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Introduction

Ushering in a new era in fisheries and plankton acoustics

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The ICES-sponsored fisheries and plankton acoustic symposia are meant to bring together those from around the world who use active acoustics to improve our understanding of marine and freshwater environments. These symposia have brought the community together since 1973, and their proceedings have been "bookmarks" for the progress and innovation of fisheries and plankton acoustics (Table 1).

From Echosounders to the Cloud: Transforming Acoustic Data to Information was no different. This was the eighth in the series of fisheries acoustics symposia, and 2023 was the 50th anniversary of these symposia. We brought 150 scientists and engineers, 34 of whom were early career scientists (ECSs), from 26 countries representing all inhabited continents together in Portland, Maine, USA, during 27–30 March 2023. Of the 150 participants, 105 were males and 45 were females, importantly, the ECSs had a nearly 50%–50% ratio with 18 males and 16 females, which is a trend we hope will continue.

The goal of the symposium was to facilitate exchange among the spectrum of scientists and engineers who develop acoustic instrumentation, collect data, and transform electronic data to information critical for observing the status of and conserving fisheries and ecosystems. Many institutions monitor multiple facets of the ecosystem and have accumulated decades-long datasets and terabytes of data and information. The fisheries and plankton acoustics community continues to develop and evaluate new acoustic instrumentation and to package them with other sensors on crewed and remote/autonomous platforms to observe components of the ecosystem that until now have been too expensive or impossible to monitor. In response to this rapid increase in data, the community has evolved to integrate multiple data processing streams to address ecosystem science using "big data" analytics such as artificial intelligence and machine learning to provide information used by resource managers and policymakers. This information can be used for improved decision-making for ecosystem management. The abstracts from this symposium are provided as Supplemental Material and reflect the spectrum of science and technology that is the foundation of observing ecosystems acoustically and the continued evolution of analyzing those data.

We chose the title of the symposium because our perception is that there is a transition in the fisheries and plankton acoustics community. In the 1970s and 1980s, commercial and academic efforts developed robust echosounders that could be calibrated to an absolute standard and provide reliable data over time scales of weeks to years. The community was dominated by acousticians, engineers, and those fisheries scientists brave enough to break away from the traditional sampling methods to use this "new" tool. The ICES working group on Fisheries Acoustics, Science and Technology (WGFAST) was addressing freshwater and marine ecosystem questions using analog echosounders, and while successful at observing these ecosystems at very different scales than using nets or other observational gear, the emphasis was on the acoustic methodology. We were trying to interpret and quantify what we were seeing on the echograms and what those bytes meant in the "real" world. Assessments of commercial fish stocks were the first challenges in the use of active acoustics, giving rise to numerous exchanges with the ICES working group Fishing Technology and Fish Behaviour (WGFTFB) in order to better understand the impact of fish behavior on the uncertainties in assessments. Developments in technology and the use of several acoustic frequencies have revealed that what we see on echograms is not a single view, but "seascapes" depending on the frequencies used. Research is continuing on the acoustic properties of zooplankton, micronekton, and fish, giving an essential place to the acoustic approach, not only in stock assessments, but also in the ecosystem approach to the study of environments.

Recently, our perception is that the community is changing to one that is focused on science and data rather than engineering and the field is evolving towards utilizing echosounders as data collection tools rather than a focus on the tools themselves. Science and management have always been at the root of what our community does, so has there been a complete switch or is the change more nuanced? It may not be that our overall goals and challenges have changed, but how the community approaches those goals and challenges seems to have evolved. One example of this is the increase in the number of papers presented over the years at the fisheries acoustics' symposia that used artificial intelligence methods to analyze data. We searched titles and abstracts from each symposium's proceedings using the terms: artificial intelligence, machine learning, neural network, and deep learning. We found that the Aberdeen symposium in 1996 was the first to include neural networks with three papers, then one paper at the Montpellier symposium in 2003, and one paper at the Bergen symposium in 2009. In contrast, this symposium had 16 presentations and posters that used artificial intelligence methods and one

Table 1. Previous fisheries and plankton acoustics' symposium proceedings.

