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LETTER

The biodiversity adaptation gap: Management actions for marine protected areas in the face of climate change

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Abstract

Marine protected areas (MPAs) are a crucial component of international biodiversity conservation commitments, yet are increasingly affected by climate change. No synthesis or analysis exists of the specific on-the-ground management actions that have been taken by MPA managers in response to climate change. Here, we extract, evaluate, classify, and analyze adaptation responses from 646 existing, English-language MPA management plans preselected for their consideration of climate change. Our synthesis documents 213 unique management actions, of which only a fraction (4.7%) were on-the-ground adaptative measures directed at enhancing biodiversity conservation; in contrast, almost half (45.5%) were monitoring measures. Our analysis highlights the apparent paucity of documented management actions addressing the challenging task of limiting climate change impacts on biodiversity within MPAs—a “biodiversity adaptation gap”. By compiling a community resource of adaptation approaches that can be further expanded and disseminated, we hope to contribute to the effort to adapt MPA networks to climate change.

KEYWORDS

adaptation, biodiversity, climate change, governance, management actions, management plan, marine conservation, marine-protected areas, mitigation

1 | INTRODUCTION

Ongoing and accelerating anthropogenic climate change is impacting ecosystems around the world (IPCC, 2023; Lenoir et al., 2020). Both marine and terrestrial biomes are at risk, with the physical, biological, and chemical environments changing at unprecedented rates (IPBES, 2019; IPCC, 2022). In marine systems, climate change is affecting oceanographic properties such as temperature and pH (Hastings et al., 2020), biogenic habitats such as coral reefs through an increased frequency of bleaching events (Sully et al., 2019), species distributions (Lenoir et al., 2020; Pecl et al., 2017; Worm & Lotze, 2016), and animal biomass (English et al., 2022). These impacts have cascading consequences for marine ecosystem functioning and provisioning (IPCC, 2022; Tittensor et al., 2021). In addition, other anthropogenic stressors, such as overfishing (Cheung et al., 2018), pollution (Cabral et al., 2019), and habitat destruction (Gissi et al., 2021) are likely to exacerbate the negative impacts of climate change, with cumulative and synergistic consequences for marine ecosystems and biodiversity.

In recognition of anthropogenic impacts upon marine biota, the international community has increasingly recognized marine ecosystems in biodiversity-focused policy processes and targets, such as the Aichi Targets (CBD, 2011), the Sustainable Development Goals (United Nations, 2015), and the Kunming-Montreal Global Biodiversity Framework (CBD, 2022). An important part of these commitments is area-based targets for biodiversity conservation, particularly through marine protected areas (MPAs). For Aichi Target 11 and Sustainable Development Goal 14, the areal target was to protect 10% of coastal and marine areas by 2020; for the Kunming-Montreal Global Biodiversity Framework it is 30% by 2030. MPAs can help to safeguard threatened species and sensitive habitats, increase local biodiversity, and restore food webs (Edgar et al., 2014; Laffoley et al., 2019; McCook et al., 2010; Sala et al., 2013). International targets require such networks to be effective, yet climate change impacts have the potential to undermine the benefits that they accrue, both in coastal areas and the High Seas (Bruno et al., 2018; Tittensor et al., 2019; Wilson et al., 2020). This poses a particular challenge in marine environments given that species are moving poleward around four to six times faster on average than in terrestrial systems (Lenoir et al., 2020; Pecl et al., 2017).

Although climate change considerations can be included in the design process for new MPAs or networks through modifying site selection and design (McLeod et al., 2009; Tittensor et al., 2019), the best approaches to adapting to climate change in existing MPAs remains unclear. To date, evidence suggests that efforts to concretely implement direct management actions (in contrast to high-level ambitions) to account for climate change impacts in MPAs are limited (O'Regan et al., 2021; Wilson et al., 2020).

Quantitative evaluations of climate change planning in MPAs remain scarce (Wilson et al., 2020). O'Regan et al. (2021) compiled a collection of MPA management plans and calculated a climate change robustness index to assess whether plans considered climate change at all. However, no further analysis of adaptation strategies or actions was conducted, leaving a lack of understanding of any significant gaps in specific climate adaptation actions in MPA management plans. To ensure the continued effectiveness of biodiversity protection in MPAs, it is crucial to understand and disseminate the concrete adaptation measures available to MPA managers. As such, our work serves as a step in not only examining the specific actions documented within MPA management plans but also in then ensuring that practitioners have streamlined access to the array of actions being taken.

