International Quiet Ocean Experiment (IQOE)

Final Report to SCOR and POGO

Peter L Tyack, Scottish Oceans Institute, University of St Andrews, (UK)
Carrie Wall Bell, University of Colorado Boulder (USA)
Christ de Jong, TNO (The Netherlands)
Lise Doksaeter Sivle, Institute of Marine Research (Norway)
Tess Gridley, Sea Search and Namibian Dolphin Project (Namibia/South Africa)
Bruce Martin, JASCO Applied Sciences (Canada) Ltd.
Miles Parsons, Australian Institute of Marine Science (Australia)
Filipa Samarra, University of Iceland (Iceland)
Steve Simpson, University of Bristol (UK)
Karolin Thomisch, Alfred Wegener Institute (Germany)
Ed Urban, Scientific Committee on Oceanic Research (USA)

A project endorsed by

Foreword

This report from the International Quiet Ocean Experiment (IQOE) has emerged as a result of the foresight of scientists who have dedicated their time, energy, ingenuity and intellect to exploring a genuinely new frontier.

The IQOE emerged from that great well of originality which is the mind of Jesse Ausubel. Not only did he see the frontier that few others in the oceanography community appreciated but he also recognised that ignorance of what lay beyond that frontier meant that human activity could be inadvertently harming the ocean.

IQOE had, at its core, the hypothesis that humans were adding sound to the ocean and that this has the potential to change its biological structure. The transmissibility of sound in the ocean also means it can be used to sense the ocean and tell us much about its biological and physical properties.

The frontier in this case is being broken down by increasingly sophisticated autonomous and intelligent technology for detecting, filtering and classifying sound sources. It involves signal processing of prodigious amounts of data across multiple dimensions.

But it is also a frontier set by our cognitive capabilities. Whereas we are tuned to a diurnal existence, using light both passively and actively to manage our dynamic relationship with the environment, many ocean organisms are tuned to see the world in sound rather than light. Whether they see colour in sound in the same way as we see it in light is a question with deep philosophical meaning. Certainly, just surveying sonograms from the biological components of ocean soundscapes creates a whole new appreciation of biodiversity.

IQOE has begun to open our eyes to subjects as diverse as the nature of perception and the warming of the planet. But establishing a new seam at the coal face of oceanography when there are so many other important areas to study was never going to be easy. Historically, ocean sound had sat in the domain of the secretive submarine warfare community. Just the idea of “tuning in” to the ocean soundscapes has had to deal with multiple sociological and political hurdles.

This report is very honest about where progress has been made and where more work needs to be done. At the outset, IQOE had all the right ambitions and these have necessarily had to be clipped to fit reality, but it is the legacy which is important. Ocean sound, even if not yet quite mainstream relative to other traditional fields of oceanography, is now well on its way to being so.

IQOE naturally evolved into a programme shaped to support an emerging field. The networks of researchers which have been created and the boost in capability, like the low-cost acoustic recorders and multiple collaborative initiatives to share data and software, create the essential legacy. Before IQOE, it might have been a stretch to identify an ocean acoustics research community. Now, that has changed.

IQOE has been a huge achievement. By opening our eyes to the richness of the world around us it is a great illustration of why I think we all get involved in doing research.

Ian Boyd
Founding IQOE Co-chair

Executive Summary

IQOE was a decadal program (2015-2025) devoted to global ocean passive acoustic observations and research. The IQOE Science Plan (Tyack, 2015) stated that IQOE would address 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 anthropogenic sound in the ocean?
3. What are the trends in anthropogenic sound levels across the global ocean?
4. What are the current effects of anthropogenic sound on important marine animal populations?
5. What are the potential future effects of sound on marine life?"

Sound is the best way to sense sources that are far away in the ocean because sound propagates so much better than electromagnetic radiation in seawater. Humans focused on underwater sound for distant sensing in the 20th Century when national navies developed acoustic methods to detect ships. However, marine animals evolved sophisticated underwater hearing millions of years ago to take advantage of sound in the ocean. As biologists came to appreciate the important role that sound plays for marine life, it became clearer that anthropogenic noise may pose a risk. Payne and Webb (1971) raised the first concern about the effects of anthropogenic sound on marine life. They calculated that low-frequency calls of fin whales could have been detected >250 km away in a pre-industrial ocean but would only be detected 82 km away in average noise of motorized shipping. Their calculations were hindered by lack of good data on trends and distribution of ocean sound and the sources that produce them. IQOE aimed to reduce these data gaps, many of which still persisted at the beginning of the project in 2015.

Hundreds of projects have studied how marine animals react to the experimental playback of sound, but IQOE recognized the lack of studies on the effect of reducing noise. The name IQOE stems from a central goal – an International Year of the Quiet Ocean (IYQO) – which would focus on studying the effects of reducing sound from an ecosystem perspective and longer time and spatial scales than contemporary research. Changes in human activities due to COVID-19 ended up producing our IQYO; Tyack et al. (2021) describe how IQOE helped prepare researchers to develop a global network of ocean sound observations to document changes in ocean sound during IQYO and the ecosystem effects of these changes.

IQOE achieved the following outcomes:

- Fostered an international community of ocean acousticians and bioacousticians helping to achieve IQOE aims
- Provided an authoritative body to endorse national and regional projects
- Compiled an international metadatabase of passive acoustic observations
- Advanced the use of bioacoustic metrics for marine biodiversity and the development of GLUBS
- Declared 2020 as the Year of the Quiet Ocean to promote analysis of the effect of the COVID-19 pandemic on ocean sound and on effects of COVID quieting on marine life
- Developed and beta-tested a prototype low-cost ocean acoustic recording system
- Proposed Ocean Sound as an Essential Ocean Variable, accepted by the Global Ocean Observing System, and developed an implementation plan for this EOV
- Developed the MANTA software platform and encouraged the development of the OPUS data portal
- Publicized ocean sound to the wider scientific community and public as an important global change issue
- Helped build new capacity for ocean acoustic observations among early career scientists and in developing countries

These achievements are discussed in greater detail in the IQOE Outcomes section below. Some of the initial goals of IQOE were not met, in large measure because it was not possible to raise enough funding for the scale of global fieldwork initially envisioned. However, the global ocean acoustics community that was brought together by IQOE is interested in continuing a series of working groups based upon many of the IQOE outcomes. Here is a list of some of the working groups planned that should continue beyond IQOE:

- Implementation working group for the Ocean Sound EOV
- Working group to manage a global network of ocean sound observations
- Working group to develop calibrated scientific acoustic recorders for GOOS platforms
- Working groups for characterizing biological, physical, and human sound sources and acoustic metrics for marine biodiversity
- Working group for capacity building including training with low-cost recorders
- Working group to maintain the flow of information across the global interdisciplinary community brought together by IQOE to stimulate curiosity-driven research, and to focus applied research on resolving critical societal needs related to climate change, ocean health, and detecting threats, the themes of the Global Ocean Observing System

An international workshop is planned for September 2026 to chart how to implement these initiatives and to canvass the community for other activities that are important to maintain or develop for ocean sound research and observations.

