphere (Cvitanovic, Marshall, Wilson, Dobbs, & Hobday, 2014; Garnett, Zander, Hagerman, Satterfield, & Meyerhoff, 2018; Hobday, Chambers, & Arnould, 2015). Climate adaptation often requires action based on an incomplete knowledge of the system. The relatively urgent need to respond to the impacts of climate change thus requires an active adaptive management approach. Climate adaptation will work best if the conservation action is proactive-future actions can benefit from trials and experiments now while populations are robust, rather as a high-risk last resort action (Alderman & Hobday, 2017).

1.2 | Challenges and needs

Despite these challenges, international organizations and the scientific community are calling for adaptation action to save species and ecosystems (IPCC, 2018; Stein et al., 2013). Although there is a growing focus on climate adaptation, and both frameworks and theory have been proposed in recent years (e.g., Hobday et al., 2015; Prober et al., 2019), implementation of on-the-ground adaptation is lagging. This discrepancy is also demonstrated by a mismatch between identified risk and on-ground action for government recovery plans of threatened species (Delach et al., 2019; Hoeppner & Hughes, 2019). Adaptation is inherently difficult to track and evaluate in many contexts (Berrang-Ford et al., 2019; Dilling et al., 2019). As such, there has been little synthesis of how climate adaptation interventions for biodiversity conservation have performed, though some have begun the process (Greenwood, Mossman, Suggitt, Curtis, & Maclean, 2016; Mawdsley, O'Malley, & Ojima, 2009; Prober et al., 2019; Stein et al., 2013). Charismatic or iconic fauna often are the focus of conservation studies or programs, due to relative ease of public and government support (Albert, Luque, & Courchamp, 2018). Hence, we focus on climate

adaptation interventions for iconic fauna, generally defined as native fauna widely recognizable and valued by the public. We included all birds, mammals, and reptiles as well as some other charismatic fauna outside these groups (e.g., butterflies).

This emerging field consists of many emergency responses and small-scale trials; hence this review is timely as the field develops and limited publications exist. Our aim was not to be exhaustive but to glean useful information (including key themes, limitations, and approaches) from this field, from a compilation of studies published online. For accelerated action in this space to occur, evidence of effectiveness and principles for best practice are needed. The need for climate adaptation, and a robust and tested framework for implementing options, will continue to grow as per the climate changes relative to historical conditions (IPCC, 2018). With limited time and resources, progress in this field will depend on sharing knowledge across jurisdictions and nations.

Here, we collate and analyze conservation interventions that have assisted iconic fauna to adapt to climate change. We aim to answer the questions: What types of actions are being implemented? How are they being implemented and evaluated? Are they successful? We then highlight and synthesize what has been accomplished in this field and offer recommendations for future climate adaptation research and management approaches. This article presents the first global overview of climate adaptation interventions for iconic fauna and provides an overview of on-ground interventions that have occurred to-date.

2 | METHODS

The applied field of climate adaptation interventions for iconic fauna is relatively recent, which meant our initial attempts at a systematic literature search did not reveal the many studies that we knew existed. We present our systematic map from peer-reviewed scientific databases, alongside an ad hoc, snowballed search to complement our formal search. This additional ad hoc search allows us to show the richness of actions that have occurred but are not within the published, scientific domain. We present methods and results from both searches and compare and contrast their outputs.

2.1 | Eligibility criteria

• Eligible populations or subjects (P): Iconic native fauna at the individual, community, or population scale, recognizable by the public.

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- Eligible intervention (I): the eligible intervention in question is a climate adaptation intervention. This includes action where the threat targeted was directly climate or weather-related, or actions that were not acting on a climate threat, but the species was under current or future pressure from climate change. We only included actions that had already occurred, not ideas or plans for climate adaptation.
- Eligible comparators (C): All types of study design will be included with the experimental design type recorded.
- Eligible outcomes (O): Any outcome or related impacts on the target species.

