WORKING GROUP ON FISHERIES ACOUSTICS, SCIENCE AND TECHNOLOGY (WGFAST)

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International Council for the Exploration of the Sea
Conseil International pour l'Exploration de la Mer

H.C. Andersens Boulevard 44-46
DK-1553 Copenhagen V
Denmark
Telephone (+45) 33 38 67 00
Telefax (+45) 33 93 42 15
www.ices.dk
info@ices.dk

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Editor

Michael Jech

Author

Michael Jech

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i Executive summary

The Working Group of Fisheries Acoustics, Science and Technology (WGFAST) focuses on the development and application of science and technology to observe the marine environment. In this report, WGFAST summarizes 38 presentations addressing the three themes: "Acoustic methods to characterize populations, ecosystems, habitat, and behaviour", "Acoustic characterization of marine organisms", and "Emerging technologies, methodologies, and protocols" and the discussions addressing these three themes. Common themes throughout these sessions were the increasing use of autonomous vehicles for collecting data and the increasing use of advanced statistical methodologies to process and quantitatively interpret acoustic data. Acoustical, environmental, and "ground-truthing" data are being collected beyond using traditional vessel-based surveys providing multiple data streams to characterize ecosystems. Many of the presentations highlighted "big data" statistical methodologies to fully utilize these data and improve our understanding of ecosystems.

This report also summarizes the WGFAST responses to the Working Group on International Pelagic Surveys (WGIPS) concerning potential sampling bias of shallow fish schools and to the Workshop on Atlantic chub mackerel (*Scomber colias*) (WKCOLIAS) concerning catchability of large chub mackerel (*Scomber colias*) in European waters, and WGFAST formed a group to address a methodological request from the WGIPS. WGFAST reviewed updates from the International Organization for Standardization (ISO) liaison, Topic Group on Collecting Quality Underwater Acoustic Data (TGQUAD) chair, Topic Group on Acoustic Metadata (TGMETA) chair, and Workshop on Acoustic Backscattering Models (WKABM) chair. With a goal of advancing the use of fisheries acoustic data in fisheries and ecosystem science, WGFAST continues to promote development of open-source data formats and software for interpreting acoustic data. WGFAST members are active participants in ICES' efforts in "Big Data" (i.e. data archive and discovery; open-source software to read, process, and analyse acoustic data; open-source data formats; and applications of artificial intelligence (AI) and machine learning (ML) methods), and continue to develop new and innovative methods to inform conservation and management of ecosystems.

This report also outlines future plans for the working group, including details for the 2022 meeting and proposals for a 2023 WGFAST/ICES Symposium and two joint sessions for the 2022 ICES Annual Science Conference.

ii Expert group information

Expert group name	Working Group on Fisheries Acoustics, Science and Technology (WGFAST)
Expert group cycle	Multiannual fixed term
Year cycle started	2020
Reporting year in cycle	2/3
Chair(s)	Michael Jech, USA
Meeting venue(s) and dates	19-20, 22-23 April 2021, Online meetings (hosted by the Institute of Marine Research in Bergen, Norway) (156 participants)

1 Report on Terms of Reference

1.1 ToR a)

The report collating information on acoustic-related research and surveys is due in year 3. During the meeting, WGFAST discussed requesting additional information from members on their connections to ecosystem and assessment expert groups (EGs) as part of this ToR. A number of members are currently participating in or have ties to other ecosystem and stock assessment expert groups. This information will be added to the report and collated in year 3.

1.2 ToR b)

Present recent work in fisheries acoustics

Although the meeting was held remotely, sessions addressing the three topics: "Acoustic methods to characterize populations, ecosystems, habitat, and behaviour"; "Acoustic characterization of marine organisms"; and "Emerging technologies, methodologies, and protocols" were held. Presentations (See Annex 3: for abstracts) and discussions comprised these sessions. Summaries of each session are given here.

Session I: Acoustic methods to characterize populations, ecosystems, habitat, and behaviour

A total of 18 presentations were given in the session. The session covered a wide range of topics with applications on different components of the marine ecosystem using a variety of tools and platforms.

The use of autonomous vehicles to study the dynamics of fish population was highlighted in a few studies. Levine et al. used Saildrones in combination with moored echosounders and ship-based surveys to characterize the dynamics of the age-0 fraction of the arctic cod population in the Chukchi Sea. The results indicated that age-0 gadids are moving northward advected by currents but also driven by increasing temperatures. Pedersen et al. investigated the seasonal changes on sandeel distribution and abundance using Saildrones in the North Sea. Saildrones provided good quality data and seemed to perform better than the RV under inclement weather. The sandeel biomass estimates from the Saildrones were higher than the ship-based estimates probably due to the smaller surface dead zone of the Saildrone's data. Multi-platform active acoustics was also used to develop tools and techniques to monitor carbon dioxide seeps over carbon storage sites in a shallow water area (Ryan et al., Downie et al.) The main challenge was to distinguish between biological scatterers and CO2 bubbles that have very similar acoustic characteristics.

Predator-prey interactions and micronekton dynamics were examined. Receveur et al. estimated "preyscapes" (micronekton) over a subtropical area in the southwest Pacific using EK60 data. The relationship between preyscapes and the main predators distribution was significant for some of the predators considered. The effect of climate change on prey abundance was also investigated indicating an overall decrease in the next years but the results suffered from high uncertainty. Annasawmy et al. characterized krill aggregations using moored echosounders and classify different swarm types based on morphological, numerical and spatial metrics. Predator dives recorded in the echograms were investigated in relation to the swarm types. Campanella

et al. presented results of a survey conducted over remote seamounts in the southern Atlantic highlighting the presence of increased productivity and biomass of meso-pelagic and benthopelagic fish over seamounts with specific topographical and hydrodynamic features.

The use of optics as ground-truthing tool was explored by Salvetat et al. who presented results of a survey that used a combination of active acoustics and optical tools (towed camera) to investigate fish distribution around a tropical archipelago off Brazil and Scoulding et al. who investigated the micronekton community in the Southern Ocean using ship-based acoustics, trawls and optical and acoustic sensor on a profiling platform.

Several presenters highlighted the impact of changing various survey settings on the precision of the acoustic density estimates. Sakinan et al. evaluated the effects of using a depth-corrected TS-length equation on the herring estimates from the HERAS survey. The depth correction resulted in small changes in the biomass proportions at age for the younger ages. Berger et al. presented the results of a simulation exercise to evaluate the effects of survey speed on herring biomass estimates. A general formula was proposed to evaluate the accuracy of NASC measurements based on school size and sampling rate. Boyra et al. showed that uncertainty and probability of bias of the acoustic estimates increased with increasing ping rates. Heterogeneity metrics can help predict the level of uncertainties as a function of the ping rate.

Two talks discussed acoustic target classification. Ariza et al developed a method based on the Functional Data Analysis to classify the acoustic backscatter at multiple frequencies into discrete acoustic assemblages that overlapped with the main water mass systems in the study area. Le Bouffant et al. developed a bottom detector based on Random Forest classification using EK60 data that was able to identify seagrass using EK60 data.

Other presentations included Warren et al. who described a new acoustic survey aimed at monitoring zooplankton and nekton in the New York Bight to develop ecosystem indicators. The potential use of alternative platforms such as moorings and gliders was discussed. Makris et al. showed the use of the OAWRS (Ocean Acoustic Waveguide Remote Sensing) to detect and estimate instantaneously the distribution of fish shoals over wide areas. Bairstow et al. explored the use of a shape catalogue to improve Target Strength estimations for krill with sizes that fall in the transition zone between Rayleigh and Mie scattering. Handegard et al. presented an overview of the current activities and results of a newly established research centre (CRIMAC) including models of broadband scattering, use of optical systems and autonomous vehicles, machine learning on large volumes of acoustic data.

Given the presence of many presentations that showed the integration of many different tools that collect different source of data (acoustic, optics, physical oceanography, etc.) also using alternative platforms, the group discussed if the calculation of absolute estimates of abundance/biomass is still relevant. It was highlighted that relative indices can be useful to characterize certain ecosystem processes but that absolute abundances still remain the final goal to achieve.

Session II: Emerging technologies, methodologies, and protocols

There were 9 presentations in this session covering a wide variety of topics ranging from the use of new platforms for collecting acoustic backscatter data, and challenges related to the use of broadband sensors to complementary techniques and methods from non-acoustic fields that may help in understanding acoustic data. The conversation following the presentations discussed the benefits (and limitations) of these new methods particularly with respect to the collection of ground-truthing information and whether WGFAST should coordinate or partner with other ICES WG (or other groups) to take advantage of the non-acoustic methodologies.

Two major themes emerging from this session were the use of new platforms (gliders, uncrewed surface vessels) for acoustic surveys and novel uses of echosounder data. Additionally, multiple

talks explored how best to interpret fisheries survey data when traditional trawl-based methods were not possible.

The session began with a study (Campanella et al.) using 200 kHz echosounder data to measure a physical oceanographic feature (the mixed layer depth) which worked quite well over a large geographic region during annual surveys. The authors noted that this approach may be affected by organism abundance (and DVM) and determining whether the scattering was from organisms or from turbulence/pycnocline was an area that needed further study.

Several talks were linked by operating acoustic sensors on novel, non-ship platforms. The Zoglider is a SeaGlider equipped with a custom-built two-frequency (200kHz, 1 MHz) acoustic system and a camera system to identify marine organisms (Gastauer et al.). The system has been field tested in several different oceanic regimes along the coast of California with both the acoustic, camera, and CTD systems able to measure differences between 3 different coastal habitat areas. The shadowgraphs produced by the optical system cover a wide range of organisms ranging from small phytoplankton and other microscopic organisms up to smaller krill, however the dominant organism in most habitats were copepods.

A stationary, remotely-operated echosounder was deployed in a lake in Cambodia (Horne et al.) which collected real time data that was pushed to the cloud for analysis and processing by remotely-located scientists. Systems like this can provide unique and valuable information for fishery monitoring and/or management, particularly in regions without a fishery monitoring effort in place (or only fisher-dependent catch data). The talk also noted the difficulty of interpreting backscatter data in a habitat with many different sizes and types of fishes.

A pair of talks discussed the use of Saildrone platforms to conduct fisheries surveys in the Pacific Ocean. The 2020 Bering Sea walleye pollock ship-based fishery survey was not conducted due to the covid pandemic, however three Saildrones were able to complete a survey in the region albeit at a slightly coarser transect spacing (De Robertis et al.). Historical data from the past two decades of the pollock survey was used to generate a strong relationship between backscatter and fish biomass and this approach was also tested to determine how the loss of one year of data would affect the robustness of this technique. Remarkably (given the timing of the survey) the Saildrone data were collected, analyzed, and used in the November fishery management discussion. A bit further south, the US and Canadian hake fishery survey was collected with concurrent (within a few days) Saildrone coverage of the same transect lines (Chu et al.). Agreement between the vessel and Saildrone surveys was good in terms of the overall biomass estimated, however there were differences when specific trackline backscatter was compared between the two platforms. This talk also examined how biological information (from fishery catch data for example) may be used in conjunction with the Saildrone data.

All of these talks presented unique datasets that may provide significant insights into different habitats, but all are limited in their ability to collect biological data on the acoustic scatterers in the water (at least in terms of the traditional net or trawl sampling).

Other talks in the session focused on how new methods or protocols could improve our understanding of acoustic data. A project in Scotland combined an echosounder, a camera deployed on a fishing line, and a skilled fisher to examine the in-situ target strength of individual Atlantic cod (Dunning et al.). The analysis utilized backscatter models and target tracking to estimate fish tilt angle and the effect on the measured TS of the fish which was caught, had its length measured, and then released. A unique aspect of this study was that only a single fish was wanted near the fish hook (i.e. in the measurement zone), since multiple fish would cause difficulty in ascribing the TS information to the measured fish. So ironically if too many fish were present the proper data couldn't be collected.

Many talks throughout the week focused on the advantages of broadband echosounders and the work presented by Khodabandeloo et al. investigated the issue of crosstalk from broadband echosounders between different frequencies. For simultaneously pinging systems, a 38kHz EK80 operating at full power will produce harmonics that can be detected by 70, 120, and 200 kHz systems. This was clearly visualized by seeing bottom echoes on the three higher frequencies when they were not transmitting and only the 38kHz system was pinging. Recommendations for operating at reduced power settings for simultaneous pinging systems were provided, with the caveat that this would reduce the operational range of these systems.

A ship-based study utilized a Simrad EC150-3C combined ADCP/echosounder to study the movements of herring, specifically their spawning migration (Ona et al.). The ability of this system to collect both velocity data (via the 4 off-axis beams) as well as a traditional split-beam echosounder provides a unique way to track the progression and movement characteristics of schools as they are encountered over a larger survey area. It was pointed out that a Motion Reference Unit (MRU) is an important part of this instrument and that data quality can be dependent on the specific MRU used.

Molecular biology is an unusual topic at WGFAST, but Trenkel et al. discussed the use of eDNA to provide information about the presence of different species of fish in terms of improving acoustic survey ground-truthing. There was a lot of interest in the potential applications of this method which can be done through water sample collection, however there are many unknowns regarding the temporal and spatial (both horizontal and vertical) variability in an eDNA signal, how many marker (reference) profiles are used in the analysis, and DNA shedding rates from different organisms.