Introduction

Origin of IQOE

Like most international projects, the International Quiet Ocean Experiment (IQOE) was developed over a period of several years. In 2009, Jesse Ausubel of Rockefeller University noted in a commencement address that international programs on global environmental change had neglected changes in light and sound pollution resulting from increased human activity worldwide (Ausubel, 2009).

Ausubel had been a major driver of a decadal program (2000-2010) on marine biological diversity called the Census of Marine Life. Ausubel believed that ocean sound had not been properly addressed as an element of global change, and that decreasing human sound in the ocean could help us learn more about the effects of sound on marine organisms and benefit both the organisms and sustainability of stakeholders who add sound to the ocean.

A systematic approach was used to develop the IQOE idea, starting with an exploratory meeting, followed by a large open science meeting. The Scientific Committee on Oceanic Research (SCOR) and the Partnership for Observation of the Global Ocean (POGO) convened an exploratory meeting in 2010 at the University of Rhode Island, supported by the Alfred P. Sloan Foundation, to discuss the need for an international project to document sound levels in the ocean, whether sound levels are changing and, if so, what impact such changes might have on marine organisms. The outcome of this meeting was documented in a 2011 article in Oceanography magazine (Boyd et al., 2011). Meeting participants concluded that (1) it would not be practical or economically feasible to shut off ocean sound worldwide for a long-enough period to observe changes in the behavior of marine organisms, (2) there could be benefit in a major new research project to study sound in the ocean, and (3) an international open science meeting should be held to broaden input of the global scientific community to determine whether a new research project should be started and, if so, to identify the aims of the project.

SCOR and POGO convened an open science meeting in 2011, hosted by UNESCO's Intergovernmental Oceanographic Commission (IOC) at UNESCO Headquarters in Paris, France.

Approximately 150 individuals participated in the meeting. Outputs from the meeting were crafted into an IQOE Science Plan, published as Tyack et al. (2015), which served as the launch point of IQOE.

Mode of Operation

IQOE was guided by an international Science Committee (SC) of 10 members, with a project manager provided by SCOR and assisted by the POGO Chief Executive Officer. In 2016, the SC selected an initial set of working groups that supported the project's goals. The initial working groups were augmented later by additional working groups and task teams identified by the SC. IQOE working groups and task teams facilitated the critical need to convene more specific expertise around certain topics and to broaden participation from the global community. The IQOE SC and staff communicated regularly with SCOR and POGO and the executive directors of these organizations. Annual presentations were made at POGO and SCOR meetings.

Less financial support than originally envisioned limited the development of all aspects of the IQOE science plan, leading to increased focus on other opportunities

IQOE is the first fully global project on ocean acoustics and bioacoustics. It was originally envisioned as an international project that would attract significant financial resources (millions of USD) to conduct international field research and observations. The project would be staffed by one or more full-time professionals. As time progressed, this financial expectation was not met, which made it impossible to implement the field program laid out in the IQOE Science Plan (Tyack et al., 2015). The lack of funding for staffing also hindered the project's scope and outcomes. However, despite the limitations of modest funding, IQOE has been able to contribute to the fields of ocean acoustics and bioacoustics in several significant ways, which will be described in this report. After development of the IQOE Science Plan, the IQOE Science Committee conducted its work through several working groups to address particular needs (e.g., standardization and calibration) or to focus on specific regions (e.g., the Arctic and areas with high biodiversity), which made it possible to involve a greater cross-section of the global ocean acoustic community. The project also evolved to include passive acoustic observations and metadata.

Offshore energy and shipping companies, along with other maritime industries that have an interest in the mission of the IQOE, were reluctant to support research that might affect their operations. Initial successes in relations with the International Maritime Organization and maritime industries were set back by the COVID-19 pandemic. During COVID, many organizations retreated into themselves and focused simply on survival. While the U.S. National Oceanic and Atmospheric Administration (NOAA) and other national ocean agencies followed the program with interest, no national agency became its champion in the intergovernmental arena or provided funding for project activities. As mentioned, the modest funding and lack of staffing were challenging. Happily, the IQOE did not run into difficulties with either environmental activist groups or national navies. IQOE development was timely in that it coincided with the increasing deployment of non-military ocean acoustic recorders, and IQOE may have stimulated this process. A key focus of IQOE was studying the effects of sound on marine life by subtracting rather than adding noise, both through "natural experiments" (periods when human and other sources of noise greatly diminish, as after a major storm) and potentially through an organized period of time during which human sources might be minimized in some areas.

IQOE focused on ocean sound as an environmental variable that could be observed through passive acoustic observations, that is, listening to sound rather than "active acoustics," which injects sound as a tool to study the ocean (e.g., sonars). Thus, IQOE did not experience opposition from environmental advocacy groups that acoustic tomography experiments encountered in the past. IQOE faced neither opposition nor much cooperation from national navies, as most participants have been non-military acousticians. Lacking funding for field research and observations, IQOE focused on standardization, calibration, software development, and digital libraries. More informatics infrastructure, as well as the development and acceptance of an Ocean Sound Essential Ocean Variable (EOV) were needed before an aggressive, widespread field program could be implemented.

IQOE directly contributed to and/or encouraged the development of the Making Ambient Noise Trends Accessible (MANTA) software platform (Miksis et al., 2021), the Open Portal to Underwater Soundscapes (OPUS), and the Global Library of Underwater Sounds (GLUBS).

