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Review

A good idea or just an idea: Which adaptation strategies for conservation are tested?

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ABSTRACT

Several highly cited review articles identify recommended adaptation strategies for conservation. However, those reviews do not include evaluation of whether the recommended adaptation measures were tested and found to be effective in reducing climate change vulnerability. The basic question of this paper is to determine if there has been assessment of the potential effectiveness of adaptation recommendations for conservation reported in the published literature, and if so, what kind of assessment was used. To answer this question, literature was surveyed from the references in previous review papers focused on climate change adaptation recommendations, and augmented by a targeted literature search to identify studies that assess the effectiveness of recommended adaptation actions listed in those reviews. Identified studies were categorized by study type according to a hierarchy of adaptation efficacy testing. The result was a very modest number of studies that experimentally tested adaptation efficacy ($n = 13$), including only one indicating the chosen strategy did not achieve its intended goal, and only one study that tested efficacy through monitoring. For some of the recommendations, only one efficacy-assessing paper was identified. There appears to be a significant shortage of studies presenting evidence that would be most useful in determining if a recommended action is likely to confer the desired conservation improvement, as well as a stagnation in the growth of the field. This points to a need for more efforts to monitor and evaluate the effectiveness of adaptation recommendations for biodiversity management. Without it, we cannot learn which are the good ideas.

1. Introduction

As with any emerging field, ideas must be generated before actions can be taken, and actions must be taken before their effectiveness can be determined. For the past few decades, climate change adaptation ideas have developed into recommendations which in turn have begun to be implemented. Several reviews (Heller and Zavaleta, 2009; McLaughlin et al., 2022; Skikne et al., 2021; Beller et al., 2020; Hewitt et al., 2011) have surveyed the field to determine the most frequently proposed actions. McLaughlin et al. (2022) count and categorize the "ecological recommendations for biodiversity management with climate change" from 1985 to 2007 and from 2007 to 2017, and close by highlighting the "critical need for increased testing and monitoring" of these recommended actions. In response to this need for more testing, this paper sets out to determine how much testing and monitoring of adaptation actions has been undertaken to support the most frequently recommended categories of adaptation actions for conservation management (including marine, freshwater, and terrestrial) identified by McLaughlin et al. (2022). This task was undertaken by reviewing their cited studies and surveying the broader literature for additional studies that document such analysis. Understanding which climate change adaptation actions are effective is crucial to all efforts to improve conservation outcomes in a changing climate. This will let us know what are good ideas and what are just ideas – an important distinction to make given limited resources and increasing urgency as climate change continues to affect natural systems.

Previous reviews have clearly stated that they were not evaluating the efficacy of the recommendations presented (McLaughlin et al., 2022), rather they document the range and frequency of adaptation action identification or implementation (McLaughlin et al., 2022; Reside et al., 2018; Skikne et al., 2021; Heller and Zavaleta, 2009). Determining if there is an existing body of evidence for these most recommended adaptation strategies is the next step in developing the field and providing defensible guidance.

Evidence-supported adaptation recommendations may help overcome some of the barriers identified for adaptation, implementation,

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and innovation (Jantarasami et al., 2010; Barnett et al., 2015; Lonsdale et al., 2017; McLaughlin et al., 2022). For example, if conservation practitioners are risk averse, knowing that a measure proved effective in a similar application could encourage adoption and a shift from historical conservation approaches that are vulnerable to climate change. Similarly, it can increase awareness of other suitable options, thereby expanding conservation practitioners' toolkits.

Additionally, evidence-based assessments of adaptation efficacy are a critical component of building the field of climate change adaptation. As with the call for evidence-based conservation in general, the benefits would include "become more effective and attract increased support from society" (Salafsky et al., 2019) and meeting the "urgent need for mechanisms that review available information and make recommendations to practitioners" (Sutherland et al., 2004). These goals are vital for conservation and, given the scale and speed of climate change, of perhaps even greater importance for adaptation (Lynch et al., 2022). This paper describes a targeted literature search undertaken to identify where there is an evidence base and what kind of evidence it includes. In turn, where gaps and limited research in efficacy testing are identified, it highlights the need for such evidence gathering as a standard part of adaptation practice to expedite learning in this growing and important field.

2. Methods

The goal of this paper was to find where evidence exists in the literature to evaluate the effectiveness of the most frequently recommended adaptation categories for conservation management (Table 1) as presented by McLaughlin et al. (2022). This evidence could be the testing or implementation with monitoring of these adaptation actions.

Two review approaches were employed. We began with the 332 papers evaluated by McLaughlin et al. (2022). The papers that fit both the McLaughlin et al. (2022) and the Heller and Zavaleta (2009) "top 10" (resulting in 16 categories with rank order ties) recommended adaptation approach categories (Table 1) were identified. This resulted in 130 papers.

We found a very small number of papers cited by McLaughlin et al. (2022) that explicitly tested adaptation actions. This, and the fact that McLaughlin et al. (2022) did not use testing of adaptation as criteria for inclusion of papers in their review, prompted us to conduct a separate, targeted literature review. In this targeted review, we specifically tried to find papers that explicitly evaluated adaptation actions using Google Scholar as the primary tool for identifying relevant publications, with supplementary searches conducted on Web of Science, BioOne, Scopus, and ScienceDirect. The search filter was broad, involving combinations of search terms that are diagnostic of papers related to the adaptation field such as:

- **Management**: adaptation, restore/restoration, protect/protection, conservation, reserve, protected area, relocation, refugia, connectivity, reforestation, reintroduction, assisted migration, landward migration, geophysical heterogeneity, genetic/phenotypic diversity, climate-adaptive genetics, biodiversity
- **Efficacy**: adaptive management, effective/effectiveness, monitor/monitoring, evaluate/evaluation
- **Climate change and variables**: precipitation, wildfire, air temperature, flooding, habitat extent, sea level rise, extreme weather, erosion, sea surface/ocean/water temperature, range shift, acidification, drought, salinity, invasive/non-native species

We retained papers that contained the following elements: climate change, management/adaptation strategy, and a monitoring or evaluation technique. This process identified 269 papers that were then screened to determine potential relevance, defined as studies where implemented adaptation strategies are monitored for effectiveness or otherwise tested. Articles that focused on theoretical approaches, or that were reviews of the literature were excluded.

In order to determine the role a paper might play in assessing adaptation, a hierarchy of adaptation efficacy testing (Table 2) was created. We used this hierarchy to categorize all papers (those identified in McLaughlin et al., 2022 and our independent literature search) according to the kind of evidence being presented, ranging from "general guidance-based and climate-informed adaptation identification" to "experimentally tested climate adaptation," with intermediary approaches including "climate and biology-informed adaptation (modeling and conservation tested)" (note "conservation tested" means that the assessment did not evaluate its effectiveness as an adaptation strategy, rather it had been used successfully in general conservation

Table 1
Most often recommended adaptation actions for conservation (derived from Table 1 of McLaughlin et al., 2022).

