29 July 2021

Ambassador Peter Thomson
UN Secretary-General's Special Envoy for the Ocean

Your Excellency,

On behalf of the Global Ocean Acidification Observing Network, GOA-ON, we are pleased to respond to your open letter to the Intergovernmental Oceanographic Commission of the United Nations Educational, Scientific and Cultural Organization (IOC-UNESCO). Here, we offer answers to your questions regarding the known science of ocean acidification and its impacts. We also would like to take this opportunity to profoundly thank you for raising the issue of ocean acidification on the global stage.

GOA-ON is a collaborative international network organized at the global scale, connecting members all over the world who are working on aspects of ocean acidification from local and regional through global scales. The network was established in 2012 by the scientific community and has three sponsors (IOC-UNESCO, NOAA - National Oceanic & Atmospheric Administration, and IAEA OA-ICC - the International Atomic Energy Agency Ocean Acidification International Coordination Centre). Since that date, GOA-ON's membership has swelled to over 870 scientists who hail from 105 countries, making it a truly global network. GOA-ON is designed to address three high-level goals:

1. Improve our understanding of global ocean acidification conditions
2. Improve our understanding of ecosystem response to ocean acidification
3. Acquire and exchange data and knowledge necessary to optimize modelling for ocean acidification and its impacts.

Since its inception, GOA-ON has established its leadership in the field of ocean acidification; key efforts include expert advice throughout the development of the methodology for the UN Sustainable Development Goal (SDG) 14.3.1 Indicator ("*Average marine acidity (pH) measured at agreed suite of representative sampling stations*"); an interactive portal for ocean acidification observing data from a wide range of platforms, as well as derived data products; development and operation of a scientific mentorship program (Pier2Peer) and global capacity building efforts in partnership with other networks and agencies; participation in the Commonwealth Blue Charter and the Community of Ocean Action on Ocean Acidification; and the successful development of a Decade programme "OARS - Ocean Acidification Research for Sustainability", which has recently been endorsed as an Ocean Decade Action for the UN Decade of Ocean Science for Sustainable Development (2021-2030).

GOA-ON is coordinated by an active Executive Council of experts representing both the scope of ocean acidification science (chemistry, biology, modeling, data QA/QC and management, observing technology, etc.) and the eight geographically distinct 'regional hubs' of GOA-ON spanning the globe (Africa, Arctic, Latin America, Mediterranean, North America, NE Atlantic, Pacific Islands, and Western Pacific).

The GOA-ON co-chairs, on behalf of the Executive Council and the GOA-ON membership, submit the following responses to your questions. We are happy to provide further elaboration or follow-up at any time. Above all, we wish to thank you for the extraordinary leadership you have shown to date in championing ocean issues, and we are thrilled that you are extending the dialog further into discussion of ocean acidification.

1. At what level of ocean acidification does the ocean's calcium-carbonate based life-forms - shellfish, vertebrates, certain phytoplankton and zooplankton – cease to exist?

   In short, there is not one single level of ocean acidification, a threshold or tipping point if you will, that will be lethal for all calcium carbonate-based life-forms, or even any single life-form. This is due to the enormous amount of variability that exists between species, and between individuals of the same species. An individual organism's vulnerability to ocean acidification is determined by a host of physiological, ecological, and environmental processes. Some of the biggest factors in setting an organism's vulnerability include the availability of energy to maintain key physiological processes under stressful conditions, the interaction of ocean acidification with other environmental stressors, such as warming and oxygen loss, acting on the individuals, the prevalence and rate of local adaptation to different conditions, the strength of ecological interactions within an ecosystem (e.g., competition and predation).