What made progress possible? Several factors worked together to help IQOE advance specific areas of ocean acoustics since 2015:

- Cooperation from the global community of hundreds of scientists who participated in the IQOE Science Committee, working groups, task teams, workshops, and other related activities. All international projects rely on scientists to volunteer their time to carry out project work and advocate for the project to funding agencies. Through continued demonstration of its value, IQOE developed a critical mass of human resources.
- Sustained annual financial support from SCOR and the Lounsbery Foundation to hold meetings of the IQOE Science Committee. SCOR also provided part-time staff support for IQOE, funded a working group for the Global Library on Underwater Biological Sounds (GLUBS) and contributed to the development of low-cost ocean acoustic recording systems.
- Targeted support from POGO on more observational aspects of IQOE, including development of specifications for an Ocean Sound Essential Ocean Variable (EOV, https://goosocean.org/document/22567), development of the Ocean Sound EOV Implementation Plan (Tyack et al., 2023), and development of a low-cost ocean acoustic recording system.
- Targeted support from the Richard Lounsbery Foundation and the Monmouth University/ Rockefeller University joint marine initiative for specific IQOE purposes, which will be discussed in greater detail below: (1) development of the MANTA software platform, (2) development of GLUBS, (3) data collation and analysis for the World Ocean Passive Acoustic Monitoring (WOPAM) Day, (4) implementation of an online library of ocean acoustics and bioacoustics papers, and (5) supporting open access for the book *Exploring Animal Behavior Through Sound:* Volumes 1 and 2, in electronic form.

IQOE Outcomes

As mentioned above, some of the original IQOE goals were not fully met, and in other areas such as standardization, IQOE working groups could transition to appropriate venues such as ISO. IQOE also stimulated a series of outcomes that were not fully predicted at the outset and that have changed the field, growing and strengthening the ocean acoustics community, and expanding the temporal and spatial scope of ocean acoustic research. Here we provide more detail on several of these outcomes. Most of these would not have occurred either as soon, or at all, without the work of IQOE.

Fostered an international community of ocean acousticians and bioacousticians

In 2015, there was no global network of passive acoustic monitors nor a coordinated international research community for ocean acoustics or bioacoustics. This gap served as a motivation for IQOE, but hindered its progress. Ocean acoustics tends to be organized nationally, rather than internationally, due to the historic role of ocean acoustics in national security. Research on sound in the ocean also has funding sources and scientific communities that are fragmented and isolated across different disciplines. In some ways, IQOE may have been established too early, in that the ocean acoustics and bioacoustics communities had so little experience in working together globally. On the other hand, IQOE provided a catalyst to help these communities work together by providing a platform for international cooperation and by advocating for inclusion of acoustic measurements in national, regional, and global ocean observing systems and encouraging the next generation of leaders in this field. The IQOE Website (www.iqoe.org) and global distribution of 15 IQOE Newsletters (https://www.iqoe.org/newsletters), provided a means to connect and center the international scientific community around IQOE goals and to disseminate information about the activities of endorsed projects. IQOE has also held online workshops — on acoustic observations in the Arctic Ocean and on the development of low-cost hydrophones and recorders — to engage the broader international

community in IQOE activities. These were especially important activities during the COVID-19 pandemic, when the ability for scientists to meet in person was significantly reduced.

The fields of ocean acoustics and bioacoustics are relatively “stovepiped” at national and even regional scales, but also in terms of the scientific meetings at which the topics are discussed, academic departments, journals, funding sources, and other factors. To address this, IQOE promoted and facilitated acousticians to reach out actively to the broader oceanographic community, for example, through articles in Oceanography magazine (Boyd et al., 2011) and Eos (Tyack et al., 2021). IQOE designed the Ocean Sound EOV as a cross-disciplinary EOV that measures a physical variable—sound—which provides information on abiotic variables that are important climate variables, such as rain, wind, and sea ice, as well as biological variables that are important for studying ocean health, and sound-producing threats such as earthquakes and explosions. The development of the EOV and its implementation plan have brought together a broader array of ocean acousticians from academia, government and industry than usually work together.

Endorsed national and regional projects

IQOE implemented a process to endorse national and regional projects, providing letters that were submitted as part of the project proposals, indicating that the projects were consistent with IQOE goals and activities. IQOE also endorsed already approved projects that were relevant to IQOE. Ten projects were endorsed, mostly before the projects were approved:

1. ADEON (Atlantic Deepwater Ecosystem Observatory Network)
2. DEMASK (Development and Evaluation of noise MAnagement Strategies to Keep the North Sea healthy)
3. JOMOPANS (Joint Monitoring Programme for Ambient Noise North Sea)
4. JONAS (A Joint program for Ocean Noise in the Atlantic Seas)
5. NRS (NOAA/NPS Ocean Noise Reference Station Network)
6. PHYSIC (Ports, Humpbacks, Y Soundscapes In Colombia)
7. QUIETSEAS (Assisting (sub) regional cooperation for the practical implementation of the MSFD second cycle by providing methods and tools for Descriptor 11 (underwater noise))
8. SanctSound (NOAA Navy Sanctuary Soundscape Monitoring Project)
9. SATURN (Solutions @ Underwater Radiated Noise)
10. TANGO (Rerouting shipping lanes in the Kattegat – effects on soundscape and ecosystem)

Endorsed projects raised their own support with no financial contributions from IQOE, but IQOE received feedback that endorsement had a positive impact on project approval for several projects. Endorsed projects were highlighted regularly in the IQOE Newsletter and on the IQOE Website, providing increased international visibility and information exchange related to the projects. Some regional projects—particularly ADEON and JOMOPANS—worked together to develop standards for processing acoustic data that helped to meet the goals of the IQOE standardization working group. However, not all projects reported back on their accomplishments in relation to IQOE goals. Given the difficulties IQOE encountered raising funds for global ocean observation, the regional monitoring programs such as ADEON, JOMOPANS, and SanctSound provide important regional observation networks that will help the GOOS Ocean Sound EOV as it moves from regional networks to implementing a global network.

Compiled a global list of passive acoustic observations

In 2015, IQOE drew attention to the absence of publicly available time series of underwater sound on ecologically important frequencies throughout the global ocean and to the difficulty of accessing the time series that do exist. Reports of data up to 2000, mostly from the northeast Pacific Ocean concluded that sound was generally increasing in this area (e.g., Ross 2005), but papers including more recent data have recognized that sound is not increasing everywhere and has actually been decreasing in some areas (Andrew et al., 2011; Miksis-Olds et al., 2013; Miksis-Olds and Nichols,

2016; Robinson et al. 2019, Ainslie et al. 2025). Since 2020, IQOE has compiled a metadatabase of ocean sound observations (Figure 1); a publication is under development to describe and publicize the metadatabase. The availability of a global metadatabase of PAM observations and establishment of a global network of ocean sound observations is vital for tracking changes in ocean sound, implementation of the Ocean Sound EOV, and better management of ocean sound to minimize any detrimental impacts on marine organisms. The compilation of locations of ocean sound observations also indicates the uneven distribution of sound recordings worldwide, particularly in the Southern Hemisphere.

