



A Global Assessment of Climate Change Adaptation in Marine Protected Area Management Plans

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Marine protected area (MPA) efficacy is increasingly challenged by climate change. Experts have identified clear climate change adaptation principles that MPA practitioners can incorporate into MPA management; however, adoption of these principles in MPA management remains largely unquantified. We conducted a text analysis of 647 English-language MPA management plans to assess the frequency with which they included climate change-related terms and terms pertaining to ecological, physical, and sociological components of an MPA system that may be impacted by climate change. Next, we manually searched 223 management plans to quantify the plans' climate change robustness, which we defined as the degree of incorporation of common climate change adaptation principles. We found that climate change is inadequately considered in MPA management plans. Of all plans published since 2010, only 57% contained at least one of the climate change-related terms, "climate change," "global warming," "extreme events," "natural variability," or "climate variability." The mean climate change robustness index of climate-considering management plans was 10.9 or 39% of a total possible score of 28. The United States was the only region that had plans with climate robustness indices of 20 or greater. By contrast, Canada lags behind other temperate jurisdictions in incorporating climate change adaptation analysis, planning, and monitoring into MPA management, with a mean climate change robustness index of 6.8. Climate change robustness scores have generally improved over time within the most common MPA designations in Oceania, the United Kingdom, and the United States, though the opposite is true in Canada. Our results highlight the urgent need for practitioners to incorporate climate change adaptation into MPA management in accordance with well-researched frameworks.

Keywords: climate change robustness, text analysis, adaptive management, biodiversity conservation, monitoring, sea level rise

INTRODUCTION

Marine species and habitats are under threat from many local and global stressors, including exploitation, coastal development, pollution, invasive species, shipping, underwater noise, and disease (Dulvy et al., 2003; Crain et al., 2009; Avila et al., 2018). Preventing or reducing stressor impacts by creating marine protected areas (MPAs) has become the cornerstone of marine biodiversity conservation. Coastal nations committed to meeting Aichi Target 11 of the Convention on Biological Diversity's (CBD) Strategic Plan for Biodiversity 2011–2020 to protect at least 10% of

their coastal and marine areas through the use of MPAs or other effective area-based conservation measures by 2020 (United Nations Environment Programme [UNEP], 2010). In 2021, this target is likely to be increased to 30% by 2030, with at least 10% of this area under strict protection (United Nations Environment Programme [UNEP], 2020). Currently, only 7.6% of the world's oceans are protected, though this value increases to 17.5% in marine areas under national jurisdiction (UNEP-WCMC et al., 2021).

Increasingly, climate change is challenging the efficacy of MPAs (Soto, 2002; Bruno et al., 2018). Protected areas are traditionally created under the assumption that the distribution and abundance of the biodiversity they protect is static, which is not the case under a changing climate (Hagerman et al., 2010; Hole et al., 2011; Abrahms et al., 2017). Climate change is driving ocean warming, acidification, and deoxygenation, increasing the frequency and magnitude of coastal storms, and changing ocean circulation patterns (Hoegh-Guldberg and Bruno, 2010; Doney et al., 2012; Poloczanska et al., 2016; Knutson et al., 2021). These changes are in turn altering the distribution, phenology, abundance, size, and physiology of marine species, which will have significant impacts on ecosystems and human coastal communities (Pecl et al., 2017; Bindoff et al., 2019; English et al., 2021). Additionally, sea level rise will cause saltwater intrusion, erosion and inundation, and loss of natural, cultural, and historical sites (Bindoff et al., 2019). Consequently, climate change is contributing to population declines even in MPAs and necessitating the protection of species and habitats not just where they are currently located but also where they will be (Diamond et al., 2017).

Despite these challenges, well-designed and managed MPAs can be used as a mitigation and adaptation tool under a changing climate. MPAs, MPA networks, and other approaches to marine spatial planning can contribute to the resistance and resilience of species, communities, and ecosystems to climate change through several pathways (Groves et al., 2012; Carr et al., 2017; Roberts et al., 2017; Kroeker et al., 2019). As examples, MPA networks can ensure continued protection as species shift their distributions or protect genetic diversity across a species' range; large MPAs can support larger populations that might rebound from or be more resistant to climate impacts because they are more likely to contain higher genetic diversity (e.g., Reusch et al., 2005; Munguía-Vega et al., 2015); MPAs that extend across a range of depths can allow for shifts in species' depth distribution to track environmental gradients (as reviewed by McLeod et al., 2009; Carr et al., 2017); and MPAs may increase the resilience of species or ecosystems to climate change pressures by reducing other threats such as fishing pressure or pollution (Lawler, 2009; but see Côté and Darling, 2010). However, MPA efficacy and the success of the MPA as a climate change mitigation and adaptation tool depends on the degree of consideration given to climate change in MPA design and management (Edgar et al., 2014; Tittensor et al., 2019).

In climate-robust MPA management, climate change adaptation is incorporated in several structured steps (Geyer et al., 2017; Tittensor et al., 2019; Wilson et al., 2020 and references therein). First, MPA planners or managers must

assess the vulnerability of ecological, physical, and sociological features of the MPA to climate change impacts. Second, they must identify climate change adaptation objectives and fully operational strategies (**Table 1**). Fully operational climate change strategies are legally feasible, socially acceptable, and possible actions existing government systems can take with available resources or data. They must be specifically defined and preferably quantitative, so that success can be tracked (Halpern et al., 2012; Collie et al., 2013). Third, managers must monitor ecological, physical, and sociological features to assess climate change impacts and MPA effectiveness under climate change. Monitoring programs must identify indicators to track the status of the features and indicators of physical change due to climate change itself (e.g., pH, temperature) to link any change in feature condition with climate change (Carr et al., 2011, 2017; McLeod et al., 2019). The indicators should link back to the specific objectives of the MPA. They should also track spatial and temporal trends in other human threats inside and outside the MPA that could be driving trends in indicator status (McLeod et al., 2019; Dunham et al., 2020). Last, managers must identify specific and quantitative targets and thresholds, again linked back to MPA objectives. A target is a desired condition of an indicator or performance toward an objective, and a threshold (i.e., limit) is a condition or marked change that would elicit management action (Samhouri et al., 2011, 2012; **Table 1**). Targets and thresholds are value-based and can take the form of single numbers such as a desired and minimum population size, respectively, or they can be probabilistic, such as probabilities of population persistence. Clearly defined targets and thresholds facilitate adaptive management (Gregory et al., 2012), where new information acquired through monitoring or experience is continually used to update management objectives, strategies, and methods (Holling, 1978; Walters, 1986). Adaptive management is well suited to responding to uncertainty around climate change impacts and allows MPA management plans to be updated as needed (Ban et al., 2011).

Despite this existing body of knowledge on how to incorporate climate change adaptation in MPA management, several interview-based studies of individuals involved in MPA planning or implementation have found that conceptual frameworks and approaches are not being adequately and consistently translated into practice (Cvitanovic et al., 2014; Hopkins et al., 2016; Whitney and Ban, 2019). Similarly, recent reviews of the primary literature and/or MPA case studies have found little evidence of integration of climate change considerations in MPA design and management (Tittensor et al., 2019; Wilson et al., 2020). However, a recognized weakness of these scientific literature reviews is that they only show a glimpse of the full picture because government and NGO management efforts are rarely documented in primary literature (Tittensor et al., 2019).

A more informative approach to evaluating the incorporation of climate change adaptation in management is to look for evidence directly in MPA management plans, as has been done in British Columbia, Canada (Heck et al., 2012) and Germany (Geyer et al., 2017). Here, we expanded upon these works by compiling English-language MPA management plans from across the globe and conducting a text analysis of

TABLE 1 | Examples of key MPA management plan components, as defined in this study. Examples show how climate change can be considered.