2.2 | Systematic map search method

Search terms used are listed in Table 1. We deliberately did not use any terms of specific adaptation actions we knew existed (e.g., translocation, supplementary feeding) because we did not want to bias results using our prior knowledge. The complete search string was:

> (Climat* <u>NEAR/5</u> Adapt*) AND (Biodiversity OR Wildlife OR Fauna OR Vertebrate OR Species OR Animal* OR Bird* OR Mammal* OR Reptile* OR Amphibian* OR Insect* OR Fish*) AND (Conserv* OR Interven* OR Protect* OR Manag* OR Act* OR Restor* OR Renovat* OR Artificial*)

Excluded studies included climate adaptation for ecosystem services, agriculture, urban design, forestry, fisheries, ecoregions, or national parks. Studies on local adaptation as an evolution biology concept and climate change vulnerability assessments were also commonly excluded. This search string was used on 16th October 2020 in Clarivate Analytics Web of Science Core Collection (http://apps.webofknowledge.com/) and Elsevier's SCOPUS (http://www.elsevier.com/online-tools/scopus). No restrictions on document type or year published were applied. All database, search engine and grey literature searches took place in English. Searches were performed using University of Tasmania library subscriptions accessed using the affiliation of team members. A total of 9,011 articles were returned by this search.

2.3 | Data coding strategy

Table 2 displays the information that was extracted from each identified action, including all categories and detailed definitions. Articles were screened by title initially, followed by abstract and then at full text level.

Торіс	Population: Iconic species	Intervention: Climate adaptation intervention	Comparators: All study designed considered	Outcomes: All impacts considered
(Climat [*] NEAR adapt [*])	Biodiversity	Conserv*	NA	NA
	Wildlife	Interven [*]		
	Fauna	Protect*		
	Vertebrate	Manag [*]		
	Species	Act [*]		
	Animal [*]	Restor [*]		
	Bird [*]	Renovat [*]		
	Mammal [*]	Artificial [*]		
	Reptile [*]			
	Amphibian [*]			
	Insect [*]			
	Fish [*]			

TABLE 1 Terms synonymous with our research topic used in our systematic map search to capture relevant literature

Note: No search terms for the comparators or outcomes were used, as all study designs are relevant to our research question. The asterisk indicates searches included plurals and alternative word endings. Search terms were run in a single search with the Boolean operator "OR" used to separate search terms within each column group and the operator "AND" used to separate between each column group. Thus, returned search results must include at least one search term from each column group.

ROSES flow diagram for systematic maps (Haddaway, Macura, Whaley, & Pullin, 2017) has been adapted for this study with the number of relevant articles remaining at each level of screening reported (Figure 1). A list of relevant titles with subsequent screening can be accessed in Data S1. Coding and extraction of metadata for the eight relevant articles is located in the Data S2 file. Different species targeted by the same action were individually included, as were different actions for the same species.

Although we do not consider our systematic map exhaustive due to the applied nature of the field, we believe our findings provide valuable insight into this emerging approach to offset climate change effects. Furthermore, comparing these systematic map results with actions encountered during ad hoc search methods highlight the interventions that are absent in the scientific domain.

2.4 | Ad hoc search methods

Beginning in March 2018 we searched Web of Science, Google, Google Scholar and Google News to find published and unpublished studies within our scope. In total we found 112 actions using these searches, subsequent snowballing searches, the Conservation Evidence database (conservationevidence.com), additional studies known to the authors, or studies discovered serendipitously by the authors until March 1, 2019. Table 3 displays examples of interventions found using these searches, and the full list of actions we encountered is in Data S3. We coded the data identically to our systematic map, using further searches and additional sources to fill in information gaps from the original source. We highlight the richness of this emerging field of conservation practice by supplementing these results with that of our systematic map.

3 | RESULTS

The challenges of performing this synthesis is also one of our key findings—that climate adaptation actions we uncovered during our ad hoc search were often a quick response to a real-time threat using managers' unique understanding of the system on a limited budget. As such, it was difficult to find information on the detailed methods and results for these actions, as well as any subsequent monitoring or evaluation.

