A WORD FROM OUR PARTNER

Introducing the International Quiet Ocean Experiment

New international research and observations of sound in the ocean and its effects on marine organisms

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Sound in the ocean arises from a variety of sources. Since Earth's ocean formed early in the history of the planet, sound from geological processes such as subsea earthquakes, volcanos, and landslides has reverberated sporadically through the ocean. Physical processes such as wind, waves, rainfall, and ice movements and cracking add sound to the ocean incessantly, though with fluctuating intensity and geography. Finally, organisms have evolved many ways of producing sounds in the ocean. Marine life contributes sounds ranging from the clicking of snapping shrimps, which can dominate coastal acoustic habitats, to the complex songs of whales. The animal sounds have varied over time, differed in various locations, and probably waxed and waned over Earth's history as diversity, distribution, and abundance of different types of organisms have changed.

Very recently in terms of the history of sound in the ocean, humans have added new sounds. In the beginning, these sounds were concentrated near shore, extending into the open ocean as humans began to exploit marine resources and travel over the ocean surface for commerce and national defense, and explore and extract minerals on and beneath the seafloor.

Because hearing has evolved as the dominant sense in many marine animals, concerns have arisen over the potential for human-added sound to compete with natural sounds to which marine animals have adapted over their evolutionary histories. Since observations began around the time of World War II, scientists have observed that sound levels have increased, for example in the northeast Pacific Ocean. However, our knowledge of trends in ocean ambient noise is poor because we have measured sound over time in very few locations, and have not yet standardized procedures for measurement and analysis.

Frequency (or pitch) of sounds in the ocean is important to consider. Lower frequency sounds are absorbed less by seawater and travel further than higher frequency sounds. Different marine animals hear different frequencies, just as land animals, where dogs can hear sounds at higher frequencies and elephants at lower frequencies than can humans. In the ocean, dolphins, porpoises, and sperm whales are high-frequency specialists, and large baleen whales are low-frequency specialists. The way in which most fish sense sound limits their hearing to low frequencies, but some fish have specialized adaptations that enable high-frequency hearing. Because scientists have measured the hearing capabilities of very few marine species, generalizing or predicting how increases in sound levels affect all animals or marine, beyond very broad statements about risk, is not yet possible.

Development of the International Quiet Ocean Experiment

From 2000 to 2010, ocean scientists successfully carried out a coordinated international investigation of diversity, distribution, and abundance of marine life called the Census of Marine Life, involving hundreds of expeditions spanning near shore to mid-ocean, seafloor to sea surface, and microbes to mammals. As the Census came to a close, one of its founders, Jesse Ausubel (Rockefeller University, New York City), contended that studies of global change neglected sound in the ocean. Documenting what was known and needed to be learned about sound in the ocean would be timely, because ocean sound is increasingly regulated worldwide with meager knowledge. Ausubel helped raise funds to convene an international meeting of scientists who study sound in the ocean and its effects on marine organisms to explore what research and observations should be undertaken to improve our understanding. This meeting resulted in a plan for a new international research program called the International Quiet Ocean Experiment (IQOE).