Here, we present an in-depth analysis of specific climate change-related management actions in MPAs across the world that had management plans in English, or English translations readily available. We used the pre-filtered set of 646 MPA management plans assessed for climate change language by O'Regan et al. (2021) and added additional MPA policy documents and plans to extract, categorize, and evaluate the specific and concrete actions that have been employed to adapt to climate change. To achieve this, we created a framework to enable the identification of specific MPA operational actions that facilitate adaptation. Actions were subsequently synthesized, categorized, and analyzed to provide an assessment of specific climate adaptation measures that are in place across the global (English language) MPA network. We then compiled all identified actions into an open, updateable community database to enable wide dissemination of potential climate adaptation management measures to practitioners. To the best of our knowledge, this database is the first repository of its kind for either marine or terrestrial protected areas; few opportunities and platforms exist that allow for the knowledge exchange of specific MPA management actions between practitioners (though see the Open Communications for the Ocean [OCTO] community [https://octogroup.org/] and the Big Ocean peer-learning network [https://bigoceanmanagers.org/]). Through constructing this database, we also contribute to the establishment of an open knowledge-sharing system centered around climate change adaptation actions (Tittensor et al., 2019; Recommendation 1).

2 | METHODS

2.1 | Creating a database of management plan actions

An augmented management plan database was created from the management plans examined in O'Regan et al. (2021), and we subsequently added any additional management plans and government policy documents referenced therein that were identified as potentially also having climate adaptation actions or relevance. Each document was read in full to ensure that no relevant material was missed. Each section that had any mention of climate change was assessed to see if there were any relevant actions (see Section 2.2). Due to language limitations, only management plans in English could be included, and as such, the bulk (84%) of management plans were from the USA, although the remaining plans did span the globe (Figure 1).

FIGURE 1 Global distribution of marine protected areas (MPAs) (shown as red pins on the map) for which the English-language management plans were examined to extract actions to adapt to climate change.

2.2 | Climate change action analysis

To categorize the actions related to climate change within each management plan, a specific definition of what an adaptation "action" consisted of was required. To this end, we amended the commonly used strategic, measurable, achievable, result-oriented, and time-bound (SMART) criteria (Doran, 1981) and modified them to define and contrast actions versus statements of intent or purpose. We named this revised framework specific, measurable, existing, task-oriented, time-bound (SMETT; Table 1) and subsequently defined a climate change–relevant action item as satisfying two or more of the five SMETT categories. Although SMART is a concept focused on the development of goals for future work, SMETT is focused on existing measures that are already in force and already being applied. As such, we had to develop a framework that would allow us to separate actions from goals: the "existing" from the "hoped-for" or "aspirational". In management plan language, often aspirational statements depict goals rather than concrete actions. The SMETT criteria are tailored to help extract and identify the presence of concrete actions within the text.

2.3 | Classification of results

All climate-linked actions were classified into a scheme that included four main categories: *Monitoring*, *Research*, *Management*, and *Outreach* (Table 2). The *monitoring* category refers to on-the-ground actions measuring and tracking climate change–induced impacts on ecosystems and species and their changes over time. The *Research* category includes any scientific endeavors investigating existing biodiversity and its risk from climate change and/or future projections. It differs from the *Monitoring* category in that it includes analytical components (see below) rather than just observations. The *Management* category involves administrative or operational measures that deal with the day-to-day operation of the MPA, enabling climate-smart management. Lastly, the *Outreach* category comprises actions involving climate change–related communication and education directly relating to biodiversity protection and conservation measures. We did not include actions around curtailing the carbon footprint of MPAs, nor actions taken to adapt the visitor experience in response to climate change (e.g., modifying parking lots due to increased storm frequency), as such actions are

TABLE 1 Definition and examples of specific, measurable, existing, task-oriented, time-bound (SMETT) criteria used to define climate change actions within MPA management plans.

