

CHANNELING HOPE FOR REEFS

A Series of Perspectives from Young Coral Reef Scientists

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Coral Reefs could be gone in 30 years.
(National Geographic 2017)

The Great Barrier Reef has lost half its corals. (The New York Times 2020)

Earth's coral reefs could be gone by 2100.
(NBC News 2020)

From Australia's Great Barrier Reef to the Caribbean islands, the message is clear: coral reefs are struggling. Many that have dedicated their lives to these ecosystems are seeing them vanish in front of their eyes. Coral reef scientists wake up to this reality every day and have been waking up to this reality for a long time! The increasing amount of negative news reports can be discouraging and exhausting. These messages of hopelessness can be especially demotivating to young and early career

scientists. There is, of course, a valid need to highlight the urgency of our situation in order to inspire action. However, in parallel, there is also a need to focus on opportunities and actions that can change our current course—both to motivate the next generation of scientists and society.

Despite the negative headlines, there are plenty of reasons to be optimistic and to have hope that there may be a positive outcome for coral reefs. In recent years, increasing public and political awareness has led to a number of new movements in reef conservation internationally. Indeed, awareness of the importance of our reefs and our oceans at large has given rise to the next United Nations Decade subject: The UN Decade of Ocean Science. Most importantly, though, is that these efforts range far beyond just scientists and scientific byproducts. The global community, from concerned locals to passionate citizens far from reefs, plays an increasingly significant role in the fight to save coral reefs. Scientific research provides the backbone for well-informed actions and decision-making processes at local and international scales. But scientific efforts must go hand in hand with community engagement and advocacy. As such, hope for the future of coral reefs lies at the intersection of science and society.

In order to succeed in bringing science into societal decision-making, scientists, and academic institutions must undergo a transformation—structural and functional. Signs that this transformation has already begun are everywhere: from the growing engagement of scientists in community outreach events to the increasing presence of scientists on twitter. Academia may be old fashioned in regards to many aspects, but, as with every generation, the young are bringing fresh perspectives. Early career scientists now channeling hope for coral reefs within their research as well as in their interaction with society.

It is from this vision of hope in coral reef science beyond research that this article series was born. A group of six young marine scientists, connected through their mutual experiences in ASLO's Limnology and Oceanography Research EXchange (LOREX) program, joined together to discover what gives them hope for the future of coral reefs. Of course, fundamentally, we are confident that our research findings are increasingly leading to a more in-depth understanding of coral reef ecosystems and ultimately contributing to more informed decision making. But through our work we discovered that our hope for ensuring the future of coral reefs ultimately did not stem from data itself—its roots are in communication and collaboration.

In the following articles, we describe why we have hope for coral reefs and how we envision science and academia transforming so hope continues to grow across all sectors of society (Fig. 1). We introduce the importance of science, marine protected areas, and marine spatial planning in ensuring short and long-term improvements of ecosystem's health. Next we focus on the importance of communication and collaboration, within academic institutions and communities, and the value placed on these initiatives. Finally, we discuss the future of academia itself, how we need to adapt to changes in expectations of professional scientists and the importance of providing equal opportunities and increase diversity. There is much left to do, but the vision of these six marine scientists is one of opportunities and optimism. Because as long as we have reefs to save, there is hope.