"Top 10" Ecological recommendations for conservation management[a]	Heller and Zavaleta (2009) "Top 10"	McLaughlin et al. (2022) "Top 10"
Increase Connectivity	√	√
Protect or restore ecosystem structure or function	√	√
Manage the matrix	√	
Manage at larger scales, or across scales	√	√
Manage for flexibility/uncertainty	√	
Adaptive management	√	√
Species reintroductions within known range	√	
Protect geophysical heterogeneity	√	
Manage invasive species	√	
Manage for genetic/phenotypic diversity	√	√
Mitigate non-climatic threats	√	√
Manage for climate change refugia		√
Climate-adaptive assisted migration (species and populations)		√
Forest Management		√
Manage for climate-adaptive genetics		√
Target future conditions through habitat protection or restoration		√

[a] There are >10 in the "Top 10" due to rank order ties. Additionally, the recommendation "conduct monitoring" was omitted as this is a necessary component of the testing being examined in this review.

Table 2
Hierarchy of adaptation efficacy.

	Level	Description
1	General Guidance-based and Climate-informed Adaptation Identification	Recommendation is made based on personal understanding of climate change, the action is listed previously in a paper or guidance, or it is made to address a climate change threat/hazard/impact based on general climate projections.
2	Climate and Biology-informed Adaptation: Modeling and Conservation Tested	Recommendation is identified based on modeling species or habitat responses to climate change; or arises from actions generally used for conservation where effectiveness has been equated to efficacy in the ability to ameliorate the impacts of climate change.
3	Climate Adaptation with Effectiveness Monitoring	Recommendation is an implemented action that has been monitored to assess its effectiveness including evaluation of near-term markers and long-term expectations.
4	Experimentally Tested Climate Adaptation	Recommendation is an action that has explicitly been taken to reduce climate vulnerability and efficacy has been assessed by hypothesis or comparison testing (ideally including controls).

practice) and "climate adaptation with effectiveness monitoring" (Fig. 1). This analysis focused only on those papers that fit into one of these categories, omitting those that did not assess adaptation. The hierarchy approach helps us better describe a continuum of treatment of adaptation in the literature, from general assumptions of how adaptation might function under climate change to explicitly, experimentally testing adaptation strategies to determine where there is evidence to support those "top 10" recommendations, as well as where there are likely gaps in the evidence. All papers were sorted into the "ecological recommendation for biodiversity management" categories from McLaughlin et al. (2022), with papers from McLaughlin et al. (2022) kept in the categories to which they were assigned by those authors.

To further understand where and when adaptation efficacy is being evaluated, we also explored additional features of the categorized papers, including their geographic distribution (what continents are represented in the research), the diversity of taxa (single or multiple species or groups), and patterns in timing of publications (the number of adaptation papers published across years).

3. Results

Given the focus of this review on identifying evidence to assess the effectiveness of recommendations for adaptation strategies, papers in Categories 2 and above (Table 2) were the primary focus of further analysis. All of the papers that fit these categories, from the initial pool of references in McLaughlin et al. (2022) as well as from the targeted literature survey, are presented in Table 3. In several cases, individual studies addressed more than one adaptation strategy recommendation category and are therefore listed multiple times in Table 3.

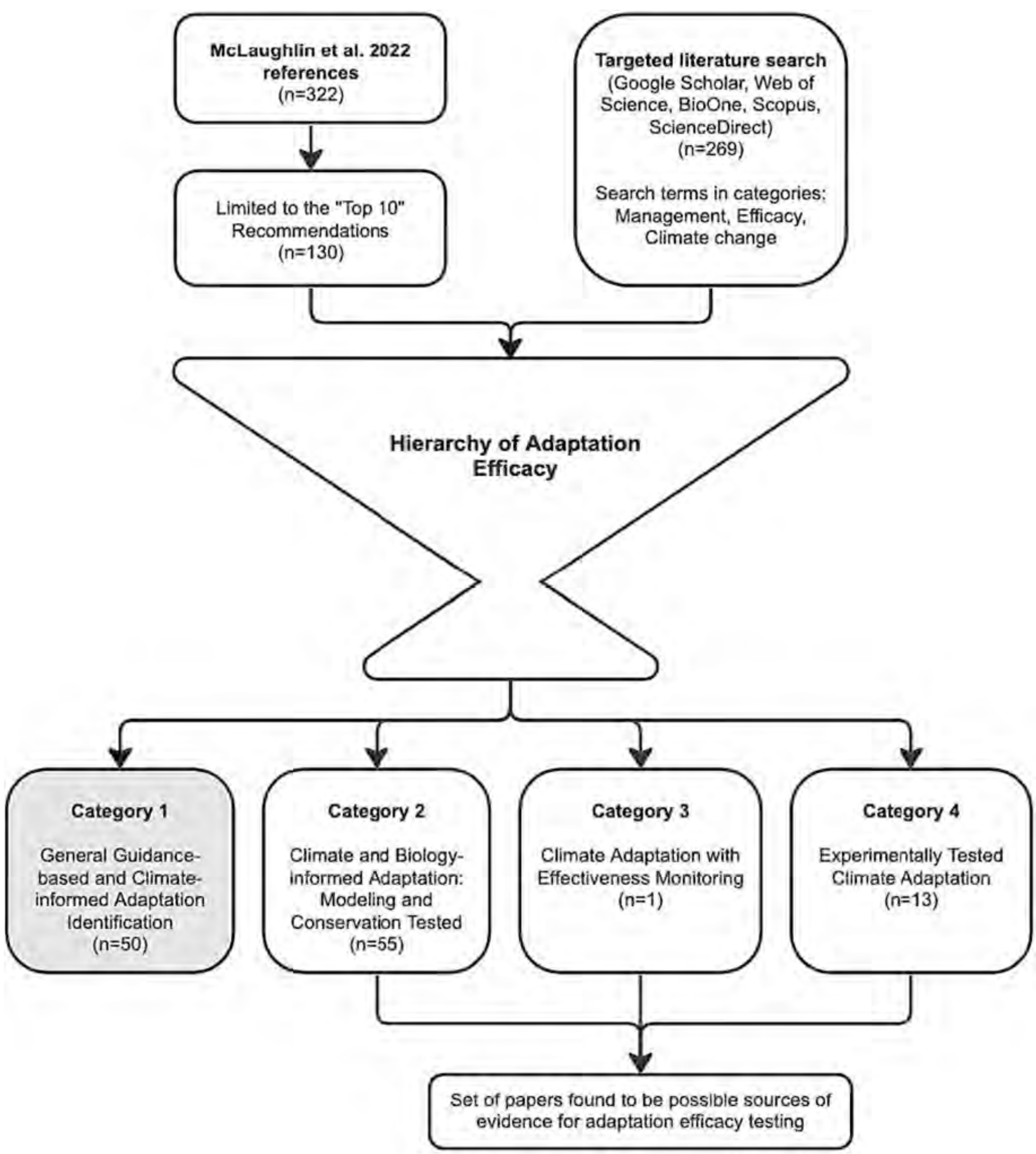

Fig. 1. Overview of the methodology employed for filtering and selecting relevant research using the hierarchy of adaptation efficacy.