Term	Definition	Examples
Objective	Management aims.	To maintain the biological integrity, diversity, and environmental health of coastal habitats in the MPA in the face of human pressures, including climate change and sea level rise.
Strategy	Specific actions, tools, or techniques that may be used to achieve an objective.	Within 2 years, work with researchers at a neighboring academic institution to model probable impacts of sea level rise on estuarine marsh habitat in the MPA (e.g., assess water quality, sediment accretion rates, vegetation communities); within 3 years, relocate parking and related facilities in response to climate change and design a new energy-efficient visitor centre to reduce energy use.
Indicator	An attribute that acts as a sign or signal of the status of an ecological, physical, or sociological component of the MPA.	An ecological indicator could be abundance, percent cover, or recruitment of at-risk species or communities/species of value; a physical indicator could be water quality or sea level; and a sociological indicator could be park visitor traffic.
Metric	The typically quantitative variable(s) measured to determine the status of an indicator.	Ecological abundance metrics could include catch per unit effort, number of bird nests, or area of vegetation communities; a metric of water quality could be water temperature or pH; and a metric of visitor traffic could be the number of pedestrians to visit the MPA or transits through the MPA by vessels. Some metrics may perform the function of both indicator and metric (e.g., water temperature).
Target	The optimal or desired condition of the indicator.	A goal population size (e.g., measured in catch per unit effort) or percent cover of a habitat type.
Threshold	A minimum condition or marked change in condition that would elicit management or restoration action.	A minimum population size or percent cover of a habitat type.

the management plans to assess the frequency with which climate change-related terms, plus terms pertaining to ecological, physical, and sociological components of an MPA system that may be impacted by climate change, appear in MPA management plans. While we are aware that MPA monitoring plans generally contain more in-depth information on the precise monitoring protocols that will be followed, we focused our text analysis on MPA management plans because many

MPAs do not yet have monitoring plans, and management plans outline the objectives and strategic framework on which monitoring plans are based. We also manually searched a subset of management plans to quantify the degree to which management plans exhibit climate change robustness, as defined by evidence that each of the four steps identified above was completed and incorporated climate change adaptation. We devote particular attention to Canadian MPA management results to highlight locally relevant issues and opportunities for improvement.

MATERIALS AND METHODS

Management Plan Search

In February 2019, we obtained the World Database on Protected Areas [WDPA, UNEP-WCMC and IUCN (2020)] list of protected areas and filtered the list to all protected areas that the WDPA identified as marine ($n = 15,174$; hereafter referred to as MPAs). We subsequently filtered the list to all MPAs having a management plan and where English was identified as an official language of the parent nation ($n = 1,338$). We added Canadian MPAs that were missing from the resulting list, given our knowledge of this jurisdiction. We completed a manual Google search to retrieve each of the MPA management plans on the list. We allowed for snowball searches, opportunistically adding any MPAs not already on the list as they were discovered during our search. This led us to expand the original list of 1,338 MPAs to 1,517 MPAs.

If successfully located, a management plan had to meet a set of criteria to be included in the review: it had to be (1) written in English; (2) produced by a legally mandated organization or government agency; (3) focused on the area-based conservation of marine waters, which included estuaries and tidal wetlands; and (4) for a designated MPA (i.e., no longer in the planning stage). In cases where the sections/chapters of the management plan were posted online as individual PDFs, the PDFs were combined into one PDF. In some cases, management documents such as purpose statements or management advice statements were considered management plans for the purposes of the study. For example, ~76% of provincially designated MPAs in British Columbia, Canada have purpose statements but less than 10% have detailed management plans (Heck et al., 2012).

We completed our PDF search in December 2019. We located a management plan that met the criteria for 1,000 of the 1,517 MPAs. Management plans could not be located for 384 MPAs. The remaining MPAs were excluded because they did not have management plans that met all four search criteria (36 of these because they were not written in English). 132 of the management plans pertained to more than one MPA (e.g., an MPA network), so this resulted in a final list of 649 management plans (saved as PDFs). We documented the MPA designation for each plan (e.g., National Wildlife Refuge, Special Area of Conservation, Ramsar Site); these designations were specified on the title page of the plans.

Creating a Text Corpus

We extracted the text from the 649 management plans to create a text corpus using the `pdftools` package (Ooms, 2020) of the statistical software R version 4.0.2 (R Core Team, 2020). Two of the 649 PDFs (one from Canada and one from Australia) had poor optical character recognition and were excluded from the corpus. We categorized the plans as originating from one of 10 regions: Africa ($n = 7$), Antarctica ($n = 1$), Asia ($n = 2$), Canada ($n = 149$), the Caribbean ($n = 7$), Central America ($n = 3$), Europe ($n = 9$), Oceania ($n = 23$), the United Kingdom ($n = 195$), and the United States ($n = 251$; **Supplementary Figure 1**). A csv file listing the names of the plans included in the analysis and the code used to create the text corpus and for subsequent analyses can be found at <https://github.com/sachaoregan/MPA-climate-text-analysis> and on Zenodo at <https://doi.org/10.5281/zenodo.5138563> (O'Regan et al., 2021). We extracted the total number of words in each PDF. We also extracted the publication year for all PDFs by searching for the 1st 4-digit string within the first 10,000 characters. If the first 4-digit string was preceded by the word “act,” “act of,” “regulation,” “regulations,” we took the second 4-digit string to be the publication year because the first year on some PDF title pages was the year of enactment of legislation, not the publication year. We did the same with the first 4-digit string if it was preceded by “DTI,” as there were a series of MPA management plans where “© DTI” preceded a year under the cover page photo.

We manually checked the results of the publication year extraction for all PDFs where no year was returned ($n = 7$) and where the year returned was 2000 or earlier ($n = 70$), and manually confirmed the publication year for a sub-sample ($n = 30$) of all publications published after 2000 where the first and second 4-digit string were fewer than 200 characters apart. All publication years returned from the sub-sampled management plans published after 2000 were correct. The publication year was incorrect for 24 of the management plans published in 2000 or earlier. Most commonly, the year of publication was incorrect, or no year of publication was retrieved because no year was specified, the date format in the PDF was “yy,” or the date was outside the character limit. When publication year was not specified, we manually searched these PDFs for the most recent years referenced in the text and used these to estimate the likely year of publication. In the end, we manually corrected the year of publication for 31 management plans. The two oldest management plans were published in the United States and Canada in 1980 and the most recent plans were published in 2019.

Text Analysis

Consideration of Climate Change Effects

Using R, we searched the text corpus for five climate change-related terms: “climate change,” “global warming,” “extreme events,” “natural variability,” “climate variability.” We calculated the frequency of the climate change terms per 10,000 words for each management plan. We saw anomalously high frequencies of the term “climate change” in Canadian MPAs published since 2016 that corresponded with the renaming of Environment

Canada, a federal department of the Government of Canada, to Environment and Climate Change Canada. Therefore, we searched for and excluded all instances of “Climate Change Canada.”

Management plans that contained at least one of the five climate change terms—hereafter referred to as climate-considering plans—were then searched for terms that reflected ecological (e.g., “biodiversity,” “distribution,” “abundance”), physical (e.g., “temperature,” “nutrient,” “circulation”), or sociological (e.g., “catch,” “recreation,” “tourism”) components of the system that are impacted by climate change. These component terms were selected because they regularly appeared in four of the most highly cited reviews published in the last two decades on the responses of marine organisms to climate change or the impacts of climate change on marine organisms (Hoegh-Guldberg and Bruno, 2010; Doney et al., 2012; Poloczanska et al., 2013, 2016) and the Intergovernmental Panel on Climate Change (IPCC) Special Report on the Ocean and Cryosphere in a Changing Climate (Bindoff et al., 2019). The text search function returned all terms containing all or part of the search term (e.g., “fisher” also returned “fishery,” and “fisheries”), with the exception being the component term “pH,” which had to be followed by a space. We calculated the frequency of the climate component terms per 10,000 words for each management plan.

