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Supplementary Materials for

Integrating climate adaptation and biodiversity conservation in the global ocean

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Supplementary Materials

Section S1. Methods for review of climate change adaptation in MPAs

We reviewed the literature to examine how climate change adaptation has been incorporated into the design and management of marine protected areas (MPA). Google Scholar was searched using the search terms in Table S2 in April 2019. Articles were first screened for inclusion based on their title containing the keywords or similar. During each stage of screening, papers that referred to protected areas in general, or protected areas in marine, terrestrial, or other habitats were retained. We also retained any grey literature report that was found (e.g., NGO report, government report) but did not actively search any NGO or government site. Next, the abstract of articles with titles that included the keywords or similar terms were then screened for inclusion. Articles with abstracts that contained keywords or similar were then downloaded for screening of the entire article. The reference list of downloaded papers was also used to identify any papers that were missed in the initial literature search. In total, 524 papers were downloaded, 175 of these were determined to not be relevant after further screening, and 98 were found to be marine specific.

The marine specific papers were then sorted into three categories. The first category was for papers that provide a theoretical discussion of climate change adaptation in MPAs, MPA networks, marine reserves, or other designations of a protected area in the marine environment, all included in the term MPA hereafter. Papers in this category include subject matter reviews, general planning frameworks, and theoretical statements on how climate change adaptation could be incorporated into MPA design or management (e.g., increase connectivity, protect climate refugia). Papers in the second category provide a practical example of how climate change adaptation can be incorporated into MPA design and most included a spatial prioritization component with software such as Marxan. The third category was for articles that describe on the ground implementation of an existing or new MPA that explicitly considered climate change adaptation in its design or management plan.

Results

Of the 98 downloaded marine specific papers, 63 discussed climate change adaption strategies (category 1) (*6*, *7*, *17*, *18*, *30*, *38*, *43*, *50*, *80–134*), 29 gave practical examples of how climate change adaptation can be incorporated (category 2) (*22*, *23*, *40*, *135–160*), and 6 had on the ground implementation of climate change adaptation in an MPA (category 3; Figure 1; table S1) (*15*, *16*, *161–164*). The examples that considered climate change adaptation in the design phase did so with general rules of thumb for increasing climate change resilience (*6*, *18*) and are geographically clustered in and around the Coral Triangle (Table S3). Only one example was found for where climate change was considered in the management plan, and one for objectives (Table S3).

Table S1. References for the marine specific papers that incorporated climate change adaptation in MPA design or management presented in Fig. 1.

Discussion of climate change adaptation	**Practical example of climate change adaptation**	**Implementation of climate change adaptation**
(*6*, *7*, *18*, *84–92*, *30*, *93–102*, *38*, *103–112*, *45*, *17*, *113–121*, *50*, *122–131*, *80*, *132–134*, *81–83*)	(*22*, *23*, *142–151*, *39*, *152–160*, *135–141*)	(*15*, *16*, *161–164*)

Table S2. Google scholar search term results for April 2019.

Search term	Number of results
“climate change adaptation” AND “protected area”	13,300
“climate change adaptation” AND “protected area design”	135
“climate change adaptation" AND “protected area network”	946
“marine protected area” AND “climate change” OR “marine reserve” AND “climate change”	3890

Table S3. Examples where climate change adaptation has been implemented in the design or management of an MPA.

MPA	Country	Stage	Climate change incorporation	Reference
Greater Farallones National Marine Sanctuary	USA	Management	“Climate-Smart Conservation Program to integrate climate change monitoring, mitigation, preparedness and education into sanctuary management”	(*15*)
Marine Parks	Australia	Objectives	The Marine Park Act of Australia states one of the objectives of marine parks is “the adaptation to the impacts of climate change in the marine environment”	(*16*)
Kimbe Bay Marine Management Area	Papua New Guinea	Design	Used general rules of thumb to design a new climate resilient MPA network	(*161*)
Kubulau MPA network	Fiji	Design	Used general rules of thumb to design climate resilient MPA networks to redesign an existing MPA network in partnership with the local community	(*162*)

Raja Ampat MPA network	Indonesia	Design	Used general rules of thumb to design a new climate resilient MPA network	(*163*)
Savu Sea Marine National Park	Indonesia	Design	Resilience to climate change is part of design principles and application. Design process identified and then protected the most resilient areas to climate change threats.	(*164*)

Section S2. Methods for derivation assessing MPA vulnerability (see Fig. 2)

Historical surface temperature variability

Global 1 x 1° gridded monthly sea surface temperature (SST) data were extracted from the Met Office Hadley Centre Sea Surface Temperature data set between 1900 and 2018 *(165)*. These data are reconstructed from SST observations from the Met Office Marine Data Bank and the Comprehensive Ocean-Atmosphere Data Set (ICOADS). For each grid cell, the detrended SST series were obtained by taking the residuals from a fitted linear regression model with year as a covariate. We then calculated the range and standard deviation of the residuals to obtain proxies of SST variability that are independent of long-term trends attributable to climate change.

As a sensitivity check, we also used shorter-term (1980-2018) but more temporally resolved (daily) SST observations obtained from the NOAA AVHRR Pathfinder Version 5.3 (PFV5.3), acquired from the US National Oceanographic Data Center and the Group for High-Resolution Sea Surface Temperature. The PFV5.3 data are an updated version of the Pathfinder Version 5.1 and 5.2 collections *(166)*. Pathfinder SST observations were extracted as daily, 4km^2 gridded observations, but for consistency were interpolated using nearest neighbor methods to 1 x 1°.

Future surface temperature exposure

We used the time of emergence (ToE) as an index of future climate exposure. ToE estimates were calculated as the year in which mean SST emerges from the background of natural variability and was obtained from *(167)* on a global 1 x 1° grid.

Temperature variability and emergence within MPAs

Information regarding the spatial distribution of all marine protected areas (MPAs) was assessed using the World Database on Protected Areas (WDPA) spatial shapefile *(168)*. Since the resolution of the temperature and exposure observations was coarse (1°) relative to the size of many MPAs, temperature fields were related to MPAs in a two-step process. Firstly, the global 1° grid was overlaid on a spatial shapefile of MPAs to identify cells that were within the boundaries of MPA. Next, for all MPAs that did not have any overlaid cells, we identified the grid cell centroid that was geographically nearest, according to the great circle distance, to that MPA centroid. Through this process, each individual MPA was assigned at least one 1° grid cell, with the larger MPAs being assigned more.