Year	Symposium Proceeding
1977	Hydro-Acoustics in Fisheries Research, Rapports et Proces-Verbaux des Reunions du Conseil International pour l'Exploration de la Mer, vol. 170, edited by A. R. Margetts.
1983	Symposium on Fisheries Acoustics, FAO Fisheries Report No. 300, FIRM/R300, edited by O. Nakken and S. C. Venema. ISBN # 92–5-101450–7.
1990	Developments in Fisheries Acoustics, Rapports et Proces-Verbaux des Reunions du Conseil International pour l'Exploration de la Mer, vol. 189, edited by W. Karp.
1996	Fisheries and Plankton Acoustics, ICES Journal of Marine Science, Vol. 53, no. 2, edited by E. J. Simmonds and D. N. MacLennan.
2003	Acoustics in Fisheries and Aquatic Ecology. Part 1. ICES Journal of Marine Science, Vol. 60, no. 3, edited by D. N. MacLennan.
2003	Acoustics in Fisheries and Aquatic Ecology. Part 2. Aquatic Living Resources, Vol. 16, no. 3, edited by J. Massé and F. Gerlotto.
2009	The Ecosystem Approach with Fisheries Acoustics and Complementary Technologies, ICES Journal of Marine Science, Vol. 66, no. 6, Edited by D. Demer and D. N. MacLennan.
2016	Marine Ecosystem Acoustics, ICES Journal of Marine Science, Vol. 73, no. 8, edited by V. Trenkel.

dedicated session to advanced analytical techniques. In addition, the scientific disciplines that acoustics can support with information have expanded through technological developments, from biology and management through biogeochemistry to physical oceanography.

The sheer size (terabytes) and length (decades) of available datasets is impressive and represents another evolution of this field. The missions of collecting and analyzing acoustic data have grown from local or regional single-species stock assessments to global estimates of biomass, such as those proposed by Xabier Irigoien and co-authors for mesopelagic fish (Irigoien et al. 2014), and effects of climate change on the global pelagic community as measured and predicted by Alejandro Ariza and co-authors (Ariza et al. 2022). Data management has been a fundamental topic since we started recording and digitizing echosounder signals, so the importance has not waned, but how we manage our data has advanced. As we become globally connected, institutions and agencies are making their data FAIR (findability, accessibility, interoperability, and reuse; https://www.go-fair.org/fair-principles). The fisheries and plankton acoustics community is in concert to address the challenges of FAIR data. Data no longer reside solely on a hard drive connected to a personal computer or on an intra-institutional network; they are findable and accessible on the internet (e.g. https://www.ncei.noaa.gov/maps/water-column-sonar). Adoption of open metadata conventions (e.g. ICES 2016) and data formats (e.g. Macaulay and Peña 2018) is allowing interoperability and uses beyond fisheries stock assessment. Advances in analytical methods are evolving from standard statistical tests to artificial intelligence and machine learning "big data" analytics. These advances have the potential to expand the reusability of data that were originally collected for single-species stock assessment to ecosystems, trophic food webs, and biological communities.

Data are different from information. When a resource manager or ecosystem modeler needs to know how many prey are available for a fisher or apex predator, they do not need raw data, they need information based on the data that we collect. We, as a community, are best suited to transform those data into the information needed for resource management and conservation. Our three keynote speakers provided expertise in areas where information derived from acoustic data can be useful. They presented overarching perspectives on offshore wind development (Andrew Lipsky, the lead for NOAA NEFSC's offshore wind development), ecosystem management (Michael Fogarty, NEFSC's lead ecosystem scientist (retired)), and the sociological connections to fishing and ecosystems (Kathryn Mills, ecosystem scientist at the Gulf of Maine Research Institute), so that we can better understand what the needs are and we can develop strategies to address those needs using existing and new technologies, platforms, and analytical methods.

The talks during the conference were largely representative of the wide range of scientific challenges involving acoustic approach. We had a total of 115 presentations, with 77 oral and 38 poster presentations that were organized under four theme sessions: Organism Detection: Models, Measures, and Classification; Advancements in Acoustic Devices, Platforms, and Combined Technologies; Data Integration: Analytics; and Data Integration: Application to Ecosystem, Conservation, and Society (Supplemental Material). The Scientific Steering Committee organized and chaired the sessions.

The ***Organism Detection: Models, Measures, and Classification*** theme session was chaired by Gavin Macaulay (Aqualyd, Wakefield, New Zealand), Naig Le Bouffant (Ifremer, Brest, France), Sven Gastauer (Thünen Institute of Sea Fisheries, Bremerhaven, Germany), and Babak Khodabandeloo (Institute of Marine Research, Bergen, Norway). This session had 24 oral and 12 poster presentations with 14 coming from early career scientists. This session covered acoustic modeling, target strength measurement, and target classification (from both active and passive acoustics). Acoustic scattering models are becoming more widely available and are more commonly used with increasing sophistication. They have been important for many years for interpreting narrowband data but are now especially crucial for supporting the interpretation of broadband backscatter. In this session, presentations on the effects of scattering-model parameterization on the model outputs were investigated in detail, new species were modeled, and the acoustic method was extended to ecosystems and species where it has not previously been used (Loranger et al. Supplementary Material; Mangeni et al. Supplementary Material); from zooplankton to mesopelagic communities (Barbin et al. Supplementary Material; Chacate et al. 2024, Macaulay et al. Supplementary Material; Kashindye et al. Supplementary Material) to the largest fishes. Target strength (TS) of several new species at different lengths or life stages were presented from