Climate Change Analysis, Planning, and Monitoring

We sought to identify to what degree the climate-considering management plans had incorporated in-depth climate change impact analysis, planning, or monitoring. To focus on those climate-considering plans most likely to have incorporated these elements, we filtered the list of climate-considering management plans to those that contained at least two of the words “metric,” “indicator,” “transects,” “survey,” “target,” and “threshold” and that contained greater than three instances of one of the two words. We acknowledge that this would have omitted plans that only used synonyms of these terms, although this filtering step only removed 66 plans. We then manually reviewed the filtered list of plans ($n = 223$) for evidence of accordance with well-established criteria in effectively integrating climate change adaptation into MPA management (Geyer et al., 2017; Tittensor et al., 2019; Wilson et al., 2020 and references therein). We scored each of the management plans in this filtered list on degree of accordance with these criteria using a series of questions. We assigned “No” a score of 0, “Planned” a score of “1,” and “Yes” a score of 2. We assigned “Yes” and “Ongoing” an equivalent score of 2 in the case of question 5 and “Planned” and “Some” an equivalent score of 1 in the case of questions 10 and 11. “NA” in response to question 8 was scored as 0. We then summed the individual question scores for each MPA management plan to calculate a total climate change robustness index for each plan in a manner adapted from a recent German protected area management plan text analysis (Geyer et al., 2017). A perfect climate change robustness score was 28 (the highest possible scores for each question are included after each question in parentheses below).

Evidence of climate change effects analysis:

1. Did the plan discuss any past, present, or future effects of climate change on ecological, physical, or sociological components of the MPA (Yes/No for each of the three component types)? We did not discriminate on the level of detail (6 points).

Evidence of climate change planning:

2. Did the plan contain one or more objectives (see definitions and examples in **Table 1**) that explicitly mentioned climate change or one of its effects, such as sea level rise (Yes/No)? (2 points).
3. Did the plan contain one or more strategies that explicitly mentioned climate change or one of its effects, such as sea level rise (Yes/No)? (2 points).

Evidence of climate change monitoring:

4. Did the plan explicitly commit to monitoring or adapting to climate change (Yes/No)? (2 points).
5. Did the plan discuss baseline conditions in the MPA or state that they would be surveyed in the future (Yes/Ongoing/Planned/No; Ongoing was entered if the plan stated that some type of baseline monitoring had already begun; Planned was entered if the plan stated that the MPA intends to complete baseline monitoring in the future)? (2 points).
6. Did the plan list monitoring indicators of ecological, physical, or sociological components or state that they would be established in the future (Yes/Planned/No)? (2 points).
7. Did the plan list monitoring metrics for the indicators or state that they would be established in the future (Yes/Planned/No)? It was assumed that plans with a stated intent to establish indicators would also decide on metrics (2 points).
8. Were the indicators explicitly linked to climate change? That is, did they directly track climate changes OR were “climate change” or “sea level” mentioned in the same sentence as the indicator (Yes/No/NA; NA was entered if there were no indicators listed or planned)? (2 points).
9. Did the plan contain detailed survey/monitoring methods (Yes/No)? (2 points).
10. Did the plan list targets for the condition of the indicators or state that targets would be established in the future (Yes/Some/Planned/No; Some was entered if there were targets for some indicators but not all)? (2 points).
11. Did the plan list thresholds for the condition of the indicators or state that thresholds would be established in the future (Yes/Some/Planned/No)? (2 points).
12. Did the plan mention other climate change monitoring or mitigation efforts being completed by agencies other than park staff (Yes/No)? (2 points).

To score each plan, we did not read the plans in their entirety but searched the plans using the built-in PDF viewer find function to locate the following terms and jump to the relevant sections of text: “climate change,” “warm,” “sea level,” “objective,” “strategies,”

“monitor,” “indicator,” “target,” “threshold,” “metric,” “parameter,” “baseline.” We also searched for “favorable condition,” “limit,” “desired condition,” “trigger,” “performance measure,” which were used in plans from some jurisdictions in lieu of “target” or “threshold.”

We examined whether the climate change robustness scores improved over time within the regions with enough management plans to look at temporal trends (Canada, Oceania, United Kingdom, United States). Within these regions, we visualized whether trends in robustness scores varied by MPA designation type for a subset of the MPA designations most common in the regional datasets (i.e., Canadian MPAs and National Parks; UK Special Areas of Conservation and Special Protection Areas; US National Estuarine Research Reserves and National Wildlife Refuges; Ramsar Sites). To do this, we fit a negative binomial generalized linear model with a log link function, expressing climate change robustness score as a function of MPA designation type.

Manual Search of Canadian *Oceans Act* Monitoring Plans

As previously stated, we were conscious of the fact that MPA monitoring plans would likely contain more in-depth information on the precise monitoring protocols that would be followed during MPA operation than management plans. We also wanted to determine whether statements of intent to select monitoring indicators, targets, and/or thresholds in management plans were acted upon in the monitoring plans. Therefore, we completed a small test of these assumptions in our Canadian jurisdiction by compiling the monitoring plans available for Canadian *Oceans Act* MPAs. We then conducted a manual search of the monitoring plans to answer once again questions 4 through 11 in the preceding section to determine whether monitoring plans had higher scores across these criteria than the management plans.

Of the 14 *Oceans Act* MPAs in Canada, eight had management plans. We found designated monitoring plans for four of the eight MPAs with management plans (Fisheries and Oceans Canada, 2010a, 2011a,b, 2012), reviews of monitoring plan indicators, protocols, and strategies for two MPAs (Fisheries and Oceans Canada, 2010b, 2014), and the most recent management plan progress report for an additional MPA (Fisheries and Oceans Canada, 2016). For those MPAs without monitoring plans, we used the monitoring plan reviews and management plan progress reports to infer the responses to the climate change monitoring questions (we refer to all documents as monitoring documents hereafter). Note that one of the MPAs with a monitoring plan, the Eastport MPA, was not included in the management plan climate change robustness score analysis because it did not have a climate-considering management plan.

RESULTS

Consideration of Climate Change Effects

Of the 647 management plans, 289 (45%) contained at least one of the climate change-related terms “climate change,” “global

warming,” “extreme events,” “natural variability,” or “climate variability,” (i.e., were climate-considering management plans) (Figure 1 and Supplementary Figure 1). The first time “climate change” appeared in any management plan was in 1996 in the United States Florida Keys National Marine Sanctuary management plan. “Global warming” appeared for the first time in 1999 in the US Narrow River Special Area management plan but has dropped off in usage in the last decade. The frequency of the terms in management plans generally increased in most regions from 2000 to 2015 (Supplementary Figure 2). Notwithstanding this trend, of the 362 plans published since 2010, only 57% contained at least one of the climate change-related terms. Canada has lagged behind the United States, Europe, and Oceania in its mention of “climate change,” though the frequency of this term in Canadian management plans has generally increased over the last decade (Figure 2). The frequency of “climate change” was nearly three times greater in the 2018 Great Barrier Reef Marine Park 2050 Long-Term Sustainability Plan than in other plans. “Climate variability” and “extreme events” were the least frequently used climate change terms. “Extreme events” featured in only 19 management plans across the United States and United Kingdom, as well as in four Australian (within Oceania) management plans. In 2000, the United Kingdom was the first to use the term “extreme events” in relation to climate change in any management plan.

In the 289 climate-considering management plans, the most frequently used terms that reflected ecological components of the MPA system were “distribution,” followed by “abundance,” and “biodiversity” (Supplementary Figure 3). The most mentioned physical terms were “temperature,” “nutrient,” and “salinity.” “Sea level rise” was the fourth-most frequently mentioned physical component term. The proportion of Canadian climate-considering MPA management plans that included ecological and physical ecosystem component terms was relatively low compared to management plans from other regions (Figures 3A,B). For example, “recruitment,” “invasive,” “biomass,” “connectivity,” “resilience,” “reproduction,” and “extinction” appeared in only 5–29% of Canadian management plans, depending on the term, but were generally many times more common in all regions except Antarctica (Figure 3A). “Sea level rise” featured in half or fewer of the climate-considering MPA management plans within every region except in the Caribbean and the United States, where 85% (129/151) of the MPA management plans contained this term (Figure 3B). “Recreation,” “culture,” and “fisher” were not only the most frequently used terms that reflect sociological components of the MPAs, but the most frequently used terms across all three system component types (Supplementary Figure 3). In Asia, the Caribbean, and Central America, “fisher,” “catch,” “infrastructure,” and “harvest” universally featured in all climate-considering MPA management plans produced in these regions (Figure 3C). By contrast, many of the sociological terms appeared relatively infrequently in United Kingdom MPA management plans (e.g., “catch” appeared in fewer than 45% of the United Kingdom plans versus over 91% in other regions).

