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Mapping coral reefs

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Coral reefs support more than a quarter of the world's marine biodiversity, and therefore, accurate mapping of their location and composition is vital. In this issue, Lyons et al. present a framework that maps the distribution and composition of coral reefs worldwide in a higher resolution than previously.

People have long been fascinated by world maps, from the earliest Babylonian clay tablet of the 6th century BC to Ptolemy's 2nd-century world map, to Europe's best 15th-century world maps that helped guide Columbus to seek new territory. Columbus expected clear sailing from Spain to the East Indies (Indonesia), as the presence of America was unknown to Europeans, as were local navigation hazards, such as coral reefs. As fate would have it, Columbus's flagship was grounded on a coral reef in the Bahamas in 1492. Some of the earliest maps of coral reefs came from the endeavors of Captain James Cook in 1770, who mapped the Great Barrier Reef in Australia, and Darwin's voyages, which enabled him to map numerous reefs in the Pacific and Indian oceans.[1] Despite these efforts, many other sailors met their final fate on coral reefs. Indeed, coral reefs were merely thought of as navigational hazards by European sailors, whereas Indigenous inhabitants lived in the "Sea Country" for millennia. Ironically, coral reefs are now famous for protecting human coastal communities from storm waves and providing fresh seafood for millions of people globally. Coral reefs also support more than a quarter of the world's marine biodiversity. Therefore, mapping the exact location of coral reefs globally has long been a societal goal. A recent article in *Cell Reports Sustainability* by Lyons et al.,[2] entitled "New global area estimates for coral reefs from high-resolution mapping," has brought us closer to achieving that goal.

The study by Lyons et al. builds on previous mapping efforts using a new, transparent, globally consistent, and repeatable framework that maps the distribution and composition of coral reefs worldwide. The distribution of coral reefs is presented at a high resolution of 5 m. The authors synthesized more than 0.5 million multi-spectral images of reefs collected between 2018 and 2020 using a constellation of hundreds of small (30 cm) satellites, which fly at different altitudes and provide daily imagery of the entire planet. The images were used to train a cloud-based machine-learning reef classifier for depths between 0 and 15 m. The reef classifier predicted 11 geomorphic zones and 6 benthic reef classes between the latitudes 30° north and south worldwide. The classifier was validated using more than 400 field datasets and tested by end users to improve the final map product, made available as Allen Coral Atlas, version 2. The map shows that the Earth supports nearly 350,000 km^2 of shallow reefs, of which about one-quarter support coral habitats. The extent of coral habitats varies geographically, with some countries supporting more than other countries. For example, Indonesia, Australia, the Philippines, Cuba, and Papua New Guinea each support more coral habitats than any other country.

The updated Allen Coral Atlas mapping framework reveals more coral reefs than previous maps made in the 1990s. The atlas is useful in demarcating national, regional, and local resources, especially for those jurisdictions with minimal scientific resources. It also provides vital data for coastal management, conservation targets, and spatial planning. The atlas is routinely used by coral-reef scientists and has facilitated predictions of fish communities at varying geographic scales[3] and reef connectivity.[4]

The classification accuracy of geomorphic zones varies from 89% to 46%, whereas the classification accuracy of the benthic-substrate classes varies from 80% to 49%. These differences in classification accuracy will incentivize researchers to target specific features of the reef to improve accuracy. Rapidly improving technology will likely increase the benthic classes and extend the maps beyond the 15-m depth, mapped by Lyons et al.[2] Mapping deep reefs beyond 15 m is urgently needed to understand the extent of connectivity between shallow and deep reef systems.[5] Improving maps of coral reefs in turbid waters is also necessary, as such turbid-water reefs are potentially acting as climate-change refuges.[6]

Mapping where coral reefs are located spatially is a monumental achievement of modern technology, and the online and open-source format of the Allen Coral Atlas allows for flexibility in updating. The high-resolution mapping is an essential tool in conservation planning and will help improve predictions of observed reef patterns. For example, mapping bright and dark spots of fishes[7] and corals[8] identifies where fish biomass or coral cover is higher or lower than spatially expected and which environmental variables are likely to drive these spatial deviations. These geographical patterns need to be evaluated in tandem with information on genetic connectivity, biodiversity, conservation management, and restoration efforts.

Traditional maps, however, are static, yet coral reefs are dynamic systems. Inserting temporal dynamics into map features is the next important step forward. Although the geomorphic zones, identified by Lyons et al.,[2] are unlikely to change rapidly, the composition of coral reefs can change abruptly,[9] which will influence the distribution of the benthic-reef classes. For example, marine heatwaves are increasing in severity and frequency,[10] which influence reef composition and

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biogeochemical processes, such as reef growth[11] and rates of coral recovery.[12] Integrating the dynamics of reef composition into maps would improve our understanding of the interplay between spatial patterns and biogeochemical processes.

Understanding and predicting these pattern-process interactions are more than merely academic curiosities, as many low-lying countries, such as those located on coral-reef atolls rely on coral reefs to sustain their livelihoods and protect their shorelines. Can coral reefs adjust to ocean warming? Where will coral reefs most likely keep up with sea level rise? Identifying possible climate-change refuges during these unprecedented times of ocean warming is urgently needed and is one of humanity's greatest challenges. Like Columbus more than 500 years ago, we are at the precipice of a voyage into unchartered waters. Will coral reefs survive global climate change, or will the computer-generated maps of modern times become a historical record from the Anthropocene?

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DECLARATION OF INTERESTS

The author declares no competing interests.

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