The discussion that followed the talks had several themes. New, unmanned platforms are likely to become more widely used whether to access remote habitats, reduce operational costs relative to manned surveys, or other factors. But the group clearly recognizes the importance of the ground-truthing data in terms of the parameters (species, sizes, gender, etc.) collected by traditional trawls. Devising ways to collect this information from other groups (e.g. commercial fishery) or methods (such as eDNA, optical systems) may become more and more prevalent in future years. In a world where ecosystems (and their constituent species) may be changing or moving due to climate change, there is a concern that historical relationships that have been developed may not be applicable when the ecosystem itself is also changing.

Session III: Acoustic characterization of marine organisms

There were 11 presentations. The main topics included 1) size estimates and classification of acoustic targets using broadband and multifrequency narrowband data, 2) application of unsupervised machine learning techniques to characterize different organisms from both broadband and multifrequency narrowband data, and 3) the study of scattering models for better interpretation of broadband acoustic data.

Paul Fernandes estimated sizes of northeast Atlantic mackerel and Mueller's pearlside by fitting a distorted-wave Born approximation (DWBA) scattering model (mackerel) and a resonance scattering model (pearlside) to measured backscatter at 8-20 kHz. The resulting size estimates of both species were close to measured mean lengths of fish from trawls. Mette Dalgaard Agersted applied agglomerative clustering analysis to identify different mesopelagic gas-bearing target types based on their broadband TS frequency responses (50-80 kHz) collected with an acoustic submerged profiler. Echo-counting estimated vertical densities of target types and suggested that a fraction of the mesopelagic community is overlooked at lower frequencies. Julek Chawarski used unsupervised clustering (HDBSCAN) for pattern recognition of wideband TS frequency responses (35-45 kHz) of mesopelagic micronekton collected with a WBAT. TS measurements

were further used for identification of size differences vertically and to detect diel vertical migration patterns. Alicia Maurice investigated an unsupervised classification approach on wideband acoustic images collected in CW: 18 kHz and FM: 38, 70, 120, 200 and 333 kHz. Different clustering algorithms were tested on a known dataset and Local Linear Embedding (LLE) dimension reduction technique + K-means clustering method succeeded in identifying different types of scattering organisms, including small fish schools. Yawen Zhang applied unsupervised clustering analysis on historic acoustic multifrequency data of Atlantic herring schools. Three steps of automated machine learning workflow were applied: 1) acoustic classification, 2) contour-based fish school detection, 3) fish school identification. Automated annotations based on machine learning were very similar to manual annotations of herring schools. Pablo Escobar-Flores presented a tool to estimate swimbladder size and density of fish based on wideband acoustic frequency response data (12-85 kHz). Parameters from a model organism were used to initialize and optimize the scattering model. The study highlighted importance of obtaining broadband acoustic data at lower frequencies to capture resonance. The presented tool can also be applied on other animal groups for density estimation. Réka Domokos developed an acoustic descriptor for identification of the "Deep-7" fish species. TS was measured on tethered fish and *in situ* acoustic measurements were ground-truthed by optics. TS and fork length equations were developed to estimate biomass and corresponded to previous observations. Deep-7 species were successfully identified from other species based on aggregation characteristics. Gary Vargas presented a new approach to classify acoustic features in echograms based on its coordinates in a three-dimensional frequency space. The method allowed to automatically classify features in multifrequency echograms, after building a library with the frequency response of the dominant targets in the area. Fabio Campanella proposed a method to identify the Mixed layer Depth, based on the location of associated biological layers or the pycnocline microstructure, both detected with narrowband echosounders. Muriel Dunn tested the reliability and limitation of using broadband scattering models to estimate zooplankton densities from acoustic data collected with autonomous vehicles, when no biological samples are available. To this end, the scattering properties of dominant zooplankton species were measured *in-situ*, and results were compared with the models. Babak Khodabandeloo presented a new target strength model for swimbladdered mesopelagic fish, which included spherical gas surrounded by an elastic layer representing the swimbladder wall and a viscous layer representing the fish flesh. These features allowed to include detailed species-specific parameters to better represent the physical properties of the fish.

The discussion of the session touched upon the new insights provided by broadband single target observations and the challenges to analyse and interpret the results. Acoustic probes lowered into the mesopelagic zone now allow to see multiple thin layers and broadband signals can provide details about the species diversity, size, and orientation of the targets found within these layers. This will require more complex target strength models along the frequency spectrum. Frequency response is not always consistent, even in apparently single-target records. This opened a discussion about the interpretation of this phenomena, whether they are different target or the same target exhibiting different frequency responses. Methods to represent the frequency response of single-target tracks were discussed.

Training opportunities

WGFAST reviewed whether training opportunities (e.g. ICES training courses) in the use of acoustic backscatter models and applications of artificial intelligence (AI) and machine learning (ML) to fisheries acoustic data will be appropriate in 2022. These two fields are maturing quickly and WGFAST will discuss at the 2022 meeting whether to hold training courses in either of these fields.

Data and information gaps

Discussions as part of the theme sessions highlighted gaps in knowledge and how these gaps lead to uncertainty in acoustic measurements and estimates. WGFAST discussed how these gaps can be used to prioritize challenges in fisheries acoustics. We will continue to discuss and evaluate these topics as potential training opportunities as they mature

1.3 ToR c)

This ToR was discussed as another way (see ToR a) to facilitate interaction among WGFAST and other EGs, especially ecosystem, assessment, and machine learning EGs. WGFAST has evolved from a group solely dedicated to the engineering and evaluation of acoustic instrumentation to one that integrates multiple data streams to address ecosystem science and is using AI and ML methods to deals with "big" data, e.g. decades-long time-series, and application of those data to ecosystem monitoring and assessment.

WGFAST proposed two theme sessions to the 2022 ICES ASC: "Processing and interpreting big data using machine learning: Acoustic, optic, and other observations in marine environments" in partnership with Working group on Machine Learning in Marine Science (WGMLEARN); and "New insights from combining observations in ecosystem understanding" in partnership with Working Group on Integrative, Physical-biological and Ecosystem Modelling (WGIPEM).

1.4 ToR d)

WGFAST received an update from TGMETA on its progress and updates to the acoustic metadata and the AcMeta convention. This ongoing effort continually evolves with the needs of the community. Tim Ryan stepped down as the chair and WGFAST recognized his successful tenure as leader of that group. Erin Labrecque has assumed the chair. Erin has a great deal of expertise in metadata and Github logistics. The AcMeta convention is now available on the ICES GitHub site: https://github.com/ices-publications/AcMeta.

1.5 ToR e)

The CRR, "Collecting Quality Echosounder Data in Inclement Weather" is on track to be published in 2021. TGQUAD submitted a draft of the CRR in December 2020 and a copy-edited version is being addressed in June 2021.

2 Discussion Topics

2.1 ICES ISO Liaison

Toby Jarvis (Australia) is the ICES liaison to the International Standard Organization (ISO). The ISO working groups of interest are ISO/TC43/SC3/WG2 Underwater acoustical terminology and ISO/TC43/SC3/WG4 Standard-target method of calibrating active sonars.

The main topic of discussion centred about whether WGFAST and the fisheries acoustics community should begin to adhere to ISO nomenclature and symbology rather than that which have been advocated by MacLennan et al. (2002) and Demer et al. (2015), and used by the WGFAST community for many years. The group decided that Toby Jarvis should develop a table of comparisons between WGFAST and ISO nomenclature and then bring the matter to the WGFAST meeting in 2022 for further discussion on whether the differences are meaningful and substantial and whether a formal review should be proposed.

2.2 Open Data Format

The move towards developing data formats for "raw" (data acquired and recorded by acoustic instrumentation) and "processed" (raw data that have had algorithms applied for generation of acoustic-based estimates of abundance and biomass) data that are open source, i.e. formats that are self-describing and/or adhere to standards and formats developed by the scientific community rather than manufacturers of the acoustic instruments, is gaining acceptance by WGFAST and the members of the broader acoustic community.

Nils Olav Handegard, Laurent Berger, and Gavin Macaulay provided an update for developing an open-source data format. The goal is to have a standardized open format for unambiguous quantitative use of acoustic backscatter collected by the scientific sonar systems utilized by the fisheries acoustic community. Currently, this movement has been limited to specific instruments and/or specific researchers who are developing these formats. WGFAST discussed ways to move this development forward in a coherent way. The WGFAST agreed to form a subgroup analogous to TGMETA that would provide a more formal structure and a forum for discussion and implementation of open-source formats and efforts. This subgroup will be formed in 2021 and will update WGFAST at their annual meetings.

2.3 WKABM Update

Sven Gastauer updated WGFAST on the workshop for Acoustic Backscatter Modelling (WKABM). The first meeting was held remotely on 7-8 April 2021 and had 23 participants. The goals of the workshop were to: review and select commonly used acoustic scattering models and their application and relevance to fisheries acoustics; review and select methods to organize digital morphology and anatomical data of aquatic organisms; review and recommend software platforms and languages to develop and disseminate the open-source models and code; recommend benchmark methodology to compare acoustic scattering models to canonical shapes and field/laboratory data; and develop a set of standardized shapes to test and compare acoustic scattering models.

WKABM will meet intersessionally between WGFAST meetings and will meet in conjunction with the WGFAST meeting in 2022. At the conclusion of the workshop, the participants will decide whether to propose a formal working group to move this effort forward.

2.4 Symposium 2023

2023 will be eight years since the latest ICES Symposium on underwater acoustics that was held in Nantes, France in 2015. Michael Jech (USA) offered to host the 2023 symposium in the north-east US and will complete the application to host an ICES symposium, which is due in December 2021.

3 Scientific Advice

3.1 WGFAST response to WGIPS

WGFAST received a query from Working Group of International Pelagic Surveys (WGIPS) to provide advice on whether survey speeds above 10 kts will affect measures of integrated volume backscatter and thereby bias acoustic-trawl (AT) estimates of Atlantic herring when herring schools are shallow. Laurent Berger, Benoit Berges, Dezhang Chu, David Demer, Michael Jech, and Naig Le Bouffant drafted a response that was submitted to WGIPS.

Summary of the response:

There are many potential sources of uncertainty in AT estimates, but the group focused on estimating the effects of increased transect speed, which result in reduced horizontal sampling resolution. Simulation software (OASIS, developed by Ifremer) was used to calculate the theoretical effects of vessel speed using data acquisition parameters used during the AT surveys. Overall, the accuracy was minimally affected by sampling interval (combination of vessel speed and transmit interval), but precision was affected where the size of the equivalent sampling unit relative to the number of school detections is important for generating estimates with acceptable variance.

The WGFAST recommended that the IESSNS:

- Analyse existing/historical survey data collected at different vessel speeds to explore effects of vessel speed on estimates of herring biomass.
- Conduct field experiments to quantify any effects on estimates of herring biomass resulting from changes in behaviour and signal quality when surveying at different vessel speeds. In the simplest design, each ship would randomly run transects at 10 or 13 kts, and the data would be evaluated for any statistical differences. During this experiment, some protocols, such as acoustic frequency (38 kHz) and the transducer beam width (7o) and depth (ship dependent) may be unchanged. However, other factors, such as recording range and transmit interval, could be optimized to mitigate the effects of vessel speed.
- Explore modification to its protocol to optimize the transmit interval to improve school detection probability.

3.2 WGFAST response to WKCOLIAS

WGFAST received a query from the workshop on Atlantic chub mackerel (*Scomber colias*) (WKCOLIAS) that dealt with catchability of large chub mackerel. The workshop aimed to compile and analyse data on the abundance, distribution, and biology of chub mackerel in Atlantic European waters, to explore the connectivity between European and Northwest African populations, to propose stock units in the ICES region, and to identify stock assessment approaches. The paucity of large chub mackerel in commercial fisheries and scientific surveys catches in European waters could be due to an actual paucity of large individuals or a catchability issue. WGFAST was asked to address catchability. Mathieu Doray, Paul Fernandes, Michael Jech, Richard O'Driscoll, Hassan Moustahfid, and Nikolay Timoshenko (via correspondence with H. Moustahfid) provided responses.

Summary of the responses:

- The consensus indicated that capturing large individuals of fast swimming species, such as the mackerel species (e.g. *Trachurus* and *Scomber* spp.) is difficult, especially when sampling during scientific surveys.
- Capturing these fast swimming species is a combination of net size, vessel characteristics, tow speed and duration, and expertise of the bridge.
- Commercial fishers often develop specialized gear (e.g. large nets, large mesh, trawl sensors), vessels (e.g. increased horsepower), and methods (e.g., fast tow speeds, long duration) to capture large numbers of these species to make the catches economically feasible.
- Scientific surveys are often conducted on vessels that deploy many types of gear, bridge and deck expertise is often not specialized, and net catches are meant to be representative rather than voluminous.

WGFAST recommended:

- Either supplemental to or as a replacement for trawling, try "hook and line" sampling. Previous experience suggests it can provide representative samples and size distribution.
- Investigate spatial and temporal distribution, and potential changes in distributions.
- Investigate alternative ways to deploy midwater trawls.
- Investigate positioning small camera systems at locations where suspected large mackerel may be.

4 Next Meeting and Location

The next meeting is scheduled for 25-28 April 2022 in Dakar, Senegal.

