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REVIEW

Principles for climate resilience are prevalent in marine protected area management plans

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Abstract

Climate change is threatening marine systems, and its widespread and dynamic effects are creating challenges for designing and managing marine protected areas (MPAs). The majority of recommendations for climate-resilient MPAs focus on enhancing ecological resilience to disturbance and updating management strategies to respond as changes occur. Here, we assess how existing recommendations for climate resilience are applied in real-world MPA management, using criteria from five key management components: objectives, assessments, design, monitoring, and management. Our review evaluates 172 management plans for 555 MPAs across 52 countries and written in nine languages. We find that MPA management plans contain many underlying scientific and management principles for promoting resilience to climate change, even when "climate change" or related terms are not specifically included: plans include long-term objectives (93.6%), threat-reduction strategies (99.4%), monitoring programs (97.7%), and adaptive management (93%). However, there is substantial variation in the degree to which plans explicitly incorporate climate change into their strategies, from not mentioning it at all (21.5%) to developing detailed climate change-specific action plans (20.9%), with most somewhere in between. In addition to identifying common gaps across management plans, we also provide practical examples of activities MPA managers are undertaking to address climate change.

KEYWORDS
area-based management tools, climate change, conservation, management, marine protected area, resilience

1 INTRODUCTION

Marine protected areas (MPAs) are an increasingly common ecosystem-based management tool used to achieve a wide variety of goals by restricting local activities that have direct negative effects on species and habitats (Grorud-Colvert et al., 2021). Rising temperatures, ocean acidification, increasing storms and heatwaves, sea ice loss, and sea level rise are pushing ecosystems past tipping points to altered states, many of which are becoming irreversible (Cheung & Frölicher, 2020; IPCC, 2021). Protecting ocean areas from extractive activities is increasingly important in the face of climate change to reduce cumulative human impacts (He & Silliman, 2019; O'Hara et al., 2021). However, climate change challenges traditional MPA management because climate change impacts can rarely be directly mitigated within MPA boundaries (Brito-Morales et al., 2022). Scientists, policymakers, and resource managers must determine how to plan for and respond to dynamic climate change threats amidst other interacting stressors, such as overexploitation, pollution, and development.

To address these challenges, climate change must be integrated across all aspects of MPA design and management (Tittensor et al., 2019). Adaptive management, in which goals and actions are updated based on monitoring and assessments, is widely cited as a critical approach for both managing protected areas generally (Pomeroy et al., 2004, and references therein) and for specifically addressing the uncertainty associated with climate change (Peterson et al., 1997; Tompkins & Adger, 2004; Wilson et al., 2020). Core components of adaptive management most relevant to managing MPAs in the face of climate change include clearly defining objectives, assessing current and future threats, implementing systematic spatial design strategies, monitoring, and regularly re-evaluating management measures (Kingsford et al., 2011; Tanner-McAllister et al., 2017; Wilson et al., 2020). Where objectives are clear and vulnerability assessed, it is much easier to include assessment of climate change vulnerabilities. Guidelines for incorporating climate adaptation into the siting and design of reserves have also been developed (Gaines et al., 2010; Green et al., 2014; McLeod et al., 2009). These spatial design measures—such as protecting critical and representative habitats, considering connectivity among areas, setting thresholds for minimum size and coverage (Gaines et al., 2010; Green et al., 2014; McLeod et al., 2009), and complementing static protection with dynamic strategies (D'Aloia et al., 2019; Rilov et al., 2019; Tittensor et al., 2019)—are largely based on mechanisms by which protection may enhance ecological resilience to disturbance and, therefore, also promote adaptation to climate change (Carr et al., 2017; Roberts et al., 2017; but see Bates et al., 2019). Monitoring can track change through time and provide insights for specific climate indicators, supporting the development of additional management measures. Adaptive management requires an iterative process through which information is regularly updated to tailor strategies to address key sources of uncertainty, including climate change (Bormann & Stankey, 2009; Stankey et al., 2005).

Despite the prevalence of these recommendations for climate-resilient MPAs, recent reviews suggest that climate adaptation strategies for MPA planning and management may not be commonly implemented (O'Regan et al., 2021; Tittensor et al., 2019; Wilson et al., 2020). These studies synthesize recommendations for climate resilience within a conservation planning framework (Wilson et al., 2020) and provide examples of climate-relevant actions from the peer-reviewed literature (Tittensor et al., 2019), but note that examples are often theoretical and unimplemented (Tittensor et al., 2019; Wilson et al., 2020). Extending beyond the scientific literature, an analysis of MPA management plans highlights that just over half of management plans (57%, $n = 647$) include explicit climate change language (O'Regan et al., 2021).

However, in evaluating the climate change responsiveness of MPA management, it is important to assess both explicit climate-related provisions and the structural elements that may have a strong indirect influence on the ability to manage for change. In practice, many guidelines for climate resilience can be applied generally—without explicitly referencing climate change—and still promote climate adaptation; the same strategies that bolster general ecosystem resilience likely also provide resilience to climate change effects (Carr et al., 2017; Roberts et al., 2017), and adaptive management can facilitate effective responses to climate change impacts even when not intentionally applied as a climate change strategy. Integrating climate change explicitly in spatial design strategies does carry additional benefits by assuring that climate effects are prioritized, particularly in settings when climate impacts are well understood and can be directly addressed by specific design elements (Rassweiler et al., 2020). Similarly, explicitly incorporating climate change within each adaptive management component facilitates proactive efforts to address climate change adaptation (Marmorek et al., 2019).