both *in-situ* and *ex-situ* environments (Kang et al. Supplementary Material; Lucca and Warren 2024; Santivanez-Yuffra et al. Supplementary Material; Schaber et al. Supplementary Material). The impact of target orientation (Saavedra et al. Supplementary Material), depth, and changes in TS due to natural behavior or physiology was also discussed (Perez-Arjona et al. Supplementary Material). Comparisons between scatter model results and existing target strength relationships that bridge the traditional way of estimating animal length to new and innovative methods were presented (Hentati-Sundberg et al. Supplementary Material). Machine learning and artificial intelligence methods addressing acoustic target classification are the future for analyzing acoustic data, as evidenced by inclusion in several presentations (Grados et al. Supplementary Material; Maslov et al. Supplementary Material; Matt et al. Supplementary Material; Pedersen et al. 2024, Vohra et al. Supplementary Material). The influence of different biological validation methods on classification was discussed (Whitman et al. Supplementary Material; Wieczorek et al. Supplementary Material), and sampling uncertainties for different surveys were presented. Broadband signals and data are now ubiquitous and several presentations highlighted progress in the processing techniques of broadband signals (Berges et al. Supplementary Material; Dunn et al. 2024, Gastauer et al. Supplementary Material; Khodabandaloo et al. Supplementary Material; Yang et al. 2024).

The ***Advancements in Acoustic Devices, Platforms, and Combined Technologies*** theme session was chaired by Haley Viehmann (Echoview, Hobart, Australia), Tim Ryan (CSIRO, Hobart, Australia), Joe Warren (Stony Brook University, Stony Brook, USA), and Alina Wieczorek (NIWA, Wellington, New Zealand). The session had a total of 19 oral and 10 poster presentations, with six of these talks from early career scientists. Presentations highlighted how new and existing technologies can be utilized to address familiar and arising challenges in fisheries and plankton acoustic research. One of these challenges is the differentiation of organisms within multi-species aggregations, as is often found in deep scattering layers in the open ocean (Peña et al. Supplementary Material; Silva et al. Supplementary Material). Environmental DNA (eDNA) sampling (Sunnarborg et al. Supplementary Material) and acoustic observations from submersible broadband echosounders (Benoit-Bird et al. Supplementary Material; Campanella et al. Supplementary Material) are promising tools to address this challenge. Presentations included examples of emerging benefits of these tools, as well as discussion of potential issues, such as organism identification, interpretation of environmental DNA signals, and appropriate calibrations for submersible broadband echosounders. Another widely addressed topic of this session was how unmanned submersibles, surface vehicles, and aerial drones (Lawrence et al. 2024, Scoulding et al. Supplementary Material) can be used to augment and, in part, replace traditional (i.e. hull-mounted) methods for hydroacoustic sampling (Godo et al. Supplementary Material; Johnson et al. Supplementary Material). Use of these remote platforms was mainly driven by specific research questions, including increased survey coverage (De Robertis et al. Supplementary Material), targeting difficult-to-survey areas (Dornan et al. Supplementary Material; Horne et al. 2024, Smith et al. Supplementary Material) such as in and around offshore wind farms, and increasing the range, resolution, quality, and species (Doray et al. Supplementary Material) of survey data. Given the rise in remotely operated and monitored platforms, there was discussion about (real-time) data transfer and storage, and the associated cost and benefits, which are specific to project needs and data requirements. Outside of these overarching topics, presentations included insights on the use of seafloor backscatter for single beam echosounder calibration (Le Bouffant et al. Supplementary Material), the use of multibeam data to elucidate fish positioning (Milne et al. Supplementary Material), light avoidance by fish and other organisms (Geoffroy et al. Supplementary Material), monitoring gas bubbles from CO_2 injection sites (Ryan et al. Supplementary Material), an innovative method for measuring target strength using Mills-cross split-beam processing (Matte et al. 2024), and use of low-frequency sound to detect and enumerate fish (Diachok et al. Supplementary Material; Imaizumi et al. Supplementary Material).