5 References

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Annex 1: List of participants

Name	Institute	Country (of institute)	E-mail
Koki Abe	Japan Fisheries Research and Education Agency	Japan	abec@fra.affrc.go.jp
Mette Agersted	Institute of Marine Research, Norway	Norway	metteagersted@gmail.com
Nicolás Alegría Landeros	INPESCA	Chile	nalegria@inpesca.cl
Tonny Algroey	Kongsberg Maritime AS	Norway	tonny.algroy@simrad.com
Anibal Aliaga	TASA	Peru	anibaljar@gmail.com
Lars Nonboe Andersen	Kongsberg Maritime	Norway	lars.nonboe.andersen@kongsberg.com
Charles Anderson	NCEI/CIRES	USA	charles.anderson@noaa.gov
Angelee Pavanee Annasawmy	University of Washington	France	pannasawmy@yahoo.com
Alejandro Ariza	IRD	Spain	alejandro.ariza@ird.fr
Sigvaldi Árnason	Marine and Freshwater Research Institute	Iceland	sigvaldi.arnason@hafogvatn.is
Fiona Bairstow	St Andrews	UK	fjb5@st-andrews.ac.uk
Laure Barbin	IRD	France	laure.barbin@ird.fr
Birkir Bardarson	MFRI	Iceland	birkir.bardarson@hafogvatn.is
Laurent Berger	Ifremer	France	laurent.berger@ifremer.fr
Arnaud Bertrand	IRD	France	Arnaud.Bertrand@ird.fr
Arthur Blanluet	Queensland University	France/Australia	arthur.blanluet@noos.fr
Kevin Boswell	Florida international university	USA	kevin.boswell@fiu.edu
Guillermo Boyra	AZTI	Spain	gboyra@azti.es
Patrice Brehmer	IRD	Senegal	Patrice.brehmer@ird.fr
Andrew Brierley	University of St Andrews	UK	asb4@st-andrews.ac.uk
Martina Bristow	University of East Anglia	UK	martina.bristow@uea.ac.uk
Steven Brodet	Kongsberg Underwater Technology	Sweden	steve.brodet@km.kongsberg.com
Jan Buermans	ASL Environmental Sciences Inc.	Canada	jbuermans@aslenv.com
Lucio Calise	Zunibal SL	Spain	lucio.calise@zunibal.com
Fabio Campanella	Cefas	UK	fabio.campanella@cefas.co.uk

Julek Chawarski	Centre for Fisheries Ecosystem Research	Canada	julek.chawarski@mi.mun.ca
Dezhang Chu	NOAA Fisheries, NWFSC	USA	dezhang.chu@noaa.gov
Jeff Condiotty	Kongsberg Underwater Technology	USA	jeff.condiotty@km.kongsberg.com
Rodolfo Cornejo Urbina	IMARPE	Peru	rcornejo@imarpe.gob.pe
Martin Cox	Australian Antarctic Division	Australia	martin.cox@aad.gov.au
Alex De Robertis	NOAA Fisheries	USA	Alex.DeRobertis@noaa.gov
David Demer	NOAA / NMFS /SWFSC	USA	david.demer@noaa.gov
Réka Domokos	Pacific Islands Fisheries Science Center, NMFS, NOAA	USA	reka.domokos@noaa.gov
Mathieu Doray	Ifremer	France	mdoray@ifremer.fr
Tracey Dornan	British Antarctic Survey	UK	tarna70@bas.ac.uk
Ryan Downie	CSIRO	Australia	ryan.downie@csiro.au
Muriel Dunn	Memorial University of Newfoundland / Akvaplan-niva	Norway	muriel.dunn@mi.mun.ca
James Dunning	University of Aberdeen	UK	j.dunning.18@abdn.ac.uk
Pablo Escobar-Flores	NIWA	New Zealand	pablo.escobar@niwa.co.nz
Paul Fernandes	University of Aberdeen	UK	fernandespg@abdn.ac.uk
Sophie Fielding	British Antarctic Survey	UK	sof@bas.ac.uk
Peer Fietzek	Kongsberg Maritime	Germany	peer.fietzek@km.kongsberg.com
Tonje Forland	Institute of Marine Research	Norway	tonje.nesse.forland@hi.no
Sven Gastauer	Thünen Institute for Sea Fisheries	Germany	sven.gastauer@thuenen.de
Stephane Gauthier	Fisheries and Oceans Canada	Canada	stephane.gauthier@dfo-mpo.gc.ca
Maxime Geoffroy	Fisheries and Marine Institute of Memorial University of Newfoundland	Canada	maxime.geoffroy@mi.mun.ca
Teresa Sofia Giesta da Silva	Marine and Freshwater Research Institute	Iceland	teresa.silva@hafogvatn.is
Silvana Gonzalez	University of Washington	USA	silgonz@uw.edu
Natalia Gorska	Institute of Oceanology Polish Academy of Science	Poland	gorska@iopan.pl
Daniel Grados	IMARPE	Peru	danny.grados@gmail.com
Jerome Guiet	UCLA	USA	Jerome.c.guiet@gmail.com
Mariano Gutierrez	Humboldt Institute	Peru	msgutierrezt@gmail.com

Jeremie Habasque	IRD	France	jeremie.habasque@ird.fr
Nils Olav Handegard	IMR	Norway	nilsolav@hi.no
Daniel Hasselman	Fundy Ocean Research Center for Energy	Canada	dan.hasselman@fundyforce.ca
Hiroyuki Higashiyama	FURUNO ELECTRIC CO., LTD.	Japan	hiroyuki.higashiyama@furuno.co.jp
Taina Honkalehto	NOAA Fisheries	USA	Taina.Honkalehto@noaa.gov
John Horne	University of Washington	USA	jhorne@uw.edu
Lawrence Hufnagle	NOAA Fisheries	USA	lawrence.c.hufnagle@noaa.gov
Briony Hutton	Echoview Software	Australia	briony.hutton@echoview.com
Ilysa Iglesias	University of California, Santa Cruz and NOAA Southwest Fisheries Science Center	USA	iiglesia@ucsc.edu
Tomohito Imaizumi	National Research Institute of Fisheries Engineering, Japan Fisheries Research and Education Agency	Japan	imat@affrc.go.jp
Jan Arge Jacobsen	Faroe Marine Research Institute	Faroe Islands	janarge@hav.fo
Michael Jech	NOAA/NEFSC	USA	michael.jech@noaa.gov
Teunis Jensen	DTU Aqua	Denmark	tej@aqua.dtu.dk
Espen Johnsen	Institute of Marine Research	Norway	espen.johnsen@hi.no
Jennifer Johnson	WHOI	USA	jjjohnson@whoi.edu
Sigurður Jónsson	Marine and Freshwater Research Institute, Reykjavík, Iceland	Iceland	sigurdur@hafro.is
Rachel Kahn	MIT-WHOI Joint Program	USA	rkahn@whoi.edu
Olavi Kaljuste	Swedish University of Agricultural Sciences	Sweden	olavi.kaljuste@slu.se
Zacharias Kapelonis	Hellenic Centre for Marine research	Greece	zkapelonis@hcmr.gr
Ailbhe Kavanagh	Marine Institute	Ireland	ailbhe.kavanagh@marine.ie
Babak Khodabandeloo	Norwegian Institute of Marine Research	Norway	babak.khodabandeloo@hi.no
Thor Klevjer	IMR	Norway	thor.klevjer@hi.no
Rolf Korneliussen	Institute of Marine Research	Norway	rolf.korneliussen@hi.no
Rokas Kubilius	Institute of Marine Research	Norway	rokas@hi.no
Erin LaBrecque	US Marine Mammal Commission	USA	erinlab@gmail.com
Niklas Larson	IMR, Aqua, SLU	Sweden	niklas.larson@slu.se
Andone Lavery	Woods Hole Oceanographic Institution	USA	alavery@whoi.edu
Naig Le Bouffant	IFREMER	France	naig.le.bouffant@ifremer.fr

Anne Lebourges-Dhaussy	IRD	France	anne.lebourges.dhaussy@ird.fr
Wu-Jung Lee	University of Washington Applied Physics Laboratory	USA	wjlee@apl.washington.edu
Robert Levine	University of Washington	USA	leviner@uw.edu
Lilian Leiber	University Belfast Marine Laboratory	UK	L.Lieber@qub.ac.uk
Scott Loranger	Woods Hole Oceanographic Institution	USA	sloranger@whoi.edu
Zhen Lu	postdoctoral researcher	Japan	roshin@affrc.go.jp
Susan Lusseau	DTU Aqua	Denmark	smalu@aqua.dtu.dk
Gavin Macaulay	Institute of Marine Research	Norway	gavin.macaulay@hi.no
Nicholas Makris	MIT	USA	makris@mit.edu
Alicia Maurice	Ifremer	France	alicia.maurice@ifremer.fr
Emilio Mayorga	University of Washington	USA	mayorga@apl.washington.edu
Louise McGarry	FORCE: Fundy Ocean Research Center for Energy	Canada	louise.mcgarry@fundyforce.ca
David McGowan	NOAA AFSC	USA	david.mcgowan@noaa.gov
Chelsey McGowan-Yallop	Scottish Association for Marine Science	UK	sa06cm@sams.ac.uk
Denise McKelvey	Alaska Fisheries Science Center, NOAA Fisheries	USA	denise.mckelvey@noaa.gov
Satoshi Misonoo	FURUNO ELECTRIC CO., LTD.	Japan	satoshi.misonoo@furuno.co.jp
Hassan Moustahfid	NOAA	USA	hassan.moustahfid@noaa.gov
Fran Mowbray	Fisheries and Oceans Canada	Canada	Fran.Mowbray@dfo-mpo.gc.ca
Miad Al Mursaline	MIT/WHOI	USA	mmursaline@whoi.edu
Lauren Nelson	IOTC	Seychelles	lauren.nelson@fao.org
Miguel Nogueira	FURUNO	Spain	miguel.nogueira@furuno.es
Michael O'Malley	Marine Institute	Ireland	Michael.O'Malley@Marine.ie
Steven O'Connell	Marine Scotland Science	UK	Steven.O'connell@gov.scot
Ciaran O'Donnell	Marine Institute	Ireland	Ciaran.odonnell@marine.ie
Akira Okunishi	FURUNO ELECTRIC CO., LTD.	Japan	akira.okunishi@furuno.co.jp
Egil Ona	Institute of Marine Research	Norway	egil.ona@imr.no
Patricia Ordonez	ZUNIBAL SL	Spain	patricia.ordonez@zunibal.com
Egoitz Ormaechea	Zunibal	Spain	egoitz.ormaetxea@zunibal.com
Antonio Palermino	CNR-National Research Council, IRBIM-Institute for Marine Biological Resources and Biotechnologies	Italia	antonio.palermino@irbim.cnr.it

Sandra Parker-Stetter	NOAA-AFSC-MACE	USA	sandy.parker-stetter@noaa.gov
Hjalte Parner	ICES	Denmark	hjalte.parner@gmail.com
Audun Oppedal Pedersen	University of Bergen	Norway	audun.pedersen@outlook.com
Geir Pedersen	Institute of Marine Research	Norway	geir.pedersen@hi.no
Heikki Peltonen	Finnish Environment Institute	Finland	heikki.peltonen@syke.fi
Hector Pena	Institute of Marine Research	Norway	hector.pena@hi.no
Marian Peña	IEO	Spain	marian.pena@ieo.es
Salvador Peraltilla	Peruvian National Fisheries Society	Peru	speraltilla@snp.org.pe
Vladislav Petrusevich	DFO, NAFC	Canada	vladislav.petrusevich@dfo-mpo.gc.ca
Elizabeth Phillips	NOAA	USA	elizabeth.phillips@noaa.gov
Marissela Pozada	IMARPE	Peru	marissela.pozada.herrera@gmail.com
Roland Proud	University of St Andrews	UK	rp43@st-andrews.ac.uk
Madhu Ramakrishnan	ICAR-Central Institute of Fisheries Technology	India	madhucift@gmail.com
Aurore Receveur	Thuenen Institute	Germany	aurore.receveur@9online.fr
Frank Reier Knudsen	Kongsberg Maritime	Norway	frank.reier.knudsen@km.kongsberg.com
Josiah Renfree	NOAA	USA	josiah.renfree@noaa.gov
Patrick Ressler	NOAA Alaska Fisheries Science Center	USA	patrick.ressler@noaa.gov
Shani Rousseau	Fisheries and Oceans Canada	Canada	shani.rousseau@dfo-mpo.gc.ca
Tim Ryan	CSIRO	Australia	Tim.ryan@csiro.au
Serdar Sakinan	Wageningen Marine Research	Netherlands	serdar.sakinan@wur.nl
Julie Salvetat	UFRPE, IRD	France	ju.salvetat@gmail.com
Kouichi Sawada	Japan Fisheries Research and Education Agency, Fisheries Technology Institute	Japan	ksawada@fra.affrc.go.jp
Matthias Schaber	Thünen Institute of Sea Fisheries	Germany	matthias.schaber@thuenen.de
Ben Scoulding	CSIRO	Australia	ben.scoulding@csiro.au
Elor Sepp	Estonian Marine Institute	Estonia	elor.sepp@ut.ee
Jacob Sobin	Kongsberg Maritime	USA	jacob.sobin@km.kongsberg.com
Valentina Staneva	University of Washington	USA	vms16@uw.edu
Chelsea Stanley	Institute of Ocean Sciences	Canada	chelsea.stanley@dfo-mpo.gc.ca

Jonas Sundberg	Swedish University of Agricultural Sciences	Sweden	jonas.sundberg@slu.se
Chris Taylor	NOAA Ocean Service	USA	Chris.Taylor@noaa.gov
Michala Techau	Strategic Innovation Ltd	UK	m.techau@strategic-innovation.co.uk
Rebecca Thomas	NOAA/NWFSC	USA	rebecca.thomas@noaa.gov
Verena Trenkel	Ifremer	France	verena.trenkel@ifremer.fr
Sam Urmy	NOAA Alaska Fisheries Science Center	USA	sam.urmy@noaa.gov
Jeroen Van Der Kooij	Cefas	UK	jeroen.vanderkooij@cefas.co.uk
Gary Vargas	Universidade Federal Rural de Permanbuco	Peru	garyrvc@gmail.com
Carrie Wall	University of Colorado Boulder / NOAA NCEI	USA	carrie.wall@noaa.gov
Ivar Wangen	Kongsberg Maritime	Norway	ivar.wangen@simrad.com
Joseph Warren	Stony Brook University	USA	joe.warren@stonybrook.edu
David Warwick	Seafish	UK	david.warwick@seafish.co.uk
Tim Whitton	Bangor University	UK	t.whitton@bangor.ac.uk
Alina Wieczorek	Marine Institute Ireland	Ireland	Alina.Wieczorek@marine.ie
Jinshan Xu	Fisheries and Oceans of Canada	Canada	jinshan.xu@dfo-mpo.gc.ca
Yawen Zhang	University of Colorado Boulder	China	yawen.zhang@colorado.edu
Zhaozhong Zhuang	MIT-WHOI	USA	zzhuang@whoi.edu
Aleksander Żytko	Institute of Oceanology, Polish Academy of Science	Poland	azytko@iopan.pl

Annex 2: Resolution

A **Working Group on Fisheries Acoustics, Science and Technology** (WGFAST), chaired by J. Michael Jech*, USA, will work on ToRs and generate deliverables as listed in the Table below.