Categories	Definition	Example
Specific	Is the action clearly defined and/or identified?	Determine the current quality and extent of the vegetative buffer and fringe to address impacts of climate change (St. Thomas East, USVI)
Measurable	Are there clear benchmarks that can be measured and tracked over time?	Establish three monitoring stations within each of two existing salt marsh areas (and an additional six stations in each area of impounded wetlands), with surface elevation tables and marker horizons; read surface elevation table measurements minimally four times per year (seasonally), but ideally once per month, to track seasonal and periodic storm effects on marsh elevation (Prime Hook National Wildlife Refuge, USA)
Existing	Is this an activity that is already occurring, that is, currently happening?	Maintain current baseline data collections, particularly those that provide data for future needs such as possible oil spills, climate change, and sea level rise (Padilla Bay, USA)
Task-oriented	Is there a specific piece of work required to be completed?	Re-run the SLAMM model when high-resolution light detecting and ranging (LiDAR) data become available (Island Bay, USA)
Time-bound	Is there a time component attached to the statement, that is, a deadline or defined time for completion?	By 2015, Grand Bay NERR staff, 10 researchers, and/or coastal managers are engaged with the Reserve to monitor and study how locally relevant climate impacts affect natural communities (Grand Bay, USA)

Abbreviation: SLAMM = Sea Level Affecting Marshes Model.

outside the scope of our research; we focus on actions directly involving biodiversity protection and conservation.

Actions within the *Research* category were broken down into two sub-categories, *Baseline Establishment* (actions such as establishing what is at risk and where) and *Projection* (actions that forecast abiotic factors and potential impacts using computer models). Similarly, the *Management* category was subdivided into two sub-categories: *Adaptive measures* (on the ground, physical actions being taken by MPA practitioners) and *Administrative measures* (all bureaucratic processes relevant to execute these measures).

These categories were then subsequently used to create an open-access, online database to facilitate knowledge exchange between practitioners and ensure that the insights gained from this study can be updated by the community and used to inform MPA management. This database can be accessed at https://osf.io/rgk3b/ or via DOI 10.17605/OSF.IO/RGK3B.

3 | RESULTS

We identified 213 unique climate-related actions in the MPA management plans and documents evaluated. Overarching and reccurring examples include identifying species and habitats at risk from climate change (e.g., Gulf Islands National Seashore Park, USA); regularly measuring explicit climate change indicators, including storm frequency and storm intensity (e.g., National Marine Sanctuary of American Samoa, USA); and integrating an adaptive management framework into routine planning (e.g., Biscayne National Park, USA). Of the four principal categories of *Monitoring*, *Research, Management*, and *Outreach* (Figure 2), three-quarters of the 213 actions were from either *Monitoring* (97; 45.5%) or *Research* (66; 31%). *Management* included 37 actions (17.4%), whereas 13 actions (6.1%) were classified in the *Outreach* category.

3.1 | Breakdown by category

Monitoring actions, which formed the largest category (45.5% of the total), generally focused on either tracking changes in individual species (e.g., the timing of migrations or population counts) or on abiotic data collection (e.g., changing sea surface temperatures or salinity) within the MPA. In the case of Kakadu National Park (Australia), the action was to maintain preexisting monitoring programs but reorient them toward species and ecosystems at risk due to climate change.

The *Research* category comprised two sub-categories: *Baseline establishment* (50 actions or 23.5% of total actions) and *Projection* (16 actions or 7.5%) (Figure 2). An example found across multiple management plans was the use

TABLE 2 Definitions and examples of the categories of climate change–related actions found within the management plans of marine protected areas (MPAs).

Categories	Sub-categories	Definitions	Examples
Monitoring		Any action measuring climate change impacts through documenting, surveying, or recording the biotic and abiotic factors within the protected area and their change over time	Establish three monitoring stations with each of two existing salt marsh areas with surface elevation tables and markers (Prime Hook National Wildlife Refuge, USA)
Research	Baseline establishment	Any form of scientific investigation or analysis regarding biodiversity and climate change impacts	Determine the current quality and extent of the vegetative buffer and fringe to address impacts of climate change (St Thomas East End Reserves, US Virgin Islands)
	Projection		Work with the Service's South Florida Ecosystem Team and Massachusetts Institute of Technology to develop a climate change and sea level rise model (Matlacha Pass National Wildlife Refuge, USA)
Management	Adaptative measures	On-the-ground changes to the administration of the park, both through bureaucratic and operational measures	Investigate and prioritize for acquisition, adjacent upland areas within the approved acquisition boundary for marsh migration and other effects from climate change (Don Edwards San Francisco Bay National Wildlife Refuge, USA)
	Administrative measures		In the presence of accelerated climate change, adaptive management is an increasingly important management-decision process. The refuge will employ adaptive management as a standard operating procedure (Siletz Bay National Wildlife Refuge, USA)
Outreach		Actions involving communicating information or practices around climate change, to either the public or operating partners	Update roadside exhibits with climate change–related content and quick response (QR) codes (Wallops Island National Wildlife Refuge, USA)

of risk assessment models such as the Sea Level Affecting Marshes Model (SLAMM). Notably, actions in this category tended to lack connection to subsequent follow-up operational measures.

