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Editorial: Coral reef research methods

James Davis Reimer[1,2]*, Nina Yasuda[3]* and Shashank Keshavmurthy[4]*

[1]Molecular Invertebrate Systematics and Ecology Lab, Faculty of Science, University of the Ryukyus, Okinawa, Japan, [2]Tropical Biosphere Research Center, University of the Ryukyus, Okinawa, Japan, [3]Aquatic Conservation Laboratory, Department of Ecosystem Studies, Graduate School of Agricultural and Life Sciences, The University of Tokyo, Tokyo, Japan, [4]Biodiversity Research Center, Academia Sinica, Nangang, Taiwan

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John Hiscott,
Istituto Pasteur Italia Cenci Bolognetti Foundation, Italy

*CORRESPONDENCE
James Davis Reimer
jreimer@sci.u-ryukyu.ac.jp
Nina Yasuda
ninayausda@gmail.com
Shashank Keshavmurthy
coralresearchtaiwan@gmail.com

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Editorial on the Research Topic
Coral reef research methods

1 Introduction

Coral and coral reefs are facing increasing existential threats to their existence as a result of stress from human-accelerated climate change and other various human pressures (Hughes et al., 2017; Le Nohaïc et al., 2017; Hughes et al., 2019) Due to these increasing threats, there has been increase in the activity of researchers to understand the effects of various stressors, and also into examinations of how to mitigate and conserve corals and coral reef ecosystems into the future.

To accomplish such research, scientists employ various methodologies and techniques as part of their research protocols. However, often these methods and techniques are not standardized (Hughes et al., 2003), and in addition potentially important sampling schemes and/or effective methods may be overlooked (Weinberg, 1981; Plaisance et al., 2011; Alzate et al., 2014; McLachlan et al., 2020; Thurber et al., 2022), thus missing chances to increase the potential efficacy of the research being performed.

This special issue, "Coral Reef Research Methods", is a collection of 20 original research papers. These papers can be broadly divided into three categories: 1) introductions to and explanations of new methods of coral reef research, 2) verifications of useful methods, including comparisons of old and new methodologies, and 3) exploratory papers examining the previously unexamined taxa or ecosystems, which can also provide insights into sampling schemes, research designs, and general coral reef biogeographic patterns. Here, in this editorial, we summarize the 20 papers included in this Research Topic, and add thoughts on the potential future directions of coral reef research methodologies.

2 Introductions to and explanations of new methods of coral reef research

Just over one-third of the papers (=7/20) in this Research Topic introduce novel methods for investigating coral reefs. These new methods range from ecological survey and field methodologies to *in vitro* and laboratory protocols, and are each briefly introduced below.

One of the chief struggles many coral reef researchers have faced is how to quantify and obtain meaningful data from the complex and often highly rugose structure of coral reefs. Included in this Research Topic are three different methods, each aiming to make the acquisition of field data from the intricate morphology of coral reef ecosystems easier and more accurate. A primary example is show by Aston et al., who have developed protocols for extracting structural metrics from three-dimensional reconstructions of corals. Importantly, their results indicate that even a simple metric such as scleractinian coral colony diameter combined with morphotaxa information can explain the large majority of sheltering provisions of the colony. As well, six of seven morphotaxa appear to have similar habitat provisioning characters. These results indicate that despite the complex structure of individual coral colonies, calculations of habitat space may be governed by common rules, hinting at the development of powerful future ecological analytical methods; this paper represents an important step in this direction.

Similarly, Masucci et al. compared the size, shape, and fractal diversity of coral rubble from natural and artificial coastlines around Okinawa, Japan. The methodology utilizes free software and images, and was able to clearly discern between rubble from natural and artificial coastlines. With an increase in coastal armoring (Masucci & Reimer, 2019), and the importance of coral rubble in the provisioning of habitat space for infaunal organisms (Masucci et al., 2021), this method promises to become an important tool in environmental monitoring of coral reefs.

Recently, mesophotic coral ecosystems (MCEs) have been investigated in increasing detail, particularly with respect to the ecology, physiology, reproduction, and molecular ecology of scleractinian corals. Nativ et al. have optimized a protocol for the fluorescence imaging estimation of *in-situ* coral recruitment patterns from shallow to mesophotic depths. As dive and observation times are limited in MCEs, development and optimization of protocols such as their FluorIS method is timely. As this non-invasive method is based on a single camera, and increases speed over past methodologies, the understanding of coral recruitment patterns in MCEs should become more accessible into the future.

The remaining four papers in this subsection of this Research Topic span the bridge between *in situ* data collection and laboratory methods.

