SHORT- AND LONG-TERM VISIONS FOR PROTECTING CORAL REEFS

Keiko W. Wilkins, Angelique Rosa-Marín, Maha Cziesielski, Hunter Hughes, Connor Love, and Catherine Nowakowski

Coral reef ecosystems face a number of local threats, including increasing human populations, coastal development, fisheries, and pollution, which cause severe destruction on reefs, while global anthropogenic climate change is altering the environment of coral habitats. Due to these stressors, there is a crucial need to reevaluate and implement effective management practices to protect coral reefs immediately and in the long term. Broadscale management techniques currently exist, including a wide variety of conservation, technological, ecological, and monitoring techniques, to name but a few. However, due to the complexity of coral reef ecology and local and regional differences, understanding and identifying effective management practices to address corals' present and future fate is challenging.

Given these difficulties, maintaining the future health of coral reefs can often seem like a daunting task for early-career researchers. However, increasing understanding of coral reef ecosystems through scientific and economic research, as well as a surge in technological innovations, has led to improved management ambitions, techniques, and implementations which have resulted in successful recovery and rejuvenation of previously threatened reefs (Duarte et al. 2020). These successful endeavors provide hope, not only for early-career scientists, but also for those who have been fighting for the protection of reefs for decades, that it is not too late to take action. With the development of more tools and improved knowledge, there are also increasing ambitions to protect reefs from local as well as global anthropogenic stressors. There are several actions which we can take to improve current management strategies (Fig. 1). As early-career researchers, we provide our perspectives on promising immediate and long-term coral reef protection strategies which are currently being developed and applied that show hopeful steps to ensuring the future of reef ecosystems.

IMMEDIATE ACTION FOR REEF PROTECTION

Currently, there are a few research-based management strategies which we believe can be effective. In the short term, one hopeful management strategy which is currently used widely is the designation of marine protected areas (MPAs), which manage specific conservation objectives. Incorporation of new research findings has greatly improved these management practices and led to much success. MPAs have become widespread in various social and economic situations with 26.9 million km^2 of the ocean protected by them (http://mpatlas.org/) and with coverage increasing by 8% per year (Worm 2017). We have seen that this management tool has successfully improved the recovery of fish populations by managing overfishing, controlling local stressors, and recovering habitats (Duarte et al. 2020). We believe that hope for the immediate protection of coral reefs comes primarily from international efforts led by the International Union for Conservation of Nature (IUCN) to protect 30% of the ocean by 2030 through the implementation of a network of MPAs. MPAs have shown much promise thus far, but there is room for improvement. Expanding current MPAs by 5% has been estimated to improve future fish stocks by as much as 20% (Cabral et al. 2020). We believe that the implementation of long-term managing programs can reduce local stressors. For that effectiveness to be realized, an assessment of the conservation needs of the specific MPAs are required due to the wide diversity of coral reef ecosystems and local vs. global stressors acting upon them. After a needs-based evaluation, continued monitoring should help inform specific follow-up management practices, such as the use of bioindicators and biomonitoring approaches. We believe if we take immediate action to improve MPA practices with the changing environment, we can continue to alleviate stressors in corals in the future.

Although MPAs have led to many success stories of marine habitat protection, we see several other areas for improvements. The benefits of MPAs on marine populations are often insufficient due to the young age of MPAs, lack of resources, and lack of enforcement (Duarte et al. 2020). Notably, to see positive outcomes and gain benefits from MPAs, they must be well established. However, most MPAs are less than 10 yr old, and there is often a time delay between an intervention and its effects. Hence, besides ensuring effective resource management, we must have patience to see these efforts bear fruit. MPAs require many resources to be an effective management tool, and current MPAs often do not have sufficient resources to uphold management for long periods. Of the current registered MPAs, 65% report an insufficient budget, and 91% have reported limited staffing (Gill et al. 2017). In addition, MPAs may not always be the most effective techniques for all types of regions, so region-specific policies for MPAs need to be drafted to ensure success. Local communities often are not involved in the development of MPA policies within their regions. Acceptance of these rules and regulations is easier when the local community's goals are considered and met. We need to incentivize stewardship practices in local communities and authorities to ensure the enforcement of the managed areas. Finally, MPAs are most effective when combined with other management tools. Through improved maintenance and support, MPAs could build resilience to climate change and provide a more sustainable solution in the future (Roberts et al. 2017).

