ICES SYMPOSIUM

MARINE ECOSYSTEM ACOUSTICS – OBSERVING THE OCEAN INTERIOR IN SUPPORT OF INTEGRATED MANAGEMENT

25-28 MAY 2015
NANTES, FRANCE
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BOOK OF ABSTRACTS

We thank the following commercial sponsors for their support:

Symposium Overview

Marine ecosystem acoustics is an approach that utilizes acoustics as the primary tool for understanding, assessing, and monitoring marine ecosystems. The approach holds the potential of becoming a principal contributor to operational Ecosystem Based Management (EBM). It is part of the strategy to move towards integrated management within ICES, but also elsewhere. The potential of marine ecosystem acoustics cannot be realized without systematic cross disciplinary interactions and cooperation within fields such as fisheries acoustics, physics, engineering, biology, oceanography, ecology, and ecosystem modelling. The ability of acoustics to resolve ecosystem processes at the spatio-temporal scales at which they occur fosters improved and new ecosystem understanding, such as quantification of physical forcing and biological responses, and patterns in prey-predator distribution and interactions, which are a prerequisite for EBM.

The primary aim of this symposium is to bring together scientists and ideas from various fields to facilitate and catalyze interdisciplinary interactions with acoustics as the central tool to further the development of marine ecosystem acoustics.

The Symposium will review and discuss recent developments in acoustic methods and technologies used to characterize and manage marine and freshwater ecosystems. Particular emphasis will be placed on technologies used to measure diverse aspects of the aquatic environment, techniques for data analysis, and the integration of multiple data sets to elucidate functional ecological relationships and processes. Contemporary challenges and future directions of these objectives will be identified.

This is the 7th ICES sponsored Symposium on Fisheries Acoustics and Technology investigating aquatic ecosystems. Previous symposia were held in Bergen, Norway (1973, 1982, and 2008), in Seattle, USA (1987), in Aberdeen, Scotland (1995), and in Montpellier, France (2002).

The Symposium is organized around three main themes:

1. Recent developments in acoustic sensor and platform technologies
2. Acoustic characterization of aquatic organisms, ecosystem structure, and ecosystem processes
3. The contribution of acoustics to integrated ecosystem assessments and management.

Several sessions are set up for each main theme. Keynote speakers will give talks on the major themes.

Symposium Convenors

Nils Olav Handegard, Institute of Marine Research, Norway
Verena Trenkel, Institut Francais de Recherche Pour l’Exploration de la Mer, France
Tom Weber, University of New Hampshire, USA

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Pierre Petitgas, Institut français de recherche pour l'exploitation de la mer, France
Xianyong Zhao, Yellow Sea Fisheries Research Institute, China

Keynote Addresses

Advances in Platforms and Sensor Technologies to Support Integrated Management

Jules S. Jaffe, Marine Physical Lab, Scripps Oceanography, U. C. San Diego.
Monday, May 25, 2015 09:30-10:15; Auditorium 450

As pelagic ecosystems continue to be stressed by human encroachment, it becomes increasingly important to have improved information about species distribution and abundance for integrated management. With improvements in sensor technologies and deployment from a variety of platforms, opportunities exist for obtaining this information. In the case of optics and acoustics, the ever-decreasing costs with enhanced performance presents new opportunities. In addition, many benefits can be envisioned by deploying these new sensors using swarms of smaller, ultra quiet, autonomous underwater vehicles. In this presentation I will present results from my group that have addressed these issues on several frontiers. In one case, we measured in situ wide-band target strength with concurrent optical imaging of zooplankton to identify the taxa, size, and orientation dependence. We have also developed a new scanning laser LIDAR imaging system for autonomous vehicle deployment that could be combined with active sonar to achieve similar results obtained with the plankton, only now on larger, more motile organisms. Our current program in developing very small underwater vehicles recently resulted in measurement of 3-dimensional currents using a swarm of 16 miniature, self-ballasting vehicles. Equipped with a sensitive hydrophone the mini-floats are envisioned to be useful in measuring sonic landscapes. With increasing demand for quantitative assessment of ecosystem status, the development of a next generation of less expensive, more definitive tools for providing this information beckons.

From scatters to processes

Arnaud Bertrand, Institut de Recherche pour le Développement (IRD), France.
Tuesday, May 26, 2015 14:00-14:45; Auditorium 450

Living organisms follow non-random yet non-uniform distributions and tend to aggregate in patches. Both physical forcing and organism behaviour are implicit in the initiation and maintenance of this patchiness, with the latter increasing in importance with each step up the trophic chain. Observations on fine scale ocean dynamics (10 m to kms) do exist but are too fragmented to facilitate the development of comprehensive models over a range of scales. For this reason, the incorporation of these processes in models of marine ecosystem dynamics is still in its infancy, particularly at scales below the mesoscale. Underwater acoustic techniques have an unrealized potential for multi- component observations of abiotic and biotic characteristics that can overcome previous limitations. A growing number of studies is taking advantage of recent improvements (e.g. multifrequency, broad band) to simultaneously characterise physical structures (e.g. thin layers, internal waves, submeso- and mesoscale eddies) and organisms patterns of distribution across scales from meters to thousands of kilometres. From several examples, this presentation aims at illustrating the potential of acoustics to obtain simultaneous information on ecosystems abiotic and biotic structures, which permit to study genuine processes (i.e. not simple correlations). We will see how across-scale structures that create hotspots, which concentrate organisms ranging from zooplankton to seabirds, and that behaviour can magnify this physically-induced bottom-up spatial structuring.

Tips for acoustic scientists on exploiting the gold mine: integrated ecosystem assessments

Mark Dickey-Collas, ICES, Copenhagen

Thursday, 28 May, 2015 11:00-11:45; Auditorium 450

In this presentation I shall look at what integrated ecosystem assessment (IEA) means to different people. I will show that IEAs make assessments more complex and multi-layered. Understanding the impacts of human pressures on the state of the ecosystem is central to IEA. The challenge for us biologists, ecologists and physicists is that we must now engage with societal governance issues like never before. In the IEA system, science is used to describe and explore the panorama of the ecosystem for decision makers. There is no right answer. When working in the IEA system we must learn to synthesise information of varying credibilities and qualities. Acoustic techniques have many characteristics that are of great value to IEA – they are non-destructive, provide spatial information and provide huge amounts of real time 3D data at varying resolutions. These data are underutilized and deserve more attention. But data are no knowledge; we cannot manage on the basis of data streams only. So the challenge to acoustic scientists is to turn the data gold mine into a knowledge goldmine.

SECTION I

ABSTRACTS FOR ORAL PRESENTATIONS

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Long-term buoy-based observations of fish and zooplankton behavior and abundance, and their environment

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Acoustic-trawl surveys are routinely conducted in the California Current to estimate the distributions and abundances of hake and Pacific sardine, other species of fish, and zooplankton. Hake and sardine typically spawn in the Southern California Bight (SCB) from January to March and March to May, respectively, migrate north during late spring and summer to feed off Oregon, Washington, and British Columbia, and then migrate back to the SCB in the fall. These behaviors, and recruitment successes, are modulated by intra- and inter-annual variations in the environment. To continuously monitor physical-chemical forcing and biotic responses, instrumented buoys are positioned in the oceanic and upwelling regions off Point Conception (located between the nominal spawning and feeding regions), and nearshore in the SCB. In addition to measuring the physical, chemical, and planktonic environment, these buoys acoustically resolve fish and zooplankton to approximately 300-m depth using a customized echosounder with an adaptive-sampling camera. These data are used to monitor diel and seasonal migration times and rates; adapt shipboard sampling; characterize the three-dimensional habitats of fishes; and enable differentiation of landings from sub-populations. A three-year time-series suggests that an expanded array of instrumented moorings could provide data to estimate the biomasses of migrating fish populations.

Insights into deep-sea seamount ecosystems from moored echosounders

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The use of acoustic surveys combined with trawling is the main method for monitoring the abundance of New Zealand deepwater fish populations. The need to understand variables such as species composition, target strength, acoustic availability of fish, and trawl performance, makes this a complex process with a high level of uncertainty. The recent use of moorings combining complementary acoustical and optical technology has provided new insights, and led us to a better understanding of the advantages and limitations of both observation techniques. The approach is illustrated using data from two mooring deployments on the Morgue seamount on the north Chatham Rise, where an important aggregation of orange roughy occurs. Acoustic measurements of fish tracks from a moored 38 kHz Simrad EK60 echosounder allowed us to observe the evolution of the target strength distribution over time, providing information on changes in species composition. The results of the acoustic analysis were then be matched to video observations giving indications of both species composition and fish density by depth.

Do Antarctic krill avoid underwater gliders?

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Antarctic krill (Euphausia superba) is a key species in the marine ecosystem of the Southern Ocean but a better understanding of the response of krill to changes in the physical environment is required. Autonomous Underwater Vehicles (AUVs), such as long-duration gliders carrying acoustic sensors, have been used to map the distribution of Antarctic krill. This has the potential to greatly expand the duration and extent of existing krill monitoring efforts.

Gliders fitted with calibrated 120 kHz single-beam echo-sounders were deployed off the Western Antarctic Peninsula (WAP) to examine on-shelf krill distribution. Gliders are approximately 2 m long, are highly energy efficient and produce very little noise or vibrations. They are thus an ideal platform for surveys of fish and krill, though krill avoidance remains to be quantified.

As the glider descends through the water column, multiple measurements of discrete acoustic targets are made at variable ranges from the echo-sounder. We observed no avoidance of the glider by krill up to a distance of 5 m. However, no krill were observed closer than 5 m to the glider. We discuss the variability within recorded profiles to derive insights into instrument sensitivity and the behavioural consequences to glider survey of krill swarms.

A new platform to acoustically survey deepwater fish from industry trawl nets

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Commercial fishing vessels are often used to survey small or remote fisheries using the echo integration method to quantify biomass. Accurate biomass estimates require high confidence species identification and robust target strength (TS) estimates. For deepwater (700 m to 1000 m) fish such as orange roughy, deeply towed platforms are required to overcome weather, range and frequency dependant limitations of vessel-acoustics. To achieve this from fishing vessels a novel approach has been to utilise the infrastructure of the demersal trawl net and attach an instrumented acoustic-optical system (AOS). The AOS contains multi-frequency acoustics, video and stereo digital cameras while the net can collect biological samples and commercial catch. This has allowed multiple lines of evidence to decode the species composition of complex ecosystems. In appropriate regions comparative vessel mounted and AOS biomass estimates were similar with no systematic bias due to herding or avoidance of the net. Echo integration transect surveys obtained biomass estimates at 38 kHz and 120 kHz using TS estimates based on previous AOS surveys. These biomass estimates are now accepted inputs into stock assessment processes.

Marine Acoustic Telemetry: Tracking Three-Dimensional Fish Behavior

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The persistent monitoring capability provided by acoustic telemetry systems allows us to study behavior, movement, and resource selection of mobile marine animals. Current marine acoustic telemetry systems are challenged by localization errors and limits in the number of animals that can be tracked simultaneously. A newly installed system was designed to provide detection ranges of up to 1 km, to reduce localization errors to less than 1 m, and to increase to 500 the number of unique tags simultaneously tracked. The design builds on the experience of more than a decade developing acoustic telemetry systems for freshwater environments.
Copper rockfish (Sebastes caurinus) were selected for field trials of this new system because their high site-fidelity and small home ranges provide ample opportunity to track individual fish behavior while testing our ability to characterize the movements of a species of interest to management authorities. To evaluate the use of acoustic telemetry for investigating the behavioral responses of the fish to the fine-scale, three-dimensional features of their environment, a high-resolution, photomosaic mapping survey of the seafloor will supplement the telemetry study.

Direct Observation of Predation Using Acoustic Tags

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The application of acoustic tags and 3D tracking technology has proven to be a useful technique for studying fish behavior in fresh water and marine environments. The information collected by tracking tagged fish has been used for evaluating the effectiveness of fish bypass systems at dams and barriers designed to direct migrating fish. However, in many of these studies, predation of the fish species of interest has an impact on the results of the study. In some case, the fact that predation has occurred can be inferred from the fish 3D tracks. However, in many cases, it is isn't possible to infer which tag returns are from free swimming fish and which are from predated fish. This paper describes a new type of acoustic tag that directly detects when the tagged fish has been eaten by a predator. When the predation event is detected, the signal transmitted by the acoustic tag is modified to indicate that predation has occurred while at the same time still providing specific tag identification and a signal suitable for three dimensional tracking. Field results for this new predation detection tag are presented.

The Robotic Revolution in Fisheries Acoustics

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Here, we describe our vision for how an unmanned robotic vehicle, the Liquid Robotics Wave Glider, can be used to transform fisheries acoustics into a science more consistent with the new ocean-observing paradigm. Wave Gliders harness wave energy for propulsion and solar energy to power their communications, control, navigation, and environmental sensing systems. This unique utilization of wave and solar energy allows Wave Gliders to collect acoustic and other ocean environmental data sets for extended periods of time. Recently, we developed a multi-frequency, split-beam echo sounder system for Wave Gliders that enable them to collect acoustic data sets comparable to those collected with manned survey vessels. A fleet of Wave Gliders collecting such data can dramatically improve the synopticity as well as the spatial and temporal coverage of acoustic stock assessment surveys. With improved stock assessments, fisheries managers will have better information to set quotas that maximize yields to fishermen and reduce the likelihood of overfishing. Improved observational capabilities also would enable fisheries scientists and oceanographers to more closely monitor the responses of different fish stocks to climate variability and change.

Echosounders radiation modelling for the assessment of acoustical impact to marine mammals

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Attention is currently focusing on the impact of anthropogenic sound sources on marine life, particularly marine mammals. Indeed, several unusual cetacean strandings linked to high-power sonar operations have been observed in the past, raising considerable reactions in public opinion. Fisheries, oceanography and seafloor-mapping make extensive use of echosounders; this paper aims to present the order of magnitude of sound radiated by such acoustic sources, in relation with their potential impact on marine mammals. The echosounder characteristics and geometrical configurations are first summarized, for both single- and multi-beam configurations. Next, numerical results from several case studies are compared with currently accepted threshold values for marine mammal sound exposure in terms of both maximum received level and cumulative sound exposure level. This comparison makes clear that, while echosounders may transmit at high sound pressure levels, the very short duration of their pulses and their strong spatial selectivity make them unlikely to cause actual damage to marine mammal auditory systems, according to current knowledge. There remains a possibility that echosounders may affect marine mammal behavior at ranges on the order of kilometers; however, the likelihood and biological effects of such behavioral responses to sound remain poorly understood at present.

Characterising the prey field around Blue Whales in the Southern Ocean: A mixed-modality acoustic survey

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In the Southern Ocean Antarctic krill is the staple prey of blue whales. While it has been hypothesised that blue whales play an important role in the Antarctic ecosystem, little is known about their foraging decisions, particularly at small spatial scales. Recently developed passive acoustic systems provide a reliable means for locating blue whales in the Antarctic, and concurrent use of active acoustic systems enables the investigation of not only the distribution and behaviour of blue whales, but also that of their prey. At sub-10 km scales blue whales may forage opportunistically, or alternatively target areas with particular spatial distributions of krill. Using data from vertical echosounders, the distribution of krill in the vicinity of blue whales exhibiting contrasting behaviours was described using school-based metrics, specifically packing density and spatial clustering. Examining the small-scale prey-field will inform spatially explicit modelling of blue whale habitat; if blue whales are insensitive to local small-scale prey distribution, then larger scale modelling may be adequate, conversely blue whale sensitivity to the local prey field will necessitate regular surveys and more detailed modelling.

Passive and active, predator and prey; using acoustics to study interactions between cetaceans and forage fish

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Fisheries acoustics surveys provide potential platforms for deploying passive acoustic equipment to detect cetacean vocalisations. Passive acoustic methods are developing as viable alternatives to visual surveys, particularly for small, inconspicuous species such as the harbour porpoise (Phocoena phocoena). Visual surveys, and passive acoustic monitoring using a towed hydrophone array, were carried out during an acoustic survey of clupeids in the Clyde Sea and surrounding sea lochs, to identify spatial relationships between porpoises and their prey. Methods were developed to process passive acoustic data, successfully identifying porpoise echolocation clicks whilst discriminating them from the transmitted 120 kHz echosounder pulse and its reflections. To date, this has been a confounding factor which has made these survey techniques potentially incompatible. A significantly higher biomass of fish was found in the northernmost regions of the Clyde and high numbers of harbour porpoises were also detected in these regions. As such, the distributions of porpoises and their prey were found to be linked. This study demonstrates that high frequency passive acoustic monitoring can be used effectively alongside multifrequency fisheries echosounder surveys to provide novel insights into the trophic interactions between these species, and inform management in line with the ecosystem approach to fisheries.

Neural Networks for the localization of biological and anthropogenic sources at neutrino deep sea telescope

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In the Ligurian sea takes place an outstanding joint effort between astroparticle physicists and marine
biologists named ANTARES. Astrophysics and marine biology come to work closely at underwater observatories which can
be used on the one hand for the light and acoustic detection and localization of high energy neutrinos and on the other hand to acquire information about deep sea marine organisms and in particular marine mammals. This is currently the largest neutrino telescope operating in the Northern Hemisphere.
This presentation will describe the methods and results obtained for tracking in real-time both the movements of a set of widely spread 36 acoustic sensors and the movements of nearby marine mammals and ships in real-time.
An extremely interesting part of this research was certainly the use of neural networks to estimate the position of the sensors. The neural networks provided an elegant closed form solution with a satisfying accuracy in real-time.
The neural network approach for localization furthermore proved in this context that it would also be a suitable technique for the growing range of systems requiring low energy consumptionand thorough resource management such as autonomous underwater vehicles and wavegliders.

Migration timing of fin whales monitored by passive acoustic method in the southern Chukchi Sea

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Migration timing of fin whales (Balaenoptera physalus) to the Arctic Sea are suggested to be triggered by plankton influx from the Bering Sea, and/or soaring of local productivity. Using passive and active acoustic monitoring method, we aimed to understand the relationship between migration timing of fin whales to the southern Chukchi Sea and physical and biological environments. We deployed an Acoustic Underwater Sound Monitoring System and an Acoustic Zooplankton Fish Profiler in the southern Chukchi Sea from June 2012 to June 2014. Simultaneously, sea temperature, salinity and sea ice concentrations were observed by additional mooring systems and satellite data. A custom made program to extracted fin whale calls automatically. Most of the calls were detected from 16 August to 20 October 2012 (66 days) and 25 June to 1 November 2013 (100 days). Period with calls in 2013 was longer than that in 2012. The length of calling duration corresponded to no sea ice concentration period. The beginning of the calling period was related to increasing zooplankton abundance. The end of calling period was related to drop of sea temperature and salinity. Our results suggested that transport of water mass from Bering Sea influence on migration timing of fin whales.

Characterising diversity and variation of fish choruses in Darwin Harbour

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The diversity, intensity and periodicity of fish calls and choruses can provide a wealth of information on spatial and temporal distribution of soniferous fish and, on occasion, the environmental factors with which these patterns correlate, or are driven by. One extension of such information is an indictor of system health through on-going monitoring of the local soundscapes. At three sites in Darwin Harbour, Australia, underwater noise recordings have been taken consistently for the past two years,using underwater sea-noise loggers, located on the harbour floor. These recordings have detected numerous fish calls and seven choruses, offering the opportunity to map some of their temporal patterns. The region is highly diverse in vocal fish in comparison with other areas of Australia, highlighting the need to accurately document such sounds for comparison with recordings of similar species from other locations. This paper characterises the fish contribution to the Darwin Harbour biological soundscapes, where possible identifying the sources and detecting links between temporal patterns in sound production (or received levels) and environmental drivers, such as season and tide. The paper also highlights the difficulties associated with monitoring multiple choruses of numerous species occurring concurrently, over the same frequency band.

Complementary density estimates of fish layers with echo sounder and scientific sonar

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When estimating abundance of pelagic fish stocks where parts of the stock may be close to the sea surface, there is a need to observe the complete water-column, not just a narrow sector under the cruising ship usually observed by echo sounders. The effective observation volume in the fairly narrow echo sounder beams close to the vessel is small when surveying small pelagic schools close to the sea surface, and the acoustic blind zone created by transducer draft and acoustic near field may be substantial when an instrument keel is used. Capelin (Mallotus villosus L.) is typically distributed in mid-water and show weak vessel avoidance and is therefore considered ideal for abundance estimation based on echo sounder data, due to, while mackerel (Scomber scombrus L.) and herring (Clupea harengus L.) some years have vertical distributions extending towards the sea surface, increasing the probability for a variable survey bias.
In the present study a multi-frequency echo sounder and a scientific multi-beam-sonar have been used to map the horizontal and vertical distribution of capelin and herring to give complementary density estimates from a fairly silent vessel. Blind zone corrections to the biomass estimates are presented at 5 nautical mile intervals.

Trials of parallel survey using ME70 and EK60 for some pelagic fishes

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The YOKO-MARU is a research vessel belongs to the Seikai National Fisheries Research Institute in the western area of JAPAN. She equipped a new multi beam echosounder SIMRAD ME70 which is expected to be active in future research. The East China Sea is one of important fishing area of small pelagic fishes, sardine, anchovy, chub mackerel, and jack mackerel, and R/V YOKO-MARU investigates mainly around this area. Though echo integration survey using a vertical echosounder EK60 is the standard method estimating of abundance or biomass, fish avoidance reactions from vessels sometimes cause uncertanty in a survey for small pelagic fishes, especially. A multi beam echosounder ME70 has vertical scanning acoustic beams, and it is able to scan widely below a vessel. Moreover, ME70 is calibrated, so it can obtain quantitative information from target fishes. In this study, we discuss about results of trials of parallel use of ME70 and EK60 with synchronized pinging and future acoustic surveys by R/V YOKO-MARU.

A real-time modular program for tracking and classification of large marine organisms using multibeam sonar

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Given the increasing development and maintenance activities (i.e., dredging, construction, etc.) in nearshore coastal waters, robust methods are needed for efficient real-time detection of protected and endangered species to serve as a warning system for injury mitigation. A real-time modular software package (MarVis-RT) was developed for detection, tracking and classification of large marine organisms (i.e., manatees. turtles, sea lions) using data from a multimode multibeam sonar. The MarVis-RT software package was specifically tuned to receive network packets from the new Kongsberg Mesotech M3 multibeam sonar, allowing for real-time viewing and processing. The real-time processing comprises the ability for remapping to an image matrix, dynamic background subtraction, shape detection, smoothing and contouring. Detected object speed and size was incorporated into the classification algorithm allowing for confidence in tracking and identification. Results are presented from example data of West Indian manatees and California sea lions. Following this initial effort, real-time images can be acquired and processed from an off-the-shelf multibeam imaging sonar, yielding simultaneous tracking and classification of multiple targets within a field of view.

Calibration of omni-directional fisheries sonar using split beam target positioning

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The recently released scientific data format from the Simrad SX90 and SU90 fisheries sonar, the accuracy and resolution is sufficient for scientific purposes. For biomass estimation on surveys it is a necessary that the equipment is calibrated. In recent years, numerous calibration trials have been conducted on both the SX90 and SU90 fisheries sonars, where each trial has led to new discoveries and new calibration protocols. The conclusion of the calibration will be presented as two parts.First presented is a suggestion of how to perform a sonar calibration, positioning the reference target inside each acoustic beam either by the split beam method or by target amplitude interpolation between neighbouring beams. Simulations are made in order to study accuracy, benefits and limitations of each positioning method. Further, the results from a full calibration is presented, along with an interpretation of calibration overall accuracy.

A new fish school segmentation method for fishery sonar

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Omnidirectional fishery sonars are widely used on research and fishing vessels and can observe fish schools over larger volumes than vertically oriented echosounders. Unbiased characterization of fish school size and shape by a new segmentation method is presented for fishery sonars. The method resolves the problem of enlarged school extents due to signal smearing in overlapping beams by segmenting the schools in two steps. In the first step, a threshold defined by a fixed value above the estimated ambient signal level (including noise and unwanted targets) is applied, and excludes the background level from the segmentation. In the second step, the highest backscatter level of the school, estimated from the segmentation mask from the first step, is used to define a new threshold optimized using simulations, to produce an unbiased estimate of the horizontal area of the school. The second threshold is below the highest backscatter level of the school, and takes into account the size of the school as estimated by the first segmentation mask but is independent of the range from the sonar. Examples of the performance of the segmentation method on simulated and real data are shown.

School biomass estimates using digital omnidirectional fisheries sonar

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Low frequency (26 - 30 kHz) omnidirectional fisheries sonars (Simrad SX90 and SU90) were used to measure the acoustic backscatter and dimensions of herring (Clupea harengus) and mackerel (Scomber scombrus) schools from fishing vessels between 2012 and 2014. Detailed sonar sampling of each school included operations at slow vessel speeds and fixed distances to the school, similar to pre-catch school inspection procedures during commercial fishing. Calibrated digital sonar data were processed using new school segmentation procedures, including school area correction procedures. Data on segmented schools from horizontal and vertical sonar beams were used to compute school volume and mean acoustic backscattering strength (Sv). Using mean lateral target strength estimates and fish length and weight, individual school biomass estimates were derived. Biomass estimates were compared with purse seine catches of the same schools, and the accuracy of the estimates assessed in relation to the significant parameters used.

In situ acoustic observations of Atlantic Bluefin tuna (Thunnus thynnus) with high resolution multi-beam sonar

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Field studies to investigate the ability/adaptability of a high frequency multi-beam sonar to document, monitor, and quantify bluefin tuna was undertake at several fishing sites (commercial and recreational) off PEI and at a tuna pen in Nova Scotia. The preliminary results of this study clearly illustrate that bluefin tuna can be detected and tracked acoustical within the swath the multi-beam sonar. Estimates of natural swimming speeds were made by tracking targets from ping to ping within the swath. Range restrictions/limitations were imposed depending upon sea state and water depth. In rough seas the surface layer became too turbulent (air bubbles) to consistently separate noise from fish like targets. Whereas in shallow water (20-30m) the full detection range of the sonar could not be used due to the acoustic beams intercepting with the bottom. Water depths > 50-60m allowed the full range of the sonar to be utilized uncluttered. Adjustment of the tilt angle of the sonar was used to optimize observations with a pan and tilt unit. In summary the results indicate that there is good potential for the utilization of multi-beam sonar to monitor and quantify bluefin tuna in a broad scale fishery independent survey.

Multibeam echosounder reveals fish swimming behaviour.

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Three dimensional (3D) echograms provided by multibeam echosounders reveal 3D morphological features of fish schools, that are already used to optimise the identification haul strategy and improve the scrutinising process during acoustic fish biomass assessment surveys. The schooling behaviour of fish in the immediate vicinity of the surveying vessel imaged by multibeam echosounder may also provides information on the dominant fish orientation relative to the incident soundwave, that ultimately affect fish echo amplitude.
We here compare in situ and modelled herring target strengths at different angles and frequencies to assess the influence of fish scattering directivity and orientation on acoustic measurements. Potential impacts of fish avoidance reaction to the survey vessel on biomass estimates are discussed.

Fish length accuracy of DIDSON data: the need of repeated measurements

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Acoustic cameras are increasingly used to monitor fish populations in rivers. They provide fish morphological and behavioural information. Fish length is directly reachable from DIDSON (Dual frequency Identification SONar) images. During four surveys, more than 50 fish (atlantic salmons, silver carps, sea trouts and rainbow trouts), which true length (total length) was previously measured, have been recorded in the DIDSON detection beam. Multiple views of each fish have been analysed with Soundmetrics software, two operators measuring each fish several times. The results showed a high intra-individual length measurement variability, but no significant difference between the mean measured length and the true fish length. Moreover, no operator effect, fish body angle effect and range effect have been detected. General linear mixed model showed that the smallest fish (length 55 cm) were underestimated in comparison of true length. Using bootstrap method, the sufficient number of measurement per fish to obtain wise length accuracy (95% confidence interval) has been estimated.

Optimizing transmit interval and logging range while avoiding aliased seabed echoes

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Acoustic surveys are typically conducted using fixed settings for the echosounder transmit-pulse («ping») interval and data-logging range, even when surveying multiple species at different depths. If the transmit-pulse interval is set long enough to sample to the range of the farthest (deepest) species, mitigating bias, then closer (shallower) species may be under sampled, reducing measurement precision. We present an algorithm to dynamically minimize both the logging range and transmit-pulse interval, ensuring that the logging range equals or exceeds the range to the seabed and is less than or equal to a chosen maximum data-logging range, while avoiding aliased seabed echoes, commonly known as false bottoms, by adjusting the minimized transmit interval such that the seabed reverberation from a previous transmission is not included in the data logged for the current transmission. Additionally, the algorithm measures background noise to improve estimates of seabed range and classification. This scheme increases the horizontal resolution, signal-to-noise ratio, and processing speed of the data, and reduces the total data volume and storage-space requirement. It is particularly useful when conducting acoustic surveys targeting multiple species with differing spatial distributions. An example implementation of the algorithm is demonstrated for a commonly used scientific echosounder (Simrad EK60).

Acoustic seabed classification for assessment of fish habitat refined using images from a remotely operated camera

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Habitats of demersal and benthic organisms must be characterized and mapped for accurate assessments of their populations. Recently, it was shown that the seabed may be classified using data from vertical, split-beam echosounders, and a model parameterized with acoustic estimates of slope, roughness, normalized backscattering strength, and coefficients representing variation by frequency and incidence angle. These seabed classifications were interpreted and validated using published surficial geological attribute maps with resolutions on the order of 10^4 m^2, but the acoustic data indicated greater variability at finer scales. Here, the classifications are refined using seabed images representing scales of 10^1 m^2, collected from a remotely operated vehicle (ROV). First, images of seabed in the study area were ascribed to seven classes of primary lithology, from mud through high-relief rock reef, and to 25 classes of combined primary and secondary lithology. Then, a refined seabed classifier, based on a nearest-neighbors algorithm and using the acoustic model parameters, was trained on a subset of the lithology-class data. Finally, lithology classes of an independent subset were used to evaluate classification performance. This classifier accurately predicted 95% of the primary lithology class types, and 92% of the primary-plus-secondary lithology classes.

Comparative studies and field measurements of the acoustic absorption coefficient in seawater

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The absorption coefficient of seawater is an important component to the sonar equation underlying fisheries and zooplankton acoustic investigations. The equations currently considered most accurate and widely used for calculating the coefficient are the three decades-old work of Francois and Garrison (1982, J. Acoust. Soc. Am. 72: 896- 907, and 72: 1879-1890). However, there is evidence to suggest that these equations are inadequate for the higher frequency applications that have become increasingly important in ecosystem-based acoustic surveys and management. Comparative studies among the different formulas will be presented. In situ measurements of acoustic absorption were conducted onboard the R/V G. O. SARS in the Norwegian fjords from 2011 to 2014. It was found that the absorption coefficient at 333 kHz was about 18.5 dB/km more than that given by Francois and Garrison's work, which could lead to an uncertainty in biomass estimates of about 50% more at a range of 100 m. In addition, inaccurate absorption coefficients will also introduce a depth-dependent bias on frequency response and impair acoustic echo characterization and species identification/classification that strongly rely on relative frequency response.

A unifying theory explaining different formulations of power budget equations and calibration factors commonly used for fish abundance estimation

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Acoustic methods used in fish abundance estimation and species identification rely on power budget equations and calibrated systems, involving expressions for the backscattering cross section, volume backscattering coefficient, and calibration factors. Different formulations of these quantities are used in modern scientific echosounder and sonar systems, such as the Simrad EK500 and the more recent Simrad EK60, ES60, ME70 and MS70 systems. The lack of sufficient documentation in prior literature, on the actual power budget equations and calibration factors employed, and their relationships to the traditional theory of fish abundance measurement, has caused some uncertainty and confusion among users.
The paper presents a unifying theory that seems to explain the different power budget equations and calibration factors that are employed in the mentioned systems. This includes how they are related, and their relationship to the traditional and generic (instrument independent) theory of fish abundance measurement. Inconsistencies in prior literature are explained and corrected.
For improved control with systematic errors and drift, such as from calibration to oceanic survey, prior expressions are also extended to provide more complete power budget equations, by accounting for electrical termination, representation of echo integration, and the full range of electrical and acoustical echosounder parameters.

Ultra wideband transducer

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The broadband technology is already indispensable in the field of the biotelemetry as well as acoustic estimation methodology of biomass resources. Broadband technology can deal with more information compared with the measurement technique by the single frequency up to now, and can expect improvement of measuring accuracy and diversification of information. The ultra wideband transducer that we have developed has achieved the small deviation characteristic within wideband which overturns common sense and its manufacturing is easy to produce. A prototype of transducer could be realized within the 12dB ripple of sound pressure level in 2.5 octaves of frequency bandwidth from 38kHz to 190kHz. Its bandwidth of 152kHz is extremely wide in underwater acoustic field. The relative bandwidth of conventional transducer is about under 0.2 values. The relative bandwidth of the broadband transducer developed recently is about 0.7 values and 1.1 octaves, for example BW=±40kHz for center frequency=110kHz. How to design the ultra wideband transducer is introduced and the frequency characteristic of proto type transducer is shown. The application using the ultra wideband transducer is also introduced.

Application of broadband echosounders for detection and characterization of targets near boundaries

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There has been a recent emergence of broadband acoustic backscattering techniques for characterizing fish and other marine organisms. Broadband technology allows backscatter to be measured continuously over a range of frequencies, thereby increasing the amount of information available for target characterization. Broadband matched-filter-based signal processing techniques can also significantly improve the range resolution of the measurements. While the range resolution of narrowband systems is determined by the duration of the transmitted signal, the range resolution of broadband systems, after matched-filtering, is determined by the bandwidth of the signals. In principle, the cm-scale range resolution of broadband systems should allow improved discrimination of targets near boundaries, such as fish near the seafloor. However, a common problem associated with matched-filter-based signal processing techniques is the presence of processing sidelobes, which are particularly problematic when one target is significantly stronger, comparable to the primary return of the weaker target, as is the case for fish near the seafloor. We present results of physics-based modeling and laboratory measurements that address approaches for optimizing broadband signal choice and processing techniques for minimizing the deleterious effects of matched-filter processing sidelobes for detecting and characterizing targets close to boundaries.

Identification of fish species using a wideband forward looking sonar on a pelagic fishing trawler

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Fisheries policies in many parts of the world are increasingly focussing on bycatch limitations. This is also true for the new EU Common Fisheries Policy, which will implement a landing obligation in a phased approach. From 2015 onwards, pelagic fisheries in EU waters will need to land all catches from regulated species. Consequently, there is a need for improved fishing selectivity. Forward looking sonars are commonly used by pelagic fishers to localize fish schools. Being able to use them for fish species identification at long range, prior to the catch, would be a great cost saver. With sonar technology evolving quickly, larger frequency bands are broadcast underwater at affordable cost for the industry. Wideband implies higher resolution in the resulting sonar images. This paper focuses on the development of an algorithm for fish species identification using a novel multi-beam forward-looking wideband sonar. It uses statistical analysis of fish school echoes in high-resolution sonar images. A real-time demonstrator is implemented on-board of a pelagic fishing trawler from Jaczon BV. The classification results are compared with catch data. The classification scores obtained, for the four most important commercial species are significantly better than random guesses and show potential for future commercial use.

Pre-catch sizing of herring and mackerel using broadband acoustics

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The price of caught fish can depend strongly on their length or weight. This creates a strong motivation and need for pre-catch size estimation, particularly in purse seine fisheries. While it is customary to release unwanted schools, this can cause high mortality in the fish. We present initial measurements and at-sea trials of an acoustic system and real-time processing algorithm that estimates the length of Atlantic herring (Clupea harengus L.) to within +/- 3 cm. The algorithm is also applied to Atlantic mackerel (Scomber scombrus L.), with similar results. Horizontal broadband backscatter was measured from tethered fish at all rotation angles and used to develop and test three complimentary size estimation methods based upon target tracking, target strength, pulse stretching and spectral analysis of resolved targets. A 3-degree beam angle transducer affixed to the bottom of a ship's drop-keel, with mechanically controllable pointing angle, operating from 160 to 260 kHz was then used to collect data from individual fish in and around schools. Software was developed to implement these methods in real-time and applied to the at-sea dataset. The system shows promising results on adult herring and mackerel, but should be tried further on other size groups and fish species.