Table 3
Level of evidence for each of the "top 10" ecological recommendations for biodiversity management with climate change" identified by McLaughlin et al. (2022) and Heller and Zavaleta (2009). Citations listed in **bold** are from a targeted literature survey beyond the McLaughlin et al. (2022) reference. Citations listed in [brackets] show the strategy to not confer the desired advantage. Several papers appear in more than one "ecological recommendations for conservation management" category.

Ecological recommendations for biodiversity management	2: Climate and biology-informed adaptation: conservation tested and modeling	3: Climate adaptation with effectiveness monitoring	4: Experimentally tested climate adaptation
Increase Connectivity	Bagchi et al., 2012, Emslie et al., 2015, Galatowitsch et al., 2009, Kreyling et al., 2010, Oliver et al., 2015, Ramirez-Villegas et al., 2014, Rüter et al., 2014, Zimbres et al., 2012		
Protect or restore ecosystem structure or function	Aguirre-Gutiérrez et al., 2015, [Bruno et al., 2019], Carassou et al., 2013, Carroll, 2010, Ellis et al., 2007, Emslie et al., 2015, Ferrario et al., 2014, [Graham et al., 2015], Jarvis et al., 2008, Kattwinkel et al., 2011, Luo et al., 2015, Mason et al., 2015, Micheli et al., 2012, Montero-Serra et al., 2019, Pichancourt et al., 2014, Prober et al., 2012, Smith et al., 2018, Taira et al., 2017, Thorne et al., 2013, Ureta et al., 2012, West and Salm, 2003	Perkins et al., 2020	**Anthony et al.,** 2011, [Selig et al., 2012], Stagg and Mendelssohn, 2010, Thorne et al., 2019
Manage the matrix	Ignatavicius and Toleikiene, 2017		
Manage at larger scales, or across scales	Li et al., 2016, Ramirez-Villegas et al., 2014, Rüter et al., 2014, Zimbres et al., 2012		
Manage for flexibility/uncertainty	Bagchi et al., 2012		
Adaptive management	Alagador et al., 2014, Bagchi et al., 2012, Galatowitsch et al., 2009, Temperli et al., 2012		
Species reintroductions within known range	Beever et al., 2010, Mason et al., 2015		
Protect geophysical heterogeneity	Greenberg et al., 2015		
Manage invasive species	Ficetola et al., 2009, Gallardo et al., 2017, Prober et al., 2012, Tracey et al., 2015		
Manage for genetic/phenotypic diversity	Galatowitsch et al., 2009, Ignatavicius and Toleikiene, 2017, Mason et al., 2015, Pfeifer-Meister et al., 2013		Ehlers et al., 2008, Reusch et al., 2005, Wilson et al., 2016
Mitigate non-climatic threats	Adams-Hosking et al., 2011, Ellis et al., 2007, Kattwinkel et al., 2011, Pearce-Higgins et al., 2019, Van Teeffelen et al., 2015, Wooldridge, 2009		Shaver et al., 2018
Manage for climate change refugia	Adams-Hosking et al., 2011, Catry et al., 2011, Gallardo et al., 2017, Jarvis et al., 2008, Jones et al., 2016, Li et al., 2016, Morelli et al., 2017, Ramirez-Villegas et al., 2014, Thorne et al., 2013, Van Teeffelen et al., 2015, West and Salm, 2003		Carroll et al., 2011
Climate-adaptive assisted migration (species and populations)	Galatowitsch et al., 2009, Jarvis et al., 2008, Joyce and Rehfeldt, 2013, Pfeifer-Meister et al., 2013, Rüter et al., 2014, Schreiber et al., 2013, St Clair and Howe, 2007, Taira et al., 2017		Gray et al., 2011, Wilson et al., 2016
Forest Management	Boisramé et al., 2017, Carroll, 2010, Galatowitsch et al., 2009, Joyce and Rehfeldt, 2013, **O'Neill et al.,** 2008, Pardos et al., 2017,		**D'Amato et al.,** 2013, Gray et al., 2011, Russell and Krakowski, 2012

(continued on next page)

Table 3 (*continued*)

Ecological recommendations for biodiversity management	2: Climate and biology-informed adaptation: conservation tested and modeling	3: Climate adaptation with effectiveness monitoring	4: Experimentally tested climate adaptation
	Pichancourt et al., 2014, St Clair and Howe, 2007, Temperli et al., 2012		
Manage for climate-adaptive genetics	Aguirre-Gutiérrez et al., 2015, Joyce and Rehfeldt, 2013, **O'Neill et al.,** 2008, St Clair and Howe, 2007, Ureta et al., 2012		Gray et al., 2011, Parker et al., 2011
Target future conditions through habitat protection or restoration	Alagador et al., 2014, Beever et al., 2010, Butterfield et al., 2017, Carroll, 2010, D'Amen et al., 2011, Emslie et al., 2015, Gallardo et al., 2017, [Graham et al., 2015], Greenberg et al., 2015, Jones et al., 2016, Kreyling et al., 2010, Keane et al., 2017, Li et al., 2016, Luo et al., 2015, Marini et al., 2009, Oliver et al., 2015, Rüter et al., 2014, Van Teeffelen et al., 2015, West and Salm, 2003, Zimbres et al., 2012		Gray et al., 2011, [Selig et al., 2012], Thorne et al., 2019, Wilson et al., 2016

3.1. McLaughlin et al. (2022) results

Of the 130 papers identified in the 2022 review by McLaughlin et al. related to one or more of the "top 10" recommendation categories, more than half (58 %) are studies that do not assess adaptation efficacy. Thirty-six papers were categorized as Category 2 or higher. Of these papers, 31 were in Category 2 (Climate and Biology-informed Adaptation: Modeling and Conservation Tested), five in Category 4 (Experimentally Tested Climate Adaptation), and none were found that met the criteria of Category 3 (Climate Adaptation with Effectiveness Monitoring) (Fig. 2).

The 31 papers from McLaughlin et al. (2022) that received a ranking of Category 2 explicitly included modeling of specific metrics, such as the demography or persistence of one or more species or habitats under climate change projections, and explicitly stated adaptation recommendations for the conservation of the targeted species or systems studied.