Another current management tool which complements MPAs is the use of marine spatial planning (MSP), which results in the targeted designation of MPAs. MSP has solved many management issues by considering the complexities in the marine environment, which make management challenging. The overall aim of MSP is to provide a strategic plan for management. Many countries have successfully implemented MSP. For instance, one of the greatest success stories is the Great Barrier Reef Marine Park (GBRMP; Douvere 2008). Australia has implemented spatial planning and zoning which protects coral reefs while also allowing space for human activity to continue (Day 2002). Their plans have continuously changed since their first enactment in 1981 to match the changing marine policies and the changing environment. This is a great example of protection, but the well-funded nature of the GBRMP highlights the inequities which exist. Many reef ecosystems are near coastal communities which do not have access to these vast resources which has led to less successful implementation in these areas. The challenges with MSP are largely attributed to improper assessment, monitoring, and implementation strategies. In order to ensure a high level of success with MSP as a technique, clear oversight and continual monitoring are necessary. The GBRMP sets a great example to future projects and gives us hope that these management strategies can be successfully applied with adequate resources. Future management plans should take inspiration from older protected

FIG. 1. In both the short and long term, we see these actions (above arrow) as steps toward goals (below arrow) that will ultimately improve protection of coral reef ecosystems.

areas and learn from what has worked, while also adapting to what did not. Re-assessment of MSP should occur every few years to reflect developments in socioeconomic and environmental parameters to keep up with and implement the benefits of evolving information in the field.

LONG-TERM STRATEGIES FOR REEF PROTECTION

Current strategies for managing anthropogenic effects on coastal and reef environments are only part of the solution. While MPAs and MSP are effective, they do not stop climate change associated alterations such as ocean acidification, temperature increase, and hypoxia. Heat stress and associated mass bleaching events are of primary concern. In the last 10 yr, research has seen exceptional steps forward in understanding the molecular underpinnings of temperature tolerance of the corals including not only the coral host, but also associated symbiotic algae and the microbiome, known as the coral holobiont (Cziesielski et al. 2019). The understanding of basic holobiont function lends itself to another style of management, which production of specific stress markers (i.e., metabolites or transcripts) will be expressed in all coral species/populations and can be used as indicators for stress levels of different types of stressors.

Deciphering the genetic traits which determine tolerance, as well as the underlying mechanisms of metabolic and chemical communication between symbiotic partners, is fundamental in our efforts to help coral reefs survive climate change. Hope that corals are indeed capable of adapting to warmer oceans has often come from reefs which exist in the warmer waters of the Red Sea, where corals have often been hailed as particularly heat resilient (Osman et al. 2018; Kleinhaus et al. 2020). Scientists have recently succeeded in new assisted evolution approaches which enabled lab grown temperature tolerant symbionts to be taken up by coral larvae and overall increase coral's heat tolerance (Buerger et al. 2020). If these efforts continue to show success in a variety of coral and symbiont species, hope exists for the reseeding of dead reefs with more tolerant coral offspring helping to replenish many of the damaged populations.

While these developments are of significance, it is important to remember that we are far from conserving reef diversity as a whole. Due to phenotypic variations from one coral colony to another, it is imperative to remember that not all colonies will experience stress the same way (see review Cziesielski et al. 2019). The role which phenotypic variation plays in genetic adaptation and responses are so far only broadly understood. Furthermore, relationships between corals and their symbionts are inherently complex and selective. Thus, a heat tolerant algae may not necessarily be accepted into host tissue or, if it is, may not necessarily confer thermal tolerance. The complexity of the coral holobiont and the intricacy of genetic markers and responses require significantly more work. Here, it will require not only researchers working on various parts of the holobiont to come together, but also for marine scientists to look for expertise regarding mechanisms and methods from other fields. If we wish to conserve coral reef diversity as a whole, immediate action toward effective MSP and MPA planning will have to occur in parallel to continued long-term investments into understanding fundamentals of molecular mechanisms and developing tools for assisted evolution.

