An ACT 2003 Workshop Report

A Workshop of Developers, Deliverers, and Users of Technologies for Monitoring Coastal Environments:

Developing Acoustic Methods for Surveying Groundfish

Rockport, Maine
February 26-28, 2003

Sponsored by the Alliance for Coastal Technologies (ACT) and NOAA's Center for Coastal Ocean Research in the National Ocean Service.

Hosted by the Gulf of Maine Ocean Observing System (GoMOOS).

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ACT WORKSHOP: DEVELOPING ACOUSTIC METHODS FOR SURVEYING GROUNDFISH

EXECUTIVE SUMMARY

The Alliance for Coastal Technologies (ACT) Workshop "Developing Acoustic Methods for Surveying Groundfish" was convened at Rockport, Maine, February 26-28, 2003, with sponsorship by the Gulf of Maine Ocean Observing System (GoMOOS), an ACT partner organization.

The goals of the workshop were: (1) to advance understanding of operational survey applications of acoustics for estimating fish stock abundance, (2) to gain acceptance and support for the broad application of acoustic survey techniques in coastal waters, and (3) to define specific mechanisms, funding requirements, and research priorities to foster the development and application of acoustic methods to benefit coastal fisheries.

To achieve these goals, representatives of four different activities were invited to participate. These included researchers with working experience in operational acoustic surveying techniques, fishery managers, fishermen, and sonar and sonar-related manufacturers. Working groups were convened within the workshop to address the use of acoustics in groundfish stock assessment, the application of acoustics, limitations of acoustic methods, and remedies for these.

Four general recommendations were made:

- Further develop acoustic methods for application to groundfish surveying.
- Encourage education and training on Fisheries acoustic methods.
- Examine existing data including acoustic, physical capture and fishery derived data for new or changing applications of acoustic surveying to groundfish.
- Prepare specifications for the sonar and sonar-related manufacturers to adapt or develop commercial fishery echo sounder systems to enable commercial fishing vessels to contribute useful quantitative data on groundfish.

Three additional recommendations were directed to ACT with its resources of both organizational and technological resources:

- Increase awareness of the potential of acoustic methods for groundfish surveying.

- Disseminate current information on acoustic methods for surveying groundfish and keep the community informed through a website.

- Form a subcommittee to draft performance specifications for acoustic systems to be used in groundfish surveying.

In summary, the participants at the workshop agreed that acoustic methods are credible sources of information for groundfish stock assessments. At the same time, the methods can provide much new information about groundfish biology: geographical distribution, behavior, movements, and association with bottom habitat types and other organisms. There are resources available nationally for developing acoustic methods. These consist of on-going acoustic survey programs at NMFS, research vessels carrying scientific echo sounders, echo-data postprocessing systems in routine use, fishing vessels that can serve as platforms of opportunity, formal programs for engaging fishermen in research, acoustic calibration techniques and facilities, research and operational expertise, sonar manufacturers, and the Alliance for Coastal Technologies. Through partnerships of the research community, fishery managers, fishermen and sonar and sonar-related manufacturers, acoustic methods can be refined and adapted for much wider use in surveying groundfish resources.

ALLIANCE FOR COASTAL TECHNOLOGIES

There is widespread agreement that an Integrated Ocean Observing System is required to meet a wide range of the Nation's marine product and information service needs. There also is consensus that the successful implementation of the IOOS will require parallel efforts in instrument development and validation and improvements to technology so that promising new technology will be available to make the transition from research/ development to operational status when needed. Thus, the Alliance for Coastal Technologies (ACT) was established as a NOAA-funded partnership of research institutions, state and regional resource managers, and private sector companies interested in developing and applying sensor and sensor platform technologies for monitoring and studying coastal systems. ACT has been designed to serve as:

- An unbiased, third-party testbed for evaluating new and developing coastal sensor and sensor platform technologies,

- A comprehensive data and information clearinghouse on coastal technologies, and

- A forum for capacity building through a series of annual workshops and seminars on specific technologies or topics.

The ACT workshops are designed to aid resource managers, coastal scientists, and private sector companies by identifying and discussing the current status, standardization, potential advancements, and obstacles in the development and use of new sensors and sensor platforms for monitoring and predicting the state of coastal waters. The workshop goals are to both help build consensus on the steps needed to develop useful tools while also facilitating the critical communications between the various groups of technology developers, manufacturers, and users.

ACT is committed to exploring the application of new technologies for monitoring coastal ecosystem and studying environmental stressors that are increasingly prevalent worldwide. For more information, please visit www.actonline.ws.