Improving MPA management in the face of climate change requires clearly understanding the extent to which climate change guidance is currently applied. Here, we evaluate both implicit and explicit applications of climate change management principles in MPAs globally. We review publicly available management plans to assess the extent to which MPA management employs key recommendations for climate resilience and adaptive management, as synthesized by Tittensor et al. (2019) and Wilson et al. (2020). For each plan, we determine the level of climate change management responsiveness—from general awareness to climate-specific actions—to comprehensively assess both the structural elements of the plan that provide indirect climate resilience as well as the application of direct climate-specific strategies. Our evaluation also reveals common gaps in addressing climate change in MPA management. We highlight practical examples of climate adaptation strategies in use in real-world MPAs, which provide useful context for practitioners interested in improving MPA management in the face of climate change.

2 | METHODS

2.1 | Identifying MPA management plans

Individual protected areas were identified through the Marine Conservation Institute's MPAtlas database, which compiles information on global marine protection (Marine Conservation Institute, 2021). The initial list of all MPAs (n = 20,933) was restricted to coastal or MPAs that were already implemented (as of 2020) and likely to prohibit at least some extractive activities (Supplemental Methods in the Supporting Information). We focus on MPAs that restrict extractive and destructive activities because they have demonstrated the strongest evidence for positive conservation benefits (Lester et al., 2009; Sala & Giakoumi, 2018) and are most likely to have public-facing management plans available for review. Our goal was to obtain a globally representative sample of management plans. These criteria resulted in 1609 individual areas. For each area, internet searches were conducted to locate public-facing management plans (Supplemental Methods and Table S1 in the Supporting Information). When a plan was located, it was downloaded and saved for review. Each plan was thoroughly reviewed for specific criteria (Supplemental Methods and Table S2 in the Supporting Information). Plans written in languages other than English were translated into English using the Google Translate document translation tool prior to review (Google Cloud Document Translation, 2021). If multiple management plans were located for the same area, only the most recent plan was reviewed. Additional planning documents, including climate change action plans, monitoring plans, and assessment reports, were also reviewed if they were referenced in the original plan, available for download, and clearly applicable to one or more of the review criteria. References for all reviewed documents are included in the Supporting Information (Table S3).

Searches yielded 172 management plans, covering 555 MPAs. Some MPAs are managed regionally, so a single plan can cover several areas. Of the 172 plans, 110 apply to a single area and 62 apply to at least two identified areas. Plans span 52 countries and one Area Beyond National Jurisdiction and include all major ocean basins except the Arctic. The earliest plan was published in 1991, and 75.6% of plans were published between 2010 and 2020. Plans are written in nine languages, with the majority English (59.9%, n = 103) followed by Spanish (18.0%, n = 31), Portuguese (7.0%, n = 12), and French (6.4%, n = 11). The management plans cover all protected area size classes as defined by MPAtlas (Marine Conservation Institute, 2021) and span over 6.6 million square kilometers of protected ocean area. All details collected from each plan are provided in the Supporting Information (Table S4).

All data analyses and visualizations were conducted in R (R Core Team, 2021). The data that support the findings of this study are openly available on GitHub here: https://github.com/lopazanski/mpa-climate-change

2.2 | Assessing MPA management for climate change

To determine the extent to which climate change is considered in management planning, each plan was reviewed for specific criteria (Supplemental Methods and Table S2 in the Supporting Information; Figure 1). Our criteria were developed based on synthesized guidelines for climate resilience and adaptation principles for MPAs (Tittensor et al., 2019; Wilson et al., 2020), grouped by the components of the management planning process. Specifically, we determine how many MPA management plans: (i) include objectives that support long-term ecosystem-based management, (ii) conduct vulnerability assessments or otherwise evaluate threats, (iii) incorporate resilient or dynamic spatial design strategies to determine MPA size and placement, among other factors, (iv) implement comprehensive monitoring programs, and (v) plan to update management goals or actions through adaptive management and/or include additional climate change management strategies. These components are consistently highlighted across climate change conservation planning frameworks (Wilson et al., 2020) and therefore provide a useful guide to comprehensively evaluate climate change strategies across all aspects of MPA management, including both spatial design strategies (iii) and other key components of adaptive management (i, ii, iv, and v).

For each component, we recorded the degree to which the plan follows recommendations for climate resilience through three increasing levels of climate change inclusion: discussion of the concept ("general awareness"), actions following common scientific recommendations for resilience ("recommended action"), and actions applied explicitly to address climate change or with climate change