The first World Ocean Passive Acoustic Monitoring (WOPAM) Day (8 June 2023) created a dataset of globally synchronized aquatic soundscape recordings from more than 100 partners in 34 nations at about 300 sites, from tropical islands to ice-covered seas (and included some freshwater ponds and rivers). The first WOPAM Day generated a large set of observations worldwide that might provide a useful snapshot of ambient ocean sound. WOPAM's global collaborative recording effort also engages diverse audiences to understand the importance of underwater sound around the world. The Lounsbery Foundation awarded a grant for a post-doctoral fellow to coordinate recording efforts, establish partnerships with conservation organizations, facilitate creative engagement with musicians and sound producers from many countries, and help analyze and publish the results of the 2023 WOPAM Day efforts. While this grant is not under the direction of IQOE, it was intended to contribute to the project's overall aims and objectives. A second WOPAM Day was held in 2024 and a third in 2025; the activity is envisioned to continue as an annual event. Participants in WOPAM Days are well positioned to become major participants in the future global ocean sound observing network. Through the multidisciplinary collaborations fostered by the WOPAM Project, such recording efforts have been used in creative educational exhibitions in The Deep Aquarium in Hull, UK, co-creation of original music compositions, and speaking opportunities at international events such as the United Nations Oceans Conference (2025). The WOPAM Project is thereby well situated to continue within its collaborative and multidisciplinary community which shares many goals with GLUBS and IQOE.

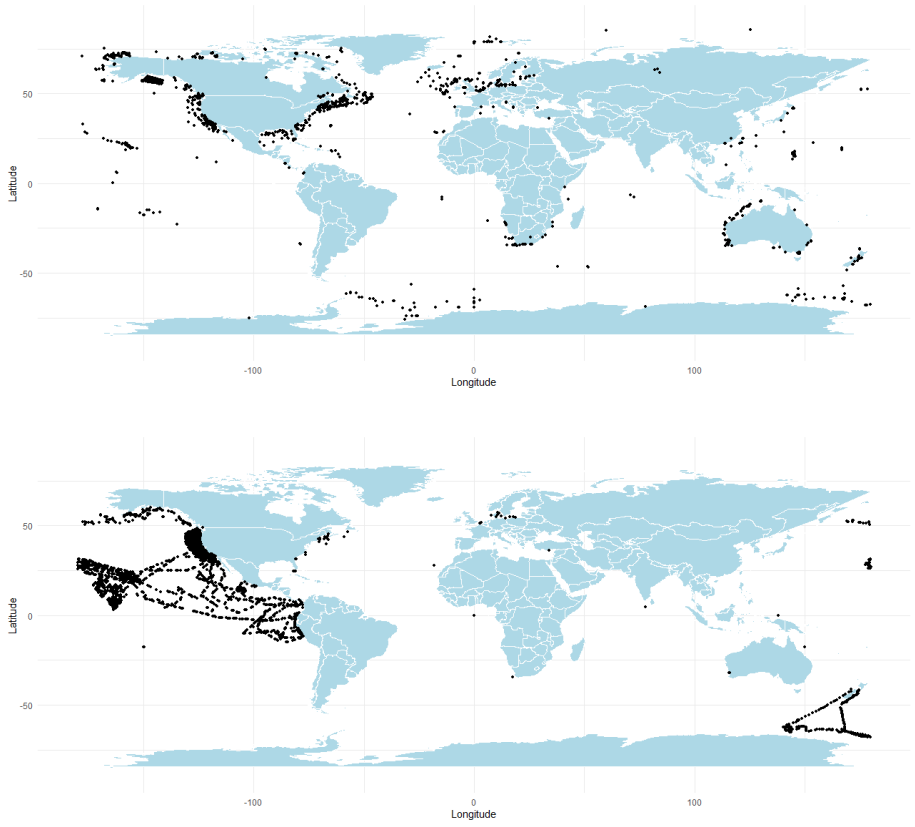

Figure 1. (Top) Map of all ocean observations in the IQOE PAM Metadatabase of 1 day or greater duration as of 30 April 2025, n = 4,893 records. (Bottom) Map of all ocean sound observations in the IQOE PAM Metadatabase of 1 day or less duration as of 30 April 2025, n = 99,879 records. Produced by Ed Urban, IQOE.

Advanced the use of bioacoustic metrics for marine biodiversity and developed GLUBS

The IQOE Working Group on Acoustic Measurement of Ocean Biodiversity Hotspots synthesized information about the usefulness of bioacoustic metrics for assessing marine biodiversity (Mooney et al., 2020). This same group developed the idea of a Global Library of Underwater Biological Sounds (GLUBS) (Parsons et al., 2022), to provide an online system to archive underwater biological sounds with the capability of classifying sounds from unknown sources (Figure 2). GLUBS worked to get species-specific sounds included in the World Register of Marine Species and the Ocean Biodiversity Information System (Looby et al., 2023; Figure 3). GLUBS also led a Research Topic in Frontiers of Remote Sensing on Detection and Characterization of Unidentified Underwater Biological Sounds, including 11 articles. These efforts could contribute to future activities to better understand the health and behavior of marine organisms, based on the sounds they produce. The use of passive acoustic monitoring to assess ecosystem functions has progressed during the IQOE years (e.g., Williams et al., 2025) and the availability of the IQOE PAM Metadatabase could help identify locations and times where recordings of ocean sound, including marine animal vocalizations, could contribute to machine learning efforts.

