UTILIZING ADVANCED TECHNOLOGY TO CHARACTERIZE AN UNKNOWN PELAGIC ECOSYSTEM

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Abstract: The implementation of the ecosystem approach has increased the use of acoustics during surveys of pelagic organisms. How can data from acoustic sensors be exploited to describe the structure and distributions of aquatic organisms in a new area? A Census of Marine Life survey on the mid-Atlantic ridge during summer 2004 was used as an opportunity to develop a practical approach. The Norwegian vessel, G. O. Sars, is an acoustically-quieted platform equipped with a five-frequency (18 kHz, 38 kHz, 70 kHz, 120 kHz, 200 kHz) echosounder, acoustic Doppler current profilers (ADCP), multibeam sonars, an acoustic deep-towbody, and two remotely operated vehicles. The paucity of information on species composition and acoustic characteristics of aquatic organisms limited the ability to conduct a traditional acoustic biomass survey. Our analytic strategy quantified acoustic structure and dynamics independent of biological sampling and then integrated acoustic characterizations using density and target strength observations with biological community composition and length frequency data. This approach differs from traditional surveys in that species were not assigned to backscatter thresholds or water column regions at the onset of analysis. Near-real-time analytic products were used to monitor biomass distributions throughout the water column: daily echograms, target strength data from the towbody, and frequency-differenced echograms. We observed persistent biological layers at different depths in the water column. Frequency differencing was used to separate biological components within layers. Layers or components of layers migrated toward the surface during dark hours. Modes of target strength frequency distributions and trawl catch compositions differed among layers and through the water column. Conversion of acoustic backscatter to numeric or biomass estimates will be based on functional groups within layers. The use of acoustic and net technologies can be integrated with near-real-time analytic results to quantitatively characterize pelagic ecosystems.

Keywords: acoustics, ecosystem assessment, multifrequency, pelagic
1. INTRODUCTION

There are many areas in the world’s oceans where components or entire ecosystems are poorly known and understood. The Census of Marine Life (CoML) initiative, formalised in 1997, is an international research program designed to assess and explain the diversity, distribution, and abundance of marine organisms throughout the world's oceans (see http://www.coml.org/coml.htm). Responding to the call for exploratory research in oceanic waters, Norwegian scientists developed a collaborative CoML pilot project focusing on macrofauna of the northern mid-Atlantic Ridge (MAR) from Iceland to the Azores. The objective of the Mar-Eco program is “to describe and understand the patterns of distribution, abundance and trophic relationships of the organisms inhabiting the mid-oceanic North Atlantic, and identify and model the ecological processes that cause variability in these patterns.”

This project reflects the philosophy of early oceanographic expeditions and, at the same time, demonstrates the latest sampling approaches and technologies. Early oceanographic expeditions resulted in the 1854 description of the MAR as a potential ‘telegraph plateau’ by Lt. M.F. Maury as it could be used to support a trans-Atlantic telegraph cable. The British Challenger expedition (1872-1876) led by C.W. Thompson and J. Murray was equipped with dedicated scientific sampling instruments and used them to measure depths, temperatures, current velocities, and sample the biology of all the world’s oceans. In a 1910 follow-up expedition led by Murray and J. Hjort, the Norwegian steam ship Michael Sars sampled the depths of the Atlantic from north to south. The 2004 MarEco survey combined a state-of-the-art vessel, the G.O. Sars, equipped with the latest acoustic and net sampling technologies, a suite of specialized sampling equipment, and a crew of international scientists with expertise spanning plankton to marine birds.

The MarEco cruise is a case study of a survey attempting to characterize an entire ecosystem. The goal was to map, count, and identify all constituents of a somewhat unknown ecosystem. Recent international adoption of the ecosystem approach in resource management necessitates the use of new technologies and approaches when taking inventory and interpreting ecosystem components. To fulfil this mandate, both established research programs and new survey efforts will require sampling in an expanded number of trophic levels and an increase in the analyses, integration, and understanding of ecosystems. Given the expansive volumes and diverse terrains of the world’s oceans that require assessment, integration of current and developing remote sensing technologies with traditional direct sampling techniques is expected to increase. The goal of the fisheries acoustics group during the first leg of the MarEco cruise was to use available technologies and analytic tools aboard the G.O. Sars to efficiently sample nekton in waters above the mid-Atlantic Ridge without knowing the composition and associated behaviour of constituent nekton species. This paper reports the approach and current results of that effort.