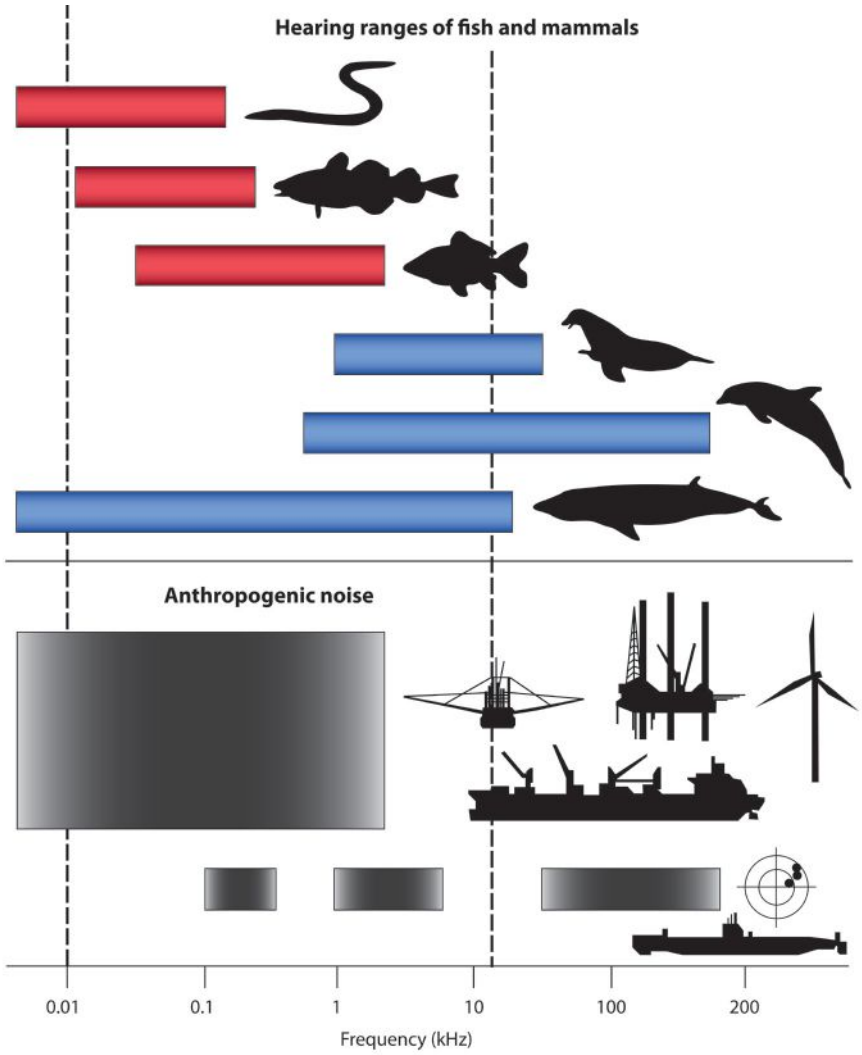

Figure 1. Diagrammatic representation of the overlap between the hearing ranges of different kinds of fish and mammals and the frequency of sound produced by different human-generated sources. Reproduced from Slabbekoorn, H., N. Bouton, I. van Opzeeland, A. Coers, C. ten Cate, and A.N. Popper. 2010. A noisy spring: The impact of globally rising underwater sound levels on fish. Trends in Ecology & Evolution 25:419-427.

Underlying IQOE are five fundamental questions:

1. How have human activities affected the global ocean soundscape compared with natural changes over geologic time?
2. What are the current levels and distribution of sound in the ocean?
3. What are the trends in sound levels across the global ocean?
4. What are the current effects of human sound on important marine animal populations?
5. What are the potential future effects of sound on marine life?

The Scientific Committee on Oceanic Research (SCOR) and the Partnership for Observation of the Global Ocean (POGO), who sponsored the meeting with the Intergovernmental Oceanographic Commission (IOC), agreed to incubate the IQOE and subsequently foster the program.

IQOE Implementation

SCOR and POGO formed a 10-person IQOE Science Committee, which met in 2016, 2017, and 2018 to begin implementation. Early action of the Science Committee formed working groups of experts on issues important across the project, such as data management and

standardization of measurements, and groups made up of specialists for areas in which studies of ocean sound are particularly urgent, such as high-biodiversity areas and the Arctic Ocean.

The **IQOE Working Group on Acoustic Measurement of Ocean Biodiversity Hotspots** is reviewing the usefulness of sound as a tool to monitor diversity of animals in areas such as kelp forests and coral reefs. Hydrophones can continuously monitor these areas non-invasively to learn about cycles and patterns, complemented with visits by scuba divers and other kinds of survey teams to assess biodiversity visually. See the working group webpage at www.iqoe.org/groups/reefs.