	MEETING DATES	VENUE	REPORTING DETAILS	COMMENTS (CHANGE IN CHAIR, ETC.)
Year 2020	22 April	Online meeting	Interim report by 22 May 2020 to ACOM-SCICOM	Michael Jech takes over as chair
Year 2021	19-23 April	Online meeting	Interim report by 30 June 2021 to ACOM-SCICOM	
Year 2022	25-28 April	Dakar, Senegal	Final report by 30 June 2022 to ACOM-SCICOM	

ToR descriptors

ToR	Description	Background	Science plan codes	Duration	Expected Deliverables
a	Collate information on acoustic related research and surveys, and interactions with ecosystem and assessment expert groups.	a) Science Requirements b) Advisory Requirements A summary of the information will be presented in the final report	3.1, 3.2, 3.4	3	Report
b	Review presented recent work within the topics: "Acoustic methods to characterize populations, ecosystems, habitat, and behaviour"; "Acoustic characterization of marine organisms"; and "Emerging technologies, methodologies, and protocols". Provide guidance by identifying: (1) where training opportunities could be developed; and (2) gaps in knowledge and challenges that should be prioritized by the community.	Create a venue for informing the group members on recent activities and seeking input to further development. An overview of the different contributions and guidance will be presented in the annual report	3.3, 4.1, 4.4	1, 2, 3	Presentations
c	Organize a conference session on integrating fisheries acoustics with ecosystem assessment and monitoring at an international scientific meeting such as ASC.		3.1, 3.2, 4.1	2 or 3	Conference session
d	Develop, and maintain acoustic metadata and data format conventions and coordinate with acoustic survey groups.	Data format conventions for acoustic metadata and data are required for efficient data interchange and processing of acoustic data, but are lacking in the fisheries acoustics field. CRR 341 (2018) and SISP 4 (2016) have partially addressed this need,	3.2, 3.5, 4.2	1, 2, 3	Updated metadata convention publication (new guide/handbook series) Revised sonar-netcdf4 convention publication that includes echosounder

		but further types of data and acoustic equipment need to be supported.			data (new guide/handbook series
e	Develop and recommend procedures for collecting and processing quality acoustic data in inclement weather.	Acoustic data are collected from a variety of vessels that respond to inclement weather in diverse ways. Procedures are needed to provide quality control for data collected in inclement weather to stock assessment.	3.3, 3.6	1	CRR; recommendations on methodology improvements to acoustic survey coordination groups to implement on surveys and update SISPs

Summary of the Work Plan

Year 1	Produce the annual overview of recent developments within the field. Produce an ICES CRR recommending procedures for collecting and processing quality acoustic data in inclement weather. Develop and maintain metadata and acoustic data formats.
Year 2	Produce the annual overview of recent developments within the field. Propose a conference session at an international scientific meeting. Develop and maintain metadata and acoustic data formats.
Year 3	Produce the annual overview of recent developments within the field. Collate information on acoustic related research and surveys. Develop and maintain metadata and acoustic data formats. Publish new guides with updated metadata convention and revised sonar-netcdf4 convention publication that includes echosounder data.

Supporting information

Priority	Fisheries acoustics and complementary technologies provide the necessary tools and methods to implement the ecosystem approach to fisheries management within ICES and research into their application and further development is vital.
Justification for venue 2022 (in non-ICES member country)	WGFAST has a long and rich history of collaborating with our West African partners, and hosting a meeting in Senegal will facilitate the participation of scientists from Africa (particularly West Africa and the south Mediterranean area), improve the exchange of science and communication on Fisheries Acoustics, Science and Technology between European and African colleagues, and promote the UN Ocean decade initiative. We expect to recruit several new members to WGFAST and even at higher levels, gain new "observatory" countries for ICES in Africa.
Resource requirements	No new resources will be required. Having overlaps with the other meetings of the Working, Planning, Study and Topic Groups increases efficiency and reduces travel costs.
Participants	The Group is normally attended by some 60-100 members and guests.
Secretariat facilities	None.
Financial	No financial implications.
Linkages to ACOM and groups under ACOM	Stock assessment groups using acoustic abundance indices.
Linkages to other committees or groups	The work in this group is closely aligned with complementary work in the FTFB Working Group. The work is of direct relevance to a number of data collection and coordination groups within EOSG (e.g. WGIPS, WGBITS, WGISUR)

Linkages to other organizations	The work of this group is closely aligned with similar work in FAO, the Acoustical Society of America, the South Pacific Regional Fisheries Management Organization, the Commission for the Conservation of Antarctic Marine Living Resources, and the American Fisheries Society.

Annex 3: Presentation Abstracts

Acoustic Methods to Characterize Populations, Ecosystems, Habitat, and Behaviour

Development of a Pelagic Zooplankton and Nekton Acoustic Survey in the New York Bight

Joseph D. Warren[1], Brandyn M. Lucca[1], Hannah B. Blair[3]

[1]*School of Marine and Atmospheric Sciences, Stony Brook University, 239 Montauk Hwy, Southampton, NY 11968 USA, joe.warren@stonybrook.edu, brandyn.lucca@stonybrook.edu, hannah.blair@stonybrook.edu*

The New York Bight is a continental shelf habitat that is home to numerous pelagic organisms supporting a variety of commercial and recreational fisheries. As part of a state-funded ocean indicator monitoring project, we developed a vessel-based, seasonal, active acoustic survey to quantify the distribution and abundance of pelagic zooplankton and nekton in conjunction with net, trawl, and CTD sampling. With just over two years of data collected, we have successfully measured seasonal variations in backscatter attributed to zooplankton or fish in the region. But we have had limitations with our ability to successfully cover the entire survey area during many cruises and with successfully fishing our midwater trawl to capture ground truth data. Due to these issues, we plan on modifying our sampling strategies (and remaining budget neutral) and shifting some effort from the vessel to moored echosounder systems. Feedback from the WGFAST membership on ways to improve or modify our sampling would be welcome.

Seamount fish distribution investigated by acoustics in remote areas of the South Atlantic Ocean.

Campanella Fabio[1], Collins Martin A.[2], Young Emma[2], Laptikhovsky Vladimir[1], van der Kooij Jeroen[1], Whomersley Paul[1]

[1]*Centre for Environment, Fisheries and Aquaculture Science. Pakefield Rd, Lowestoft, NR33 0HT, UK*

[2]*British Antarctic Survey, High Cross, Madingley Rd, Cambridge, CB3 0ET, UK*

Seamounts have long been recognized as hotspots for pelagic productivity and diversity in the world's open ocean habitats. Such characteristics make seamounts attractive targets for fisheries. As these unique habitats are localised and relatively small, they are vulnerable to overexploitation. Mapping and quantitative assessments of the fish biomass at different seamounts are crucial prerequisites to understand the dynamics of these important ecosystems and their vulnerability. We used fisheries acoustic methods to investigate the distribution and abundance of fish and micronekton on and around five little studied seamounts of Tristan da Cunha, a sub-tropical remote area in the South Atlantic Ocean. The results confirmed increased productivity at the seamounts, compared to the surrounding open ocean with higher acoustic backscatter values particularly at the shallower seamounts. Fish largely dominated the backscatter on most of the seamounts especially over the plateau areas where large densities of prey fish, primarily the mesopelagic *Maurolicus inventionis*, were detected. Very large bentho-pelagic fish aggregations were also observed that resulted in very high estimates of biomass. Aggregations of this size and magnitude, have, to our knowledge, never been mapped or quantified using acoustic methods. Specific physical processes, such as enhanced retention and vertical mixing that were identified by an oceanographic model, may be some of the drivers of the enhanced fish biomass detected.

Acoustic seascape partitioning through Functional Data Analysis

Alejandro Ariza[1], Anne Lebourges-Dhaussy[2], David Nerini[3], Etienne Pauthenet[4], Gildas Roudaut[2], Ramilla Assunção[5] and Arnaud Bertrand[1]

[1]*Institut de Recherche pour le Développement. Sète, France, alejandro.ariza@ird.fr & arnaud.bertrand@ird.fr*

[2]*Institut de Recherche pour le Développement. Plouzané, France, anne.lebourges.dhaussy@ird.fr & gildas.roudaut@ird.fr*

[3]*Aix-Marseille Université. Marseille, France. david.nerini@univ-amu.fr*

[4]*Sorbonne Universités. Paris, France. etienne.pauthenet@locean.ipsl.fr*

[5]*Universidade Federal de Pernambuco. Recife, Brazil. ramillavieira@hotmail.com*

Acoustic seascapes are nowadays regularly registered during oceanographic surveys, providing valuable information to investigate on the abundance and distribution of diverse pelagic organisms. Despite its utility to explore life in the ocean and the vast amount of information available, we lack scalable numerical methods to describe and classify pelagic communities based on echosounder data, this being usually conducted through human-subjective partitioning of the acoustic seascape. Here we propose an objective approach based on functional data analysis. We use acoustic backscattering as a function of depth, simultaneously at three frequencies, to parameterize the vertical distribution of distinct acoustic targets and classify the seascape accordingly. The method is described and tested with data collected at 38, 70, and 120 kHz in continental and oceanic waters off Northeast Brazil. Acoustic seascape partitioning mirrored the distribution of major current systems in the area, describing distinctive communities between slope-boundary and open-ocean areas, and between spring and fall hydrological regimes. The seascape consistency and the spatio-temporal coherence of the regions classified show that the method is reliable to describe acoustically-detected community assemblages and proved efficient at delineating biogeographical fronts in the ocean.

Recent Advances in Instantaneous Wide-Area Sensing of Fish Population Density and Behaviour with Ocean Acoustic Waveguide Remote Sensing

Nicholas Makris[1], Olav Rune Godø[2], Josef Michael Jech[3], Gavin J. Macaulay[2], Purnima Ratilal[4], Ankita D. Jain[1], D. H. Yi[1], Shourav Pednekar[1], Byunggu Cho[1],

1MIT, Cambridge MA, makris@mit.edu;

2IMR, Bergen Norway, olavruneg@gmail.com;

3Northeast Fisheries Science Center, Woods Hole MA, michael.jech@noaa.gov;

4Northeastern University, Boston MA, purnima@ece.neu.edu

Cod, capelin and herring populations were surveyed over wide areas in their Nordic Seas spawning grounds with Ocean Acoustic Waveguide Remote Sensing (OAWRS) in February through March of 2014. Spatial charts of instantaneous population density were obtained for entire cod shoals spanning tens of kilometers in the Lofoten region (Fish Fish 2019), as well as similarly sized capelin shoals in the Barents Sea and herring shoals in the Alesund region. By multi-spectral OAWRS imaging, the relative density of species in mixed shoals were instantaneously distinguished and charted remotely over wide-areas in

the Barents Sea revealing meso-scale predator-prey interactions. Similar multispectral imaging enabled herring shoal depth to be instantaneously estimated over wide areas during spawning

migrations to Georges Bank (Remote Sensing 2018). With cod shoal parameter information obtained from OAWRS in 2014, historic Lofoten cod data was re-analyzed revealing that in the mid-20th century, the total Lofoten cod population apparently came precariously close to the mean size of a single shoal during previous and current periods of much higher total population (Fish Fish. 2019). This is consistent with previous qualitative observations that cod stock collapses elsewhere in the North Atlantic coincided with the disappearance of large spawning shoals. Lofoten cod shoal size was found to follow a log-normal distribution, consistent with theoretical expectations.