2. METHODS

Numerous remote and direct sampling technologies were utilized on the G.O. Sars during the first leg (June 6 – July 2) of the Mar-Eco cruise. Acoustic data was continuously collected since leaving Bergen Harbour. A five-frequency (18 kHz, 38 kHz, 70 kHz, 120 kHz, 200 kHz), splitbeam echosounder (Simrad EK-60) was synchronized with an acoustic
Doppler current profiler (ADCP, RDI ocean surveyor) and a multibeam sonar (Simrad EM300). Pulse interval rate of the acoustic equipment was set above 4 seconds to allow time for echoes to return from depth and to minimize interference.

At 18 pre-determined stations, the water column was sampled to a depth of 3000 m using a variety of instruments. Due to time constraints, stations were divided into short or long stations. At ‘short’ stations, a CTD/ADCP rosette, an Underwater Video Profiler (UVP), and macrozooplankton and pelagic trawls were deployed. Long sampling stations added a multinet to sample smaller zooplankton (180 μm mesh size).

Prior to or at the conclusion of sampling at each station, acoustic backscatter (i.e. target strength) from individual animals within scattering layers was measured using a deep towbody equipped with 38 kHz and 120 kHz EK-60 echosounders. The towbody was lowered to within 1000 m of the bottom or to a depth below the lowest observed scattering layer when no deep targets were present. At the deepest depth, the acoustic sampling range was set to 1000 m or 250 m depending on the presence of acoustically visible targets on the vessel-mounted, 18 kHz echogram. Pulse repetition rate was set at 0.7 seconds. Pulse duration was set at 512 μs to increase the ability to resolve individual targets. Depth, pitch, and roll of the tow body were monitored and recorded for the duration of each deployment. Data dropouts occurred at random due to cable length.

Midwater trawls were conducted at each station. An Åkra midwater trawl with three independently operated codends was used as the primary trawl gear. A timer was programmed to open and close each codend at specific depths prior to setting the net. Fishing depth was monitored using Scanmar net monitoring equipment, specially modified to operate to 3,000 m. Live specimens were caught in a metal aquarium that was fitted to one of the codends. Catches from all codends were sorted to species, if possible, individually catalogued, and then frozen. Additional tissue or whole samples were preserved for genetic or diet studies.

To obtain visual confirmation of acoustic targets and to inspect deployment locations of other acoustic instrument deployments, the remote operated vehicle (i.e. ROV) Aglantha was used to inspect backscattering layers during two dives. Light supplemented video was monitored and recorded during descent to and ascent from the bottom. The vessel’s 18 kHz echosounder collected data during ROV deployments.

2.1. Analytic Approach

The paucity of information on acoustic characteristics of pelagic organisms within the MAR limited the ability to conduct a traditional acoustic biomass survey. As an alternative, we used backscatter patterns to guide our analyses. Our strategy was to quantify the acoustic structure independent of biological sampling and then to integrate relative density and acoustic size (i.e. target strength) data with biological community composition and length frequency data to estimate biomass. This integrated ecosystem approach differs from a traditional acoustic survey in that species or species groups were not arbitrarily assigned to backscatter thresholds or water column regions at the onset of analysis.

A combination of data types were used in the integrated analysis:

Daily echograms: We compiled 18 kHz, 38 kHz, and 120 kHz echograms for each 24 hour period beginning at midnight UTC. These echograms were used to observe spatial and temporal patterns within diel cycles. Initial inspection of the echograms revealed two consistent features: backscatter concentrations in layers whose intensity depended on frequency, and movement of whole or partial layers at night to surface water with subsequent
stacking or mixing of layers at pre-dawn. These initial observations were used to further structure our monitoring, near-real time data visualizations, and analyses.

**Target strength data:** The deep towbody was deployed at the start or end of each station to collect target strength data at ranges shorter than those from vessel mounted transducers. This geo-referenced data stream is matched to the vessel echogram to identify membership of individual target strengths within backscattering layers.