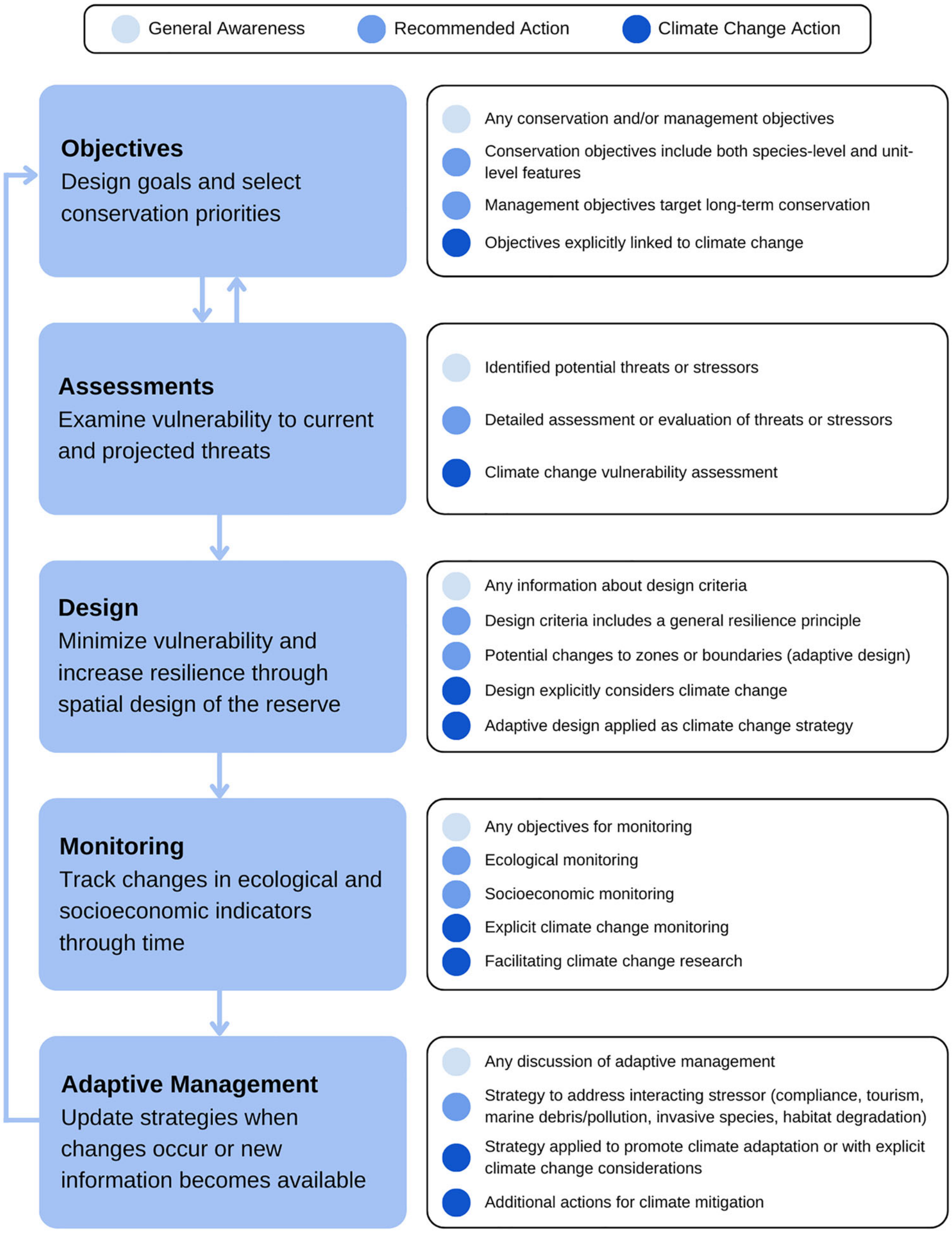

FIGURE 1 The evaluation framework is used to assess the inclusion of climate change principles in marine protected area management plans. Blue boxes (left) show the main assessment categories and white boxes (right) summarize the detailed criteria used for this assessment. Small blue circles indicate the level of climate change incorporation, defined as general awareness (light blue), following recommended actions based on scientific principles of resilience (medium blue), and explicit climate change actions (dark blue). Framework components were adapted from Wilson et al., 2020 and evaluation criteria include recommendations cited therein. The full list of evaluation criteria with specific methods for each is provided in the Supporting Information (Table S2).

considerations ("climate action"). Although adaptive management encompasses all components, we discuss it last to evaluate additional strategies used to address climate change that are not captured elsewhere. We also provide examples of each principle in use in a real-world MPA. These examples were selected to provide a globally representative subset from diverse MPAs. The full list of all explicit climate change strategies collected is provided in the Supporting Information (Table S5).

3 | RESULTS

3.1 | General climate change recognition

Climate change or its effects are explicitly mentioned in 78.5% ($n = 135$) of plans (Figure 2 and 3). Plans that mention climate change vary in the degree to which they incorporate adaptation and mitigation into their strategies. Climate change discussion ranges from solely mentioning

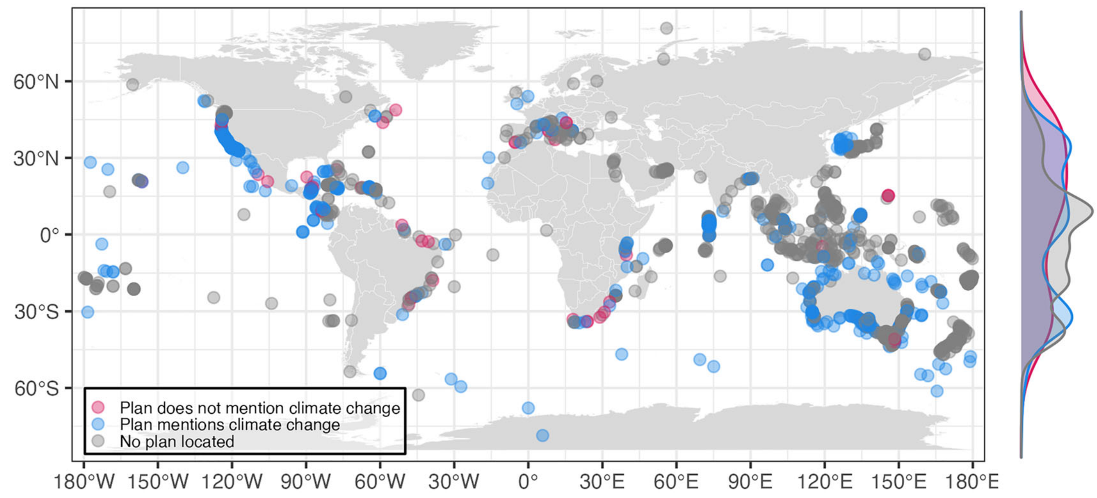

FIGURE 2 Overview of climate change inclusion in marine protected area management plans. Each circle is located at the centroid of an individual marine protected area that met the inclusion criteria for our study (n = 1609). Gray circles indicate areas where no publicly available management plan was located. Blue circles indicate areas with a management plan that mentions climate change; pink circles indicate areas with a management plan that does not mention climate change. The right vertical axis displays the latitudinal density of results from each category.

it (9.3%, $n = 16$) to developing detailed climate change-specific action plans (20.9%, $n = 36$), with most falling somewhere in between by providing at least one explicit climate change strategy (48.3%, $n = 83$).