ACT Headquarters is located at the UMCES Chesapeake Biological Laboratory and is staffed by a Director, Chief Scientist, and several support personnel. There are currently seven ACT Partner Institutions around the country with sensor technology expertise, and that represent a broad range of environmental conditions for testing. The ACT Stakeholder Council is comprised of resource managers and industry representatives who ensure that ACT focuses on service-oriented activities. Finally, a larger body of Alliance Members has been created to provide advice to ACT and will be kept abreast of ACT activities.

GOALS FOR THE ACOUSTIC WORKSHOP

The ACT workshop on developing acoustic methods for surveying groundfish was convened February 26-28, 2003 in Rockland, Maine. The workshop addressed three goals:

(1) To advance understanding of operational survey applications of acoustics for estimating fish stock abundance,

(2) To gain acceptance and support for the broad application of acoustic survey techniques in coastal waters, and

(3) To define specific mechanisms, funding requirements, and research priorities to foster the development and application of acoustic methods to benefit coastal fisheries.

ORGANIZATION OF THE WORKSHOP

The workshop was sponsored by ACT and hosted by the Gulf of Maine Ocean Observing System (GoMOOS), one of ACT's Partner Institutions. The acoustic workshop was convened by Kenneth Foote at Woods Hole Oceanographic Institution in Woods Hole, Massachusetts and Thor Lassen of Ocean Trust in Arlington, Virginia with the support of GoMOOS and ACT. Kenneth Foote, Thor Lassen, and Philip Bogden and Josie Quintrell from GoMOOS served as facilitators for the workshop and breakout discussion sessions. Orientations on GoMOOS and ACT were given by Philip Bodgen and Mario Tamburri, respectively, on the first evening.

Workshop participants (Appendix 1) included researchers versed in operational acoustic surveying, federal and state stock assessment scientists who participate in groundfish management, sonar and sonar-related manufacturers, and groundfish industry members.

Plenary presentations on the use of acoustic groundfish surveys were given in the morning of the second day by George Rose from Memorial University of Newfoundland, Kenneth Foote and Bill Michaels from the Northeast Fisheries Science Center, and Bill Karp from the Alaska Fisheries Science Center. In the evening, John Boreman, Deputy and Acting Science and Research Director of the Northeast Fisheries Science Center, spoke on the subject of the vision of NOAA Fisheries for acoustic sampling. He placed this in the broader context of the need to upgrade fish surveying techniques. On the third day, the representatives of the sonar and sonar-related manufacturers described their acoustic instruments that are being used or could be adapted for surveying groundfish.

Working group discussions focused on four subjects:

(1) Evaluation of acoustic methodologies for operational survey applications,

(2) Echo sounding and sonar technology for operational surveys,

(3) Management questions and potential uses of acoustic survey data, and

(4) Challenges and priorities for establishing broad acoustic surveys of fish stocks.

OVERVIEW OF ACOUSTIC METHODS AND TECHNOLOGY

Acoustics has been used to observe fish underwater since at least 1935, when the Norwegian scientist Oscar Sund reported observing echoes from cod in Vestfjorden near Lofoten in northern Norway. Following the Second World War scientists began conducting experiments to determine fish target strength, which led to development of quantitative methods to measure fish density in the 1960s, specifically to the echo counting and echo integration methods described below.

The rationale for developing and using acoustic methods is to increase knowledge of groundfish stocks. The methods and technology of surveying fish accessible by acoustic beams, including groundfish in the semi-pelagic state, are presented under the following headings: objectives of operational surveying, basic acoustic methods, key issues, limitations, recent developments, and national resources.

Objectives of Operational Acoustic Surveying

Five objectives of operational acoustic surveying are enumerated here, beginning with the elemental acoustic measurement and concluding with the search for associations of echo data with the bottom topography.

(1) *Measurement of numerical density of fish concentration.* The primary measurement is that of acoustic density in the sampled volume. The concentration of the target fish can be quantified, if sufficient information exists for separating the resulting numerical measures into those due to the target fish, i.e. signal, and those due to other scatterers; i.e., noise. Further knowledge is required to convert an acoustic value to a biological or physical measure of fish concentration.

(2) *Description of geographic distribution.* The geographic distribution of target fish or other organisms can be mapped through the basic acoustic measurements, as taxonomically classified.

(3) *Abundance estimation.* Estimates of abundance can be produced by integrating values of density over an area or throughout a volume, depending on whether the density is expressed per unit surface area or per unit volume, respectively. This is often expressed as the total number or mass of target fish, further distinguished by size or age group.