The **IQOE Working Group on Arctic Acoustic Environments** is focusing its initial efforts on locating historical data on ambient sound in the Arctic Ocean, where climate is changing especially rapidly, and identifying observing systems that could be quickly and affordably enhanced with acoustic sensors. See the working group webpage at www.iqoe.org/groups/arctic.

The **IQOE Working Group on Standardization** will convene a workshop on "Guidelines for observation of ocean sound" to develop international guidelines for IQOE based on practices implemented by IQOE-endorsed projects and national committees. See the working group webpage at www.iqoe.org/groups/standardization.

The **IQOE Working Group on Data Management and Access** will cooperate with the other IQOE working groups to determine how best to create a global database of ambient sound to which it is easy to contribute observations, and which forms a reliable and accessible archive. See the working group webpage at www.iqoe.org/groups/data.

In 2016, IQOE began endorsing national and regional projects that contribute to the accomplishment of IQOE's objectives. Five projects have been endorsed so far:

ADEON: Atlantic Deepwater Ecosystem Observatory Network — ADEON is gathering time series of acoustic and environmental data (space-based remote sensing, hydrographic sensors, and biologic sensors) over multiple years to better understand how human, biologic, and natural abiotic components create the soundscape and ecosystem dynamics of the Outer Continental Shelf off the southeastern United States.

JOMOPANS: Joint Monitoring Program for Ambient Noise North Sea — JOMOPANS aims to develop a framework for a fully operational joint monitoring program for ambient sound in the North Sea to provide the tools necessary for managers, planners, and other stakeholders to incorporate the effects of ambient noise in their assessment of the environmental status of the North Sea, and to develop measures to improve it.

JONAS: A Joint Program for Ocean Noise in the Atlantic Seas — JONAS aims to assess the risks of sound on biodiversity, focusing on sensitive species in the northeast Atlantic Ocean by streamlining ocean noise monitoring and risk prediction. Cost effective, risk-based approaches to monitoring and modeling noise will be developed.

PHYSIC: Ports, Humpbacks, Y Soundscapes In Colombia — PHYSIC is performing a Before-After Control-Impact (BACI) study of ambient sound and humpback whale vocalizations related to port construction in Colombia.

TANGO: Rerouting shipping lanes in the Kattegat, effects on soundscape and ecosystem — Maritime authorities in Sweden and Denmark have proposed a rerouting of the main shipping routes into the Baltic, scheduled for 2020. This creates a unique opportunity to study the effects of ship noise in a shallow sea. A range of parameters will be measured in the existing shipping lane, the