Fish distribution from acoustic and video data around a tropical Archipelago

Julie Salvetat[1,2], Nicolas Bez[2], Jeremie Habasque[3], Anne Lebourges-Dhaussy[3], Gildas Roudaut[3], Monique Simier[2], Paulo Travassos[1], Gary Vargas[1] and Arnaud Bertrand[1,2,4]

[1]*Universidade Federal Rural de Pernambuco, Recife, Brazil, ju.salvetat@gmail.com, pautrax@hotmail.com, garyrvc@gmail.com, arnaud.bertrand@ird.fr;*

[2]*Institut de Recherche pour le Développement (IRD), MARBEC, Univ Montpellier, CNRS, Ifremer, IRD, Sète, France, ju.salvetat@gmail.com, nicolas.bez@ird.fr, monique.simier@ird.fr, arnaud.bertrand@ird.fr;* [3]*IRD, UMR LEMAR, Ifremer/IRD/ CNRS/ UBO, Technopole Brest Iroise, 29280 Plouzané, France, jeremie.habasque@ird.fr; anne.lebourges.dhaussy@ird.fr, gildas.roudaut@ird.fr;* 4*Universidade Federal de Pernambuco, Recife, Brazil, arnaud.bertrand@ird.fr.*

Tropical waters hold the major part of marine biodiversity, but in most cases, tropical fish distribution and biomass estimates are based on visual observation (divers or operated videos), which are restricted in space and time. Application of active acoustics is still in its infancy in these waters, partly because acoustics alone cannot differentiate between the many species present. To lift out this lock, we combined bi-frequency (70 and 200 kHz) acoustics to video observations to describe 3D fish distribution in the Fernando de Noronha archipelago off Northeast Brazil, which encompasses a marine protected area, preventing extractive biological sampling. Video records were used to enumerate and identify fish and sediment characteristics. Simultaneous scrutinizing of video and echogram allowed identifying and classifying all the echoes into fish functional groups and two triggerfish species. The biomass of the most abundant species observed, black triggerfish, was estimated at 235 t using geostatistics. Groups distribution as well as the 'non-fish' part of the data, were analysed in relation to habitat characteristics obtained from acoustic data and video such as depth, rugosity and sediment type, in order to provide a detailed comprehensive 3D description of fish distribution and their environment around the archipelago.

A multiplatform acoustic-based approach to classifying abundance, distribution, and transport of age-0 gadids on the Chukchi Sea shelf

Robert Levine[1], Alex De Robertis[2], Daniel Grunbaum[3], Chris Wilson[4], Ed Farley[5], Calvin Mordy[6], Phyllis Stabeno[7]

[1]*School of Oceanography, University of Washington, Seattle, WA, USA, leviner@uw.edu;*

[2]*Alaska Fisheries Science Center, NMFS, Seattle, WA, USA, alex.derobertis@noaa.gov;*

[3]*School of Oceanography, University of Washington, Seattle, WA, USA, random@uw.edu;*

[4]*Alaska Fisheries Science Center, NMFS, Seattle, WA, USA, chris.wilson@noaa.gov;*

[5]*Alaska Fisheries Science Center, NMFS, Juneau, AK, USA, ed.farley@noaa.gov;*

[6]*Cooperative Institute for Climate, Ocean, and Ecosystem Studies, University of Washington, Seattle, WA, USA, mordy@uw.edu;*

[7]*NOAA Pacific Marine Environmental Laboratory, Seattle, WA, USA, phyllis.stabeno@noaa.gov*

Acoustic-trawl (AT) surveys of the Chukchi Sea during summers 2012 and 2013 determined that pelagic fishes were dominated by age-0 Arctic cod (Boreogadus saida), with few adults present in the region. This suggests that either survivorship of age-0 fish is very low or that they emigrate to other areas as they grow. To evaluate the role of the region as a nursery for these age-0 fish, we conducted AT surveys in 2017 and 2019 and repeat acoustic surveys from autonomous surface vehicles in 2018. Throughout this period, bottom-moored echosounders continuously measured fish abundance and movement at several locations. These observations indicate that the abundance and species composition of midwater fishes on the Chukchi Sea shelf is highly variable over seasonal and interannual time scales. Seasonally, abundance was very low in winter, increased in May, and reached peak abundance in late summer. In all years, the highest abundance in summer was observed in the northern Chukchi. The distribution of age-0 gadids is predominantly driven by transport, and an increase in age-0 pollock abundance in 2017 and 2019 suggests that environmental conditions now enable species from the south to colonize the Chukchi Sea, at least on a seasonal basis.

Improving the accuracy of krill target strength using a shape catalogue

Fiona Bairstow[1], Sven Gastauer[2,3], Luke Finley[4], Tom Edwards[1], C.Tom A. Brown[1], So Kawaguchi[5] and Martin J. Cox[5]

[1]*SUPA, School of Physics and Astronomy, University of St Andrews, KY16 9SS, United Kingdom, fjb5@st-andrews.ac.uk, tje@st-andrews.ac.uk, ctab@st-andrews.ac.uk;*

[2]*Scripps Institution of Oceanography, University of California, San Diego, La Jolla, CA, United States;*

[3]*Thünen Institute of Sea Fisheries, Bremerhaven, Germany, sgastauer@ucsd.edu;*

[4]*Elgin Associates Pty Ltd, Hobart, Australia, luke.finley@elgin.com.au;*

[5]*Australian Antarctic Division, Department of Agriculture, Water and Environment, 203 Channel Highway, Tasmania 7050, Australia, so.kawaguchi@aad.gov.au, martin.cox@aad.gov.au.*

Antarctic krill play a dominant role in the unique ecology of the Southern Ocean. Precautionary catch limits, set by the Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR), aim to ensure the sustainability of commercial krill fishing. These catch limits are based on biomass estimations, obtained from acoustic-trawl and net surveys. The acoustic observations of volume backscattering strength are scaled to numerical krill density using modelled values of krill target strength. Such models are typically scaled with measured length distributions and estimated orientation distributions. While the length distributions are accessible from net samples, there is little consensus on the method for estimating krill orientation leading to a limiting factor in the accuracy of biomass calculations. In this talk, I will explore the use of a shape catalogue to improve target strength calculations of krill with physical dimensions that fall on the transitions between Rayleigh and Mie scattering domains. Furthermore, I will outline the effects of animal shape on backscattering cross-section (linearised target strength) for a range of orientation distributions.

On the development of active acoustic methods for a Measurement, Monitoring and Verification (MM&V) program at a proposed shallow water Carbon Capture and Storage site.

Tim Ryan, Rudy Kloser, Ryan Downie, Ben Scoulding, Haris Kunnath, Andreas Marouchos, David Hughes, Andy Ross

Carbon dioxide storage projects (Carbon Capture and Storage [CCS]) are being developed globally and have the potential to play an important role in the reduction of atmospheric carbon emissions. Offshore Gippsland (Victoria) is a shallow-water location that is widely recognised as one of the most attractive basins for CCS in Australia. Establishing a robust measurement, monitoring and verification (MM&V) program is needed from both a regulatory and public acceptance perspective. In partnership with Australian National Low Emissions Coal Research and Development (ANLEC R&D), CSIRO have investigated a number of tools that could be applied for use in a comprehensive MM&V program in a shallow marine environment, including oceanographic modelling, chemical and acoustic sensors, the latter being the focus of this presentation. The acoustic program was primarily based on fisheries acoustics technology that can detect gas bubbles at extremely low levels. A combination of fixed and mobile platforms have been trialled. Systems included Saildrones, ship-based acoustics, a moored seafloor lander with AZFP upward looking echosounder and an echosounder with a bespoke 360 degree rotating side-looking transducer to detect gas releases at long ranges (~400m). The effectiveness of active acoustic methods for MMV has been demonstrated at this location.

Acoustic detection of shallow-water seagrass

Naig Le Bouffant[1], Céline Cordier[1], Laurent Berger[1]

[1]*Ifremer Centre de Brest, CS 10070 - 29280 Plouzané, naig.le.bouffant@ifremer.fr, celine.cordier@ifremer.fr, laurent.berger@ifremer.fr*

Coastal areas covered by seagrass communities are considered as major interest habitats, for their role in marine fauna nursering and hot-spot of biodiversity. Their health is investigated as potential bio-indicator of costal water quality. One aspect that needs to be monitored is their spatial distribution and density. As they grow in very shallow water environment, satellite and airborne acquisitions are convenient (photograpy, lidar, hyperspectral). But ground truthing remains an issue, and acoustic acquisitions provide relevant description of water column. Fishery acoustics protocols can be derived to this topic, but face specific difficulties. Layer echo-integration near the bottom provides a primary proxy of seagrass presence, but requires to adapt bottom detection to the case of highly dense reflectors stucked to sea bottom.

Different dedicated French coastal areas have been surveyed with 120kHz EK60, with the objective of seagrass detection, and ideally identification and estimation of their density. The method will be presented here, with the development of a specific bottom detector, and first results of geographical seagrass detection through Random Forest classification performed on acoustic features. Tools are developed within Movies3D software and through Python codes linked to Movies3D librairies.

Why monitor the pulse of naturally occurring acoustic signals as part of a shallow water subsea CCS MMV program?

Ryan Downie[1], Tim Ryan[1], Ben Scoulding[1], Rudy Kloser[1]

[1]*CSIRO Oceans and Atmosphere, Commonwealth Scientific and Industrial Research Organisation, GPO Box 1538, Hobart, Tasmania 7001, Australia, ryan.downie@csiro.au; tim.ryan@csiro.au; ben.scoulding@csiro.au; rudy.kloser@csiro.au*

Multiple efforts to establish subsea Carbon Capture and Storage (CCS) Measurement Monitoring and Verification (MMV) programs have identified that echosounders installed on a range of platforms are capable of detecting, quantifying, and monitoring controlled releases of CO2 in gaseous form. It is anticipated that the primary challenge when implementing active acoustic MMV programs in shallow coastal seas, will be the ability to distinguish CO2 bubble streams in the water column from other naturally occurring acoustic signatures. A review of archived active acoustic data, from a region in SE Australia where CCS activities are anticipated, identified that naturally occurring acoustic signals from the surface bubble layer, schooling zooplankton and/or fish with gas-filled swimbladders, diving seabirds and/or seals are common and resemble the acoustic signals of CO2 bubble streams. Here we use an upward looking four frequency echosounder, ASL Acoustic Zooplankton Fish Profiler, to characterise the daily, seasonal and interannual variation in naturally occurring acoustic signals over a three-year period that could be incorrectly identified as bubble streams (false-positives). Results from a trial of acoustic verification methods, baited remote underwater video assays and net sampling, indicate that the dominant scatterers are likely to be zooplankton and fish schools. The application of simple volume backscatter thresholds, with values obtained from controlled experimental release studies, reduces the rate of false positives significantly.

Antarctic krill aggregation structures and predator-prey interactions at Deception and Nelson Islands, Antarctica

Pavanee Angelee Annasawmy[1], John Kenneth Horne[1], Christian Sam Reiss[2], George Randy Cutter[2], Gavin John Macaulay[3]

1School of Aquatic and Fishery Sciences, University of Washington, Seattle, WA, USA

2NOAA Southwest Fisheries Science Centre, San Diego, USA

3Institute of Marine Research, Bergen, Norway

Antarctic krill (Euphausia superba) is a vital component of the Southern Ocean's food web as an important phytoplankton grazer, microzooplankton and copepod predators and prey for numerous top predators such as Adelie penguins, seabirds, seals and baleen whales. During this study, Kongsberg WBAT and Nortek Signature 100 echosounders fixed on moorings were deployed in two hydrographically different sites in the Antarctic Ocean: Deception Island (Bransfield Front and significant bathymetric steering), and at Nelson Island (continental shelf site with weaker mesoscale activities). Aggregations of krill were characterized using numerical and morphological characteristics (NASC and mean depth) and echometrics (center of mass, inertia, equivalent area, aggregation index, and proportion occupied) and categorized using hierarchical clustering techniques. Six krill aggregation categories were investigated relative to environmental conditions (current velocity and percentage lunar illumination). "V"-shaped predator dives were recorded from the echograms and were investigated relative to the aggregation types identified. Predator dives occurred closer to Nelson and Deception Islands compared to the site farther into the Bransfield Strait. Predator dives also occurred over the most common swarm types. This study will advance knowledge on krill aggregation structures and predator interactions at Deception and Nelson Islands using moored platforms with echosounders.

Using acoustic data to study the pelagic ecosystem: impact of climate change on forage fauna and predator-prey relationships.

Aurore Receveur[1], Valerie Allain[2], Frederic Menard[3], Anne Lebourges-Dhaussy[4], Christophe Menkes[5]

[1]aurore.receveur@9online.fr ;OF, Thuenen Institute of Baltic Sea Fisheries, Rostock, Germany,

[2]valeriea@spc.int; OFP/FEMA, Pacific Community, 95 Promenade Roger Laroque, BP D5, 98848 Nouméa, New Caledonia.

[3]frederic.menard@ird.fr ; MIO, Aix Marseille Univ, Université de Toulon, CNRS, IRD, 13288Marseille, France.

[4]anne.lebourges.dhaussy@ird.fr; LEMAR, IRD, Univ. Brest, CNRS, Ifremer, Campus Ifremer, BP70, Plouzané, France

[5]christophe.menkes@ird.fr ;ENTROPIE, UMR 9220, IRD, Université de la Réunion, CNRS, Université de La Nouvelle-Calédonie, Ifremer, BP A5, 98848 Nouméa, New Caledonia

Micronekton is a key component of the pelagic ecosystem, but largely unknown. We used acoustic data (EK60, 38kHz) collected in the Southwest Pacific to obtain preyscapes (i.e. backscatter on regular grid) integrated over different vertical layers (FAST meeting Seattle, 2019; Receveur et al., 2019). Here, we used these robust predicted preyscapes with two goals:

(1) To assess the impact of climate change on micronekton. We compared the future acoustic preyscapes to the predictions of an ecosystemic model (SEAPODYM). We globally found the same evolution with the two methods in the epipelagic layer, but large discrepancies deeper.

