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A method for incorporating climate change modelling into marine conservation planning: An Indo-west Pacific example

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ABSTRACT

Marine protected areas (MPA) are rapidly being established to minimize the impact of anthropogenic disturbances, yet, while climate change is acknowledged as a growing threat, very limited research exists about how to directly incorporate climate-related disturbances into MPA design. Using the conservation planning software Marxan and the Indo-west Pacific as a study region, an illustrative approach is developed here that incorporates climate change projections into the process of identifying priority areas for marine conservation. Conservation targets were set at 10% and 30% of areas that continually held sea-surface temperatures less than 1 °C above maximum non-extreme historic temperatures (derived from satellite imagery from 1984–2009). This approach allowed for continuity in conservation objectives across both space and time by identifying the geographic extent of thermal stress in the region and illustrating how conditions would change in future years. Achievement of targets was found to be flexible, but some areas were more important than others for achieving these targets. Interannual trend analyses were carried out for three climate models under two climate change scenarios to examine spatial and temporal patterns of thermal stress. Spatial patterns of thermal stress varied throughout the region. Results of the conservation approach were compared to the trend results to see whether the trends might be a simpler approach for accounting for climate change impacts in conservation planning (i.e., one feature could be used instead of more than 1000). The interannual analyses had a low overlap with the Marxan results, and hence are not a suitable substitute for the approach shown here. This study showed that inclusion of climate-related disturbances in marine conservation planning is feasible and should become common practice, together with targets for biodiversity.

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Introduction

In marine conservation efforts, marine protected areas (MPA) are increasingly being established in order to ameliorate the impact of human-use disturbances [1,2]. Anthropogenic climate change is a growing concern for marine ecosystems because of the many negative impacts associated with it. For example, future climatic conditions are predicted to lead to shifts in species distributions [3], alter ocean current strength and direction affecting population connectivity [4], and exceed maximum thermal thresholds for some species [5]. Present day patterns of biodiversity will thereby be altered, undermining the ability of established MPAs to protect the same taxa in future years that they were initially designed for [6–8]. However, while climate change is recognized as a key threat to marine systems, to date MPA planning and design has rarely addressed climate-related disturbances directly in a spatially explicit manner.

Addressing climate change through MPAs is a challenge. The root cause of climate change — increased atmospheric greenhouse gas (GHG) concentrations — is beyond the scope of marine management, and MPAs cannot explicitly protect against related disturbances. However, MPAs do provide relevant strategies to sustain biodiversity and ecosystem processes at local and regional scales. For instance, MPAs restrict direct, localized, anthropogenic threats such as overfishing, minimizing the synergistic impact of other stressors [9]. The reduction of other disturbances is hypothesized to increase resilience of an ecosystem to climatic stress [5,9]. However, evidence for this hypothesis is mixed: whereas Carilli et al. [10] observed that areas with a decreased amount of local stress showed faster recovery rates to coral bleaching events induced by high sea-surface temperatures, Côté and Darling [11] suggested an increase in local stress (i.e., unprotected areas) allows for a greater portion of

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disturbance–tolerant taxa to establish, thereby increasing ecosystem resilience to climatic stress. Approaches to MPA design will vary depending on the veracity of the hypothesis that the reduction of local stressors increases resilience to climactic stress. If true, a focus on protecting either a portion of areas under different climactic stress regimes, or those that are most likely to be affected by climactic disturbances if reefs are in a healthy state [12,13], would be sensible. However, if MPAs do not increase resilience to climactic stressors, protection focus would be on areas less likely to be affected by climactic disturbances [11]. In the absence of a consensus between processes that enhance resilience and the best practice for spatial protection, the safest solution is likely to ensure those areas less affected by climatic disturbances are protected [11].

Incorporating climate change dynamics into conservation planning requires information about the future, or potential futures, of the magnitude and rate of change. Coupled atmospheric-ocean general circulation models (AOGCM) project global climate conditions under a variety of atmospheric GHG concentration scenarios [14]. These projections can be used to identify spatiotemporal patterns of change, and infer anticipated biological responses [15]. For example, climate change modelling has shown spatial and temporal patterns in thermal stress for waters around the globe [16], the Great Barrier Reef [6], the Coral Triangle [13], and the Caribbean [16]. Unfortunately, while AOGCMs and model projections are readily, and often freely available, to date they have rarely been included in marine conservation planning [13,17]. Even though challenges are associated with using AOGCMs in conservation planning efforts (e.g., miss-match between model resolution and the scale of conservation efforts, and uncertainties in both the biological response and model accuracy [18]), now more than ever conservation planning must begin considering and planning for climate-related disturbances in the marine environment.