The *Management* category (Figure 2) was divided into two sub-categories: *Administrative measures* (12.7%) and *Adaptive measures* (4.7%). An example of the *Administrative measures* sub-category is the definition of climate-related decision-making hierarchies (e.g., Kakadu National Park, Australia). The *Adaptive measures* sub-category (10 actions) included any operationalizing of biodiversity adaptation approaches, such as regulations in the Prime Hook National Wildlife Refuge (USA) allowing for natural replenishment of sediments to enable the marsh to keep pace with sea-level rise (Table 3). This was the sub-category/category with the fewest actions—yet the one most pertaining to concrete measures aimed at ensuring the continued effectiveness of MPAs for biodiversity conservation.

Finally, the *Outreach* category (6.1%) was the smallest category, with actions centered on communications with the public on climate change and its local effects. For example, the Wallops Island National Wildlife Reserve (USA) incorporates quick response (QR) codes onto roadside signage to keep park visitors alerted to climate change-related content.

4 | DISCUSSION

Integrating climate change considerations into spatial marine conservation measures such as MPAs is a relatively new challenge, yet its growing impacts underscore the urgent need to include it as a focal point of MPA

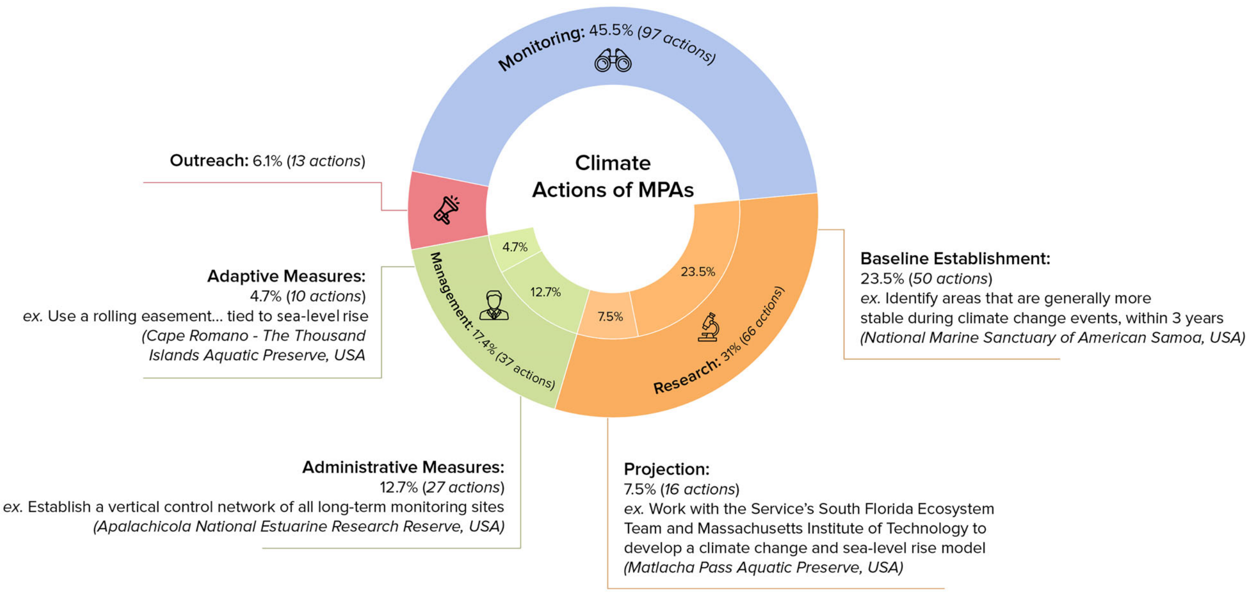

FIGURE 2 Breakdown of climate change actions into categories, with examples given for sub-categories from *Management* and *Research*.

TABLE 3 Full set of examples of the actions classified under the Adaptive measures sub-category.