   So, while there is great variation, the take home message is that we are already at levels of ocean acidification where changing carbonate chemistry is likely to be exerting additional stress on calcifying organisms, with seawater becoming ever more corrosive to marine life. On an ecosystem scale, this can result in ecosystem collapse and loss of ecosystem services because the additional stress leaves them vulnerable to other factors. For example, coral reefs, for which the calcium carbonate skeletons of reef building corals provide essential structure, are experiencing a reduction or cessation of calcification and therefore growth. In addition, as ocean acidification progresses, coral skeletons may become more brittle, leading to the loss of ecosystem services which they provide, such as the protection of coastlines from storms. Another example for the already existing impact of ocean acidification is the severe effects on the oyster aquaculture industry on the West coast of the US, requiring adaptation measures. We have evidence that some calcified organisms are showing signs of severe shell or skeletal dissolution in nature at the present time. As carbon dioxide (CO_2) continues to increase ocean acidification, and as other stressors like warming temperatures and decreasing oxygen also increase, it is difficult to predict a level for viability, but we know that we are at concerning levels already. Ecological/economic models predict that some Bering Sea King Crab species will have declined enough due to ocean acidification that commercial fisheries will be significantly economically impacted by 2100.

The urgency of the situation should be recognized, as the expression of ocean acidification will only grow with time at current or even reduced carbon emissions. Effects are manifest in many ways and with complex interactions. While adaptation in ecological systems is possible, some species cannot escape as they are linked to specific habitats. The deep ocean is showing signs of acidification to depths of 3000 meters that is enhanced by a climate-related reduction in large-scale circulation (e.g., there are published examples from the Sea of Japan and the deep Atlantic). Polar areas naturally take up more carbon dioxide because of their lower temperatures, but cold-water species will have to face higher acidification if they stay or warmer temperatures if they move away. Some species rely on hard calcified structures (e.g., deep-water and tropical coral reefs) as their habitat, so if the foundations of these habitats are lost, many more species are affected. Additionally, interactions between ocean acidification with other stressors, including ocean-scale variability like El Niño-Southern Oscillation (ENSO) which affects tropical and subtropical ecosystems, are largely unknown.

2. At what level of ocean acidification is other marine life severely affected?

   Ocean acidification is likely to impact most marine life as pH is a critical physiological parameter and a master variable for water quality, such as the bioavailability of toxic metals or nutrients to organisms. Thus, any perturbation can lead to severe consequences. Calcification (the production of calcium carbonate structure, such as a shell or exoskeleton) is only one of the processes impacted by ocean acidification. Whilst non-calcified species may be thought of as being less directly vulnerable to ocean acidification than calcifying species because they do not directly rely on calcium carbonate to build their structure, this is not necessarily the case. Many non-calcified organisms have been shown to be directly impacted by changes in carbonate chemistry at a physiological level. In addition, at an ecological level, all marine organisms exist within complex ecosystems and food-webs where the loss of a single species can have consequences for those species that remain. We are already in the midst of a biodiversity crisis and ocean acidification will only exacerbate this.

   Again, it is not possible to give a global level or threshold, as this varies by species and environment, just as it is impossible to establish one cholesterol level or blood pressure that is lethal to humans. But we do know that if you remove or weaken one key link in the food web it can indirectly impact other parts of that web. Therefore, in response to ocean acidification, marine ecosystems will see a shift in the species composition, as the more resilient species have a competitive advantage. However, it is highly likely that these surviving matrices will be less diverse, structurally simpler and are likely to deliver significantly reduced services. Habitat rich structures, such as coral reefs, become less complex; there will be fewer habitable places for the richness of biodiversity currently present.

3. How will continued ocean acidification reduce the capacity of the ocean to act as a carbon dioxide sink and what would the consequences be for atmospheric warming?