Systematic map

Our systematic map identified nine actions targeting eight different species. Seven of these actions were in response to a direct climate threat. Taxa targeted included birds (n = 4), fish (n = 2), invertebrates (n = 2), and one reptile. Three actions occurred on islands. The highest conservation listing for a species targeted was

TABLE 2 Examples of climate adaptation actions in conservation

Example A: Supplemental feeding "The Great Knot Food Drop"



The coldest winter in decades wiped out the major food source for the critically endangered Great Knot, which uses intertidal zones in eastern Asia as a crucial stopover spot for replenishing energy to finish their migration. Ecologists saw the disaster unfolding, as hungry birds were arriving and not finding any food. An international effort to raise half a million dollars began and over 500 tons of local farmed clams were spread along the intertidal zone to huge success, tens of thousands of birds were observed feeding, with no leftovers!

ABC News (2018). "Food drop to save migratory shorebirds from starvation in China." Available at: https://www.abc.net.au/news/2018-04-12/food-dropto-save-migratory-shorebirds-from-starvation-inchina/9640988 Last accessed December 8, 2019

Example B: Translocation "Australia's rarest reptile explores new habitats"



The western swamp tortoise has been bred in captivity since 1987 by Perth Zoo. Translocations are now occurring to sites outside their natural range, as current sites are drying out and unsuitable, and new sites are predicted to be better habitat under future climate conditions. Science Mag (2016). "Relocating Australian tortoise sets controversial precedent." Available at: https://www. sciencemag.org/news/2016/08/relocating-australiantortoise-sets-controversial-precedent Last accessed December 8, 2019

Example C: Habitat improvement "Hope Floats: Chicks hatch on the Tern Raft"



Artificial nesting rafts were launched in 2017 in Langstone Harbor, UK, to provide additional nesting space for tern species. Common terns are beaten back from their winter migration by black-headed gulls who dominate the available space of this ideal breeding location. The RSPB blog provides construction and design details to assist other raft building attempts. Royal Society for the Protection of Birds (2017). "A raft at the Oyster beds?" Available at: https://community. rspb.org.uk/placestovisit/langstoneharbour/b/ weblog/posts/quot-tern-rafts-quot-at-the-oysterbedsa-new-habitat-for-some-of-our-breeding-seabirds Last accessed December 8, 2019



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vulnerable (n = 2), with the remaining either near threatened (n = 1), least concern (n = 3), or not listed (n = 3).

Ad hoc search

In contrast, our ad hoc search identified 112 actions targeting 69 different species. Forty-five percent of actions were in response to a direct climate threat. Half of the actions in our database (54%) were for birds (and seabirds were the focus of 28% of actions), a quarter (24%) targeted mammals, and the remaining covered reptiles, amphibians, insects, or fish (Figure 2a). A total of 38% of actions occurred on islands, which with seabirds on islands accounting for 25% of actions across 19 different species. Seven non-seabird species were targeted on islands. Species with a long, slow life history strategy (K-selected species) were 73% of species targeted. The IUCN Red List Conservation status of species in our database was spread across all classifications (Figure 3b).

Least concern and endangered species were equally targeted, between 23 and 24% of actions fell in each of these, followed by 18% of actions targeting both critically endangered and vulnerable species. We also found six actions that targeted unlisted species, and one action was for a data deficient species.

How are interventions being 3.1 implemented and evaluated?