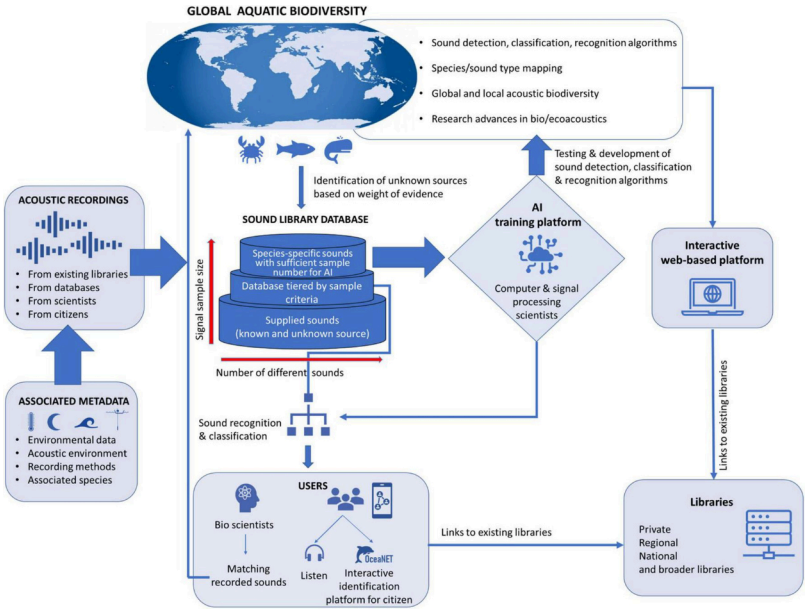

Figure 2. Structure of the Global Library of Underwater Biological Sounds. Adapted from Figure 2 from Parsons et al. (2022), "Sounding the call for a global library of biological underwater sounds," Frontiers in Ecology and Evolution, 10:810156, CC BY 4.0.

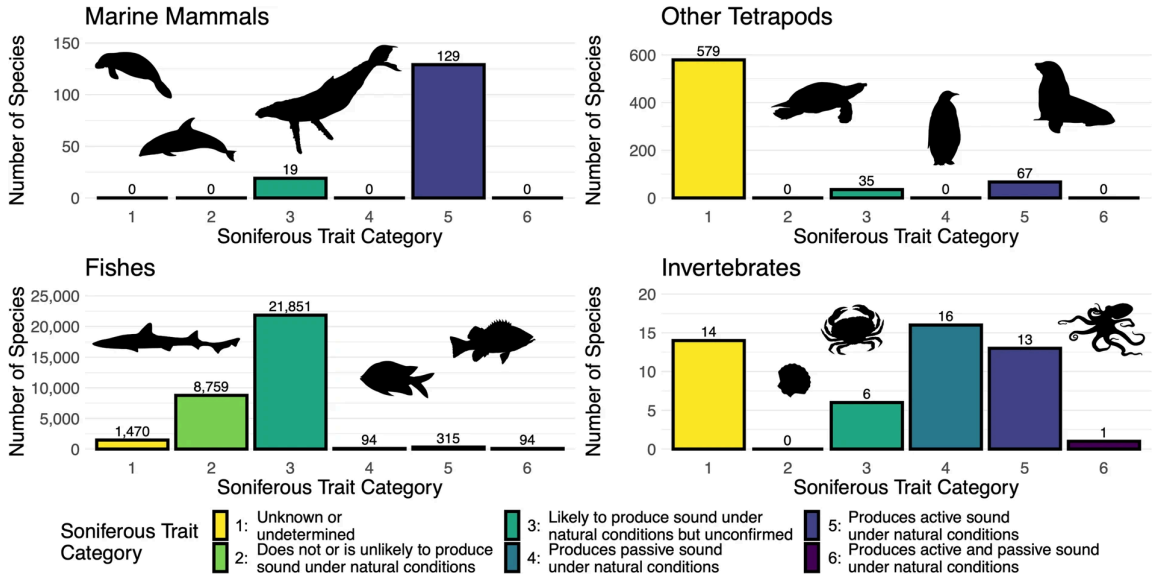

Figure 3. Bar graphs showing the number of aquatic and semi-aquatic species and subspecies placed in each soniferous trait category. The panels separate each taxa grouping, with images included to represent them. Figure 2 from Looby et al. (2023), "Global inventory of species categorized by known underwater sonifery," Scientific Data 10:892, CC BY 4.0.

Promoted the analysis of the effect of the COVID-19 pandemic on ocean sound

IQOE was first envisioned as a project to study the effects of decreases in ocean sound at basin scales, although no clear path was obvious for achieving this goal. Initial explorations suggested that intentional silencing of anthropogenic sounds in large regions of ocean would be prohibitively expensive and impractical. The peak of the COVID-19 pandemic in 2020-2021 provided a natural experiment that could demonstrate how changes in human activities would affect sound in the ocean. IQOE helped to stimulate ocean sound observations between 2015 and 2020, began compiling ocean sound observations early in the pandemic, proposed a special issue of Frontiers in Marine Science that hosted papers on the effects of the pandemic on ocean sound (Seger et al., 2021), and collated papers on the impacts of the pandemic on ocean sound (see https://iqoe.org/covid-pause-papers). IQOE leaders published a paper in the geoscience newspaper Eos to publicize the importance of acoustic observations collected during the pandemic that are useful for addressing problems well beyond the acoustics community (Tyack et al., 2021) and an opinion article in IPS News (Ausubel and Urban, 2021). IQOE has assembled a team of early-career scientists to produce a synthesis of available articles that reported on the effects of the COVID epidemic on ocean sound, including a qualitative analysis of those effects. Another article is planned to provide a more quantitative assessment of COVID impacts.

Developed and beta tested a prototype low-cost ocean acoustic recording system

IQOE convened an online workshop in late 2021 to explore the concept of low-cost ocean acoustic recording systems. Three virtual sessions were held over two days so that people could participate in live discussions during normal work hours from all around the globe. Workshop participants were particularly enthusiastic about two applications of lower-cost underwater acoustic recorders: (1) versions that could be calibrated and deployed widely as part of the Global Ocean Observing System, and (2) a less-expensive version that could be used for shorter-term deployments for research, education, and citizen science.

The availability of affordable underwater acoustic recorders will play a pivotal role in advancing marine bioacoustics, a field essential for understanding and protecting marine biodiversity. By deploying low-cost underwater acoustic recorders whose design will be freely available, widespread and sustained monitoring of underwater soundscapes can expand. This democratization of technology not only supports scientific research but also empowers communities of scientists and educators in developing regions, enhancing global participation in ocean monitoring and conservation.

IQOE and POGO launched a Task Team on Low-Cost Hydrophones for Research, Education, and Citizen Science in 2023 to promote affordable underwater acoustic recorders dedicated to research, education, and citizen science. Comprised of biologists, acousticians, engaged citizens, and engineers, the team has pinpointed key enhancements in underwater acoustic recorders to optimize their application in research, education, and citizen science applications.