**Frequency response:** Frequency-dependent backscatter among layers was used to characterize and potentially separate species assemblages within layers [1,2]. A one half hour test data set was initially used to examine backscatter characteristics of each layer. Potential metrics that could be used to identify, characterize, and discriminate backscatter layers were examined. Sv frequency-differenced and TS frequency-differenced echograms were produced for each combination of the five frequencies. Variance among groups of three frequency data channels was also investigated as a summary metric. All combinations of frequency pairs were used to produce Sv differenced echograms for the test data set. Results of this analysis were compared to and used as a guide to form backscatter categories.

**Identifying acoustic backscattering layers:** Data on species identifications, community diversity, species-specific length frequencies, and locations in the water column were used to ‘convert’ acoustic layers to biological layers. Initial classification of all echograms will be performed using KORONA, a software package being developed to classify echograms based on backscatter characteristics. Once each layer has been classified and associated with its biological constituents, a numeric or biomass estimate can be calculated using the data. It is anticipated that acoustic layers will be composed of functional species groups that contribute to observed backscatter.

**Integrating results:** Having translated acoustic to biological layers, the final step in the analysis will compare biological distribution patterns to coincident environmental conditions. Potential physical variables include: temperature, salinity, fluid dynamics, light intensity, and weather conditions. Explicit temporal variables to be considered include time of day and lunar cycle.

3. **RESULTS**

One of the first products produced during analyses of acoustic data was a daily echogram for the 18 kHz and 38 kHz data (Fig. 1).

*Fig. 1. Daily echogram for June 9, 2004 at 38 kHz showing biological backscattering layers and layer migration. Echogram spans approximately 21:00 to 05:00 local time.*
An initial striking feature that remained constant throughout the survey was the presence of biological layers. Dense biological backscattering layers occurred from the surface to a depth of approximately 800 m. Additional layers occurred between 1000 m and 2000 m depth. Backscatter intensities differed among and within layers with Sv values ranging from –75 dB to –50 dB. A regular diel migration was observed in layers above 700 m with all or components of layers migrating toward surface starting approximately one hour prior to local sunset and a downward migration that started one hour before local sunrise. Isolated layers would complete a migration of over 300 m in both directions during the cycle.

Mean volume backscatter differencing, the difference in backscatter intensity between pairs of frequencies, was used to identify layer components. Since the intensity of reflected sound is dependent on the size, orientation, and composition of targets within a layer, we expected to see contrasts among observed layers and among frequency pairs. Depending on how your eye draws boundaries, there are six or seven layers with different backscatter intensities in the test data set above 400 m (Fig. 2). Differences in backscatter intensities between frequency pairs exceeded a maximum of 20 dB. A positive or negative value only depends on the order of frequencies used.

Fig. 2. Echograms illustrate frequency-dependent backscatter (Sv) characteristics among layers: 38-18 kHz (left), 120-18 kHz (middle), 120-38 kHz (right).

Data from the echosounder mounted on the towbody showed a distribution of single targets throughout the water column (Fig. 3). The towbody had a tendency to ride nose-up while being towed at depths greater than 500 m, which may bias conversion of target acoustic sizes to organism lengths due to animal orientation relative to the incident sound wave.

Animals observed in video streams from the ROV did not match those caught in either the macrozooplankton or Åkra midwater trawls. The 18 kHz echograms from the vessel showed disturbance and or avoidance of the ROV and cable by aquatic organisms during both descent and ascent to the surface. Disturbance was greater during ascent compared to that observed during descent. Based on the avoidance observed in vessel echograms, the ROV was used to confirm identity and relative densities of acoustic targets.
Acoustically labelling layers and layer components is the next analytic step. Characteristic reference areas in echograms at each frequency are used to classify and discriminate observed layers. Based on frequency-dependent backscatter, the frequency response, each pixel in an echogram is then placed in one of the categories or classified as unknown. At this time, choosing the number of discriminators and identifying when categories are different is an ad hoc process. Categories are easy to define when the biological constituents are few, known, differ in acoustic scattering characteristics, and are physically separated in the water column. We are finding that the process of identifying distinct regions to be used as discriminators within and among layers is a challenge. This process is currently underway and the choice of echogram regions that will be used as final discriminators will be supplemented with depth-specific trawl catch data before final pixel classification is completed.

