



Review

Management strategies for coral reefs and people under global environmental change: 25 years of scientific research



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ABSTRACT

Coral reef ecosystems and the people who depend on them are increasingly exposed to the adverse effects of global environmental change (GEC), including increases in sea-surface temperature and ocean acidification. Managers and decision-makers need a better understanding of the options available for action in the face of these changes. We refine a typology of actions developed by Gattuso et al. (2015) that could serve in prioritizing strategies to deal with the impacts of GEC on reefs and people. Using the typology we refined, we investigate the scientific effort devoted to four types of management strategies: mitigate, protect, repair, adapt that we tie to the components of the chain of impact they affect: ecological vulnerability or social vulnerability. A systematic literature review is used to investigate quantitatively how scientific effort over the past 25 years is responding to the challenge posed by GEC on coral reefs and to identify gaps in research. A growing literature has focused on these impacts and on management strategies to sustain coral reef social-ecological systems. We identify 767 peer reviewed articles published between 1990 and 2016 that address coral reef management in the context of GEC. The rate of publication of such studies has increased over the years, following the general trend in climate research. The literature focuses on protect strategies the most, followed by mitigate and adapt strategies, and finally repair strategies. Developed countries, particularly Australia and the United States, are over-represented as authors and locations of case studies across all types of management strategies. Authors affiliated in developed countries play a major role in investigating case studies across the globe. The majority of articles focus on only one of the four categories of actions. A gap analysis reveals three directions for future research: (1) more research is needed in South-East Asia and other developing countries where the impacts of GEC on coral reefs will be the greatest, (2) more scholarly effort should be devoted to understanding how adapt and repair strategies can deal with the impacts of GEC, and (3) the simultaneous assessment of multiple strategies is needed to understand trade-offs and synergies between actions.

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1. Introduction

Ocean acidification (OA) and climate change, including rising sea surface temperatures (SST), change in cyclone patterns, sea-level rise, and de-oxygenation, will adversely affect coral reef ecosystems in the coming decades (Cinner et al., 2016; Hoegh-Guldberg et al., 2014; Pendleton et al., 2016b). These global environmental changes (GEC) and their interactions will impact the goods and services provided by coral reefs upon which human populations depend (Brander et al., 2012; Pendleton et al., 2016a). Coral reefs support local and national economies (Burke et al., 2011), for instance by providing habitats for many species of fish on which local fishers depend (Teh et al., 2013), but also providing revenues from tourism and coastal protection. People, communities, and nations are vulnerable to the effects of GEC on coral reefs (Hughes et al., 2012).

Identifying ecosystems and human populations that are vulnerable to environmental change does not shed much light on appropriate response strategies (Hinkel, 2011). Vulnerability or impact assessments do not systematically identify which actions could reduce vulnerability (Tulloch et al., 2015). A necessary approach to reduce impacts and vulnerability is to identify the range and mix of possible actions (Ranger and Garbett-Shiels, 2012; Wilby and Dessai, 2010). Several scientific papers have attempted to help decision-makers and managers deal with the adverse effects of GEC on coral reefs by identifying management options (e.g. Mcleod et al. (2013); Rau et al. (2012)). However, they often focus on a narrow set of actions that can be taken within a specific management approach such as Marine Protected Areas (e.g. Green et al., 2014; Keller et al., 2009), a specific threat (e.g. ocean acidification) or a specific ecological process such as coral adaptation to warming (van Oppen et al., 2015). Of course, not all strategies are available or recommended in every situation, but a focus on too few strategies can be misleading (e.g. protective measures (Hilborn, 2016)). Evaluating a broader range of available strategies, and indeed combinations of actions, helps managers to estimate the trade-offs of different management approaches (Bozec et al., 2016). Multiple strategies may be needed to deal with different parts of the problem.

A new science of solutions is emerging to help guide the choice of action, especially regarding climate change adaptation (Hinkel and Bisaro, 2015; IPCC, 2014). A synthesis of management strategies, based on an understandable conceptual framework can help managers and decision makers consider different policy actions within the complexity of coral reefs social-ecological systems (SES). Such a typology of management strategies has the advantage of making sense of a large number of actions while enabling conditions to evaluate and articulate their advantages and barriers (Biagini et al., 2014). It is therefore important to evaluate the broad range of possible management strategies available in a typology, in order to implement the most appropriate strategies and to avoid maladaptation (Magnan et al., 2016).

One common way of dividing solutions to climate change, used

by the Intergovernmental Panel on Climate Change (IPCC), is between mitigation and adaptation (IPCC, 2014). Mitigation involves reducing the amount of greenhouse gases (GHG) while adaptation involves solutions to cope and to adapt to the adverse effects of climate change. This dichotomy reflects societal decisions but does not fully reflect the complexities of social-ecological systems. A number of management strategies, notably on coral reefs SES, show that mitigation and adaptation actions are not exclusive. The concept of adaptation to climate change usually only includes human adaptation, therefore fails to reflect the ecological components of coral SES. A typology that encapsulates the societal as well as the ecological components of the system is therefore needed.

Gattuso et al. (2015) proposed a typology to deal broadly with the impacts of carbon dioxide (CO₂) on the marine environment. Four major categories of actions are described in this typology to reduce the risk posed by CO₂ on ocean ecosystems and ecosystem services: mitigate, protect, repair, adapt. We do not know of literature reviews that attempt to use this typology for coral reefs SES and therefore we build on this typology and refine it specifically for coral reefs SES.

In addition to constructing a typology, a systematic literature review is important to investigate how science is currently addressing solutions to respond to the challenge posed by GEC on coral reefs. First, science has a critical role to play in shaping adaptation policy and reducing vulnerability of the marine environment (Ekstrom et al., 2015), and in guiding the allocation of resources (Di Marco et al., 2017). An understanding of the global scientific endeavor can help guide future research and better integrate science in policy-making. Second, we do not know of any evaluation that attempts to link the current scientific effort devoted to managing GEC and coral reefs and that evaluates the degree to which this scientific effort covers places that contain high biodiversity, provides ecosystem services, and will be the most affected by GEC. The spatial distribution of exposure and of dependence on ecosystem services is not homogeneous (Pendleton et al., 2016a). Because of this uneven spatial distribution, it is important to evaluate whether the scientific literature sheds light on the places that will be the most impacted.

The first goal of this paper is to review the scientific literature to structure, using a typology, the suite of management actions that could be available to deal holistically with the entire chain of GEC impacts from climate change and OA on coral reefs, their resilience, and the services they provide to people. This typology organizes information to enable managers and decision-makers to assess the effectiveness of actions in their local settings. The second goal of this paper is to understand how the scientific effort targeted at coral reefs, GEC, and management is distributed through space, time, and categories of action. Through this systematic literature review, we hope to identify gaps in the global coverage of research and also gaps in our understanding of the range of strategies to deal with the impacts of GEC.

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