For example, Steinberg et al. have developed a new method for quantifying the endosymbiotic Symbiodiniaceae (=zooxanthellae) counts and chlorophyll concentrations for octocorals. While such methods already exist for Scleractinia, much less studies have applied these methods to octocorals and other anthozoans that are often major components of coral reefs to increase biodiversity (Epstein and Kingsford, 2019), and our understanding of even their basic biology lags behind that of Scleractinia. Efforts like Steinberg et al. are a welcome addition to better understand the total biodiversity of coral reefs.

Assessing coral diversity is one of the biggest challenges facing conservation efforts of coral reef ecosystems, particularly given the incredibly high diversity of these ecosystems (Knowlton et al., 2010), and also the ever-increasing loss of biodiversity (De'ath et al., 2012). Shinzato et al. provide new environmental DNA (eDNA) primer sets to better assess reef-building coral species *via* 12S and cytochrome oxidase subunit 1 (COI) sequences, and their initial analyses indicate high scleractinian specificity and utility. With the rapid development of the eDNA field, these primer sets should aid future efforts to more rapidly and accurately monitor coral reefs.

Conducting experiments on endosymbiotic zooxanthellae in culture has been severely limited by the inability to successfully establish *in vitro* cultures for the large majority of Symbiodiniaceae (Santos et al., 2001; Chakravarti and Van Oppen, 2018; Wang et al., 2021), and thus there are major gaps in our understanding of the cellular mechanisms of these symbionts. Kawamura et al. successfully developed an *in vitro* line of Symbiodiniaceae in symbiosis with coral cells for future experimentation and manipulation, representing a critical step forward in our ability to examine these keystone symbionts.

Finally, Yuyama et al. applied RNA interference technology involving gene knockdown to understand and modify the expression of genes involved in stress tolerance level sand fluorescence emission in coral juveniles, providing an important molecular tool for future analyses of coral planulae and polyps.

3 Verifications of useful methods, including comparisons of old and new methodologies

Ecological research on coral reefs has a comparatively long history with the field of coral reef science, with numerous papers published through time. Despite this, there are still basic issues regarding standardizing monitoring and survey techniques. In this Research Topic, four articles (one-fifth of the total; 4/20 papers) have examined the verification and improvement of current methods, or compared more newly developed methods with older methods, as outlined below.

Kuo et al. have suggested improvement to one of the Point Intercept Count (PIC) methodology of examining coral reef benthos *via* the proposing sampling at finer intervals than has been standard. In general, PIC examines the presence or absence of taxa at set intervals, often of 50 cm or 1 m, but the findings of Kuo et al. based on research from Taiwan suggest finer scale intervals of 10cm may be needed to more accurately obtain benthic community data.

Yamakita et al. applied the Ecologically or Biologically Significant Marine Areas (EBSA) concept from the Convention on Biological Diversity (CBD) to examine results in Japanese coastal waters considering coral cover change in association with climate change and including genetic diversity data of Scleractinia and blue corals. While such examinations are usually performed on charismatic or endangered megafauna, they can be equally applicable to other organisms. Their results indicated relative importance of temperate areas for the first time which was not obvious in the traditional assessments, but also highlighted sampling bias in the form of a general lack of data from warm temperate Japan, demonstrating the need for more in-depth genetic analyses of coral reef organisms.

Bang et al. compiled data from four different methods of resilience analyses on coral reefs in southern Taiwan, and compared results. While there was little agreement among the different datasets with each other, or with general baseline data, all indicated high resilience in the region, possibly due to the well-known occurrence of local upwelling. Surprisingly, "the most successful assessments were those that empirically quantified ecological processes and local factors with only a few indicators, rather than broader approaches that measured many indicators", indicating that future, well-chosen datasets may provide broad analytical power in examining coral reef resilience.

Barrera-Falcon et al. compared coral data from an underwater digital photogrammetry protocol (UWP) of coral reefs in Cozumel, the Caribbean, with other, more commonly utilized methods including Point Intercept (PT), video transects (VT), and the Atlantic and Gulf Rapid Reef Assessment (AGRRA) protocol. Their results highlighted the sensitivity of the UWP method to colony abundance, species richness, smaller-sized species, and consistently returned a lower percentage coverage than other methods. As more researchers are increasingly using photogrammetry-based methods, such comparisons carry importance in understanding how best integrate these new methods into datasets.