Adaptive measures	Examples	Site
Boundary expansion	Prioritize for acquisition, lands within the approved acquisition boundary that have feasible opportunities to address sea-level rise impacts	Don Edwards San Francisco Bay National Wildlife Refuge, CA, USA
Purchase upland areas	Prioritize for acquisition, adjacent upland areas within the approved acquisition boundary for marsh migration	Don Edwards San Francisco Bay National Wildlife Refuge, CA, USA
Expansion of biological feature	Expand the mangrove fringe—address climate change models from the strategy plan	St. Thomas East End Reserves, St. Thomas, U.S. Virgin Islands
Boundary Implementation	Implementation of the reserve zone would reduce the impacts of (…) climate change	Biscayne National Park, FL, USA
Maintain connectivity	Maintain regional habitat connectivity and refugia that allow species dependent on park resources to better adapt to changing conditions	Gulf Islands National Seashore, FL, USA
Prioritize parcels that allow for upslope migration	Priority may also be given to parcels that allow for the upslope migration of marsh habitats	Grand Bay National Estuarine Research Reserve, MI, USA
Flexible shoreline management	To utilize in the near future is known as a rolling easement and can be tied to changing conditions such as climate change and sea-level rise	Rookery Bay—National Estuarine Research Reserve, FL, USA
Managed retreat	Permit the natural replenishment of sediments; the use of artificial renourishment or assisted accretion may be appropriate	Prime Hook National Wildlife Refuge, DE, USA
Nature-based solution	Embankments of tidal areas will, as a principle, be prohibited, and the loss of biotopes through sea defense measures will be minimized	National Park Wadden Sea (GER, DNE, NLD)
Reinforcing existing structures	Reinforcement of existing dikes will be carried out at the location of existing dikes and, preferably, on the land side	National Park Wadden Sea (GER, DNE, NLD)

Note: All actions found within the management plans of marine protected areas (MPAs).

management (Tittensor et al., 2019). Many MPAs were conceived and created to address local-to-regional issues (e.g., overfishing, protection of specific species or habitats), with limited scope to protect against a global issue such as climate change (Bruno et al., 2018). As the drivers of climate change lie beyond the marine environment, the efficiency of addressing them through marine spatial conservation measures is limited. The task of identifying, collecting, and comparing solutions and actions from MPAs around the globe may provide an important step for helping to build resilient protected areas.

Previous studies (O'Regan et al., 2021; Tittensor et al., 2019; Wilson et al., 2020) have suggested that climate change is infrequently addressed concretely in ongoing MPA management. Here, we find that even within the most robust and climate-smart management plans, there exists a "biodiversity adaptation gap" between ambitions and actions, with operational solutions still relatively rare, at least as documented in management plans. The "biodiversity adaptation gap" refers to the gap between the need for management actions in the face of climate change and having such actions in place. This signals an area of need to ensure the success of MPAs moving forward.

Our analysis uncovered 213 climate change actions, of which only 4.7% directly assist species, ecosystems, or biodiversity to cope with the impacts of climate change. Although not all management actions may be captured by or documented in management plans, they are the place where operationalized approaches are likely to be found. This lack of biodiversity-related adaptive actions is likely caused by a lack of capacity, funding, or other pressing priorities (Gill et al., 2017) rather than any lack of ambition or recognition of the issue (Tittensor et al., 2019). There are other significant pressures and priorities, funding constraints, and capacity limitations for MPA management bodies, as well as difficulties with identifying precisely how to respond to climate change impacts. The low count of actionable measures signals a gap between a high-level recognition of the problem and on-the-ground actions.

As evident from our results (Figure 2), the bulk of climate actions within assessed MPAs center on monitoring and research. This focus is perhaps unsurprising, as many MPAs may, unfortunately, lack the baseline or ongoing data (Ward-Paige & Worm, 2017) needed at the appropriate scale to detect, measure, and respond to the changing climate. A principal element of *Research* actions involved running computer models to project climate change impacts (which may enable the development and prioritization of other adaptation approaches in the future). As it stands now, the actions within each category are siloed, and for the overwhelming majority, there are no subsequent actions earmarked to address the results from the *Monitoring* and *Research* categories.

The actions in the *Management* category, specifically the *Adaptive measures* sub-category, have the most potential for widespread adaptation. Ideally, once scientific baselines are documented and risks to those baselines from climate change are understood (Roux et al., 2022), the next step is to develop an adaptation action in response. For example, in the Don Edwards San Francisco Bay National Wildlife Refuge (USA), modeling was conducted in 2010 to identify what habitat changes were projected due to sea-level rise (a *Research* action). This was followed by a *Management* action to investigate and prioritize the acquisition of adjacent land that would be able to address the loss of habitat.