Most of the papers in Category 2, particularly those addressing single or multiple species within a taxon, focused on using the outcomes of their research to help inform the designation and management of reserves or other types of habitat management to support the species in question. In several cases, researchers identified a geographic mismatch

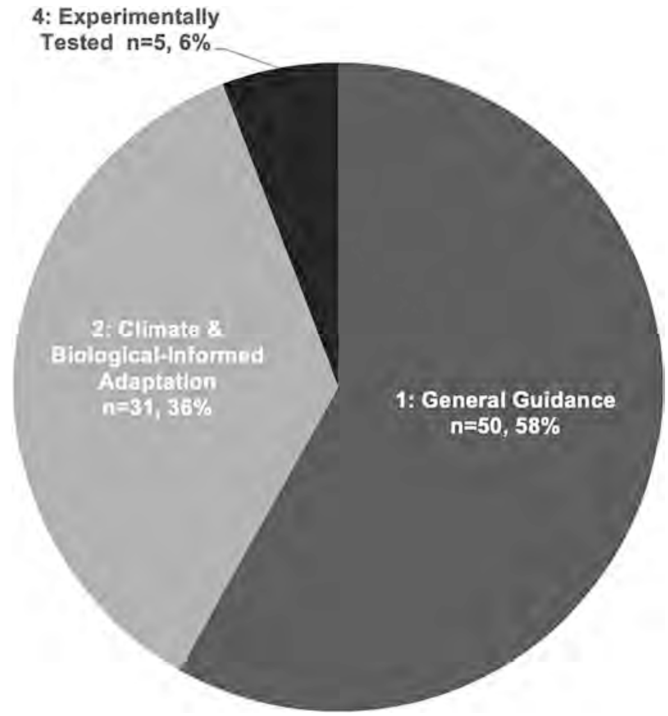

Fig. 2. Hierarchy of adaptation efficacy categorization (see Table 2 for definitions) of papers from McLaughlin et al. (2022). No studies met the criteria of Category 3 (Climate Adaptation with Effectiveness Monitoring).

between current protected areas and those that would be required to meet the ecological needs of species given projected climate change. In a few cases, papers provided recommendations for specific management interventions based on the modeled outcomes: for example, Catry et al. (2011) made recommendations for the materials and orientation of kestrel nest-boxes that could support lower rates of dehydration and mortality in nestlings under climate change; and Ficetola et al. (2009) used climate projections to evaluate the future distribution of invasive slider turtles as a basis for informing control efforts to reduce this population.

Five papers in the McLaughlin et al. (2022) review were assigned to Category 4 as having assessed the effectiveness of implemented adaptation actions by hypothesis or comparison testing. These studies matched seven of the "top 10" adaptation recommendation categories (Table 3). Three of the five studies (Carroll et al., 2011; Ehlers et al., 2008, and Wilson et al., 2016) conducted adaptation actions and monitored species' responses under conditions to simulate expected climate change predictions, such as thermal stress and drought/drying; another study evaluated assisted migration potential for aspens (Gray et al., 2011), and one looked at primary productivity in the context of managing marsh surface elevations in the context of sea level rise (Stagg and Mendelssohn, 2010).

Six continents were represented in the studies covered in McLaughlin et al.'s (2022) review; however, most of the research occurred in North America ($n = 10$) and Europe (n = 10), with only three studies each in Africa and South America, two each in Asia and Australia, and one paper focused on modeling without specific geography. Eleven papers focused on modeling and recommendations for single species (e.g., spotted owl, snow leopard, slider turtles), while the other 20 papers in this group focused on multiple species or taxa. Two studies were focused primarily on modeling climate change outcomes for habitats or ecosystems rather than individual species or populations.

3.2. Additional search results

Of the 269 papers identified in the targeted survey beyond those cited in McLaughlin et al. (2022), 33 were in Category 2 or higher. There is a similar pattern to the kind of efficacy assessments, in Category 2 or higher, that have been undertaken (Fig. 3b and c) in these additional papers. In both datasets, Category 2 makes up the majority of the assessments, with some in Category 4 (experimentally tested), and one example of Category 3 (effectiveness monitoring) (Fig. 3).

3.3. Category 2

Of the additional publications reviewed, 24 received a rating of Category 2. The majority of Category 2 (n = 17) studies fell within “protect or restore ecosystem structure or function” or “target future conditions through habitat protection and restoration” recommendations, with eight of these focused specifically on corals and coral reefs. The majority of coral studies were based largely on conservation practices such as marine protected areas, fishing restrictions, and species protection. Bruno et al. (2019) identified 18 studies that measured coral resistance and/or recovery from large-scale disturbances in well-enforced no-take reserves and control sites (considering only direct empirical field tests) and found no measurable increase in the resilience of coral communities to global stressors within marine protected areas, despite other documented benefits (e.g., protection/restoration of biodiversity). Graham et al. (2015) came to a similar conclusion that reefs in no-take marine reserves were no more likely to recover than reefs located outside of protected areas, suggesting that they have little influence on post-disturbance recovery even if they do have some benefits on coral cover in the absence of disturbance. Montero-Serra et al. (2019) found that while the structural dynamics of coral reef species may be enhanced by being located within marine protected areas, it was unclear if the protected area would build resilience in coral communities to climate change. When looking at species other than corals, Micheli et al. (2012) found that marine reserves may increase the resilience of pink abalone (*Haliotis corrugata*) in mass mortality events caused by climate change.

Non-coral-related studies showed that protected areas could provide resistance to biological invasions (Gallardo et al., 2017), however, a greater quantity focused on adaptation strategies such as restoration (Keane et al., 2017; Smith et al., 2018) and climate change refugia (Morelli et al., 2017), as well as adaptive management, forest management, and climate-adaptive genetics (Temperli et al., 2012; O'Neill et al., 2008; Joyce and Rehfeldt, 2013).

3.4. Category 3

Only one publication was identified as Category 3 on the hierarchy of adaptation efficacy. Perkins et al. (2020) monitored the effects of no-take marine reserves on the resilience of a reef and kelp system to an urchin invasion coinciding with warming regional marine temperatures. The study modeled the percentage of urchin barrens in an east coast Tasmanian no-take reserve and nearby control sites using time-series imagery. Data were collected over five years and showed that the no-take reserve did improve resistance to the initial establishment of urchin barrens, however, the data did not indicate that there is a recovery from barrens once they are already established within a no-take reserve.

