SPOTLIGHT

Ocean Acidification Capacity Is Needed at All Levels to Develop a Multistakeholder Ocean Acidification Action Platform

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THE NEED

Ocean acidification (OA), an alteration of seawater chemistry caused primarily by anthropogenic carbon emissions, is a global issue. However, the local expression of OA can vary widely in nearshore waters around the world. This is due to localized factors such as river input, eutrophication, topography, location (e.g., temperature), and sensitivity of local species. Human impacts from OA also vary depending on societal uses of the ocean and its resources. Managers, policymakers, and governments need to understand the status and susceptibility of their regions in order to make effective decisions and drive policy. In the early 2000s, scientists recognized the need for a global ocean acidification observing system and called for a coordinated approach to effectively assess global as well as local status with consistent methods. As a result, the Global Ocean Acidification Observing Network (GOA-ON) was formed in 2012 with three goals: (1) to improve understanding of global OA conditions, (2) to improve understanding of ecosystem responses to OA, and (3) to acquire and exchange data and knowledge necessary to optimize modeling of OA and its impacts (Newton et al., 2015; Tilbrook et al., 2019).

Since its inception, GOA-ON has grown from 62 scientists representing 23 nations to over 1,000 scientists representing more than 100 countries (**Figure 1**). However, significant development is still needed to produce a network with truly global capacity. GOA-ON, and the affiliated United Nations Ocean Decade Program Ocean Acidification Research for Sustainability (OARS), aim to foster the development of OA science, including the impacts on marine life and marine ecosystems. These efforts are key in order to achieve Sustainable Development Goal (SDG) target 14.3, "Minimize and address the impacts of OA, including through enhanced scientific cooperation at all levels," and to translate OA science to broader policy, management, and public communities.

STRATEGIES

Given wide global variability in resources and capabilities, a multitude of approaches are required to construct an OA capacity development strategy. Consequently, members of GOA-ON and OARS collaborate with many partners, including the Intergovernmental Oceanographic Commission of UNESCO (IOC-UNESCO), the Ocean Acidification International Coordination Center of the International Atomic Energy Agency (IAEA), The Ocean Foundation, and the Ocean Acidification Program of the US National Oceanic and Atmospheric Administration (NOAA). Together, these organizations follow several complementary approaches for training and development: (1) establishment of regional hubs; (2) in-person trainings, including techniques for biological and chemical measurements; (3) online teaching and courses that provide an introduction to OA measurements and the utilization of related data; (4) Pier2Peer, a scientific mentorship program that matches senior researchers with early career scientists to facilitate expertise exchange and international collaboration; and (5) support of infrastructure building, particularly GOA-ON in a Box (see https://www.goa-on.org/resources/kits.php).

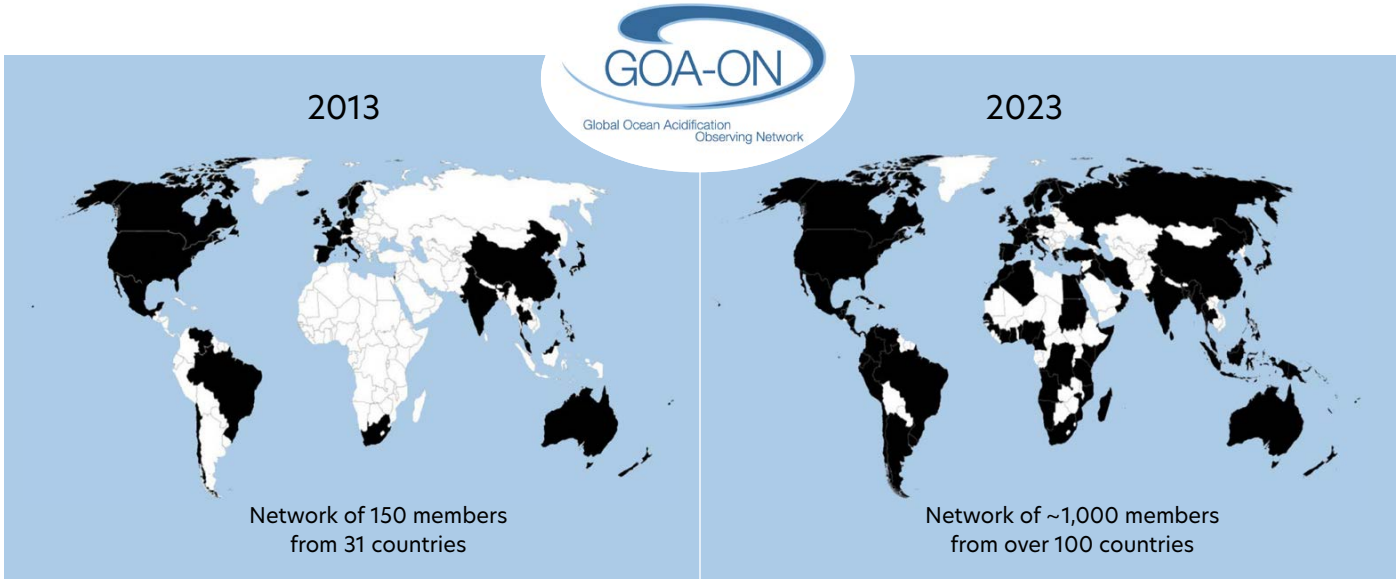

FIGURE 1. The growth in national affiliations of members in the Global Ocean Acidification Observing Network (GOA-ON) from 2013 to 2023.