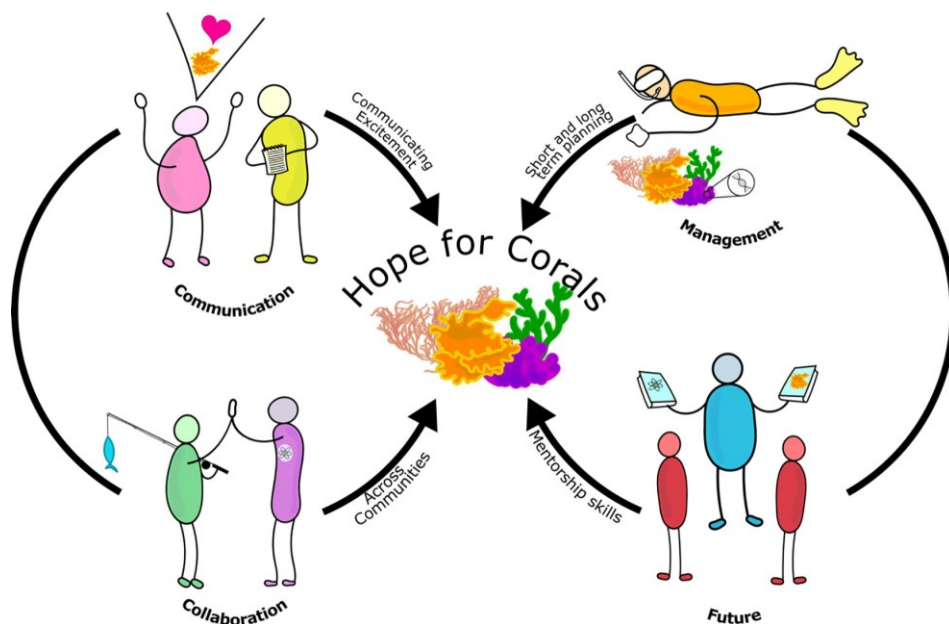


FIG 1. Schematic demonstrating how the sections Management, Communication, Collaboration, and Future directions are interconnected as well as how they all contribute to a positive feedback cycle around generating hope for coral reefs.

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SHORT- AND LONG-TERM VISIONS FOR PROTECTING CORAL REEFS

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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. Broad-scale 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 km² 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



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.

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; Douvère 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 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 reseeded 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.

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COMMUNICATING HOPE FOR CORAL REEFS

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There is hope for coral reefs and communicating excitement around coral reef research and discoveries is a key opportunity to grow it. Amidst the trawling scars and gear tangles on the Northwestern Hawaiian Ridge and Emperor Seamounts, researchers have identified signs of coral recovery since protection measures were expanded 30–40 years ago (Baco et al. 2019). It is expected that coral ecosystems will take centuries or more to recover from anthropogenic influence, and the discovery that improvements can be seen in decades is reason to celebrate. The current narrative tone for coral reefs revolves around difficulties to restore their ecosystems and conserve the species. This often means combating the communications conundrum that comes with the constant imagery of dead and dying reefs that are used so often to depict the climate crisis.

To convey the urgency and scope of the challenges without causing people to lose hope we need to shift the narrative. By engaging broader audiences in case studies like the Emperor Seamounts that show what management actions can achieve, the gleam of hope it inspires can provide

an impactful promise (Duarte 2020). Things can get better. Yes, it is impossible to deny the increased urgency and concern our community feels around coral ecosystems, but we also need to prioritize space for the increased excitement around new discoveries and successful management practices. Therefore, our goal is to harness that excitement we hold and to share it with those entering the field, as well as a broader audience, so we can foster productive conversations as we continue to strengthen and improve our actions to save coral reefs.

To communicate this excitement, we need to find ways for our audiences to connect to and identify the strong link between coral reefs and humans. Therefore, putting corals into a context that your audience is both engaged in and can relate to will help fuel the conversation. This can be done by changing the delivery of our narrative and in turn, our dialogue around corals. Presenting coral reefs as a standalone, struggling system that is already bound to be doomed makes saving them seem like a hopeless task. This set up can quickly lead to the end of a conversation: “No, I don’t see what I can do about this. Coral reefs are dying anyways.” By making the change from *No* to *Yes*, you completely reframe the argument and open the conversation to many more possible outcomes: “Yes, corals are dying, but evidence shows there is hope for their survival, therefore we must take care of them and make proactive decisions” (Palermo 2014). A second method to reshape the way we present science narratives is to incorporate elements of humanity and vulnerability. This approach emphasizes what we have in common—emotions—and helps make the content more relatable. This could look like sharing personal narratives of those who experience how the loss of coral reefs in their communities redefined their socioeconomic framework (McKinnon et al. 2016). By sharing emotions with our audiences, we connect through vulnerability and trust. By communicating optimism, we move another step in the direction of mobilizing people to act.

In addition to changing our tone, we can present the scientific method as a narrative process; delivering it in the context of a story gives our message both more power and structure (Olson 2015). Learning how to apply storytelling skills to communicate excitement takes practice that can be accelerated through training. Therefore, seeking out workshops that target these skills, such as Improve 2020 (www.palermoinprovttraining.com) and The Story Collider 2020 (www.storycollider.org/workshops), can be an invaluable undertaking.