3.5. Category 4

Of the papers reviewed in the general literature search, we ranked eight as Category 4 (Fig. 3). One paper, Selig et al. (2012), found the recommendation to not be effective (Table 3). In assessing marine protected areas for coral reef management, the authors concluded that the strategy was ineffective in reducing the effects of warm water temperatures on coral cover declines, citing potential shortfalls in design or sizing of the MPAs under study. The remaining seven Category 4 papers all tested, with positive results, the effectiveness of an adaptation action using quantitative metrics, and matched six of the “top 10” adaptation recommendation categories (Table 3). A majority (n = 4) were conducted in North America, one in Europe, and two in Australia. Ecosystems evaluated in this category included coral reefs, oysters, seagrass, and tree species of economic and ecological importance. The two papers that described adaptation strategies for tree species spanned time periods of decades in order to capture relevant metrics such as tree height and growth rates under management strategies of translocation across climatic zones (Russell and Krakowski, 2012) and thinning and response to drought (D'Amato et al., 2013). The other studies in this category were focused on more proximate metrics such as water chemistry, sedimentation, and invertebrate growth, and were evaluating much

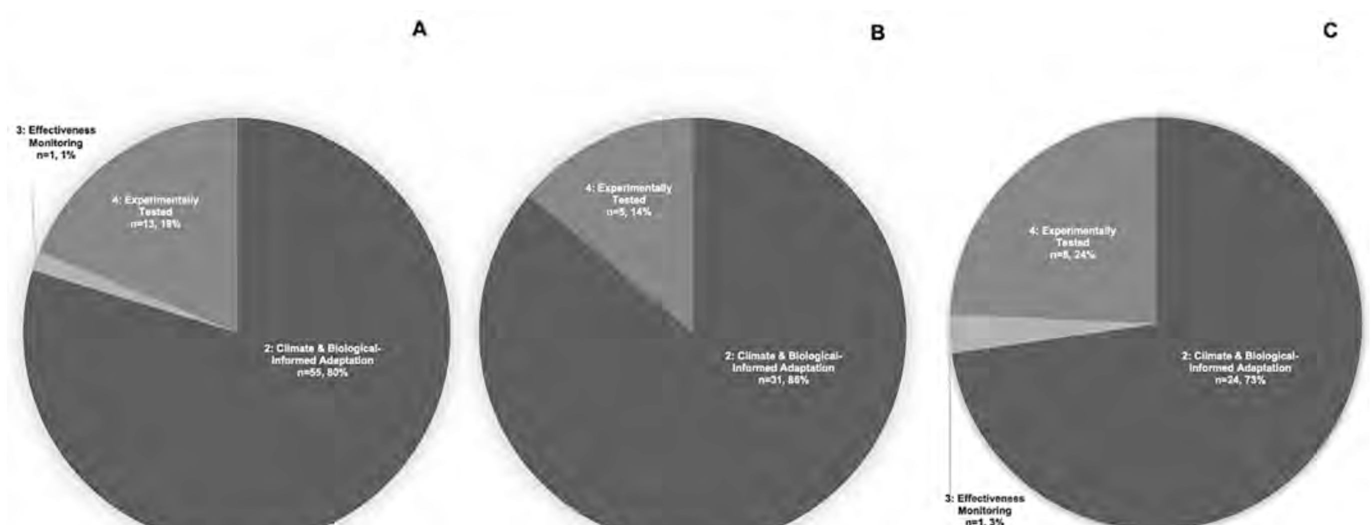

Fig. 3. Hierarchy of adaptation efficacy of papers categorized at or above 2 for a) all of the papers considered in this review, b) the references from McLaughlin et al. (2022), and c) for the additional targeted review.

shorter time periods of weeks to a few years.

Five continents were represented in these studies with the majority occurring in North America ($n = 9$) and Europe ($n = 5$). The remaining ten studies occurred in Australia ($n = 3$), Asia ($n = 3$), and Africa ($n = 1$), and three studies had a global focus. Ten of the studies focused on modeling and recommendations for a single species (e.g., pink abalone, whitebark pine, trembling aspen, Welsh black grouse, cordgrass, lodgepole pine) and four for multiple species or taxa. One study focused on habitat-level recommendations and nine of the studies focused specifically on coral species or coral reefs.

3.6. By recommendation

The recommendation categories with the most assessment to date, as demonstrated by the largest number of studies in the hierarchy of adaptation efficacy Categories 2 and greater, include "protect or restore ecosystem structure or function" and "target future conditions through habitat protection or restoration" (Fig. 4). In both cases there are more than twenty studies, including four each in Category 4 wherein the approaches were experimentally tested, although in one of these studies (relevant to both recommendations) the finding was that the recommendation was not effective (Selig et al., 2012). "Protect or restore ecosystem structure or function" is unique in that it is the only recommendation for which a Category 3 study was identified that assessed effectiveness by monitoring implementation (Perkins et al., 2020). In the mid-range of evidence are recommendations with 7 to 12 studies, including "increase connectivity," "manage for genetic/phenotypic diversity," "mitigate non-climatic threats," "manage for climate refugia," "climate-adaptive assisted migration (species and populations)," "forest management," and "manage for climate-adaptive genetics." Recommendation categories with the fewest studies identified (<5) include "manage the matrix," "manage at larger scales or across scales," "manage for flexibility/uncertainty," "adaptive management," "species reintroductions within known range," "protect geophysical heterogeneity," and "manage invasive species."

Papers that recommended adaptive management but ranked below a Category 2 either (1) did not include effectiveness testing or implementation of adaptation strategies, but rather included adaptation as a general recommendation or guiding principle (e.g., Yashina, 2011; Green et al., 2017) or (2) were a synthesis/compilation of reviews and recommendations of adaptation actions (e.g., Abbott and Le Maitre, 2009). Papers reviewed that received a Category 2 ranking in the adaptive management category (i.e., Galatowitsch et al., 2009; Alagador et al., 2014; Temperli et al., 2012; Bagchi et al., 2012) included the recommendation as a result of modeling and did not experimentally test or monitor an implemented instance of adaptive management. Galatowitsch et al. (2009) and Alagador et al. (2014) used modeling to look at climate change impacts on habitats and species and how adaptation strategies (e.g., increase connectivity, manage for genetic/phenotypic diversity, assisted migration, habitat protection or restoration, and forest management) would influence this impact. As a result of their findings, the studies recommended that an adaptive management framework could benefit managers looking to address climate change adaptation in their work, but did not directly test this recommendation. Temperli et al. (2012) used modeling (LandClim model) to test climate change impacts and forest adaptive management strategies on the provisioning of forest goods and services (including the benefits of forest diversity to the ecosystem at large). Bagchi et al. (2012) used models to forecast the results of the interaction of climate impacts and adaptation strategies, but adaptive management was not directly experimentally