Identification of commercially important species by wideband acoustic data collected on pelagic fishing vessels

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Fisheries policies in many parts of the world are increasingly focussing on bycatch limitations. This is also true for the new EU Common Fisheries Policy, which will implement a landing obligation in a phased approach. From 2015 onwards, pelagic fisheries in EU waters will need to land all catches from regulated species. Consequently, there is a need for improved fishing selectivity. Echosounders are important instruments commonly used on pelagic fishing vessels to facilitate catch operations. Fish species identification algorithms based on frequency-specific acoustic scatter properties have recently shown potential. However, these multifrequency techniques suffer from measurement variability around the individual point-values per frequency. The sometimes marginal differences between species causes these techniques to remain limited tools for improving catch selectivity. Wideband techniques cover a broad frequency band and can provide continuous backscatter measurements. Both the improved resolution and frequency diversity can potentially provide more accurate statistical information about fish identity, size and densities. Here we describe wideband data collected with novel hardware installed on a commercial fishing vessel. Species classification methods based on the wideband signal and fish school morphology were applied. The potential to distinguish the most important commercial species is evaluated by comparing classification results with catch data.

Examining the wide band frequency responses of common reef fishes- comparisons between models and measures

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Many heavily exploited fishes are crucial to the ecosystem function of reefs. A central challenge to quantifying change in coral reefs and their ecosystem services is the acquisition of spatially and temporally appropriate data to examine patterns in diversity and abundance of coral reef fishes, and in particular exploited target species. Wideband acoustic technology offers a promising tool that might allow inference at relevant taxonomic and spatiotemporal scales. Using the boundary element method with high-resolution computed tomography data, we examine numerically modeled acoustic scattering responses (12-250 kHz) of dominant reef fishes across a range of orientations. The modeled wideband scattering responses are compared with in situ measurements of wideband scattering from reef fishes obtained using the Simrad EK80 echosounder. Preliminary analyses suggest that wideband scattering responses in this frequency range are sensitive to the fine-scale morphological variations among common reef fish species. Further analysis will give insight into the appropriate frequency domain to examine the efficacy for taxonomic resolution.

Broadband frequency response of fisheries species measured in a tank and ocean

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The target strength (TS) is the most important parameter to estimate the stock of fish. In recent years, broadband frequency response of individual fish was suggested to be a key to identify species. We measured the TS spectra with respect to the tilt angle of fishes (TS spectrum pattern) in a large acoustic experimental tank (10×15×10 m) and in an open ocean. Subject species were red seabream?averaged fork length: 30.5 cm, standard deviation: ±0.9?and sample number: N=8?, Japanese jack mackerel (22.1 cm, ±0.7?N=10?, chub mackerel (30.4 cm, ±4.2?N=10? and Japanese sardine (15.3 cm, ±4.7?N=9? in the tank. Intra-species variation of image cross correlation of the TS spectrum pattern was smaller than inter-species variations. The TS spectrum patterns were compared with the theoretically calculated values by using Kirchhoff-ray mode model. Theoretically calculated TS spectrum patterns well matched with the experimentally measured ones. The species differences among TS spectrum patterns seemed to be caused by shape, angle, and position difference of multiple scattering targets including swimbladder. The wideband split-beam system was proved to provide differences of TS spectrum pattern depending on fish species. [Supported by CREST JST]

Broadband discrimination of Antarctic krill

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Acoustic surveys are conducted to assess the biomass of Antarctic krill. The method by which echoes from krill have been identified has evolved from visual scrutiny of single-frequency echograms, to 2-frequency dB-differencing, to 3-frequency algorithmic classification. The purpose of the echo-classification has been to reduce estimation bias by exclusion of echoes from other zooplankton (including ice krill), fish, squid and ice crystals. It has been suggested that in some instances echoes from non-swimbladder fish are erroneously included as 'krill'. Here we present broadband data (Simrad EK80 from 25-170 kHz) that show how these taxa can be distinguished. Broadband surveys have the potential to improve accuracy of krill biomass estimation, and so contribute to ecosystem-based management of Southern Ocean ecosystems.

Acoustic Observations of Fish and Zooplankton Over a Wide Frequency Band (15 - 400 kHz)

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Measurements of acoustic backscattering made over wide frequency bands offer the potential for improved species discrimination relative to traditional narrowband methods by characterizing more fully the frequency response of scatterers. In January of 2014 we collected field measurements with Simrad wideband transceivers (WBTs) and transducers with center frequencies of 18, 38, 70, 120, 200, and 333 kHz installed in a surface towed body. Acoustic data spanning bands within an overall range of 15 - 400 kHz were collected with the EK80 software, along with bottom trawl and zooplankton net samples. Measurements of volume backscattering strength relative to frequency (i.e., spectra) in aggregations of euphausiids (Meganyctiphanes norvegica) clearly resolved the transition from the Rayleigh to geometric scattering regimes, consistent with the size of animals sampled with nets. Spectral responses were used in concert with backscattering strength to map size and packing density within aggregations. Volume backscattering spectra in aggregations dominated by butterfish (Peprilus triacanthus) or dogfish (Squalus acanthias) revealed a complex frequency response, suggestive of soft tissue and bone dominating scattering in different portions of the frequency band. Target strength spectra for individual targets were also resolved, indicating the presence of fish in the vicinity of euphausiid aggregations.

Integrated acoustic, optical, and net studies of euphausiid ecology in the Gulf of Maine

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The ecological role and importance of euphausiids in the Gulf of Maine region is only poorly understood, in part due to difficulties sampling them with traditional net systems. A series of three cruises targeting euphausiids was conducted along the margins of Georges Bank, involving a combination of broad-scale mapping surveys to identify euphausiid aggregations and adaptive small-scale surveys over 48 hour periods to characterize diel patterns of variability. One cruise examined the association of euphausiids with submarine canyons while the other two were coordinated with fisheries acoustic/trawl surveys and timed to capitalize on seasonal changes in herring predation on euphausiids in order to examine the influence of predation on euphausiid behavior. Euphausiids were sampled with a suite of complementary instruments, including depth-stratified nets (MOCNESS), a Video Plankton Recorder, a multi-frequency (43, 120, 200, 420 kHz) echosounder, and a towed broadband echosounder (35 to 600 kHz); acoustic observations were also used to characterize fish. Euphausiids were discriminated from other scattering sources based on their frequency response, followed by inversions for length and abundance. Distinct spatial and temporal variability was observed in euphausiid abundance, patch structure, community composition, and diel vertical migrations, associated with changes in environmental conditions and predation pressure.

Zooplankton monitoring in Yamada bay using two moored multi-frequency acoustic profilers

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Large zooplankton which are transported to the pacific coasts of northern Japan by the Oyashio current are important prey for juvenile salmon. Prediction of the arrival of large zooplankton to the coast is required in order to determine the release timing of juveniles from hatchery stations. In order to monitor the zooplankton, a multi-frequency acoustic zooplankton fish profiler (125, 200, 455, 769 kHz, AZFP, ASL Environmental Sciences) with temperature-depth and temperature-salinity sensors was moored at 15 m below the surface. And acoustic and physical data were collected for six months at the mouth of Yamada bay, Iwate, Japan from 17 Jan. to 19 Jun. in 2013. In 2014, another profiler was deployed at another site of the mouth of Yamada bay from 16 Feb. to 19 Jun. An inversion method was applied to estimate zooplankton density at various sizes. Estimated density of large zooplankton (2.5 - 3.0 mm) increased when the Oyashio current came over to the bay. A time-lag of two days between the peaks of the zooplankton densities estimated by each profiler was observed in 2014 and it was considered due to the current direction in the bay. This work was supported by AFFRC, Japan.

Acoustic backscatter based estimates of zooplankton biomass in the Salish Sea, British Columbia, Canada

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Ocean Networks Canada's costal cabled observatory, VENUS, includes several upward facing, platform-mounted ASL bio-acoustic profilers. Here we estimate total and size-specific biomass using data from two such profilers: 1) a 200kHz profiler located at ~96m in Saanich Inlet, for which eight years of data exist; and 2) an ASL multi-frequency (38, 125, & 200kHz) profiler located nearby in the central Strait of Georgia (~299m depth) with a one year time series. We have developed an automated algorithm which captures the seasonal cycle of euphausiid (krill) biomass throughout the long-term bio-acoustic time series for Saanich Inlet. Euphausiid-specific biomass was targeted (and calculated) by limiting echo range and removing background gain in order to more confidently remove fish and instrument noise artifacts. Applying a similar algorithm to the multi-frequency data allowed us to calculate three distinct size-class specific biomass estimates based on minimum organism size. To further improve our zooplankton biomass estimate at the multi-frequency site we used the lower frequencies to identify and remove fish and other large targets from the 200kHz channel. Here we demonstrate the utility of autonomous platforms to measure seasonal patterns in size-specific biomass.

Acoustic measurement and classification of migrating epipelagic and mesopelagic scattering layers in the Gulf of Mexico

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Migrating layers of marine organisms in the Gulf of Mexico were observed over the upper 1000 m of the water column using multiple frequency (18, 38, 120, and 200 kHz) scientific echosounders during the summer of 2011. Backscatter data were used to characterize the spatial and scattering properties of the layers and scattering differences were used differentiate layers from one another. Through the use of theoretical scattering models, we identified the organisms that (most likely) composed these layers. Vertical movement rates and timing of the migrations differed amongst layers which supported the acoustic classifications. Acoustic data were compared with net trawls to confirm the identity and size of the marine organisms present in the water column. The use of multiple acoustic frequencies provides important information about the composition of the scattering layers which provides insights into interactions in a part of the ocean where relatively little is known about in terms of the spatial and temporal distribution of the marine organisms that inhabit the mesopelagic region.

Contribution of resonant backscatterers to phantom sound scattering layers in the Bay of Biscay

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Series of acoustic pelagic surveys yet contain unexplored higher resolution multi-frequency data that may provide information on the zooplankton distribution. Zooplankton and micro-nekton are supposed to contribute to ubiquitous sound scattering layers (SSLs) whose composition remains unknown. We present a study combining acoustic and ground-truthing data to characterize the Bay of Biscay dense SSLs. Multi-frequency acoustic data were collected in front of the Gironde estuary using a Simrad EK60 echo-sounder operating at 18, 38, 70, 120 and 200 kHz. Ground-truthing consisted of micro-nektonic net haul. The SSL composition was investigated by resolving both forward and inverse problems. The method allows to: relate the in-situ acoustic response to the theoretical backscatter of biological samples and provide insights on the size and acoustic properties of the backscatterers that were not properly sampled. The results suggest that most of the in-situ SSL backscatter was produced by gas-bearing organisms, namely fish larvae. Larger gas-bearing organisms were contributing to a significant part of the backscattering but were not caught by traditional samplers. This approach reduces the possible hypotheses regarding the nature of organisms producing dense SSLs and outline the need for more adequate acoustic and ground-truthing tools to characterize SSLs.

Remote species identification of coral reef fish communities: advances and challenges

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Coral reef ecosystems are among the most diverse and productive in our oceans. Over 4000 species of teleost fishes are associated with coral reefs, raising challenges to monitor the abundance and the distribution of reef fish in order to develop an effective conservation policy and to evaluate the effect of management actions. Fisheries acoustics is one of the tools that is widely used in fishery assessments. Remote species identification becomes central in these cases. The majority of the methods used for remote species identification have been applied in the pelagic environment and there is a very limited knowledge on the acoustic characteristics of coral reef species. A variety of approaches have been used that exploit the frequency response of species (related to the presence of the swimbladder and its morphology), morphology of schools, and habitat-based modeling approaches. We review long-term marine ecosystem acoustic surveys in the US Caribbean and evaluate metrics that may be helpful in the remote identification problem. The work proposed here is an attempt aimed at improving the marine ecosystems acoustics for the study of coral reef fish communities. Challenges and implications of the approaches used in this work are presented and discussed.

Acoustic identification and measurements of weak targets such as jellyfish and zooplankton in mixed aggregations

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In mixed layers where several target categories are present, current multi-frequency identification algorithms are unable to properly separate and identify the weaker target category. This is because the backscatter from the stronger target usually dominates the echo intensities from the weaker targets even if they are numerically inferior. In particular this occurs at ranges where the pulse volume is large and both strong and weak scattering categories occur as multiple targets within the same pulse volume. In this paper, it is demonstrated that a stepwise top thresholding method combined with spatial filtering can reveal two or several target categories, especially when the target strength of the two categories are quite different, as is the case when jellyfish and zooplankton layers are mixed with swimbladdered fish. The method also reveals the true frequency response of the weak targets, a necessity for the target identification process. Subsequently, the abundance of the weak and strong targets can be estimated independently. The method is demonstrated on data on jellyfish from the Benguela Current Upwelling system and on zooplankton layers from Norwegian fjords.

Acoustic detection and characterization of cod eggs and larvae

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Accidental releases of oil associated with its subsea extraction can adversely affect the health of fish eggs and larvae. Knowledge of the spatial and temporal occurrence of eggs and larvae allows for management of oil operations to reduce the risk of deleterious effects. Eggs and larvae have very low acoustic reflectivity and to estimate the feasibility of in-situ acoustic detection of typical cod (Gadus morhua) egg densities (10-2000 eggs per cubic meter), a set of ex-situ measurements were carried out. The broadband (160-260, 300-360 kHz) backscatter characteristics of both cod eggs and larvae were measured in a small tank under controlled conditions. The age of the eggs and larvae ranged from newly-spawned (1.4 mm diameter) up to 10 weeks, encompassing the period when the gas-filled swimbladder develops. Controlled quantities of eggs and larvae were released into the acoustic beam and observed for several minutes with both acoustics and video. The backscattering strength and potential in-situ characterization parameters as a function of age and life stage were then derived. Oscillatory patterns in the ping-to-ping backscatter from swimming larvae were also observed, which were apparent in the per-ping frequency-dependent backscatter and correlated with the swimming motions of the larvae observed by video.

The classification of migrating populations in the high Arctic using multi-frequency acoustic data

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Diel vertical migration (DVM) plays a key role in the carbon cycle, and has recently been seen to continue throughout winter, despite previous assumptions that all populations entered a state of diapause. Identifying the composition of this migrating community is important because the efficiency of the energy transfer from surface to deep ocean will vary with species.
Using a novel acoustic classification method, species of copepod and krill of different size classes (10-20 mm and 1-5 mm) were identified along with their corresponding DVM behaviour.
Multi-frequency (125, 200, 455, 769 kHz) acoustic data was collected over an eight month period in 2014 using a moored Acoustic Zooplankton Fish Profiler at a high-Arctic (Kongsfjorden, Svalbard) location. The data was analysed using a probabilistic clustering method, the results of which were fitted to frequency response curves formed from distorted wave Born approximation scattering models.
Preliminary results of winter (January and February) data at Kongsfjorden show that krill are the most likely group to be responsible for mid-winter DVM behaviour.
A more complete understanding of winter DVM behaviour will lead to better predictions on the effect of reduced sea ice cover on the energy flow in the Arctic ocean.

Krill or Icefish? Classification of Southern Ocean echotraces using Random Forests

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Reliable target identification persists as an issue for acoustic surveys. Krill (Euphausia superba) swarms at South Georgia are typically identified through a combination of expert scrutiny and analysis of the difference in mean volume backscattering between 38 and 120 kHz (?MVBS, dB). Scattering properties of krill are however similar to the many co-occurring fish species which do not possess swim bladders. One species in particular, the mackerel icefish (Champsocephalus gunnari) forms substantial pelagic aggregations which can be difficult to distinguish acoustically from large krill layers. Icefish are currently assessed using bottom-trawl gear, but these estimates are biased because of the species' semi-pelagic distribution. Random Forests were constructed using acoustic and net sample data from ground-truth aggregations of species in order to classify echotraces. The algorithm classified krill, icefish and mixed aggregations of fish with 88% accuracy. Depth and longitude were of highest importance for classifying echotraces, however, ?MVBS, minimum volume backscattering (dB) and horizontal roughness coefficients all held high importance in echotrace classification. Random forests proved to be a powerful means of objective species classification, providing scope for using acoustic surveys to assess this commercially important species.

Alternative ground truth techniques for fisheries acoustics

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Fisheries acoustics surveys are effective tools in marine resource assessment and marine ecology. An ongoing challenge in applying acoustics is the identification of echotraces and significant advances have occurred in recent years with the application of multiple and broadband frequencies. There is, however, still the need to ground-truth any echotrace identification method and this is usually achieved by obtaining simultaneous net samples. Here, two alternative methods for ground-truthing are examined: line fishing and video cameras. These methods were deployed during a survey of Atlantic mackerel (Scomber scombrus), a fast swimming small pelagic fish which forms enormous schools in the North Sea during autumn. Line fishing was actually more efficient than pelagic trawling (the standard technique) and provided length frequency distributions that were not significantly different; it also provided insights into the depth distribution of fish sizes. A small video camera was deployed into schools, providing spectacular footage, species identification, and, uniquely, fish orientation. Image analysis was then applied, producing tilt-angle distributions which are important to understand target strength, an uncertain parameter in mackerel abundance estimation. These techniques are complementary to traditional trawling methods, but provide alternative insights into fish behaviour whilst satisfying standard requirements of identification and supplying biological samples.

Allocating backscatter using a flexible, non-parametric Bayesian mixture model

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Accurate partitioning of backscatter data is crucial when estimating species-specific population abundances. Current classification methods are typically subjective categorizations by an analyst or objective, rule-based classifications that lack uncertainty estimates. We adapted a semi-supervised, non-parametric Bayesian mixture model to allocate multifrequency backscatter between known and unknown species categories. The Dirichlet Process Mixture Model creates and allocates backscatter to categories based on data attributes as new data are encountered. Advantages of this approach include: providing interpretable Bayesian credible intervals around Sv estimates; no required assumption on the number of categories; and the flexibility to adjust clustering resolution to include knowledge of species communities and incorporate other prior knowledge. We implemented our model on 2007 Eastern Bering Sea, Walleye Pollock survey data collected at four frequencies, using five categories of previously trawl-verified, single-species training data. Our model produced 14 clusters which were labeled in nine categories (single and mixed species) based on survey trawl data and Gaussian properties of Sv difference clusters. For each category we produce 90% credible intervals of transect average backscatter (NASC). Regressing NASC estimates on label-matched estimates from previously published analyses, we find high correlations (r^2 > 0.90) between analyses across our intervals.

Do ribbonfish swim vertically? ~ Relationship between their body angle and acoustic intensity ~

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Ribbonfish (Trichiurus japonicus), generally schooling at sea bottom in daytime and dispersing to surface in nighttime are considered to change body angle in accordance with their distribution. To monitor distribution and biomass of ribbonfish, the relationship between their body angle and echo intensity is necessary. We observed swimming of ten ribbonfish recorded by digital video camera and measured their swimming characteristics (Tilt angle, and Dorsal-fin movement) in the water tank of aquarium Umitamago using two-dimensional acceleration data-loggers. Also, we measured TS of 12 ribbonfish within degree range -20~90° in water tank of National Research Institute of Fisheries Engineering. In these experiments, ribbonfish stayed at tilt angle of 72.96 ±5.16° (Mean±SD) and moved horizontally at 27.11±7.87°. Additionally, their TS were -58.42 ±4.39dB at staying and -48.66±2.34dB at horizontal moving. From these results and previous study, ribbonfish are considered to stay at vertical tilt angle as a part of schooling at sea bottom in daytime and move horizontally to feed prey at surface in nighttime. In conclusion, it's possible to monitor distribution and biomass of ribbonfish by measuring their swimming body angle at sea bottom and surface.

Target strength measurement of euphausiid, copepod and amphipod by the tethered method

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Zooplankton such as euphausiid, copepod and amphipod are an integral component of oceanic ecosystems. In acoustic biomass estimates, the target strength (TS) of marine organism is one of the key parameter to estimate stock abundance. As zooplankton is small in size and in acoustic backscattering, it was generally difficult to measure precise target strength of zooplankton. Recently, a system that can measure acoustic backscattering of small animals was developed in NRIFE. In this study, we measured the target strength of euphausiid, copepod and amphipod as a function of the incident angle of the ensonified wave at 120 kHz and 200 kHz in the living state. The TS measured were compared with the theoretical predictions by the Distorted-Wave Born Approximation-based deformed-cylinder model (DWBA model). Sound speed contrast was measured beforehand. After measuring TS, we measured density contrast using the same sample. Measurements and predictions agreed well for euphausiid and amphipod. For copepod, however, some specimens agreed well and some not. Predictions and measurements agreed well in the case that the ratio of the oil sac's volume to the body's one is low. Scattering from the body with oil sac should be considered in theory.

Target strength of herring and mackerel in dorsal and lateral aspect for sonar biomass estimation

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If horizontally observing sonars are to be used for fish biomass estimation, the mean target strength in lateral aspect should be better quantified at several frequencies. An acoustic echo sounder probe, carrying four broadband echo sounders has been lowered into herring and mackerel layers, and the TS(f) measured with calibrated split beam methods. The transducers were used in both vertically and horizontally observing modes. Lateral TS(f) for adult herring and mackerel will be presented and compared to the conventional dorsal TS(f) over the frequency band 60 ? 450 kHz, and furthermore compared with empirical measurements of the directivity pattern of individual herring and mackerel, the TS(f,?).

Lateral aspect acoustic frequency response of adult saithe (Pollachius virens)

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Laterally observing fisheries echosounders are useful in specific applications, such as to inspect surface blind zones from a vessel, to observe wild fish gathering under fish-farm nets or for bottom-mounted acoustic landers with both vertical and horizontal acoustic beams. The frequency response (r(f)) measured from the dorsal aspect is frequently used to identify species, but it is not clear if dorsally measured r(f) is useful for identifying laterally observed fish. The r(f) of free-swimming wild saithe was measured with stationary and laterally oriented split-beam echosounders at 70, 120, 200, 333 kHz, suspended in mid-water (22 m, bottom depth 41 m). Simultaneously recorded imagery (video and stereo-photo) were used for species identification and sizing. Fish aggregating close to a small fish-farm were observed. Saithe of 45-55 cm in length was observed in small schools of varying density and recorded at 5-35 m range while swimming in and out of the acoustic observation volume. The SV(f)-based, TS(f)-based and fish track average TSTrack(f)-based acoustic frequency responses were derived. Lateral saithe r(f) increased smoothly with frequency, which is the opposite trend to dorsal aspect r(f) reported in the literature.

Target strength of the key species in the Northern Demersal Scalefish Fishery (NDSF), Western Australia

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The NDSF extends over a vast area in waters off the Northwest Coast of Western Australia. Targeted species in the area are mainly found within mixed demersal schools composed of various high value species (snappers, emperors and cods) and reef fishes. In order to establish an ecosystem-based management approach, an improved quantitative understanding of the abundance, dynamics and distribution of targeted and non-targeted species within and outside the fishing grounds is needed.

An acoustic data collection program has been established in 2012, collecting calibrated, multi-frequency data from a commercial trap fishing boat during its normal operation, to collect continuous high resolution information on species distribution and abundance. In order to increase accuracy of abundance estimates, target strengths of key species were modelled and measured in-situ. Fish samples of key species were scanned in a CT (Computational Tomography) scanner, to gain data on the internal structure of the fish. An image analysis routine was developed to automatically extract the 3 dimensional coordinates of the swimbladder and the shape of the fish. The Kirchhoff Ray Mode (KRM) approximation model with a Bayesian estimator was implemented to model the TS of the fish based on their shape, swimbladder characteristics, weight and length.

In situ determination of the impact of offshore pile driving on juvenile sea bass Dicentrarchus labrax

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To determine the impact of underwater sound generated by offshore pile driving, a field experiment was carried out on board of a piling vessel, exposing 68 and 115 days-old sea bass to the sound generated during 1.5 hours of pile-driving. The number of strikes ranged from 1740 to 3070, with a single strike sound exposure level between 181 and 188dB re1µPa².s, resulting in cumulative sound exposure levels ranging from 215 to 222dB re1µPa².s. Immediate and long-term survival of the exposed fish was high. However, exposed fish responded to the impulsive underwater sound by a 50% reduction in oxygen consumption rates (a secondary stress response) compared to the control groups. Data on cortisol concentrations will indicate whether juvenile sea bass also show primary stress responses. Under optimal lab conditions, we did not see effects on the fitness of the juvenile fish beyond the sound exposure period. However, it remains unknown whether the reduced fitness of juvenile fish is limited to the pile driving period in the real world as well. Our results indicate that impulsive sound close to the source creates sound pressure levels above the stress threshold, but below the lethal threshold for small sea bass.

Insights into fish and seabird behaviour, hydrodynamic features, and predator-prey interactions from the integration of a multibeam sonar and a multifrequency echosounder on the FLOWBEC seabed platform in marine renewable energy sites

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The FLOWBEC project integrated a multibeam sonar, multifrequency EK60 echosounder, ADV and fluorometer into an autonomous seabed platform to investigate the environmental and ecological effects of installing and operating wave and tidal energy devices at a range of physical and trophic levels. Five 2-week deployments were completed at the European Marine Energy Centre in the presence and absence of renewable energy structures, complemented by 3D hydrodynamic models and concurrent shore-based X-band radar.
Novel processing techniques mask surface-connected turbulence and extract birds, fish schools and marine mammals for tracking and classification, ground-truthed by concurrent shore-based observations. Co-registration of targets between instruments increases the information available, providing quantitative measures including frequency response from the EK60, and target morphology and behavioural interactions from the multibeam sonar.
Dive profiles, depth preferences, predator-prey interactions, fish schooling behaviour and the effect of hydrodynamic processes during foraging events throughout the water column can be analysed in conjunction with the hydrodynamic impacts of marine renewable energy devices, revealing how animals forage within dynamic marine habitats and whether individuals face collision risks. This information could de-risk the licensing process and, with a greater mechanistic understanding at demonstration scales, the predictive power could reduce the monitoring required at commercial sites.

Ears to the ground and eyes on the horizon: acoustic and videographic assessment of mid-water ecology for ecosystem-based management in large oceanic Marine Protected Areas

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The widespread increase in the number and spatial extent of pelagic marine protected areas (MPAs) has fuelled a demand for non-extractive methods of monitoring commercially important species of pelagic fish within them. Here we report on a novel non-extractive approach, linking visual and acoustic sampling, that enables monitoring across multiple trophic levels, and improves understanding of pelagic ecology required for ecosystem-based fisheries management. Stereo-baited remote underwater video systems (BRUVS) provide point samples on the status of fish assemblages, enabling generation of sensitive estimates of population size spectra. Acoustic sampling around mid-water BRUVS, when nested within larger-scale line-transect surveys, can extend point-estimates from BRUVS to the scale required for large MPAs. We conducted a series of pilot studies in the world largest contiguous no-take MPA (The Chagos Marine Reserve) and use the data to assess the status of pelagic fish populations such as tunas and oceanic sharks at three different habitats: seamounts; shelf, and open water.

Using acoustics to observe fine scale schooling behaviour in open ocean and controlled net pen experiments

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Underwater acoustics is well suited to observe fine scale behavioural across a range of different scales. This paper presents several techniques that have been developed to observe and quantify schooling behaviour using acoustics; from free ranging schools to wild-caught schooling fish in controlled net pen experiments. A method to attribute rapid changes in backscatter within a school to internal turning waves was developed, and we applied this method to free ranging herring schools where turning waves on the order of 10m/s were detected. This was combined with fine scaled observations on herring in a net pen, where a high frequency sonar was used to estimate swimming speeds and internal correlation structures in swimming velocity. The dynamic response in the fish to fast moving objects was quantified in terms of turning waves and direct responses, and we demonstrate how the setup including open ocean experiments and controlled net pen experiments can be used to investigate the fine scaled behavioural response to different stressors such as underwater noise, vessel noise, seismic or sound.

Predator-prey dynamics: Micronekton schooling inside the deep scattering layer in response to foraging Risso's dolphins

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Using split-beam echosounders integrated into a deep-diving autonomous underwater vehicle (AUV) in combination with ship based acoustics and direct sampling we explored scattering layers off the Channel Islands, California. High-resolution behavior and acoustic recording tags revealed that Risso's dolphins foraged within each of three distinct layers identified. Using the AUV to obtain echoes from individual scatterers within layers, we found that rather than the homogeneously mixed aggregations identified from the ship-based data, layers were internally organized into distinct, small patches of scatterers of similar size and taxonomy adjacent to contrasting patches. The size of these patches was not related to geometric distance but rather to the number of animals in the group which remained constant as taxonomic group and individual length varied. We observed that the inter-individual spacing within these patches was significantly smaller when Risso's dolphins detected with the echosounders were within 5 m of the patch. These effects, however, were only detected for the largest classes of fish and medium and large squid; no predator effects were detected in smaller individuals of these groups or in crustaceans, identifying the key prey targeted by Risso's dolphins. This new tool is revealing the dynamic relationship between mesopelagic predators and prey.

Social behavior in mesopelagic jellyfish

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We made records of diel migrating jellyfish Periphylla periphylla using both hull mounted (38 kHz) and submerged (200 kHz) echosounders. The acoustic data showed that jellyfish formed small, ephemeral groups, which also was documented photographically using ROV. The records of jellyfish were made at the upper fringe of an acoustic scattering layer consisting of krill, where about 10% of the jellyfish engaged in social behavior. The hypothesis that forming teams can improve capture rates of agile prey was supported by a simple model. Although the adaptive value of group formation remains speculative, we clearly demonstrate the ability of these jellyfishes to locate and team up with each other at depth. The study documents the potential of using echosounders in unveiling novel behavioral traits among jellyfish.

Multibeam echosounder reveals species-specific fish school features

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In multispecies environments, relating fish schools acoustic attributes and species composition, based on monobeam, 2-dimensional (2D) echosounder is generally challenging. This is likely due to the fact that 2D echosounders provide data on slices, rather than on entire schools, due to the narrowness of their beam. We revisit the link between fish schools acoustic attributes and species composition based on three-dimensional (3D) acoustic data provided by the ME70 multibeam scientific echosounder, whose larger sampling volume and higher resolution allow to finely characterise entire fish schools. Acoustic schools observed during PELGAS surveys in areas with various levels of species mixing are extracted from 2D and 3D echograms. 2D and 3D morphological, positional and density school attributes are related to species compositions to: i) assess the discriminatory power of mono vs. multibeam data, ii) investigate species-specific school characteristics. Multibeam school data allow for a better visual and automatic species discrimination than monobeam ones. The analysis of 3D data reveal large differences between Biscay sardine and anchovy schools: sardine generally form amoeboid, very dense schools, whereas anchovy congregate in elongated, ribbon-shaped, less dense schools. These species-specific school shape differences are discussed in the context of the species eco-ethology.

Physical and behavioral interactions determining mysid prey distribution

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Physical and behavioral factors that lead to a persistent, nearshore aggregation of mysids off the central Oregon coast, in the California Current Ecosystem were investigated. Mysids are a critical zooplankton prey group supporting a number of fish and marine mammal predators, including a resident population of gray whales. Mysid distributions were observed using a combination of shipboard and moored multi-frequency echosounders co-located with temperature and current meters. Plankton net sampling collected representative samples for ground-truthing acoustic samples, and visual surveys were conducted for the distribution of marine mammals. The mysid population, consisting of 4 species with distinct life-stage cohorts, was found distributed in a narrow band parallel to shore despite persistent tidal and along-shore currents. The persistence of this important prey population was regulated in this physically dynamic region by the interaction of behavior and physics. The interaction of animal behavior and physical forces play an important role in determining the distributions patterns of mesozooplankton we observe in the oceans.

Dusk and dawn vertical migrations of overwintering sprat (sprattus sprattus)

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An upward-facing, bottom-mounted 200-kHz echosounder was applied to study vertical distribution and individual swimming behavior of sprat throughout an entire winter in a Norwegian fjord. Being cabled to shore for power and data transmittance, the echosounder provided continuous measurements at a temporal resolution of seconds. A normal vertical migration pattern with schooling during the day and a generally shallower distribution at night was observed. However, it also appeared that part of the sprat population persistently carried out inverse diel vertical migrations at dusk and dawn. At dusk, when the sprat started migrating to shallower waters in schools, several individuals left the schools and sank back to deep waters again. At dawn, individual sprat migrated upwards and aggregated in schools in upper waters. Shortly after this, the sprat returned back to depth in schools. The time window of upward migration lasted for about 20 minutes, which also was the average time the sprat stayed in shallow waters before migrating downwards again. The IDVM behavior followed the timing of sunrise and sunset throughout the entire winter and likely reflected antipredation windows where the sprat possibly optimized the trade-off between food intake and predation risk.

Abundance and spatial distribution of polar cod in the Canadian Beaufort Sea (Arctic Ocean) during the ice-free season

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Polar cod (Boreogadus saida) constitute more than 95% of the pelagic fish assemblage in the Canadian Beaufort Sea, an area of the Arctic Ocean facing both climate change and oil and gas development activities. Despite the importance of polar cod as the main prey of most marine mammal predators of the region, in particular ringed seals (Pusa hispida) and belugas (Delphinapterus leucas), the total abundance and spatial distribution of this key fish species remain unknown. Summer hydroacoustic surveys were conducted from 2011 to 2014 with a Simrad EK60 multi-frequency echosounder, and the echoes were validated by net deployments. Spatial distribution of polar cod was assessed using kriging techniques and the relation with local hydrography. Total abundance estimated using geostatistics was compared to the energetic requirements of the main predators to verify if the polar cod stock can sustain their consumption. This survey represents the first systematic acoustic study covering the shelf and slope of the Canadian Beaufort Sea during summer, and provides baseline data to monitor the effects of climate change and anthropogenic activities on the marine ecosystem of the region.

Comparison of acoustic biomass and top-predator distribution in the Northwestern Hawaiian Islands

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The mean biomass of main trophic groups (apex predators, other secondary consumers, and herbivores) in the Northwestern Hawaiian Islands (NWHI) appears to be higher than in the Main Hawaiian Islands (MHI). Dense communities of mesopelagic organisms that accumulate around the NHWI are similar in spatial pattern to the mesopelagic boundary community observed in the MHI. These studies focused on shallower communities in and near reefs and did not investigate biomass living in deeper waters that some apex predators rely on for food. Some odontocete cetaceans dive to depths greater than 1200 meters to feed. To examine the relationship between odontocete predators and prey, a Simrad EK60 echosounder operating at 38 and 70 kHz collected acoustic biomass data throughout the NWHI from May 7 - June 4, 2013. Visual surveys for marine mammal presence were conducted concurrently with the echosounder. The spatial distribution of acoustic biomass in the mesopelagic layer from approximately 400 - 800 meters depth was compared to physical and biological parameters including sighting locations of 37 deep-diving odontocetes, bathymetry, sea surface temperature, and surface chlorophyll, using a generalized additive model (GAM). Comparison of these parameters will further the understanding of factors contributing to odontocete distribution in the NWHI.

Distribution of the Small Pelagic Fish Populations in the North Eastern Levantine Sea.

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The decreasing stocks of traditionally targeted fish species such as large pelagics and demersals caused a shift on the fishery towards small pelagic fishes along the eastern coast of Turkish Mediterranean. The aim of this study was to assess the distribution of the small pelagic fish populations in the region using acoustics methods to generate an effective fishery management advice. The data were collected between 2009 and 2011 during five hydro-acoustic surveys conducted with Simrad EY-60 operating at 120kHz. Environmental conditions were determined from CTD casts and satellite images. Generalized additive models were used to investigate the habitat preferences. Thermal stratification found as an important factor determining the distribution of species. The species with warm water preference occupied a temperature range between 24ºC-27º C and concentrated in the regions around river plumes and eutrophic regions. The species inhabiting cooler water displayed and offshore-ward distribution below the thermocline. The study area being a warm region seems to provide advantage to summer spawning species such as Sardinella aurita which concentrated in dense patches as associated with high chlorophyll concentration. However, if the fishing pressure increases this population may disappear as it is already tackling with competition due to opportunistic Lessepsian invaders.

Modelling fish distribution using high resolution acoustic and fishery data: Bay of Biscay anchovy as case study

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Acoustic surveys provide high resolution data to estimate and map fish spatial distribution. However most of these surveys are conducted annually, and the seasonal dynamics of these populations are poorly known. Here we explore how high spatial and temporal resolution fishery data derived from the Vessel Monitoring System (VMS) can be used to better understand population movement and distribution over time. When both type of data are available, a log Gaussian Cox process is proposed to explain what drives locations of fishing operations and catches per unit of effort. This marked point process is thought to have its intensity varying spatially and preferentially according to a latent Gaussian random field, here derived from the acoustically surveyed fish distribution, and other covariates such as fish length, distance to harbor or potential revenues. Then, taking advantage of the availability of fishery data in time, the model is used to forecast monthly spatial distributions over time. This approach is applied to Bay of Biscay anchovy using acoustic data from the PELGAS series and fishery data for years 2008-2012. Results are discussed with respect to fishery data characteristics. High resolution maps that have been produced, will improve our understanding of this pelagic ecosystem structure.