3.2 | Defining goals and objectives

Defining the goals and objectives for an MPA provides a clear basis for evaluating effectiveness of the protected area over time (Grorud-Colvert et al., 2021). We classified objectives into two categories: conservation objectives, which outline what features the area intends to protect, and management objectives, which specify broader actions within the area. Recommendations for climate resilience suggest defining conservation objectives using both fine-filter (i.e., individual species) and coarse-filter (i.e., groups of species or habitats) approaches, which ensure protection of important or vulnerable species while also capturing the range of biodiversity across landscapes (Tingley et al., 2014; Wilson et al., 2020). While managing for climate change requires a primary focus on long-term conservation (Frazão Santos et al., 2020), management objectives should also explicitly incorporate climate change (Tittensor et al., 2019), such as by prioritizing climate change across actions for monitoring and assessments.

Conservation objectives are specified in 87.8% of plans ($n = 151$), and 78.5% ($n = 135$) describe both fine- and coarse-filter features (Figure 3). All plans have at least one management objective and 93.6% ($n = 161$) contain objectives matching at least one long-term conservation category (e.g., maintaining ecosystem function and/or biodiversity through time, enhancing overall system resilience or promoting adaptation, establishing baselines and/or monitoring changes through time, providing a natural reference area for distinguishing long-term changes from typical variation; see Supplementary Methods in the Supporting Information). Explicit climate change management objectives are present in 60.5% ($n = 104$) of plans, and 41.9% ($n = 72$) also have an additional general objective to promote adaptation or resilience to climate change.

The Kisite-Mpunguti, Malindi, and Watamu reserves in Kenya outline conservation objectives using a tiered prioritization approach: after selecting unit-level features (e.g., critical habitats), they identify species-level features (e.g., reef fish) and key attributes (e.g., abundance) within each feature. Each level is qualitatively assessed for vulnerability to stressors and threats, including climate change, and linked to specific goals, indicators, and monitoring methods (Kenya Wildlife Service, 2015, 2016a, 2016b).

3.3 | Assessing vulnerability to current and future threats

Determining appropriate management strategies in a changing environment requires assessing current and future threats within the area to understand which aspects of the MPA may be most vulnerable. Vulnerability assessments should evaluate both climate change threats and other stressors relevant to the area (Otero et al., 2013; Tingley et al., 2014; Wilson et al., 2020), as interactions