The ocean's role in absorbing anthropogenic carbon dioxide (CO_2) lessens the rate of atmospheric warming, and without it, the planet today would have already reached well over 1.5 °C warming, the Paris Agreement's current long-term target to substantially reduce the risks and impacts of climate change. As the ocean absorbs CO_2, the resulting changes in ocean chemistry reduce the ocean's "buffering capacity" (which decreases by 10% for every 100 µatm increase in pCO_2). As the buffering capacity decreases, so does the ability for the ocean to absorb more CO_2. While the ocean will continue to take up CO_2 in the future as atmospheric concentrations continue to rise, the ocean's role in absorbing anthropogenic CO_2 will gradually diminish. The decreasing buffering capacity of the oceans varies with both temperature and CO_2 content such that in the polar regions the pH decrease is more rapid than in the temperate or tropical regions. Consequently, many of the biological impacts observed thus far occur at the higher latitudes or in open-ocean or coastal upwelling regions, which also exhibit low buffer capacity. Additionally, increasing ocean temperatures caused by rising global temperatures will lead to stronger stratification of ocean waters. This decrease in ocean mixing limits the transfer of carbon dioxide, nutrients, and oxygen in the water column, affecting biological processes and the ocean's role as a carbon sink.

4. Is it IOC's view that Member States are sufficiently equipped with the necessary knowledge to adapt to and mitigate ocean acidification?

In short, no. While GOA-ON has played a leading role in facilitating better observations of the changes in the chemistry of the oceans, more research is needed. Priorities include, linking observed changes in chemistry with biological responses, which will require both field and laboratory studies of changing environmental conditions and biological responses, against a backdrop of increasing temperature, deoxygenation, and changing carbonate chemistry. More effort is needed to expand effective monitoring, especially in complex and dynamic coastal systems, where often the current values and short-term variability in the carbon chemistry are unknown, let alone the biological responses of species and ecosystems. New methods and technologies are needed that make the process of data gathering simpler, cheaper, and thereby making the ability to take ocean acidification measurements more easily achievable and by a wider representation around the globe. Better integration of different observing strategies (satellites, oceanographic cruises, buoys, and models) will enhance both global and local knowledge. There is also work to be done in ensuring that high quality data are not only collected, but are also managed in a way that promotes visibility and access. Alongside training, this can increase the global capability to undertake quality observations and understand the underlying drivers and consequences of OA.

GOA-ON and IOC work together very closely to close the capacity gap, that is the current uneven status in the world's capacity for conducting ocean acidification research. The GOA-ON experts are jointly working with the IOC Secretariat to help Member States to conduct ocean acidification measurements and to detect the impacts of ocean acidification to inform the development of strategies to adapt to and mitigate ocean acidification.

Observations must also lead to a greater predictive capability that can advise society and decision makers. For instance, conservation policy and strategy need to incorporate predicted future pressures to provide climate smart marine protected areas and adapt fisheries management plans. It is of the utmost importance that observations fit regional and local needs for adaptation and mitigation to allow an informed understanding of the consequences for species, ecosystems, and associated services. This requires that monitoring strategies and implementation work closely together with the development of better biological understanding.

5. What are the biggest knowledge gaps that society must address, and in which it must invest, in order to make informed decisions on adaptation and mitigation of ocean acidification?

There are several areas in which the scientific community has identified knowledge gaps; we detail four of these below. In short, there are large geographic gaps in the open ocean which could be filled by autonomous observing systems with further development. In more dynamic coastal waters, there is a substantial need for addressing local long term observational and knowledge gaps to inform both capacity needs, potential local solutions, and local/regional decision making. And across both open and coastal systems, increased focus on understanding biological responses to ocean acidification, and multiple stressors that can amplify its effect, is needed. Lastly, this work must be conducted through an equity lens, which is currently lacking.

GOA-ON and our Decade Programme, OARS (Ocean Acidification Research for Sustainability - Providing society with the observational and scientific evidence needed to sustainably identify, monitor, mitigate and adapt to ocean acidification; from local to global scales), together with our partners, are uniquely placed to identify scientific needs and gaps, which enable GOA-ON to develop strategies to meet these needs, and to provide an assessment of the state of ocean acidification and its impacts, based on the strength of the global network and regional hubs. OARS will, over the coming Decade, increase capacity building efforts to ensure more high-quality observations take place at the relevant temporal and regional scales to permit informed decisions on ocean acidification mitigation and adaptation processes on global, regional, and local levels, while producing data to further the global understanding of ocean acidification processes, its drivers and future scenarios.