(2) To understand predator-prey relationships. We statistically linked the abundance/occurrence of nine predators (fishes, cetaceans, and seabirds) to their prey abundance, measured with the vertical acoustic preyscapes. We showed that acoustically-derived prey abundance estimates improved the habitat models for five out of the nine predators. We offered a first step in the understanding of climate change impact and predator-prey relationships, however, the results suffered from uncertainty. The next step, to improve the robustness of preyscapes, will be to transform the acoustic signal into micronekton biomass by specie/group. Acoustic data, in such region with a high level of micronekton species diversity, are promising but further developments are needed.

Who's who in the zoo? Sampling micronekton in the Southern Ocean

Ben Scoulding[1], Rudy Kloser[1], and Caroline Sutton[1]

[1]*CSIRO, Oceans and Atmosphere Flagship, GPO Box 1538, Hobart, TAS 7001,*

Australia, ben.scoulding@csiro.au, rudy.kloser@csiro.au, caroline.sutton@csiro.au

Carbon sequestration is the long-term storage of carbon on land and in the ocean. The biological gravitational pump was thought to be solely responsible for the transport of carbon from the surface waters to the deep ocean. However, it is now recognised that other processes are involved including biological transport. An important, yet understudied, component of this is the mesopelagic migrant pump which can lead to substantial amounts of carbon being actively transported to mesopelagic depths through the vertical migration of micronekton. Micronekton are free-swimming, taxonomically diverse, pelagic animals around 2-20 cm in size and comprise of some of the most abundant animals in the oceans. A significant part of the micronekton community undertakes daily vertical migration (DVM). Micronekton contribute to the transport of carbon by feeding in the shallows and pooing in the deep. Understanding the number of individuals and the range of species undertaking DVM, as well the biogeochemistry of micronekton is an important step for understanding their role in the carbon cycle. Here, we present findings from a recent Southern Ocean voyage where three different samplers (acoustics, optics, and trawls) were used to describe the micronekton communities at three Southern Ocean sites.

Mapping spatiotemporal changes in acoustic abundance of lesser sandeel with autonomous surface vehicles

Geir Pedersen[1], Arne Johannes Holmin[1], Sakura Komiyama[2], Espen Johnsen[1]

[1]*Institute of Marine Research, Nykirkekaien 1, 5004 Bergen*

[2]*University of Bergen, Postboks 7800, 5020 Bergen*

Lesser sandeel (*Ammodytes marinus*) is a key species in the North Sea and preyed on by a great variety of marine mammals, fish and seabirds. It also sustains the largest fishery in this ecoregion. However, the recruitment and stock sizes has dramatically fluctuated the last decades, and several area structured management systems are implemented to prevent local depletion and severe ecosystem impacts. The species has a peculiar life history where it burrows into sandy habitats, while forming large pelagic schools at daytime to feed on zooplankton during a short feeding season peaking in May. Strong habitat dependency and high stationarity make it particularly sensitive to anthropogenic stressors and climate change. Every spring, traditional ship-based acoustic-trawl surveys map geographical distribution and stock development in NEEZ, but an assessment of the cumulative anthropogenic impacts on sandeel require more persistent monitoring of the physical and biological components of the ecosystem. Two Saildrones performed repeated acoustic mapping of important lesser sandeel grounds during spring/summer 2019. Here we present the general performance of the vehicles and the quality of these acoustic data. We also assess the spatial and temporal changes in abundance of lesser sandeel and compare the Saildrone- and vessel-based survey results.

CRIMAC - Center for Research-based Innovation in Marine Acoustic Abundance Estimation and Backscatter Classification.

Nils Olav Handegard[1], Tonje Nesse Forland[1], Espen Johnsen[1], Geir Pedersen[1], Maria Tenningen[1], Egil Ona[1]

1Institute of Marine Research, Nykirkekaien 1, 5004 Bergen, nilsolav@hi.no.

CRIMAC is a recently established centre for Research-based Innovation funded by the Research Council of Norway. This presentation gives an overview of the current results and plans for the centre. CRIMACs objective is to advance the frontiers in fisheries acoustic methodology and associated optical methods, and to apply such methods to surveys for marine organisms, fisheries, aquaculture and the energy sector. To meet these objectives, we have set up a net pen infrastructure where we can do fine scale broad band measurements on a range of different marine species, and we collect and catalogue in situ broad band data from surveys. We are also working on models of broadband scattering, where we are particularly interested in modelling the detailed spectra of individual targets. Verification methods using optical systems and dropped probes are also being tested, and we will present a few results where we use an in-trawl camera system. IMR has recently procured several autonomous vehicles, and we are working on machine learning methods for analysing large volumes of acoustic data, including an approach on embedding these methods in the vehicles. Possibilities for future collaboration and joint projects with the centre will be presented.

Sensitivity of HERAS index calculation

Serdar Sakinan[1], Benoit Berges[1]

[1]*Wageningen Marine Research, Haringkade 1, 1976 CP Ijmuiden, Netherlands, serdar.sakinan@wur, benoit.berges@wur.nl*

International North Sea Herring Survey (HERAS) survey, estimates the size and distribution of the herring stock in the region through collection of and acoustic and trawl data. The stock index estimated by the HERAS survey is influential in the stock assessment model and in turn to the fisheries advice process. For the past 5 years, the StoX software (developed by IMR – Norway) and connected R codes that has been in use for processing, interpretation and harmonisation of the survey data, which substantially simplifies the work and streamlines the procedures. In this work different sources of uncertainties were assessed such as survey design, biological sampling scheme, and potential error in the calibration of echosounders though iterated tests in the STOX environment.

Effects of Survey Speed on Herring Biomass Estimates

Laurent Berger[1], Benoit Berges[2], Dezhang Chu[3], David Demer[4], Mike Jech[5] and Naig Le Bouffant[1] (alphabetical)

[1]*Ifremer Centre de Brest, CS 10070 - 29280 Plouzané, laurent.berger@ifremer.fr, naig.le.bouffant@ifremer.fr;* [2]*Wageningen Marine Research, Wageningen University and Research, IJmuiden, Noord Holland, 1976 CP, NETHERLANDS, benoit.berges@wur.nl;*

[3]*NOAA Fisheries Northwest Fisheries Science Center 2725 Montlake Boulevard East Seattle, Washington 98112, USA Dezhang.Chu@noaa.gov;*

[4]*NOAA FisheriesSouthwest Fisheries Science Center 8901 La Jolla Shores Drive La Jolla, California 92037, USA, David.Demer@noaa.gov;*

[5]*NOAA Fisheries Northeast Fisheries Science Center 166 Water Street Woods Hole, Massachusetts 02543, USA Michael.Jech@noaa.gov.*

In 2020, the ICES Workshop on Scrutinizing of Acoustic Data from the IESSNS Survey asked WGFAST to investigate whether survey speeds above 10 kts will affect measures of integrated volume backscattering coefficients (sA) for 38kHz echosounders on small schools of herring located in shallow water and thereby bias acoustic-trawl-method estimates of herring biomass. The response provided by WGFAST in late 2020 presented here summarizes the potential impact of increased ship on fish behaviour, echo classification, horizontal sampling resolution, and signal quality and gives recommendations on field experiments to quantify the impact. A specific simulation exercise is also presented and provides a basis for evaluating the effect of fish schools distribution and data acquisition parameters on integrated volume backscattering coefficients. Based on the simulations, precision of density estimates is maximal if each school located along the acoustic transect is sampled at least once. A general conservative formula is hence proposed for horizontal inter-sample distance for maximal precision of density estimates depending on school size and beamwidth at the depth of the school.

Impact of an increasing ping rate on acoustic-based abundance

Guillermo Boyra[1], Iosu Paradinas[2], Iñaki Rico[1], and Udane Martinez[1]

[1]*AZTI, Herrera Kaia. Portualdea z/g 20110 Pasaia (Gipuzkoa) Spain, gboyra@azti.es;*

[2]*SOI, University of St Andrews, St Andrews, Fife, KY16 8LB, Paradinas.iosu@gmail.com,*

[3]*AZTI, Herrera Kaia. Portualdea z/g 20110 Pasaia (Gipuzkoa) Spain, irico@azti.es;*

[4]*AZTI, Herrera Kaia. Portualdea z/g 20110 Pasaia (Gipuzkoa) Spain, umartinez@azti.es;*

The ping rate, the time lapse between two consecutive acoustic pings, is the main parameter affecting along-transect resolution in an acoustic survey. The increase of acoustic detection range

(e.g., to include mesopelagic species), as well as the alternation of pinging by different acoustic sensors to avoid interference or cross-talking, might cause the ping rate to increase, hence reducing acoustic sampling resolution. The purpose of this work is to study, using a resampling exercise, whether ping rate affects the mean acoustic backscattering energy (NASC), causing increase of uncertainty and/or bias in acoustic-based abundance estimations. The analysis consisted in the echointegration at the maximum resolution (1 ping) of a portion of transects of a real acoustic survey, followed by a sequence of resamples on the echointegrated data to simulate the increase of ping rate. The mean NASC was calculated for each of the simulated increasing ping-rates. Acoustic data was grouped in different heterogeneity levels (measured by means of the Gini "inequality" index), to study the possible incidence of this factor on the increase of uncertainty and bias with decreased sampling resolution.

Acoustic Characterization of Marine Organisms

Sizing fish with broadband acoustics

Paul Fernandes[1], James Dunning[1], Phil Copland[2], Alan Fenwick[1] & Dezhang Chu[3]

[1]*School of Biological Sciences, University of Aberdeen, Aberdeen, AB24 2TZ, Scotland, UK, fernandespg@abdn.ac.uk.*

[2]*Marine Scotland Science, Aberdeen, Scotland UK.,*

[3]*NOAA/NMFS/NWFSC/FRAM, 2725 Montlake Blvd. E., Seattle, WA 98112, USA.*

There are a number of situations where estimating the size of fish prior to capture would be of an advantage, not only during scientific surveys of fish, but also during certain commercial fishing activities. One example is mackerel, where in the north-east Atlantic the stock is the most valuable single species fishery in Europe, worth over US$1.5 billion per annum. Mackerel fetches a higher price per kilo for larger fish, so it would benefit fishermen to determine the size of fish prior to capture. Many of the more common commercial fish have resonance peaks in their broadband spectra that are beyond the range of most sonars. In this study we deploy an adapted sub-bottom profiler to measure broadband spectra of fish schools between 8 and 20 kHz. Theoretically, small mackerel have a different broadband scattering spectrum to larger ones, with a transition point from Rayleigh to geometric scattering close to the range of our sonar. We deployed the Edgetech sonar in the North Sea in October 2015 to determine the broadband spectra of mackerel schools. We also detected several pearlside schools, which have resonant peaks in their spectra at. Fitting a resonant scattering model to these allowed to estimate their size too.

Broadband acoustic data identifies different mesopelagic gas-bearing organisms and reveal their spatial and vertical distribution patterns

Mette Dalgaard Agersted[1*], Thor A. Klevjer[1], Babak Khodabandeloo[2], Yi Liu[2], Webjørn Melle[1]

[1]*Plankton research group, Institute of Marine Research, P.O.Box 1870 Nordnes, NO-5817 Bergen, Norway*

[2]*Ecosystem acoustics research group, Institute of Marine Research, P.O.Box 1870 Nordnes, NO-5817 Bergen, Norway, mette.dalgaard.agersted@hi.no, thor.klevjer@hi.no, babak.khodabandeloo@hi.no, prs_liuyi@hotmail.com, webjoern.melle@hi.no*

Broadband acoustic data was collected by a submerged acoustic platform within the mesopelagic zone (200-1000 m depth) in the central Northeast Atlantic. Mesopelagic gas-bearing targets were separated into seven different target groups by applying an unsupervised clustering algorithm on their broadband acoustic (54-78 kHz) backscattering frequency responses. Densities and vertical distribution patterns of the different target types, estimated by echo counting, differed between areas, and three distinct regions were observed: south (<20°N), central (22-40°N) and north (>40°N). The frequency response data suggests that a large part (>30%) of the mesopelagic gas-bearing targets had a resonance frequency closer to 70 kHz than to 38 kHz, and low backscattering at 38 kHz. This would result in underestimation of abundance/biomass when applying acoustic data measured at 38 kHz and assuming resonance close to this frequency, which is often the case in mesopelagic studies. This conceptual study highlights the importance of separating targets into different target groups in order to obtain correct backscatter information for more accurate abundance estimates. It furthermore demonstrates an application of broadband acoustic data to investigate and obtain knowledge on mesopelagic organisms and mesopelagic ecosystem structure.

Unsupervised clustering of wideband acoustic probe measurements reveals the vertical structure of a mesopelagic fish community

Julek Chawarski[1], David Coté[2], Maxime Geoffroy[1,3]

[1]*Centre for Fisheries Ecosystems Research, Marine Institute of Memorial University of Newfoundland and Labrador, St. John's, NL, Canada*

[2]*Fisheries and Oceans Canada, Northwest Atlantic Fisheries Centre, St. John's, NL, Canada*

[3]*Faculty of Biosciences, Fisheries and Economics, UiT The Arctic University of Norway, N-9037 Tromsø, Norway*

Mesopelagic fish are widespread and abundant in the global oceans. They play an important role in nutrient cycling via the biological carbon pump and could be targeted by future fisheries. However, great uncertainty remains around biomass estimates of mesopelagic fish due to difficulties in estimating their size and density. Using a lowered wideband acoustic probe paired with shipboard acoustics and biological sampling, we investigated the applicability of unsupervised clustering coupled with echo-trace detection to classify frequency-response curves. This approach provided new insights into the vertical structure of mesopelagic fish of the Labrador Sea. The glacier lanternfish *Benthosema glaciale* dominated the mesopelagic fish community and their Target Strength generally increased with depth, suggesting a vertical zonation in size. Furthermore, daily vertical migration patterns were restricted to smaller fish residing above 450 m. Density estimates based on echo counting varied between 0.8 to 4.5 ind. 10^{-3} m^{-3} The minimal parameterization used our analysis offers an example of a semi-automated acoustic analysis framework that could increase precision of mesopelagic fish surveys and improve our understanding of pelagic fish ecology.