Small pelagics in the North Sea ? Long-term spatial distribution patterns of two ecosystem key-players

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The small pelagics herring (Clupea harengus) and sprat (Sprattus sprattus) play key roles in the North Sea ecosystem, both as predators and prey. Environmental influences have been hypothesized to affect the dynamics of both species in different ways. While herring year class strength has been consistently weak since 2002 due to reduced survival during the larval stage, a factor that was directly attributed to environmental variability, no such direct effect has been hypothesized for sprat. However, changes in zooplankton community structure seem apparent, albeit with unknown implications on sprat stocks and so far no observed trends in their recruitment. Both stocks are surveyed with an ICES coordinated, annual international acoustic survey (HERAS). The survey provides abundance and biomass indices for, amongst others, North Sea autumn spawning herring and sprat since the year 2000 and covers the North Sea, the area West of Scotland and the Malin Shelf. Here we document long-term spatial distribution patterns of both herring and sprat in the North Sea based on species dis-aggregated hydroacoustic data and corresponding trawl catches and use geostatistical descriptors, spatial indices and environmental variables to investigate possible distributional changes and their and underlying causes.

Antarctic krill in Marguerite Bay: resolving the detail using underwater gliders

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The Western Antarctic Peninsula (WAP) is undergoing rapid changes in climate, with increasing ocean and air temperatures and rapidly declining sea ice duration. As a result, the water column structure and marine ecosystem are likely to undergo rapid change in the coming decades. Marguerite Bay and other locations along the WAP are sites of high krill abundance, thought to be source regions for populations found across the Scotia Sea. To understand the physical controls on krill abundance and retention in this region, we characterized the Antarctic Peninsula Coastal Current (APCC) within Marguerite Bay and its influence on primary productivity.
In 2014, two underwater gliders were deployed to undertake concurrent physical and biological measurements of hydrography, primary productivity and krill abundance and distribution. The gliders were equipped with ES853 120 kHz echosounders, pointing downwards and sampling at a rate of 0.25 Hz. Krill targets were identified using a thresholded schools analysis technique (SHAPES), and acoustic data were converted to krill density using the stochastic distorted-wave Born approximation (SDWBA) target strength model. Preliminary results are presented from the two month deployment.

Stuck between a rock and a hard place: Zooplankton vertical distribution and hypoxia in the Gulf of Finland, Baltic Sea.

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In the Gulf of Finland, a pronounced hypoxic layer develops when there is an inflow of anoxic bottom water from the Central Baltic Sea, which could be a barrier for vertical migrants. The distributions of crustacean zooplankton (mysid shrimp and the copepod Limnocalanus macrurus), gelatinous zooplankton (Aurelia aurita), and fish were studied using acoustics and nets. Vertical profiles of oxygen concentration were taken and the physiological impact of hypoxia on mysids was investigated using biochemical assays. The acoustic data showed peaks of crustacean zooplankton biomass in hypoxic (75 m), whereas fish and A. aurita medusae were found in normoxic (5 - 6 ml l-1) upper layers (

Acoustics to quantify the impact of physical structures on biological components along scales

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The downward displacement of the oxycline depth as estimated by acoustics provides a robust estimation of ocean surface turbulence. To characterise these physical processes and determine their impact on biological components we used acoustic data acquired during 12 scientific surveys performed along the Peruvian coast. We applied an original wavelet-based method to extract and characterise the physical space-scale structures as well as the patches of zooplankton and pelagic fish. We further made a typology of the physical structures and defined clusters corresponding to the internal wave scale (

Observing temporal processes in an ecosystem hotspot over an annual cycle with high resolution acoustic

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Ecosystem understanding stems from sampling which entangles spatial and temporal variation and thus fails to resolve basic temporal details.

The Lofoten-Vesterålen Ocean Observatory, in operation for more than one year, collects temporally resolved data on biomass densities, vertical distributions and behavioural characteristics. It is situated on an ecological hotspot supporting the productive fish stocks of the Barents Sea. Oceanographic sensors provide information about the drivers behind the observed phenomena, and interpretation of the acoustic data is supported by catch data from scientific surveys and commercial catches.

The data quantify large flux of oceanic biomass of cod and herring over the winter season where the time of arrivals and departures can be precisely estimated. Detailed target tracking of individuals in combination with biomass distributions of cod show clear changes in individual and group spawning behavior from the beginning of February to the end of April. The ecosystem is strongly affected by internal waves and strong currents and variable influx of Atlantic waters sometimes flushing over the area. Behavioural characteristics from seconds to seasons uncover inter and intra specific interactions including feeding interactions. We discuss the observatory approach in the context of understanding ecosystem processes and supporting stock assessment.

The distribution and behavior of mesopelagic organisms in tropical waters: A comparative approach between Indian and South Pacific Oceans, from acoustic measurements at 38 kHz.

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Mesopelagic organisms have a pivot role in the marine high-seas ecosystems. They consume the lower trophic levels and constitute the basic preys of top-predators which are important resources from the ecologic and economic viewpoints, particularly in the Indian and in the Pacific Oceans. They start also to be considered as a new, huge, potential protein resource. In this context and through several surveys performed during 2009-2014, this work aims at comparing the Mozambique Channel (MESOP surveys), and the exclusive economic zone (EEZ) of New Caledonia (NECTALIS surveys). These two areas are at the same southern latitude (~20°S) and encounter eddies phenomenon. However they present different conditions: one is in a channel (Indian Ocean) and the other one is in a completely open area influenced by an oligotrophic warm north water mass and a rich cold south water mass (south-west Pacific). The catches of tuna in those two areas vary by a factor ~10 at the advantage of the Mozambique Channel. Our comparison focuses on the vertical distributions of mesopelagic organisms, and on indicators characterizing these layers, such as depths of various percentages of the total sA value, number of layers, densities, relationships with hydrological conditions and composition of the layers.

Characterising pelagic habitats at ocean basin scales in partnership with commercial fishers.

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Ecosystem dynamics of the pelagic ocean are directly influenced by the physical and chemical properties of the water masses that surround them. Physical and biological oceanographers have made recent advances in understanding how large scale physical and chemical processes influence primary productivity at a global scale. Understanding how these processes influence mid-trophic zooplankton and micronekton productivity at similar scales is the challenging next step. Acoustic methods have been identified as one way to characterise and monitor mid-trophic organisms at ocean basin scales. Single and multi-frequency acoustic data are now routinely collected across southern hemisphere ocean basins as part of Australia's Integrated Marine Observing System (IMOS). This program aims to monitor mid-trophic components of marine ecosystems at ocean basin scales through time. Central to achieving this aim is the need to identify dominant scatters for respective acoustic frequencies within distinct pelagic habitats. Here we provide initial results from an acoustic and biological approach to characterise zooplankton and micronekton communities of two differing water masses in the Indian Ocean using commercial fishing vessels as sampling platforms. We outline the limitations of the sampling and future biological sampling needed to interpret the larger scale acoustic data.

Towards an acoustic derived mesopelagic biogeography of ocean basins.

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Net primary production derived from ocean colour satellites is used for segmenting and evaluating the temporal and spatial dynamics of epipelagic (0-200 m) habitats in the world's oceans. Extrapolating epipelagic habitats to describe mesopelagic (200-1000m) habitats is limited by a lack of observations of their species composition, biomass and energetic exchanges. Mesopelagic habitat has the largest concentration of the oceans micronekton biomass, are consumers of primary and secondary production as well as prey for higher trophic level species. Acoustic data can be used to characterise both epipelagic and mesopelagic habitats but large uncertainties remain in their interpretation. Using an acoustic-ocean-basin monitoring database, acoustic metrics for 16 pelagic habitats in the Indian, Southern and Pacific oceans were summarised. Day and night mesopelagic acoustic backscatter correlated strongly with net primary production for most but not all epipelagic habitats. These acoustic derived metrics of mesopelagic habitat can be biased towards resonant scatterers of various sizes depending on the acoustic frequency. Using in-situ multi-frequency acoustic, optical and net sampling the bias to species specific acoustic scattering is quantified. This knowledge can improve the understanding of mesopelagic biomass, energetic exchange and variability to contribute to an ecological geography of the world's mesopelagic oceans.

Acoustic classification of meso-pelagic communities

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The principal structure of the ocean's meso-pelagic community is formed from ubiquitous biological layers, which can span entire ocean basins, contain millions of tonnes of biomass and are primarily made up of zooplankton and small fish. Biological layers were extracted from 38 kHz echosounder data, obtained from a wide selection of research institutes and online databases, using a recently developed image processing technique. Layer characteristics, such as water-column position and backscatter strength, were used to categorize layer formations into distinct classes. These layer classes provide a means to quantify mid-trophic level communities, which are currently poorly understood. By standardising layer analysis, pelagic ecosystem change can be consistently monitored and assessed.

Vertical distribution of organisms in pelagic marine ecosystems: a dual acoustic and modelling approach

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Understanding and predicting the functional role of biodiversity in marine ecosystem dynamics and how physical variability of the ocean affects ecosystem functioning is a key issue. The focus of this study is to use acoustic data to provide vertical distribution information of three generic communities (epipelagic, migrant mesopelagic and non-migrant mesopelagic) in order to estimate their physiological and behavioural parameters for applications of an end-to-end ecosystem model, APECOSM (Apex Predators ECOSystem Model). In APECOSM, the vertical distributions of organisms in the generic communities are critical because they control spatial co-occurrence and hence the trophic interactions of the different communities. Vertical distributions of the communities are assumed to result from size-dependent advection-diffusion processes. The parameterisation of the three generic APECOSM communities was conducted using environmental (ambient light, oxygen, temperature) and acoustic data collected in the western Indian Ocean. An observation model reproducing the available one-dimensional data was developed. Parameters were estimated using the Automatic Differentiation Model Builder (ADMB) software. According to the mechanistic basis of APECOSM, regional estimates are then assessed against observations in other regions to test and potentially improve the parameterisation, and eventually validate the global scale predictions of the vertical distributions of APECOSM's communities.

Acoustic data assimilation for estimating energy transfert parameters of a micronekton model

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SEAPODYM Forage is a micronekton model used to simulate foraging fields of top predators (tunas, swordfishes, turtles, seals...). In this framework, micronektonic organisms are divided into 6 functionnal groups according to their diel vertical migration. Their dynamics is driven by temperature and oceanic currents. Micronekton production is modeled as a percentage of energy transfer from primary production to mid-trophic level (E=4%). This amount of energy is allocated to each group with transfert energy coefficients. These coefficients are not reachable throught direct observations : this work uses data assimilation to assess them. Data assimilated into the model are ratios of biomass over the water column - calculated from 38kHz-acoustic density used as a proxy of micronekton biomass.
A negative log-likelihood function (mainly distance between observations and model estimations) is minimized with help of a gradient descent method (Quasi-Newton algorithm). Gradients are estimated with an adjoint code.
We present an illustration of assimilation experiments with multiple transects in various environments.\\

Bayesian Hierarchical Modeling of Uncertainty In Acoustic Estimates for Mysid Density Estimation In the Great Lakes

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Organism abundance can be usefully assessed using hydroacoustic survey sampling. However, the process of converting raw acoustic signals into estimates of density and abundance can be noisy and complicated. Researchers are often faced with several issues: Are the methods we use to calculate mean density and abundance the best that are statistically available? If we are to put effort into increasing sample size or refining estimates, where should we focus our attention? Once we understand the uncertainty associated with a given step in the estimation process, how do we incorporate that uncertainty when characterizing the final estimates? In this paper, we develop a mechanism that uses Bayesian hierarchical modeling to address known sources of uncertainty in the acoustic assessment process. Estimation steps are followed sequentially from Sv to mean density and the estimated variation is carried along through each step in the process. The structure of the analysis facilitates examination of the effects of the various steps on the quality of the final outputs. Acoustic scientists can use this approach to help prioritize their own research and assessment designs. The method is applied to estimating the density of Mysis relicta in the Great Lakes, USA.

Prior knowledge: incorporating acoustic abundance indices into Bayesian assessments

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An integrated approach is required between scientists that collect acoustic data, assessment modellers that use it, and fisheries managers that set harvest limits. We describe our experiences using examples from two New Zealand southern blue whiting (SBW) stocks. Both stocks are assessed using Bayesian statistical catch-at-age models, with regular acoustic surveys providing fisheries-independent estimates of spawning SBW abundance. Acoustic estimates are modelled as relative indices with a ?catchability coefficient' (q), defined as the ratio of the survey estimate to actual spawning stock biomass. The value of q is estimated in the model, but has an informed prior distribution based on knowledge about likely availability of fish to the survey, and uncertainties around acoustic target strength, target identification, and calibration. This survey and assessment approach has worked well for the Campbell Plateau SBW stock, where the survey covers the entire spawning SBW area, and q is assumed constant in all years. Resulting assessments have proved robust, and q can be well-estimated from available data. Model-based assessment has worked less well for the Bounty Platform SBW stock, where an unknown proportion of the spawning stock is surveyed in each year, leading to a simpler management approach.

Does paying attention to length distributions produce better acoustic densities?

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During the annual acoustic surveys in the Gulf of Lions (PelMed), opportunistic trawls are located when significant detections are observed. Length distributions are then allocated to each EDSUs by an ad hoc and expert procedure. Length being an important parameter of the computation of an acoustic fish density, we applied a newly developed geostatistical technique to estimate the length distribution anywhere in the study area based on the observed length distribution and on some external driving factors (e.g. depth). This estimation is based on the decomposition of each histogram on a basis of N orthogonal Legendre functions so that each histogram is represented by a set of N coefficients. The method used here consists in cokriging those N-1 coefficients and in using the cokriged estimated coefficients to build the length distribution anywhere in the field. Comparison is made between this new approach and the traditional one. Finally, this also provided interesting ecological information on sardine, anchovy and sprat length-specific spatial distribution, small fish being more coastal in all 3 species.

Increasing the precision in acoustic estimates of patchy distributed fish

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Acoustic surveys are traditionally carried out along transects, where the nautical area backscattering coefficient is integrated over a distance, providing an estimate of the average density and its variance in the surveyed area. Drawing conclusions about temporal and spatial changes in density can however be difficult if the precision of the estimates is low. As precision is correlated with survey coverage and degree of spatial patchiness in density, it is important to establish a theoretical basis for the effect of patchiness and schooling behavior on the survey reliability. Further, to improve the quality of acoustic survey estimates of schooling species there is a need to establish future survey routines incorporating different acoustic observation technologies. Here, we examine recorded data of the spatial distribution of two schooling species, sandeel and herring, which represent high and low degree of patchiness, respectively. Based on these data we simulate a large range of schooling and density structures, and present a method for estimating the degree of patchiness from echosounder data collected along transects. We estimate the precision in acoustic density estimates as a function of patchiness, and show how the precision is improved when including multi-beam echosounder and sonar data, and adaptive sampling designs.

Marine Ecosystem Acoustics in Untrawlable Habitats to Support Fishery and Ecosystem Management

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Marine ecosystem assessments are most informative when they provide measures of absolute abundance or biomass for key taxa to manage resources for fisheries and other ecosystem services. Unfortunately, there are very few assessment methods that are unbiased or unselective for size or species, or are confounded by habitat types. Acoustic surveys present some advantages over traditional extractive sampling, especially in untrawlable habitats like reef and structured habitats. However, well known challenges remain that hamper our ability to deliver metrics and indicators that can serve fishery and ecosystem management goals. Some of the challenges (e.g., the acoustic ?deadzone', remote species identification) may forever plague our surveys and may never be overcome. We outline an initiative and experimental approach to account for several biases in fishery acoustic (and optical) surveys in coral reefs and similarly complex habitats. Indeed, we also show examples where acoustic surveys can provide insights into the biases of optical survey conducted from unmanned platforms such as towed cameras, remotely operated vehicles and autonomous underwater vehicles. It is likely that pairing of survey technologies and including acoustics will continue to provide the most robust methods for conducting marine ecosystem assessments.

Direct assessment of juvenile Atlantic bluefin tuna: integrating sonar and aerial results in support of fishery independent surveys

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Given pronounced shifts in distribution and availability to coastal fisheries, direct assessment approaches for Atlantic bluefin tuna (Thunnus thynnus, ABFT), including formulation of experimental designs and pilot surveys for abundance estimation, are needed. In the western Atlantic, aerial surveys are highly feasible for surface bluefin schools, but individuals at depth and those obstructed by other tuna cannot be documented. Our goals are to design, implement, and analyze a fisheries-independent survey of juvenile ABFT using aerial images gathered simultaneously with sonar data. Aerial imagery provides the horizontal projection of the school, and can identify individuals in the upper few meters, while the sonar data provides information on vertical size of the school and estimate number of individuals not captured in aerial photographs. By integrating acoustic and aerial data estimates of school biomass and other metrics (e.g., sizes of individuals within schools, aggregation behavior) are obtained. Although not without challenges, the analytical techniques developed by integrating these quantitative methods will provide more objective, multi-dimensional information on ABFT schools. Direct assessment also offers a means of tracking shifts in coastal distribution of highly mobile ABFT, especially as traditional indices of abundance may no longer be appropriate.

Stock assessment of the striped venus clam Chamelea gallina using habitat mapping

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The striped venus clam Chamelea gallina is a small-sized commercial bivalve which is very abundant on the coastal sandy bottoms of the western Adriatic sea. The spatial distribution of this species is strictly related with the sediment texture, gradually changing from the shoreline to offshore as the sediment turn from very fine sand to muddy-sand.

Up to date the stock of this resource has been assessed through systematic fishing surveys based on hauls at increasing depths. However, these surveys do not take into account the variability of sediment type, despite of the strong link between this environmental feature and the recruitment and survival of clams on the seabed.

This paper presents the results of a new interdisciplinary approach to evaluate the striped venus stock based on an integrated analysis of multibeam bathymetric and acoustic backscatter data, grain size information and catch data of clam obtained from dredge survey.

In respect to the traditional methodology this approach provides information of depth and sediment texture which can be used to assess the area of distribution of the striped venus clam allowing, at the same time, to save men work both at sea and in the laboratory to sample and analyze the resource.

Euphausiids and walleye pollock: comparing the distribution and abundance of predator and prey in the Bering Sea and Gulf of Alaska

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In the Bering Sea and the Gulf of Alaska, euphausiids (?krill', principally Thysanoessa spp.) are a key link between primary producers and higher trophic level predators including marine mammals, seabirds, and fish. In particular, they constitute approximately 30-50% of the diet of walleye pollock (Gadus chalcogrammus), whose stock supports one of the largest commercial fisheries in the world. Using multifrequency acoustic backscatter data (18, 38, 120, and 200 kHz) from acoustic-trawl surveys of walleye pollock and targeted net sampling of euphausiid backscatter, new time series of euphausiid abundance have been created in both the Bering Sea (2004-2012) and the Gulf of Alaska (2003-2013). These data offer a new opportunity to examine the relationship between and abundance trends in euphausiids and walleye pollock in these two systems. Previous work in the seasonally ice-covered Bering Sea has shown that euphausiid abundance was better predicted by water temperature and location than by the abundance of walleye pollock. We constructed similar models of euphausiid abundance using Gulf of Alaska data in order to compare and contrast these two high-latitude ecosystems. We will also discuss how abundance trends from these time series are being used in resource management.

Empirical modelling of density-dependence in spatial distributions with a non-linear geostatistical approach: anchovy and sardine in the Bay of Biscay

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Acoustic surveys provide knowledge on spatial distributions of fish stocks across a large range of spatial scales and survey series demonstrated their variations over time. Among other drivers, density dependence is a major source of variation in spatial distributions as local concentrations change with global abundance. Here we explore more generic models than the ones suggested sofar using a non-linear geostatistical approach. The spatial distributions over time are characterized by a set of thresholds defining classes of values and their corresponding geometrical sets in space. The method of Min/Max Autocorrelation Factors (MAF) was applied on the presence/absence of the geometrical sets. Empirical models using MAFs as factors were developed by year to characterize how classes of values were organized spatially relatively to one another. Such models may mix diffusion and abrupt features in spatial distributions. Applying the procedure over the survey series allowed to understand how classes of values readjusted spatially when population abundance varied. The procedure was applied on the anchovy and sardine acoustic data series in the Bay of Biscay, for which large variations in spatial distribution and abundance occurred since 2000. Results are discussed in light of the aggregative behaviour of the two species across scales.

Quantification on Distribution and Supporting Service of Eelgrass beds with Seasonal Variation Using Acoustic Method

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Eelgrass beds have many ecosystem services such as supporting services, including carbon circulation. Quantification of eelgrass beds distribution taken along seasonal variation is important. In this study, objectives were to monitor seasonal variation in eelgrass beds using acoustic method and quantify carbon circulation function widely. Acoustic data of Eelgrass beds was obtained in north and east coastal area near Ikunojima islands, Hiroshima, Japan. Surveys were conducted nine times during 2011 to 2013 for monitoring seasonal variation. Acoustic data were used for estimation of spatial distribution by geostatistical method. Carbon sink and fixation values were used the data reported from National Research Institute of Fisheries and Environment of Inland Sea (2011) to quantify supporting services in survey area. Distribution area of eelgrass beds were maximum in May (average thickness 0.94m±S.D.0.28), and minimum in November (0.58m±S.D.0.09) of each year. Distribution area, carbon sink and fixation of north area were larger than east area of each season. It was considered that the distribution trends are different in survey areas and changed year by year because of bottom topography and wind direction. Widely quantification to supporting services of eelgrass beds would be useful information for conservation of coastal ecosystem.

Evaluation of a Waste Water Discharge Plume Using Scanning Split-Beam and 3D Acoustic Tag Tracking Techniques

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As part of a study to assess the thermal impacts of discharge of waste water effluent, a hydroacoustic monitoring study was combined with a concurrent 3D acoustic tag tracking study. In the spring of 2012, fixed aspect, scanning, split-beam hydroacoustic techniques were applied in the Sacramento River, directly downstream of a treated waste water effluent pipe. Hourly estimates were made of fish density, target strength, and direction of movement utilizing two split-beam hydroacoustic transducers scanning a total of 14 different aiming angles. In addition, 298 Chinook salmon smolts and 99 predatory fish were surgically implanted with acoustic tags and released. An area approximately 100 m upstream and 100 m downstream of the discharge were monitored, and the tagged out-migrating Chinook smolts and tagged predator movements were tracked in 3D. The impact of the discharge plume appeared to have little impact on the Chinook smolts' downstream outmigration. In addition, densities of predators around the discharge pipe were relatively low. Some predation on Chinook smolts was observed, but no predation events occurred in the discharge pipe monitoring area. This was a successful implementation combining fixed location scanning hydroacoustic and 3D acoustic tag tracking techniques.

Paradigm shift, fishing industry data to management uptake

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In fisheries around the world that have long term access rights, the major asset of a fishing company is typically their quota base. These access rights provide quota owners with the incentives to ensure sustainable utilisation of their assets and to actively participate in the science, assessment and management activities. Industry vessels with modern, calibrated, digital acoustic equipment following systematic scientific sampling protocols provide ideal platforms to gather acoustic data for biomass estimation. Observations from these vessels, which can be at sea for more than 320 days each year, have provided data on spatial and temporal changes that can significantly influence stock assessments. The difficulty of acoustically assessing deepwater species composition and biomass within mixed species aggregations has been addressed with a multi-frequency acoustic system deployed on the headline of a trawl net. This uptake of technology was identified by the New Zealand fishing industry as critical to having world's best scientific practices to inform our sustainable management. Critically the need to reduce the uncertainty in estimates of biomass using industry scientific data has changed the perceived paradigm in orange roughy assessments with management uptake. Future needs and developments of this technology and its application are outlined.

School and gear dynamics in purse seining, studied with multibeam sonar

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Understanding fishing gear performance and fish reactions to the gear is essential for efficient and sustainable fishing. In this study the dynamics of herring (Clupea harengus) and mackerel (Scomber scombrus) schools captured by the commercial purse seiners, «Artus» and «Kings Bay », were studied with a Simrad MS70 multibeam sonar (75-112 kHz). The sonar was mounted on RV «G.O. Sars» and the recordings covered the whole purse seine and the enclosed school within each single transmission. The catches were taken in the Norwegian and the North Sea in 2013 and 2014. Fish densities and school distribution in the net were estimated as the net was hauled and the available volume was gradually reduced. One of the challenges was to distinguish the school echoes from the net and the air bubble echoes created by propellers of the fishing vessel. Criteria for extracting school data from inside the net were established based on differences in the backscattering strengths from the net and the school and by setting a blind zone around the vessel based on the range of the air bubbles from the vessel. The results are important for reducing slipping mortality and improving catch control in purse seine fisheries.

Fishing vessels as Scientific Platforms: Indicators and Protocols for an Ecosystem Approach to Pelagic Fisheries

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Acoustic data from fishing vessels present a series of advantages and limitation that requires first some specific scientific research from the technical as well as methodological points of view before using them for scientific purposes.
Once validated, the data from fishing vessels provide a unique source of indicators for an ecosystem approach to fisheries. Some examples from results of offshore surveys in Chile on spawning areas and a series of workshops (2011-2014) on acoustic data from the jack mackerel Peruvian fishing fleet are given. Indicators have been extracted on diverse metrics such as geographic distribution and location, the number and morphology of schools; acoustic density; the relationship of schools with oceanographic variables, etc.
The paper discusses the importance of these indicators as contributors for an EAF focused on pelagic fish. They are particularly necessary in a scenario of climate change, where regime shifts are unpredictable. Moreover the implication of fishers can be seen as the interface between the real ecosystems and the virtuality of the models used to explore solutions.

Fishermen spatial behavior and fish acoustic biomass: two sides of the same coin?

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In many fisheries throughout the world, scientific acoustic surveys are key to estimate the spatial distribution and biomass of fish species for fisheries management. However, the campaigns can only be made a few times a year due to the costs they imply. Another approach could be to consider fishermen as 'samplers' or indicators of fish presence. Their spatial behavior could be used for obtaining a proxy of prey presence. But, does it provide the same information than acoustic campaigns? In this work and for the first time, we studied the relationships between fishermen and scientific information for assessing fish spatial distribution. We used Vessel Monitoring System data from the Peruvian purse-seine anchovy (Engraulis ringens) fishery. We analyzed three anchovy fishing seasons where scientific surveys were also performed. We evaluated the strength of the correlation between spatial patterns of both fishermen and acoustic surveys such as the distance to the coast and the covered area. Our findings show a significant and strong correlation in those patterns. This work opens the possibility of using fishermen data for obtaining information on fish spatial distribution for periods when scientific surveys are not performed.

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SECTION II

ABSTRACTS FOR ORAL & POSTER PRESENTATIONS

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Developments in acoustics and technologies

SALTSE: post-processing software to estimate area scattering coefficients (SA), target strength (TS) and fish length (L) in multispecies aggregations in situ

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Software «SALTSE» (Area Scattering Coefficients, Length and Target Strength Estimation) is designed for post-processing and analysis of echograms recorded by SIMRAD echo-sounders (files of BI-500 and RAW-formats). It works in the Microsoft Windows XP operation system and higher. The program shows simultaneously several successive echograms on the monitor screen, makes it possible to highlight the areas (as layers) on the echogram to process, to show the histograms of target strength TS of selected single objects in the chosen layer and the histograms of their length L for standard L-intervals in the linear scale, recalculated from the histograms of TS simultaneously for several objects. The program calculates and stores values of the scattering linked to the coordinates at a specified step in depth and a distance traveled, in a format suitable for further processing (programs of electronic tables - Microsoft Excel and others). At the same time, it can save files and data to make histograms of target strength and object length for whole layer. When connecting the database with the parameters of the objects and results of control trawls it's also possible to save the distribution of abundance and biomass of objects by both length classes and depth.

Insights into deep-sea seamount ecosystems from moored echosounders

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The use of acoustic surveys combined with trawling is the main method for monitoring the abundance of New Zealand deepwater fish populations. The need to understand variables such as species composition, target strength, acoustic availability of fish, and trawl performance, makes this a complex process with a high level of uncertainty. The recent use of moorings combining complementary acoustical and optical technology has provided new insights, and led us to a better understanding of the advantages and limitations of both observation techniques. The approach is illustrated using data from two mooring deployments on the Morgue seamount on the north Chatham Rise, where an important aggregation of orange roughy occurs. Acoustic measurements of fish tracks from a moored 38 kHz Simrad EK60 echosounder allowed us to observe the evolution of the target strength distribution over time, providing information on changes in species composition. The results of the acoustic analysis were then be matched to video observations giving indications of both species composition and fish density by depth.

Calibration of a Furuno FCV30 echosounder and comparison with a 38 kHz Simrad EK60

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There is increasing interest internationally in collection of acoustic data from fishing vessels, and such data are now routinely used in the assessment of New Zealand deepwater species. Although, the commercial Furuno FCV30 echosounder appears to have the capability to output and record scientific quality data, this instrument has not been used previously to collect acoustic survey data. As part of a survey for black cardinalfish from FV Amaltal Mariner in March 2010, an attempt was made to calibrate a FCV30 and comparative trials were carried out with a Simrad EK60. These trials consisted of running a short transect alternately with the EK60 and FCV30 echosounders several times. This poster describes analyses of the data to evaluate the possibility of validating the Furuno FCV30 echosounder as an instrument for scientific data collection. Full validation of the FCV30 as a scientific instrument was not achieved, as the data available in this study were limited. However, the analysis reveals some potential as well as key issues, and makes recommendations for provision of additional instrument specifications and further data collection.

Identification of commercially important species by wideband acoustic data collected on pelagic fishing vessels

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Fisheries policies in many parts of the world are increasingly focussing on bycatch limitations. This is also true for the new EU Common Fisheries Policy, which will implement a landing obligation in a phased approach. From 2015 onwards, pelagic fisheries in EU waters will need to land all catches from regulated species. Consequently, there is a need for improved fishing selectivity. Echosounders are important instruments commonly used on pelagic fishing vessels to facilitate catch operations. Fish species identification algorithms based on frequency-specific acoustic scatter properties have recently shown potential. However, these multifrequency techniques suffer from measurement variability around the individual point-values per frequency. The sometimes marginal differences between species causes these techniques to remain limited tools for improving catch selectivity. Wideband techniques cover a broad frequency band and can provide continuous backscatter measurements. Both the improved resolution and frequency diversity can potentially provide more accurate statistical information about fish identity, size and densities. Here we describe wideband data collected with novel hardware installed on a commercial fishing vessel. Species classification methods based on the wideband signal and fish school morphology were applied. The potential to distinguish the most important commercial species is evaluated by comparing classification results with catch data.

Direct Observation of Predation Using Acoustic Tags

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The application of acoustic tags and 3D tracking technology has proven to be a useful technique for studying fish behavior in fresh water and marine environments. The information collected by tracking tagged fish has been used for evaluating the effectiveness of fish bypass systems at dams and barriers designed to direct migrating fish. However, in many of these studies, predation of the fish species of interest has an impact on the results of the study. In some case, the fact that predation has occurred can be inferred from the fish 3D tracks. However, in many cases, it is isn't possible to infer which tag returns are from free swimming fish and which are from predated fish. This paper describes a new type of acoustic tag that directly detects when the tagged fish has been eaten by a predator. When the predation event is detected, the signal transmitted by the acoustic tag is modified to indicate that predation has occurred while at the same time still providing specific tag identification and a signal suitable for three dimensional tracking. Field results for this new predation detection tag are presented.

Traceable calibration of calibration spheres

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Metal spheres that are commonly used to calibrate echosounder backscatter measurements are not typically calibrated themselves. This is a potentially serious problem that can lead to large errors in acoustic fish and zooplankton biomass estimates, especially if the sphere does not have the assumed properties. We present a process that provides a metrologically traceable method to calculate and verify sphere target strength. The process estimates compression and shear wave speed in each sphere and hence provides individual sphere target strength estimates. Each sphere is then permanently marked with a unique identification code that does not affect the acoustic characteristics of the sphere. The sphere properties are recorded in a database with the identification code as a key, allowing for reliable recording and tracking of sphere properties over extended time periods. Traceability of the sphere material property estimates to metrological standards is demonstrated. The method is applied to ten tungsten carbide spheres from two different production batches to illustrate the variability in sphere backscatter and the potential error in assuming nominal material properties. The introduction of scientific broadband echosounders, where several spheres are used in the calibration procedure motivated this proposed procedure.

School biomass estimates using digital omnidirectional fisheries sonar

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Low frequency (26 - 30 kHz) omnidirectional fisheries sonars (Simrad SX90 and SU90) were used to measure the acoustic backscatter and dimensions of herring (Clupea harengus) and mackerel (Scomber scombrus) schools from fishing vessels between 2012 and 2014. Detailed sonar sampling of each school included operations at slow vessel speeds and fixed distances to the school, similar to pre-catch school inspection procedures during commercial fishing. Calibrated digital sonar data were processed using new school segmentation procedures, including school area correction procedures. Data on segmented schools from horizontal and vertical sonar beams were used to compute school volume and mean acoustic backscattering strength (Sv). Using mean lateral target strength estimates and fish length and weight, individual school biomass estimates were derived. Biomass estimates were compared with purse seine catches of the same schools, and the accuracy of the estimates assessed in relation to the significant parameters used.

A new fish school segmentation method for fishery sonar

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Omnidirectional fishery sonars are widely used on research and fishing vessels and can observe fish schools over larger volumes than vertically oriented echosounders. Unbiased characterization of fish school size and shape by a new segmentation method is presented for fishery sonars. The method resolves the problem of enlarged school extents due to signal smearing in overlapping beams by segmenting the schools in two steps. In the first step, a threshold defined by a fixed value above the estimated ambient signal level (including noise and unwanted targets) is applied, and excludes the background level from the segmentation. In the second step, the highest backscatter level of the school, estimated from the segmentation mask from the first step, is used to define a new threshold optimized using simulations, to produce an unbiased estimate of the horizontal area of the school. The second threshold is below the highest backscatter level of the school, and takes into account the size of the school as estimated by the first segmentation mask but is independent of the range from the sonar. Examples of the performance of the segmentation method on simulated and real data are shown.

Complementary density estimates of fish layers with echo sounder and scientific sonar

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When estimating abundance of pelagic fish stocks where parts of the stock may be close to the sea surface, there is a need to observe the complete water-column, not just a narrow sector under the cruising ship usually observed by echo sounders. The effective observation volume in the fairly narrow echo sounder beams close to the vessel is small when surveying small pelagic schools close to the sea surface, and the acoustic blind zone created by transducer draft and acoustic near field may be substantial when an instrument keel is used. Capelin (Mallotus villosus L.) is typically distributed in mid-water and show weak vessel avoidance and is therefore considered ideal for abundance estimation based on echo sounder data, due to, while mackerel (Scomber scombrus L.) and herring (Clupea harengus L.) some years have vertical distributions extending towards the sea surface, increasing the probability for a variable survey bias.
In the present study a multi-frequency echo sounder and a scientific multi-beam-sonar have been used to map the horizontal and vertical distribution of capelin and herring to give complementary density estimates from a fairly silent vessel. Blind zone corrections to the biomass estimates are presented at 5 nautical mile intervals.

Pre-catch sizing of herring and mackerel using broadband acoustics

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The price of caught fish can depend strongly on their length or weight. This creates a strong motivation and need for pre-catch size estimation, particularly in purse seine fisheries. While it is customary to release unwanted schools, this can cause high mortality in the fish. We present initial measurements and at-sea trials of an acoustic system and real-time processing algorithm that estimates the length of Atlantic herring (Clupea harengus L.) to within +/- 3 cm. The algorithm is also applied to Atlantic mackerel (Scomber scombrus L.), with similar results. Horizontal broadband backscatter was measured from tethered fish at all rotation angles and used to develop and test three complimentary size estimation methods based upon target tracking, target strength, pulse stretching and spectral analysis of resolved targets. A 3-degree beam angle transducer affixed to the bottom of a ship's drop-keel, with mechanically controllable pointing angle, operating from 160 to 260 kHz was then used to collect data from individual fish in and around schools. Software was developed to implement these methods in real-time and applied to the at-sea dataset. The system shows promising results on adult herring and mackerel, but should be tried further on other size groups and fish species.

In situ acoustic observations of Atlantic Bluefin tuna (Thunnus thynnus) with high resolution multi-beam sonar

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Field studies to investigate the ability/adaptability of a high frequency multi-beam sonar to document, monitor, and quantify bluefin tuna was undertake at several fishing sites (commercial and recreational) off PEI and at a tuna pen in Nova Scotia. The preliminary results of this study clearly illustrate that bluefin tuna can be detected and tracked acoustical within the swath the multi-beam sonar. Estimates of natural swimming speeds were made by tracking targets from ping to ping within the swath. Range restrictions/limitations were imposed depending upon sea state and water depth. In rough seas the surface layer became too turbulent (air bubbles) to consistently separate noise from fish like targets. Whereas in shallow water (20-30m) the full detection range of the sonar could not be used due to the acoustic beams intercepting with the bottom. Water depths > 50-60m allowed the full range of the sonar to be utilized uncluttered. Adjustment of the tilt angle of the sonar was used to optimize observations with a pan and tilt unit. In summary the results indicate that there is good potential for the utilization of multi-beam sonar to monitor and quantify bluefin tuna in a broad scale fishery independent survey.