Climate Change Analysis, Planning, and Monitoring

Most of the climate-considering MPA management plans (223/289) contained at least three instances of our filtering terms; these 223 plans were therefore flagged as most likely to have incorporated in-depth climate change impact analysis, planning, or monitoring (Supplementary Figure 1). This management plan list included five from Africa, one each from Antarctica and Asia (i.e., Philippines), 13 from Canada, two from Central America (i.e., Belize), five from the Caribbean, three from Europe (i.e., Netherlands), 10 from Oceania (i.e., Australia), 44 from the United Kingdom, and 139 from the United States. A manual review of the 223 plans revealed that none of the Antarctic and Asian plans, and only one of the Caribbean plans reviewed the ongoing or likely future effects of climate change on the MPA’s ecological, physical, or sociological components (Figure 4A). Only two of the Canadian management plans discussed climate change effects (Tarium Nirvutait MPA and Quttinirpaaq National Park). The majority of European and American climate-considering MPA management plans had sections devoted to the discussion of climate change effects on ecological and physical components of the MPA (Figure 4A). Management plans that discussed climate change effects on sociological components of the MPA were only found in Canada, Europe, Oceania, the United Kingdom, and United States; such discussions were far rarer relative to reviews of climate change effects on ecological and physical components of the MPA (Figure 4A).

Climate change planning, as evidenced by the inclusion of climate change objectives and strategies or actions within the MPA management plan, was absent from the Asian and Caribbean management plans, and absent from all but one Canadian (Quttinirpaaq National Park), one European, and nine United Kingdom management plans (Figure 4B). Of the United States management plans, 38% included objectives pertaining to climate change and 56% specified one or more strategies or actions that directly referenced climate change (Figure 4B).

Most of the 223 MPA management plans (68%) included statements of commitment regarding monitoring climate change and/or its impacts on the MPA (Figure 5). In contrast to most other regions, only 38% of the Canadian management plans and 50% of the United Kingdom management plans made a clear commitment to monitor climate change within the MPA. Almost all MPA management plans (95%), regardless of region, specified indicators that were or would be monitored or expressed a plan to choose indicators in the future (Figure 5). However, the linkage between the state of these indicators and climate change was not always made explicit. For example, an MPA management plan that did not make this linkage might state that estuarine vegetation growth and community composition will be monitored as indicators of estuarine health; whereas an MPA management plan that made the linkage explicit might state that estuarine vegetation growth and community composition will be tracked alongside sea level to monitor the impacts of sea level rise on estuarine health. In Asian MPA management

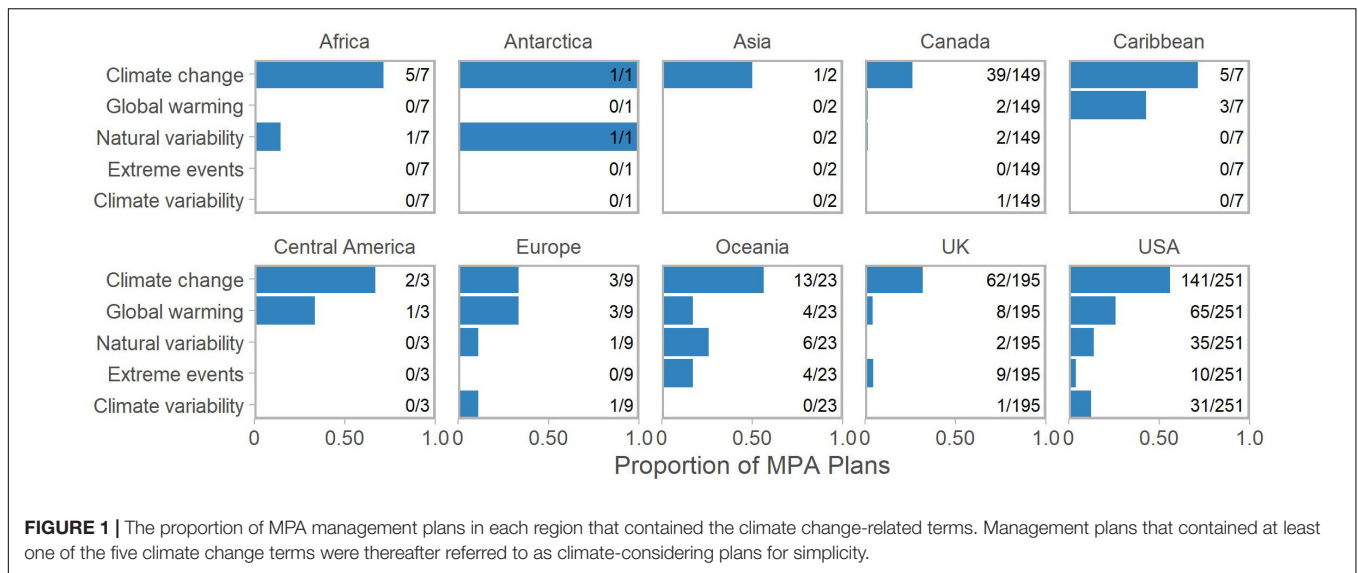


FIGURE 1 | The proportion of MPA management plans in each region that contained the climate change-related terms. Management plans that contained at least one of the five climate change terms were thereafter referred to as climate-considering plans for simplicity.