In protected area management, a management paradigm considered the most effective way to deal with ecosystem-based issues is the generalized model of adaptive management (Tony, 2020). This is an iterative framework for making decisions and managing natural resources in an uncertain and dynamic environment (Rist et al., 2013; Westgate et al., 2013). It emphasizes the need for continuous learning, evaluation, and flexibility in managing complex, dynamic systems. The model consists of key components: defining a problem and goal setting, implementing management actions, monitoring, evaluating, and adjusting the implemented management actions (if need be), and re-iterating (Westgate et al., 2013). This framework enables managers to navigate complexity and uncertainty while achieving the ecological, social, and economic goals of protected area management. Although there are multiple examples of MPA management plans recommending the use of such a paradigm, analysis of the actions we uncovered showed that this iterative process has not been fully operationalized. This was evident from the disconnect between the categories and the skew toward monitoring actions without the monitoring of impacts of management actions. The latter is an integral part of the climate-adaptive management paradigm.

One important finding was that many actions are being taken in response to a single impact of climate change: sea-level rise. This is likely because sea-level rise presents the greatest potential for tangible response actions in coastal MPAs, such as buying land further inland to assist with the relocation of habitats such as salt marshes. In contrast, for other impacts of climate change like warming and acidification it is harder to identify tools or actions by which managers can limit those impacts, in particular for open ocean MPAs. The general applicability of actions may be restricted; for example, actions that may be relevant to coastal or intertidal habitats may not be relevant to large open ocean MPAs. Furthermore, as mentioned above, actions are rarely interlinked across categories, which would enable a more consolidated response. The lack of connection between actions from the different categories signals a disconnect between categories and may undermine how one category of actions can help support or guide actions in other categories.

Our review also uncovered that, within US-based management plans, there was a set of repeating climate change actions that stemmed from the United States National Park Service (NPS) Climate Change Action Plan (2012), a set of nationally mandated guidelines that outline all climate change–related actions that must be included within US National Parks. This demonstrates that the trickle-down effect of nationally mandated policies is important not just in setting examples but also in guiding actions at local and regional levels.

Increased international collaboration has been proposed as the most promising near-term mechanism for states to develop active and comprehensive marine conservation programs (Hind et al., 2015). To this end, our database serves as a tool to aid in the exchange of knowledge and build collaboration aimed at addressing the novel and daunting challenge of climate change. Moreover, an open-source database that is promoted among MPA practitioners ensures that our results do not remain solely within the academic sphere but can be widely disseminated to those that need this information and ensure its applicability within marine conservation.

There are necessarily some limitations to the scope of our analyses. We were reliant on (1) management plans that were accessible and downloadable online and (2) were written in English, or with an English translation readily available. There are many MPAs that do not have English management plans and that could have actions that are not in our database. Furthermore, not all relevant actions may be documented in management plans, and, by necessity, such plans are updated at regular or irregular intervals. Our results therefore need to be regarded as a snapshot of current conditions. However, it is worth mentioning that if actions are not outlined in management plans, their accountability and importance remain uncertain. As management plans are updated, or new actions are documented therein, our analysis can be repeated to evaluate how the integration of climate change concerns into MPAs is progressing over time (Recommendation 3, Tittensor et al., 2019). Doing so would also lead to additional actions in the MPA climate change adaptation database for managers to refer to and consider, ultimately helping to bridge the biodiversity adaptation gap.

5 | CONCLUSION

Our in-depth review and analysis of MPA management plans identified only few concrete and biodiversity-focused climate adaptation actions within the global protected seascape. Those actions that do exist are heavily skewed toward monitoring and research, whereas direct operational responses around climate change adaptation are sparse (Table 3). Although MPA managers and scientists everywhere recognize the challenges posed by climate change to marine biodiversity, there remains a clear gap in terms of operationalization, likely due to a lack of resources, information, prior examples, capacity, time, or other competing priorities. This suggests a strong need to fill this "biodiversity adaptation gap" by further developing the concrete actions required to ensure that MPAs can achieve their conservation goals in a changing ocean. The database developed here may be a starting point in bridging this gap, serving as a unique resource for greater sharing and communication of potential actions, an important step as MPAs move beyond a focus on research and toward concrete climate adaptation actions with direct impacts on biodiversity conservation.

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DATA AVAILABILITY STATEMENT

The MPA climate change adaptation database is freely available from OSF (DOI 10.17605/OSF.IO/RGK3B).

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