Systematic map 3.1.1

Our systematic map identified actions from Australia (n = 3), New Zealand (n = 2), Europe (n = 2), and North America (n = 2). All actions were deployed in situ, except one. All occurred over non-short timescales, except one. There was an even split between terrestrial (n = 5) and marine (n = 4) environments, most actions were risk-tolerant (n = 7, see Table 3 for definition. The most

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TABLE 3 Classification categories with definitions of each climate adaptation action in our database

Source of information		
Original source	Source where authors first noted the action, including knowledge of the authors, a systematic web of science literature search, a Google ad hoc literature search, or from the conservation evidence database.	
Primary source	Where we obtained the most reliable information for filling in the details for our database. Categories included: Peer-reviewed publications, government document, government media, non-profit organization document or media, popular media including news websites, or personal knowledge.	
Species and threat faced		
Taxonomic group	Amphibian, bird, fish, insect, mammal, or reptile.	
Conservation status	International Union for the Conservation of Nature (IUCN) Red List status.	
Life history strategy	K-selected or r-selected.	
Threat targeted	Dominant threat targeted by action. Classified as climate change, introduced species and disease, resource shortage or stochastic risk.	
The action		
Continent	Continent where action occurred.	
Island	Whether the action occurred on an island or not.	
Biome	Whether the action occurred in an aquatic or terrestrial biome.	
Time-span	Either short or not-short. Short actions were one-off, short-term (i.e., one season) occurrences. Not-short actions included long-term, continuing actions or repeated short-term actions.	
Year started	The start of field activities, not including any planning or preparation time.	
Conservation method	"Ex situ" or "in situ" conservation.	
Climate vulnerability targeted	Based the IPCCC (Intergovernmental Panel for the Convention of Climate Change) vulnerability framework, did the action target the species exposure (E; remove from stress) sensitivity (S; cope with stress, when exposed) or did it aim to increase the species adaptive capacity (AC; compensate for stress at same, or any other location, that the population lives).	
What was done?	Actions classified as: Artificial breeding activities, community program or policy, increasing resources, reducing negative interactions with other species, and translocation.	
Risk	We classed adaptation actions along a continuum (as proposed by Heller & Zavaleta, 2009) from risk- adverse measures (i.e., boost resilience, more of the same for example, mitigate other threats) to risk- tolerant approaches (i.e., pre-emptive interventions to model predictions).	
Climate link	We classified each action as whether the climate motivation for the action was direct or indirect.	
Outcome of the action		
Study design	Study design of each action to assist in interpreting outcome confidence (Christie et al., 2019). Study designs included: After (A, sampling impacted population after impact), Before–After (BA, sampling impacted population before and after impact), Control-Impact (CI, sampling impacted population and control population after impact), Randomized Controlled Trial (RCT, same as CI but impact and control are applied randomly), and Before-After-Control-Impact (BACI, sampling impact and control population before and after impact).	
Overall outcome	Overall outcome of the action noted as positive or not positive (either negative or neutral), which included both anecdotal outcomes based on personal observation as well as statistically significant changes in effect size.	

commonly targeted threat was climate change impacts (n = 5), but introduced predators or disease were the target of three and one targeted resource shortage. Increasing resources was the most common action (n = 5), followed by reducing negative interactions with other species (n = 3) and one action in this database was a translocation. The earliest implementation of an action was in 1990, with another three actions

beginning in or before 2000, and the remaining four occurring after 2010.

3.1.2 | Ad hoc search

Actions found using our ad hoc search document an increasing trend in the number of actions that have been



FIGURE 2 Classification of climate adaptation interventions for iconic fauna found in our ad hoc search, bar length displays the total number of actions and data label displays the number of different species; (a) the taxa of species targeted; (b) the direct threat that was targeted by the action; (c) the type of action that was used; and (d) the study design of the action



FIGURE 3 Number of climate adaptation actions for iconic fauna found in our ad hoc search by (a) geographic region with shading representing the number of actions encountered by adhoc methods (either through the authors personal knowledge or encountered incidentally by the authors) or encountered using traditional search methods (through a deliberate search of published literature, databases, or gray literature); (b) the conservation status of species targeted as listed under the IUCN Red List, with cultured categories representing the number of actions that targeted different taxa groups

implemented over time (Figure 4). Eighty-six percent of actions occurred in a developed nation, defined as Annex 1 Parties to the United Nations Framework Convention on Climate Change (UNFCCC, 2019). Forty-three percent of actions occurred in either Australia or New Zealand (Figure 3a). The approach was evenly spread between ex-