The Task Team has designed and built a prototype system (Figure 4) that meets both technical specifications and user requirements for passive acoustic monitoring devices (Chapuis et al., 2024). This effort was aided by a survey of the community of potential users (see results). Ninety percent of 134 survey respondents believe that a low-cost system is necessary and a majority believe that the system should be calibratable.

The group plans to produce and distribute prototype systems to a selected group of beta testers including researchers, students, citizen scientists, conservationists. Feedback will be collected from beta testers to improve the design for a final, market-ready, open-source device. The Task Team will also establish a distribution platform and educational resources (including workshops and training sessions) to promote use of the device. SCOR and POGO have provided funding for the production of 25-50 prototypes for beta testing. The group hopes to attract an equipment producer to market the

systems, in an arrangement such as used for the AudioMoth by Open Acoustic Devices, to keep the design freely available.

Figure 4. (Left) Photograph of prototype low-cost underwater acoustic recorder and its waterproof housing. (Right) Photograph of prototype low-cost underwater acoustic recorder in situ. Figure from Lucille Chapuis, La Trobe University.

Adoption of Ocean Sound as an Essential Ocean Variable and Development of an Implementation Plan

The Global Ocean Observing System (GOOS) is designed to make measurements of essential ocean variables (EOVs) selected to provide data that are critical for meeting societal needs. The original list of GOOS EOVs did not include ocean sound despite its importance for understanding many ocean processes, including distribution and abundance of marine organisms and human impacts on these organisms, and also measurement of physical variables such as rain, wind over the ocean and sea ice. POGO supported an IQOE working group that suggested to the IQOE Science Committee (SC) that IQOE propose a specification sheet for an Ocean Sound EOV. The POGO-supported acoustic working group in 2016-2018 created a proposal for such an EOV. The specification sheet was adopted by GOOS in 2021 with the expectation that IQOE would oversee the development of this EOV. Following this approval, the IQOE SC set up a committee to produce an implementation plan, which was published in 2023 (Tyack et al., 2023). Progress in the development of the EOV within the GOOS framework can provide a major stimulus for nations to establish new observing programs for ocean sound. IQOE is currently planning activities to promote implementation of this EOV and it is important for a post-IQOE group to focus on implementing the EOV.

Supported the development of the MANTA software platform and encouraged the development of the OPUS data portal

An important need at the beginning of IQOE was a standardized analysis tool for processing acoustic waveforms to produce consistently processed, calibrated time series products of sound pressure levels in hybrid millidecade bands. This tool enables comparisons among soundscapes and identification of ambient ocean sound trends required by ocean stakeholders. The Lounsbery Foundation funded the development of the MANTA software package to achieve this goal (see https://bitbucket.org/CLO-BRP/manta-wiki/wiki/Home). Python Passive Acoustic Monitoring (PyPAM), developed after MANTA, provides an alternative tool to process underwater sound observations for some applications (see https://github.com/lifewatch/pypam).

The Alfred Wegener Institute for Polar and Marine Research in Bremerhaven, Germany designed and launched the Open Portal to Underwater Soundscapes (OPUS) to visualize and explore ocean acoustic data, including data processed using MANTA. OPUS does not rely on financial support from IQOE, but its design clearly contributes to achieving IQOE goals (see https://opus.aq/). The OPUS team has begun work to serve the IQOE PAM Metadatabase.

Publicized ocean sound to the wider scientific community and public as an important global change issue

Many of the environmental variables derived from ocean sound were virtually unknown to the public and much of the ocean science community at the beginning of IQOE. Efforts of IQOE (coincident with efforts from other sources, for example, the excellent Discovery of Sound in the Sea (DOSITS)) have increased the visibility of ocean sound issues. IQOE sponsored an issue of ECO magazine (Urban et al., 2019) and an opinion article in IPS News (Ausubel and Urban, 2021). Several news releases publicized ocean sound as an issue and IQOE's work to address this issue. Science and environment reporter Alice Huton wrote a long, lively and informative article for the UK Guardian newspaper about IQOE in May 2023 (https://www.theguardian.com/environment/2023/may/15/listen-to-a-toadfishs-grunt-ai-helps-decode-a-symphony-of-ocean-sounds). IQOE co-sponsored a workshop in 2018 with the Acoustical Society of America on "Approaches for Studying Effects of Sound on Marine Organisms and Ecosystems". A Wikipedia page was developed for IQOE (see https://en.wikipedia.org/wiki/International_Quiet_Ocean_Experiment) by Artash Nath, while a high school student in Canada.

Helped build new capacity for ocean acoustic observations among early career scientists and in developing countries

With regard to capacity building, GLUBS in particular has fostered a new generation of dynamic researchers and organizers. IQOE has helped boost the African Bioacoustics Community, networked from Sea Search Research and Conservation (Tess Gridley, South Africa). The activity on low-cost underwater acoustic recording systems will also be helpful in building capacity for ocean acoustics worldwide. A major goal of the planned ocean sound workshop in September 2026 will be to "pass the torch" to the next generation of acoustic scientists.

IQOE Achievements Measured Against its Original Goals

It is worthwhile to assess IQOE achievements against its original goals (IQOE Science Plan Tyack, 2015) to "address 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 anthropogenic sound in the ocean?
3. What are the trends in anthropogenic sound levels across the global ocean?
4. What are the current effects of anthropogenic sound on important marine animal populations?
5. What are the potential future effects of sound on marine life?"

IQOE has focused almost exclusively on questions 2 and 3, laying the groundwork for answering the questions by compiling the IQOE PAM Metadatabase and helping develop methods to standardize data for analysis. Questions 1, 4, and 5 may also become more approachable by the increased availability of ocean sound observations. For example, Miksis-Olds and Nichols (2016) and Ainslie et al. (2025) analyzed data from the Comprehensive Test Ban Treaty Organization (CTBTO) to estimate trends in sound across the global ocean along with identifying dominant sources of low-frequency sound energy at the CTBTO hydrophone sites. The lack of sufficient funding made it impossible to fully answer any of the five questions, but IQOE has increased the ability to answer them and, as described above, has achieved other goals that were not anticipated in 2015.