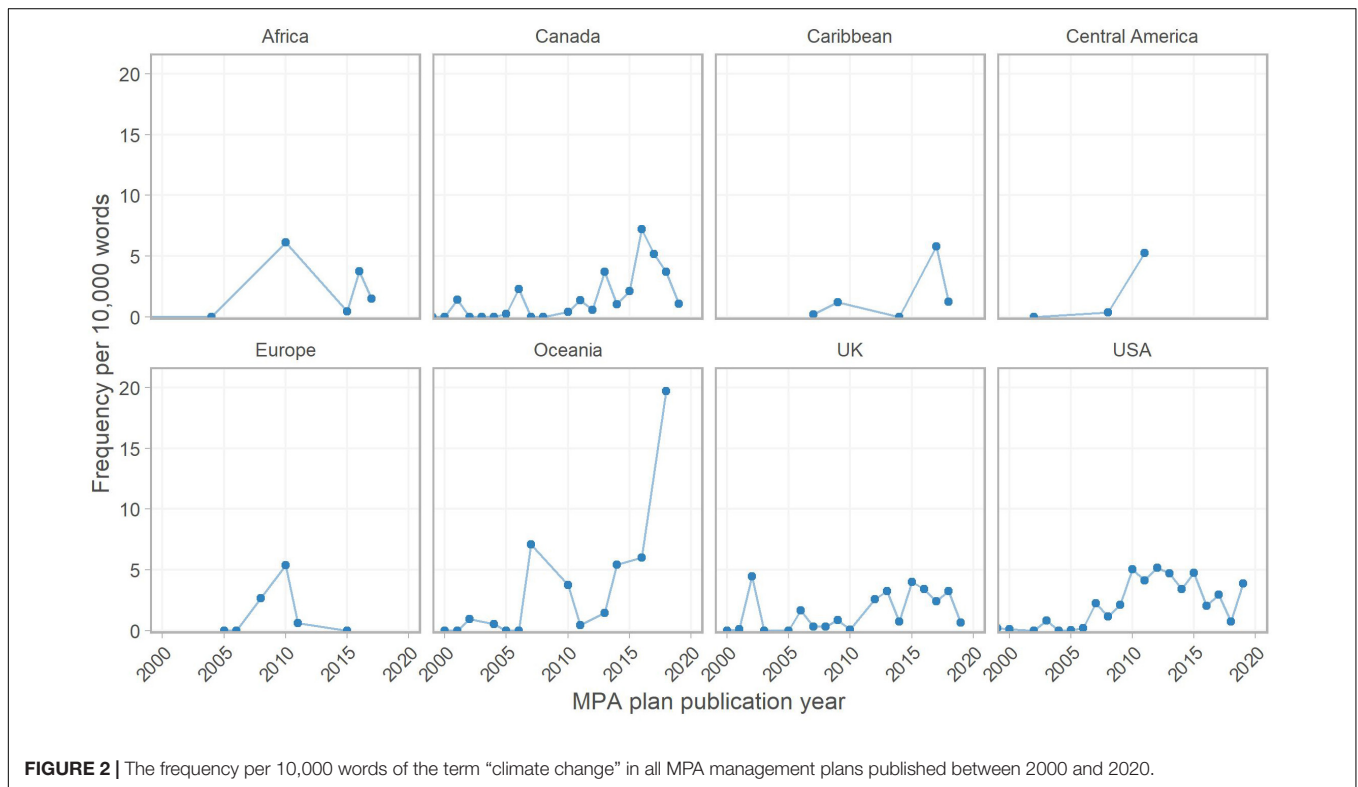
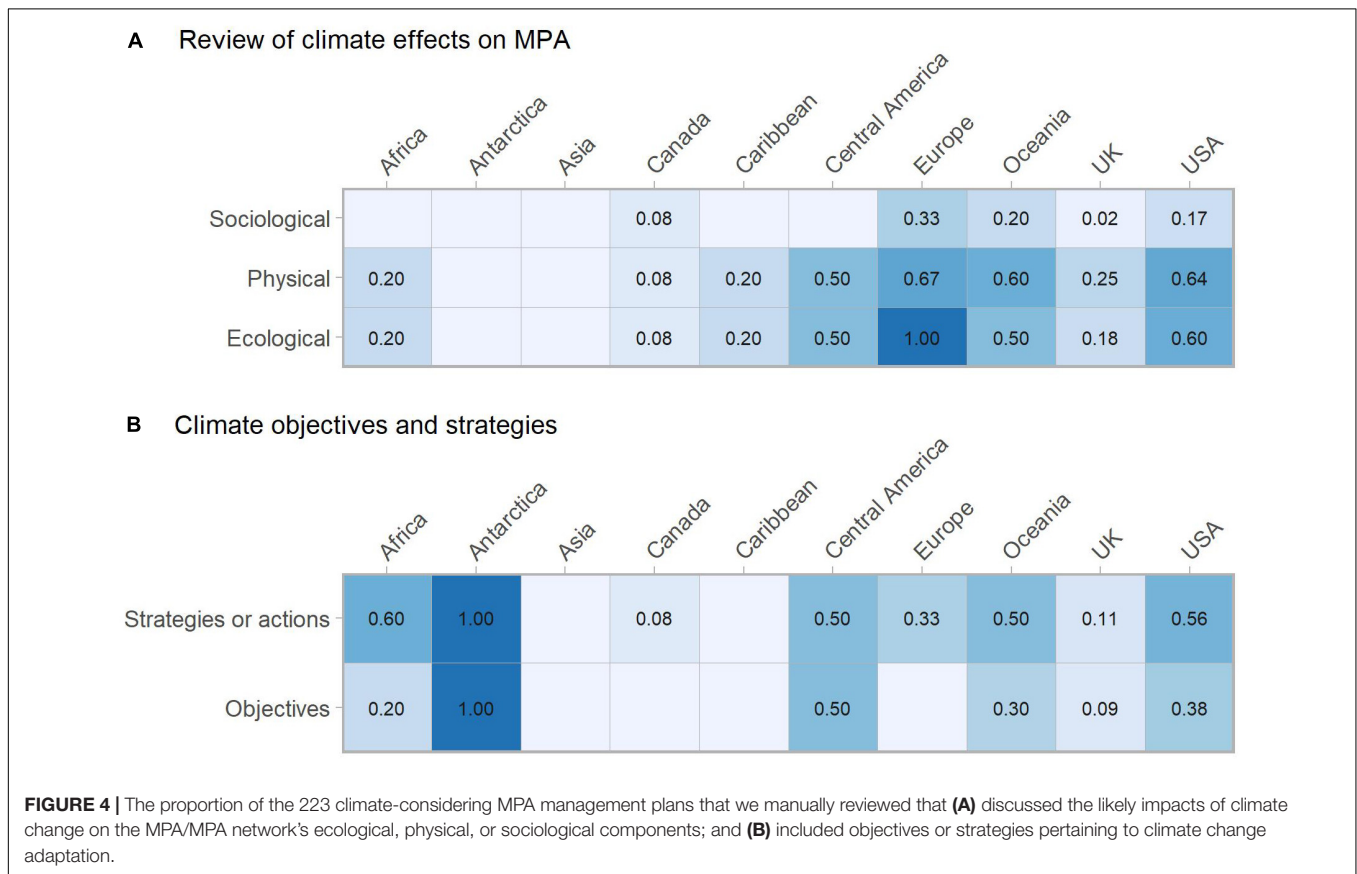
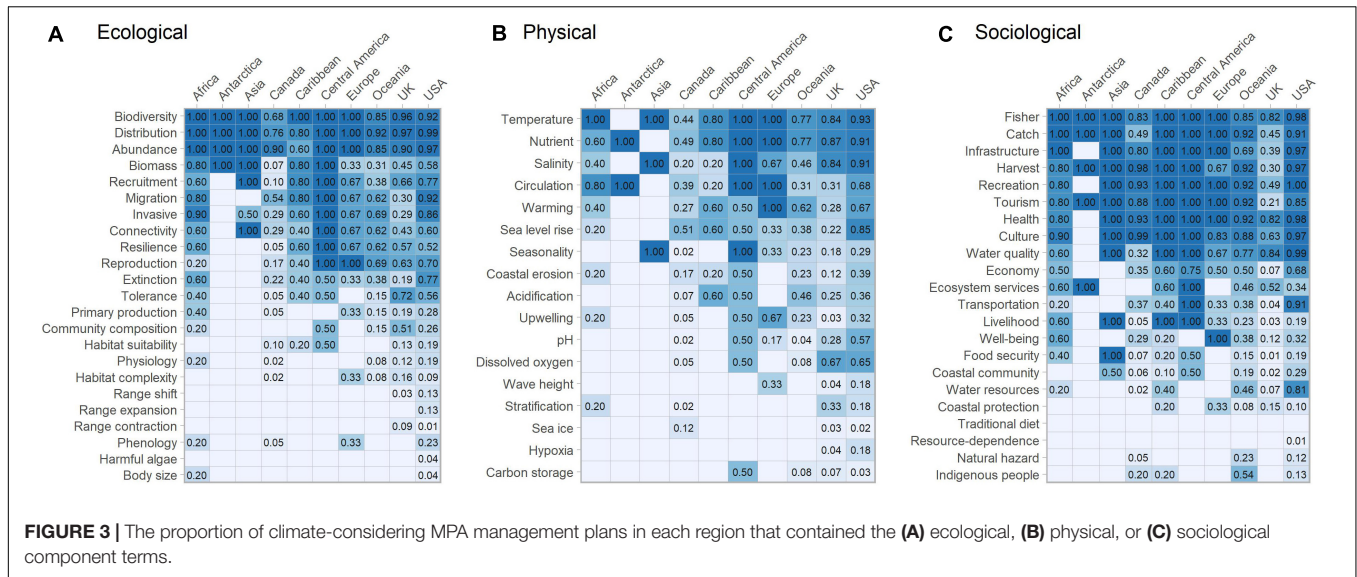


FIGURE 2 | The frequency per 10,000 words of the term “climate change” in all MPA management plans published between 2000 and 2020.

plans, any indicators listed were explicitly linked to climate change (Figure 5). None of the Antarctic, Caribbean, European, and few of the United Kingdom (18%) or Canadian (30%) MPA management plan indicators (existing or planned) were linked to climate change (Figure 5). Of the United States MPA management plans, 96% identified (107/139) or were planning to select (26/139) indicators, and of these plans, 49% related the indicators back to monitoring climate change or its effects.