FIGURE 4 Number of climate adaptation actions for iconic fauna, found in our ad hoc search, implemented over time in 5-year bins, categorized by (a) the direct threat that was targeted by the action and (b) the type of action that was used

situ (50%) and in-situ (50%) actions. Only 10% of actions occurred in an aquatic, as opposed to terrestrial, biome. Seventy-one percent of action were classified as occurring over a "not-short" timescale, so were either repeated or lasted multiple seasons. We classed 75% of actions as risk-tolerant, as oppose to risk-adverse. This suggests that adaptation interventions are often associated with higher levels of risk (risk-tolerant) compared with risk-adverse methods used in traditional conservation. The threat most commonly targeted was resource shortage (46%), followed by climate change (34%; Figures 2b and 4a). Most actions sought to either increase resources or involved a translocation (38 and 37%, respectively; Figures 2c and 4b). We found 66% of actions occurred after 2000, and 39% of actions occurred after 2010 (Figure 4).

3.2 | Are interventions successful?

3.2.1 | Systematic map

Five actions captured by our systematic map had robust study design including "control-impact" (n = 3) and "randomized controlled trial" (n = 2), however the remaining four did not include a control measure and were "before-after" design (n = 1) or just "after" (n = 3). All except one study (two actions) presented an effect size of the intervention. There was similar numbers of overall positive (n = 5) and not-positive (n = 4) outcomes of the nine actions.

3.2.2 | Ad hoc search

In contrast, our ad hoc search results presented "after" as the most common study design (61%), which samples the population post-impact. Only one action in our database employed the gold standard BACI (before–after-controlimpact) study design (<1%). Twenty-one actions (19%) used a study design with controls (CI: "control-impact," RCT: "randomized-control-trial" or BACI design). Only 13 of these reported their results, allowing effect size to be determined.

For 91% of actions, the outcome reported by the practitioner and used in our study is qualitative, that is, whether the project was considered a success overall, as no control or statistically significant effect could be determined. Indeed, some of these perceived positive outcomes are based solely on anecdotal observation of species present. Eighty-eight actions reported an overall positive outcome (79%) and 24 reported "not-positive" results (21%). Not-positive outcomes include overall negative outcomes (n = 13), actions with insufficient data (n = 2), actions reporting no effect (n = 2), no reported outcome (n = 6), and actions at a stage too early to have an outcome (n = 4).

Of note is the percentage of negative outcomes differed between actions which reported a control and effect size, and actions which did not. Thirteen actions in our database reported a control (i.e., had robust statistical design of BACI, CI, or RCT) and reported their empirical results and effect size. Over half of these (n = 7) reported a "not-positive" outcome, (six being negative and one "other or neutral"). For all other actions which did not have an experimental control or did not provide empirical data, 8 % had a negative outcome (and 17% had a "not positive" outcome, which includes "neutral or other" results).

The 13 actions which had a control and gave empirical results were grouped by action type. For both "reducing negative interactions with other species" (n = 3) and "translocation" (n = 2), all actions reported positive outcomes. For actions which aimed at "increasing resources," seven actions of these were classed as not positive, and one with a positive outcome. No actions classed as "artificial breeding activities" provided a control and empirical data.

4 | DISCUSSION

It was difficult to capture the breadth of studies that have no doubt occurred globally to assist iconic fauna to adapt to the current or future impacts of climate change. The emerging nature of this conservation approach did not lend itself well to a traditional, systematic literature search. In fact, only nine actions were uncovered using these standard methods. These nine actions spanned 24 years and represented multiple taxa, countries, conservation approaches, and outcomes (Data S2). To uncover the full extent of what has occurred in this field, and to learn and improve future actions, we supplemented structured database searches with opportunistic and snowball techniques. We uncovered an additional 112 actions using these ad hoc methods and created a supplementary dataset which we will use for comparisons throughout the discussion (located in Data S3).