First approach to unsupervised classification of broadband fisheries acoustic data for ecosystem monitoring

Alicia Maurice[1], Laurent Berger[2], Mathieu Doray[3]

[1]*Ifremer, Unité Ecologie et Modèles pour l'Halieutique, rue de l'Ile d'Yeu, B.P. 21105, 44311 Nantes Cedex 03, e-mail: alicia.maurice@ifremer.fr*

[2]*Ifremer, Centre Bretagne - ZI de la Pointe du Diable - CS 10070 - 29280 Plouzané, e-mail: laurent.berger@ifremer.fr*

[3] *Ifremer, Unité Ecologie et Modèles pour l'Halieutique, rue de l'Ile d'Yeu, B.P. 21105, 44311 Nantes Cedex 03, e-mail: mathieu.doray@ifremer.fr .*

The commercial availability of a calibrated broadband echosounder system operating at fisheries acoustic frequencies on a variety of platforms (vessels, moorings, gliders, drones …) has led to an increase of broadband fisheries acoustic data collection. Broadband acoustic images (BAI) provide detailed spectral information which can be used to classify a larger variety of scatterers. However, their handling and analysis poses computational, analytical ('curse of dimensionality') and validation challenges. Building upon the hyperspectral image community legacy, we present the first results of unsupervised classifications of BAI collected near an offshore windmill in the Bay of Biscay (BoB, France). BAI were produced by echo-integrating broadband fisheries acoustic data on a fine mesh grid, using the pymovies_3D Python package. Shallow dimension reduction and classification techniques were tested on a reference dataset comprising spectral broadband signatures of scatterers identified in the BoB. Classification techniques performing well on this standard reference 'echoscape' were then applied to classify in-situ BAI, in an attempt to detect areas where scatterers form groups with similar spectral properties. Mean frequency spectra of identified clusters will be compared to scaterrers models and biological sampling data collected in the area, in an attempt to characterise the local pelagic ecosystem.

Identifying Atlantic herring schools from decades of multifrequency echosounder data using unsupervised machine learning

Yawen Zhang[1], Michael Jech[2], Qin Lv[1], and Carrie Wall[3,4]

[1] *University of Colorado Boulder, Department of Computer Science*

[2] *NOAA Northeast Fisheries Science Center*

[3] *University of Colorado Boulder, Cooperative Institute for Research in Environmental Sciences*

[4] *NOAA National Centers for Environmental Information*

In 1999, the NOAA Northeast Fisheries Science Center began acoustic-trawl surveys to monitor the Atlantic herring (*Clupea harengus*) population in the Gulf of Maine and Georges Bank due to the stocks important economic and ecological role for the commercial lobster industry. To date, scientists rely on manual scrutiny or limited automation to analyze these data by delineating noise and acoustic signals from which statistical analyses can be applied. These manual methods are time-consuming and impractical for large scale studies. To address the challenge of efficiently analyzing these large, complex datasets, we have applied machine learning to identify patterns related to Atlantic herring. We focused on calibrated, multiple frequency single-beam data collected from 1999 to 2019 off the Atlantic coast that are archived at the NOAA National Centers for Environmental Information and accessible online through Amazon Web Services. Based on the biologist's step-by-step process to identify Atlantic herring schools, we investigated methods that can automate this process. Our new pipeline consists of 3 steps: (1) applying a contour-based method to detect potential targets, (2) automatically extracting different categories of features, (3) applying a clustering method to identify herring schools. We will explore different scales of data in different regions, evaluate the latency of pattern analysis, and validate the accuracy of the patterns found with domain experts.

Sizing of vertically migrant mesopelagic fish species using low-frequency broadband acoustics

Escobar-Flores, P.C.[1], Ladroit, Y.[1], O'Driscoll, R.L.[1]

[1]*National Institute of Water and Atmospheric Research, 301 Evans Bay Parade, Hataitai, Wellington 6021, New Zealand*

Low-frequency broadband acoustics can provide useful information about the acoustic properties and size distribution of mesopelagic organisms. Most mesopelagic fish species undergo diel vertical migration (DVM), experiencing large changes in pressure that alter the acoustic properties of gas-bearing swimbladders species. The dominant species of the mesopelagic fish community around New Zealand, the myctophid *Lampanyctodes hectoris* and the sternoptychid *Maurolicus australis*, undergo DVM as dense and continuous scattering layers. We collected opportunistic wideband data (covering 12 to 200 kHz) onboard RV Tangaroa, where we observed migrating layers of *L. hectoris* and *M. australis*. We fitted a normalised volumetric scattering model to the frequency response of different sections of the migrating layers and estimated the scale and shape parameter of a Weibull distribution to describe the size range of targets contained in the associated volume. From these results, assuming a proportion of fish volume occupied by the swimbladder, we were able to calculate the size distribution of fish and to observe changes in swimbladder size during the DVM.

On the development of acoustic descriptors for semi-demersal fish identification to support monitoring stocks

Réka Domokos[1]

[1]*Ecosystems Sciences Division, Pacific Islands Fisheries Science Center, National Marine Fisheries Service, NOAA, 1845 Wasp Blvd, Bldg. 176, Honolulu, HI 96818, reka.domokos@noaa.gov.*

Despite worldwide economic importance of lutjanid snappers, there are critical data gaps hindering accurate abundance estimates of these species, impeding stock management efforts. Development of an active acoustics method could fill many of these data gaps, significantly benefiting stock assessment of snapper species that form typically mixed-species assemblages in non-trawlable regions. These methods are well suited for resource surveys but require the ability to derive accurate size estimates from target strength (TS) and the separation of echoes from species within the stock. This work evaluates the feasibility of active acoustics for surveying a Hawaiian bottomfish stock, referred to as the Deep-7 complex, consisting of six species of lutjanid snappers and a single grouper. Acoustic backscatter data and complementary methodologies were used to model TS and develop acoustic descriptors such as aggregation shape, size, and density, individual swimming pattern, distance from bottom, and bottom depth for Deep-7 species. Paired observations of *in situ* TS and fork-length (FL) gave an estimated bulk relationship of $23.01 \cdot \log_{10}(\mathrm{FL}) - 72.18$. The success of 25 accuracy tests indicates the effectiveness of the developed echo allocation parameters. Preliminary results imply that acoustics could be successfully used to monitor Deep-7 with broader applicability upon adapting methodology to other regions.

E-Score: A new approach to improve multifrequency classification

Gary VARGAS[1], Gildas ROUDAUT[2], Anne LEBOURGES-DHAUSSY[2], Jérémie HABASQUE[2], Alejandro ARIZA[3], LUCENA FRÉDOU Flávia[1], Arnaud BERTRAND[3]

[1]*Universidade Federal Rural de Pernambuco, Recife, Brazil, garyrvc@gmail.com; flavia.lucena@pq.cnpq.br;* [2]*Institut de Recherche pour le Développement (IRD), UMR 6539 LEMAR IFREMER/IRD/CNRS/UBO, Technopole Brest Iroise, 29280 Plouzané, France, gildas.roudaut@ird.fr, anne.lebourges.dhaussy@ird.fr, jeremie.habasque@ird.fr;* [3]*IRD, MARBEC, Univ. Montpellier, CNRS, Ifremer, IRD, Sète, France, alejandro.ariza@ird.fr, arnaud.bertrand@ird.fr.*

Multifrequency classification is still an ongoing science, particularly in high species diversity ecosystems. Here, we propose a semi supervised classification method based on the relative frequency response (E-score). It consists in defining ellipses in the multifrequency space to classify acoustics groups called echoclasses. In a first step, we identified and isolate a large number (~1000) of structures of homogeneous relative frequency response named 'echotype' using k-means clustering. Second, we decompose the shape of S_v differences frequency distribution using Functional PCA multifrequency S_v values of each echotype. Third, we use a hierarchical clustering on a suitable number of these principal components to classify the multifrequency functions into echoclasses. Finally, using all multifrequency data corresponding to each echoclass, we delineated echoclasses in the multifrequency space by using an ellipse with confidence interval. This method was applied on multifrequencies (38, 70 and 120 kHz) data collected off northeast Brazil in spring 2015 and fall 2017, a tropical region characterized by a high biodiversity. Six and seven echoclasses were defined for each survey, respectively. The results showed coherent distribution of echoclasses corresponding to specific assemblages of scatters (e.g. fish-like, fluid-like). The validation of the method is performed on the base of trawl sampling.

AZKABAN: An *ex situ* experiment for informing the inverse method

Muriel Dunn[1,4], Geir Pedersen[2], Sünnje Basedow[3], Malin Daase[3], Lionel Camus[4], Stig Falk-Petersen[4] and Maxime Geoffroy[1,3]

[1]*Fisheries and Marine Institute of Memorial University of Newfoundland, 155 Ridge Rd, St. John's, NL A1C 5R3, Canada, mbd@akvaplan.niva.no, maxime.geoffroy@mi.mun.ca;*

[2]*Institute of Marine Research, Nykirkekaien 1, 5004, Bergen, geir.pedersen@hi.no;*

[3]*UiT the Arctic University of Norway, Hansine Hansens veg 18, 9019 Tromsø, sunnje.basedow@uit.no, malin.daase@uit.no;*

[4]*Akvaplan-niva, Hjalmar Johansens gate 14, 9007 Tromsø, lionel.camus@akvaplan.niva.no, stig.falk.petersen@akvaplan.niva.no;*

Autonomous vehicles equipped with echosounders can dramatically extend the spatial and temporal resolution of a research cruise, but active acoustic data still rely on additional data sources for biological estimates. Here, we use the inverse method to predict the abundance of targets in a sound scattering layer. Limitations of the inverse method have been reduced by recent developments and improvements to broadband echosounders and scattering models. Furthermore, we inform the inverse method by providing size measurements of acoustically-dominant scatterers to the scattering models. To explore the capabilities of the informed inverse method, we designed the AZKABAN (Arrested Zooplankton Kept Alive for Broadband Acoustic Net) experiment, a 2 m x 2 m x 8 m aluminium frame that holds a WBAT and transducer 4m above a 12 000 L cuboid zooplankton net. We calibrated two split-beam transducers (200 kHz and 333 kHz) inside AZKABAN before populating the net with monocultures of copepods and cod larvae. Calibration results suggest that measurements from AZKABAN will permit a sensitivity analysis of the informed inverse method. For a given ecosystem, validating the informed inverse method could improve the abundance estimates from acoustic data collected with autonomous vehicles.

Viscous-Elastic fluid filled sphere for target strength model of swimbladdered mesopelagic fish

Babak Khodabandeloo[1*], Mette Dalgaard Agersted[2], Thor A. Klevjer[2], Gavin J. Macaulay[1], and Webjørn Melle[2]

[1]*Ecosystem acoustics research group, Institute of Marine Research, P.O.Box 1870 Nordnes, NO-5817 Bergen, Norway*

[2]*Plankton research group, Institute of Marine Research, P.O.Box 1870 Nordnes, NO-5817 Bergen, Norway*

[*]*babak.khodabandeloo@hi.no; mette.dalgaard.agersted@hi.no; thor.klevjer@hi.no;*

gavin.macaulay@hi.no; webjoern.melle@hi.no.

Backscattering models are useful tools to understand the measured backscattered acoustics and to deduce the biological information such as size, weight, and species identification. Gas bearing organisms, e.g. swimbladdered fish, are strong acoustic reflectors and acoustically distinct from organisms lacking one. Here, target strength of organisms were measured *in situ* over a wideband (38 and 50-260 kHz) using a towed platform between 200-1000 m depth. Based on biological sampling (trawl and multinet) and photographic evidences, the measured gas bearing organisms are most likely swimbladdered mesopelagic fish, not physonect siphonophores. Subsequently, backscattering was modelled over the wide frequency range using a two layers viscous-elastic spherical gas model and compared to the measured TS of individuals. The model includes a spherical gas (swimbladder) which is surrounded by an elastic layer (swimbladder wall tissue) encompassed by a viscous layer (fish flesh). The model captures not only the measured TS in the resonance region, but also some of the observed features at higher frequencies. Using this physics-based model, the estimated parameters can be better related to the physical properties of fish.

Emerging Technologies, methodologies, and Protocols

An acoustic approach to estimate the Mixed Layer Depth

Fabio Campanella[1], Jeroen van der Kooij[1], Liam Fernand[1]

[1]*Centre for Environment, Fisheries and Aquaculture Science. Pakefield Rd, Lowestoft, NR33 0HT, UK*

The depth of the surface mixed layer (MLD) in the world oceans is an important characteristic that influences many physical and chemical and biological processes in the water column. Where shelf waters stratify, the mixed layer depth (MLD) is delineated by the pycnocline. Changes of the extent of this layer affect the exchange of gases, heat, mass and momentum between the ocean and the atmosphere. Recent studies have highlighted the possibility of measuring water stratification using active acoustic through scientific echosounders. In this work we apply a method to detect and map the distribution of stratification by using narrowband echosounder data collected over a large area that included the Western English Channel and Celtic Sea from 2012 to 2019. The approach is based on the identification of the scattering layers located at the depth of the pycnocline that can be attributed to biological scattering or direct scattering from the oceanic microstructure in the water column. The relationship between the thermocline and the scattering layers was modelled using machine learning methods to predict the intensity and extent of the stratification with large scale in the whole study area. The approach was effective at identifying areas of stratification with a very good level of accuracy and relatively low computational time.