Characterising the prey field around Blue Whales in the Southern Ocean: A mixed-modality acoustic survey

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In the Southern Ocean Antarctic krill is the staple prey of blue whales. While it has been hypothesised that blue whales play an important role in the Antarctic ecosystem, little is known about their foraging decisions, particularly at small spatial scales. Recently developed passive acoustic systems provide a reliable means for locating blue whales in the Antarctic, and concurrent use of active acoustic systems enables the investigation of not only the distribution and behaviour of blue whales, but also that of their prey. At sub-10 km scales blue whales may forage opportunistically, or alternatively target areas with particular spatial distributions of krill. Using data from vertical echosounders, the distribution of krill in the vicinity of blue whales exhibiting contrasting behaviours was described using school-based metrics, specifically packing density and spatial clustering. Examining the small-scale prey-field will inform spatially explicit modelling of blue whale habitat; if blue whales are insensitive to local small-scale prey distribution, then larger scale modelling may be adequate, conversely blue whale sensitivity to the local prey field will necessitate regular surveys and more detailed modelling.

Broadband discrimination of Antarctic krill

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Acoustic surveys are conducted to assess the biomass of Antarctic krill. The method by which echoes from krill have been identified has evolved from visual scrutiny of single-frequency echograms, to 2-frequency dB-differencing, to 3-frequency algorithmic classification. The purpose of the echo-classification has been to reduce estimation bias by exclusion of echoes from other zooplankton (including ice krill), fish, squid and ice crystals. It has been suggested that in some instances echoes from non-swimbladder fish are erroneously included as 'krill'. Here we present broadband data (Simrad EK80 from 25-170 kHz) that show how these taxa can be distinguished. Broadband surveys have the potential to improve accuracy of krill biomass estimation, and so contribute to ecosystem-based management of Southern Ocean ecosystems.

Quantitative analysis of nearfield effects on standard target calibration

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Performing accurate calibration of acoustic systems is necessary for fisheries acoustics applications. Field calibrations are normally conducted in the transducer farfield. However, the rigorous farfield conditions may not be satisfied due to geographic and logistical limitations and actual calibrations may have to be conducted in the nearfield. To use the nearfield calibrations for farfield applications correctly, a theoretical investigation into the nearfield effects is presented here. It involves multi-frequency (18, 38, 70, 120, and 200 kHz) echosounders commonly used in the fisheries acoustic communities (Simard EK60). This study focuses on the transition from the Fresnel (radiative nearfield) to Fraunhofer (farfield) distances. Results of numerical evaluations indicate that after appropriate compensations, the errors at all frequencies resulting from nearfield calibration at the Fresnel distance is the diameter of the transducer and l is the acoustic wavelength) can be reduced from around 1.8 dB to less than 0.03 dB . The results from this work can potentially be applied to multi-frequency echosounder systems such as a Simrad ME70, MS70, and/or SX90.

A Bayesian approach to quantify the non-uniqueness in a nonlinear inversion method for simultaneous estimation of animal abundance, size, and scattering model parameters

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Applications of multi-frequency acoustic data to marine species identification and classification have increased rapidly in the past decade since multi-frequency echosounder/sonar systems have become widely accepted internationally as standard survey systems in fisheries acoustics. Inversion techniques play a key role in these applications. The conventional linear inversion approach can provide estimates of abundance and length of the species of interest, but can produce erroneous estimates for more complicated problems when uncertainty in scattering model parameters is not negligible. In such cases, an iterative nonlinear inversion scheme may be more suitable since it allows the inversion kernel, which is associated with scattering model parameters, to change at every iteration. However, the inherent non-uniqueness of the nonlinear inversion resulting from local minima of the cost function can produce inconsistent parameter values that are dependent on initial values and the characteristics of the scattering models. To overcome this difficulty, a Bayesian approach is used to predict the probability of the inferred parameter values from the nonlinear inversion. Numerical simulations based on the synthetic data and field data are presented, demonstrating that the inversion non-uniqueness can be mitigated by weighting the different sets of estimated parameter values based on their probability.

Comparative studies and field measurements of the acoustic absorption coefficient in seawater

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The absorption coefficient of seawater is an important component to the sonar equation underlying fisheries and zooplankton acoustic investigations. The equations currently considered most accurate and widely used for calculating the coefficient are the three decades-old work of Francois and Garrison (1982, J. Acoust. Soc. Am. 72: 896- 907, and 72: 1879-1890). However, there is evidence to suggest that these equations are inadequate for the higher frequency applications that have become increasingly important in ecosystem-based acoustic surveys and management. Comparative studies among the different formulas will be presented. In situ measurements of acoustic absorption were conducted onboard the R/V G. O. SARS in the Norwegian fjords from 2011 to 2014. It was found that the absorption coefficient at 333 kHz was about 18.5 dB/km more than that given by Francois and Garrison's work, which could lead to an uncertainty in biomass estimates of about 50% more at a range of 100 m. In addition, inaccurate absorption coefficients will also introduce a depth-dependent bias on frequency response and impair acoustic echo characterization and species identification/classification that strongly rely on relative frequency response.

Counting and sizing of bluefin tuna schools by automated analysis of long-range sonars in fishing vessels

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This study presents a new approach for automated analysis in tuna long-range sonar. Actually the standardized CPUE of the Bay of Biscay baitboat fleet is used as the only abundance index. Omni mode Long Range Sonars (LRS) are used to search for tuna, they are believed to provide data about the number and size of tuna schools in the search area, independent of food availability and feeding behavior. As these sonars are analogic and non-scientific, all the information collected is ephemeral, so our goal is to record sonar screen shots extensively in a large number of fishing vessels during the tuna fishing campaigns and design an automated methodology for analyzing these images as a way to store and utilize all this currently wasted data. With the aim of facing this challenge, a Semi-Automated Image Processing (SAIP) technique which performs a morphological binary classification of sonar images of tuna, an Optical Character Recognition (OCR) application for sonar screen dumps and a temporal analysis of images based on a Kalman filter, which works with the data obtained with the previous approaches (SAIP and OCR), are presented.

Hybrid seafloor characterization using Multibeam Echosounder data

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Multibeam Echosounder (MBES) is increasingly becoming suitable for marine habitat mapping and various classification methods, diversifying in terms of classification algorithms, automation and MBES involved data features, are requiring scientific attention.
On the other hand, the improved quality and volume of MBES data, as well as the increased demand for mapping products, is driving the desire for repeatable seafloor mapping approaches, analogous to the automated classification of satellite imagery in terrestrial remote sensing.
In this context, the proposed study investigates how to tailor a hybrid classification approach, successfully developed for terrestrial Land Cover mapping and incorporating the advantages of pixel and object based classifications, to seafloor characterization.
Dataset includes full-coverage bathymetry, backscatter intensity and their derived textural / statistical features while sediment samples are used as ground-truths to drive the feature selection («Relief-F» approach), train the supervised classification (AdaBoost classifier) and last aid the research evaluation.
Experimental results show how to improve the overall acoustic seabed classification integrating MBES data along with their derivatives and sorting segmented regions into seafloor thematic classes in terms of membership class percentages. Moreover, the final habitat data is GIS-ready, hence suitable to be directly used for marine spatial and temporal planning and resource management.

Do Antarctic krill avoid underwater gliders?

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Antarctic krill (Euphausia superba) is a key species in the marine ecosystem of the Southern Ocean but a better understanding of the response of krill to changes in the physical environment is required. Autonomous Underwater Vehicles (AUVs), such as long-duration gliders carrying acoustic sensors, have been used to map the distribution of Antarctic krill. This has the potential to greatly expand the duration and extent of existing krill monitoring efforts.
Gliders fitted with calibrated 120 kHz single-beam echo-sounders were deployed off the Western Antarctic Peninsula (WAP) to examine on-shelf krill distribution. Gliders are approximately 2 m long, are highly energy efficient and produce very little noise or vibrations. They are thus an ideal platform for surveys of fish and krill, though krill avoidance remains to be quantified.
As the glider descends through the water column, multiple measurements of discrete acoustic targets are made at variable ranges from the echo-sounder. We observed no avoidance of the glider by krill up to a distance of 5 m. However, no krill were observed closer than 5 m to the glider. We discuss the variability within recorded profiles to derive insights into instrument sensitivity and the behavioural consequences to glider survey of krill swarms.

Calibration of omni-directional fisheries sonar using split beam target positioning

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The recently released scientific data format from the Simrad SX90 and SU90 fisheries sonar, the accuracy and resolution is sufficient for scientific purposes. For biomass estimation on surveys it is a necessary that the equipment is calibrated. In recent years, numerous calibration trials have been conducted on both the SX90 and SU90 fisheries sonars, where each trial has led to new discoveries and new calibration protocols. The conclusion of the calibration will be presented as two parts.First presented is a suggestion of how to perform a sonar calibration, positioning the reference target inside each acoustic beam either by the split beam method or by target amplitude interpolation between neighbouring beams. Simulations are made in order to study accuracy, benefits and limitations of each positioning method. Further, the results from a full calibration is presented, along with an interpretation of calibration overall accuracy.

A real-time modular program for tracking and classification of large marine organisms using multibeam sonar

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Given the increasing development and maintenance activities (i.e., dredging, construction, etc.) in nearshore coastal waters, robust methods are needed for efficient real-time detection of protected and endangered species to serve as a warning system for injury mitigation. A real-time modular software package (MarVis-RT) was developed for detection, tracking and classification of large marine organisms (i.e., manatees. turtles, sea lions) using data from a multimode multibeam sonar. The MarVis-RT software package was specifically tuned to receive network packets from the new Kongsberg Mesotech M3 multibeam sonar, allowing for real-time viewing and processing. The real-time processing comprises the ability for remapping to an image matrix, dynamic background subtraction, shape detection, smoothing and contouring. Detected object speed and size was incorporated into the classification algorithm allowing for confidence in tracking and identification. Results are presented from example data of West Indian manatees and California sea lions. Following this initial effort, real-time images can be acquired and processed from an off-the-shelf multibeam imaging sonar, yielding simultaneous tracking and classification of multiple targets within a field of view.

Sailbuoy Unmanned Surface Vehicle as an active acoustic measurement platform for biomass detection and monitoring; sensor integration, tests, and demonstration mission

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The Sailbuoy is a commercially available unmanned surface vehicle for marine measurements. The vehicle relies on wind for propulsion and has station-keeping abilities, as well as the possibility of running transects. Batteries and solar panels power the vehicle's autopilot and sensors, and the vehicle is designed specifically for long-term deployment and harsh environmental conditions. Due to the compact and robust design, the vehicle is easily deployed from either small or large vessels. A version of the Sailbuoy has been developed with the ability to carry acoustic sensors. The «acoustic» Sailbuoy includes a deep keel for transducers, as well as a custom control and data handling system. The sensors and vehicle are controlled via 2-way communication through the Iridium satellite system, and the custom data system stores data in the vehicle and transmits processed data and echograms (images) automatically to shore. A description of the platform and its acoustic data handling system are given with performance results from two near shore tests and a demonstration mission in the North Sea.

Passive and active, predator and prey; using acoustics to study interactions between cetaceans and forage fish

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Fisheries acoustics surveys provide potential platforms for deploying passive acoustic equipment to detect cetacean vocalisations. Passive acoustic methods are developing as viable alternatives to visual surveys, particularly for small, inconspicuous species such as the harbour porpoise (Phocoena phocoena). Visual surveys, and passive acoustic monitoring using a towed hydrophone array, were carried out during an acoustic survey of clupeids in the Clyde Sea and surrounding sea lochs, to identify spatial relationships between porpoises and their prey. Methods were developed to process passive acoustic data, successfully identifying porpoise echolocation clicks whilst discriminating them from the transmitted 120 kHz echosounder pulse and its reflections. To date, this has been a confounding factor which has made these survey techniques potentially incompatible. A significantly higher biomass of fish was found in the northernmost regions of the Clyde and high numbers of harbour porpoises were also detected in these regions. As such, the distributions of porpoises and their prey were found to be linked. This study demonstrates that high frequency passive acoustic monitoring can be used effectively alongside multifrequency fisheries echosounder surveys to provide novel insights into the trophic interactions between these species, and inform management in line with the ecosystem approach to fisheries.

A new platform to acoustically survey deepwater fish from industry trawl nets

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Commercial fishing vessels are often used to survey small or remote fisheries using the echo integration method to quantify biomass. Accurate biomass estimates require high confidence species identification and robust target strength (TS) estimates. For deepwater (700 m to 1000 m) fish such as orange roughy, deeply towed platforms are required to overcome weather, range and frequency dependant limitations of vessel-acoustics. To achieve this from fishing vessels a novel approach has been to utilise the infrastructure of the demersal trawl net and attach an instrumented acoustic-optical system (AOS). The AOS contains multi-frequency acoustics, video and stereo digital cameras while the net can collect biological samples and commercial catch. This has allowed multiple lines of evidence to decode the species composition of complex ecosystems. In appropriate regions comparative vessel mounted and AOS biomass estimates were similar with no systematic bias due to herding or avoidance of the net. Echo integration transect surveys obtained biomass estimates at 38 kHz and 120 kHz using TS estimates based on previous AOS surveys. These biomass estimates are now accepted inputs into stock assessment processes.

Volume backscattering strengths of Antarctic krill aggregations measured using broadband signals

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Volume backscattering strengths of Antarctic krill aggregations in situ were measured using broadband signals. The purpose of the measurement was to infer the size of krill from the backscattering spectral shapes. Acoustic samplings were performed by a pulse-echo system consists of a pair of newly developed transducers and other commercially available equipment. The observation was conducted over the continental shelf in the Indian Ocean sector of the Southern Ocean (65.2°S, 107.5°E) on 26 January 2014 by the training and research vessel Umitaka Maru. The transducers were suspended downward from the vessel at 5-m depth. The transmitted signal was a linear frequency modulated signal with a frequency sweep of 20 to 200 kHz. The pulse duration of 10 ms was employed. The volume backscattering strengths was measured at the frequency range of 80 to 180 kHz. The measured spectral shape had a peak at 120 kHz and looked like the Rayleigh-to-geometric scattering transition region of fluid-like animals. The measured spectral shape was fitted to a theoretical scattering spectrum of 35-mm-long fluid-like elongated animals. The inferred size of 35 mm coincided with the mean length of Antarctic krill sampled by a net observation immediately after the acoustic sampling.

Application of acoustic telemetry system for monitoring depth of fishing gear to improvement of operational efficiency in small-scale fisheries

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Various acoustic instruments, such as echo sounders, sonars and gear performance sensors, have been used in marine fisheries. These instruments can support smart operations that are low cost and low impact. The gear performance sensors, used for monitoring a fishing gear during operations are designed to be used for large fishing gears such as trawl or purse seine, and so it's not available for small-scale fisheries that have significantly effects on local ecosystem. In this study, technique of acoustic telemetry system for observing aquatic animals was applied to monitoring depth of fishing gears for improving operational efficiency in small-scale fisheries. The system is consisted of a compact acoustic transmitter (pinger), a hydrophone and receiver. The system displays depth of a fishing gear that is sent from the pinger attached to the gear in real-time. The system was evaluated the effectiveness by implementation in hooks and lines fishing. The results showed that the system could monitor continuous depth of the fishing gear, having fishermen adjust the gear depth accurately and easily. Therefore the system can prevent wasted operation leading to excessive use of fuel and also may prevent a loss of fishing gears by snagging on the bottom causing ghost fishing.

DIDSON data and Sonar5-Pro, an efficient tool to estimate upstream migration of Atlantic salmon?

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The non-intrusive hydroacoustic technology has a large potential to monitor migratory fish populations in rivers. The use of high frequency, multibeam sonars has greatly improved data resolution with sonars operating effectively as cameras. Fish behavioural and some morphological characteristics can be analysed to improve fish species identification and allowing population abundance to be estimated. Data analysis has to follow this improvement: a DIDSON automatic tracking tool has been developed in the Sonar5-Pro® software. Our tests show that target detection is efficient and swimming direction information is relevant, but fish abundance is dramatically over-estimated, particularly in high flow conditions. Furthermore, fish length can be largely under-estimated. Specific criteria for Atlantic salmon adults, such as the length or the swimming speed, are used and each selected track checked. Between August 2013 and July 2014, more than 60 000 targets have been filtered from the 3 millions tracked by the Sonar5-Pro tool. About 400 salmons have been identified. The efficiency of this methodology has been evaluated on our monitoring site and on files from another site in the UK. The efficiency is discussed, pointing the ways we can decrease the number of unwanted targets in Sonar5-Pro selection without losing accuracy on salmon's migration.

The GeoHab Backscatter Working Group: Definition of Guidelines and Recommendations for Seafloor Backscatter Measurements by Hydrographic Multibeam Echosounders

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The Marine Geological and Biological Habitat Mapping (GeoHab) group gathers a community of geoscientists and biologists around the topic of marine habitat mapping, with a strong technological component. During its 2013 annual meeting, a workshop dedicated to multibeam seafloor backscatter concluded the need for better coherence and common agreement on acquisition, processing and interpretation of data. Subsequently, the GeoHab Backscatter Working Group (BSWG) was created, with the mandate of proposing best practices for the acquisition and processing of seafloor backscatter, and providing recommendations for further development of backscatter acquisition systems and processing software.
The group brings together researchers, end-users, sonar manufacturers and software developers, with the goal of producing realistic guidelines and providing feedback on how hardware and software tools can be improved. Co-written by specialists of the various fields involved, the guide presented at the GeoHab meeting in May 2015 covers six main topics:
backscatter fundamentals user needs seafloor backscatter measurements acquisition best practices backscatter processing
Designed to reach a wide audience of scientists, engineers, operators and stakeholders all using sonar backscatter for seafloor-mapping applications, the BSWG report proposes fundamentals of the topic, a state-of-the art of techniques, and a number of recommendations for future systems and processing.

Fish length accuracy of DIDSON data: the need of repeated measurements

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Acoustic cameras are increasingly used to monitor fish populations in rivers. They provide fish morphological and behavioural information. Fish length is directly reachable from DIDSON (Dual frequency Identification SONar) images. During four surveys, more than 50 fish (atlantic salmons, silver carps, sea trouts and rainbow trouts), which true length (total length) was previously measured, have been recorded in the DIDSON detection beam. Multiple views of each fish have been analysed with Soundmetrics software, two operators measuring each fish several times. The results showed a high intra-individual length measurement variability, but no significant difference between the mean measured length and the true fish length. Moreover, no operator effect, fish body angle effect and range effect have been detected. General linear mixed model showed that the smallest fish (length 55 cm) were underestimated in comparison of true length. Using bootstrap method, the sufficient number of measurement per fish to obtain wise length accuracy (95% confidence interval) has been estimated.

Identification of fish species using a wideband forward looking sonar on a pelagic fishing trawler

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Fisheries policies in many parts of the world are increasingly focussing on bycatch limitations. This is also true for the new EU Common Fisheries Policy, which will implement a landing obligation in a phased approach. From 2015 onwards, pelagic fisheries in EU waters will need to land all catches from regulated species. Consequently, there is a need for improved fishing selectivity. Forward looking sonars are commonly used by pelagic fishers to localize fish schools. Being able to use them for fish species identification at long range, prior to the catch, would be a great cost saver. With sonar technology evolving quickly, larger frequency bands are broadcast underwater at affordable cost for the industry. Wideband implies higher resolution in the resulting sonar images. This paper focuses on the development of an algorithm for fish species identification using a novel multi-beam forward-looking wideband sonar. It uses statistical analysis of fish school echoes in high-resolution sonar images. A real-time demonstrator is implemented on-board of a pelagic fishing trawler from Jaczon BV. The classification results are compared with catch data. The classification scores obtained, for the four most important commercial species are significantly better than random guesses and show potential for future commercial use.

Comparison between two acoustic cameras: the DIDSON and the BlueView

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Acoustic cameras are increasingly used to monitor fish populations in rivers: they can substitute for optical systems in turbid water where these last ones fail. Different manufacturers develop different types of acoustic cameras, with different capacities and costs. Data from two devices are compared from a same location during one week: a Dual frequency Identification SONar (DIDSON) from Soundmetrics Corp. and a P900-45 BlueView camera from BlueView Technologies. The DIDSON camera is set in high frequency mode (1.8 MHz) and has a field of view of 29°. The BlueView camera opening angle is higher (45°), but its frequency is lower (900 kHz). Despite these differences, the detection beams of the two cameras are crossed. 167 fish between 8 cm and 61 cm are detected and manually measured with the camera's softwares. The BlueView camera detects only 41% of fish detected by the DIDSON. Significant mean differences are observed between the measured fish length by the two cameras and for the fish detection duration (number of detected second in the crossed beam) which is two times shorter for the BlueView. The efficiency of the BlueView camera appears to be not suitable for fish monitoring in rivers comparatively to the DIDSON one.

Characterising diversity and variation of fish choruses in Darwin Harbour

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The diversity, intensity and periodicity of fish calls and choruses can provide a wealth of information on spatial and temporal distribution of soniferous fish and, on occasion, the environmental factors with which these patterns correlate, or are driven by. One extension of such information is an indictor of system health through on-going monitoring of the local soundscapes. At three sites in Darwin Harbour, Australia, underwater noise recordings have been taken consistently for the past two years,using underwater sea-noise loggers, located on the harbour floor. These recordings have detected numerous fish calls and seven choruses, offering the opportunity to map some of their temporal patterns. The region is highly diverse in vocal fish in comparison with other areas of Australia, highlighting the need to accurately document such sounds for comparison with recordings of similar species from other locations. This paper characterises the fish contribution to the Darwin Harbour biological soundscapes, where possible identifying the sources and detecting links between temporal patterns in sound production (or received levels) and environmental drivers, such as season and tide. The paper also highlights the difficulties associated with monitoring multiple choruses of numerous species occurring concurrently, over the same frequency band.

Migration timing of fin whales monitored by passive acoustic method in the southern Chukchi Sea

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Migration timing of fin whales (Balaenoptera physalus) to the Arctic Sea are suggested to be triggered by plankton influx from the Bering Sea, and/or soaring of local productivity. Using passive and active acoustic monitoring method, we aimed to understand the relationship between migration timing of fin whales to the southern Chukchi Sea and physical and biological environments. We deployed an Acoustic Underwater Sound Monitoring System and an Acoustic Zooplankton Fish Profiler in the southern Chukchi Sea from June 2012 to June 2014. Simultaneously, sea temperature, salinity and sea ice concentrations were observed by additional mooring systems and satellite data. A custom made program to extracted fin whale calls automatically. Most of the calls were detected from 16 August to 20 October 2012 (66 days) and 25 June to 1 November 2013 (100 days). Period with calls in 2013 was longer than that in 2012. The length of calling duration corresponded to no sea ice concentration period. The beginning of the calling period was related to increasing zooplankton abundance. The end of calling period was related to drop of sea temperature and salinity. Our results suggested that transport of water mass from Bering Sea influence on migration timing of fin whales.

Ultra wideband transducer

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The broadband technology is already indispensable in the field of the biotelemetry as well as acoustic estimation methodology of biomass resources. Broadband technology can deal with more information compared with the measurement technique by the single frequency up to now, and can expect improvement of measuring accuracy and diversification of information. The ultra wideband transducer that we have developed has achieved the small deviation characteristic within wideband which overturns common sense and its manufacturing is easy to produce. A prototype of transducer could be realized within the 12dB ripple of sound pressure level in 2.5 octaves of frequency bandwidth from 38kHz to 190kHz. Its bandwidth of 152kHz is extremely wide in underwater acoustic field. The relative bandwidth of conventional transducer is about under 0.2 values. The relative bandwidth of the broadband transducer developed recently is about 0.7 values and 1.1 octaves, for example BW=±40kHz for center frequency=110kHz. How to design the ultra wideband transducer is introduced and the frequency characteristic of proto type transducer is shown. The application using the ultra wideband transducer is also introduced.

Broadband frequency response of fisheries species measured in a tank and ocean

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The target strength (TS) is the most important parameter to estimate the stock of fish. In recent years, broadband frequency response of individual fish was suggested to be a key to identify species. We measured the TS spectra with respect to the tilt angle of fishes (TS spectrum pattern) in a large acoustic experimental tank (10×15×10 m) and in an open ocean. Subject species were red seabream?averaged fork length: 30.5 cm, standard deviation: ±0.9?and sample number: N=8?, Japanese jack mackerel (22.1 cm, ±0.7?N=10?, chub mackerel (30.4 cm, ±4.2?N=10? and Japanese sardine (15.3 cm, ±4.7?N=9? in the tank. Intra-species variation of image cross correlation of the TS spectrum pattern was smaller than inter-species variations. The TS spectrum patterns were compared with the theoretically calculated values by using Kirchhoff-ray mode model. Theoretically calculated TS spectrum patterns well matched with the experimentally measured ones. The species differences among TS spectrum patterns seemed to be caused by shape, angle, and position difference of multiple scattering targets including swimbladder. The wideband split-beam system was proved to provide differences of TS spectrum pattern depending on fish species. [Supported by CREST JST]

Trials of parallel survey using ME70 and EK60 for some pelagic fishes

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The YOKO-MARU is a research vessel belongs to the Seikai National Fisheries Research Institute in the western area of JAPAN. She equipped a new multi beam echosounder SIMRAD ME70 which is expected to be active in future research. The East China Sea is one of important fishing area of small pelagic fishes, sardine, anchovy, chub mackerel, and jack mackerel, and R/V YOKO-MARU investigates mainly around this area. Though echo integration survey using a vertical echosounder EK60 is the standard method estimating of abundance or biomass, fish avoidance reactions from vessels sometimes cause uncertanty in a survey for small pelagic fishes, especially. A multi beam echosounder ME70 has vertical scanning acoustic beams, and it is able to scan widely below a vessel. Moreover, ME70 is calibrated, so it can obtain quantitative information from target fishes. In this study, we discuss about results of trials of parallel use of ME70 and EK60 with synchronized pinging and future acoustic surveys by R/V YOKO-MARU.

Software for rapid visualisation and analysis of multi beam echosounder water column data

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Once focussed on the collection and processing of seafloor bathymetric and backscatter data, in recent years multi beam echosounders have also been used increasingly to map and quantify the spatial and temporal distribution of in-water targets. Whether the subject is fish, mammals, zooplankton, habitat, seeps or suspended sediment, the operation of multi-beam systems is accompanied by an inherent need to rapidly process vast volumes of data for visual scrutiny. To ease this need, software (named ?water column viewer') has been designed for a user to quickly conduct an initial review of data, and to create average across and/or along track data to allow easy presentation and analysis. The viewer is capable of reading s7k (Reson), raw (Kongsberg) and 83b (Delta T/Odom) files. This presentation will demonstrate the use of the viewer for detecting water column targets such as fish, seeps, and sediment plumes; calibrating multi beam echosounders through the calculation of Scattering Volume (Sv) and Target Strength values; and disseminating large water column datasets for reports.

A unifying theory explaining different formulations of power budget equations and calibration factors commonly used for fish abundance estimation

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Acoustic methods used in fish abundance estimation and species identification rely on power budget equations and calibrated systems, involving expressions for the backscattering cross section, volume backscattering coefficient, and calibration factors. Different formulations of these quantities are used in modern scientific echosounder and sonar systems, such as the Simrad EK500 and the more recent Simrad EK60, ES60, ME70 and MS70 systems. The lack of sufficient documentation in prior literature, on the actual power budget equations and calibration factors employed, and their relationships to the traditional theory of fish abundance measurement, has caused some uncertainty and confusion among users.
The paper presents a unifying theory that seems to explain the different power budget equations and calibration factors that are employed in the mentioned systems. This includes how they are related, and their relationship to the traditional and generic (instrument independent) theory of fish abundance measurement. Inconsistencies in prior literature are explained and corrected.
For improved control with systematic errors and drift, such as from calibration to oceanic survey, prior expressions are also extended to provide more complete power budget equations, by accounting for electrical termination, representation of echo integration, and the full range of electrical and acoustical echosounder parameters.

Multibeam echosounder reveals fish swimming behaviour.

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Three dimensional (3D) echograms provided by multibeam echosounders reveal 3D morphological features of fish schools, that are already used to optimise the identification haul strategy and improve the scrutinising process during acoustic fish biomass assessment surveys. The schooling behaviour of fish in the immediate vicinity of the surveying vessel imaged by multibeam echosounder may also provides information on the dominant fish orientation relative to the incident soundwave, that ultimately affect fish echo amplitude.
We here compare in situ and modelled herring target strengths at different angles and frequencies to assess the influence of fish scattering directivity and orientation on acoustic measurements. Potential impacts of fish avoidance reaction to the survey vessel on biomass estimates are discussed.

An evaluation of the range limits for multibeam echosounder measurements of sediment suspended by demersal trawl fishing

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The resuspension of sediment by towed demersal fishing gear has been related to benthic infaunal mortality, the release of nutrients and the suspension of phytoplankton cysts and copepod eggs. To better understand these impacts it is important to accurately quantify the amount of sediment put into the water column by the fishing gear. Multibeam echo-sounders (MBES) have previously been demonstrated to be an effective tool for the logging of water column acoustic backscatter and subsequently quantifying the sediment load in suspension in shallow water of less than 20 m depth.

The work presented here investigates the depth range to which such MBES measurements can be usefully used. Experimental trials were carried out in which acoustic backscatter data were collected with a RESON 7125 MBES at distances of up to 90m behind a towed sledge to image the spatial and temporal evolution of suspended sediment plumes at depths from 50m to 60m. Suspended Sediment Concentration (SSC) data were obtained with a Laser In-Situ Scattering and Transmissometry (LISST) 100X and grab samples of the sandy sediment were also taken from the bed to quantify the suspended sediment load in the plumes. The effective range of this novel methodology is presented and discussed.

Bottom echo reduction using adaptive beamforming

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In a sonar being used to survey demersal fish stocks, the bottom echo is a major source of interference. A method of improving detection with a phased array is to use adaptive beamforming in which the beam pattern is automatically adjusted to reduce the contribution from strong sources. This has been tested in a series of ultrasonic experiments in the laboratory. The adaptive process will be outlined, and the experimental setup will be described. The array output with conventional and adaptive beamformers will be compared for surfaces representing flat and sloping, sandy and rocky bottoms.

3D-Multibeam Echosounder Target Strength Measurement Evaluation

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While mono-beam echosounders are widely used in fishing activities and science, uses of multibeam echosounders (MBES) (ME70, WASP) increase and are very promising. A new kind of multibeam echosounder (SEAPIX), working in a symmetric Mills cross configuration at 150kHz, combines a wide aperture 120° x 120° with 64 2°-wide beams, allows volumic coverage, IHO special order bathymetry and a high accuracy of fish school detection. Simultaneously, SEAPIX is able to measure with accuracy Target Strength (TS) of scattered fish, processing interferometric calculations, e.g. the split-beam method. To demonstrate its measurement capability, we in situ compared the SEAPIX MBES with a reference split-beam echosounder (SIMRAD EK60, 70 kHz, 11° split-beam transducer). The survey was performed in a deep lake (Lake Bourget, France), where previous acoustic measurements and fishing surveys were done. The performances of the two sounders were analyzed and the TS distributions from the two devices statistically tested, proving the capacity of the SEAPIX sounder to measure this important metrics.

Small pelagics multifrequency fingerprints in the Adriatic Sea

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Acoustic surveys have been carried out in the Adriatic Sea to estimate the abundance and spatial distribution of small pelagic fish since 1976; a progressive approach towards the use of multifrequency technique was adopted, switching from the traditional 38 kHz to the latest configuration with 38, 120 and 200 kHz. Additional frequencies can provide information on the nature of the acoustic targets; post-processing software nowadays offer useful tools to combine data in such a way that the «multifrequency approach» can really help operators to have common baselines during the scrutinization process. In order to collect acoustic data in the best way according to the modern technology available, a new acoustic platform was built with the lowest possible degree of spatial separation among transducers. Several monospecific aggregations were studied in order to try to identify species-specific responses at different frequencies. A collection of ground-truthed echotraces were considered in association with the relative multifrequency « fingerprints». These exercises show a good potential in helping scrutinizers to have common references during biomass analysis in order to reduce differences in the interpretation.

Acoustic seabed classification for assessment of fish habitat refined using images from a remotely operated camera

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Habitats of demersal and benthic organisms must be characterized and mapped for accurate assessments of their populations. Recently, it was shown that the seabed may be classified using data from vertical, split-beam echosounders, and a model parameterized with acoustic estimates of slope, roughness, normalized backscattering strength, and coefficients representing variation by frequency and incidence angle. These seabed classifications were interpreted and validated using published surficial geological attribute maps with resolutions on the order of 10^4 m^2, but the acoustic data indicated greater variability at finer scales. Here, the classifications are refined using seabed images representing scales of 10^1 m^2, collected from a remotely operated vehicle (ROV). First, images of seabed in the study area were ascribed to seven classes of primary lithology, from mud through high-relief rock reef, and to 25 classes of combined primary and secondary lithology. Then, a refined seabed classifier, based on a nearest-neighbors algorithm and using the acoustic model parameters, was trained on a subset of the lithology-class data. Finally, lithology classes of an independent subset were used to evaluate classification performance. This classifier accurately predicted 95% of the primary lithology class types, and 92% of the primary-plus-secondary lithology classes.

Optimizing transmit interval and logging range while avoiding aliased seabed echoes

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Acoustic surveys are typically conducted using fixed settings for the echosounder transmit-pulse («ping») interval and data-logging range, even when surveying multiple species at different depths. If the transmit-pulse interval is set long enough to sample to the range of the farthest (deepest) species, mitigating bias, then closer (shallower) species may be under sampled, reducing measurement precision. We present an algorithm to dynamically minimize both the logging range and transmit-pulse interval, ensuring that the logging range equals or exceeds the range to the seabed and is less than or equal to a chosen maximum data-logging range, while avoiding aliased seabed echoes, commonly known as false bottoms, by adjusting the minimized transmit interval such that the seabed reverberation from a previous transmission is not included in the data logged for the current transmission. Additionally, the algorithm measures background noise to improve estimates of seabed range and classification. This scheme increases the horizontal resolution, signal-to-noise ratio, and processing speed of the data, and reduces the total data volume and storage-space requirement. It is particularly useful when conducting acoustic surveys targeting multiple species with differing spatial distributions. An example implementation of the algorithm is demonstrated for a commonly used scientific echosounder (Simrad EK60).

Application of broadband echosounders for detection and characterization of targets near boundaries

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There has been a recent emergence of broadband acoustic backscattering techniques for characterizing fish and other marine organisms. Broadband technology allows backscatter to be measured continuously over a range of frequencies, thereby increasing the amount of information available for target characterization. Broadband matched-filter-based signal processing techniques can also significantly improve the range resolution of the measurements. While the range resolution of narrowband systems is determined by the duration of the transmitted signal, the range resolution of broadband systems, after matched-filtering, is determined by the bandwidth of the signals. In principle, the cm-scale range resolution of broadband systems should allow improved discrimination of targets near boundaries, such as fish near the seafloor. However, a common problem associated with matched-filter-based signal processing techniques is the presence of processing sidelobes, which are particularly problematic when one target is significantly stronger, comparable to the primary return of the weaker target, as is the case for fish near the seafloor. We present results of physics-based modeling and laboratory measurements that address approaches for optimizing broadband signal choice and processing techniques for minimizing the deleterious effects of matched-filter processing sidelobes for detecting and characterizing targets close to boundaries.

Echosounders radiation modelling for the assessment of acoustical impact to marine mammals

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Attention is currently focusing on the impact of anthropogenic sound sources on marine life, particularly marine mammals. Indeed, several unusual cetacean strandings linked to high-power sonar operations have been observed in the past, raising considerable reactions in public opinion. Fisheries, oceanography and seafloor-mapping make extensive use of echosounders; this paper aims to present the order of magnitude of sound radiated by such acoustic sources, in relation with their potential impact on marine mammals. The echosounder characteristics and geometrical configurations are first summarized, for both single- and multi-beam configurations. Next, numerical results from several case studies are compared with currently accepted threshold values for marine mammal sound exposure in terms of both maximum received level and cumulative sound exposure level. This comparison makes clear that, while echosounders may transmit at high sound pressure levels, the very short duration of their pulses and their strong spatial selectivity make them unlikely to cause actual damage to marine mammal auditory systems, according to current knowledge. There remains a possibility that echosounders may affect marine mammal behavior at ranges on the order of kilometers; however, the likelihood and biological effects of such behavioral responses to sound remain poorly understood at present.