Our larger, ad hoc dataset reveals an increasing trend in the number of actions that have been implemented over time. An increasing trend of climate adaptation considerations in biodiversity conservation has also been documented by others (Greenwood et al., 2016; Mawdsley et al., 2009; Prober et al., 2019; Stein et al., 2013). We expect continued growth of this field as climate pressures increase and species become more vulnerable, and consequently, a growing awareness and acceptance of climate adaptation as a mainstream conservation strategy. The applied nature of climate adaptation interventions may contribute to limited reporting of actions and comprehensive information in peer-reviewed journals, as was found during our systematic search of this field (Data S2). This highlights the need for publishing these actions (with both positive and negative results) and for the consistent use of keywords, in traditional journal formats or other databases. We do not claim to have located all adaptation actions that have occurred for

iconic fauna, however, we searched widely to discover studies published online.

4.1 | Outcomes and reporting

For the nine actions included in our systematic map, only five had robust experimental design with a control measure. Our ad hoc dataset reported mostly positively perceived outcomes (79% of actions). However, robust and systematic science behind these reported positive outcomes was lacking, with just 21 (19%) studies reporting results alongside a control and only 13 of these documenting actual results. Interestingly, actions which conducted robust experimental design had a much higher proportion of negative outcomes than those which made broad claims on the success of their action without empirical or statistical evidence. This highlights the importance of properly evaluating adaptation actions, to reduce risk of exaggerating success.

We expected there to be a substantial number of negative outcomes, because climate adaptation is often experimental. This is demonstrated by the fact that three quarters of the actions in our ad hoc database were classed as risk-tolerant, and seven of nine from the systematic map. However, failures for climate adaptation actions were not commonly reported. As with most science, negative results are not celebrated or published as often (Browman, Ruse, Allchin, Hull, & Underwood, 1999). We emphasize the need to publish and promote failures or neutral results, as there are likely many lessons to learn. When working with threatened species, making the same mistakes more than once is particularly problematic, so sharing and learning from failures should be emphasized. Alternatively, a possible bias in the abundance of positive outcomes is the unavoidable presence of a priori knowledge, and a preference of practitioners toward implementing actions that they have strong reason to believe will be successful, especially when working on interventionist projects.

Furthermore, "gold-standard" experimental design (BACI and RCT) was not common practice for the climate adaptation actions in either dataset (Figure 2d). With ecological studies, there are logistical difficulties to having a randomized, repeated study so evaluations made from the outcomes of these actions are not robust (Christie et al., 2019). This highlights a key difficultly in evaluating climate adaptation actions, that the context of climate adaptation interventions does not lend itself to systematic, statistical study design. Indeed, many of the climate adaptation interventions we uncovered were seemingly small-scale, low-budget trials based on the personal knowledge of people working on the species, with no intensive monitoring or evaluation (Data S3). In comparison, large and expensive undertakings such as renewable energy construction projects or marine protected area creation are often required to have well-resourced monitoring and evaluating programs. Additional barriers to evaluation, and thus evidence-based decisions, have been reported in the literature, both for conservation (Ferraro & Pattanayak, 2006; Rose et al., 2018; Sanders, Miller, Bhagwat, & Rogers, 2021; Walsh, Dicks, Raymond, & Sutherland, 2019) and in other fields (Bach-Mortensen & Montgomery, 2018; Jones et al., 2013). Lack of time, capacity, or incentive by practitioners, to engage with setting up the intervention to allow for robust evaluation, collecting the correct and right amount of data and in data management and evaluation methods afterward, are all pathways for the resources spent on an intervention to be lost (Buxton et al., 2021). Furthermore, in applied science, if something seems to be working, implementing controls and exposing individuals to a detrimental treatment can pose an ethical dilemma fisheries bycatch mitigation, (e.g., Hamilton & Baker, 2019). This myriad of reasons can provide an explanation for the limited actions we found in peerreviewed literature. For stakeholders to invest in climate adaptation, and for motivation to act in the first place, strong evidence is required (Salafsky et al., 2019), which relies on robust study design (Josefsson et al., 2020).. We highlight this mismatch as a key area of need for further thought and development, (e.g., Schleicher et al., 2020).