Lessons learned

In the past decade, IQOE has learned several lessons in the process of developing the variety of activities described earlier:

- IQOE proves that passive acoustic monitoring can be a useful complement to other methods used to assess important climate variables, biodiversity, and ecosystem health.
- Understanding the effects of sound on marine life requires experiments and observations to study the effect of reducing exposure as well as increasing exposure.
- The ocean acoustics community is highly motivated to coordinate and collaborate but needs institutional structures to maintain a network of ocean sound observations and to curate an internationally distributed ocean sound metadatabase that is stable over the long term.
- GOOS offers a potential framework for coordinating funding and operations of a network of ocean acoustic observations.
- There is significant momentum in implementing ocean sound as an EOV as a result of the collective innovation and knowledge in the ocean acoustics and bioacoustics communities, promoted by IQOE, which will further the visibility and value of ocean sound.
- Ocean acoustics is a powerful way to capture the attention and imagination of the general public.

Significance of IQOE

IQOE produced key documents, software, databases and other legacy products, and initiated several activities that will continue to benefit the ocean acoustics and bioacoustics communities for years beyond the end of the project. IQOE fostered international cooperation and coordination of activities that promoted regional research and development of infrastructure that would not have happened without this project, despite modest funding and mostly managed and supported by the time of volunteers.

Future International Cooperation in Ocean Acoustics and Bioacoustics

Since IQOE was envisioned as a decadal program, it ended on 31 December 2025. However, the IQOE community is enthusiastic to continue an international project to promote cooperation in ocean acoustics and bioacoustics, maintaining required ongoing components of IQOE beyond 2025 as a legacy of the project. The IQOE Science Committee set up a separate committee to plan a new effort that will focus on passive acoustic observations in the ocean and implementation of the Ocean Sound EOV. It will also serve as the home for IQOE activities that continue beyond 2025. The new committee will seek to engage SCOR and POGO as the organizational hosts of the new activity. The future project will be well positioned to participate in activities such as the GOOS Physics and Climate Panel and Biology and Ecology Panel, World Ocean Assessments, the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) and those related to climate change. A key outcome could be development of calibrated acoustic recorders designed for integration into existing GOOS platforms such as Argo floats and the OceanSITES deepwater reference stations. Another key outcome would be organizing a global network of operators of ocean acoustic observations to identify gaps in global coverage and work to fill these gaps to develop a fully mature global observing system for ocean sound. Management of large open-access databases for ocean sound is another challenge requiring a working group with specialized skills and capabilities to tap into organizations equipped to curate these data over the long term.

Other topics that are ripe for progress include the broader deployment of particle motion detectors and better integration of hydrophones on autonomous platforms (e.g., gliders and ocean bottom seismometers) into the community of ocean sound observers.

References

(those marked with "" are attributable fully or in part to IQOE)*

*Ainslie, M.A., Robinson, S.P., Harris, P.M., Tyack, P.L., Halvorsen, M.B., Cheong, S.H., Livina, V. and Wang, L.S. 2025. Ocean soundscapes and trends from 2003 to 2021: 10–100 Hz. *Journal of the Acoustical Society of America*, *157*(6):4358-4384.

Andrew, R.K., B.M. Howe, and J.A. Mercer. 2011. Longtime trends in ship traffic noise for four sites off the North American West Coast. *Journal of the Acoustical Society of America* 129(2):642-651

Ausubel, J.H. 2009. Rethinking Light and Sound. *SEED Magazine*. Studying Marine Life's Brief Break from Human Noise.

*Ausubel, J. and E. Urban. 2021. https://www.ipsnews.net/2021/04/studying-marine-lifes-brief-break-human-noise/

*Boyd, I.L., G. Frisk, E. Urban, P. Tyack, J. Ausubel, S. Seeyave, D. Cato, B. Southall, M. Weise, R. Andrew, T. Akamatsu, R. Dekeling, C. Erbe, D. Farmer, R. Gentry, T. Gross, A. Hawkins, F. Li, K. Metcalf, J.H. Miller, D. Moretti, C. Rodrigo, and T. Shinke. 2011. An International Quiet Ocean Experiment. *Oceanography* 24(2):174–181, doi:10.5670/oceanog.2011.37.

*Chapuis, L., M. Burca, T. Gridley, X. Mouy, A. Nath, S. Nedelec, S. Seeyave, J. Theriault, E. Urban, R. Williams, and W.M.X. Zimmer. 2024. Development of a low-cost hydrophone for research, education, and community science. *OCEANS 2024* - Halifax, Halifax, NS, Canada, 2024, pp. 1-7, https://ieeexplore.ieee.org/document/10754094

*Looby, A., Erbe, C., Bravo, S. et al. 2023, Global inventory of species categorized by known underwater sonifery. *Sci Data* 10, 892, https://doi.org/10.1038/s41597-023-02745-4

Miksis-Olds J.L., D.L. Bradley; and X. M. Niu. 2013. Decadal trends in Indian Ocean ambient sound. J. *Acoust. Soc. Am.* 134, 3464–3475, https://doi.org/10.1121/1.4821537

*Miksis-Olds, J., P.J. Dugan, S. Martin, H. Klinck, D.K. Mellinger, D.A. Mann, D.W. Ponirakis, and O. Boebel. 2021 Ocean Sound Analysis Software for Making Ambient Noise Trends Accessible (MANTA). *Frontiers in Marine Science*, vol. 8:703650, https://www.frontiersin.org/journals/marine-science/articles/10.3389/fmars.2021.703650/full

Miksis-Olds, J.L. and S.M. Nichols, 2016. Is low frequency ocean sound increasing globally? *The Journal of the Acoustical Society of America* 139:501-511. DOI: 10.1121/1.4938237.

*Mooney, T.A., L. Di Iorio, M. Lammers, T-H. Lin, S. Nedelec, M. Parsons, C. Radford, E. Urban, and J. Stanley. 2020 Listening forward: approaching marine biodiversity assessments using acoustic methods. *R. Soc. Open Sci.* 7:201287.

*Parsons, M.J., T.-H. Lin, T.A. Mooney, C. Erbe, F. Juanes, M. Lammers, S. Li, S. Linke, A. Looby, S.L Nedelec, I.C. Van Opzeeland, C.A. Radford, A.N. Rice, L. Sayigh, J. Stanley, E. Urban, and L. Di Iorio. 2022. Sounding the call for a global library of biological underwater sounds. *Frontiers in Ecology and Evolution* 10:810156. doi: 10.3389/fevo.2022.810156

Payne, R. and D. Webb, 1971. Orientation by means of long range acoustic signaling in baleen whales. *Annals of the New York Academy of Sciences*, *188*(1):110-141.