Acoustic Observations of Fish and Zooplankton Over a Wide Frequency Band (15 - 400 kHz)

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Measurements of acoustic backscattering made over wide frequency bands offer the potential for improved species discrimination relative to traditional narrowband methods by characterizing more fully the frequency response of scatterers. In January of 2014 we collected field measurements with Simrad wideband transceivers (WBTs) and transducers with center frequencies of 18, 38, 70, 120, 200, and 333 kHz installed in a surface towed body. Acoustic data spanning bands within an overall range of 15 - 400 kHz were collected with the EK80 software, along with bottom trawl and zooplankton net samples. Measurements of volume backscattering strength relative to frequency (i.e., spectra) in aggregations of euphausiids (Meganyctiphanes norvegica) clearly resolved the transition from the Rayleigh to geometric scattering regimes, consistent with the size of animals sampled with nets. Spectral responses were used in concert with backscattering strength to map size and packing density within aggregations. Volume backscattering spectra in aggregations dominated by butterfish (Peprilus triacanthus) or dogfish (Squalus acanthias) revealed a complex frequency response, suggestive of soft tissue and bone dominating scattering in different portions of the frequency band. Target strength spectra for individual targets were also resolved, indicating the presence of fish in the vicinity of euphausiid aggregations.

Examining the wide band frequency responses of common reef fishes- comparisons between models and measures

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Many heavily exploited fishes are crucial to the ecosystem function of reefs. A central challenge to quantifying change in coral reefs and their ecosystem services is the acquisition of spatially and temporally appropriate data to examine patterns in diversity and abundance of coral reef fishes, and in particular exploited target species. Wideband acoustic technology offers a promising tool that might allow inference at relevant taxonomic and spatiotemporal scales. Using the boundary element method with high-resolution computed tomography data, we examine numerically modeled acoustic scattering responses (12-250 kHz) of dominant reef fishes across a range of orientations. The modeled wideband scattering responses are compared with in situ measurements of wideband scattering from reef fishes obtained using the Simrad EK80 echosounder. Preliminary analyses suggest that wideband scattering responses in this frequency range are sensitive to the fine-scale morphological variations among common reef fish species. Further analysis will give insight into the appropriate frequency domain to examine the efficacy for taxonomic resolution.

Multibeam Sonar Evaluation for Biological Monitoring Programs

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Availability of alternate sampling platforms and increased mandatory sampling expands the use of acoustic technologies in biological monitoring programs. Two common data requirements for monitoring applications are detecting and tracking targets, and characterizing changes in distributions and densities of zooplankton, fish, marine mammals, and seabirds. Many countries also require operating permits that may constrain source levels and frequency bandwidths of acoustic instruments. Under controlled conditions, we evaluated the Kongsberg Mesotech M3 multibeam sonar's source levels, frequency bandwidths, and target detection capabilities in imaging and high resolution operating modes as a candidate for biological monitoring at marine renewable energy sites. Measured source levels on axis depended on power and beam angle, with values ranging from 204.3 to 167.7 dB re 1 mPa. Backscattered energy at the first lower harmonic (250 kHz) dropped 45 dB and was not detectable above system noise at 125 kHz. A static calibration sphere (38.1 mm) target was detectable at a range of 6.5 m, with larger static and dynamic targets ranging between approximately 3 and 14 m. Field trials will be used to extend target range detections and to examine the ability to communicate with other instruments.

The Python Open Source Echosounder Toolkit

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During acoustic surveys of marine ecosystems, fisheries scientists need to quickly interpret large amounts of echosounder data and decide whether and where to sample for targeted organisms. This paper introduces the Python Open Source Echosounder Toolkit (py-OSET) which was designed to facilitate this process by providing real-time visualization of echosounder data from multiple systems, and to serve as a framework for implementation of algorithms to detect, locate, and identify fish or the seabed.
Its features include the ability to capture network data broadcasts from multiple scientific fisheries research echosounders, and present the user with a near real-time synoptic 4-dimensional visualization (spatial locations over time) of the aggregated echo intensities in a common Cartesian coordinate system. The transformed data can be saved to an SQLite database compatible with geographic information systems.
The py-OSET software is written in the Python programming language and distributed under the GNU General Public License. The license allows users to redistribute and/or modify the code under well-defined terms. In its first release, py-OSET supports network data broadcasts from the Simrad ME70 and EK60 scientific multibeam and multifrequency echosounders. The paper gives an overview of the software architecture, the current status, and our vision for future development efforts.

The Robotic Revolution in Fisheries Acoustics

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Here, we describe our vision for how an unmanned robotic vehicle, the Liquid Robotics Wave Glider, can be used to transform fisheries acoustics into a science more consistent with the new ocean-observing paradigm. Wave Gliders harness wave energy for propulsion and solar energy to power their communications, control, navigation, and environmental sensing systems. This unique utilization of wave and solar energy allows Wave Gliders to collect acoustic and other ocean environmental data sets for extended periods of time. Recently, we developed a multi-frequency, split-beam echo sounder system for Wave Gliders that enable them to collect acoustic data sets comparable to those collected with manned survey vessels. A fleet of Wave Gliders collecting such data can dramatically improve the synopticity as well as the spatial and temporal coverage of acoustic stock assessment surveys. With improved stock assessments, fisheries managers will have better information to set quotas that maximize yields to fishermen and reduce the likelihood of overfishing. Improved observational capabilities also would enable fisheries scientists and oceanographers to more closely monitor the responses of different fish stocks to climate variability and change.

Use of a high resolution multi-frequency acoustic instrument for characterization of vertical ecosystem structure in the North Bering and Chukchi seas.

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We undertook high resolution multifrequency acoustic studies of zooplankton in the North Bering and Chukchi seas. Our approach combines an Acoustic Zooplankton and Fish profiler (AZFP) with an Acoustic Doppler Current Profiler (ADCP), zooplankton net tows as well as collection of data regarding water properties. The four channel Acoustic Zooplankton and Fish profiler (AZFP) operated at 125 kHz, 200 kHz, 455 kHz, and 769 kHz. The ADCP operated at 150 kHz. Typically, strong near surface backscatter (bs) was due to bubble plumes. Layers of plankton were usually located between 35 m and 50 m. We detected a range of different layering patterns related to the water property data. Strong backscatter below 40 m indicated range revealed limitations of the higher frequencies due to sound attenuation. The multi-frequency aspect of the observations was used to identify the type of scatterers causing the observed backscatter. Once layers were identified, corresponding backscatter versus frequency data were fitted using a least squares approach. Negative slopes were observed in bubble plumes. The probable zooplankton layer also had negative, but a significantly less steep slope. The probable phytoplankton layer (identified by high fluorescence) had increasing backscatter with increasing frequency.

Neural Networks for the localization of biological and anthropogenic sources at neutrino deep sea telescope

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In the Ligurian sea takes place an outstanding joint effort between astroparticle physicists and marine
biologists named ANTARES. Astrophysics and marine biology come to work closely at underwater observatories which can
be used on the one hand for the light and acoustic detection and localization of high energy neutrinos and on the other hand to acquire information about deep sea marine organisms and in particular marine mammals. This is currently the largest neutrino telescope operating in the Northern Hemisphere.
This presentation will describe the methods and results obtained for tracking in real-time both the movements of a set of widely spread 36 acoustic sensors and the movements of nearby marine mammals and ships in real-time.
An extremely interesting part of this research was certainly the use of neural networks to estimate the position of the sensors. The neural networks provided an elegant closed form solution with a satisfying accuracy in real-time.
The neural network approach for localization furthermore proved in this context that it would also be a suitable technique for the growing range of systems requiring low energy consumptionand thorough resource management such as autonomous underwater vehicles and wavegliders.

Can a bottom-moored echosounder array provide a survey-comparable index of abundance?

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When fish form recurring spawning aggregations, moored echosounders may produce comparable abundance indices to those from shipboard surveys at a lower cost. Moored echosounder measurements can also provide insights into the behavior and duration of spawning aggregations. Two decades of acoustics data from an annual survey of spawning walleye pollock in Alaska were analyzed to determine that as few as three moored echosounders may provide an index of pollock abundance comparable to that produced by the survey (~25% prediction error). The primary uncertainty in the moored echosounder approach is knowledge of the spatial-representativeness of long-term observations from a single location, which will depend on the behavior of the fish. In February to May 2015 we will deploy a trawl-resistant mooring instrumented with a new 70 kHz split-beam echosounder (Wide Band Autonomous Transceiver) to compare abundance estimates from the moorings to those from ship surveys. These observations will be used to quantify how spatially representative the mooring observations are and to evaluate the feasibility of designing a mooring array (number and placement of moorings) capable of providing abundance information. Here, we present how previous surveys were used to select optimal mooring locations, and pre-deployment tests of the new echosounder system.

Long-term buoy-based observations of fish and zooplankton behavior and abundance, and their environment

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Acoustic-trawl surveys are routinely conducted in the California Current to estimate the distributions and abundances of hake and Pacific sardine, other species of fish, and zooplankton. Hake and sardine typically spawn in the Southern California Bight (SCB) from January to March and March to May, respectively, migrate north during late spring and summer to feed off Oregon, Washington, and British Columbia, and then migrate back to the SCB in the fall. These behaviors, and recruitment successes, are modulated by intra- and inter-annual variations in the environment. To continuously monitor physical-chemical forcing and biotic responses, instrumented buoys are positioned in the oceanic and upwelling regions off Point Conception (located between the nominal spawning and feeding regions), and nearshore in the SCB. In addition to measuring the physical, chemical, and planktonic environment, these buoys acoustically resolve fish and zooplankton to approximately 300-m depth using a customized echosounder with an adaptive-sampling camera. These data are used to monitor diel and seasonal migration times and rates; adapt shipboard sampling; characterize the three-dimensional habitats of fishes; and enable differentiation of landings from sub-populations. A three-year time-series suggests that an expanded array of instrumented moorings could provide data to estimate the biomasses of migrating fish populations.

Characterizing the vertical migratory behaviours of rockfishes and detecting their presence near the seabed

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Acoustic-optical surveys are conducted in the Southern California Bight (SCB) to estimate the distributions and abundances of rockfishes, and classify and map their seabed habitats. This survey technique uses multi-frequency biplanar interferometry to accurately estimate the range to the seabed; characterize, classify, and image the seabed; and estimate the height above the seabed where rockfishes may not be acoustically resolvable, also known as the «dead zone height.» The acoustic-detection probability for rockfishes depends on the species, their behaviour, and the oceanographic and seabed environment. Here we present the results of buoy- and ship-based experiments designed to characterize the diel migratory behaviours of rockfishes versus variations in their environment, and to explore the possibility of detecting the presence or absence of rockfishes in the dead zone. Rockfish behaviours were observed using an echosounder with multiplexed side- and up-looking transducers, deployed on a reef near the seabed, and from a stationary vessel on the sea-surface. The acoustic observations were validated with independent optical measures of rockfish species and their sizes, using a remotely operated vehicle.

Marine Acoustic Telemetry: Tracking Three-Dimensional Fish Behavior

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The persistent monitoring capability provided by acoustic telemetry systems allows us to study behavior, movement, and resource selection of mobile marine animals. Current marine acoustic telemetry systems are challenged by localization errors and limits in the number of animals that can be tracked simultaneously. A newly installed system was designed to provide detection ranges of up to 1 km, to reduce localization errors to less than 1 m, and to increase to 500 the number of unique tags simultaneously tracked. The design builds on the experience of more than a decade developing acoustic telemetry systems for freshwater environments.
Copper rockfish (Sebastes caurinus) were selected for field trials of this new system because their high site-fidelity and small home ranges provide ample opportunity to track individual fish behavior while testing our ability to characterize the movements of a species of interest to management authorities. To evaluate the use of acoustic telemetry for investigating the behavioral responses of the fish to the fine-scale, three-dimensional features of their environment, a high-resolution, photomosaic mapping survey of the seafloor will supplement the telemetry study.

A probabilistic approach to calculate the Sv fractions for small pelagic fishes and zooplankton with a bifrequency system

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A common practice in acoustic data post-processing is to set, a priori, the Sv intervals for small pelagic fishes (f) and zooplankton (zp), which may induce a bias in biomass estimations. In order to reducing bias, a method based in the joint probability event P(f*zp) is evaluated. The parameter P(f*zp)=0.25 corresponds with the maximum overlap zone between acoustic signals, under a frequency distribution. Fish shoals and deep scattering layers were identified from echograms recorded with 38 and 120 kHz split beam echosounders in the Gulf of California, México, and 30 (when possible) Sv values were obtained from each. From both frequencies, the P(f*zp) =0.25 scenario is reached for a -62 to -56 dB Sv interval. The maximum likelihood estimators (L), calculated from a binomial model were, for P(f) y and P(zp), L(f)= 0.14 and L(zp)=0.11 respectively, and corresponds to a P(f,zp)=0.48, wich is consistent with the joint probability values previously estimated. The 95% upper (-44 dB for f) and 5% lower (-70dB, for zp) limits were defined from their probability distribution. Thus, for small pelagic fishes we choose an Sv interval from -56 to -44 dB, and from -70 to -62 dB for zooplankton in this area.

Characterising the acoustic footprint of Australia's new research vessel RV Investigator

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The RV Investigator is Australia's new noise quietened Marine National Facility (MNF) vessel built to comply with the DNV silent-R specification. This radiated noise specification was based on the ICES 209 CRR specification designed with the main goal of minimising vessel avoidance for fisheries surveys. Noise quietening was specified for RV Investigator to improve the acoustic detection of instruments and reduce the vessel's noise footprint on the environment for research activities. Traditionally DC propulsion motors are used to achieve radiated noise compliance; in this case AC propulsion motors have been used. Initial noise measurements show the RV Investigator is 20 dB (factor of 100) quieter than the previous MNF vessel, RV Southern Surveyor which will significantly improve acoustic instrument performance. The new acoustic systems on the RV Investigator range from sub-bottom profilers, Doppler current profilers, multi-frequency and multi-beam water-column echo-sounders and low to mid frequency multi-beam bathymetry echo-sounders.

Acoustics characterisation and classification of ecosystems and ecosystem processes

Methods and results of the estimation of acoustic target strength (TS) in situ for the main commercial fish stocks in the Nordic Seas

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Acoustic target strength (TS) and its dependence on length L (TS-L relationship) for different fish species in situ are of key importance for the assessment of fish stocks by hydroacoustic methods when conducting ecosystem trawl-acoustic surveys. TS-L relationship applied in the Nordic Seas is based on a small amount of data on fish TS in situ that were obtained 30-35 years ago and they require verification and updating. This paper presents methods and results of the estimation of TS and TS-L relationship in situ at 38 kHz frequency for the main commercial fish species in the Nordic Seas, done by PINRO in 2000-2014. Using meta-analysis of findings on fish TS in situ we obtained new and more valid TS-L relationship for the fish species as follows: in the Barents Sea for cod Gadus morhua (L=5-145 cm), haddock Melanogrammus aeglefinus (L=10-80 cm), saithe Pollachius virens (L=5-115 cm), polar cod Boreogadus saida (L=3-29 cm), capelin Mallotus villosus villosus (L=3-20 cm) and redfish Sebastes mentella (L=6-47 cm); in the Kara Sea for polar cod Boreogadus saida (L=9-22 cm), in the Norwegian Sea for blue whiting Micromesisteus poutassou (L=18-44 cm) and in the Irminger Sea for redfish Sebastes mentella (L=25-49 cm).

On relationship between acoustic target strength (TS) of the main commercial fish species in situ and the depth of their habitats in the Nordic Seas

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Knowledge of the relationship between target strength (TS) of marine fish in situ, their length (L) and the depth (H) of their habitats is key importance for the assessment of their stocks by hydroacoustic methods when conducting ecosystem trawl-acoustic surveys. The TS-value is highly dependent on a swim bladder. TS-H relationship is insufficiently studied. Some scientists suppose that the volume of the swim bladder and the TS-value decreases significantly with depth. In 2000-2014 PINRO estimated TS in situ for main marine fish species in the Nordic Seas at different depths. This paper presents TS data of adult fish in situ related to depths of their habitats for the fish species: in the Barents Sea for cod Gadus morhua of 45-145 cm at 50-550 m depths, polar cod Boreogadus saida of 20-29 cm at 100-320 m depths, capelin Mallotus villosus villosus of 14-20 cm at 60-260 m depths, redfish Sebastes mentella of 25-50 cm at 220-550 m depths; in the Irminger Sea for redfish Sebastes mentella of 30-45 cm at 250-750 m depths. No significant decrease in TS with depth was found. TS changes with depth were within the variations caused by behavior, spatial orientation, physical and biological condition of fish.

Spatial distribution and migrating behaviour of mesopelagic species in the Bay of Biscay during the 2013 and 2014 JUVENA surveys

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We describe the distribution and migration patterns of mesopelagic species sampled during two JUVENA surveys. We compare the different scenarios encountered and the possible causes of variation. We also compare recordings beyond 200 m depth with the mesopelagic layers from other regions described in the literature. In 2013 Krill was found widely spread in different school forms and depths: a) oceanic: small oval schools at 30 m and 100 m depth, b) slope: big and amorphous schools, and c) shelf: bottom layers. Very little krill was found in 2014 up to 200 m depth, however, sampling echograms till higher depths that year allowed to locate krill layers widely spread at a common depth of 300 m. Migration from those layers to the surface were recorded. Maurolicus muelleri was found close to 200 m depth in oceanic waters in 2013, while a much shallower distribution was recorded in 2014, very close to juvenile anchovy schools, that was deeper that year. Other lanternfish were detected at the slopes, canyons and deep layers. Plankton nets were performed to obtain lengths distributions. The deepening of the krill distribution in 2014 could be related with the higher temperatures experienced that year and/or predator abundance increase.

Side-aspect target strength measurements of live giant jellyfish Nemopilema nomurai Kishinouye derived from ex situ experiments

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As jellyfish species is swimming in a slanted state under the natural condition, there is necessary to know side-aspect target strength (TS) information for the acoustic surveys. Unfortunately, because of insufficient information regarding the acoustic characteristics of jellyfish, acoustic methods have so far been used in only a few studies for understanding the distribution pattern and abundance of jellyfish. In this stud, the side-aspect TS measurements of live giant jellyfish Nemopilema nomurai Kishinouye were derived from ex situ experiments at 38 and 120 kHz. The acoustic measurements were made using split-beam transducers. The TS measurements were made of 17 individual jellyfish (bell diameter in air, Dair = 18?79 cm, wet weight, W=500-2400 g) at both frequencies. Each jellyfish was tethered in seawater using a monofilament line that vertically penetrated its bell's centre. Least-squares regression fits of TS vs. log(Dair) were TS38kHz=25.4?log10Dair?89.0 (r=0.79) and TS120kHz=28.5?log10Dair?99.1 (r=0.72), respectively. Comparing with downward TS distribution of the giant jellyfish (Kang et al., 2013), the side-aspect TS is relatively higher than downward TS. These ex situ side-aspect TS measurements may be used in sonar operations or side-view acoustic surveys to estimate the distributions and biomasses of N. nomurai.

Zooplankton monitoring in Yamada bay using two moored multi-frequency acoustic profilers

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Large zooplankton which are transported to the pacific coasts of northern Japan by the Oyashio current are important prey for juvenile salmon. Prediction of the arrival of large zooplankton to the coast is required in order to determine the release timing of juveniles from hatchery stations. In order to monitor the zooplankton, a multi-frequency acoustic zooplankton fish profiler (125, 200, 455, 769 kHz, AZFP, ASL Environmental Sciences) with temperature-depth and temperature-salinity sensors was moored at 15 m below the surface. And acoustic and physical data were collected for six months at the mouth of Yamada bay, Iwate, Japan from 17 Jan. to 19 Jun. in 2013. In 2014, another profiler was deployed at another site of the mouth of Yamada bay from 16 Feb. to 19 Jun. An inversion method was applied to estimate zooplankton density at various sizes. Estimated density of large zooplankton (2.5 - 3.0 mm) increased when the Oyashio current came over to the bay. A time-lag of two days between the peaks of the zooplankton densities estimated by each profiler was observed in 2014 and it was considered due to the current direction in the bay. This work was supported by AFFRC, Japan.

Target strength of the key species in the Northern Demersal Scalefish Fishery (NDSF), Western Australia

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The NDSF extends over a vast area in waters off the Northwest Coast of Western Australia. Targeted species in the area are mainly found within mixed demersal schools composed of various high value species (snappers, emperors and cods) and reef fishes. In order to establish an ecosystem-based management approach, an improved quantitative understanding of the abundance, dynamics and distribution of targeted and non-targeted species within and outside the fishing grounds is needed.
An acoustic data collection program has been established in 2012, collecting calibrated, multi-frequency data from a commercial trap fishing boat during its normal operation, to collect continuous high resolution information on species distribution and abundance. In order to increase accuracy of abundance estimates, target strengths of key species were modelled and measured in-situ. Fish samples of key species were scanned in a CT (Computational Tomography) scanner, to gain data on the internal structure of the fish. An image analysis routine was developed to automatically extract the 3 dimensional coordinates of the swimbladder and the shape of the fish. The Kirchhoff Ray Mode (KRM) approximation model with a Bayesian estimator was implemented to model the TS of the fish based on their shape, swimbladder characteristics, weight and length.

Acoustic classification of meso-pelagic communities

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The principal structure of the ocean's meso-pelagic community is formed from ubiquitous biological layers, which can span entire ocean basins, contain millions of tonnes of biomass and are primarily made up of zooplankton and small fish. Biological layers were extracted from 38 kHz echosounder data, obtained from a wide selection of research institutes and online databases, using a recently developed image processing technique. Layer characteristics, such as water-column position and backscatter strength, were used to categorize layer formations into distinct classes. These layer classes provide a means to quantify mid-trophic level communities, which are currently poorly understood. By standardising layer analysis, pelagic ecosystem change can be consistently monitored and assessed.

Acoustic detection and characterization of cod eggs and larvae

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Accidental releases of oil associated with its subsea extraction can adversely affect the health of fish eggs and larvae. Knowledge of the spatial and temporal occurrence of eggs and larvae allows for management of oil operations to reduce the risk of deleterious effects. Eggs and larvae have very low acoustic reflectivity and to estimate the feasibility of in-situ acoustic detection of typical cod (Gadus morhua) egg densities (10-2000 eggs per cubic meter), a set of ex-situ measurements were carried out. The broadband (160-260, 300-360 kHz) backscatter characteristics of both cod eggs and larvae were measured in a small tank under controlled conditions. The age of the eggs and larvae ranged from newly-spawned (1.4 mm diameter) up to 10 weeks, encompassing the period when the gas-filled swimbladder develops. Controlled quantities of eggs and larvae were released into the acoustic beam and observed for several minutes with both acoustics and video. The backscattering strength and potential in-situ characterization parameters as a function of age and life stage were then derived. Oscillatory patterns in the ping-to-ping backscatter from swimming larvae were also observed, which were apparent in the per-ping frequency-dependent backscatter and correlated with the swimming motions of the larvae observed by video.

Lateral aspect acoustic frequency response of adult saithe (Pollachius virens)

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Laterally observing fisheries echosounders are useful in specific applications, such as to inspect surface blind zones from a vessel, to observe wild fish gathering under fish-farm nets or for bottom-mounted acoustic landers with both vertical and horizontal acoustic beams. The frequency response (r(f)) measured from the dorsal aspect is frequently used to identify species, but it is not clear if dorsally measured r(f) is useful for identifying laterally observed fish. The r(f) of free-swimming wild saithe was measured with stationary and laterally oriented split-beam echosounders at 70, 120, 200, 333 kHz, suspended in mid-water (22 m, bottom depth 41 m). Simultaneously recorded imagery (video and stereo-photo) were used for species identification and sizing. Fish aggregating close to a small fish-farm were observed. Saithe of 45-55 cm in length was observed in small schools of varying density and recorded at 5-35 m range while swimming in and out of the acoustic observation volume. The SV(f)-based, TS(f)-based and fish track average TSTrack(f)-based acoustic frequency responses were derived. Lateral saithe r(f) increased smoothly with frequency, which is the opposite trend to dorsal aspect r(f) reported in the literature.

Lateral aspect acoustic frequency response of gas bubble plumes

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There is an increased need to detect, identify and monitor natural and manmade seabed gas leaks. Fisheries echosounders are well suited to monitor large volumes of water and acoustic frequency response (r(f)) is commonly used to identify fish and zooplankton species. Information on gas plume r(f) would be valuable for automatic detection of subsea gas leaks, for separating bubble plumes from natural targets like swimbladder-bearing fish. Controlled leaks were produced with a specially designed instrument frame suspended in mid-water (43 m) in a sheltered fjord. The frame was equipped with echosounders, stereo-camera and gas-release nozzles. The frequency response of laterally observed methane, carbon dioxide and air plumes (0.040-29 L/min) were measured at 70, 120, 200 and 333 kHz, with bubble sizes determined optically. Under the experimental conditions, no difference in acoustic backscattering between gas types could be identified. The observed bubble size range (1-25 mm) was comparable to the one reported in literature for natural cold seeps of methane. A negative r(f) with increased frequency was measured, namely r(f) of about 0.7, 0.6 and 0.5 at 120, 200 and 333 kHz when normalized to 70 kHz. Measured plume SV(f)-based r(f) is also compared to bubble TS(f)-based and modelled r(f).

Target strength of herring and mackerel in dorsal and lateral aspect for sonar biomass estimation

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If horizontally observing sonars are to be used for fish biomass estimation, the mean target strength in lateral aspect should be better quantified at several frequencies. An acoustic echo sounder probe, carrying four broadband echo sounders has been lowered into herring and mackerel layers, and the TS(f) measured with calibrated split beam methods. The transducers were used in both vertically and horizontally observing modes. Lateral TS(f) for adult herring and mackerel will be presented and compared to the conventional dorsal TS(f) over the frequency band 60 ? 450 kHz, and furthermore compared with empirical measurements of the directivity pattern of individual herring and mackerel, the TS(f,?).

Acoustic multi-frequency species identification from commercial fishing vessels

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Remote acoustic identification of fish and zooplankton is a long-running objective to reduce uncertainties associated with acoustic ecosystem surveys. The relative frequency response measured simultaneously at multiple calibrated frequencies is the main acoustic feature used to characterise the acoustic targets. However, also scattering strength and information on geographical species distribution are used. Environmental and fisheries policies governing some of the most important and largest pelagic fishing industries puts an increasing emphasis on catch selectivity due to laws intended to minimise bycatch. Acoustic hardware available on modern pelagic vessels is currently of similar design and performance to those used on research vessels. Scientific methods of acoustic species identification, or more precisely acoustic categorization, currently in place could therefore potentially also be applied to improve fishing selectivity. Lessons learned and methods developed previously for scientific objectives were applied here to multifrequency data collected on commercial fishing vessels. The performance of the approach was evaluated by comparing classification results with trawl catches. The reliability of the categorisation was improved with additional filtering of the raw acoustic data to account for common fishing vessel noise sources that jeopardise the data quality. Examples are shown, and the potential of the method is discussed.

Acoustic identification and measurements of weak targets such as jellyfish and zooplankton in mixed aggregations

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In mixed layers where several target categories are present, current multi-frequency identification algorithms are unable to properly separate and identify the weaker target category. This is because the backscatter from the stronger target usually dominates the echo intensities from the weaker targets even if they are numerically inferior. In particular this occurs at ranges where the pulse volume is large and both strong and weak scattering categories occur as multiple targets within the same pulse volume. In this paper, it is demonstrated that a stepwise top thresholding method combined with spatial filtering can reveal two or several target categories, especially when the target strength of the two categories are quite different, as is the case when jellyfish and zooplankton layers are mixed with swimbladdered fish. The method also reveals the true frequency response of the weak targets, a necessity for the target identification process. Subsequently, the abundance of the weak and strong targets can be estimated independently. The method is demonstrated on data on jellyfish from the Benguela Current Upwelling system and on zooplankton layers from Norwegian fjords.

Comparison of acoustic biomass and top-predator distribution in the Northwestern Hawaiian Islands

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The mean biomass of main trophic groups (apex predators, other secondary consumers, and herbivores) in the Northwestern Hawaiian Islands (NWHI) appears to be higher than in the Main Hawaiian Islands (MHI). Dense communities of mesopelagic organisms that accumulate around the NHWI are similar in spatial pattern to the mesopelagic boundary community observed in the MHI. These studies focused on shallower communities in and near reefs and did not investigate biomass living in deeper waters that some apex predators rely on for food. Some odontocete cetaceans dive to depths greater than 1200 meters to feed. To examine the relationship between odontocete predators and prey, a Simrad EK60 echosounder operating at 38 and 70 kHz collected acoustic biomass data throughout the NWHI from May 7 - June 4, 2013. Visual surveys for marine mammal presence were conducted concurrently with the echosounder. The spatial distribution of acoustic biomass in the mesopelagic layer from approximately 400 - 800 meters depth was compared to physical and biological parameters including sighting locations of 37 deep-diving odontocetes, bathymetry, sea surface temperature, and surface chlorophyll, using a generalized additive model (GAM). Comparison of these parameters will further the understanding of factors contributing to odontocete distribution in the NWHI.

Distribution of the Small Pelagic Fish Populations in the North Eastern Levantine Sea.

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The decreasing stocks of traditionally targeted fish species such as large pelagics and demersals caused a shift on the fishery towards small pelagic fishes along the eastern coast of Turkish Mediterranean. The aim of this study was to assess the distribution of the small pelagic fish populations in the region using acoustics methods to generate an effective fishery management advice. The data were collected between 2009 and 2011 during five hydro-acoustic surveys conducted with Simrad EY-60 operating at 120kHz. Environmental conditions were determined from CTD casts and satellite images. Generalized additive models were used to investigate the habitat preferences. Thermal stratification found as an important factor determining the distribution of species. The species with warm water preference occupied a temperature range between 24ºC-27º C and concentrated in the regions around river plumes and eutrophic regions. The species inhabiting cooler water displayed and offshore-ward distribution below the thermocline. The study area being a warm region seems to provide advantage to summer spawning species such as Sardinella aurita which concentrated in dense patches as associated with high chlorophyll concentration. However, if the fishing pressure increases this population may disappear as it is already tackling with competition due to opportunistic Lessepsian invaders.

Acoustic measurement and classification of migrating epipelagic and mesopelagic scattering layers in the Gulf of Mexico

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Migrating layers of marine organisms in the Gulf of Mexico were observed over the upper 1000 m of the water column using multiple frequency (18, 38, 120, and 200 kHz) scientific echosounders during the summer of 2011. Backscatter data were used to characterize the spatial and scattering properties of the layers and scattering differences were used differentiate layers from one another. Through the use of theoretical scattering models, we identified the organisms that (most likely) composed these layers. Vertical movement rates and timing of the migrations differed amongst layers which supported the acoustic classifications. Acoustic data were compared with net trawls to confirm the identity and size of the marine organisms present in the water column. The use of multiple acoustic frequencies provides important information about the composition of the scattering layers which provides insights into interactions in a part of the ocean where relatively little is known about in terms of the spatial and temporal distribution of the marine organisms that inhabit the mesopelagic region.

Contribution of resonant backscatterers to phantom sound scattering layers in the Bay of Biscay

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Series of acoustic pelagic surveys yet contain unexplored higher resolution multi-frequency data that may provide information on the zooplankton distribution. Zooplankton and micro-nekton are supposed to contribute to ubiquitous sound scattering layers (SSLs) whose composition remains unknown. We present a study combining acoustic and ground-truthing data to characterize the Bay of Biscay dense SSLs. Multi-frequency acoustic data were collected in front of the Gironde estuary using a Simrad EK60 echo-sounder operating at 18, 38, 70, 120 and 200 kHz. Ground-truthing consisted of micro-nektonic net haul. The SSL composition was investigated by resolving both forward and inverse problems. The method allows to: relate the in-situ acoustic response to the theoretical backscatter of biological samples and provide insights on the size and acoustic properties of the backscatterers that were not properly sampled. The results suggest that most of the in-situ SSL backscatter was produced by gas-bearing organisms, namely fish larvae. Larger gas-bearing organisms were contributing to a significant part of the backscattering but were not caught by traditional samplers. This approach reduces the possible hypotheses regarding the nature of organisms producing dense SSLs and outline the need for more adequate acoustic and ground-truthing tools to characterize SSLs.

Got data? Increasing the accessibility of acoustic data for the advancement of fisheries science

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Acoustic technologies are of increasing importance for studies examining aquatic ecosystems. Single and multibeam echosounders routinely collect active acoustic data that are used to estimate biomass, conduct trophic- and species-level identification, measure school and patch morphology and behavior, and characterize habitat for commercially and ecologically important fish and invertebrate species. These systems deliver valuable information for ecosystem-based fisheries management but they also produce massive amounts of data that are costly and complicated to maintain. In collaboration with the National Marine Fisheries Service, the National Geophysical Data Center is archiving acoustic data collected from NOAA and academic fleets. Through these efforts, terabytes of acoustic data are now available to researchers and the public around the world. Benefits of this central repository include increased collaboration across institutions and the ability for researchers to address cross-cutting scientific questions to advance the field of marine ecosystem acoustics. Visualization products are being developed to allow researchers to understand the quality and composition of large archived data volumes more easily. These products illustrate multifrequency acoustic data in a single image using a novel color scale. Passive acoustic data can be even more complex to archive, and complementary efforts to archive passive acoustic data will be discussed.

Construction of advanced bio-logging systems for high rates of data-recovery - a challenging study to clarify the dynamics of fish populations and communities -

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The monitoring of marine top predators, primarily fish species, provides important insights into marine ecosystems. Recently, bio-logging techniques involving electronic data-storage tags and acoustic transmitters have been increasingly used to understand migratory fish movement and behavior. The number of tags, however, is normally limited due to coasts, and the tag recovery rate is still low. In this study, therefore, to reveal the population and community dynamics of fishes in open waters, we will develop a new variety of small, low-cost, large-data-capacity and multifunctional tags, and implement the high recovery rete of the data. This study consists of the following for development:(1) two types of archival tags (small-sized tags and customizable-multifunctional tags), (2) the energy harvesting system installed in the tag, (3) the data receiving system onboard multi-platforms, and (4) the inter-individual communication system based on hydro-acoustic methods. Lastly, combining them, we will develop a new bio-logging system and test the practical utility of this system using wild herrings and bonitos in open waters off Japan. The new technology will overcome the bottleneck of conventional bio-logging techniques, and will lead to a breakthrough in marine ecosystem studies.

In situ target strength measurements of sandfish Arctoscopus japonicus

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This study is aimed to estimate acoustic backscattering characteristics of Sandfish Arctoscopus japonicus using a 38 and 120 kHz split-beam echosounder. The survey was carried out by hydro-acoustics and coastal gillnet in the Go-sung, northeastern sea of Korea. The sampling net was fixed and hauled to the bottom at five stations for only one day, and total 346 sandfish were caught (among 241 numbers of male and 105 numbers of female). Then, its fork length (FL) of male and female was shown in the bimodal mode: the FL range was 14.6-19.8 cm (mean FL; 17.0 cm) for male and 16.3-24.5 cm (mean FL; 19.6 cm) for female. In case of hydro-acoustical characteristics, in situ TS of sandfish ranged in -79.8~-59.1 dB, and the mean TS is -75.3 dB for male and -65.1 dB for female at 38 kHz; in situ TS of sandfish ranged in -79.9~-56.2 dB, and the mean TS is -74.3 dB for male and -64.1 dB for female at 120 kHz. The mean TS of male was about 10 dB higher than that of female at each dominant frequency. These results can be effectively used to estimate its immigration and abundance in northeastern coastal areas.

Social behavior in mesopelagic jellyfish

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We made records of diel migrating jellyfish Periphylla periphylla using both hull mounted (38 kHz) and submerged (200 kHz) echosounders. The acoustic data showed that jellyfish formed small, ephemeral groups, which also was documented photographically using ROV. The records of jellyfish were made at the upper fringe of an acoustic scattering layer consisting of krill, where about 10% of the jellyfish engaged in social behavior. The hypothesis that forming teams can improve capture rates of agile prey was supported by a simple model. Although the adaptive value of group formation remains speculative, we clearly demonstrate the ability of these jellyfishes to locate and team up with each other at depth. The study documents the potential of using echosounders in unveiling novel behavioral traits among jellyfish.