Location of actions 4.2

All actions within our systematic map, and 86% of actions encountered during our ad hoc search, occurred in developed countries, which we defined as Annex I parties to the UNFCCC convention (UNFCCC, 2019). Developed countries typically have more resources to expend on conservation (Waldron et al., 2013). As a climate adaptation grows as a conservation strategy, we expect that most growth will occur in developed countries. It is therefore important to facilitate the exchange of information and knowledge to developing countries where vulnerability to climate change is also high (Mendelsohn, Dinar, & Williams, 2006). Although cost is usually not reported in conservation (Pienkowski, Cook, Verma, & Carrasco, 2021), as the majority of actions we uncovered were not associated with elaborate monitoring, research, or evaluation programs it is reasonable to assume that current climate adaptation on the ground is not typically large-scale or well-resourced compared with traditional large-scale conservation initiatives such as establishing protected areas. It seems instead that the

know-how and confidence to implement these risktolerant strategies came from experienced people with a strong theoretical background of the system they were working in. Almost half of the actions (five of nine actions within our systematic map and 43% of actions from our ad hoc search) occurred in Australia or New Zealand. As all authors of this study are based in this region, our expertise and awareness of climate adaptation in this area is greatest. However, Australia and New Zealand still ranked as the most common locations in the robust results of our systematic map (five of nine) and even after excluding studies identified from personal knowledge through our ad hoc searching (Figure 3a). We believe actions occurring in Australia and New Zealand are representative of climate adaptation interventions occurring in developed countries, and so do not believe interpretation of any results needs to consider this geographic skew. Ninety percent of actions found using ad hoc methods occurred in a terrestrial biome, highlighting the logistical difficultly of intervening in the marine environment. However, this was not comparable with our systematic map results with roughly equal occurrences of marine and terrestrial interventions. For marine fauna that interact with coastal areas such as seabirds, coastal environments can provide an opportunity for intervention (e.g., targeting nesting habitat).

4.3 **Common interventions**

Under the IPCC's framework for assessing climate vulnerability, actions can target a species' exposure, sensitivity, or adaptive capacity to climate change impacts (Hobday et al., 2015). We found evidence of actions that fell into all three categories in both datasets. For example, moving nests away from storm surges reduces exposure to climate impacts, supplementary feeding in years of suboptimal conditions reduces a species sensitivity to climate impacts, and releasing captive-bred individuals into a population increases the adaptive capacity of a population. Increasing resources was the most common approach in both datasets. This is an intuitive approach and covers a broad range of actions including supplementary feeding, creating new habitat, and improving existing habitat. Generally, this is a risk-tolerant approach. Translocation is a long-standing and established conservation practice (Griffith, Scott, Carpenter, & Reed, 1989), with one occurrence found in the systematic map, and 37% of actions using ad hoc methods. The global conservation community can be considered as experienced with this technique, and again intuitively, it makes a lot of sense to move species to more suitable environments.

Species garnering high levels of attention, funding and investment are often the subject of long-term researcher interest or programs. Therefore, it is likely that many species in our database were "pet" study species and climate adaptation work was undertaken on the species due to relative ease rather than as an urgent conservation measure. For these long-term research programs, there is significant knowledge of the study species, and many resources and start-up costs are already in place, that is, a climate adaptation intervention can piggy-back on existing field programs. This could contribute to the spread of actions across IUCN Red List statuses-from least concern to critically endangered species for our ad hoc dataset (Figure 3b), and all actions targeting species listed as vulnerable or below in the systematic map. This suggests practitioners are implementing adaptation strategies for species of different extinction vulnerabilities, and for actions in our systematic map, mostly on species with lower conservation concern. This is encouraging, as we need to be testing these strategies while populations are still robust and not when they are critically endangered and cannot afford to make mistakes. It is important to highlight the limitations of the IUCN classification system, and that the priorities of local managers and a nuanced and intimate understanding of a species may not be reflected in the IUCN classification, due to political or funding barriers, or even the very structure of the system. However, the Red List classification does provide a good baseline to compare across species.