Investing in these soft social skills calls for applying the value we place in scientific publications and presentations to broader public engagement efforts as well. This can include written or video logging (blog or vlog), as well as social media platforms. These platforms are well suited for sharing stories and developing personal connections; by distributing science in this format, we are fostering a broader audience connection than was historically possible. Social media posts can simultaneously reach communities from island nations to the most inland schools while enabling conversations between every location and promoting discussion far past the traditional show and tell methods. Additionally, these platforms are well suited for short anecdotes, which is important because the more specific the stories are that we provide, the more effective our communication will be. By carving out individual narratives from the often overwhelming, broader context, we can then present approachable problems with relatable, easier to act on solutions. Taking steps to expand each scientist's ability to reach the public makes a long-term investment in the future for corals by expanding the breadth and application of our research and through building stronger communities and conversations around coral reefs.

We aim to ensure that our excitement resonates with as wide of an audience as possible; achieving this could look like reevaluating who we are communicating with while developing our research plans and goals. Corals are complex species that support the base of ecosystems all across the globe, and they require an extensive set of skills to understand and manage. Shifting from field specific collaborations to interdisciplinary teams and engagement with other communities will be key. This process should include learning how to share what makes us excited with groups outside of academia, such as both coastal and inland communities, policy makers, lawyers, shareholders and more. The level of excitement and investment we share reflects the level of investment other people can return. After all, if we cannot portray our own personal commitment, how can we expect someone else to take on saving coral reefs as their own passion too? By communicating where our personal excitement behind our careers in coral reefs comes from, we implore a powerful tool to call for motivation and action that can be directed at preserving and restoring our coral reef ecosystems.

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RETHINKING COLLABORATION FOR CORAL REEF SCIENCE

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The narrative that scientific advancement requires effort from one dedicated individual, the “mad” scientist cutoff from the help of

others, is being replaced by new generations of scientists. This new wave of scientists is adept in communication, cooperation, and allocation of unique skills to solve a unified problem. This type of collaboration is reflected as an increase in the average number of authors per paper within all disciplines (Mallapaty 2018), establishment of national and international research centers, and a rise of Big Science, in which the scale and comprehensiveness of research projects have increased (Price 1963; Westfall et al. 1993). Indeed, scientific collaboration is widespread and growing.

Coral reef science presents a unique case for collaboration between highly varied disciplines due to the overwhelming network of biota and the complex interactions with humans and climate, from local to global scales. Current and future collaborations are further placed under the pressure of a “timer,” since it is expected that the majority of coral reefs will experience annual severe bleaching by the mid-2050s (van Hooidonk et al. 2016). To adapt to this, collaboration encompassing coral reefs cannot just include working across different laboratories to publish scientific papers, but must incorporate a holistic approach beyond academia that heeds the complex and highly interconnected nature of reefs. Studying the reef system requires precise cooperative planning and allocation of international resources to achieve unified and agreed upon goals. We identified two forms of collaboration that have shown to be promising avenues to improve understanding and conservation of reefs: collaboration within scientific research and collaboration of scientists with local coral reef communities.

BIG SCIENCE PRESENTS OPPORTUNITIES FOR CORAL REEFS

The ticking clock on coral reef ecosystems as we know them requires extra diligence in coordinating research efforts around primary understanding and how to directly implement our findings. Each scientific action must be well planned and pointed towards a common goal, similar to those described by the recent Convention on Biological Diversity (UNEP 2019). In this plan, the unique approach of each scientific laboratory should be viewed as a unique puzzle piece that describes one (or several) of the key parameters of a reef system. The wide array of approaches to understand reefs can be seen as a reflection of the multitude of interactions that affects the coral holobiont itself (Cziesselski et al. 2019). Approaches can be

broadly categorized by discipline, such as sociopolitical science, economics, geology, ecology, chemistry, and climate. Variation within these broader disciplines can then be defined at the research group level by the unique approach to the reef system, i.e., the shape and area of coverage of the puzzle piece. How can we most effectively put these puzzle pieces together to build a full action plan to maximize benefit to the reefs and use resources most effectively?

We propose that to start this process as a community, we must establish committees to lay out the most immediate and important scientific goals that enable reef preservation worldwide. Committees of broad disciplines (ecology, chemistry, etc.) would have several community-nominated (with consideration of diversity and inclusion initiatives to avoid selection bias) and elected principal investigators whose research interests represent the discipline well. Committee meetings would take the form of an informal working group that could fit well into preexisting meetings, such as a Gordon or NCEAS (National Center for Ecological Analysis and Synthesis) conference. Before meeting, these committees would be responsible for sending out online surveys and communicating with scientists within their discipline to assess discipline level goals. These goals would then be formulated and communicated with the committees of other disciplines to establish overarching scientific goals and beneficial collaborations for our understanding and conservation of coral reefs. A 4-yr recurring report written by committee members with clearly defined goals for the scientific community would then serve as a framework for researchers moving forward. Formulation of these committees and dissemination of collaborative goals could be generated as a component of a preexisting organization, such as the International Coral Reef Initiative, with an emphasis on scientific goals for required understanding of reef systems. As we have all seen from the COVID-19 pandemic, a large degree of scientific work can be completed online and this could be done just the same. While the exact form of collaboration between research groups may vary, it seems clear that increased communication and community defined goals for knowledge are necessary if we are to support global coral reef preservation moving forward.