Of the many climate-related impacts in marine systems, temperature rise is one of the best studied, and particularly troubling for coral reefs. Global sea-surface temperatures (SST) are predicted to increase by 1.1–6.5 °C over the next century [19]. Coral reef habitats are believed to be one of the most threatened marine ecosystems because of their low tolerance to extreme temperatures [20]. The majority of reef building corals are already living at the upper limits of their thermal tolerance and only a small change in temperatures of 1–2 °C greater than summer mean monthly maximums are enough to induce coral bleaching—the breakdown of the symbiotic relationship between corals and zooxanthellae [15,21–24]. Bleaching is a stress response by corals to rising SSTs and occurs indiscriminately of MPA boundaries, affecting both protected and unprotected habitats [25]. Under prolonged and intense heating conditions, bleaching can lead to colony mortality, further exacerbating habitat degradation [23,26]. Bleaching events have also been attributed to declining water quality and increased solar irradiance [27], but the link between elevated SSTs and coral bleaching is indisputable [23], allowing for SST to act as an indicator of bleaching risk [13,28]. Already, SST rise has led to an estimated decline in 19% of the world's reef habitats and has surpassed all other anthropogenic threats in importance as the leading cause of coral bleaching [21,29,30].

When identifying locations for potential MPAs, systematic conservation planning is often used because it provides a framework for achieving explicit and quantitative conservation objectives with limited resources [31]. Systematic conservation planning has been applied to several major marine conservation projects including the zoning of the Channel Islands National Marine Sanctuary in California [32], the rezoning of the Great Barrier Reef (GBR) [33], and establishing the Prince Edward Islands MPA network in South Africa [34]. Despite these achievements, MPAs have traditionally been designed assuming that biodiversity, and the processes that influence biodiversity, are static features. However, disturbances associated with climate change undermine these assumptions [6], and despite climate change being a topic of interest in marine conservation since the early 1990s [35], the use of modelled projections is seldom directly incorporated into MPA planning [13]. Given the low level of protection of the oceans – only 0.65% are within MPAs [2] – there is a great opportunity to design and establish MPAs that recognize and incorporate climate change dynamics.

Although there are challenges to using modelled projections for marine conservation planning, climatic disturbances are such an important driver of change that their use will be essential for future conservation efforts. Unfortunately there is a lack of guidance on how modelled projections can be appropriately incorporated into systematic conservation planning efforts. Therefore, the aim of this study was to illustrate one approach for incorporating climate change projections directly into marine conservation planning. The study deliberately separates climate change considerations from the biodiversity objectives in order to focus only on the former, and also because biodiversity objectives are context-dependent. Sea-surface temperature is focused on as a crucial aspect of climate change.

Methods

Study region

The area of analysis was the Indo-west Pacific, from the Cocos-Keeling/Christmas Island ecoregion in the southwest, Eastern Philippines to the north, and the Coral Sea towards the southeast (Fig. 1). The study region included the Coral Triangle, a global hotspot for biodiversity in corals, marine fish, and crustaceans [29,36]. It is a global conservation priority due to the high level of biodiversity, endemism, and vulnerability to human-use pressures in the region [37,38]. In fact, within the Coral Triangle, 80% of coral reefs are already considered highly threatened and declining by 1% per year [13].

Incorporating climate change projections into conservation planning

The most popular systematic conservation planning software [39], Marxan (version 1.8.10), was used to trial a method for including climate change projections into conservation planning. Marxan is a freely available software used to analyse options for the placement of new conservation areas [39]. Because conservation funding is often limited, the goal of Marxan is to minimize the overall cost of reserve systems while still maintaining adequate representation of elements of biodiversity (a.k.a. conservation features) that need protection [40]. For illustrative purposes only the climate change model with the highest oceanic spatial resolution ($0.29^\circ \times 0.19^\circ$), Model for Interdisciplinary Research on Climate-High Resolution (MIROC-HR), was used with a focus on the B1 emission scenario (atmospheric GHG concentration reaches 550 ppm by 2100).

Because MPAs do not alleviate climate stressors per se, the approach explored here to include climate change in conservation planning was to target areas that are projected to change the least. Furthermore, it is important for a portion of the least affected areas to always be included within MPAs at each time step, thereby allowing for continuity in conservation efforts through time. The conservation features were developed as follows. Using historic data gathered from the National Oceanic and Atmospheric Administration's Optimum Interpolation Global SST version 2 (NOAA OI SST V2) with a spatial resolution of

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