We found very limited evidence of pre-emptive actions based on climate predictions, all located in our ad hoc dataset. This included one supplementary feeding event based on predictions of food shortage, and four translocations based on future climate predictions. Lots of the actions were based on knowing climate would be a broad issue for the species in the future-so acting to bolster populations with a range of conservation measures. We did not find actions that specifically considered how their long-term projects would be affected under future climate scenarios. We expect these considerations would have been considered by the practitioners, but they are not specifically stated or dealt with in the sources we had. We recommend that as part of the reporting requirements for climate adaptation actions, consideration is given to how the project will perform and be impacted by future climate scenarios, and what flexibility has been built into the project to maximize its success and longevity in these scenarios (Box 1).

Overall, climate adaptation interventions are emerging as an important conservation practice. As the field is still developing, there is no standardized procedures for implementing or reporting on these efforts, and as such, there is little formal evaluation available in the public domain. Alongside many other endeavors in conservation, there are improvements needed to ensure resources

BOX 1 Recommendations

- 1. An increase in the reporting and sharing of adaptation actions for biodiversity conservation. including those with negative outcomes (Matosin, Frank, Engel, Lum, & Newell, 2014). This allows practitioners to learn from the successes and failures of other interventions and form productive collaborations. As part of an overall increase in reporting of climate adaptation attempts, we suggest the following:
 - a. Design and implement controls measure for all adaptation actions, to allow actions to be evaluated and learnt from. When undertaking invasive management on threatened species, it is irresponsible to embark on anything less than robust science. Consider also, the importance of evidence-based conservation, and the need for quantitative data (Salafsky et al., 2019).
 - b. Report outcomes of adaptation actions, includes the effect size, sample size, time scale and control measure, and "threat (s)" being mitigated.
 - c. Create online portals or databases for conservation managers to upload their adaptation stories and results in standardized format, for ease of sharing, building networks and for others to review and analyze the field in a systematic way (e.g., CakeX, Conservation Evidence, or weADAPT).
- 2. Test "outside-the-box," innovative actions, designed for the individual study species and system. Bold, broad actions, such as translocations and captive breeding have their place, but often, simple and specialized is best. This review has shown that small, targeted actions, inspired by local, contextspecific threats, constraints, and knowledge, can be feasible and impactful to the target species. Again, the degree and significance of this impact is unknown until proper experimental design and evaluation of these studies is commonplace. Do not be afraid to try something unique-based on your experience of the system and species!
- 3. Explore and test actions that target the specific climate threat and/or capitalize on climaterelated opportunities, such as extreme events that simulate future environmental conditions. These types of actions are the next frontier for climate change interventions and will further test efficacy of conservation tools for iconic fauna in a changing world.

are not wasted, but instead, used to propel the field forward (Buxton et al., 2021). Our research is the first, to our knowledge, to take stock and assess what has been done, opening up the discourse for this field to develop a systematic approach moving forward and overall, implement more effective actions to assist iconic fauna into the future.

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CONFLICT OF INTEREST

The authors declare no conflicts of interest.

AUTHOR CONTRIBUTION

Claire Mason: Conceived the project, conducted the literature search; and wrote the manuscript with input from all authors. Alistair J. Hobday: Conceived the project. Rachael Alderman: Conceived the project. Mary-Anne Lea: Conceived the project.

DATA AVAILABILITY STATEMENT

All data from this study can be accessed at https:// research.csiro.au/teps/data

ORCID

Claire Mason bhttps://orcid.org/0000-0001-8063-5812 Mary-Anne Lea https://orcid.org/0000-0001-8318-9299

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SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section at the end of this article.

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