Diel vertical migration of mesopelagic fishes on the Northern slope of the South China Sea

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Mesopelagic fish is of the major components contributing to deep-sea sound scattering layer in the open ocean. Recent studies show that its biomass can be one order of magnitude higher than previous estimate. During an ecological survey in the northern slope of the South China Sea, the vertical distribution of deep-sea sound scattering layer was studied onboard the R/V Nanfeng from 06:00 am 26 to 22:00 pm 27 Octorber 2014 at a time series station. Acoustic data were collected using a 38 kHz Simrad EK60 echosounder, and the echo sighs were sampled with a micronekton net. During daytime, serveral distinct layers were found between 350 m and 550 m depth; at night, most fishes migrated up to form dense aggreation in the 150 surface layer, while some others remained at the 400 m to 500 m layer. The mean ascending and descending rates of the fishes were 0.9- 2.8 m/min and 2.1- 4.1 m/min, respectively. The majority of the net catches were comprised of mesopelagic fishes, dominated by myctophids. The diel vertical migration of such great biomass over a large vertical range may play an important role in material transfer and energy flow of the deep ocean ecosystem.

In situ determination of the impact of offshore pile driving on juvenile sea bass Dicentrarchus labrax

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To determine the impact of underwater sound generated by offshore pile driving, a field experiment was carried out on board of a piling vessel, exposing 68 and 115 days-old sea bass to the sound generated during 1.5 hours of pile-driving. The number of strikes ranged from 1740 to 3070, with a single strike sound exposure level between 181 and 188dB re1μPa^2.s, resulting in cumulative sound exposure levels ranging from 215 to 222dB re1μPa^2.s. Immediate and long-term survival of the exposed fish was high. However, exposed fish responded to the impulsive underwater sound by a 50% reduction in oxygen consumption rates (a secondary stress response) compared to the control groups. Data on cortisol concentrations will indicate whether juvenile sea bass also show primary stress responses. Under optimal lab conditions, we did not see effects on the fitness of the juvenile fish beyond the sound exposure period. However, it remains unknown whether the reduced fitness of juvenile fish is limited to the pile driving period in the real world as well. Our results indicate that impulsive sound close to the source creates sound pressure levels above the stress threshold, but below the lethal threshold for small sea bass.

An attempt to find the cause of unidentifiable echoes

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Recently, zooplankton-like jellyfish, which are often discounted in acoustic surveys, have become recognized as non-negligible organisms when studying changes in marine ecosystems or improving the precision of acoustical analysis. A common problem in acoustic research is that something is detected by the echo sounder but nothing is caught in the net or seen by underwater video cameras. Therefore, when this phenomenon occurred at a station in the Sea of Japan, samples were caught in pelagic trawls (mesh size: 8 mm) revealing two kinds of zooplankton that have previously been discounted in acoustic surveys: Pterotrachea coronata, which has a transparent body and a fusiform-shaped dense visceral mass called the nucleus, measuring 13?17 mm, and Cavolinia uncinata, which has a hard shell measuring 9?16 mm. The target strength (TS) of tethered samples of P. coronata and C. uncinata measured at 200 kHz in a tank with incident angles ranging from ?30° to +30° in 1° steps were ?90 to ?75 and ?78 to ?52 dB, respectively. Therefore, the acoustic scattering characteristics of C. uncinata should be further studied, because they have a large TS and are active swimmers.

Spatial dynamics of juvenile anchovy in the Bay of Biscay under a period of stable weather conditions

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In autumn 2009, the concurrence of two consecutive acoustic surveys targeting juvenile anchovy in the Bay of Biscay, and delayed 20 days between each other, made possible to monitor changes in the spatial distribution and aggregation patterns of this species under a period of stable weather conditions. These changes were produced differently between the southern and northeastern parts of the Bay of Biscay. In the South (Spanish shore) the juveniles were located off the shelf and above the thermocline in both surveys: during the first survey they occupied a larger area and for the second one they migrated around 20 n.mi. towards the shelf, forming denser aggregations compressed against the shelf break. In the Northeast (French shore) the juveniles migrated toward the coast at a similar pace as the southern ones, but crossed the shelf break, entering the continental shelf waters. These inshore juveniles were larger than the offshore specimens and were found deeper, gradually adopting the typical diurnal vertical migrations made by adult anchovy. The sharper surface temperature gradients between the shelf and the slope water in the South may have acted as an effective barrier, influencing these distinct observed spatial patterns in the two areas.

Predator-prey dynamics: Micronekton schooling inside the deep scattering layer in response to foraging Risso's dolphins

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Using split-beam echosounders integrated into a deep-diving autonomous underwater vehicle (AUV) in combination with ship based acoustics and direct sampling we explored scattering layers off the Channel Islands, California. High-resolution behavior and acoustic recording tags revealed that Risso's dolphins foraged within each of three distinct layers identified. Using the AUV to obtain echoes from individual scatterers within layers, we found that rather than the homogeneously mixed aggregations identified from the ship-based data, layers were internally organized into distinct, small patches of scatterers of similar size and taxonomy adjacent to contrasting patches. The size of these patches was not related to geometric distance but rather to the number of animals in the group which remained constant as taxonomic group and individual length varied. We observed that the inter-individual spacing within these patches was significantly smaller when Risso's dolphins detected with the echosounders were within 5 m of the patch. These effects, however, were only detected for the largest classes of fish and medium and large squid; no predator effects were detected in smaller individuals of these groups or in crustaceans, identifying the key prey targeted by Risso's dolphins. This new tool is revealing the dynamic relationship between mesopelagic predators and prey.

Antarctic krill in Marguerite Bay: resolving the detail using underwater gliders

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The Western Antarctic Peninsula (WAP) is undergoing rapid changes in climate, with increasing ocean and air temperatures and rapidly declining sea ice duration. As a result, the water column structure and marine ecosystem are likely to undergo rapid change in the coming decades. Marguerite Bay and other locations along the WAP are sites of high krill abundance, thought to be source regions for populations found across the Scotia Sea. To understand the physical controls on krill abundance and retention in this region, we characterized the Antarctic Peninsula Coastal Current (APCC) within Marguerite Bay and its influence on primary productivity.
In 2014, two underwater gliders were deployed to undertake concurrent physical and biological measurements of hydrography, primary productivity and krill abundance and distribution. The gliders were equipped with ES853 120 kHz echosounders, pointing downwards and sampling at a rate of 0.25 Hz. Krill targets were identified using a thresholded schools analysis technique (SHAPES), and acoustic data were converted to krill density using the stochastic distorted-wave Born approximation (SDWBA) target strength model. Preliminary results are presented from the two month deployment.

Spatio-temporal distribution of euphausiids in the Gulf of Alaska: an important component to understanding ecosystem processes

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Euphausiids (or «krill») are an important part of high latitude ecosystems, such as the Gulf of Alaska (GOA), as both a prey item and an ecological link between primary production and higher trophic levels. We created an index of euphausiid (principally Thysanoessa spp.) abundance in the central Gulf of Alaska using data from four summertime acoustic-trawl surveys of walleye pollock (Gadus chalcogrammus) conducted between 2003 and 2013. Acoustic backscatter at several frequencies (18, 38, 120, and 200 kHz) and targeted trawling were used to detect and classify euphausiid aggregations. Euphausiid backscatter was positively correlated with euphausiid density from targeted net samples (r2 = 0.20, n=13) and in-trawl camera footage (r2 = 0.26, n=65). Euphausiids were patchily distributed found throughout the study area, with relatively more euphausiids observed in coastal bays and troughs around Kodiak Island as compared to the surrounding continental shelf. Relative abundance and distribution of euphausiids was modeled as a function of environmental factors (including depth, water temperature, and chlorophyll a), and abundance of predators. Preliminary results indicate that predator abundance was not a strong predictor of abundance and distribution of euphausiids, similar to previously reported results from the eastern Bering Sea.

Contrasting diel distribution patterns of reef-associated fishes around standing and toppled oil and gas platforms in the northern Gulf of Mexico.

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Understanding the distribution of reef-associated fishes around artificial reefs is important to discerning their ecological function. This project sought to examine distribution of reef-associated fishes around standing and toppled oil and gas platforms in the northern Gulf of Mexico (GOM) using a multi-frequency hydroacoustic approach. Transects were continuously conducted at multiple platforms over 48 hr periods during two sampling seasons to identify variations in distributional patterns of broad categories of acoustic scatterers (fish, zooplankton, large pelagic predators, and schooling planktivores). Changes were observed in acoustic density over a diurnal cycle, which differed with habitat, depth, and distance from the structures. At both standing and toppled platforms, densities were greater in the upper water column at night, whereas during the day, densities increased in the lower water column. However, this pattern is less apparent at distances less than 100m from standing platforms, likely attributable to disruption of vertical migration patterns from light emitted and high abundance of large predators in the upper water column at standing platforms. The increased vertical structure and the associated light field around standing platforms may act to influence diel distribution of reef-associated fishes, providing further insight on the use of large artificial reefs in the GOM.

Behavioural pattern and in situ Target strength of hairtail (Trichiurus lepturus) by coupling Scientific echosounder and Acoustic camera

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Hairtail (Trichiurus lepturus) is one of most dominant fish stocks inhabiting widely in Northeast Asia. They usually swim horizontally like other fishes do, but are known to be vertically suspended with head up in coastal areas according to their unique behavioural pattern. The precise measurement of in-situ target strength depends on the swimming tilt angle as well as the specific fish echo signals from multiple echoes in its wild state. The acoustic survey was carried out at fishing ground of jigging boats with luring lamps near to coastal waters of jeju-do in Korea, and data were collected and analyzed at 2-frequency characteristics by 38 and 120 kHz on the basis of sizing and swimming tilt angle acquired by an acoustic camera at their free swimming state. The results showed that their preanal mean length was estimated to be 20.4 cm (SD: 2.9) from jigging fishing gears and their swimming tilt angle was estimated at 43.9°±17.6° using an acoustic camera. The mean TS values were -35.6 dB at 38kHz and -40.5 dB at 120kHz. These results can be verified by measuring the ex-situ TS experiments at free swimming state and/or at holding fish with tethering in the seawater tank.

Bridging the gap between fisheries and oceanography: using fisheries acoustics to monitor pelagic ecosystems in the Southern Ocean

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There is an ongoing interest in mid-trophic level organisms due to their key role in the marine ecosystem, linking zooplankton and top predators. However our understanding of this group is still very limited, and estimates of total abundance have a high degree of uncertainty. Acoustic data provide ecological information, such as spatial distribution and abundance indices, that can provide a starting point for the foundation of more advanced ecosystem indicators and models. Thirty three transects of mainly single frequency (38 kHz and 18 kHz) acoustic data were collected opportunistically during the transit of toothfish fishing and research vessels between New Zealand and the Ross Sea (Antarctica) from 2008 until 2014. These data were post-processed following Integrated Marine Observing System (IMOS) protocols, with some modifications to improve processing performance. Distribution and abundance patterns of mid-trophic levels in the Southern Ocean and their inter-annual differences were analysed and discussed. Environmental variables are used to explain distribution patterns and variability. Potential utility of acoustics on vessels of opportunity for consistent monitoring of mid-trophic level organisms is appraised, along with ecological implications.

Multifrequency study of the epipelagic food web in Alborán Sea

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In order to characterize the epipelagic ecosystem from a trophic point of view, a multidisciplinary acoustic survey was carried out in July 2013 in Alborán Sea.
A calibrated EK60 scientific echosounder (Simrad) equipped with 5 frequencies (18, 38, 70, 120 and 200 kHz) was used. Fish echotraces were groundtruthed by mean of a pelagic trawl (20mm cod end; 20m vertical opening). The main daytime epipelagic acoustic plankton layer was sampled using plankton nets with 4 different mesh sizes (250, 333, 500 and 2000 µm); the great progress was monitoring in real time the plankton net track. Finally fluorescence was recorded using a CTD (Seaberg 19+).
Our results show that primary producer (fluorescence data) can´t be acoustically clearly detected; small primary consumers (Copepoda, Cladocera) are detected at 70 kHz frequency near coast (30-45m deep). Going offshore, frequency response change due to the presence of secondary zooplankton consumers like Siphonophora, Chaetognatha, fish larvae and Apendicularia, which are the main targets detected at 18 and 38 kHz frequencies. Tertiary consumers (fish) are detected properly at 18 and 38 kHz.

At the Arctic Ocean doorstep -- baseline acoustic scattering structures as potential indicators to Arctic Ecosystem Change

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The first SI_Arctic cruise aboard the R/V Helmer Hansen took place west and north of Svalbard in August/September 2014. The purpose was to collect baseline information on physical, chemical, and biological conditions in the ice free part of the Arctic Ocean waters under Norwegian jurisdiction. As part of the survey, acoustic data for distribution and abundance estimation of water column plankton and fish were collected with calibrated EK60 echo sounder systems at 18, 38, and 120 kHz. At sea processing of the 38 kHz data during the cruise included spike-filtering, compensation for the placement of transducers, and noise removal. Plankton/mesopelagics and fish contributions to the backscattering at 38 kHz were determined by the frequency response and corroborating plankton and trawl data. Typically, there was strong patchy scattering between the surface and about 50 m throughout the area. Off-shelf there was strong scattering between 300 and 500 m that was dominated by fish close to the shelf/slope break and associated with the Warm Atlantic Water moving north into the Arctic Basin, but switched to dominance by the plankton/mesopelagics in the colder Arctic waters. The observed patterns may anticipate the direction of future changes in the pelagic ecosystem of the Arctic Ocean.

Definition and application of a specific processing tool for monofrequency acoustic data collected on fishing vessels

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The use of acoustic data collected on fishing vessels for scientific purpose is an ongoing field. Processing and analyzing the vast amount of acoustic data opportunistically collected by fishing vessels would benefit from automation. Although the automation of acoustic-data and signal processing for fishery and environmental application is developing rapidly, it is still in its infancy for the data collected by fishing vessels.

We present a methodology developed to process monofrequency acoustic data. The method has been applied to fishing trips realized by a pool of Peruvian industrial purse seiners targeting pelagic species of the Peruvian coast.
This tool includes methods developed for classic scientific data allowing the extraction of information on: (i) the depth of the lower oxycline (or upper oxygen minimum zone), (ii) the characteristics of the fish schools, (iii) the fish acoustic density, and (iv) a proxy of prey density.

Results shows that data collected by commercial fishing vessels in Peru can bring a significant contribution to understanding of the ecology, distribution, movement and abundance of pelagic species in a highly variable environment. Such information obtained from fishing vessels can noticeably complement data obtained from scientific surveys.

Abundance and spatial distribution of polar cod in the Canadian Beaufort Sea (Arctic Ocean) during the ice-free season

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Polar cod (Boreogadus saida) constitute more than 95% of the pelagic fish assemblage in the Canadian Beaufort Sea, an area of the Arctic Ocean facing both climate change and oil and gas development activities. Despite the importance of polar cod as the main prey of most marine mammal predators of the region, in particular ringed seals (Pusa hispida) and belugas (Delphinapterus leucas), the total abundance and spatial distribution of this key fish species remain unknown. Summer hydroacoustic surveys were conducted from 2011 to 2014 with a Simrad EK60 multi-frequency echosounder, and the echoes were validated by net deployments. Spatial distribution of polar cod was assessed using kriging techniques and the relation with local hydrography. Total abundance estimated using geostatistics was compared to the energetic requirements of the main predators to verify if the polar cod stock can sustain their consumption. This survey represents the first systematic acoustic study covering the shelf and slope of the Canadian Beaufort Sea during summer, and provides baseline data to monitor the effects of climate change and anthropogenic activities on the marine ecosystem of the region.

Modelling (mean) target strength of individual herring (Clupea harengus) at any aspect as a function of pressure

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Fish target strength is primarily dependent on the physical dimensions of the fish, the acoustic frequency, and the orientation of the fish. In traditional vertically observing echosounder surveys, fish are insonified in the dorsal aspect with fairly limited tilt angle variation. In oblique-angled sonar surveys, however, fish may be insonified at other aspects. For herring, target strength is also depth dependent as they cannot refill the swimbladder at depth. Understanding the depth dependent target strength from several insonification angles is thus required for quantitative measurements with sonar. The dataset used in this study consists of seven herring, imaged using magnetic resonance imaging (MRI). The herring were placed in a pressure chamber inside the MRI, and subjected to different pressures corresponding to water depths of 0, 20, 40, and 60 m. Images were acquired of each specimen at each pressure. The swimbladders were segmented and 3D models of the swimbladders for each fish and pressure were constructed. These models were then used for computing the directivity pattern of the swimbladder at any angle using the finite element method, and further to compute a mean value. Modelling results are also compared with measured dorsal and side aspect TS at different depths.

Classification of jellyfish targets in the southern Benguela upwelling ecosystem using a multi-model approach

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Biomass estimates used in the management of important small pelagic fishes is typically obtained from routine acoustic surveys. Such estimates can be confounded by internal and external factors to surveys. One of such confounding comes from co-occurrence with medusae and other organisms that may also contribute to the total sound backscattered. It is believed that such co-occurrence can possibly prevent accurate estimates of absolute biomass and distribution of commercially important species. The current study anticipates that jellyfish may not be strong acoustic scatterers at frequencies routinely employed for fisheries assessment because of their delicate bodies. The aim of this work is therefore to establish the consequences of coexisting jellyfish and small pelagic fish. In order to determine the contribution of jellyfish to the total acoustic scattering, acoustic data were collected along the west coast of southern Africa. The data was then used to train four statistical models: Artificial Neural Networks, Linear and Quadratic Discriminant Function Analysis, and Classification Tree Analysis. The accuracy and precision of correct classification of jellyfish and fin-fish was assessed. The feasibility of classification between jellyfish species and those of fish is important considering the impact that jellyfish blooms could have on acoustic estimates of species abundance.

The classification of migrating populations in the high Arctic using multi-frequency acoustic data

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Diel vertical migration (DVM) plays a key role in the carbon cycle, and has recently been seen to continue throughout winter, despite previous assumptions that all populations entered a state of diapause. Identifying the composition of this migrating community is important because the efficiency of the energy transfer from surface to deep ocean will vary with species.
Using a novel acoustic classification method, species of copepod and krill of different size classes (10-20 mm and 1-5 mm) were identified along with their corresponding DVM behaviour.
Multi-frequency (125, 200, 455, 769 kHz) acoustic data was collected over an eight month period in 2014 using a moored Acoustic Zooplankton Fish Profiler at a high-Arctic (Kongsfjorden, Svalbard) location. The data was analysed using a probabilistic clustering method, the results of which were fitted to frequency response curves formed from distorted wave Born approximation scattering models.
Preliminary results of winter (January and February) data at Kongsfjorden show that krill are the most likely group to be responsible for mid-winter DVM behaviour.
A more complete understanding of winter DVM behaviour will lead to better predictions on the effect of reduced sea ice cover on the energy flow in the Arctic ocean.

Krill or Icefish? Classification of Southern Ocean echotraces using Random Forests

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Reliable target identification persists as an issue for acoustic surveys. Krill (Euphausia superba) swarms at South Georgia are typically identified through a combination of expert scrutiny and analysis of the difference in mean volume backscattering between 38 and 120 kHz (?MVBS, dB). Scattering properties of krill are however similar to the many co-occurring fish species which do not possess swim bladders. One species in particular, the mackerel icefish (Champsocephalus gunnari) forms substantial pelagic aggregations which can be difficult to distinguish acoustically from large krill layers. Icefish are currently assessed using bottom-trawl gear, but these estimates are biased because of the species' semi-pelagic distribution. Random Forests were constructed using acoustic and net sample data from ground-truth aggregations of species in order to classify echotraces. The algorithm classified krill, icefish and mixed aggregations of fish with 88% accuracy. Depth and longitude were of highest importance for classifying echotraces, however, ?MVBS, minimum volume backscattering (dB) and horizontal roughness coefficients all held high importance in echotrace classification. Random forests proved to be a powerful means of objective species classification, providing scope for using acoustic surveys to assess this commercially important species.

Model based verification of a zooplankton identification algorithm for use in fishery surveys and an application to describe zooplankton distribution.

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Acoustic surveys are commonly used to assess the status of fisheries resources, but also provide opportunities to collect data from other components of the ecosystem. In this study we utilised data from a fisheries survey, at three frequencies (38, 120, 200 KHz), to produce echograms of mixed zooplankton. A scattering model was used to estimate the target strength of zooplankton species (determined from net samples) and predict backscatter: this was then compared to backscatter as derived from the application of a zooplankton separation algorithm (forward problem). Model predicted target strength, for the major zooplanktonic groups, was sensitive to orientation for large organisms, and to material properties for both copepods and euphausiids. The separation algorithm was able to isolate fluid-like zooplankton backscatter from other components. However, the observed backscatter, resulting from the separation, was close to the 90th percentile of the predicted backscatter for all 3 frequencies. Off the east coast of Scotland, where the survey took place, the vertical distribution of zooplankton backscatter was closely associated with the pycnocline, with maximum backscatter recorded just beneath it. Horizontal distribution patterns of integrated backscatter were more variable over the study area for the four years examined.

Acoustic backscatter based estimates of zooplankton biomass in the Salish Sea, British Columbia, Canada

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Ocean Networks Canada's costal cabled observatory, VENUS, includes several upward facing, platform-mounted ASL bio-acoustic profilers. Here we estimate total and size-specific biomass using data from two such profilers: 1) a 200kHz profiler located at ~96m in Saanich Inlet, for which eight years of data exist; and 2) an ASL multi-frequency (38, 125, & 200kHz) profiler located nearby in the central Strait of Georgia (~299m depth) with a one year time series. We have developed an automated algorithm which captures the seasonal cycle of euphausiid (krill) biomass throughout the long-term bio-acoustic time series for Saanich Inlet. Euphausiid-specific biomass was targeted (and calculated) by limiting echo range and removing background gain in order to more confidently remove fish and instrument noise artifacts. Applying a similar algorithm to the multi-frequency data allowed us to calculate three distinct size-class specific biomass estimates based on minimum organism size. To further improve our zooplankton biomass estimate at the multi-frequency site we used the lower frequencies to identify and remove fish and other large targets from the 200kHz channel. Here we demonstrate the utility of autonomous platforms to measure seasonal patterns in size-specific biomass.

Insights into fish and seabird behaviour, hydrodynamic features, and predator-prey interactions from the integration of a multibeam sonar and a multifrequency echosounder on the FLOWBEC seabed platform in marine renewable energy sites

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The FLOWBEC project integrated a multibeam sonar, multifrequency EK60 echosounder, ADV and fluorometer into an autonomous seabed platform to investigate the environmental and ecological effects of installing and operating wave and tidal energy devices at a range of physical and trophic levels. Five 2-week deployments were completed at the European Marine Energy Centre in the presence and absence of renewable energy structures, complemented by 3D hydrodynamic models and concurrent shore-based X-band radar.

Novel processing techniques mask surface-connected turbulence and extract birds, fish schools and marine mammals for tracking and classification, ground-truthed by concurrent shore-based observations. Co-registration of targets between instruments increases the information available, providing quantitative measures including frequency response from the EK60, and target morphology and behavioural interactions from the multibeam sonar.

Dive profiles, depth preferences, predator-prey interactions, fish schooling behaviour and the effect of hydrodynamic processes during foraging events throughout the water column can be analysed in conjunction with the hydrodynamic impacts of marine renewable energy devices, revealing how animals forage within dynamic marine habitats and whether individuals face collision risks. This information could de-risk the licensing process and, with a greater mechanistic understanding at demonstration scales, the predictive power could reduce the monitoring required at commercial sites.

Stuck between a rock and a hard place: Zooplankton vertical distribution and hypoxia in the Gulf of Finland, Baltic Sea.

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In the Gulf of Finland, a pronounced hypoxic layer develops when there is an inflow of anoxic bottom water from the Central Baltic Sea, which could be a barrier for vertical migrants. The distributions of crustacean zooplankton (mysid shrimp and the copepod Limnocalanus macrurus), gelatinous zooplankton (Aurelia aurita), and fish were studied using acoustics and nets. Vertical profiles of oxygen concentration were taken and the physiological impact of hypoxia on mysids was investigated using biochemical assays. The acoustic data showed peaks of crustacean zooplankton biomass in hypoxic (75 m), whereas fish and A. aurita medusae were found in normoxic (5 - 6 ml l-1) upper layers (

Ears to the ground and eyes on the horizon: acoustic and videographic assessment of mid-water ecology for ecosystem-based management in large oceanic Marine Protected Areas

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The widespread increase in the number and spatial extent of pelagic marine protected areas (MPAs) has fuelled a demand for non-extractive methods of monitoring commercially important species of pelagic fish within them. Here we report on a novel non-extractive approach, linking visual and acoustic sampling, that enables monitoring across multiple trophic levels, and improves understanding of pelagic ecology required for ecosystem-based fisheries management. Stereo-baited remote underwater video systems (BRUVS) provide point samples on the status of fish assemblages, enabling generation of sensitive estimates of population size spectra. Acoustic sampling around mid-water BRUVS, when nested within larger-scale line-transect surveys, can extend point-estimates from BRUVS to the scale required for large MPAs. We conducted a series of pilot studies in the world largest contiguous no-take MPA (The Chagos Marine Reserve) and use the data to assess the status of pelagic fish populations such as tunas and oceanic sharks at three different habitats: seamounts; shelf, and open water.

Optical measures of trawl selectivity resulting from the use of a marine mammal excluder device

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Acoustic-trawl (A-T) surveys are conducted to monitor populations of coastal pelagic fish species (CPS). The A-T analysis uses species proportions in nighttime trawl catches to apportion daytime acoustic backscatter to the various species present in the survey area. A marine mammal excluder device (MMED) in the trawl is designed to allow protected species to escape while retaining a representative mixture of the CPS assemblage. To examine escapement of CPS and protected species via the MMED, we installed a video camera with white- or red-LED lighting inside the trawl. Images collected during a summer 2013 A-T survey show that some fish of all observed species and sizes escaped via the MMED, and some small fish (e.g. anchovies) escaped through the trawl netting. Although the fractions of escaped CPS varied by species, the mixture of captured individuals was representative of all observed individuals. This finding suggests that the A-T estimates of CPS biomasses are not appreciably affected by the selectivity of the Nordic 264 trawl fitted with an MMED. Also, the MMED permitted the escape of dolphins, dogfish, and several large elasmobranchs, apparently unharmed. Also examined are the potential effects of camera lighting on the catch and escapement of CPS.

Target Strength of Pacific Hake (Merluccius productus) and associated fauna using a Drop Acoustic Information System (DAISY).

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A cabled Dropped Acoustic Information System (DAISY) was used to collect in situ target strength of Pacific Hake (Merluccius productus), opalescent squid (Doryteuthis opalescens), and myctopids (Diaphus theta) within monospecific and mixed fish aggregations off the North American Pacific Coast. The system consisted of 38 kHz and 120 kHz EK60 split-beam echosounders with a power supply mounted in a pressure cylinder coupled with an orientation sensor. This system was slowly lowered on top of aggregations while drifting, to resolve and collect information on single individuals. Target strength and swimming behavior was analyzed using target tracking algorithms. Species composition and size distribution within the targeted aggregations were obtained using a midwater trawl, and further information on layer composition was derived from integrated net-mounted video camera. Several monospecific aggregations of Pacific Hake were sampled, including layers of small Age-1 individuals. Discrete layers of opalescent squid were also sampled in association with these aggregations. Results from these monospecific aggregations were compared to results from mixed species layers of mesopelagic organisms (dominated by Diaphus theta), and aggregations with broader size distributions. The target strength values and derived equations from these experiments will be compared to historical and published values.

Characterising pelagic habitats at ocean basin scales in partnership with commercial fishers.

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Ecosystem dynamics of the pelagic ocean are directly influenced by the physical and chemical properties of the water masses that surround them. Physical and biological oceanographers have made recent advances in understanding how large scale physical and chemical processes influence primary productivity at a global scale. Understanding how these processes influence mid-trophic zooplankton and micronekton productivity at similar scales is the challenging next step. Acoustic methods have been identified as one way to characterise and monitor mid-trophic organisms at ocean basin scales. Single and multi-frequency acoustic data are now routinely collected across southern hemisphere ocean basins as part of Australia's Integrated Marine Observing System (IMOS). This program aims to monitor mid-trophic components of marine ecosystems at ocean basin scales through time. Central to achieving this aim is the need to identify dominant scatters for respective acoustic frequencies within distinct pelagic habitats. Here we provide initial results from an acoustic and biological approach to characterise zooplankton and micronekton communities of two differing water masses in the Indian Ocean using commercial fishing vessels as sampling platforms. We outline the limitations of the sampling and future biological sampling needed to interpret the larger scale acoustic data.

Towards an acoustic derived mesopelagic biogeography of ocean basins.

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Net primary production derived from ocean colour satellites is used for segmenting and evaluating the temporal and spatial dynamics of epipelagic (0-200 m) habitats in the world's oceans. Extrapolating epipelagic habitats to describe mesopelagic (200-1000m) habitats is limited by a lack of observations of their species composition, biomass and energetic exchanges. Mesopelagic habitat has the largest concentration of the oceans micronekton biomass, are consumers of primary and secondary production as well as prey for higher trophic level species. Acoustic data can be used to characterise both epipelagic and mesopelagic habitats but large uncertainties remain in their interpretation. Using an acoustic-ocean-basin monitoring database, acoustic metrics for 16 pelagic habitats in the Indian, Southern and Pacific oceans were summarised. Day and night mesopelagic acoustic backscatter correlated strongly with net primary production for most but not all epipelagic habitats. These acoustic derived metrics of mesopelagic habitat can be biased towards resonant scatterers of various sizes depending on the acoustic frequency. Using in-situ multi-frequency acoustic, optical and net sampling the bias to species specific acoustic scattering is quantified. This knowledge can improve the understanding of mesopelagic biomass, energetic exchange and variability to contribute to an ecological geography of the world's mesopelagic oceans.

Temporal and spatial dynamics of pelagic communities in a seasonally hypoxic fjord

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Oxygen depletion is a common seasonal condition in many aquatic ecosystems. Studies of extreme hypoxic conditions have shown effects on benthic and pelagic communities (e.g., habitat compression and species reorganization), but effects of moderate hypoxic conditions, which are increasingly common in coastal waters, have not been well quantified. We conducted ship-based surveys to evaluate the ecological consequences of moderate hypoxia in Hood Canal, Washington, a seasonally hypoxic fjord in the northwestern United States. Multifrequency acoustic measurements and net samples were collected monthly from summer to fall at four sites along a gradient of oxygen conditions in two consecutive years. Distribution, abundance, and behavior of predators [primarily Pacific herring (Clupea pallasi) and Pacific hake (Merluccius productus)] and their prey [primarily copepods and euphausiids (Euphausia pacifica)] were examined to understand effects of seasonal and inter-annual differences in the timing and intensity of hypoxia. In spite of low oxygen levels deeper in the water column during late summer, fish remained at depth. High-resolution acoustic data allow us to detect subtle changes in distributions and behavior of pelagic species, which can provide insight to community-level responses to hypoxia.

Midwater fish biomass still uncertain

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Irigoien et al.(2014) proposed that mesopelagic fish biomass in the world ocean is 1-2 orders of magnitude larger than a widely-cited previous estimate of ~1,000 M t. Their revised biomass estimate was based on backscatter data from a single acoustic frequency (38 kHz) along a circumglobal cruise, without consideration of the fauna's taxonomic and size composition or its depth distribution. However, mesopelagic fishes and siphonophores with gas inclusions resonate at 38 kHz as a function of gas-bladder size and depth, such that acoustic reflectance (or target strength (TS)) may vary by 1 ? 2 orders of magnitude. The effect of resonance scattering on biomass estimation is validated using a 38 kHz and 120 kHz lowered (1000 m) acoustic and optical probe and a resonance-scattering model for fish and siphonophores. As a result, the lower bound of uncertainty for this single-frequency biomass estimate is at least an order of magnitude below Irigoien et al.'s estimate (range: 6,000-200,000 M t, md: 10,000?15,000 M t). Improved resolution of mesopelagic fish biomass requires the use of multiple frequencies to exclude non-target taxa and validation of the taxonomic, size, and depth distribution of the ensonified community, so TS may be appropriately adjusted.

Distribution and density estimation of alien and native fish species using echosounder and DIDSON acoustic camera in the Yongdam Lake, Korea

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The alien species such as the bluegill (Lepomis macrochirus) and the largemouth bass (Micropterus salmoides) have been known to negative effects on ecosystems in the freshwaters of Korea. For the efficient collection of alien species using nets, hydroacoustic survey for spatial-temporal distribution and density estimation of fish was conducted 6 times between August 2013 and July 2014 in the Yongdam Lake, Korea. Acoustic data were collected using 120 kHz scientific echosounder (EK60) for acoustic transects, and using DIDSON (dual-frequency identification sonar) acoustic camera at stationary stations. Various net sampling were used to estimate the abundance of fish. The seasonal vertical distribution of fish might be strong related to vertical temperature structure. The size distribution of fish from DIDSON is highly correlated to estimate acoustic size of fish from echosounder. The fish aggregations are comprised with dominantly bluegill and other fish on the volume backscattering strength, acoustic target strength model, and net sampling data. The results suggest that the acoustic technique might be possible to offer distribution and density of fish in order to the efficient reduction of alien fishes in the inland water.

Do ribbonfish swim vertically? ~ Relationship between their body angle and acoustic intensity ~

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Ribbonfish (Trichiurus japonicus), generally schooling at sea bottom in daytime and dispersing to surface in nighttime are considered to change body angle in accordance with their distribution. To monitor distribution and biomass of ribbonfish, the relationship between their body angle and echo intensity is necessary. We observed swimming of ten ribbonfish recorded by digital video camera and measured their swimming characteristics (Tilt angle, and Dorsal-fin movement) in the water tank of aquarium Umitamago using two-dimensional acceleration data-loggers. Also, we measured TS of 12 ribbonfish within degree range -20~90° in water tank of National Research Institute of Fisheries Engineering. In these experiments, ribbonfish stayed at tilt angle of 72.96 ±5.16° (Mean±SD) and moved horizontally at 27.11±7.87°. Additionally, their TS were -58.42 ±4.39dB at staying and -48.66±2.34dB at horizontal moving. From these results and previous study, ribbonfish are considered to stay at vertical tilt angle as a part of schooling at sea bottom in daytime and move horizontally to feed prey at surface in nighttime. In conclusion, it's possible to monitor distribution and biomass of ribbonfish by measuring their swimming body angle at sea bottom and surface.

Observing temporal processes in an ecosystem hotspot over an annual cycle with high resolution acoustic

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Ecosystem understanding stems from sampling which entangles spatial and temporal variation and thus fails to resolve basic temporal details.

The Lofoten-Vesterålen Ocean Observatory, in operation for more than one year, collects temporally resolved data on biomass densities, vertical distributions and behavioural characteristics. It is situated on an ecological hotspot supporting the productive fish stocks of the Barents Sea. Oceanographic sensors provide information about the drivers behind the observed phenomena, and interpretation of the acoustic data is supported by catch data from scientific surveys and commercial catches.

The data quantify large flux of oceanic biomass of cod and herring over the winter season where the time of arrivals and departures can be precisely estimated. Detailed target tracking of individuals in combination with biomass distributions of cod show clear changes in individual and group spawning behavior from the beginning of February to the end of April. The ecosystem is strongly affected by internal waves and strong currents and variable influx of Atlantic waters sometimes flushing over the area. Behavioural characteristics from seconds to seasons uncover inter and intra specific interactions including feeding interactions. We discuss the observatory approach in the context of understanding ecosystem processes and supporting stock assessment.

In situ target strength measurements of Atlantic mackerel (Scomber scombrus) at multiple frequencies

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Atlantic mackerel is a pelagic migratory fish which supports very valuable commercial fisheries. Echo-integration surveys could provide annual estimates, with additional scope for the study of mackerel distributions throughout the year. However, this requires that mackerel target strength (TS) is well known which is not yet the case. The present study provides in situ TS data for Atlantic mackerel from measurements made at sea with split-beam echosounders operating concurrently at 18, 38, 120 and 200 kHz. The insonified fish were sampled by trawl and handlines. A novel single-target filtering procedure, which accounts for selection of suitable single target data, fish-density and signal-to-noise effects and target detection at multiple frequencies was developed to reduce multiple-fish registrations in the dataset. Empirical results suggest mean TS of -52.05 dB at 18 kHz, -59.90 dB at 38 kHz, -57.85 dB at 120 kHz and -56.77 dB at 200 kHz. This is based on averaged fish length of 33.3 cm and differs significantly from the values currently used in acoustic surveys. Empirical results at 18 and 38 kHz are compared with TS estimates from an adapted Distorted Wave, Born- Approximation model. Bayesian methods were applied to account for uncertainty in the model parameter values.