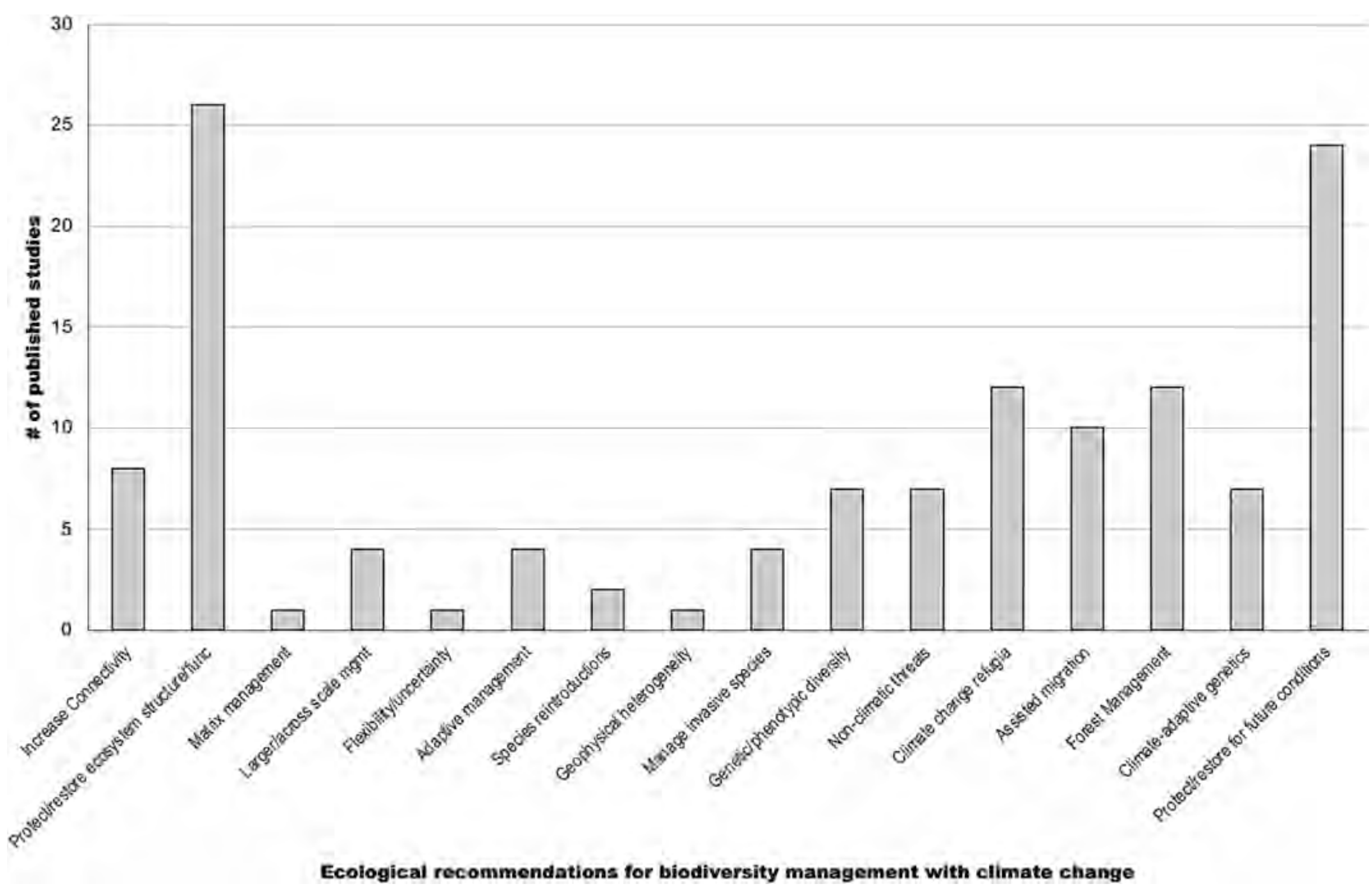

Fig. 4. Distribution of all papers identified in this review (at or above the hierarchy of adaptation efficacy Category 2) across the "top 10" ecological recommendations for biodiversity management defined in McLaughlin et al. (2022). Note that a single paper could be relevant to more than one recommendation category.

tested or monitored via an implemented action. While implementation is an inherent part of an adaptive management process, our review did not identify instances where the adaptive management recommendation was implemented beyond modeling or tested/monitored for effectiveness as an adaptation strategy.

3.7. Over time

The number of papers identified in this review as modeling or testing adaptation efficacy spanned from 2003 to 2020. Only one published study that met the criteria was identified per year for 2003, 2005, and 2007. From 2008 to 2012, there was a marked increase in papers, with variable numbers, peaking at 9 papers in 2015 (Fig. 5).

4. Discussion

Our evaluation of the papers identified in McLaughlin et al. (2022) indicated that while they contain keywords relevant to climate change and adaptation, the majority of the papers in this review do not test climate change adaptation actions. This indicates a potential shortage of literature relevant to informing decision making, which was further supported by the limited number of papers identified in the subsequent targeted literature review.

The basic question of this paper is to determine if and where there is assessment of the potential effectiveness of adaptation recommendations for conservation through the use of biologically and climatologically informed models (Category 2), implementing the actions then monitoring (Category 3), or experimentally testing them (Category 4) to evaluate their efficacy. In this analysis, there appears to be a significant shortage of studies that present the kind of evidence (Category 4) that would be most useful in determining if a recommended action is likely to confer the desired conservation improvement. There were seven recommendations for which there were fewer than five studies to have assessed their potential efficacy (Table 3). Of those seven, all are only supported by studies in Category 2, and in three cases ("manage the matrix," "manage for flexibility/uncertainty," and "protect geophysical heterogeneity") only by single papers.

Even when we identified papers as belonging in Category 4 they generally fell short of explicitly testing the effectiveness of adaptation actions. For example, we identified three papers in Category 4 in "managing for genetic/phenotypic diversity" (Reusch et al., 2005; Ehlers et al., 2008; Wilson et al., 2016), which came closest in providing information that could be used to test adaptation strategies. These studies focused on flowering plant species–one in terrestrial systems and two in marine. They place their findings in the context of implications for managing plant conservation, in terms of how they might inform adaptation efforts such as "habitat restoration for increasing connectivity" or "enhancing ecosystem resilience" or "assisted migration." Wilson et al. (2016) evaluated the success of several restoration planting mixes under varying climatic variables, but the authors stop short of specific recommendations and provide a relatively general set of recommendations for paying attention to how ecotypic variation might influence the success of planting efforts, which is fairly standard good conservation practice. Reusch et al. (2005) evaluated the influence of genetic diversity in playing an ecological role akin to species diversity in a marine seagrass bed; but while it took advantage of the "natural experiment" of a heat wave that occurred shortly after initiation, that event did not constitute an experimental treatment (there was no control), and the mechanism of recovery could not be explicitly identified, as the authors state, "whether or not this is related to resilience, the rapidity with which the organism returns to the pre-perturbation state, or a higher productivity of diverse mixtures must remain an open question because our experimental units had not attained natural densities when the heat wave hit soon after planting." Arguably none of the studies evaluated in this category explicitly test adaptation measures in a way that can be straightforwardly applied for evaluating effectiveness.