Zooglider: an autonomous underwater glider for concurrent physical, optical and acoustic sensing of marine ecosystems

Sven Gastauer[1,2], Jeffrey S. Ellen[3], Mark D. Ohman[1]

[1] *Scripps Institution of Oceanography/University of California, San Diego, La Jolla, California*

[2] *Thünen Institute for Sea Fisheries, Bremerhaven, Germany*

[3] *NIWC Pacific, San Diego*

Zooglider is an autonomous buoyancy-driven modified Spray ocean glider designed and built by the Instrument Development Group at Scripps. *Zooglider* includes a low power camera with a telecentric lens for shadowgraph imaging, a CTD unit with a fluorescence counter and two custom active acoustics echosounders (operated at 200/1000 kHz). The imaging system (Zoocam) allows a quantitative identification of particles with a size >0.25 mm and a count estimate of smaller particles. Two way communication when at station allows for adaptive sampling. Vertical sampling resolution is typically 5 cm, maximum operating depth is ~500 m, and mission duration up to 50 days. Post-deployment processing methodology classifies the optical images using advanced Deep Learning methods that utilize context metadata. *Zooglider* permits in situ measurements of mesozooplankton and marine snow in relation to other biotic and physical properties of the ocean water column. Here we present lessons learned, our current state of the Deep Learning optical identification, acoustic processing, near real-time data visualization for improved sampling strategies and the added value of a hydrophone.

Uncrewed surface vehicle (USV) survey of walleye pollock, *Gadus chalcogrammus*, in response to the cancellation of ship-based surveys

Alex De Robertis[1], Mike Levine[1], Nathan Lauffenburger[1], Taina Honkalehto[1], James Ianelli[1], Cole C. Monnahan[1], Rick Towler[1], Darin Jones[1], Sarah Stienessen[1], Denise McKelvey[1]

[1]*NOAA Fisheries, Alaska Fisheries Science Center 7600 Sand Point Way, NE Seattle WA 98115, USA*

In 2020, the developing COVID-19 pandemic disrupted fisheries surveys to an unprecedented extent. Many surveys were cancelled, including those for walleye pollock (*Gadus chalcogrammus*) in the Eastern Bering Sea (EBS), which is the largest fishery in the United States. To partially mitigate the loss of survey information we conducted a survey with uncrewed surface vehicles (USVs) equipped with echosounders. The goal was to provide data to extend the acoustic-trawl time series of pollock abundance ordinarily sampled with a fully crewed research vessel. Trawling was not possible from the USVs, so backscatter measurements were converted to pollock biomass based on an empirical relationship between pollock backscatter and biomass from previous surveys. The EBS is well-suited for this approach since pollock dominate midwater fishes in this area. This application demonstrates the unique capabilities of USVs and how they could be rapidly deployed to collect information on pollock abundance and distribution when ships were not available. We note the limitations of this approach (e.g., higher uncertainty relative to ship-based surveys) but found the results to be useful in informing the stock assessment in a situation where it was not possible to do so by other means.

Comparison of abundance and biomass estimates from an acoustic survey conducted by a NOAA Fisheries Survey Vessel and Uncrewed Surface Vehicles

Dezhang Chu[1], Julia Clemons[2], Steve de Blois[1], Stéphane Gauthier[3], Lawrence C. Hufnagle[1], John Pohl[1], Sandra Parker-Stetter[1,4], Chelsea Stanley[3], Rebecca Thomas[1]

[1]*NOAA Fisheries, Northwest Fisheries Science Center, 2725 Montlake Boulevard East Seattle, Washington 98112, USA, dezhang.Chu@noaa.gov, steve.deblois@noaa.gov, lawrence.c.hufnagle@noaa.gov, john.pohl@noaa.gov, sandy.parker-stetter@noaa.gov, rebecca.thomas@noaa.gov*

[2]*NOAA Fisheries, Northwest Fisheries Science Center, 2030 SE Marine Science Drive, Newport, OR 97365, USA, julia.clemons@noaa.govste*

[3]*Fisheries and Oceans Canada, Institute of Ocean Sciences, Sidney, BC, Canada, stephane.gauthier@dfo-mpo.gc.ca, Chelsea.Stanley@dfo-mpo.gc.ca;*

[4]*NOAA Fisheries, Alaska Fisheries Science Center, 7600 Sand Point Way N.E., Building 4, Seattle, WA 98115, USA, sandy.parker-stetter@noaa.gov*

The Northwest Fisheries Science Center and Fisheries and Oceans Canada conducted a joint Pacific Hake coast-wide acoustic-trawl survey off the west coasts of the United States and Canada in the summer of 2019 with a NOAA FSV (*Bell Shimada*) and a Canadian F/V (*Nordic Pearl*) from South to North. Five Uncrewed Surface Vehicles (USV, Saildrones) simultaneously surveyed the area from approximately 34.5° N to 48° N, covering the same survey area as *Bell Shimada*. Five Saildrones were equipped with an EK80 WBT Mini and a Combi (38/200 kHz) transducer. All USV echosounders were calibrated prior to the survey. Approximately 68% of Saildrone transects were within +/-3 days of Shimada transects. The Saildrone acoustic data were analyzed by experienced scientists to identify Hake aggregations without the biological trawl data collected by FSV. Hake biomass were estimated based on the biological information extracted from the U.S. A-SHOP data. The estimated Hake abundance and biomass based on Saildrone and A-SHOP data were about 71% and 78%, respectively, of those estimated from the FSV-based acoustic and trawl data. The reasons for such differences are being investigated with a preliminary analysis suggesting that temporal variability in hake distribution could likely be a major factor.

Species composition for acoustic biomass estimation: could environmental DNA be used?

V. Trenkel[1], P. Calvy[1], L. Berger[2], and P. Lorance[1]

[1]*Ifremer, rue de l'île d'Yeu, 44311 Nantes cedex 3, France, verena.trenkel@ifremer.fr, pascal.lorance@ifremer.fr* [2]*Ifremer, 1625 route de Sainte-Anne, 29280 Plouzané, France, laurent.berger@ifremer.fr.*

The blackspot seabream (*Pagellus bogaraveo*) was the fourth demersal species in landings from the Bay of Biscay (Northeast Atlantic) in the 1960s and 1970s. At the time, it was probably the second species in value. In the 1980s, the stock collapsed from overexploitation and catches have remained at low level since. Currently little is known about its stock status. The French longline fishery is concentrated on small rocky plateaus off Britany. To attempt collecting information on local biomass an acoustic survey was carried out using handlining for species composition and size distribution. Several challenges were encountered, an important one being the very selective nature of longlining. As an alternative method to handlining, the following year an environmental DNA (eDNA) survey was carried out in the same area. For this, surface water was filtered along transects and DNA shed by organisms into the water was extracted from the filters. Using metabarcoding and qPCR this provided semi-quantitative information on species composition. In this presentation we will discuss ideas on how and when eDNA could be combined with acoustics.

Direct measurements of the migration speed of spawning herring

Egil Ona[1], Guosong Zhang[1], Nils Olav Handegard[1], Sverre Berg[2], and Lars N. Andersen[2]

[1]*Institute of Marine Research, P.O.Box 1870, Bergen, Norway, Egil.ona@imr.no, Guosong.zhang@imr.no, Nils.Olav.Handegard@imr.no ;*

[2]*Kongsberg Maritime, Strandpromenaden 111, Horten, Norway, Sverre.berg@simrad.com, Lars.Nonboe.Andersen@simrad.com*

The Norwegian Spring Spawning herring stock migrates in January-February each year from the feeding area in the Norwegian Sea to the spawning grounds on the Norwegian coast. The biomass and age composition of the spawning stock is measured with three rented purse seiners in a standard zig-zag survey design. Depending on the progress speed of the survey and its survey design, fish migration may significantly affect in the final spawning stock estimates. Since most

of the fish in this survey migrate in dense layers in midwater or close to the bottom, only a small fraction of the moving biomass can be isolated for sonar school tracking algorithms. In February 2020, a new Kongsberg ES150C, a combined broad band echo sounder and ADCP system was mounted on one of the vessels and logged the raw and processed current data from the system. During the survey, selected data sets with strong herring backscattering were isolated and used to directly measure the migration speed and direction of the herring as well as for the surrounding water masses. For computing a representative mean migration speed for each of 13 strata, we weighed the migration speed with the acoustic density, and evaluated the potential migration error in the spawning stock estimate. Measurement methods, limitations and processing are described.

Nonlinear higher harmonics and crosstalk in broadband multi-channels echosounders

Babak Khodabandeloo[1], Egil Ona[2], Gavin J. Macaulay[3], and Rolf Korneliussen[4]

Ecosystem Acoustics Group, Institute of Marine Research, P.O. Box 1870 Nordnes, 5817 Bergen, Norway

[1]babak.khodabandeloo@hi.no; [2]egil.ona@hi.no; [3]gavin.macaulay@hi.no; [4]rolf.korneliussen@hi.no;

One of the prominent features of nonlinear acoustic propagation is the dependence of propagation speed on the acoustic pressure amplitude. A consequence is the distortion of the transmitted acoustic signal as it propagates through the medium, and hence energy leakage from the primary frequency band to harmonic frequencies. When operating several broadband echosounder channels with non-overlapping frequency bands, the generated higher harmonics from one channel may overlap and interfere with the primary frequency band of others. This interference is called crosstalk and can appear as spurious targets above and/or below the main target in pulse compressed echograms and. in addition, affect the measured backscattering frequency response of targets. Here, the nonlinear propagation of frequency-modulated acoustic waves in a directional beam are modelled and suggestions are made to reduce the crosstalk for simultaneous operation. Efficiency of the suggested method is demonstrated by measurements on the strong echo from a flat seafloor. In addition, synchronized operation of broadband echosounder channels with reduced crosstalk is confirmed by comparing the measured and theoretically estimated target strength of a calibration sphere.

SPAAMS: Solar-Powered, Autonomous, Acoustic Monitoring Systems on the Tonle Sap River, Cambodia

J.K. Horne[1], J.A. Swan[1], T.J. Tracy II[2], and G.W. Holtgrieve[1]

[1]School of Aquatic and Fishery Sciences, Box 355020, Seattle, WA 98195, USA, jhorne@uw.edu, jswan13@uw.edu, gholt@uw.edu;

[2]University of Virginia, Dept. of Computer Engineering, PO Box 400740 Charlottesville, VA 22904, tjt7a@virginia.edu

The challenge was to design an autonomous monitoring system to characterize fish migration and fishing mortality in the commercial Cambodian Dai fishery. The solution was to integrate a Kongsberg WBT mini echosounder (200 kHz), solar power, and an internet-of-things, built cellular endpoint as a monitoring package for deployment on upstream and downstream commercial fishing platforms. The echosounder was programmed to sample at 1 Hz for 15 minutes every hour of the day. The solar panel and controller supplied DC power to the echosounder, communications module, and to a battery for power during dark hours. The built cellular endpoint was a Raspberry Pi combined with a cellular modem that accessed the local wireless network to transmit raw data files to an AWS server in Singapore. The data were accessed by the Pi from the WBT

mini USB drive through a latchable hub during the 15 minutes after data acquisition. Once data were uploaded, they can be accessed on the AWS server using the SFTP protocol and downloaded for processing and analysis. Two monitoring systems were deployed from November through February, collecting data through the entire period. Fish were sampled over 24 periods once every 2 weeks.

A new *In-situ* method to estimate fish target strength

James Dunning[1], Teunis Jansen[2], Alan J. Fenwick[1], and Paul G. Fernandes[1]

[1]*University of Aberdeen, Zoology Building, University of Aberdeen, Tillydrone Avenue, Aberdeen, AB24 2TZ, UK*

j.dunning.18@abdn.ac.uk, a.j.fenwick@abdn.ac.uk, fernandespg@abdn.ac.uk

[2]*Technical University of Denmark, Anker Engelunds Vej 1, Building 101A, 2800 Kgs. Lyngby, tej@aqua.dtu.dk*

This study describes a novel *in-situ* method to estimate TS as a function of length (L), according to the standard equation $TS=20\log(L)+b_{20}$, where b_{20} is the species-specific factor to be estimated. A split-beam 38 kHz broadband transducer was pole-mounted on a stationary boat. Echotraces of single Atlantic cod (*Gadus morhua*) were identified on the echogram before deploying a fishing line, mounted with an underwater video-camera, to catch the fish. The fish were then measured in length and released. Video footage was inspected to verify a single individual attempted the bait. Measured TS was adjusted for tilt (inferred acoustically) with the use of a Kirchhoff-Approximation scattering model. The b_{20} was estimated by linear regression. Results yielded a b_{20} of -71.5 dB (± 0.67 dB C.I.). TS was observed with large variability within fish tracks (average s.d.= 4.66 dB). The low TS and high variability could not be attributed to the fish length and tilt angle. Fish physiological, behavioural aspects, and properties of broadband acoustics are considered. This method combines the benefits of associating TS from single fish of known length, typical of *ex-situ* methods, with the *in-situ* advantages of measuring the TS in their natural environment.