Spatial structure of micronekton closely related to oceanographic fronts in the South-West Indian Ocean

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Hydroacoustics were used to investigate the vertical distribution of micronekton according to water masses delineated by fronts and discriminated by analyzing spatial remote sensing data. Acoustic data were collected continuously at 38 kHz frequency during eighteen transits carried out in the South-West Indian Ocean (20-60°S, 50-80°E) between 2010 and 2014 including scientific (from MyctO-3D-MAP project) and opportunistic fishing (from Integrated Marine Observing System database) surveys. A structure in three main depth layers (surface, intermediate and deep) has been found continuously according latitude. Changes of micronektonic vertical structure were investigated along this gradient: the surface layer acoustic density and thickness decrease by going southward. The intermediate layer is generally almost empty except between 30 and 40°S. The deep layer acoustic density increases from North to South but its thickness does not change significantly. To assess the importance of these vertical changes, a spatially constrained clustering was applied on acoustic data and a positive correlation was established between vertical acoustic organization and fronts' position. We conclude that spatial organization of micronekton is structured depending on water masses and confirm the interest of collecting acoustic data from fishery vessels to complete scientific surveys that are often restricted in time and space.

Methods for determining in situ target strength measurements of pelagic species

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In order to convert acoustic data into estimates of fish abundance, an essential requirement is to determine the average target strength (TS) appropriate for the species of interest. TS can be obtained from in situ measurements using split beam echosounders and in ideal conditions these can be considered as the most representative estimates available. However, there is no comprehensive practical guide to derive in situ TS for pelagic species which also accounts for the potential problem of multiple target detections. This paper intends to act as a manual for standardized in situ TS measurements. The recommendations described here are considered as follows: survey design and choice of equipment; collection of appropriate empirical in situ data from acoustically surveyed areas which are spatially and temporally consistent with the biological information; selection of suitable data for single target detection; identification and removal of areas with high densities to reduce the acceptance of multiple targets; extraction and post-processing of single target data; validation methods including theoretical modelling, with appropriate parameterisation. The methods described in this paper can be used to improve single target selection and deliver the most representative measures of TS for use in acoustic surveys.

Acoustic data assimilation for estimating energy transfert parameters of a micronekton model

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SEAPODYM Forage is a micronekton model used to simulate foraging fields of top predators (tunas, swordfishes, turtles, seals...). In this framework, micronektonic organisms are divided into 6 functionnal groups according to their diel vertical migration. Their dynamics is driven by temperature and oceanic currents. Micronekton production is modeled as a percentage of energy transfer from primary production to mid-trophic level (E=4%). This amount of energy is allocated to each group with transfert energy coefficients. These coefficients are not reachable throught direct observations : this work uses data assimilation to assess them. Data assimilated into the model are ratios of biomass over the water column - calculated from 38kHz-acoustic density used as a proxy of micronekton biomass.
A negative log-likelihood function (mainly distance between observations and model estimations) is minimized with help of a gradient descent method (Quasi-Newton algorithm). Gradients are estimated with an adjoint code.
We present an illustration of assimilation experiments with multiple transects in various environments.\\

An in situ study of the resonant scattering properties of mesopelagic fish in the Red Sea

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A resent study has shown that mesopelagic fish are dominating the fish biomass in the worlds oceans(Irigoyen et al 2014). There are relative few studies of mesopelagic fish acoustic scattering properties to be able to accurately estimate their biomass. It is especially uncertain how the swim bladder resonance at certain frequencies and depths are effecting how accurately their biomass can be determined acoustically. In this study we measured the in situ Target Strengths in two deep scattering layers, consisting of two different small mesopelagic fish, at 4 frequencies (38, 120, 200 and 333 kHz). The scattering layers was located between 400-650 meters depth in daytime and the whole populations migrated to upper waters at night. A submergible Simrad EK60 echosounder system was lower to the daytime depth and followed the layers through their diel vertical migration, thereby measuring individual Target strengths, frequency response and changes of resonance with depth. The total water column backscattering was also compared between day and night to determine the effect of the depth change.

Estimating the net efficiency of a framed midwater trawl for juvenile walleye pollock (Theragra chalcogramma) using both acoustic and trawl methods

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To estimate fish abundance based on trawl-survey data using a framed midwater trawl (FMT), it is necessary to determine the net efficiency. In this study, we estimated the net efficiency of an FMT for juvenile walleye pollock (Theragra chalcogramma) using the ratio of catch to acoustic density. The effects on the net efficiency of net color and light condition were also examined. In June 2013 and 2014, trawl data were collected using a FMT with a greenish-blue net and with a black net, and acoustic data were collected simultaneously using a Simrad EK60 echo sounder at 120 kHz. The net efficiency was estimated by calculating the partial regression coefficient through linear regression analysis. The estimated net efficiencies for juvenile walleye pollock measuring 20-60 mm in length were 0.1 to 0.6. Net efficiencies were higher at night than during the day. There were no significant differences in net efficiency between the greenish-blue and black nets during the day, but at night, it was higher in the black net.

Acoustic-optical survey of the giant jellyfish \itshape\ bfseries Nemopilema nomurai \bf around the Tsushima Strait

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The maximum diameter of giant jellyfish \it Nemopilema nomurai \rm is over one meter. They are transported by the Tsushima current to the Sea of Japan and are sufficient to seriously damage coastal fisheries. Acoustic-optical surveys of the giant jellyfish have been conducted around the Tsushima Strait in the second half of every July from 2009 to 2014. The distribution density of the jellyfish was estimated in the daytime, from the surface to 100 m depth by visual observation (0-3 m), towing upward-looking underwater video camera (3-20 m), and quantitative echosounder (20-100 m, EK60, SIMRAD). The vessel log speed was kept to around 5 knots to obtain high-resolution echograms which enabled us to discriminate between the jellyfish echo and others. Jellyfish echoes are semi-automatically detected using morphological parameters of echoes (i.e. echo height, width, rectangularity and compactness). Obtained bell-diameter distributions from catch data of midwater trawls (LC-net, mouth opening 10 m x 10 m) were compared with the bell-diameter distribution estimated by an underwater video camera and the size distribution estimated from the detected jellyfish echoes. The mode of these distributions agreed well. The giant jellyfish were distributed in large numbers on the high temperature and low salinity water mass.

Dusk and dawn vertical migrations of overwintering sprat (sprattus sprattus)

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An upward-facing, bottom-mounted 200-kHz echosounder was applied to study vertical distribution and individual swimming behavior of sprat throughout an entire winter in a Norwegian fjord. Being cabled to shore for power and data transmittance, the echosounder provided continuous measurements at a temporal resolution of seconds. A normal vertical migration pattern with schooling during the day and a generally shallower distribution at night was observed. However, it also appeared that part of the sprat population persistently carried out inverse diel vertical migrations at dusk and dawn. At dusk, when the sprat started migrating to shallower waters in schools, several individuals left the schools and sank back to deep waters again. At dawn, individual sprat migrated upwards and aggregated in schools in upper waters. Shortly after this, the sprat returned back to depth in schools. The time window of upward migration lasted for about 20 minutes, which also was the average time the sprat stayed in shallow waters before migrating downwards again. The IDVM behavior followed the timing of sunrise and sunset throughout the entire winter and likely reflected antipredation windows where the sprat possibly optimized the trade-off between food intake and predation risk.

The distribution and behavior of mesopelagic organisms in tropical waters: A comparative approach between Indian and South Pacific Oceans, from acoustic measurements at 38 kHz.

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Mesopelagic organisms have a pivot role in the marine high-seas ecosystems. They consume the lower trophic levels and constitute the basic preys of top-predators which are important resources from the ecologic and economic viewpoints, particularly in the Indian and in the Pacific Oceans. They start also to be considered as a new, huge, potential protein resource. In this context and through several surveys performed during 2009-2014, this work aims at comparing the Mozambique Channel (MESOP surveys), and the exclusive economic zone (EEZ) of New Caledonia (NECTALIS surveys). These two areas are at the same southern latitude (~20°S) and encounter eddies phenomenon. However they present different conditions: one is in a channel (Indian Ocean) and the other one is in a completely open area influenced by an oligotrophic warm north water mass and a rich cold south water mass (south-west Pacific). The catches of tuna in those two areas vary by a factor ~10 at the advantage of the Mozambique Channel. Our comparison focuses on the vertical distributions of mesopelagic organisms, and on indicators characterizing these layers, such as depths of various percentages of the total sA value, number of layers, densities, relationships with hydrological conditions and composition of the layers.

Simple dB-differencing methods to discriminate between three pelagic fishes (sardine, sprat and boarfish)

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Acoustic data were collected on three frequencies during the autumn 2014 PELTIC survey (SW England). The study area is characterised by a diverse pelagic fish community and our aim was to objectively distinguish between different species in the acoustic data. Mackerel could be separated from other fish using a bespoke filter. However no such filter existed for the other dominant pelagic fish in the area (sardine, sprat and boarfish). We explored the relative backscatter of these fish species using pairwise Sv (dB) differences. Three-frequency Sv data were exported by school and categorized into species using information from the nearest trawl. Patterns of dB differences were consistent within sets of schools by species. Whilst overlap between species was evident, results improved by examining the pairwise frequency responses in two dimensions through contour plots with dB-difference 120-380 on the x-axis and 200-38 on the y. By combining the data from multiple schools a simple 3D model was made for each species, which was considered akin to a probability distribution function for each species frequency response. This method enables the observed backscatter in acoustic data to be attributed to a particular species with an associated estimate of uncertainty due to the classifier itself.

Target strength estimation of the euphausiid Thysanoessa raschii in an Icelandic fjord based on concurrent Video Plankton Recorder data and a theoretical scattering model

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An acoustic survey on euphausiids was carried out in an Icelandic fjord in August 2012, using echosounders at 38, 70, 120 and 200 kHz. Samples were collected using Bongo-nets and a krill-trawl. Several tows with a Video Plankton Recorder (VPR) were carried out. Quite high and fairly homogenous concentrations of euphausiids were observed, dominated by Thysanoessa raschii. A strong correlation was estimated between the zooplankton concentrations according to the analysis of the VPR data and the acoustic volume backscatter along the towing track of the VPR. Based on that relationship, the averaged estimated target strength was -96.7, -89.2, -84.0 and -81.3 dB at 38, 70, 120 and 200 kHz, respectively. The length distribution of the euphausiids was bi-modal, with peaks at 12 and 24 mm. Theoretical modelling using a distorted-wave Born approximation-based approach was used to estimate the average target strength for the observed length distribution and several observed and hypothetical distributions of orientations. The theoretical models resulted in lower target strengths at all survey frequencies. The presentation discusses several possible reasons for this discrepancy, including avoidance issues, scattering model parameterisation, and uncertainty related to the method used for acoustically discriminating the euphausiids from other scatterers.

Functional linear model for acoustic profiles

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We propose a statistical method for predicting acoustic profiles using environmental variables as predictors. The originality of this work is to consider the data as functions. We first propose a fitting method to construct the acoustic profiles, temperature and salinity profiles, where the variance of the sampling devices can be used to fix the level of smoothness. We then construct a functional linear model with bootstrapped confidence intervals where temperature and salinity profiles are used as predictors. The method is illustrated on raw data from a scientific survey performed in spring (April?May) 2009 in the Bay of Biscay (Atlantic Ocean). Results are represented with useful displaying methods which give access to the shape analysis of the different profiles.

Target strength measurement of euphausiid, copepod and amphipod by the tethered method

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Zooplankton such as euphausiid, copepod and amphipod are an integral component of oceanic ecosystems. In acoustic biomass estimates, the target strength (TS) of marine organism is one of the key parameter to estimate stock abundance. As zooplankton is small in size and in acoustic backscattering, it was generally difficult to measure precise target strength of zooplankton. Recently, a system that can measure acoustic backscattering of small animals was developed in NRIFE. In this study, we measured the target strength of euphausiid, copepod and amphipod as a function of the incident angle of the ensonified wave at 120 kHz and 200 kHz in the living state. The TS measured were compared with the theoretical predictions by the Distorted-Wave Born Approximation-based deformed-cylinder model (DWBA model). Sound speed contrast was measured beforehand. After measuring TS, we measured density contrast using the same sample. Measurements and predictions agreed well for euphausiid and amphipod. For copepod, however, some specimens agreed well and some not. Predictions and measurements agreed well in the case that the ratio of the oil sac's volume to the body's one is low. Scattering from the body with oil sac should be considered in theory.

Modelling fish distribution using high resolution acoustic and fishery data: Bay of Biscay anchovy as case study

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Acoustic surveys provide high resolution data to estimate and map fish spatial distribution. However most of these surveys are conducted annually, and the seasonal dynamics of these populations are poorly known. Here we explore how high spatial and temporal resolution fishery data derived from the Vessel Monitoring System (VMS) can be used to better understand population movement and distribution over time. When both type of data are available, a log Gaussian Cox process is proposed to explain what drives locations of fishing operations and catches per unit of effort. This marked point process is thought to have its intensity varying spatially and preferentially according to a latent Gaussian random field, here derived from the acoustically surveyed fish distribution, and other covariates such as fish length, distance to harbor or potential revenues. Then, taking advantage of the availability of fishery data in time, the model is used to forecast monthly spatial distributions over time. This approach is applied to Bay of Biscay anchovy using acoustic data from the PELGAS series and fishery data for years 2008-2012. Results are discussed with respect to fishery data characteristics. High resolution maps that have been produced, will improve our understanding of this pelagic ecosystem structure.

Physical and behavioral interactions determining mysid prey distribution

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Physical and behavioral factors that lead to a persistent, nearshore aggregation of mysids off the central Oregon coast, in the California Current Ecosystem were investigated. Mysids are a critical zooplankton prey group supporting a number of fish and marine mammal predators, including a resident population of gray whales. Mysid distributions were observed using a combination of shipboard and moored multi-frequency echosounders co-located with temperature and current meters. Plankton net sampling collected representative samples for ground-truthing acoustic samples, and visual surveys were conducted for the distribution of marine mammals. The mysid population, consisting of 4 species with distinct life-stage cohorts, was found distributed in a narrow band parallel to shore despite persistent tidal and along-shore currents. The persistence of this important prey population was regulated in this physically dynamic region by the interaction of behavior and physics. The interaction of animal behavior and physical forces play an important role in determining the distributions patterns of mesozooplankton we observe in the oceans.

Acoustic characterization of the squat lobster Munida gregaria (Decapoda, Munididae)

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The squat lobster (Munida gregaria) is a well known benthic species in the Argentine Sea (SWAO). Historically, the occurrence of shoals has been occasionally reported and were anecdotic records. However, since 2008 the presence of large pelagic swarms has become very common in Patagonian waters, extending for as much as 20 nm. The causes of this phenomenon are still a matter of research, yet it has become clear that the species behaviour together with its physical properties makes Munida gregaria suitable for its acoustic detection and thus its population assessment. The acoustic response measured in situ shows significant differences in comparison to other pelagic crustacean of similar length, showing higher TS values but a much lower TS increase with frequency, for the sound frequency range 38 kHz ? 200 kHz. Tilt angle curves of TS, obtained at 120 kHz for individuals of different sizes are presented. The larger individuals exhibited pronounced maxima and minima. Some of the physical parameters that are acoustically relevant, such as body density and sound speed contrasts, were measured experimentally and here reported.

Multibeam echosounder reveals species-specific fish school features

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In multispecies environments, relating fish schools acoustic attributes and species composition, based on monobeam, 2-dimensional (2D) echosounder is generally challenging. This is likely due to the fact that 2D echosounders provide data on slices, rather than on entire schools, due to the narrowness of their beam. We revisit the link between fish schools acoustic attributes and species composition based on three-dimensional (3D) acoustic data provided by the ME70 multibeam scientific echosounder, whose larger sampling volume and higher resolution allow to finely characterise entire fish schools. Acoustic schools observed during PELGAS surveys in areas with various levels of species mixing are extracted from 2D and 3D echograms. 2D and 3D morphological, positional and density school attributes are related to species compositions to: i) assess the discriminatory power of mono vs. multibeam data, ii) investigate species-specific school characteristics. Multibeam school data allow for a better visual and automatic species discrimination than monobeam ones. The analysis of 3D data reveal large differences between Biscay sardine and anchovy schools: sardine generally form amoeboid, very dense schools, whereas anchovy congregate in elongated, ribbon-shaped, less dense schools. These species-specific school shape differences are discussed in the context of the species eco-ethology.

Alternative ground truth techniques for fisheries acoustics

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Fisheries acoustics surveys are effective tools in marine resource assessment and marine ecology. An ongoing challenge in applying acoustics is the identification of echotraces and significant advances have occurred in recent years with the application of multiple and broadband frequencies. There is, however, still the need to ground-truth any echotrace identification method and this is usually achieved by obtaining simultaneous net samples. Here, two alternative methods for ground-truthing are examined: line fishing and video cameras. These methods were deployed during a survey of Atlantic mackerel (Scomber scombrus), a fast swimming small pelagic fish which forms enormous schools in the North Sea during autumn. Line fishing was actually more efficient than pelagic trawling (the standard technique) and provided length frequency distributions that were not significantly different; it also provided insights into the depth distribution of fish sizes. A small video camera was deployed into schools, providing spectacular footage, species identification, and, uniquely, fish orientation. Image analysis was then applied, producing tilt-angle distributions which are important to understand target strength, an uncertain parameter in mackerel abundance estimation. These techniques are complementary to traditional trawling methods, but provide alternative insights into fish behaviour whilst satisfying standard requirements of identification and supplying biological samples.

Monitoring annual changes in the squat lobster Munida gregaria swarms of San Jorge Gulf, Southern Patagonia.

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The squat lobster Munida gregaria is a benthic crustacean that inhabits in the Argentine Sea (SWAO). Particularly, in waters of San Jorge Gulf, the pelagic aggregations of this species increased greatly in number and density during recent years. Regular acoustic surveys conducted by INIDEP (2008-2012) detected the first pelagic swarms of the species, located mostly at the south-eastern end of the gulf. These swarms are characterized by mid water scattering layers whose density and spatial dimensions are variable. In some cases, the pelagic swarms extend horizontally for several nautical miles and are located at varying depths in the water column, from 20 m depth to the bottom. The analysis of the acoustic sections from this survey series revealed annual changes in the aggregations patterns as well as in the proportion of the water column being occupied by the species, with a peak value recorded in 2010.

Integrated acoustic, optical, and net studies of euphausiid ecology in the Gulf of Maine

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The ecological role and importance of euphausiids in the Gulf of Maine region is only poorly understood, in part due to difficulties sampling them with traditional net systems. A series of three cruises targeting euphausiids was conducted along the margins of Georges Bank, involving a combination of broad-scale mapping surveys to identify euphausiid aggregations and adaptive small-scale surveys over 48 hour periods to characterize diel patterns of variability. One cruise examined the association of euphausiids with submarine canyons while the other two were coordinated with fisheries acoustic/trawl surveys and timed to capitalize on seasonal changes in herring predation on euphausiids in order to examine the influence of predation on euphausiid behavior. Euphausiids were sampled with a suite of complementary instruments, including depth-stratified nets (MOCNESS), a Video Plankton Recorder, a multi-frequency (43, 120, 200, 420 kHz) echosounder, and a towed broadband echosounder (35 to 600 kHz); acoustic observations were also used to characterize fish. Euphausiids were discriminated from other scattering sources based on their frequency response, followed by inversions for length and abundance. Distinct spatial and temporal variability was observed in euphausiid abundance, patch structure, community composition, and diel vertical migrations, associated with changes in environmental conditions and predation pressure.

Vertical distribution of organisms in pelagic marine ecosystems: a dual acoustic and modelling approach

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Understanding and predicting the functional role of biodiversity in marine ecosystem dynamics and how physical variability of the ocean affects ecosystem functioning is a key issue. The focus of this study is to use acoustic data to provide vertical distribution information of three generic communities (epipelagic, migrant mesopelagic and non-migrant mesopelagic) in order to estimate their physiological and behavioural parameters for applications of an end-to-end ecosystem model, APECOSM (Apex Predators ECOSystem Model). In APECOSM, the vertical distributions of organisms in the generic communities are critical because they control spatial co-occurrence and hence the trophic interactions of the different communities. Vertical distributions of the communities are assumed to result from size-dependent advection-diffusion processes. The parameterisation of the three generic APECOSM communities was conducted using environmental (ambient light, oxygen, temperature) and acoustic data collected in the western Indian Ocean. An observation model reproducing the available one-dimensional data was developed. Parameters were estimated using the Automatic Differentiation Model Builder (ADMB) software. According to the mechanistic basis of APECOSM, regional estimates are then assessed against observations in other regions to test and potentially improve the parameterisation, and eventually validate the global scale predictions of the vertical distributions of APECOSM's communities.

Characterizing Reef Fish Communities on the West Florida Shelf: Collecting Acoustic Data Coupled with Video Data

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Characterizing fishery resources in areas of untrawlable reef habitat can be challenging since traditional sampling gears (e.g. bottom trawls) do not work effectively and can cause damage to sensitive habitat and/or the gear itself. Using a combination of non-traditional approaches, such as towed video collection coupled with a scientific echosounder for acoustic data collection, one can rapidly collect valuable fisheries-independent data ? the video can provide species identification, numbers within the field of view, and in the case of stereo cameras, lengths of observed fish. The scientific echosounder can provide location and potential numbers of fish throughout the water column and target strengths. The acoustic approach could also allow for the observances of biases associated with the survey platform and visual data collection, such as avoidance or attraction behaviors. For my proposed research, I will examine acoustic data collected from the hull-mounted EK60, (38 kHz) collected in conjunction with the video collected from a towed camera array over a series of multiple cruises (June and November 2013, and May 2014) within marine protected areas (MPAs) on the West Florida Shelf. For my poster, I will present data collection methods and some initial processing steps and limited preliminary acoustic data analysis.

EROC-ENROL: a method for controlled in-situ Target Strength measurements of pelagic fish

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Measuring fish target strength (TS) in the wild is challenging as: i) TS largely varies as a function of physical (tilt angle, depth) or physiological fish attributes, ii) the species and size composition of acoustic targets is difficult to assess in near real time. We propose a methodology for controlled in situ TS measurements based on the joint use of a Remotely Operated Vehicle (ROV) ?EROC' with a pelagic trawl fitted with the 'ENROL' codend opening system. EROC can be moved around the fishing trawl and is equipped with a Simrad EK60 70 kHz splitbeam echosounder, and a low-light black and white camera. Pelagic fish are funnelled into the open trawl and their TS is measured with the EROC echosounder in the middle of the net, where the fish swim in small groups towards the trawl mouth, against a strong current. The fish oriented swimming allows for the recording of nearly horizontal fish TS, hence controlling for the large effect of tilt angle on TS variability. Direct optical identification of the fish species composition is conducted with the EROC camera near the open codend. The methodology is used to measure in-situ TS of Biscay Engraulis encrasicolus in controlled conditions.

Using acoustics to observe fine scale schooling behaviour in open ocean and controlled net pen experiments

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Underwater acoustics is well suited to observe fine scale behavioural across a range of different scales. This paper presents several techniques that have been developed to observe and quantify schooling behaviour using acoustics; from free ranging schools to wild-caught schooling fish in controlled net pen experiments. A method to attribute rapid changes in backscatter within a school to internal turning waves was developed, and we applied this method to free ranging herring schools where turning waves on the order of 10m/s were detected. This was combined with fine scaled observations on herring in a net pen, where a high frequency sonar was used to estimate swimming speeds and internal correlation structures in swimming velocity. The dynamic response in the fish to fast moving objects was quantified in terms of turning waves and direct responses, and we demonstrate how the setup including open ocean experiments and controlled net pen experiments can be used to investigate the fine scaled behavioural response to different stressors such as underwater noise, vessel noise, seismic or sound.

Small pelagics in the North Sea ? Long-term spatial distribution patterns of two ecosystem key-players

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The small pelagics herring (Clupea harengus) and sprat (Sprattus sprattus) play key roles in the North Sea ecosystem, both as predators and prey. Environmental influences have been hypothesized to affect the dynamics of both species in different ways. While herring year class strength has been consistently weak since 2002 due to reduced survival during the larval stage, a factor that was directly attributed to environmental variability, no such direct effect has been hypothesized for sprat. However, changes in zooplankton community structure seem apparent, albeit with unknown implications on sprat stocks and so far no observed trends in their recruitment. Both stocks are surveyed with an ICES coordinated, annual international acoustic survey (HERAS). The survey provides abundance and biomass indices for, amongst others, North Sea autumn spawning herring and sprat since the year 2000 and covers the North Sea, the area West of Scotland and the Malin Shelf. Here we document long-term spatial distribution patterns of both herring and sprat in the North Sea based on species dis-aggregated hydroacoustic data and corresponding trawl catches and use geostatistical descriptors, spatial indices and environmental variables to investigate possible distributional changes and their and underlying causes.

Allocating backscatter using a flexible, non-parametric Bayesian mixture model

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Accurate partitioning of backscatter data is crucial when estimating species-specific population abundances. Current classification methods are typically subjective categorizations by an analyst or objective, rule-based classifications that lack uncertainty estimates. We adapted a semi-supervised, non-parametric Bayesian mixture model to allocate multifrequency backscatter between known and unknown species categories. The Dirichlet Process Mixture Model creates and allocates backscatter to categories based on data attributes as new data are encountered. Advantages of this approach include: providing interpretable Bayesian credible intervals around Sv estimates; no required assumption on the number of categories; and the flexibility to adjust clustering resolution to include knowledge of species communities and incorporate other prior knowledge. We implemented our model on 2007 Eastern Bering Sea, Walleye Pollock survey data collected at four frequencies, using five categories of previously trawl-verified, single-species training data. Our model produced 14 clusters which were labeled in nine categories (single and mixed species) based on survey trawl data and Gaussian properties of Sv difference clusters. For each category we produce 90% credible intervals of transect average backscatter (NASC). Regressing NASC estimates on label-matched estimates from previously published analyses, we find high correlations (r^2 > 0.90) between analyses across our intervals.

Spatial distribution of the Black Sea copepod Calanus euxinus, determined using multifrequency acoustic information.

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Black sea is one of the most interesting marine environments with its distinctive hydrographical properties and biotic communities. The copepod Calanus euxinus is one of the most important components of the midtrophic level in Black Sea and with its ability to survive in the oxygen minimum zone (OMZ). The use of multiple frequencies allows accurate discrimination of zooplankton from other backscatters which furthermore enables identification of their species, size and abundance. The purpose of this study is to a) provide an applicable method for monitoring of the standing stocks of Calanus euxinus in the Black sea by exploiting the multifrequency data collected during fisheries surveys b) elucidate their spatial structure c) assess the role of the OMZ over their vertical distribution. The acoustic data was collected with EK-60 echo-sounders onboard the R/V «Bilim» with hull-mounted transducers of frequencies 38kHz, 120kHz and 200kHz. Acoustic layers of C.euxinus were discriminated using a combination of procedures described as +MVBS and Z-score. The biomass distribution was assessed based on the TS estimation calculated using a DWBA model and mapped using geostatistics. The results of this study is the first extensive attempt to estimate the standing stock of C.euxinus in the region using acoustic methods.

Acoustics to quantify the impact of physical structures on biological components along scales

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The downward displacement of the oxycline depth as estimated by acoustics provides a robust estimation of ocean surface turbulence. To characterise these physical processes and determine their impact on biological components we used acoustic data acquired during 12 scientific surveys performed along the Peruvian coast. We applied an original wavelet-based method to extract and characterise the physical space-scale structures as well as the patches of zooplankton and pelagic fish. We further made a typology of the physical structures and defined clusters corresponding to the internal wave scale (

Meso-scale temporal and spatial distribution patterns of small pelagics in the Eastern Tropical Atlantic

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Despite their economical and ecological importance, few information exists on small- to meso-scale spatial and temporal distribution patterns of widely distributed pelagic fish species such as clupeids Sardinella aurita and Sardinella maderensis as well as carangids Decapterus rhonchus, D. punctatus and Chloroscombrus chrysurus along the western African coast in the Eastern Tropical Atlantic. Although regular previous surveys covering wide parts of the western African coast have helped in attaining insight into large-scale distribution and migration patterns, regional scales mostly have remained unstudied due to insufficient area coverage. Within the framework of an EU funded project on institutional support for fisheries management for Sierra Leone, a series of six surveys was carried out biannually from 2008 to 2011 on the shelf area off Sierra Leone investigating biomass and distribution of important fish species. Here we present results of the hydroacoustic legs of the corresponding surveys targeting small pelagics. We studied seasonal (rainy season vs. dry season) and spatial distribution patterns and with the use of geostatistics and spatial indices aimed to identify underlying causes for observed patterns.

Using High Resolution Acoustic Telemetry to Evaluate Fish Behavior Near a Bio-Acoustic Fish Fence on the Sacramento River, California, USA

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Maintaining appropriate fish passage routes for migrating species is an important goal for water diversion projects in rivers where these fish occur. While systems can be engineered that attempt to safely bypass fish, or direct them to safe passage routes, the evaluation of these systems requires in-situ observations of fish behavior. High resolution acoustic telemetry was used at Georgiana Slough in 2012 to evaluate behavioral responses of downstream migrating chinook salmon (Oncorhynchus tshawytscha) to a Bio-Acoustic Fish Fence (BAFF). Salmon smolts and also predatory fish species were surgically implanted with acoustic tags and monitored with a 32 hydrophone array to develop continuous, high resolution, geo-referenced tracks over a 500 m section of the Sacramento River at Georgiana Slough, California. These tracks were used to evaluate salmon and predatory fish behavior around a BAFF designed to direct migrating fish away from Georgiana Slough, and into the Sacramento River.

Remote species identification of coral reef fish communities: advances and challenges

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Coral reef ecosystems are among the most diverse and productive in our oceans. Over 4000 species of teleost fishes are associated with coral reefs, raising challenges to monitor the abundance and the distribution of reef fish in order to develop an effective conservation policy and to evaluate the effect of management actions. Fisheries acoustics is one of the tools that is widely used in fishery assessments. Remote species identification becomes central in these cases. The majority of the methods used for remote species identification have been applied in the pelagic environment and there is a very limited knowledge on the acoustic characteristics of coral reef species. A variety of approaches have been used that exploit the frequency response of species (related to the presence of the swimbladder and its morphology), morphology of schools, and habitat-based modeling approaches. We review long-term marine ecosystem acoustic surveys in the US Caribbean and evaluate metrics that may be helpful in the remote identification problem. The work proposed here is an attempt aimed at improving the marine ecosystems acoustics for the study of coral reef fish communities. Challenges and implications of the approaches used in this work are presented and discussed.

Acoustic monitoring of sardine Sardinops sagax, a key species in the California Current and the Gulf of California ecosystems

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Recent studies in the California Current system (CCS) using global climate models project how the distribution of fish would shift northward in the near future as greenhouse gases warm the atmosphere and, in turn, the ocean surface. These studies anticipate a re-shuffling of marine species across the whole biological community, which may lead to declines in the beneficial functions of marine and coastal ecosystems, especially predator-prey interactions. A well know representative foraging species in the CCS is sardine Sardinops sagax. A widely accepted view about sardine is that population size grows and expands geographically during warming conditions, while the opposite happens with prevailing cooling conditions. While some species shifts are being documented as CCS waters are warming, sardine population size is decreasing and reducing to the southern part of its distribution, according to our population size estimations, including acoustic surveys in 2012 and 2013. A similar decrement is observed inside the Gulf of California, a system closed to the north, where acoustic monitoring has been done since 2008. Our preliminary analysis of acoustic data and environmental variables support the hypothesis that population size variability of S. sagax responds to a natural pattern of variation on interdecadal regime time scale.

Contribution of acoustics to integrated ecosystem assessments and management

Development of Acoustic Methods for Hawaiian Semi-Demersal Fish Identification and Abundance and Biomass Estimates

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Presently, only fisheries dependent methods are used for stock assessment of economically important semi-demersal fish («Deep-7»), occupying non-trawlable habitats. To develop acoustic descriptors for Deep-7, simultaneous acoustics and complimentary methodologies were used. From in situ TS and fish length pairs, TS for Deep-7 was estimated as 22.84?log10(SL)-70.93. Representative aggregation size, density, individual swimming pattern, depth and distance from bottom were also collected. Data obtained by separating echoes consistent with those of Deep-7 indicate high spatiotemporal variability with higher number of detections during daytime than at night. Most fish were found between 120-170 m and 280-320 m depth ranges, within 50 m from bottom. Larger individuals occupied the shallower depth range and were found closer to the bottom, but school size was independent of bottom depth or distance from it. Tightly aggregated and loosely grouped fish contributed significantly to biomass and abundance. Spatial distribution, as well as schooling behavior, showed some topographical dependence. While results are preliminary, they indicate that acoustics can be successfully used to monitor Deep-7 stocks in Hawaii. Abundance and biomass estimates can be improved by finetuning acoustic descriptors from additional data points and possibly dB differencing, and by applying percent species distribution knowledge from other methodologies.

Prior knowledge: incorporating acoustic abundance indices into Bayesian assessments

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An integrated approach is required between scientists that collect acoustic data, assessment modellers that use it, and fisheries managers that set harvest limits. We describe our experiences using examples from two New Zealand southern blue whiting (SBW) stocks. Both stocks are assessed using Bayesian statistical catch-at-age models, with regular acoustic surveys providing fisheries-independent estimates of spawning SBW abundance. Acoustic estimates are modelled as relative indices with a ?catchability coefficient' (q), defined as the ratio of the survey estimate to actual spawning stock biomass. The value of q is estimated in the model, but has an informed prior distribution based on knowledge about likely availability of fish to the survey, and uncertainties around acoustic target strength, target identification, and calibration. This survey and assessment approach has worked well for the Campbell Plateau SBW stock, where the survey covers the entire spawning SBW area, and q is assumed constant in all years. Resulting assessments have proved robust, and q can be well-estimated from available data. Model-based assessment has worked less well for the Bounty Platform SBW stock, where an unknown proportion of the spawning stock is surveyed in each year, leading to a simpler management approach.

School and gear dynamics in purse seining, studied with multibeam sonar

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Understanding fishing gear performance and fish reactions to the gear is essential for efficient and sustainable fishing. In this study the dynamics of herring (Clupea harengus) and mackerel (Scomber scombrus) schools captured by the commercial purse seiners, «Artus» and «Kings Bay », were studied with a Simrad MS70 multibeam sonar (75-112 kHz). The sonar was mounted on RV «G.O. Sars» and the recordings covered the whole purse seine and the enclosed school within each single transmission. The catches were taken in the Norwegian and the North Sea in 2013 and 2014. Fish densities and school distribution in the net were estimated as the net was hauled and the available volume was gradually reduced. One of the challenges was to distinguish the school echoes from the net and the air bubble echoes created by propellers of the fishing vessel. Criteria for extracting school data from inside the net were established based on differences in the backscattering strengths from the net and the school and by setting a blind zone around the vessel based on the range of the air bubbles from the vessel. The results are important for reducing slipping mortality and improving catch control in purse seine fisheries.

Using bioacoustics and conventional netting methods to assess the initial effectiveness of a newly deployed artificial reef on fish assemblages in Xiangshan Bay near Ningbo, Zhejiang Province, China

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Objectives of the study were ascertaining the temporal variation of fish density and biomass as well as the changes in fish species composition in a surveyed area before and after deployment of an artificial reef. The study was initiated in Xiangshan Bay, Zhejiang Province, China. This survey data was collected through a SIMRAD EY60 system and bottom trinal nets pre- and post-construction of the artificial reefs, May 2011 to September 2012 inXiangshanBay. The raw data were analyzed using fisheries acoustic Echoview (Myriax) software combined with bottom trinal net data. The results showed that estimated fish density, represented by a nautical area scattering coefficient (NASC) at the artificial reef increased by 14.04, 31.10, 17.35% in May, July and September 2012 after construction of the artificial reef, and that the fish biomass increased by 8.92, 29.06, and 18.09% in these three months of 2012 in contrast to 2011. The numbers of fish species varied from 7 to 9 in May, from 10 to 14 in July and from 9 to 12 in September of 2012. These temporal changes in the fishery status were considered as being mainly due to deployment of the artificial reefs in early April 2012.