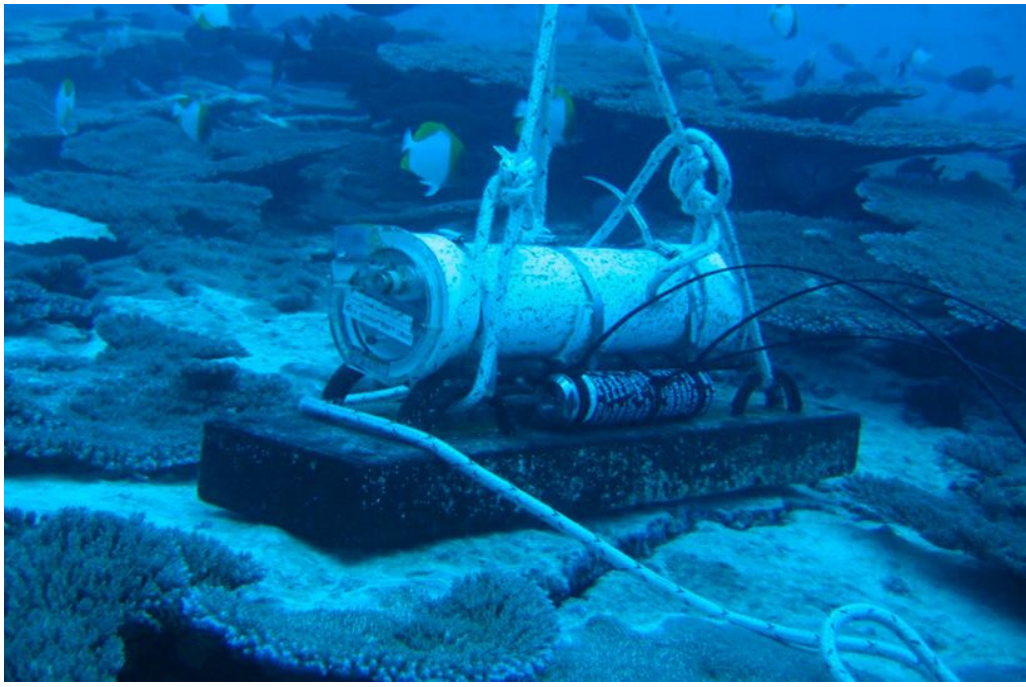

Figure 2. Ecological Acoustic Recorder (EAR). Such hydrophones form part of the tool kit of the IQOE Working Group on Acoustic Measurement of Ocean Biodiversity Hotspots. The U.S. National Oceanic and Atmospheric Administration deploys EARs at several sites around the Pacific Ocean to monitor the biology of reefs.

new shipping lane and reference areas away from the shipping lanes, for at least one year prior to rerouting, to establish a baseline, and at least one year after the change.

Selected IQOE Accomplishments

The first major accomplishment of IQOE was to bring together the ocean acoustics and bioacoustics communities in a large open science meeting in 2011 to determine what research, observations, and modeling would benefit from an international approach to improve our understanding of sound in the ocean and its effects on marine organisms. From this input and with extensive review, a leadership team developed the IQOE Science Plan and published it in 2015 with endorsements of POGO and SCOR (see www.iqoe.org/sites/default/files/files/IQOE_Science_Plan-Final.pdf).

Subsequently, IQOE worked with the Biology and Ecosystems Panel of the Global Ocean Observing System (GOOS) to develop specifications for an Essential Ocean Variable (EOV) for Ocean Sound. EOVs are being developed by the three GOOS panels to help national operators of ocean observing assets to implement observations in a coordinated and standardized manner. The POGO IQOE Working Group led the development of the Ocean Sound EOV, which GOOS approved in mid-2018. IQOE leaders have participated extensively in preparation of the acoustic dimensions of the OceanObs'19 conference, which aims to set priorities and increase resources for the next decade of ocean observing.

IQOE has developed a website that provides project information, as well as serving as a resource for the global community of ocean acousticians and bioacousticians (see www.iqoe.org/). The IQOE website includes a searchable database of publications related to ocean sound (currently with 4,689 references), an overview of international standards relevant for ocean sound monitoring, portals to databases of sound in the ocean and animal sounds in the ocean, observing systems, and meetings related to IQOE goals.