MEANINGFUL ENGAGEMENT AND INCLUSION OF LOCAL COMMUNITIES

Perhaps the most often acknowledged but least applied form of collaboration in reef science is with local communities that live on or near coral reefs. Many of these communities have a deep empirical and historical knowledge of the function of their reefs over time whereas scientific research is typically restricted to short visits (<1 yr) with brief to no temporal coverage. For modern understanding, local communities reside on reefs year-round and are in a unique position to greatly strengthen understanding of reef systems by conducting year-round observations and studies, particularly for understudied and remote reefs. Consultation of local people for traditional ecological knowledge provides high temporal coverage understanding of the reef and has been used for management strategies (Thornton and Scheer 2012), but a gap still remains between current scientific studies and local communities, creating a scientific inequity. If we are to have the most complete understanding of coral reefs and provide scientific equity to all groups involved with reefs, there needs to be meaningful teamwork with local peoples in research projects.

Local community inclusion must extend beyond a relay of information on what foreign scientists are doing on their reefs and needs to include elements such as reciprocal training (Baines 1992), community-based monitoring (Obura et al. 2002), comanagement (Fernandez-Gimenez et al. 2006), and long-term partnership (Moller et al. 2009). Offering work-for-pay opportunities and including local communities from the very beginning of projects would establish inclusion and scientific equity and would garner participation for year-round research of coral reefs. Employing local collaboration practices in rural reefs, where there is no well-established research station would also aid in filling the large gaps in our knowledge of understudied reefs (Fisher et al. 2011). Local community inclusion sets up a tone of shared responsibility to protect indispensable natural resources. One such example comes from a partnership between scientists and communities in Palau in which sedimentation stress to coral reefs was alleviated by designing taro fields to better trap sediment and moving them higher up in the watershed to protect the reefs (Richmond 2014). The benefits are immediate

and long-lasting once ties are established. Local community inclusion sparks discussions of reef health and changes on an international scale and beyond the scientific community. With such a small amount of time left to preserve reef health, we must gather and incentivize the efforts of everyone that is willing to help.

Collaboration to improve our understanding and protection of coral reefs worldwide is not only an exercise in large scale teamwork to achieve a goal, but an exercise of inclusion of diverse views and establishing trust across borders and backgrounds. Large-scale scientific collaboration, once established, will produce greater products than the sum of the efforts involved. Meaningful partnership between diverse scientific interests and local communities living with the reefs will facilitate a unified approach to protect reefs globally and lead to increased coastal resilience and climate mitigation strategies of at-risk regions. The underlying effort and success of developing a well-informed society lies in everyone's commitment to communicating and cooperating across sectors and disciplines, with some levels of sacrifice for a common unified goal being paramount. As a scientific community we must exercise our social skills as much as possible, and work with people far outside our disciplines if we are to ensure a future of coral reefs worldwide.

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LOOKING TO THE FUTURE

Perspectives from the Next Generation of Coral Scientists

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If we look to the future of coral reef science and see an inclusive and diverse field where researchers from a variety of disciplines are widely engaged with the community at large, it will herald the success of the issues discussed thus far in this series of essays (Czieielski et al. 2021; Love et al. 2021; Nowakowski et al. 2021; Wilkins et al. 2021). Interpersonal communication and collaboration are necessary to garner excitement for the future of coral reefs. It is also necessary to implement these within an open and inclusive atmosphere, to welcome and ensure diversity in future generations of scientists who will bring with them important and unique perspectives. This is not only a moral obligation; recent research demonstrates that diversity in research teams leads to more impactful publications (Freeman and Huang 2014, 2015). The dire future of the planet's coral reefs is an urgent problem that will require the best working scientific collaborations to resolve. To address this urgent problem, we have identified three aspects of coral reef science that should be focused on for future generations: connecting people to coral reefs, inclusion and diversity, and holistic training programs that prepare future generations for an evolving science.