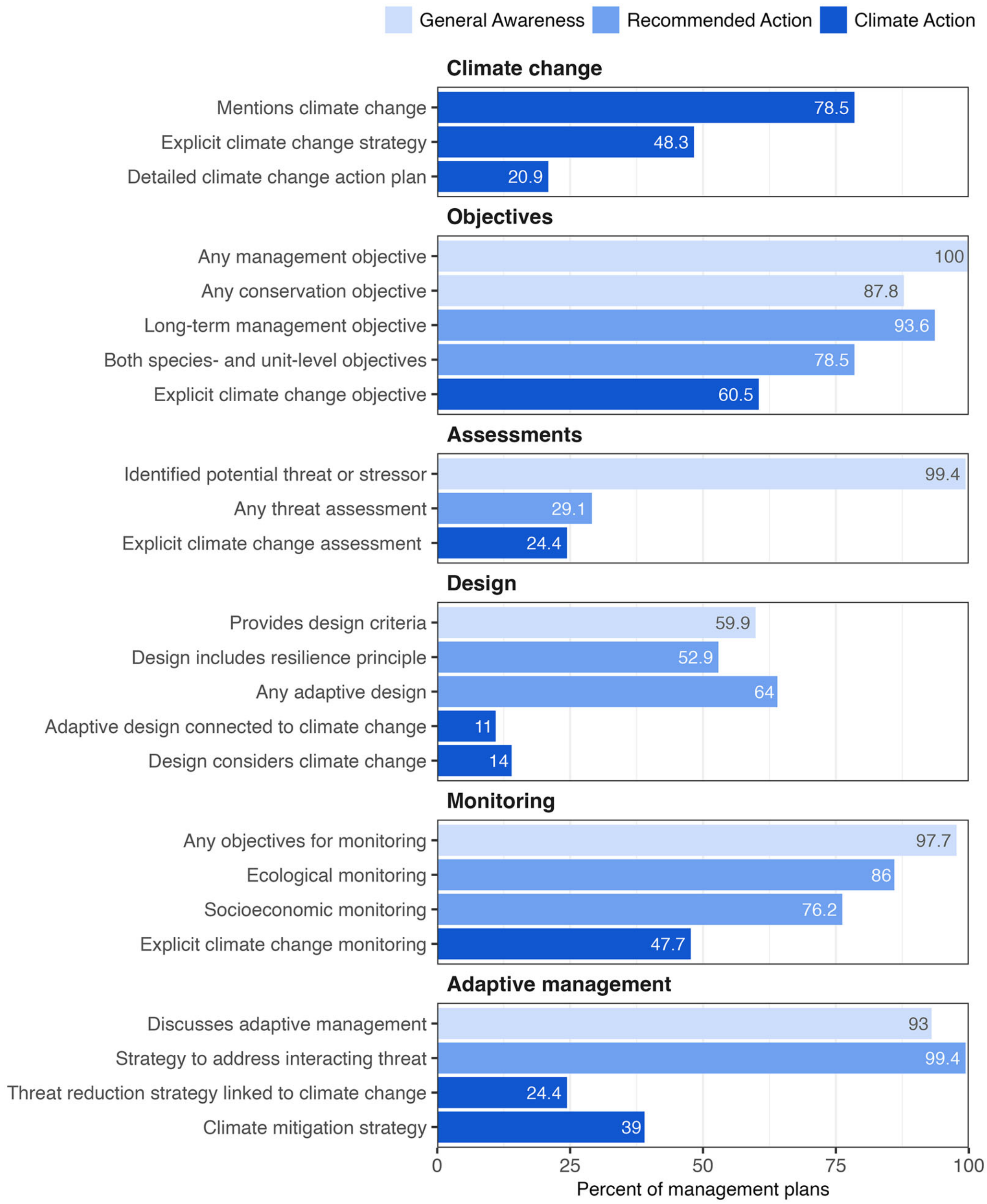

FIGURE 3 Percentage of management plans that incorporate recommended principles for climate resilience across each evaluated component. Color corresponds to the degree to which climate change is incorporated, from general management awareness ("general awareness"; light blue) to implementing commonly recommended scientific principles without climate change considerations ("recommended action"; medium blue), to applying those principles explicitly for climate change ("climate action"; dark blue).

among stressors can have cumulative effects (Cabral et al., 2019; O'Hara et al., 2021) and some threats may be more feasible to address (Mach et al., 2017). Many other common management issues—such as pollution, invasive species, or poor compliance with regulations—may contribute to ecosystem vulnerability and be easier to manage within the MPA compared to climate change itself.

Management plans describe a range of assessments to examine current and future threats, including vulnerability and sensitivity analyses, environmental risk/impact assessments, and qualitative threat assessments. Nearly all plans identify at least one major threat to the conservation values of the MPA (99.4%, $n = 171$; Figure 3). While 24.4% ($n = 42$) describe at least one assessment examining a current or future threat, fewer (9.3%, $n = 16$) report a specific climate change vulnerability assessment (Figure 3). However, 15.1% (n = 26) include objectives for future climate change vulnerability assessments, and 4.7% ($n = 8$) discuss plans for other vulnerability assessments not explicitly for climate change. In total, 42.4% ($n = 73$) of plans from 27 countries report completed or planned assessments for climate change and/or other threats.

The Great Barrier Reef Marine Park in Australia is using vulnerability assessments to identify and protect key species that assist in recovery, such as fast-growing plate corals which help replenish shelter and herbivores which limit macroalgae growth. They are developing a decision-support tool that integrates data from the assessments to map dynamic exposure and identify areas that maximize system-wide resilience benefits (Great Barrier Reef Marine Park Authority, 2017, 2018).

3.4 | Incorporating resilient spatial design strategies

After defining objectives and assessing vulnerabilities, it is critical to select appropriate actions to minimize vulnerability and increase resilience (Frazão Santos et al., 2020). One option is to address concerns through the spatial design of the reserve. Designing MPAs on the basis of increasing resilience may enhance outcomes even without explicit consideration of climate change in the design process (Rassweiler et al., 2020). For example, spreading risk through representation and replication, maximizing connectivity with size/spacing, and selecting critical habitat areas to maintain ecosystem function are each "general resilience principles" which can confer climate change resilience (Green et al., 2014; McLeod et al., 2009). However, incorporating climate change explicitly in MPA design may provide additional benefits (Coleman et al., 2017; Gerber et al., 2014; Pinsky et al., 2020). Specific recommendations include protecting future habitats and species distributions, climate refugia, and a range of climate exposures and velocities (Arafeh-Dalmau et al., 2021; Fredston-Hermann et al., 2018). While most MPA design focuses on the placement of static MPAs, complementing static networks with dynamic protective measures can help buffer against uncertainty associated with climate change (D'Aloia et al., 2019). This can range from iteratively updating zoning frameworks to confer temporary protection from certain activities to fully flexible networks that are dynamic in both space and time.

Management plans do not always provide specifics about how the MPA was designed: 59.9% (n = 103) of plans provide some detail about the design criteria used (Figure 3), mostly referencing the internal zoning plans (41.9%, $n = 72$) rather than placement of the reserve boundaries (18.0%, $n = 31$). When design information is included, it often refers to at least one general resilience principle (e.g., protecting critical species/habitats, capturing representative habitats, setting thresholds for size/spacing, considering connectivity among areas; see Supplementary Methods in the Supporting Information) without explicitly referencing climate change (52.9%, n = 91; Figure 3). For example, the British Virgin Islands Marine Protected Area Network describes aiming to protect 30% of nearshore habitats within a network of reserves of moderate size (10–100 km^2) and variable spacing, but does not reference climate change as a design consideration (British Virgin Islands National Parks Trust, 2007).