Robinson, S.P., Harris, P.M., Wang, L., Cheong, S.H., Livina, V. 2019. Evaluation of long-term trends in deep-ocean noise in the Southern Ocean. In: IEEE OCEANS 2019-Marseille:1-6.

Ross, D. 2005. Ship sources of ambient noise. *IEEE Journal of Oceanic Engineering*, *30*(2):257-261.

* Seger, K.D., R. Sousa-Lima, J.J. Schmiter-Soto, and E.R. Urban Jr. 2021. Editorial: Before-After Control-Impact (BACI) Studies in the Ocean. *Front. Mar. Sci.* 8:787959. doi: 10.3389/fmars.2021.787959

*Tyack, P.L., T. Akamatsu, O. Boebel, L. Chapuis, E. Debusschere, C. de Jong, Christ, C. Erbe, K. Evans, J. Gedamke, T. Gridley, G. Haralabus, R. Jenkins, J. Miksis-Olds, H. Sagen, F. Thomsen, K. Thomisch, and E. Urban. 2023. *Ocean Sound Essential Ocean Variable Implementation Plan*. International Quiet Ocean Experiment.

*Tyack. P.L., G. Frisk, I. Boyd, E. Urban, and S. Seeyave (eds.). 2015. *International Quiet Ocean Experiment Science Plan*, Scientific Committee on Oceanic Research and Partnership for Observation of the Global Ocean.

*Tyack, P.L., J. Miksis-Olds, J. Ausubel, and E.R. Urban Jr. 2021. Measuring ambient ocean sound during the COVID-19 pandemic. *Eos* 102, https://doi.org/10.1029/2021EO155447. Published on 4 March 2021.

*Urban, E., J. Ausubel, , C, de Jong, G. Frisk, J. Miksis-Olds, H. Sagen, S. Seeyave, S. Simpson, and P.L. Tyack. 2019. Introducing the International Quiet Ocean Experiment. *ECO Magazine.* See https://scor-int.org/wp-content/uploads/2022/08/IOOE-Article.pdf

Williams, B., B. van Merriënboer, V. Dumoulin, J. Hamer, A.B. Fleishman, M. McKown, J. Munger, A.N. Rice, A. Lillis, C. White, C. Hobbs, T. Razak, D. Curnick, K.E. Jones and T. Denton. 2025. Using tropical reef, bird and unrelated sounds for superior transfer learning in marine bioacoustics. *Phil. Trans. R. Soc. B.* 380:20240280, https://doi.org/10.1098/rstb.2024.0280.

Members of IQOE Science Committee over the life of the project

Olaf Boebel (Germany)
Ian Boyd (UK), co-chair
Bishwajit Chakraborty (India)
Chris de Jong (Netherlands)
George Frisk (USA), co-chair
Tess Gridley (South Africa)
Tony Hawkins (UK)
Bruce Martin (Canada)
Rob McCauley (Australia)
Jennifer Miksis-Olds (USA)
Miles Parsons (Australia)
Hanne Sagen (Norway)
Filipa Samarra (Iceland)
Steve Simpson (UK), co-chair
Lise Doksaeter Sivle (Norway)
Karolin Thomisch (Germany)
Jakob Tougaard (Denmark)
Peter Tyack (USA), co-chair
Alexander Vedenev (Russia)
Carrie Wall Bell (USA)

Acronyms

ADEON	Atlantic Deepwater Ecosystem Observatory Network)
CTBTO	Comprehensive Test Ban Treaty Organization
DEMASK	Development and Evaluation of noise MAnagement Strategies to Keep the North Sea healthy
DOSITS	Discovery of Sound in the Sea
EOV	essential ocean variable
GLUBS	Global Library of Underwater Biological Sounds
GOOS	Global Ocean Observing System
IOC	Intergovernmental Oceanographic Commission
IPBES	Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services
IQOE	International Quiet Ocean Experiment
ISO	International Standards Organization
IYQO	International Year of the Quiet Ocean
JOMOPANS	Joint Monitoring Programme for Ambient Noise North Sea
JONAS	A Joint program for Ocean Noise in the Atlantic Seas
MANTA	Making Ambient Noise Trends Accessible
NOAA	National Oceanographic and Atmospheric Administration (U.S.)
NPS	National Park Service (U.S.)
NRS	NOAA/NPS Ocean Noise Reference Station NetworK
OPUS	Open Portal to Underwater Soundscapes
PAM	passive acoustic monitoring
PHYSIC	Ports, Humpbacks, Y Soundscapes In Colombia
POGO	Partnership for Observation of the Global Ocean
QUIETSEAS	Assisting (sub) regional cooperation for the practical implementation of the MSFD second cycle by providing methods and tools for Descriptor 11 (underwater noise)
SanctSound	NOAA Navy Sanctuary Soundscape Monitoring Project
SATURN	Solutions @ Underwater Radiated Noise
SC	Science Committee
SCOR	Scientific Committee on Oceanic Research
TANGO	Rerouting shipping lanes in the Kattegat – effects on soundscape and ecosystem
UNESCO	United Nations Educational, Scientific, and Cultural Organisation
WOPAM	World Ocean Passive Acoustic Monitoring

Links to Activity Websites and Publications

Activity Websites

GLUBS
MANTA
OPUS
WOPAM
Low-cost hydrophones

Publications

- IQOE Newsletters
- IQOE Science Plan
- IQOE Wikipedia Page
- Declaration on the IQOE Year of the Quiet Ocean
- Ocean Sound EOV Specification Sheet
- Ocean Sound EOV Implementation Plan
- Research Topic in Frontiers of Remote Sensing on Detection and Characterization of Unidentified Underwater Biological Sounds
- Research Topic in Frontiers in Marine Science on Before-After Control-Impact (BACI) Studies in the Ocean
- Compiled list of papers on the effects of the COVID-19 pandemic on ocean sound
- IQOE Standards Workshop Report: “Guidelines for Observation of Ocean Sound”
- References for United Nations Meeting on Ocean Sound
- Joint Workshop Report: Predicting Sound Fields—Global Soundscape Modelling to Inform Management of Cetaceans and Anthropogenic Noise