Connecting the general public and stakeholders to coral reefs means implementing communicative and collaborative tools that were discussed in previous sections, such as personalizing narratives (Nowakowski et al. 2021) and local outreach (Love et al. 2021). Beyond incentivizing interpersonal outreach, coral scientists now and in the future should be more proactive about sharing their discoveries and results through the variety of platforms that exist on the internet. Laced within that communication piece (geared toward a nonscientific audience) needs to be a message of hope, with tangible goals that can be achieved through actionable plans. That same plan of action should be refined through collaborations with local stakeholders who help to manage the reef where scientific studies are

being conducted. With ample attention drawn toward interpersonal communication and collaboration, scientists can use their emotional attachment to coral reefs as a conduit to incite both excitement and action in the general public.

However, perhaps the most relevant and timely way to connect more people to coral reefs is to broaden the diversity of individuals who represent coral reef science. Toward this end, coral scientists have a particular part to play as role models. Institutions need to be mindful of this when hiring new faculty and researchers, because senior professionals that students (both current and prospective) can personally identify with are crucial for recruitment and retention (González 2006). Despite the fact that this is well-understood at the institutional level, a recent study documenting faculty recruitment of under-represented minorities (URMs) at four major institutions reported that only 4–9% of tenure-track faculty between 2011 and 2015 were from URM populations (Gumpertz et al. 2017). Worse perhaps is that the coral sciences are no exception, where URM groups are typically those most impacted by the social and economic repercussions of degrading coral reefs. Inclusion of a broader set of experiences leads to asking more important questions and therefore discovering more sustainable solutions. By missing this representation, we are missing essential opportunities that the planet's coral reefs cannot afford.

While current representation is far from ideal, steps are being taken toward addressing the lack of diversity, inclusion, and equity in STEM fields. STEM-support programs typically help URM students from various universities by arranging campus visitations, assisting with summer research opportunities, and promoting informal mentoring relationships. While many programs like this exist for general STEM fields, there are none that we are aware of specifically targeting coral research. Given the important links between coral reefs, the URM populations that typically inhabit them, and diverse research groups, this should be a priority moving forward for the future of coral science.

Expectations for professional scientists are changing. Dwindling funding opportunities coupled with increasingly available technologies are putting greater demands on the skill sets that scientists must have in order to succeed as working professionals. Graduate programs must therefore adapt to these growing demands and properly equip their graduate students with a more holistic set of tools to ensure their success beyond graduation. Coral scientists are finding

that their collaboration teams need to include more than just other researchers in the physical sciences. Economists, policy-makers, and various stakeholders are taking an interest in research being conducted on coral reefs, yet scientists are often not trained to operate in such eclectic working groups. Training for this evolving scientific environment should come in the form of collaboration through internships and opportunities within nongovernmental organizations, industry, and even on the scientific advisory staff of political candidates. Important personnel from these organizations should be regularly invited to give talks to graduate students at their local seminars, creating avenues for job opportunities outside of academia.

Much of the training of graduate students is laid at the feet of their respective mentors, who are expected to teach the budding scientists everything they need to know about life as a successful researcher. Even some of the best mentors will admit that taking on a graduate student is a “labor of love.” This monumental task of training a graduate student must be shouldered with the high demands placed on career scientists in this modern “publish or perish” professional climate. This is an unrealistic expectation that creates inefficiencies in a scientific discipline that demands efficiency to thrive in the current political and environmental climate. While workshops are offered to both graduate students and faculty members alike to improve skills in grant proposal writing, laboratory management, and classroom teaching, further attention needs to be paid toward proper training in mentoring. Many corporate structures in the business world have already instituted management classes to maximize efficiency at a variety of management levels. Coral science working groups, academic institutions, and funding bodies must recognize the merits of investing into the professional development of their

science staff and graduates moving into the future.

The next generation of coral reef scientists stands on the precipice of the unknown. Coral reefs are in an unprecedented state of decline, and if the current generation of coral scientists wishes to pass the proverbial torch of knowledge that will illuminate such an uncertain state, then they must prepare future generations for inevitable change. Encouraging coral scientists to embrace their place as role models will help garner excitement and action from the general public. Improving the state of diversity, inclusion, and equity in coral reef science will heighten both the quality and reach of coral research. Finally, providing the next generation of coral scientists with a holistic set of tools will prepare them for the rapidly changing field of professional science. If coral scientists in the coming century prove to be as adaptable as coral reefs to the coming challenges, then hope for their future is indeed well warranted.

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