Design criteria applied with explicit climate change considerations are less common (14.0%, $n = 24$; Figure 3), and roughly half refer to planned climate change design actions for the area (n = 13) rather than changes that are confirmed or underway ($n = 11$). These explicit considerations include protecting resilient areas ($n = 14$), protecting critical species and or habitats for climate resilience ($n = 13$), increasing connectivity ($n = 8$), protecting shifting distributions (n = 4), and protecting climate refugia (n = 3). The Ngarchelong Marine Managed Area in Palau contains a highly restricted "Area Managed for Coral Replenishment" zone, which protects a region that rebounded from a massive bleaching event more quickly than other areas and contributed coral spawn that facilitated recovery in nearby areas (Ngarchelong Marine Resource Planning Team, 2012).

Dynamic protection measures are discussed in 64.0% (n = 110) of plans (Figure 3): 20.9% (n = 36) describe possible changes to the external boundaries of the managed area, and 59.9% (n = 103) describe adaptive zoning frameworks (with an overlap of 17.4% including both). No reviewed plans describe spatial designs that are dynamic in both space and time simultaneously. Some management plans leverage these adaptive measures with explicit climate change considerations (11.0%, $n = 19$; Figure 3), most often by including strategies to increase protection within the managed area to promote further climate resilience, either through protecting new regions or increasing the level of protection within existing MPAs by updating zoning schemes. In Belize, multiple management plans indicate plans to review and re-evaluate zoning and boundaries throughout the regional network based on outputs from monitoring and climate change research. Recommendations within the plans include expanding the conservation zone to assist in mitigating climate impacts, incorporating high-resilience reef areas, and protecting source populations and key larval dispersal routes (Belize Fisheries Department, 2011; Foster et al., 2012; Wildtracks & SEA Belize, 2011a, 2011b, 2011c).

3.5 | Monitoring change through time

Many areas lack baseline information on current oceanic conditions and feature distributions, a necessary precursor to making design changes. Developing monitoring programs to track specific indicators can boost this scientific knowledge, determine whether MPA objectives are being met, and signal notable environmental changes (Dunham et al., 2020; Pomeroy et al., 2005). In this sense, managers may opt to address an identified vulnerability by establishing a monitoring program to track changes over time, and subsequently use information gathered to set thresholds and timelines for additional management responses (Carr et al., 2017). Recommendations highlight a need to target multiple ecological and socioeconomic indicators to monitor the effectiveness of MPAs at reaching objectives (Pomeroy et al., 2005; Sanchirico et al., 2002), as well as explicitly monitoring climate change variables and effects (Tittensor et al., 2019; Wilson et al., 2020).

Nearly all reviewed management plans describe monitoring strategies (97.7%, $n = 168$; Figure 3), however, 10.5% ($n = 18$) are noted as being in the development phase, suggesting they may not be implemented. Plans often include both ecological and socioeconomic monitoring, although ecological monitoring is slightly more common: 86% ($n = 148$) of plans list ecological indicators (e.g., physical, biological, and ecological characteristics) compared to 76.2% ($n = 131$) with socioeconomic indicators (e.g., related to human uses or interactions) (Figure 3). Climate change monitoring is explicitly described in 47.7% ($n = 82$) of plans (Figure 3). However, many of the plans that are not explicitly monitoring climate change are implementing similar strategies, such as monitoring climate-related variables or effects (e.g., oceanographic characteristics, coral bleaching, sensitive species indicators), establishing baselines, and/or focusing on discerning long-term trends relative to typical variation. An additional 52 monitoring plans have these similar strategies "implicitly" monitoring climate change, resulting in a total of 77.9% of plans ($n = 134$) tracking climate-related variables or effects.

Monitoring in the Phoenix Islands Protected Area (Kiribati) indicated that areas with good water quality and intact herbivore populations had higher potential recovery from severe bleaching events, and climate change research studies suggested that a particular lagoon may be resilient to increases in ocean acidification. The plan leverages these monitoring and research outputs into a formal recommendation to designate the lagoon reef habitat as a strict protection zone due to the high vulnerability of *Acropora* coral communities (Ministry of Environment, Lands & Agricultural Development, 2015)

Forming research partnerships is often used as a strategy to fill gaps in monitoring programs or address areas with limited capacity or resources, and 33.7% ($n = 58$) of plans discuss strategies for facilitating research on climate change and its impacts. These plans often outline priority research needs and identify potential collaborators among government agencies, nonprofit organizations, universities, or other institutions. In addition to filling knowledge gaps, partnerships can also be used to develop and implement intervention measures. The Greater Farallones National Marine Sanctuary (United States) has established priorities for research that inform future management responses to climate impacts, which includes forming partnerships to test methods for protecting and restoring kelp, wetlands, and seagrass to promote ocean acidification mitigation and carbon sequestration (U.S. National Oceanic & Atmospheric Administration, 2014, 2016b).

3.6 | Implementing management actions

Given the barriers to implementing design changes in existing MPAs, objectives and vulnerabilities can also be addressed through management actions. Adaptive management is a useful tool for addressing uncertainty surrounding potential climate effects, as strategies can be continually adjusted (Creighton et al., 2016; Peterson et al., 1997). Adaptive management strategies are featured in 93.6% ($n = 161$) of plans (Supplemental Methods in the Supporting Information; Figure 3). Timelines for reviewing and updating all goals and actions range from 1 to 25 years, with an average of 7.52 ± 3.58 years (mean ± SD). However, many plans describe updating portions of the plan at regular intervals before a complete re-drafting: 75 (43.6%) use annual or multiyear work plans to prioritize actions over shorter time periods. Adaptive management is most effective when goals and actions are iteratively updated based on information from monitoring and assessments (Marmorek et al., 2019; Tanner-McAllister et al., 2017). The Port Honduras Marine Reserve in Belize specifies indicators to track progress towards both conservation targets and management objectives, including expected timelines to reach benchmarks and acceptable limits of change. The monitoring outputs are reviewed annually and have been used to support management interventions, including increasing the percentage of the managed area where extraction is prohibited (Foster et al., 2012). Although adaptive management actions are applicable across all management components (covered in the prior sections), here we focus on two climate-relevant management strategies not yet covered elsewhere: targeting interacting stressors and actions for climate mitigation.