Less than half of MPA management plans specified any targets (42%) or thresholds (5%) for the state of their selected indicators

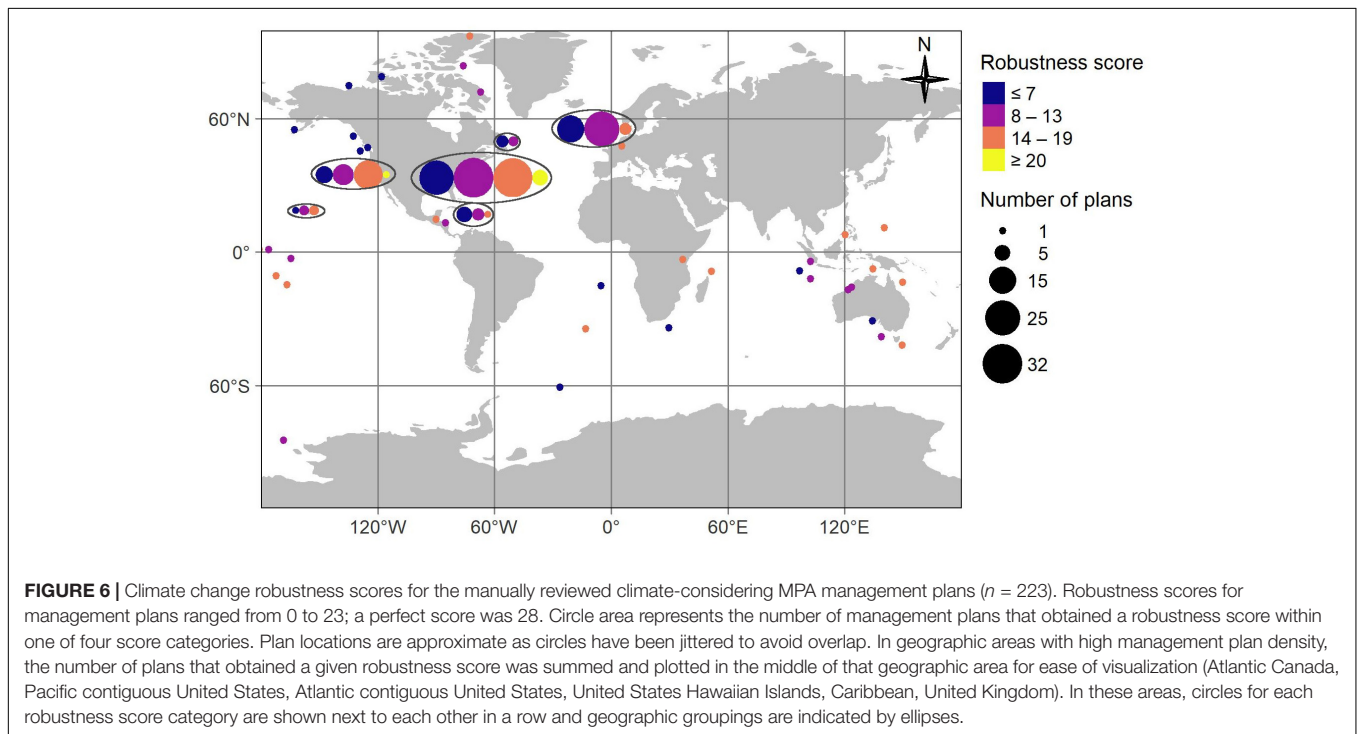
(Figure 5). Most of the United Kingdom MPA management plans included targets, but they rarely specified thresholds. In Canada, there was one MPA management plan that included targets and another that included thresholds; an additional five MPA management plans planned to set targets, five planned to set thresholds, and two planned to do both. In the United States (60%), and to a lesser degree in the United Kingdom (39%), management plans frequently cited that other agencies were engaged in related climate change strategizing, monitoring, or mitigation efforts; and that the outputs of this work would either



help inform MPA management and/or overlap with MPA climate change management efforts.

Globally, the mean management plan climate change robustness index was 10.9. Canada's mean management plan climate change robustness index was 6.8 (range: 2–14; **Supplementary Figure 4** and **Figures 6, 7**). The United States MPAs had the highest mean management plan climate change

robustness index (12 out of a total score of 28); ~4% of the United States MPA management plans had an index of 20 or greater (**Supplementary Figure 4**). The only MPA management plans with indices of 20 or greater were published in the United States. However, none of the climate-considering management plans published in the United States since 2016 have robustness scores above 17 (**Figure 7**). Within those regions

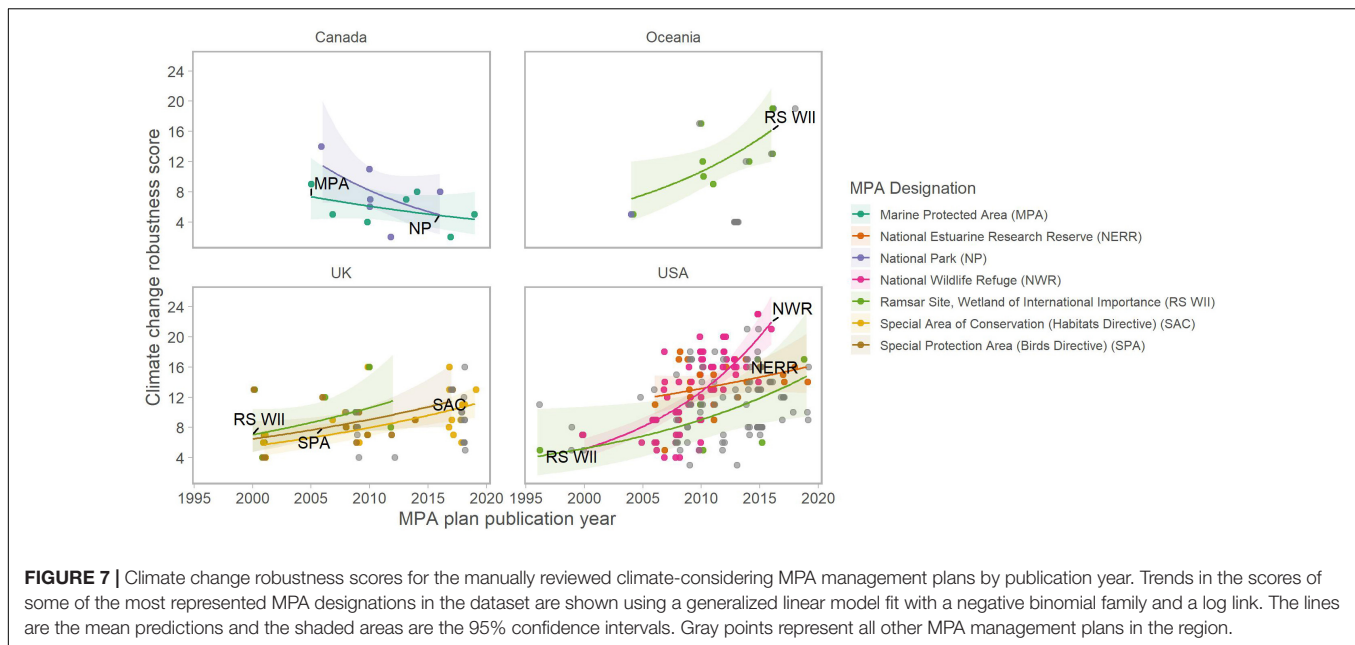


with enough management plans to look at trends over time, there has been a trend toward greater robustness scores over time within MPA designations (Figure 7). In the United States, the climate change robustness scores for management plans prepared for National Wildlife Refuges (NWR) have shown the greatest improvement, increasing from 2000 to 2016. By contrast, robustness scores have remained largely the same if not declined

in Canada's National Parks and *Oceans Act* Marine Protected Areas (Figure 7).