4 Exploratory papers examining the previously unexamined taxa or ecosystems

Finally, just under half of the papers (=9/20) in this Research Topic can be broadly classified as "exploratory" research, newly investigating coral reef ecosystems or taxa. While such papers may not be methods-based papers in the strictest sense, much can be learned from the methodologies and experimental designs they employ. Below, we briefly outline these papers.

Turbid inner bays and inshore reefs have drawn considerable attention because of terrestrial runoff and poor water quality (GBRMPA, 2020). Jones et al. examined the underwater spectral characteristics of inshore reefs on the Great Barrier Reef, and suggest that light monitoring frameworks are needed to better understand the threats to these ecosystems, particularly given their comparatively higher frequencies of turbidity events.

One common component of deeper reefs and turbid areas in the Indo-Pacific is the scleractinian genus *Pachyseris* (see DeVantier and Turak, 2017). Jain et al. examined the Symbiodiniaceae community associated with *Pachyseris* in the turbid reefs of Singapore and more pristine reefs of Papua New Guinea, finding notable differences in Symbiodiniaceae genera between locations, and highlighting the need to account for local environmental conditions in sampling schemes. Similarly, Shiu et al. demonstrated "spawning environments do not affect the bacterial composition in maternal colonies, but influence that of the offspring" in scleractinian corals, yet another indication of the importance of taking local conditions into account.

As shown by these studies, sampling designs are of great importance in biodiversity research. Recent advances in genetic analyses have enabled researchers to reveal cryptic genetic lineages in many different coral organisms (Bongaerts et al., 2011; Ladner and Palumbi, 2012; Yasuda et al., 2014; Nakabayashi et al., 2019; Richards et al., 2018). However, available local information sometimes causes confusion in the distribution of cryptic species and lineages. Taninaka et al. and Pipithkul et al. demonstrated population genetic and phylogeographic analyses covering wide ranges of coral distributions are promising and can provide important cues for patterns of speciation and diversification as well as the existence of possible past refugia. Likewise, population genetic analyses across different morphological species may indicate unexpected oceanographic boundaries (Yasuda et al.). Finally, Takata et al. examined fine-scale next-generation spatial genetic structure of the precious coral *Corallium japonicum*, showing up to dispersal scale of 11 km, thus demonstrating the need for conservation management at small and local scales.

Estimating larval dispersal ranges in ecological time-scales is critical for conservation and management, including in designing effective Marine Protected Areas, as many corals and coral reef organisms have pelagic larval dispersal. As such, there are many research papers on meta-population genetic structures of coral reef organisms based on population genetics and phylogeographic approaches. However, one of the issues that larval dispersal estimates based on genetic approaches have is that estimated meta-population genetic structures do not only reflect larval dispersal that occurred on ecological time scales but including structures that occurred during evolutionary time-scales. Horoiwa et al. estimated the population genetic structure of the Crown-of-Thorns starfish *Acanthaster* cf. *solaris* across the Ogasawara and Kuroshio regions, finding that they were homogeneous through oceanic larval dispersal simulation, indicating direct migration of larvae from the Kuroshio region and Ogasawara is physically difficult and thus implicating stepping-stone migration patterns. This study highlighted the importance of assessing larval dispersal by multiple methods to accurately understand the time scales of larval dispersal when considering conservation management.

Mokodongan et al. empirically demonstrated dispersal distances in blue corals (*Heliopora* spp.) estimated by the intercept of spatial autocorrelation analyses well agreed with the dispersal distance directly estimated in the field using settlement tiles. The study also compared more traditional (microsatellite markers) and newer (genome-wide SNPs data using MIG-seq analyses) methods and demonstrated estimated dispersal distance did not change between the two methods, although more samples were required when using microsatellite analyses.

5 Thoughts on potential future directions of coral reef research methodologies and conclusions

The twenty contributions to this Research Topic span a wide range of fields, and summarizing the findings is a difficult task. Still, we can identify some general trends. Firstly, methodologies of coral reef research are becoming increasingly powerful and complex, yet are becoming easier to use, with results indicating broad general rules and trends that may yet emerge. In short, development and utilization of new methods will lead to an increasing rate of fundamental changes in our understanding of coral reef ecosystems. We can except the future of coral reef science, despite facing the threats of climate change and increasing local stressors, to be one of key discoveries and advances in knowledge and conservation. Secondly, many of these original papers in the current collection demonstrate the importance of local conditions. Knowledge of small-scale settings and more holistic characterization of entire ecosystems will allow coral reef researchers to learn from success stories and unique settings, providing yet more information for the fight to protect coral reefs into the future.

Author contributions

SK, NY, and JR wrote, edited, and approved the final draft of the paper.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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