While there may be limited capacity to mitigate climate change threats, opportunities to target other localized impacts are often more tractable (Mach et al., 2017). Exposure to additional stressors can diminish the ecosystem's ability to withstand impacts of climate change (Halpern et al., 2008), and reducing cumulative impacts is likely to increase resilience to climate effects and minimize

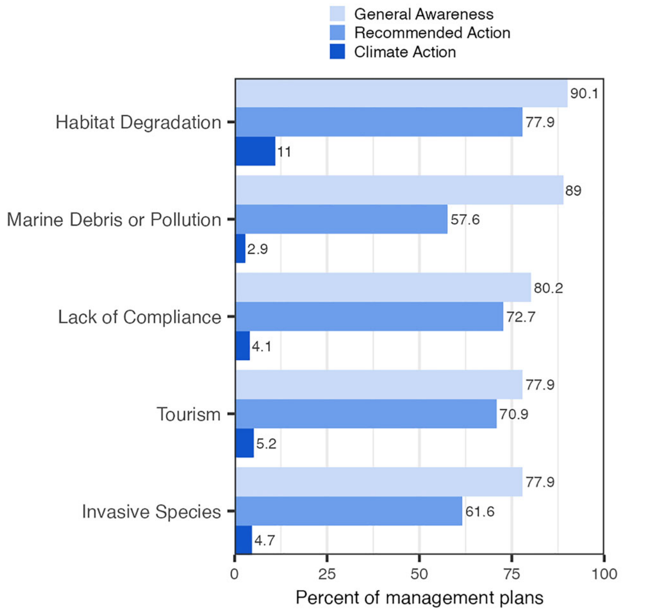

FIGURE 4 Prevalence of strategies targeting five common localized stressors: habitat degradation, marine debris or pollution, lack of compliance, tourism, and invasive species. Bars indicate the percentage of marine protected area management plans which listed the threat as a major concern ("general awareness"; light blue), described any specific strategies to address the threat ("recommended action"; medium blue) and applied those actions to promote climate adaptation or with explicit climate change considerations ("climate action"; dark blue).

overall vulnerability (Mach et al., 2017; Mcleod et al., 2019). We reviewed actions across five common localized stressors: lack of compliance with regulations, negative effects of tourism, marine debris and pollution, invasive species, and habitat degradation (Supplemental Methods in the Supporting Information). Nearly all management plans (99.4%, n = 171) both identify at least one as a prominent threat and include a strategy to address that threat (Figure 3). However, only 24.4% (n = 42) explicitly link those threat-reduction strategies to climate change (Figure 3). This pattern is similar across all of our evaluated threat categories (Figure 4). When climate change is explicitly integrated, it is often by considering climate change effects in areas where the activities occur. For example, plans from the Southern Belize Barrier Reef Complex discuss increasing enforcement efforts in areas that are identified as particularly threatened or resilient to climate change impacts (Belize Fisheries Department, 2011; Foster et al., 2012; Wildtracks & SEA Belize, 2011a, 2011b, 2011c, 2011d), and Revillagigedo National Park in Mexico plans to include climate change criteria when selecting sites for restoration and invasive species control (Secretaría de Medio Ambiente y Recursos Naturales, 2018).

Protection itself may lessen negative climate change impacts by reducing biodiversity loss, acting as a carbon sink, protecting ecological processes, supporting adaptation through protecting biological corridors, and promoting genetic exchange (Roberts et al., 2017). However, additional opportunities to target climate change mitigation should also be considered (Tittensor et al., 2019). Climate mitigation strategies are found in 39% (n = 67) of plans (Figure 3). Several plans (30.8%, n = 53) discuss the role of protection itself in mitigating the effects of climate change, primarily citing contributions to carbon sequestration or the provision of resilience benefits from supporting healthy ecosystems. Plans also describe strategies to promote sustainable reserve operations (14.0%, n = 24), including using solar power (e.g., Aldabra Atoll Special Reserve, Seychelles; Seychelles Islands Foundation, 2016), replacing older vessel engines with cleaner models (e.g., Channel Islands National Marine Sanctuary, United States; U.S. National Oceanic & Atmospheric Administration, 2016a), and considering sea level rise and storm surge hazards when planning new facilities (e.g., He'eia National Estuarine Research Reserve, United States; Hawai'i Office of Planning, 2016). Many plans describe providing educational opportunities as a key management objective and 20.3% (n = 35) emphasize programs to raise awareness about climate change and its expected effects both within and beyond MPA boundaries. For example, the Sundarbans Wildlife Sanctuaries (Bangladesh) are developing a section in the Visitor Center about the role of mangroves in climate change adaptation and mitigation (Ministry of Environment & Forests, 2010), and Phoenix Islands Protected Area (Kiribati) has a weekly evening radio quiz for local schools with questions about climate change and sustainability (Ministry of Environment, Lands & Agricultural Development, 2015). By raising awareness of climate change and its effects, these initiatives can promote action to reduce global emissions.