HOPE FOR THE FUTURE

Although there are numerous threats which coral reef ecosystems face, we continue to identify areas of hope for the survival of corals in the short and long term. These approaches will have to be adapted not only by location (i.e., local ecosystems, capabilities, and climate change impacts), but also over time. As technology and our understanding of corals continues to develop, management methods need to stay informed and up-to-date to be the most effective. Ultimately, this will require management practices, and those enforcing them, to stay flexible and dynamic in order to adjust as conditions and knowledge change. Importantly, the future implementation of successful management practices requires communication, collaboration, and mentorship (Nowakowski et al. 2021). In order to develop management plans which can adapt with time, gaps between science, industry, governments, and local communities need to be closed, and the communication channels developed. The growing international recognition that reef protection is desperately needed as well as an increase in scientific, political, and social interest in coral reefs, indicates to us as early-career scientists that there is reason to continue our work. Much learning and adapting is still left to be done in terms of management techniques, but evidence indicates that we can ensure a future for coral reefs if we act now. This awareness fuels hope and motivation in us early-career scientists to continue striving for new horizons.

References

Buerger, P., C. Alvarez-Roa, C. W. Coppin, S. L. Pearce, L. J. Chakravarti, J. G. Oakeshott, O. R. Edwards, and M. J. H. van Oppen. 2020. Heat-evolved microalgal symbionts increase coral bleaching tolerance. Sci. Adv. 6: eaba2498. https://doi.org/10.1126/sciadv.aba2498.

Cabral, R. B., D. Bradley, J. Mayorga, W. Goodell, A. M. Friedlander, E. Sala, C. Costello, and S. D. Gaines. 2020. A global network on marine protected areas for food. PNAS 117: 28134–28139. https://doi.org/10.1073/pnas.2000174117.

Cziesielski, M. J., S. Schmidt-Roach, and M. Aranda. 2019. The past, present, and future of coral heat stress studies. Ecol. Evol. 9: 10055–10066.

Day, J. 2002. Zoning lessons from the Great Barrier Reef Marine Park. Ocean Coast. Manag. 45: 139–156.

Douvere, F. 2008. The importance of marine spatial planning in advancing ecosystem-based sea use management. Mar. Policy 32: 762–771.

Duarte, C. M., and others. 2020. Rebuilding marine life. Nature 580: 39–51.

Gill, D. A., and others. 2017. Capacity shortfalls hinder the performance of marine protected areas globally. Nature 543: 665–669.

Kleinhaus, K., and others. 2020. Science, diplomacy, and the Red Sea's unique coral reef: It's time for action. Front. Mar. Sci. 7: 90.

Nowakowski, C., H. Hughes, C. Love, A. Rosa-Marín, K. W. Wilkins, and M. Cziesielski. 2021. Communicating hope for coral reefs. Limnol. Oceanogr. Bull. 30. https://doi.org/10.1002/lob.10421.

Osman, E. O., D. J. Smith, M. Ziegler, B. Kürten, C. Conrad, K. M. El-Haddad, C. R. Voolstra, and D. J. Suggett. 2018. Thermal refugia against coral bleaching throughout the northern Red Sea. GCB 24: e474–e484.

Roberts, C. M., and others. 2017. Marine reserves can mitigate and promote adaptation to climate change. Proc. Natl. Acad. Sci. USA 114: 6167–6175.

Worm, B. 2017. Marine conservation: How to heal an ocean. Nature 543: 630–631.

Keiko W. Wilkins, Kewalo Marine Laboratory, University of Hawaii at Manoa, Honolulu, HI, USA; wilkinkw@miamioh.edu

Angelique Rosa-Marín, Florida Agricultural and Mechanical University, School of the Environment, Tallahassee, FL, USA

Maha Cziesielski, Association for the Sciences of Limnology and Oceanography, Washington, DC, USA

Hunter Hughes, Department of Geological Sciences, University of North Carolina at Chapel Hill, Chapel Hill, NC, USA

Connor Love, Interdepartmental Graduate Program for Marine Sciences, University of California, Santa Barbara, CA, USA

Catherine Nowakowski, Graduate School of Oceanography, University of Rhode Island, Narragansett, RI, USA