4. DISCUSSION

Fundamental differences exist between historical expeditions and the MarEco cruise: the shift from a point sampling to a continuous sampling survey design, the amount of data collected, the ability to process some data streams in real time, and the potential for quantitative assessment. The use of scientific echosounders as the primary survey instrument allows a continuous view of biomass throughout the water column. Direct sampling gears are no longer required to be spaced at regular intervals, or aligned to physical gradients such as depth, temperature, or salinity. Direct sampling gears are now coordinated with acoustic measurements to verify species compositions and to obtain length frequency samples. At times on the cruise the two philosophies used to direct net samples conflicted. Taxonomists wanted to maintain regular depth intervals for net samples throughout the cruise while the acousticians wanted to design trawl samples relative to distinct backscattering layers that may migrate or vary in intensity depending on the time of day and latitude.

The amount of acoustic data collected by the echosounders on the first leg of the cruise represents orders of magnitude change in data volume compared to earlier mid-Atlantic ridge expeditions. Even the integration of three additional frequencies in a single echosounder represents a technological advancement over a traditional two (38 kHz and 120 kHz) frequency echosounder used during fishery acoustics assessment surveys. To emphasize the point, a special version of the processing software, Echoview (Sonardata Ltd, Hobart, Australia), used to visualize and analyze backscatter data had to be revised to accommodate
five simultaneous frequencies. A 100 megabyte raw data file contains fewer than 300 echo returns (i.e. pings) at a depth range of 3500 m and spans only 30 minutes. Total acoustic data volume from only the echosounder amounted to 126 gigabytes of data for the first leg of the cruise.

Despite large data volumes, the availability of network servers, laptop computers, and current software applications meant that all acoustic data could be viewed and quantified in near real time. Our initial goal was not to count all organisms encountered but to describe the distribution and dynamics of biomass in the water column. When the cruise started, we were not sure what we would observe nor how consistent the patterns would be over space or time. Visualization of data acquired early in the cruise was used to formulate our analytic approach. The resulting procedure facilitated the identification of ecosystem components and aids in the understanding of interactions among trophic levels and with the environment.

Analyses of acoustic data to date revealed that biological backscattering layers in the water column were present and persistent over the entire region, that there was observable structure within backscattering layers, and that layers or portions of layers undergo diel migrations. We observed frequency-dependent backscatter within and among layers and hope to exploit these differences in combination with trawl catch data to label layers. Additional acoustic data from the towbody, catch data, and optical data from the underwater video profiler (UVP) will be used to isolate size classes or even species within and among backscattering layers.

The MarEco cruise is a poignant example of what is possible and what is still not possible with today’s sampling technologies. Integrated acoustic systems facilitate real time observation and measurement of nektonic biomass from near surface to almost 4000 m depth. Synchronization with other instruments permits simultaneous collection of water movement, temperature, and salinity data. Analytic tools combined with rapid computer processing enable ongoing interpretation of data and provide current information when deciding where, when, and what equipment to use at sampling stations. These analyses may also be used to add opportunistic samples that exploit unusual or extraordinary conditions observed underway. Current net technologies permit monitoring of multiple, discrete samples that are collected during a single deployment. Catches from discrete depths are critical when identifying constituents of backscattering layers. Attaching an ‘aquarium’ to one of the midwater trawl codends also enabled the capture and transport of live fish to the surface from 3000 m depth. Some taxonomic groups such as cephalopods were not acoustically detectable by our acoustic equipment. We do not know if this was due to low animal densities or due to weak acoustic detection by our instruments. Sperm whales and other cetaceans are capable of detecting squid using sound but given that cephalopods do not contain gas-bearing organs, we do not expect large echo intensities from any single squid.

Can the nekton of a deep ocean, pelagic ecosystem be characterized? Our initial analyses describe spatial and temporal distributions of what we believe are distinct components of the ecosystem. At this time, we do not know how identified backscatter components interact with others or how energy is transferred among components. Acoustic data collected during the cruise was extensive but cannot be used in isolation to identify and describe interactions among species groups that make up ecosystem components. Integrating data streams across instruments requires explicit examination of sampling resolutions and ranges to ensure that measurements from different sources are comparable. We expect that the combination of data streams with analytic techniques will increase our understanding of nekton in the mid-Atlantic Ridge ecosystem. We also believe that the general approach used to evaluate this system will evolve to a generic method when using an ecosystem approach to resource management.
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REFERENCES