Canadian *Oceans Act* Monitoring Plans

The mean climate change monitoring score (based on questions 4 through 11) for the six climate-considering *Oceans Act* MPAs with monitoring documents increased from 5.3 (range: 2–9) for



the management plans to 8.7 (range: 6–11) for the monitoring documents. The scores improved in all MPAs except for one, and largely because all but one monitoring document identified indicators and metrics of conservation interest and detailed monitoring methods, whereas the management plans did not. However, only two of the monitoring documents explicitly stated that physical indicators directly impacted by climate change had been monitored (water temperature, pH, salinity; Fisheries and Oceans Canada (2010a, 2011b)). A third monitoring document indicated that climate indices were not currently being monitored in the MPA, but that regional climate data might be incorporated into analyses of fish population trends within the MPA in the future (Fisheries and Oceans Canada, 2010b). These three MPA monitoring documents did not mention “climate change.”

None of the monitoring documents identified target conditions for the indicators, though one alluded to thresholds (termed “triggers” in the text) that were identified in the management plan (Fisheries and Oceans Canada, 2016) and another indicated that there were plans to set thresholds in the future (Fisheries and Oceans Canada, 2011b). Only one document contained a statement that could be interpreted as an explicit commitment to monitor climate change impacts—“Understanding the current status of, and trends in, monitoring indicators in the Canadian Arctic is extremely important in light of climate change and increasing anthropogenic impacts to the environment”—but this monitoring plan otherwise included no indicators linked back to climate change, targets, or thresholds (Fisheries and Oceans Canada, 2012).

DISCUSSION

Planning for and adapting to climate change is an important challenge in MPA management and biodiversity conservation

(Soto, 2002; Abrahms et al., 2017; Bruno et al., 2018). Adaptive management frameworks for incorporating climate change adaptation into MPA management have been well-researched (Tittensor et al., 2019; Wilson et al., 2020 and references therein); however, the adoption of climate change adaptation principles in MPA management plans remains largely unquantified (Tittensor et al., 2019). In this study, we completed what is to our knowledge the most comprehensive assessment of the incorporation of climate change adaptation in MPA management across the globe. By looking for direct evidence in 647 MPA management plans through text analysis, we have found that climate change is inadequately considered in MPA management. Even when looking solely at the 362 plans published since 2010, only 57% contained at least one of the climate change-related terms: “climate change,” “global warming,” “extreme events,” “natural variability,” or “climate variability.” Globally, the mean climate change robustness index for climate-considering management plans was 10.9 or 39% of the total possible score. The United States is the only region with MPA management plans with climate robustness indices of 20 or greater. In the following sections, we seek to highlight some key findings both globally and in our home jurisdiction, Canada, and discuss approaches to overcome barriers to effective implementation of climate change adaptation in MPAs.

Climate Change Adaptation in Analysis, Planning, and Monitoring

MPAs are principally created to protect valued features such as biodiversity and ecosystem services for future human generations. For MPAs to be effective under a changing climate, management plans need to begin by clearly identifying the vulnerability of these features to climate change and set objectives and strategies that consider climate change. The most climate-robust management plans

in this analysis—USA NWR management plans published between 2010 and 2016—had substantial sections of text devoted to discussing potential climate change impacts on valued MPA features. Over the last decade, USA NWR management plans have included assessments of anticipated changes in distribution and structure of protected habitats and impacts to wildlife due to climate change, and have considered climate change in management and monitoring objectives. NWR management plans produced over this time included commitments to identify species and habitats most vulnerable to climate change or sea level rise and to develop adaptation strategies for those species and habitats in an adaptive management framework.

MPA objectives and strategies next need to be linked to quantitative, operational monitoring indicators, targets, and thresholds. Many MPA management plans, such as for UK Natura 2000 MPAs, Marine Conservation Zones, and Nature Conservation MPAs, detailed targets (referred to as “favorable conditions”) that require additional interpretation and definition before they can be fully operational. As examples of such targets, that the “quality and quantity of [a] habitat and the composition of its population in terms of number, age and sex ratio are such as to ensure that the population is maintained in numbers which enable it to thrive,” and that “structures and functions, quality, and the composition of characteristic biological communities...are such as to ensure that they remain in a condition which is healthy and not deteriorating” (from the 2018 Conservation Objectives for Fulmar Marine Conservation Zone). In these cases, the quality and quantity of habitat, the population sizes, or what is meant by “healthy” were not defined in the management plans. By contrast, the targets for indicator status provided in USA NWR management plans were frequently specific, quantitative, and therefore fully operational. For example, to “manage approximately 17 linear miles of sandy beach habitat on Assateague Island for nesting loggerhead sea turtles. Continue *in situ* nest protection such that no more than three nests over any 5-year period, and no more than one in any given year, are lost to human or predator-related causes” (from the Chincoteague and Wallops Island National Wildlife Refuges 2015 Comprehensive Conservation Plan).

Within regions, the differences in MPA management plan climate change robustness by MPA designation or administrating authority are likely due to differences in political climate, legislative requirements, guidelines, and resource availability, as others have found (Geyer et al., 2017). For instance, despite including indicators and targets, management plans for European Union Natura 2000 sites—comprised of Special Protection Areas designated under the Birds Directive and Special Areas of Conservation designated under the Habitats Directive—continue to exhibit low climate change robustness in absolute terms for such a large MPA complex. Others have identified several reasons why the Natura 2000 initiative insufficiently incorporates climate change adaptation principles (Ellwanger et al., 2012; Ibisch et al., 2012; Geyer et al., 2017). For one, the Natura 2000 initiative was designed to protect a fixed list of species and habitats at specific sites, and so the spatially static

nature of the protection goals inhibits dynamic management in response to climate change (Ibisch et al., 2012). Additionally, the guidelines for Natura 2000 management planning do not instruct on how to incorporate climate change adaptation (Geyer et al., 2017).

Though “recreation,” “culture,” and “fisher” were the most frequently appearing terms in our text analysis—more frequent than any ecological or physical component terms—our manual search of 223 climate-considering management plans revealed relatively little mention of sociological impacts of climate change. Consequently, these plans included little incorporation of social adaptation objectives, strategies, or monitoring of sociological features. This would suggest a disconnect between our valuation of socioeconomic features and ecosystem services protected by MPAs and the level of investment in vulnerability analysis and planning to protect these features from climate change. This is also consistent with findings that MPA managers and/or stakeholders more strongly support ecological (e.g., improving habitat connectivity) rather than social (e.g., developing alternative livelihoods) adaptation actions (Miller et al., 2018; Whitney and Ban, 2019).

All climate-considering MPA management plans from Asia, the Caribbean, and Central America included the terms “fisher,” “catch,” “infrastructure,” and “harvest,” and all African plans included three of these terms. In contrast to the majority of plans in other regions, most climate-considering plans in Africa, Asia, and Central America also linked MPA monitoring indicators back to climate change. While our sample size is too small to draw any strong conclusions, this pattern of linking sociological features, MPAs, and climate change is consistent with the fact that low-income or small-island nations and Indigenous peoples are more vulnerable to and will be most affected by climate change (Bell et al., 2013; Sainsbury et al., 2018). For example, countries in Africa, Asia, the Caribbean and Central America are often the most reliant on fisheries for employment, income, and nutrition (Allison et al., 2009). Additionally, countries in these regions are consistently among the most vulnerable to climate-induced changes to fisheries (Allison et al., 2009; Blasiak et al., 2017). This reliance on fisheries and marine resources combined with high vulnerability to impacts from a changing climate may increase awareness of the consequences of not managing for climate change and promote a stronger incorporation of climate change into MPA planning, implementation, monitoring, and management (Siegel et al., 2019). Some MPA systems may show limited consideration for sociological features and how climate change will impact them due, once again, to differences in protection aims, legislative requirements, and guidelines. For example, the EU Natura 2000 guidelines state that Member States should “only” use ecological criteria to select and designate sites (Metcalf et al., 2013).