When there is a study that assesses a recommendation, it can show the recommendation to not be effective. For example, Selig et al. (2012) tested the effectiveness of marine protected areas (MPAs) in response to thermal stress in corals and determined that MPAs were not an effective tool, as currently designed, in reducing the impact of thermal stress. The authors did however make recommendations for conservation measures that could decrease harm, but those are not tested in their study. Therefore, this study provides insight, but not evidence, for the measure. Two additional papers that reviewed MPAs, Bruno et al. (2019) and Graham et al. (2015), also did not find MPAs to confer more resilience to coral reef communities than compared to unprotected areas. It is interesting to note that we only identified a few papers reporting lack of

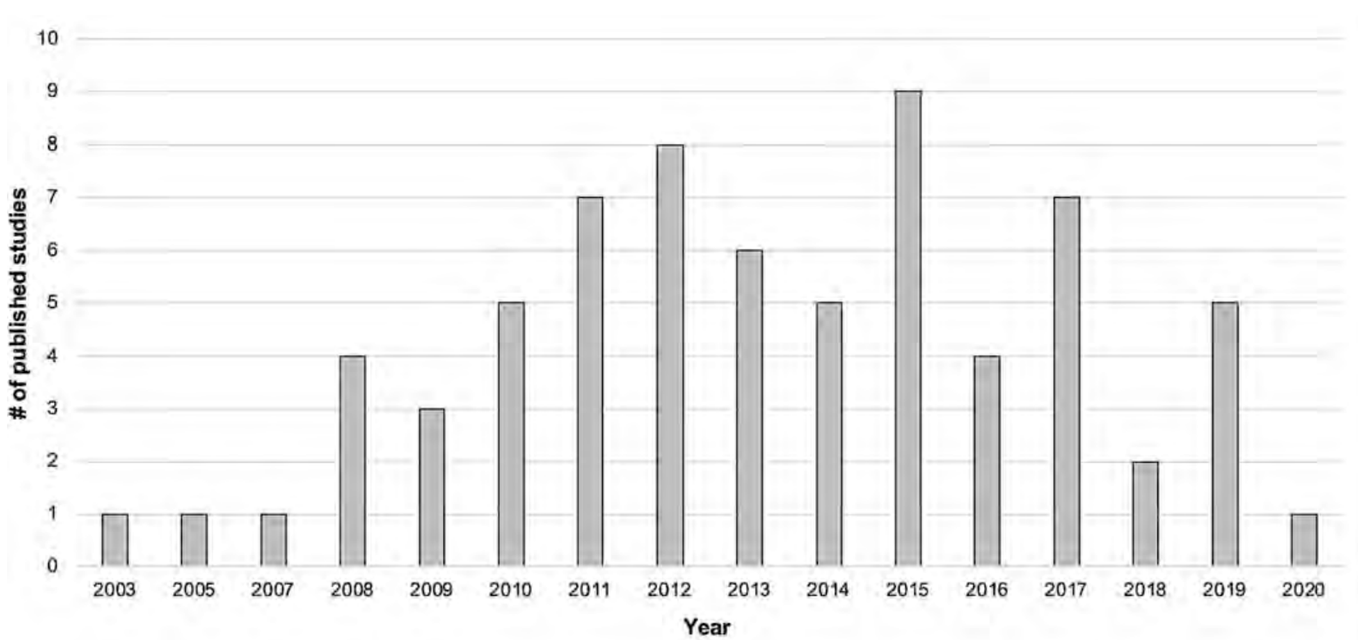

Fig. 5. Adaptation effectiveness research over time, summarized as the number of published studies in this review that modeled or tested adaptation efficacy (Categories 2–4) by year of publication.

effectiveness (suggesting that the action is not effective), which could be driven by a bias in adaptation efficacy testing against sharing negative results. This could be due to apprehension of stifling an emerging and often political field, or it could be a sense that a negative result is not interesting enough to share, although reviews of the literature would suggest that publication bias for positive results may be more widespread in the biomedical literature than the natural sciences (Koricheva, 2003; Duyx et al., 2017).

The scale at which studies we identified as higher in the hierarchy were conducted is varied, ranging from the evaluation of populations within an individual wetland system to entire continents. For the large-scale studies, recommendations regarding adaptation strategies such as "preserve design or assisted migration" tended to be made at an extremely high level, arguably necessary given the resolution of the research. From a conservation standpoint, these larger scale studies are important for defining how entire populations or species might respond to climate changes, but they do present challenges (e.g., issues of pseudo-replication and logistics) in terms of opportunities to move from theory to practice and test hypotheses about the success of adaptation measures.

The number of papers identified by this review was modest. The initial expectation was that there would be a growing body of research around the effectiveness of adaptation strategies as awareness and implementation grew. Based on the pool of papers in this review, from 2007 to 2012 there was a marked increase, however, the field seems to have plateaued since then or perhaps even diminished (Fig. 5). Recent evidence of this lack of monitoring is also supported in this special issue by Gillingham et al. This limited amount of growth in this field of research may also in part explain why the recommendations from 2022 (McLaughlin et al.) are not very different from 2009 (Heller and Zavaleta) (Table 1)—with limited evidence to indicate if a strategy does or does not confer the benefits expected of it, there is little impetus to develop new ideas. Of course, this observation could be an artifact of changing keywords, changes in priorities of the adaptation community from research to implementation during changing political cycles, or even relevant adaptation communication occurring outside of the peer-reviewed literature on which this review and McLaughlin et al. focus. In relation to this last point, The Wildlife Conservation Society's Climate Adaptation Fund supports the implementation of adaptation projects that includes evaluation, however, peer review publication of results of these projects has not been a primary focus of this work to date. This does not mean that reports of these results might not be forthcoming through other avenues.

4.1. How could the gaps be filled?

This review highlighted substantial opportunities to conduct research that can contribute to informed decision-making about climate change adaptation. For several of the top recommendation categories identified by McLaughlin et al. (2022) that address issues critical to climate change adaptation and conservation planning, only single papers were found that reported on the effectiveness or potential effectiveness of the adaptation action. These research gaps are obvious places out where resources might be directed to make progress in identifying effective strategies.

4.1.1. Effectiveness monitoring is needed

While the need for monitoring in adaptation is in almost all basic guidance on adaptation process (Peterson St-Laurent et al., 2022; United Nations Climate Change Secretariat, 2019; Stein et al., 2014), the very limited number of papers in Category 3 ($n = 1$) related to effectiveness monitoring indicates both a need to build the field of conservation adaptation and an opportunity for undertaking assessments. This evidence base could be expanded by establishing monitoring in association with new or existing adaptation management actions, or by comparing existing monitoring data (e.g., water quality, site surveys) to areas where adaptation actions have been undertaken.