Acoustic categorization of fish shoals in the Peruvian Sea with multifrequency

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Key words: acoustic categorization, multifrequency, biomass

Use of acoustics to estimate biomass of fish for purpose of fisheries management, in a multi-species ecosystem, requires surveyor experience especially when using one frequency. Now with the application of multifrequency it is possible to have a better identification of species immediately, without taking into account if the aggregations of fish, are scattered, small or large aggregations. The pelagic ecosystem in the Peruvian sea is divided into coastal and oceanic zone. One of the main species of this ecosystem is the anchovy whose biomass in the last 10 years has fluctuated between 1.5 million and 15 million tons. Distribution area of anchovy covers both areas and depends on the seasonal oceanographic conditions or events ENSO (El Niño South Oscillation). Each area has distinct biodiversity, which could confuse their identification in their first stages of life of the Peruvian anchovy with other fish when multifrequency is used. The implementation of a method to identify acoustic categories under the LSSS software support enables to improve the results of the categorization process. Determine whether a school corresponds to a single species or identify it when it is dispersed is becoming a new challenge.

A circumpolar database of mid-trophic organisms in the Southern Ocean ? The Southern Ocean Network of Acoustics.

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Understanding how the Southern Ocean responds to change is a globally relevant issue requiring circumpolar scale analyses. Sustained multidisciplinary observations are required to detect, interpret and predict change. Information on the large scale distribution of mid-trophic levels has lagged behind physical and chemical synopses. The Southern Ocean Network of Acoustics (SONA) aims to address this by implementing a self-sustaining long-term acoustic observation strategy.
Acoustic methods allow the collection of high resolution data on the distribution of mesopelagic organisms over a range of spatio-temporal scales. SONA focuses on geo-referenced calibrated water column backscatter and will address the need for standards and protocols in acoustic sampling programmes and data processing, alongside international efforts by the ICES and Commission for the Conservation of Antarctic Marine Living Resources communities, as well as national systems such as Integrated Marine Observing System (IMOS).
SONA partners representing an existing network of international scientific research and commercial fisheries resources that transit across the Southern Ocean, are signed up through direct data sharing agreements or via parallel data portals such as IMOS. Data will contribute to the Southern Ocean Observing System. Please visit www.sona.aq for more information.

Bayesian Hierarchical Modeling of Uncertainty In Acoustic Estimates for Mysid Density Estimation In the Great Lakes

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Organism abundance can be usefully assessed using hydroacoustic survey sampling. However, the process of converting raw acoustic signals into estimates of density and abundance can be noisy and complicated. Researchers are often faced with several issues: Are the methods we use to calculate mean density and abundance the best that are statistically available? If we are to put effort into increasing sample size or refining estimates, where should we focus our attention? Once we understand the uncertainty associated with a given step in the estimation process, how do we incorporate that uncertainty when characterizing the final estimates? In this paper, we develop a mechanism that uses Bayesian hierarchical modeling to address known sources of uncertainty in the acoustic assessment process. Estimation steps are followed sequentially from Sv to mean density and the estimated variation is carried along through each step in the process. The structure of the analysis facilitates examination of the effects of the various steps on the quality of the final outputs. Acoustic scientists can use this approach to help prioritize their own research and assessment designs. The method is applied to estimating the density of Mysis relicta in the Great Lakes, USA.

Stock assessment of the striped venus clam Chamelea gallina using habitat mapping

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The striped venus clam Chamelea gallina is a small-sized commercial bivalve which is very abundant on the coastal sandy bottoms of the western Adriatic sea. The spatial distribution of this species is strictly related with the sediment texture, gradually changing from the shoreline to offshore as the sediment turn from very fine sand to muddy-sand.
Up to date the stock of this resource has been assessed through systematic fishing surveys based on hauls at increasing depths. However, these surveys do not take into account the variability of sediment type, despite of the strong link between this environmental feature and the recruitment and survival of clams on the seabed.
This paper presents the results of a new interdisciplinary approach to evaluate the striped venus stock based on an integrated analysis of multibeam bathymetric and acoustic backscatter data, grain size information and catch data of clam obtained from dredge survey.
In respect to the traditional methodology this approach provides information of depth and sediment texture which can be used to assess the area of distribution of the striped venus clam allowing, at the same time, to save men work both at sea and in the laboratory to sample and analyze the resource.

Mesopelagic fish biomass and community structure over the mid-continental slope off the South China Sea based upon acoustic and midwater trawl data

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In October 2014, we conducted an acoustic and midwater trawl survey of mesopelagic fish over the continental slope off the South China Sea (CSSCS) based on depth-stratified sampling in an approximately 3600 nmi2 area using a vessel-mounted Simrad EK60 acoustic echo-sounder (38 kHz split-beam transducer) and a midwater trawl (10 mm codend mesh) and estimated biomass and community structure of mesopelagic fish. Mesopelagic fish were mainly distributed in the 200-800 m layer during the day and in the 20-100 m and 350-550 m layers at night. In the 20-100 m layer, Sv during the day was much lower (approximately 8 dB) than at night. Mesopelagic fish always gathered and then moved to surface after sunset. Fish, cephalopods and shrimp accounted for 64.2%, 6.2% and 29.6% (by number) and 70.3%, 19.3% and 10.4% (by wet weight) of catches, respectively. Myctophidae and Gonostomatidae accounted for more than 70% of fish biomass. Based on echo-integration method, our preliminary estimate of mesopelagic fish density ranged from 0.08-0.36 g/m3, with a mean of 0.15 g/m3. Whether the energy released by mesopelagic fish can provide energy for deep-ocean primary productivity is an interesting scientific problem and requires further research.

Evaluation of a Waste Water Discharge Plume Using Scanning Split-Beam and 3D Acoustic Tag Tracking Techniques

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As part of a study to assess the thermal impacts of discharge of waste water effluent, a hydroacoustic monitoring study was combined with a concurrent 3D acoustic tag tracking study. In the spring of 2012, fixed aspect, scanning, split-beam hydroacoustic techniques were applied in the Sacramento River, directly downstream of a treated waste water effluent pipe. Hourly estimates were made of fish density, target strength, and direction of movement utilizing two split-beam hydroacoustic transducers scanning a total of 14 different aiming angles. In addition, 298 Chinook salmon smolts and 99 predatory fish were surgically implanted with acoustic tags and released. An area approximately 100 m upstream and 100 m downstream of the discharge were monitored, and the tagged out-migrating Chinook smolts and tagged predator movements were tracked in 3D. The impact of the discharge plume appeared to have little impact on the Chinook smolts' downstream outmigration. In addition, densities of predators around the discharge pipe were relatively low. Some predation on Chinook smolts was observed, but no predation events occurred in the discharge pipe monitoring area. This was a successful implementation combining fixed location scanning hydroacoustic and 3D acoustic tag tracking techniques.

Quantitative sampling of zooplankton using LED light on a vertical net to confirm echosounder data

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Conventional plankton samplers, such as ring, bongo, and MOCNESS, are efficient in collecting small zooplankton, but are subject to net avoidance by large animals. Recently, a new light-emitting diode (LED)-based strobe light system was developed specifically for use on the MOCNESS by Wiebe and his research group. However, the effect of LED light on a small vertical towing net, such as a NORPAC-net, as yet to be determined. In this study, the number and size-distribution of zooplankton, collected by a vertical net equipped with and without white LED light, were compared. The net samplings were conducted by using an 80-cm-diameter ring net, hauled vertically at 1 m/s. The LED light was attached to a wire in front of the opening ring of the net. The LED light was directed upward along the wire, and flashed at 2.6-s intervals. Concurrent acoustic data were collected with the Simrad EK60 echosounder (operated 38, 120, and 200 kHz). The majority of the collected animals were euphausiids and copepods. The numbers and size of the euphausiids increased when the LED light was flashing compared with the absence of LED light. The changes in the SV, with/without the LED light will also be discussed.

Spatio-Seasonal abundance of Krill (Euphausia pacifica) Using a 2 frequency difference method

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There is a variety of zooplankton and nekton in sound scattering layer distributed in the ocean. It is difficult to estimate the density of the specific target organism because it cannot give any information to discriminate it from a lot of mixed scatters using an only single frequency. Recently, the multi-frequency analysis has been used to apply the species identification among fish and zooplankton in the sound scattering layer using a 2 frequency difference method which is analyzed by volume backscattering strength on the basis of its hydroacoustic backscattering strength characteristics at each frequency. The krill (Euphausia pacifica) plays an important role in ecosystem environment and it blooms in the Korean eastern sea during the summer season. In this study, a multi-frequency, which consists of portable scientific echosounder (EK60-38 and 120kHz) was used to analyze the krill density estimation by the extracted layer of krill using a 2 frequency difference method applied by DWBA acoustical theoretical model, and it also verified biological compositions using the net sampling as well as the patial and temporal distribution in the survey area. The survey area has various size distributions of krill so that it can give feeding biological indicators for fisheries resource assessment.

Cooperative multi-species acoustic surveys in the Aleutian Islands

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The development of multi-species cooperative acoustic surveys in the Aleutian Islands is described. In Alaska, commercial fisheries have been implicated in the slow recovery of the endangered Western stock of Steller sea lions (Eumetopias jubatus; W-SSL). To address this issue the Aleutian Islands walleye pollock (Gadus chalcogrammus; pollock) fishery was closed in 1999. Although the fishery was reopened in 2005 to accommodate an economically struggling Aleutian Island community, W-SSL critical habitat in the Aleutian Islands remained closed to pollock fishing. In 2006 through 2008 Alaska Fisheries Science Center (AFSC) fishery biologists in conjunction with an Alaska Native corporation and local fishers conducted small-scale multi-species cooperative acoustic surveys in the Aleutian Islands. The surveys were meant to provide spatially and temporally relevant estimates of groundfish biomass for setting catch limits inside W-SSL critical habitat. The surveys were designed by the AFSC biologists, but conducted by fishers on board fishing vessels using scientifically calibrated echosounders. Biological data collected from the concurrent fishery were used to characterize acoustic backscatter. This paper discusses the development of these surveys, the technical feasibility of conducting scientific grade surveys aboard fishing vessels, using fishery data to supplement acoustic surveys, and evaluates the uncertainty around the estimates.

Paradigm shift, fishing industry data to management uptake

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In fisheries around the world that have long term access rights, the major asset of a fishing company is typically their quota base. These access rights provide quota owners with the incentives to ensure sustainable utilisation of their assets and to actively participate in the science, assessment and management activities. Industry vessels with modern, calibrated, digital acoustic equipment following systematic scientific sampling protocols provide ideal platforms to gather acoustic data for biomass estimation. Observations from these vessels, which can be at sea for more than 320 days each year, have provided data on spatial and temporal changes that can significantly influence stock assessments. The difficulty of acoustically assessing deepwater species composition and biomass within mixed species aggregations has been addressed with a multi-frequency acoustic system deployed on the headline of a trawl net. This uptake of technology was identified by the New Zealand fishing industry as critical to having world's best scientific practices to inform our sustainable management. Critically the need to reduce the uncertainty in estimates of biomass using industry scientific data has changed the perceived paradigm in orange roughy assessments with management uptake. Future needs and developments of this technology and its application are outlined.

Morphometric and spatial properties of chub mackerel schools and trial comparison of their acoustic biomass and catch using an ES70 echo sounder from a purse seine fishing vessel

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An experimental fishing fleet of a large purse seine for chub mackerel consisted of a main vessel, two light vessels installed an ES70 sounder, and three carrying vessels. Most fishing operations between 13 Sep and 7 Oct 2014 were conducted in the West Sea and off the Jeju Island of South Korea after light vessels attracted mackerel aggregations at dawn. Twenty two fishing operations was confirmed based on echograms showing most parts of the purse seine net during hauling. Fish aggregations in each fishing operation were detected to describe their morphometric and spatial properties. The length and height of most aggregations were approximately 100 m and 13 m respectively. However, extremely large aggregations were found in two operations. The mean distance from the seabed was 88 m, and distributional depth was 5.2 m. Acoustic biomass in each fish operation was calculated using mean volume back-scattering strength and the volume of purse seine net. Acoustic biomass was more than twice higher than the catch. This is the first time acoustic data from a fishing vessel in South Korea has been used, and hopefully, the echo sounders of fishing vessels will be commonly used for better and sustainable fishery resources management.

Comparison among three acoustic systems to find the most efficient way to detect large anadromous fish, Chinese Sturgeon, in the Yangtze River in China

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The Chinese sturgeon, Acipenser sinensis, is a large, endemic and anadromous fish species in the continent shelf of west Pacific and the Yangtze River. The fish spend most of their life span in the ocean but swim upstream to spawn in the middle reach of the Yangtze River (approximately 1700 km from the estuary). The species, which has a huge body size (male: 250 cm and female: 400 cm) and a late maturity age (male ? 8 years and female ? 14 years), is threatened by a variety of anthropogenic activities along its long migration routes. The Gezhouba Dam, which is the first dam from the Yangtze estuary, has blocked the fish's migration since 1981. Thereafter, it is documented that the natural spawning activities of the fish occur immediately below the dam. In this study, three acoustic systems of Simrad EY 60 echosounder, Reson SeaBat T20-P multibeam sonar, and EdgeTech 272-TD scanning sonar were tentatively used to investigate the locations of the fish in 50 km reach right below the dam. The final aim is to find the most efficient way to detect A. sinensis in the enormous range of the Yangtze River.

Acoustic survey of dominant Myctophid fishes off Kyushu, Japan

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Myctophid fishes are the main components of the mesopelagic sound scattering layer, and play a significant role in marine ecosystems off Kyushu Island, one of the important fishing grounds around Japan. Thus, quantitative information of myctophid fishes is important for further understanding of marine ecosystem or for the ecosystem based fisheries management in this area. Field acoustic data and biological samples were obtained in the summer of 2012 and 2013 to estimate the species-specific distribution, biomass, and its difference between these two years. Based on swimbladder or body shape, dominant species were discriminated in echograms by differencing of two acoustic frequencies (38 and 120 kHz). Additionally, the most dominant species Diaphus garmani indicated a possible sexual discrimination by the different rate of swimbladder and non-swimbladder fishes. Habitats of dominant species were separated from each other by different oceanographic conditions in both years, and these distribution patterns also differed between two years. As reported from some areas, our acoustic observation showed that biomass of myctophid fishes was significantly larger than the previous trawling estimates.

Direct assessment of juvenile Atlantic bluefin tuna: integrating sonar and aerial results in support of fishery independent surveys

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Given pronounced shifts in distribution and availability to coastal fisheries, direct assessment approaches for Atlantic bluefin tuna (Thunnus thynnus, ABFT), including formulation of experimental designs and pilot surveys for abundance estimation, are needed. In the western Atlantic, aerial surveys are highly feasible for surface bluefin schools, but individuals at depth and those obstructed by other tuna cannot be documented. Our goals are to design, implement, and analyze a fisheries-independent survey of juvenile ABFT using aerial images gathered simultaneously with sonar data. Aerial imagery provides the horizontal projection of the school, and can identify individuals in the upper few meters, while the sonar data provides information on vertical size of the school and estimate number of individuals not captured in aerial photographs. By integrating acoustic and aerial data estimates of school biomass and other metrics (e.g., sizes of individuals within schools, aggregation behavior) are obtained. Although not without challenges, the analytical techniques developed by integrating these quantitative methods will provide more objective, multi-dimensional information on ABFT schools. Direct assessment also offers a means of tracking shifts in coastal distribution of highly mobile ABFT, especially as traditional indices of abundance may no longer be appropriate.

Modelling Jack mackerel (Trachurus Murphyi) potential habitat off Peru validated throughout industry vessels catch and acoustic data

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Ecosystem modelling is being intensively used for sustainable management. Jack mackerel (Trachurus murphy) is one of the most exploited oceanic species. It has been hypothesized that heavy exploitation in the high seas during past decades conducted to a reduction of the abundance of existing subpopulations in the South Pacific. Recruitment has also been unstable and variable from one year to the next, which negatively impacted the fishery and increased survey costs. An empirical 2D, dynamic and deterministic model has been designed to predict the potential jack mackerel habitat based on satellite oceanography data. The model has been tested since January 2011 and calibrated using catch and acoustics data. Results show a large dispersal of the fish when habitat increases with colder conditions, and inversely density increases when habitat reduces during warmer seasons.

Euphausiids and walleye pollock: comparing the distribution and abundance of predator and prey in the Bering Sea and Gulf of Alaska

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In the Bering Sea and the Gulf of Alaska, euphausiids (?krill', principally Thysanoessa spp.) are a key link between primary producers and higher trophic level predators including marine mammals, seabirds, and fish. In particular, they constitute approximately 30-50% of the diet of walleye pollock (Gadus chalcogrammus), whose stock supports one of the largest commercial fisheries in the world. Using multifrequency acoustic backscatter data (18, 38, 120, and 200 kHz) from acoustic-trawl surveys of walleye pollock and targeted net sampling of euphausiid backscatter, new time series of euphausiid abundance have been created in both the Bering Sea (2004-2012) and the Gulf of Alaska (2003-2013). These data offer a new opportunity to examine the relationship between and abundance trends in euphausiids and walleye pollock in these two systems. Previous work in the seasonally ice-covered Bering Sea has shown that euphausiid abundance was better predicted by water temperature and location than by the abundance of walleye pollock. We constructed similar models of euphausiid abundance using Gulf of Alaska data in order to compare and contrast these two high-latitude ecosystems. We will also discuss how abundance trends from these time series are being used in resource management.

Spatiotemporal analysis of kelp forest distribution characteristics in sea desertification areas using acoustic and direct sensing methods

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Desertification in kelp forests has negative effects on coastal fisheries and ecosystems, especially in northern Japan. Continuous monitoring the current distribution characteristics and changing trends of kelp forests is important for identifying the mechanisms causing desertification. The objective of this study was to evaluate kelp forest thickness, spatial distribution and sea urchin inhabitation using acoustic and direct sensing methods from 2011 to 2013 in coastal waters off Shimokita Peninsula, Aomori. Data on the presence/absence and thickness of kelp forests were collected via acoustic observation on transects using a small quantitative echo sounder. Acoustic data were geostatistically interpolated, the areas covered by kelp forests were estimated using ArcGIS. Separation of kelp forest from other seaweeds and identification of sea urchins were obtained using an underwater camera. Thickness and distribution area decreased from June to November due to harvest, only thickness decreased without harvest due to the withering. And, they were similar with low values in the same season yearly. More sea urchins were observed in barren areas than in kelp forests (mainly Saccharina japonica) and the average size was less than 6 cm. A high density of sea urchins is important reason and small size is considered as factor of desertification.

Development of a simple method for detection of sublittoral seagrass beds using a narrow multi-beam sonar system

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Seagrass meadows play important roles in coastal ecosystems such as nursery, feeding and shelter grounds for many marine organisms. Human non-stop growing population is demanding more and more resources and space, and concentrating in coastal areas. Nowadays, human activities including reclamation and pollution are threatening this important habitat. Therefore, for sustainable development, it is of the most importance to map and monitor the distribution of seagrass meadows in coastal areas, for their conservation. Although several acoustic methods for mapping seagrass beds have been developed, they required complicated processing or spatial interpolation of data. We invented a simple method that can map seagrass meadows in a sublittoral zone with a narrow muti-beam sonar system without interpolation. This method is able to detect seagrass beds based on precise bottom topography of substrates obtained from sounding data with a high spatial resolution. It is a powerful tool for mapping seagarss meadows in sublittoral zones and their conservation.

Marine Ecosystem Acoustics in Untrawlable Habitats to Support Fishery and Ecosystem Management

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Marine ecosystem assessments are most informative when they provide measures of absolute abundance or biomass for key taxa to manage resources for fisheries and other ecosystem services. Unfortunately, there are very few assessment methods that are unbiased or unselective for size or species, or are confounded by habitat types. Acoustic surveys present some advantages over traditional extractive sampling, especially in untrawlable habitats like reef and structured habitats. However, well known challenges remain that hamper our ability to deliver metrics and indicators that can serve fishery and ecosystem management goals. Some of the challenges (e.g., the acoustic ?deadzone', remote species identification) may forever plague our surveys and may never be overcome. We outline an initiative and experimental approach to account for several biases in fishery acoustic (and optical) surveys in coral reefs and similarly complex habitats. Indeed, we also show examples where acoustic surveys can provide insights into the biases of optical survey conducted from unmanned platforms such as towed cameras, remotely operated vehicles and autonomous underwater vehicles. It is likely that pairing of survey technologies and including acoustics will continue to provide the most robust methods for conducting marine ecosystem assessments.

Acoustic-based biomass and suitable habitat estimations for Sargassum horneri in Yamada Bay, Iwate, Japan

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A kind of Sargasso (Sargassum horneri) has attracted attention as a new fishery resource in Japan because it contains high amounts of functional ingredients. Yamada Bay (16 km2), in Iwate, Japan, was seriously damaged by the 2011 tsunami, and there are hopes that sustainable new fishery resources will help in the reconstruction of local industries. To evaluate the potential of sustainable new resources, this study estimated the biomass of S. horneri in Yamada Bay using acoustic data obtained with a 120 kHz quantitative echo sounder in May 2014. The biomass was calculated from area scattering strength and backscattering strength per gram dry weight (?49.6 dB/ g dry wt.). We also estimated the suitable habitat in Yamada Bay using software Maxent with presence data and environmental data. S. horneri occurred on the rope of cultivation-raft of oyster mainly, and the estimated biomass was 1.73 kg wet wt. m-2. The area of suitable habitat was about 10% of Yamada Bay. The habitat was located in the inner part of the bay. These results showed that it is possible to produce high-density S. horneri widely in the bay. S. horneri in Yamada Bay has high potential as a sustainable new fishery resource.

Quantification on Distribution and Supporting Service of Eelgrass beds with Seasonal Variation Using Acoustic Method

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Eelgrass beds have many ecosystem services such as supporting services, including carbon circulation. Quantification of eelgrass beds distribution taken along seasonal variation is important. In this study, objectives were to monitor seasonal variation in eelgrass beds using acoustic method and quantify carbon circulation function widely. Acoustic data of Eelgrass beds was obtained in north and east coastal area near Ikunojima islands, Hiroshima, Japan. Surveys were conducted nine times during 2011 to 2013 for monitoring seasonal variation. Acoustic data were used for estimation of spatial distribution by geostatistical method. Carbon sink and fixation values were used the data reported from National Research Institute of Fisheries and Environment of Inland Sea (2011) to quantify supporting services in survey area. Distribution area of eelgrass beds were maximum in May (average thickness 0.94m±S.D.0.28), and minimum in November (0.58m±S.D.0.09) of each year. Distribution area, carbon sink and fixation of north area were larger than east area of each season. It was considered that the distribution trends are different in survey areas and changed year by year because of bottom topography and wind direction. Widely quantification to supporting services of eelgrass beds would be useful information for conservation of coastal ecosystem.

A geostatistical approach to estimation of mean density and variance from 2004-2014 acoustic abundance surveys of capelin in the Barents Sea

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For continuously sampled relative abundance data as those collected in acoustic surveys, autocorrelative statistical methods such as geostatistics may be useful for estimating the mean and variance of abundance and evaluating survey design. An acoustic survey has been conducted annually in the Barents Sea since 1972 providing a major input to the capelin stock assessment. The fishery takes place before spawning, and the stock is managed to allow for a 95% probability of at least 200 000 tons of capelin escapement. The assessment model is constructed to include the sampling error of the abundance estimate. Currently, however, a fixed coefficient of variation around the survey abundance estimate based on historical acoustic and biological data is used for model input. A geostatistical approach is presented to estimate mean and variance of population density using capelin acoustic data collected at 1 nm resolution. We estimate the mean density and variance for each of the years 2004-2014 to evaluate the spatial sampling error and to monitor how variability in abundance changes between years of high and low capelin stock sizes. We use the results to evaluate sampling design and whether the current assumption of a fixed coefficient of variation is appropriate.

Estimating mortality of a particularly important prey-fish from acoustic surveys

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The lesser sandeel (Ammodytes marinus) is by far the most abundant sandeel species in the North Sea and is an important prey for fish, seabirds and sea mammals, and natural mortalities obtained from a multispecies model reveal that lesser sandeel is living under high predation pressure. Adult individuals are burrowed in the sand most of its life, however, in spring they form large non-migrating schools which feed on zooplankton layers. In the spring, standardized acoustic trawl sandeel surveys have been carried out in the Norwegian zone of the North Sea since 2009, and due to the non-migration behavior it is possible to estimate the total mortality from the age (age 1+) structured abundance estimates. Our analyses show the natural mortality of lesser sandeel seems to be much lower than the natural mortality estimated from the multispecies models. As the commercial sandeel fishing was prohibited in 2009, we managed to isolate the reduction in abundance due to natural mortality which shows that for ages M is around 50% less the previously reported. These acoustic survey results represent the fundament for a new spatial management for sandeel implemented in Norway.

Stock estimation of Limnothrissa miodon in Lake Kivu: assessment of seasonal and spatial variation of fish abundance

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Limnothrissa miodon, deliberately introduced in Lake Kivu in 1959 is the basis of fisheries for people surrounding the lake in the two sharing countries: Rwanda and Congo.
Eight hydroacoustic surveys have been conducted every three months, alternately during the rainy and the dry season to estimate its biomass and assess a seasonal pattern of fish distribution. Only the first and the third surveys provided estimates significantly lower and higher respectively, than the rest of the surveys. No significant variation of biomass has been noticed for six surveys conducted in 2013 and 2014. Fish biomass (kg/ha) was significantly higher in the South compared to the North, East and the West basins without any apparent seasonal pattern. Juveniles were constantly more abundant than adults in the four basins for both seasons, supporting the fact that L.miodon reproduces throughout the year, with no evidence of peaks of reproduction at specific periods of the year. One hydroacoustic survey per year should be enough. The stock of Limnothrissa miodon seems to be reduced compared to earlier estimates. A comparative analysis of the stock, the fishing effort and limnological parameters is needed to demonstrate whether the fish biomass undergoes cyclic fluctuations or any other trend.

Can we trust acoustic survey estimates in single stock and ecosystem assessment?

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Acoustic surveys are conducted worldwide for monitoring the state of large pelagic and semi-demersal fish stocks; such acoustic stock estimates are often used in combination with fishery dependent data in age-structured VPA assessment models. Estimated number of individuals in the landings by age and year are crucial for computing the historical stock development, whereas the scientific surveys are used to tune the models. When comparing converged VPA models with previous assessments, a striking retrospective trend is occasionally revealed, suggesting that the converged assessment output is in conflict with earlier acoustic survey estimates. This conflict is now evident for the large stock of Norwegian spring spawning herring. The retrospective trends dramatically affect the perception of the historical stock development, including ecosystem structure and function. If these converged assessments are acknowledged to accurately reflect the historical stock development, we also accept that the stock levels determined by acoustic survey estimates are quite unreliable. In this study we show that there is no evident reason to accept that the annual herring acoustic surveys should be down weighted in the assessments (indicating that they do not reflect the underlying trends in stock abundance).

Increasing the precision in acoustic estimates of patchy distributed fish

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Acoustic surveys are traditionally carried out along transects, where the nautical area backscattering coefficient is integrated over a distance, providing an estimate of the average density and its variance in the surveyed area. Drawing conclusions about temporal and spatial changes in density can however be difficult if the precision of the estimates is low. As precision is correlated with survey coverage and degree of spatial patchiness in density, it is important to establish a theoretical basis for the effect of patchiness and schooling behavior on the survey reliability. Further, to improve the quality of acoustic survey estimates of schooling species there is a need to establish future survey routines incorporating different acoustic observation technologies. Here, we examine recorded data of the spatial distribution of two schooling species, sandeel and herring, which represent high and low degree of patchiness, respectively. Based on these data we simulate a large range of schooling and density structures, and present a method for estimating the degree of patchiness from echosounder data collected along transects. We estimate the precision in acoustic density estimates as a function of patchiness, and show how the precision is improved when including multi-beam echosounder and sonar data, and adaptive sampling designs.

Fishing vessels as Scientific Platforms: Indicators and Protocols for an Ecosystem Approach to Pelagic Fisheries

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Acoustic data from fishing vessels present a series of advantages and limitation that requires first some specific scientific research from the technical as well as methodological points of view before using them for scientific purposes.
Once validated, the data from fishing vessels provide a unique source of indicators for an ecosystem approach to fisheries. Some examples from results of offshore surveys in Chile on spawning areas and a series of workshops (2011-2014) on acoustic data from the jack mackerel Peruvian fishing fleet are given. Indicators have been extracted on diverse metrics such as geographic distribution and location, the number and morphology of schools; acoustic density; the relationship of schools with oceanographic variables, etc.
The paper discusses the importance of these indicators as contributors for an EAF focused on pelagic fish. They are particularly necessary in a scenario of climate change, where regime shifts are unpredictable. Moreover the implication of fishers can be seen as the interface between the real ecosystems and the virtuality of the models used to explore solutions.

Acoustic biomass estimation of macrozooplankton in the Northern Humboldt Current System (NHCS)

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Macrozooplankton is a key component in marine ecosystems. In the northern Humboldt Current System (NHCS) off Peru macrozooplankton fuels the world biggest fish population. The NHCS also encompasses a shallow oxygen minimum zone which constrains the distribution of marine life. In this work, we used the open source software Echopen to discriminate macrozooplankton echoes and estimate the lower oxycline depth from bi-frequency acoustic data acquired during 13 surveys (6 in summer and 7 in spring) performed along the Peruvian coast. Macrozooplankton biomass was further estimated using geostatistical methods with covariates. Result show that macrozooplankton biomass strongly varied at both inter-annual and seasonal (higher in spring than summer) scales. The results are discussed according to the ecosystem productivity and its vertical structure. In particular we show how the volume and the shape of the surface oxygenated layer impact macrozooplankton abundance and distribution patterns.

Comparing hydroacoustic measurements in large estuaries at two frequencies (70 and 120 kHz).

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While acoustic methods have been used from a long time in various aquatic systems and are increasingly implemented in shallow waters, they do lack effective protocols for sampling fish populations in large estuaries. Before being incorporated into standard procedures, these methods should be field-tested to ensure their accuracy and precision and it is still a challenge. Acoustic data were in situ recorded in two European estuaries, the Gironde (France) and the Zeeschelde (Belgium) at two frequencies, 70 and 120 kHz (SIMRAD EK60). For both estuaries, hydrodynamic conditions in the area are extremely variable and are characterized by a high concentration of suspended matter. The aim of our study is the comparison of acoustic metrics (fish density and fish size distribution) from the two frequencies. Our data show that the metrics obtained from the two devices are similar in most of the case, but in different situations (high fish densities, high currents) it allows to discriminate between biota and abiotic targets. Therefore, the use of different frequencies in large estuaries is necessary.

Using Imaging Sonars to Measure Changes in the Behavior and Distribution of Fishes in the Presence of Unmanned Underwater Vehicles

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Fish surveys in high-relief environments, such as coral reefs or rocky banks, preclude the use of extractive fishing gears, which may be ineffective in rugose environments or degrade sensitive habitat. Direct count visual surveys are assumed to be a ?minimally invasive' alternative to extractive surveys and are conducted from a variety of mobile platforms, including human-occupied submersibles, remote operated vehicles (ROVs), towed imaging systems, and most recently, autonomous underwater vehicles (AUVs). Surveys based on these mobile platforms assume the vehicle does not alter the behavior or distribution of fishes. To test this assumption, we made in situ observations of fish reactions to three unmanned vehicles (ROV, AUV, and a towed camera system) using ultrasonic imaging sonars and stereo video cameras deployed on observation platforms in the Florida Middle Grounds, Gulf of Mexico. A suite of temporally-explicit metrics including abundance, orientation, and instantaneous speed, were developed to measure changes in fish abundance and behavior before, during, and after each vehicle pass. We discuss analytical considerations when measuring behavioral changes with imaging sonars, including the temporal scope of behavioral changes, metric selection, and available statistical methods.

Fishermen spatial behavior and fish acoustic biomass: two sides of the same coin?

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In many fisheries throughout the world, scientific acoustic surveys are key to estimate the spatial distribution and biomass of fish species for fisheries management. However, the campaigns can only be made a few times a year due to the costs they imply. Another approach could be to consider fishermen as 'samplers' or indicators of fish presence. Their spatial behavior could be used for obtaining a proxy of prey presence. But, does it provide the same information than acoustic campaigns? In this work and for the first time, we studied the relationships between fishermen and scientific information for assessing fish spatial distribution. We used Vessel Monitoring System data from the Peruvian purse-seine anchovy (Engraulis ringens) fishery. We analyzed three anchovy fishing seasons where scientific surveys were also performed. We evaluated the strength of the correlation between spatial patterns of both fishermen and acoustic surveys such as the distance to the coast and the covered area. Our findings show a significant and strong correlation in those patterns. This work opens the possibility of using fishermen data for obtaining information on fish spatial distribution for periods when scientific surveys are not performed.

Empirical modelling of density-dependence in spatial distributions with a non-linear geostatistical approach: anchovy and sardine in the Bay of Biscay

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Acoustic surveys provide knowledge on spatial distributions of fish stocks across a large range of spatial scales and survey series demonstrated their variations over time. Among other drivers, density dependence is a major source of variation in spatial distributions as local concentrations change with global abundance. Here we explore more generic models than the ones suggested sofar using a non-linear geostatistical approach. The spatial distributions over time are characterized by a set of thresholds defining classes of values and their corresponding geometrical sets in space. The method of Min/Max Autocorrelation Factors (MAF) was applied on the presence/absence of the geometrical sets. Empirical models using MAFs as factors were developed by year to characterize how classes of values were organized spatially relatively to one another. Such models may mix diffusion and abrupt features in spatial distributions. Applying the procedure over the survey series allowed to understand how classes of values readjusted spatially when population abundance varied. The procedure was applied on the anchovy and sardine acoustic data series in the Bay of Biscay, for which large variations in spatial distribution and abundance occurred since 2000. Results are discussed in light of the aggregative behaviour of the two species across scales.

Geostatistics in support of opportunistically recorded acoustic data: North Sea mackerel as example

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The value of acoustic data recorded on ships of opportunity is increasingly recognised. Often the benefits of access to high resolution data of the water-column outweigh the inevitable compromises associated with the collection of the data. However where possible it is important to assess, quantify and compensate for these compromises. Here we use a time series of mackerel school distribution extracted from multi-frequency acoustic data collected during the annual English part of the North Sea International Bottom Trawl Survey (IBTS). Whilst the data have provided a unique insight into this species' distribution and abundance during the feeding season, one potential limitation of the data is the seemingly haphazard spatial coverage of the data which is far removed from the traditional acoustic survey design. Geostatistic methods were applied to compensate for potential deficiencies in the survey design. Spatial correlation structure was characterized and modelled by fitting variograms. Kriging was used to weigh clustered samples and estimation variances were computed to assess the precision of estimates in areas not well covered by the design. The potential for using the IBTS as a plateform to map and assess mackerel is discussed.

BIPO INAPESCA: Mexico's new marine ecosystems observation platform

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Since 2014, Mexico's National Fishery Institute has a new research vessel in the Pacific conceived to survey the Economic Exclusive Zone. The BIPO INAPESCA is equipped with a scientific sounder with 5 frequencies, fishing sonar, a multibeam sounder, a general purpose sounder, and a sub-bottom profiler. For fishing operations the ship has a set of ITI and PI sensors. Other instruments on board are an ADCP, a CTD, a ROV, and a CUFES pump. With this platform the INAPESCA in association with other national Institutes and Universities will be able to study the more than 2,1 millions of squared km of the Mexican Pacific waters, from an ecosystem perspective collecting a wide range of data, from acoustics, environmental variables, fish eggs and zooplankton, to name a few. In the first year the Baja California peninsula and the Gulf of California have been already surveyed.

Changes in ecosystem acoustics: results from text mining of symposia abstracts

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In this poster I will present the results from text mining analyses of the abstracts of the current and previous ICES acoustic symposia as well as WGFAST working group reports. By creating and comparing lists of the most common words in each symposium and WGFAST reports it will be possible to measure the overall change in breadth and possible shifts in focus in the field of marine ecosystem acoustics. The same analysis will also identify the contribution of WGFAST to the progress in the field. An analysis of the authors will provide means to characterize the structure of the research fellow communities participating in ICES acoustic symposia and WGFAST meetings.

Does paying attention to length distributions produce better acoustic densities?

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During the annual acoustic surveys in the Gulf of Lions (PelMed), opportunistic trawls are located when significant detections are observed. Length distributions are then allocated to each EDSUs by an ad hoc and expert procedure. Length being an important parameter of the computation of an acoustic fish density, we applied a newly developed geostatistical technique to estimate the length distribution anywhere in the study area based on the observed length distribution and on some external driving factors (e.g. depth). This estimation is based on the decomposition of each histogram on a basis of N orthogonal Legendre functions so that each histogram is represented by a set of N coefficients. The method used here consists in cokriging those N-1 coefficients and in using the cokriged estimated coefficients to build the length distribution anywhere in the field. Comparison is made between this new approach and the traditional one. Finally, this also provided interesting ecological information on sardine, anchovy and sprat length-specific spatial distribution, small fish being more coastal in all 3 species.

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