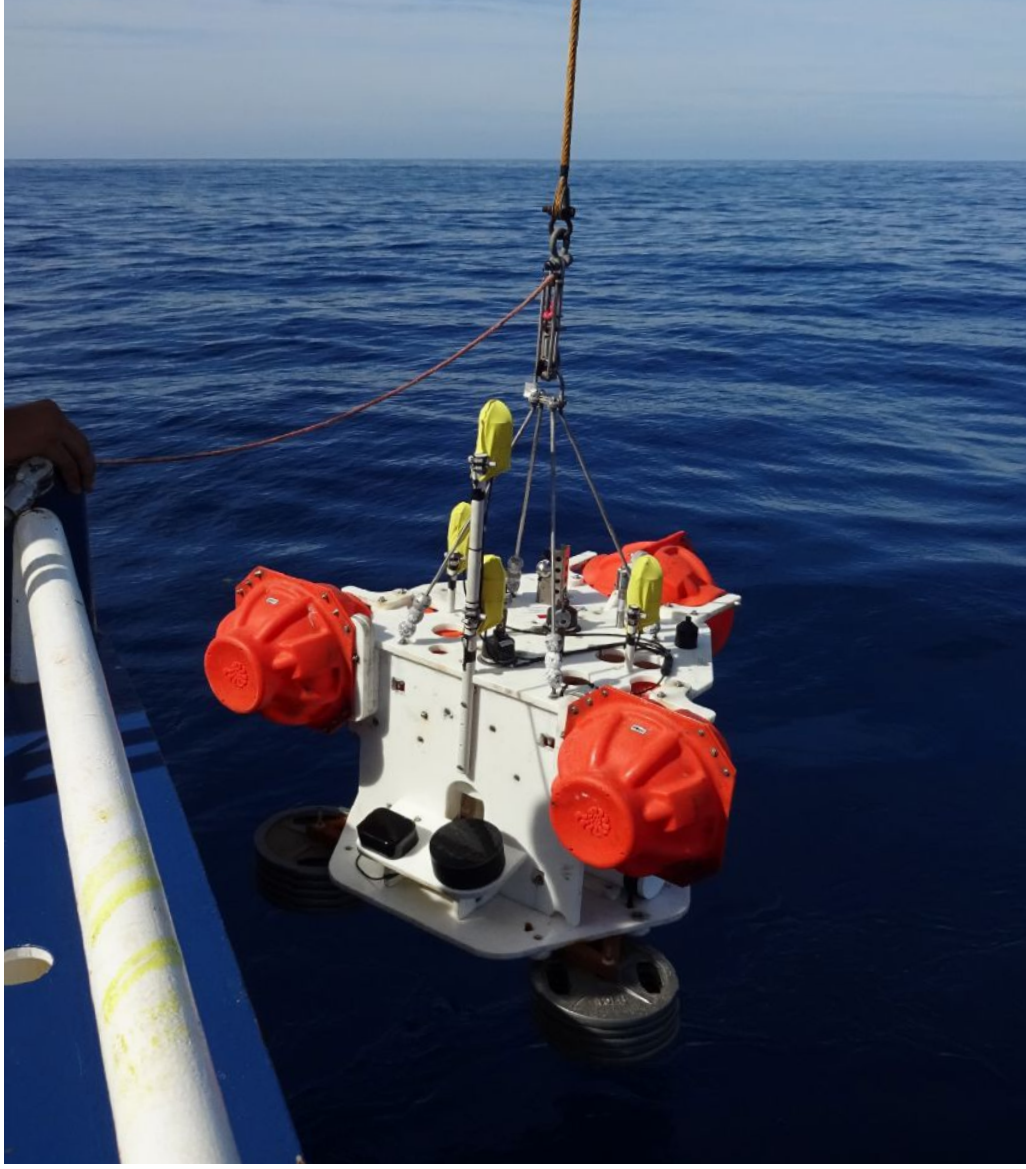

Figure 3. Deployment of ADEON bottom lander. Seven of these landers have been deployed along the Atlantic Coast, from Virginia to Florida, three in shallow waters < 400 m and four in deeper water > 400 m. All landers have passive acoustic and physicochemical sensors; the shallow landers also have been equipped with an Acoustic Zooplankton Fish Profiler system of echosounders. These landers will provide continuous data for ambient sound, sounds made by organisms, physical and chemical properties of seawater, and (for shallow landers), abundance of zooplankton and fish between the lander and the ocean surface.

Plans for the Future

Still early in its implementation, IQOE is building a foundation for its future activities and welcomes ideas and partners. During 2019, IQOE working groups will begin releasing publications related to their tasks and will build out their parts of the project. Where appropriate, the groups will create summaries for policymakers that will present the most current knowledge about ocean sound in non-technical terms. IQOE plans to hold a workshop during 2020 to continue implementation of the Ocean Sound EOV. IQOE will endorse additional projects which IQOE can help to grow and which help accomplish IQOE's scientific objectives.

Later in the program, IQOE's participants envision an unprecedented period of intense international attention to ocean sound research and observations, for example, an International Year of the Quiet Ocean, in which coordinated, standardized measurements are made worldwide, in quiet and noisy locations, to create a baseline global ocean soundscape.