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

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

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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.

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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

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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

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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

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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

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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

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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

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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?

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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

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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.

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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

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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

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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 sandeeI 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.

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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

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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

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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

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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

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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

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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

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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

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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

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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

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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

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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

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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

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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

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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

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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

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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

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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

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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?

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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

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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

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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

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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

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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.