4 | DISCUSSION

Understanding the implementation of climate adaptation strategies in MPAs is important because it provides a baseline that can be used to identify where additional efforts are needed to prepare MPAs for climate change. Our analysis suggests that MPA management plans do contain many underlying scientific and management principles for reducing vulnerability and promoting resilience to climate change, even when "climate change" or related terms are not specifically included (Figure 3). Management plans routinely include many of the structural elements that can facilitate the ability to manage for change, including long-term management objectives, monitoring programs,

FIGURE 5 Degree to which climate change is integrated into each evaluated component of marine protected area management plans ($n = 172$). Plans are ordered by their overall level of climate change inclusion across all assessed components within each region. The color indicates the level of climate change inclusion across evaluated criteria as follows: not included in the management plan ("not included"; white), discusses the concept in general ("general awareness"; light blue), includes any actions following common scientific recommendations for resilience ("recommended action"; medium blue), and applies actions explicitly to address climate change or with climate change considerations ("climate action"; dark blue). The first column indicates whether or not climate change is mentioned in the plan. Listed names refer to the main area listed in the title of the management plan, translated into English when necessary, and common designations have been abbreviated. MPA, marine protected area; NP, national park; MP, marine park; BR, biological reserve; MR, marine reserve; BR, biosphere reserve; NMS, national marine sanctuary; CA, conservation area; ES, ecological station; NWR, national wildlife refuge. (See Table S4 for full results from each management plan).

strategies to reduce localized stressors, and plans for adaptive management. In addition, plans that explicitly address climate change often do so across multiple components (Figure 5), suggesting climate change may become a consistent priority once it is included.

Our review demonstrates that climate change is often considered an imminent challenge for MPAs, and there are several explanations for why climate change still may not receive explicit recognition across management actions. Many management plans (22.1%, $n = 38$) discuss the limitations of the MPA to address climate impacts due to the scale and severity of global climate change. These plans consistently highlight that limited knowledge of current conditions or future climate effects is a hindrance to determining appropriate adaptation strategies. Some explicitly deem climate change beyond the scope of their plans, stating that climate change impacts are not manageable during the life of the plan (e.g., Flamborough Head Marine Reserve, Canal de Luis Peña Nature Reserve, Aldabra Atoll Special Reserve) (Davidson, 2016; Seychelles Islands Foundation, 2016; Valdéz Pizzini et al., 2008). MPA managers may also choose to allocate limited resources towards other threats that can be directly addressed within MPA boundaries. Nearly all of the reviewed plans describe at least one strategy to address a nonclimate change related localized threat, which may offer more immediate positive benefits to conservation features and also promote climate resilience by reducing cumulative stress on the ecosystem (Mach et al., 2017).

The best practices and examples highlighted here can be used by MPA managers to improve the climate responsiveness of any MPA. Those that are missing many key components should likely strengthen foundational management strategies before tackling climate change specifically, whereas plans that are consistently following common recommendations for resilience may be well-suited to tailor future efforts explicitly towards climate change. These insights can also be sued when designing new or expanding existing MPAs—such as to establish very large "tall" MPAs to encompass current and future species range shifts based on predicted climate velocities (Fredston-Hermann et al., 2018)—to ensure that efforts to improve marine protection also effectively build climate resilience (Roberts et al., 2017; Jacquemont et al., 2022). Importantly, while management plans provide information about planned strategies for an area, they generally lack information about the implementation and outcome of those strategies, making it difficult to assess the true impact of strategies employed. Though our assessment leverages the best available scientific guidance, there is limited empirical evidence for which climate change adaptation strategies are most effective. Program evaluation and impact assessments are needed to track climate change relevant management actions and their effects on local ecosystems. Knowledge sharing among managers can also provide helpful guidance on applicable strategies, as can existing decision support and related online tools. For example, regional network organizations (e.g., Open Communications for the Ocean [OCTO, 2023], Caribbean Marine Protected Areas Management Network and Forum [CaMPAM; Gulf & Caribbean Fisheries Institute, 2018], Network of Marine Protected Area Managers in the Mediterranean [MedPAN; MedPAN Association, 2023) connect managers and practitioners to facilitate knowledge and resource sharing and collaboration between members, often leading training on various subjects. The Climate Adaptation Toolkit for Marine and Coastal Protected Areas provides a step-by-step guide to managers considering climate adaptation, and also compiles example strategies, case studies, and data sources (Climate Adaptation Knowledge Exchange, 2023). Other resources, such as the Protected Seas Navigator tool (Driedger et al., 2023), may provide useful information to contextualize management planning within the existing MPA regulatory landscape.

This review synthesizes information from MPAs that are implemented, restrict extractive activities, and have accessible management plans ($n = 555$), but this does not represent the majority of the world's existing MPAs. Many MPAs remain unimplemented, have lower protection levels, and/or lack available management plans (Grorud-Colvert et al., 2021). Other effective area-based conservation measures are not evaluated in this review but may be used to supplement existing MPAs to further build climate resilience. While this review likely provides information from MPAs with above average management, effective management is widely cited as a prominent driver of MPA success (Gill et al., 2017). Therefore, setting and achieving basic management objectives is a necessary precursor to providing climate resilience. Well-managed MPAs may promote climate adaptation (Roberts et al., 2017) and resilience (Sala & Giakoumi, 2018) without explicit recognition of either objective in a management plan. Establishing effective management and addressing locally relevant compounding stressors should be prioritized to achieve climate resilience. Only then can the guidance summarized here be effectively deployed to improve MPA management in the face of climate change.

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SUPPORTING INFORMATION

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

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