LESSONS LEARNED

Lessons learned from the collaborative effort include the following.

- Regional hubs must be developed from the bottom up, with grassroots local leadership directing the process, defining objectives and needs, and organizing the community. To date, GOA-ON has nine regional hubs. We have found that hub genesis may take substantial time, from months to years, to complete.
- Training workshops have not only identified where scientific knowledge needs better sharing but also underscored substantial technical challenges that need to be addressed on a global basis, such as the development of low-cost and simple-to-use equipment, the sustainable production and availability of certified reference materials across salinities from estuaries to the open ocean, and the provision of affordable and accessible purified pH indicator dyes.
- Online trainings offer the possibility to increase the number of beneficiaries while reducing the need to travel. The content can provide the theoretical basis for OA research and observation. However, in order to implement OA research and observation, in-person trainings remain indispensable.
- While peer-based mentor-mentee programs, for example, GOA-ON's Pier2Peer, have been highly successful, there are pitfalls: the pool of mentors can be depleted rapidly; communication is key to success, and if either member lapses in responsiveness, effort can languish; and needs can change. A model that worked well with a smaller membership was stretched as membership grew, necessitating re-scaling of effort so participants would not be disappointed.
- Resources are strongly limited. GOA-ON in a Box is a low-cost kit used for collecting weather-quality OA measurements. Provision of these kits has sought to address some of the current knowledge and equipment gaps, but demand far outweighs funding for supplying them.
- New technologies adapted to local environments and technical capabilities will be required. Low maintenance sensors with suitable accuracy for detecting natural variability and long-term trends must be developed to advance the knowledge and understanding of coastal acidification.
- Sharing centers of excellence provide invaluable regional support, given strong local commitment and engagement. For example, the Pacific Islands Ocean Acidification Center provides ongoing training, technical support, and equipment repair, increasing autonomous regional research capacity (Smith, 2023).

INCREASING NEED

Capacity development needs have grown within the OA community, spurred by two actions. First, the establishment of the UN Sustainable Development Goals, and specifically the target SDG 14.3 and its related indicator SDG 14.3.1, focusing on marine acidity, has heightened global equity needs in capacity for OA measurement. Additionally, the UN Decade of Ocean Science for Sustainable Development offers an opportunity to focus OA efforts on seven specific outcomes (IOC-UNESCO, 2024) needed by the end of the decade. In brief, OARS aims to assure that quality data from co-designed efforts can be used for decision-making and for increasing societal awareness on a global basis. OARS strives to have capacity development permeate each outcome.

DEVELOPING A FRAMEWORK

While needs are substantial and growing with increased attention to a changing ocean, intentional consideration of how to address these needs is required. The highest-level consideration for effective capacity development is that it be fit for purpose. The aim for capacity development needs to be defined and co-designed at the outset, with a means for specifically addressing the need planned. Leaders of various OA capacity development efforts met recently to synergize efforts and identified three goals that OA capacity development trainings can serve:

- **Goal 1.** Assess exposure: Every country has the capability to report to the SDG 14.3.1. This requires holding trainings on awareness of ocean acidification and the SDG process, as well as technical trainings on OA measurements and reporting.
- **Goal 2.** Assess impacts: Every country has the local knowledge to project biological impacts. This requires a range of technical trainings at different levels of complexity, including biological monitoring, experimentation, evolution, ecology, identification of multiple stressors, and carbonate chemistry for biologists.
- **Goal 3.** Identify mitigation and adaptation strategies: Every country has a good understanding of the existing and emerging solutions, data needs, co-design, etc. This requires a combination of lectures, co-designed workshops, and formal training.

VISION FORWARD

An OA capacity development strategy informed by the current capacity development approaches, the lessons learned, and the newly defined goals encompassing the chemical and biological changes, as well as related mitigation and adaptation actions, will pave the way for capacity development that fills existing gaps and democratizes access to OA data and information. This strategy will further encourage new partners to join OA capacity development activities as geographical and thematic priorities will have been identified. We especially welcome early career professionals (e.g., via the International Carbon Ocean Network for Early Career [ICONEC; https://www.goa-on.org/iconec/iconec.php]) to help lead the effort.

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