Further details on these major gaps are provided below.

a) Global ocean assessment: Large observing and knowledge gaps have been identified in the open ocean and especially in the Southern Hemisphere (the ocean hemisphere!) and in island nations, where research funding to date has been lacking compared to the investments and research infrastructure in the Northern Hemisphere. Other remote areas include the polar ocean, especially where sea ice is retreating due to warming, island nations, particularly those with high dependencies on coral reefs, and the deep ocean. Capacity building and application of autonomous observing platforms to fill these gaps are a high priority area of investment. The required observations cannot be based on pH alone; measuring ocean acidification relies on measuring the full carbonate system, which needs temperature, salinity, oxygen, and nutrients also. Further, observations should be placed in context of other ocean-scale phenomena like El Niño, North Atlantic Oscillation, etc. Lastly, sustainable funding for sustained global observations and flow of information to both detect change and inform adaptation/mitigation strategies is required globally.

b) Coastal systems and society: The highly dynamic nature of coastal seas, and the great pressure they are under from land based and anthropogenic influences, make it particularly important to understand their natural variability and to predict the effects of ocean acidification on these systems. In these dynamic coastal waters, there is a substantial need for addressing local long term observational and knowledge gaps to inform both capacity needs, potential local solutions and local/regional decision making. Engaging with local and regional scientists and government agencies to add ocean acidification training would be effective at bridging this gap. Additionally, it is crucial to determine how specific climate-ready marine system management strategies can reduce existing environmental stresses and maximize the resilience of ecosystems to ocean acidification, information on which is currently unavailable. Operational models could support and complement long term observational programs in this area. There is also a relative lack of knowledge on system feedbacks, changing extremes, and interactions between natural variability and anthropogenic CO_2 forcing.

c) Biological response: Large knowledge gaps exist on the biological responses to multiple stressors including acidification, deoxygenation, increasing sea surface temperatures, and climate change. This gap requires combined chemical/biological studies within the GOA-ON observing system coupled with focused laboratory and modeling studies of these processes.

d) Focus on equity: More knowledge is needed to assist smaller and developing countries in gaining an understanding of ocean acidification in a global context and to incorporate policy around ocean acidification adaptation and mitigation strategies with other environmental policy measures. It is a challenge to assist countries with limited resources to make informed decisions on environmental threats, including ocean acidification and other ocean stressors, especially if there are not enough local observations to base these strategies on. The Sustainable Development Goal (SDG) 14.3.1 Indicator Methodology provides researchers and governments with guidance on how to conduct ocean acidification observations, what to measure and how, and which data to submit towards this global effort to "*Minimize and address the impacts of ocean acidification, including through enhanced scientific cooperation at all levels*". Governments can work towards achieving this goal by developing their capacity for ocean acidification observations and providing funding for training and equipment. GOA-ON will continue to support these capacity development efforts, including through OARS. Financial support, however, will be required on national and regional scales to support sustained observations and to enable the development of appropriate adaptation and mitigation strategies.

The GOA-ON community interacts closely with a range of other networks and efforts focused on ocean carbon research, ocean observation and climate change; among these partners are the Integrated Ocean Carbon-Research (IOC-R), the Surface Ocean CO_2 Atlas (SOCAT), the International Ocean Carbon Coordination Project IOCCP, the Integrated Carbon Observation System ICOS, the Global Ocean Observing System GOOS, the Marine Biodiversity Observation Network MBON and its Ocean Decade Action Marine Life 2030, as well as the Global Ocean Oxygen Network GO2NE and its Ocean Decade Action GOOD. All of these partners are essential to attaining the goals of GOA-ON and to deliver the objectives of the OARS programme.

Again, we express our thanks to you, your Excellency, for your leadership in this matter, which is so critical for more people to understand and act upon.

Sincerely,

Jan A. Newton, Senior Principal Oceanographer and Professor, University of Washington

Steve Widdicombe, Director of Science, Deputy Chief Executive, Plymouth Marine Laboratory

GOA-ON Co-chairs (on behalf of the GOA-ON members)