The ***Data Integration: Analytics*** theme session was chaired by Wu-Jung Lee (Univ. of Washington, Seattle, USA), Nils Olav Handegard (IMR, Bergen, Norway), and Carrie Wall (NOAA/NCEI, Boulder, USA). The analytics session consisted of 12 oral presentations and four poster presentations, with three coming from early career scientists. The first authors represented institutions from eight countries. Several sub-themes were highlighted from the presentations given. Open-source software (Lee et al. Supplementary Material), data preparation (Staneva et al. Supplementary Material), and data accessibility (Wall et al. Supplementary Material) are the critical first steps towards formatting and collating data so that they can be used in analytical models. Approaches to extract signal from noise are necessary for ensuring quality control of data (Kalkhoran et al. Supplementary Material). Application of artificial intelligence (Steig et al. Supplementary Material) and machine learning models and methods are at the forefront of "big data" analytics (Annasawmy et al. 2024, Duskey et al. Supplementary Material; Handegard et al. Supplementary Material; McReynolds et al. Supplementary Material). Understanding the impacts of uncertainty, errors, noise (Korneliussen et al. Supplementary Material) and sampling methods are important to understand from a methodology perspective as well as when implementing these analytical methods and results in population and ecosystem assessments (Berges et al. Supplementary Material; Dunning et al. Supplementary Material). This session contributes to an essential intermediary step transforming acoustic data to information. Scalable community tools and efficient ways to process data of small to large volumes that in turn allow scientists to extract signal or remove noise and place those details in the context of the environment are fundamental to informing fisheries acoustic science and its various applications.

The ***Data Integration: Application to Ecosystem, Conservation, and Society*** theme session was chaired by Patrick Sullivan (Emeritus Cornell University, Ithaca, USA), Alejandro Ariza (Ifremer, Nantes, France), Ndague Diogoul (Senegal Fisheries, Dakar, Senegal), Aurore Receveur (Biodiversity Institute, Montpellier, France), and Serdar Sakinan (WUR, Wageningen, Netherlands). The ecosystem session comprised 22 oral and 12 poster presentations with 11 coming from early career scientists. Large-scale distribution patterns of micronekton (Ens et al. 2024) in oceanic waters (Copeland et al. Supplementary Material; Dudeck et al. Supplementary Material; Eager et al. Supplementary Material; Kloser et al. Supplementary Material; Receveur et al. Supplementary

Material) using acoustic surveys were important topics in this session. Interesting observations about the lack of fish with resonance and gas-filled swimbladders in high-latitude systems (Klevjer et al. Supplementary Material) and the contribution of siphonophore resonance to global acoustic backscatter were highlighted. Publicly available and discoverable acoustic databases were addressed as a vital need for the community to share data (Ariza et al. Supplementary Material). Moored (Renfree et al. Supplementary Material) or drifting echosounders, and autonomous vehicles (Priou et al. Supplementary Material; Ramasco et al. Supplementary Material) that can be used to monitor ecosystems and the impact of human intervention on marine fauna were excellent examples of the application of new technology to address scientific questions. Stock assessment of small pelagic fish (Demer et al. Supplementary Material; Ongore et al. Supplementary Material; Robinson et al. Supplementary Material; Urmy et al. 2024) and assessment of tuna (Blanluet et al. Supplementary Material; Menkes et al. Supplementary Material) species were examples of management and conservation of living marine resources. Observations of individual (Thorvaldson et al. Supplementary Material) and group behavior using acoustics and observations of fish aggregations in proximity to artificial reefs (Fernandes et al. Supplementary Material) of reef fish using dual optic-acoustic systems or imaging sonar demonstrated the utility of acoustical and optical methods for shallow-water and reef environments (Salvetat et al. Supplementary Material; Sibley et al. 2024). Presentations amply met the expectations for this session. They described ecosystems and answered ecological questions using a suite of acoustic observational approaches. They also identified future challenges to improve acoustic observation of marine systems.

The symposium highlighted a number of recent developments in the discipline, including technological advances in new platforms and diversity of instrumentation, methodological innovations to analyze large quantities of data, and scientific transformations that spanned a wide spectrum of spatial and temporal scales. Moving forward, we will need new and novel capabilities, such as expertise in the use of broadband equipment, use and parameterization of analytical and numerical scattering models, and proficiency in advanced analytical statistics and methods. Biological interpretation of echograms and quantification of organisms, which are necessary for biogeochemical applications, resource management, and ecosystem monitoring, still remain as our "grand" challenges, especially in biodiverse environments. To address these challenges, we need to explore integrating complementary sampling methods and data such as optics and environmental DNA (eDNA), whose inclusion in our data and analysis models should improve classification of acoustic data to biologically meaningful taxa and metrics. Beyond our community, we need to broaden our scope and be cognizant of interactions between science and society where there is an expansion of societal expectations with regard to the information that fisheries and plankton acoustics contributes. Global-scale issues such as carbon sequestration by the ocean and effects of climate change on resources will make it even more necessary to develop global databases that are shared equitably by scientists, managers, and the public.

Finally, we would be remiss if we did not mention that for many participants, this was their first in-person meeting after a few years of purely virtual exchanges due to the COVID-19 pandemic. The pleasure of getting together and exchanging ideas face-to-face was clearly palpable and contributed to the richness of this conference. It was exciting to be together to keep the tradition of this conference moving and see the evolution of techniques, applications, and the people involved.

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Supplementary data

Supplementary data is available at *ICES Journal of Marine Science* online.

Data availability

There are no new data associated with this article.

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