The Canadian Context

Canada committed to meeting the CBD’s 2020 biodiversity targets and has committed to increase domestic MPA coverage to 25% by 2025, working toward the CBD’s proposed new

protected area target of 30% by 2030 (Canada Prime Minister's Office, 2019). As of 2019, Canada has protected 8.9% of its marine area in MPAs and conserved another 4.9% through the use of long-term fisheries closures (Environment and Climate Change Canada [ECCC], 2020). However, our results indicate that Canada is still lagging far behind other temperate jurisdictions in the depth and breadth of its MPA climate change adaptation analysis, planning, and monitoring.

Concern that Canada is not adequately incorporating climate change adaptation into MPA management is not new (Jessen et al., 2011; Lemieux et al., 2011; Heck et al., 2012). In surveys of protected area practitioners from Canadian federal, provincial, and territorial government agencies and non-governmental organizations (NGOs) conducted in 2006 and repeated in 2018, 83–85% of practitioners stated in both years that their agency had not completed a comprehensive assessment of climate change impacts on the protected area or its management implications (Barr et al., 2020). This, even though over this time frame, most marine and terrestrial practitioners had observed climate change impacts within their protected areas (Whitney and Ban, 2019; Barr et al., 2020). The absence of climate change vulnerability assessment for valued MPA components was evident in the results of our analysis. Canada's MPA management plan climate change robustness scores have not increased over the last two decades, which lends support to the finding that while our knowledge of climate change has increased over time, that knowledge has not been adequately incorporated into management (Geyer et al., 2017; Lemieux et al., 2021).

Facilitating Climate Change Adaptation in MPAs

Lower climate change robustness scores observed in this study are linked to real and perceived barriers to incorporation of climate change adaptation in MPA management. First, we continue to stress that an institutional response to the threat of climate change must be a top priority relative to managing other pressures on MPA objectives (Moser and Ekstrom, 2010; Lemieux et al., 2011; Sharp et al., 2014). The weight of evidence that climate change is having and will continue to have costly impacts on MPAs around the world calls for swift action (Sharp et al., 2014). MPA practitioners can take immediate steps to better incorporate climate change adaptation into MPA management: (1) complete vulnerability assessments to better understand how climate change will likely impact individual MPAs and MPA networks; (2) develop objectives and strategies that acknowledge and include adaptive mechanisms for responding to climate change; and (3) develop monitoring indicators that will inform on the status of an MPA as well as climate change impacts.

The lack of consideration of climate change in recent management plans is not explained by perceived uncertainty about climate change impacts and lack of knowledge about climate change adaptation strategies, but more so by the lack of capacity and financial resources necessary to incorporate climate change adaptation into MPA management (Whitney and Ban, 2019; Barr et al., 2020; Lemieux et al., 2021). Even when protected

area practitioners think that adaptation options are affordable and feasible, decision makers and policymakers continue to think that climate change is too unfeasible to address (Lemieux and Scott, 2011; Sharp et al., 2014). The shortness of most political cycles and the slow pace of institutional change exacerbates this sentiment (Lonsdale et al., 2017).

Yet, there are ways to facilitate or accelerate climate change adaptation even when agencies are challenged by a lack of internal capacity and funding. Lack of capacity can be mitigated by communicating with other government agencies and across jurisdictions to share and gather knowledge and approaches that have already been developed and tested by others (Sharp et al., 2014). Practitioners may also draw upon numerous guidance documents (Gross et al., 2016). Although none of the plans we reviewed perfectly incorporated climate change adaptation principles, our results highlighted protected area systems whose management plans can be used as examples for how to better incorporate these principles, such as recently published United States NWR plans. Making MPA funding contingent on explicit incorporation of climate change into MPA management objectives, strategies, and monitoring indicators (Tittensor et al., 2019) may additionally be a good way of ensuring that the financial resources necessary to complete this process are earmarked for this purpose from the outset. As we have found inconsistent standards of climate change adaptation implementation in protected areas across jurisdictions and administering authorities, developing clear regulations and standards documents (Barr et al., 2020) would help ensure that funds and resources are effectively used.

Last, MPA management outcomes may be supported by implementing coastal climate change strategies and/or employing frameworks to adaptively manage the cumulative risk posed by regional pressures on MPAs (e.g., tourism, fishing, pollution, shipping traffic and noise) in a changing climate. Advancements in fisheries management can provide examples as to how to better incorporate climate change in risk analyses (Dorn and Zador, 2020; Duplisea et al., 2021). Risk frameworks that account for multiple stressors can help decision-makers understand and evaluate risks (International Council for the Exploration of the Sea [ICES], 2021) and adjust management in response to climate change (Duplisea et al., 2021).

Study Limitations

Our study does have its limitations. First, our results are largely focused on temperate MPAs; the tropics were underrepresented in our study because we restricted the text analysis to English-language management plans. Second, our results reflect climate change adaptation in management plans, not monitoring plans, which, where they exist, would be more informative with regards to final selection of indicators, targets, and thresholds. For instance, USA NWR management plans, termed comprehensive conservation plans, are meant to be strategic documents and MPA practitioners must prepare more detailed "step-down" management plans, which include biological monitoring plans, habitat management plans, exotic plant control plans, etc. As another example, the Great Barrier Reef 2050 Long-Term Sustainability Plan had a strong focus on climate change impacts

on the reef and climate change objective and strategy/action setting, but its robustness score of 19 reflected the fact that indicators, metrics, and indicator targets are not included in the management plan; these components are to be finalized as part of a Reef 2050 Integrated Monitoring and Reporting Program. However, if our small case study of monitoring documents available for Canadian *Oceans Act* MPAs reflects global patterns, climate change is more likely to be inadequately considered at the monitoring stage when the management plan devotes little strategic attention to climate change. Related to the latter point, we recognize that many agencies have developed separate climate change strategy and policy plans (Preston et al., 2011), or will rely on universities or other partner institutions to conduct climate change monitoring and assist in adaptation. Not all climate change adaptation measures that may be applied in an MPA or greater coastal area may be covered in the MPA management plan. Last, this study is unable to assess how effectively management plans are implemented and enforced; “paper parks” remain a global concern (Kareiva, 2006; Thompson et al., 2008).

CONCLUSION

With an increased CBD target to protect 30% of coastal and marine areas by 2030 and climate change effects being observed in marine ecosystems and felt by coastal communities across the globe, we echo that now is the time to ensure that MPA management is as robust as possible to climate change impacts. This requires that MPA planners and managers consistently incorporate climate change adaptation into MPA management plans. Scientists must be engaged early to assess the vulnerability of valued MPA features and help inform selection of monitoring indicators, targets, and thresholds. MPA planners and managers can then incorporate this information into MPA management and monitoring plans, regularly report on climate change impacts and MPA management results, and use the results to inform future management measures in accordance with an adaptive management approach.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

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AUTHOR CONTRIBUTIONS

KH conceived of the study with early feedback from SA. KH and SA were involved in collecting the management plans. SO further developed the study methods and completed the text analyses. SF created maps and the supplementary csv file that lists the management plans included in the analysis. SO led the writing of the manuscript with the assistance of all authors.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: <https://www.frontiersin.org/articles/10.3389/fmars.2021.711085/full#supplementary-material>

Supplementary Figure 1 | MPA management plans that were included at each stage of our text analysis: **(A)** all plans in the text corpus ($n = 647$), **(B)** climate-considering plans ($n = 289$), and **(C)** manually reviewed plans with calculated climate robustness scores ($n = 223$). Symbols indicate approximate location only, not MPA area.

Supplementary Figure 2 | Total frequency of the climate change-related terms per 10,000 words in MPA management plans over time. Each point represents a single management plan.

Supplementary Figure 3 | The mean frequency per 10,000 words in the 289 climate-considering management plans of the terms representing ecological, physical, and sociological components of the system that are impacted by climate change (all terms searched for in the text analysis are shown).

Supplementary Figure 4 | Climate change robustness scores of MPA management plans by region.

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