In particular, effectiveness monitoring is of critical importance for studies that aim to show success in adaptive management. Adaptive management is recommended for biodiversity conservation on the premise that it will address uncertainties and allow for responsive measures that may increase resilience. The strategy's iterative processes allow managers to revisit their decisions and adjust processes based on new evidence, essentially "learning while doing" (Benson and Stone, 2013). While it is a recommended strategy and theoretically requires effectiveness monitoring to inform the next iteration of management decisions, the process is often stalemated during or before the implementation process, slowing down or prohibiting the implementation of the designed adaptation action. Common challenges that arise in the early stages of the adaptive management process (e.g., goal setting, design, planning, and implementation) include insufficient resources and funding, the rigidity of legal requirements, institutional flexibility, lack of involvement from key players that would sustain the process, shortcomings in operational processes, and inadequate knowledge of the social-ecological system in which the strategy is to be applied (Månsson et al., 2023; Benson and Stone, 2013). The small number of adaptive management studies identified as relevant for this review may have well been the result of this suite of hurdles to the practice.

4.1.2. Imbalance in the geography of published studies

The imbalance in the geographic composition of where the assessments were conducted (mostly North America and Europe) is not surprising given the historical imbalance in the geographic composition of English language scientific publications. This indicates a need for undertaking more adaptation recommendation assessments across a broader geography. Given that adaptation efforts have often been underway longer in countries outside of North America and Europe (Mertz et al., 2009; Obura and Grimsditch, 2009), there is ample implementation that could be assessed in marine, freshwater and terrestrial ecosystems.

4.1.3. Connecting practice to publication

There can be a disconnect between the many practitioners engaging in adaptation actions on the ground, and the monitoring and testing of such actions that would lead to greater understanding in the scientific and conservation community. Our literature review uncovered compelling case studies on adaptation that were either described as part of a larger review paper or were in the gray literature, but they were often not formally tested or published in a way that quantified the benefits of the work. This finding points to an opportunity for greater collaboration between academic researchers, who can bring to bear the resources of scientific methodology and inquiry, and conservation practitioners who may be too busy on the ground conducting management to integrate the types of experiments and monitoring that could help quantify and communicate their efforts. Collaborations with external research partners who may be able to bring value-added monitoring design and application have been shown to be a key component in supporting more comprehensive monitoring efforts (Oakes et al., 2022). For example, before-after, control-impact (BACI) study designs are commonly employed in academic research to evaluate the effects of specific treatments, and controlled studies could be applied to many of the types of adaptation case studies we encountered to provide more tested information about adaptation efficacy. Natural experiments could also fill this gap with proper objectives and data collection (Diamond, 1983).

An obvious corollary to the need for more partnerships that bring experimental design to climate-adapted conservation management is the need for more funding at this nexus. It is likely that the primary drivers for why practitioners may not incorporate explicit testing of adaptation actions include a lack of time and resources. Strong experimental design, monitoring, and implementation of these methods all require people and funding to do the work. Robust testing and monitoring programs require sustained funding and often encompass time periods both before and well after the actual action if they are to ascertain if the treatment has been effective. Clearly, there are strategies whose outcomes may operate on timescales that far outlast the study period, or even the length of individual careers (e.g., managing for future conditions, depending on how that is defined), which may not be amenable to monitoring comprehensive outcomes. In cases like these, early markers or metrics of trends that support adaptation or recovery in a desired direction can be useful. If agencies and institutions are considering ways in which they can bring added value to conservation projects, directing funds and grant opportunities for projects that incorporate direct testing of climate change adaptation effectiveness would be of great benefit to the fields of conservation and natural resource management.

We saw indications of this type of collaborative effort spanning agencies and academia in seed transfer and common garden experiments that are common to the forestry and agriculture resource management sectors. Multiple studies identified in Category 2 and above evaluated the effectiveness of establishing seed transfer zones that are informed by climate projections (e.g., Gray et al., 2011; Russell and Krakowski, 2012; Joyce and Rehfeldt, 2013). This type of seed transfer study appears to be sufficiently broadly employed, at least in forestry, that it may be considered a standard approach that can be employed in the framework of adaptive management. This body of knowledge has been integrated in some cases; for example, O'Neill et al. (2017) used a large seed transfer dataset and climate projections described by multiple published and gray literature studies (including O'Neill et al., 2008, Russell and Krakowski, 2012, Joyce and Rehfeldt, 2013) to build a set of standards for seed transfer for British Columbia to guide provincial efforts to adapt forestry practices to projected climate changes.

4.2. *Measurable markers and trends are useful when outcomes are not immediate*

Another stumbling block often suggested as an obstacle to designing and implementing studies to test the efficacy of adaptation actions is that effectiveness cannot be assessed until sometime far in the future when the impacts of climate change have come to pass. While it is true that long-term outcomes cannot be assured, this is not uniquely true to climate change as an environmental stressor. It is also true in relation to other stressors, such as land use change, pollution, and invasive species. However, in those cases, just as with climate change, it is possible to identify indicators to assess condition and trajectory. For example, in coral reef ecosystems, the effects of increasing water temperature can be assayed by monitoring the rate and extent of coral bleaching, as well as the time to recover after a bleaching event. In vegetative studies, growth and photosynthesis rates can be monitored to understand conditions. Markers such as fecundity or stress hormone can be used similarly with faunal studies. And in all cases, monitoring of presence and absence of species can be effective in understanding the effectiveness of a management intervention around climate change.

4.3. *Lower the barrier for information sharing*

With funding and time commonly shared as obstacles to conservation (Rose et al., 2018; Sanders et al., 2021) and adaptation (West et al., 2009; Bierbaum et al., 2013), both are most likely not only limiting the monitoring and evaluation of adaptation measures but also the publication of results from those efforts. Therefore, it may benefit the advancement of adaptation to use paths to sharing results that are less resource intensive than peer-reviewed publication. Perhaps replacing existing grant reporting requirements (public and private) with a simple interface to share results through searchable online repositories (e.g., Conservation Evidence, Climate Adaptation Knowledge Exchange, Climate Resilience Toolkit, California's Adaptation Clearinghouse, the now defunct USGS Climate Registry for the Assessment of Vulnerability). This could also track progress and updates on projects over time. Ideally, results would be shareable across these platforms so users could discover information more easily.

5. Conclusions

Many adaptation actions are being recommended in the scientific literature; however, there is often little evidence supporting how effective they are in actually achieving adaptation goals. Most papers identified to assess the effectiveness of the "top 10" recommendations employed a climate-informed modeling approach. Papers that actually tested adaptation methods in practice were quite rare, only a handful in the hundreds of papers we reviewed. Chiquone et al. (this issue) provides an additional example of the kind of papers this emerging field of testing adaptation efficacy will need more of. This shortage of assessments and the associated shortage of supporting evidence leads to the sense that it is still not known if most adaptation recommendations are good ideas, relegating them to still just being ideas. This is not to say that adaptation approaches should not be applied to conservation management. There are no recommendations to "take no modified action" in light of climate change. It will benefit all conservation management when there are more studies to assess the effectiveness of ecological adaptation actions, including some that compare those actions to the outcomes from inaction. It is vital to the success of conservation that both new ideas are generated and that we test those ideas to ensure they are effective in achieving good long-term conservation outcomes wherever possible.

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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