(4) *Observation of behavior.* In addition to the mentioned quantitative application of acoustics, observation of behavior is often a goal of surveying. Examples of behavior that can be quantified are position in the water column, diurnal vertical movements, and seasonal horizontal migration.

(5) *Association of water-column distribution with bottom topography.* In the case of groundfish especially, the defining behavioral orientation is to the bottom. Association of the distribution with bottom features, for example, depth, roughness, and particular features, can be very useful for distinguishing different kinds of groundfish when in a semipelagic state.

Fish as Acoustic Targets

The accessibility of various fish species to acoustic surveying has been considered in designing surveys both in terms of fish behavior (e.g., diurnal vertical migration of cod) and acoustic detection of swimbladders. The presence of a gas-filled swimbladder is generally very significant. Among pelagic species, the swimbladdered Atlantic herring is a superior acoustic target to the swimbladderless Atlantic mackerel and to squids. Among epipelagic species, pollock, redfish, scup, and silver hake, which possess swimbladders, are superior acoustic targets to spiny dogfish, which lacks a swimbladder. Similarly, the swimbladdered groundfish species of Atlantic cod, haddock, red hake, white hake, and walleye pollock, are more easily detected in comparison with the swimbladderless flounders and skates.

Basic Acoustic Methods

Transducer. The heart of any acoustic system is the transducer. By definition, this device converts one form of energy to another and vice versa. In the case of transducers used underwater, one of the most common transducing mechanisms is that of piezoelectricity. Accordingly, a pressure wave incident on the transducing material generates a voltage, and application of a voltage across the material generates a change in shape, launching an acoustic, or pressure, wave into the water.

Scientific echo sounder. Electronics are designed specifically to control the transmission and reception of pressure or acoustic waves in water. To launch an acoustic wave, transmitter electronics are designed to control the electrical excitation of the transducer in a very particular way. Similarly, electronics are designed to sense and register the voltage induced in a transducer by the incident acoustic wave. The combined package of transmitting and receiving electronics is called an echo sounder. When the various processes are sufficiently controlled or precise so that the echo sounder can be calibrated and the received signal can be processed quantitatively, the electronics package is called a scientific echo sounder. The calibration can be accomplished, for example, by means of a standard target of known acoustic target strength.

Commercial fishery echo sounder. While scientific echo sounders may be used on board commercial fishing vessels, and sometimes are, their expense for this purpose is often prohibitive. Echo sounders with much simpler assemblies of electronics are designed specifically for use on board fishing boats. Often, the sole output is a non-quantitative video signal that is displayed on a color screen. Such a commercial fishery echo sounder cannot be calibrated, hence cannot be used for ordinary scientific work.

Echogram. Data derived from an echo sounder are most simply visualized in the form of an echogram. This is a two-dimensional display in which the echo resulting from a single ping is displayed along a single line, with the signal amplitude or intensity indicated by the degree of darkening or color-coding at a displacement corresponding to the respective echo range. Echoes due to successive pings are aligned. With vertically oriented, hull-mounted transducers, the echo range corresponds to depth.

Echo counting. Echoes can be counted when the targets are sufficiently dispersed in space. By dividing the number of echo counts in a given region of the echogram by the sampling volume, a measure of target density is derived.

Echo integration. For the general situation of arbitrary density, as with a school of fish, individual target echoes may not be resolvable. In this case, the echo voltage, after detection and application of suitable range compensation, is squared and summed over a defined interval. The resulting quantity is proportional to the area backscattering coefficient. Division of this by the characteristic backscattering cross section for the target fish yields the numerical density.

Postprocessing echo sounder data. Acoustic data are generally voluminous. Echo data collected with a narrowband echo sounder at a single frequency with 0.1-m resolution over a 500-m range interval at 1 ping/s will generate data at the rate of 72 Mbyte/hour, assuming that each echo datum is represented by two bytes. Processing such data can be overwhelming without the aid of postprocessing software. This is generally available in the form of commercial software packages. It is remarked that all important decisions regarding the quality and allocation of the echo record are taken by the operator in an interactive mode. Typical operations performed with the postprocessing system include correcting for false bottom detections, assigning echo features to scatterer classes, e.g., targets and non-targets, recomputation of values of the area backscattering coefficient, and storing values of the coefficient in a database with high resolution in depth and sailed distance.

Other sonar types. In addition to echo sounders, other sonars are in use that could be adapted to quantitative fish-surveying. These sonar types include mechanically scanned sonar, sidescan sonar, interferometric sidescan sonar, multibeam sonar, Doppler sonar, acoustic Doppler profiler (ADP), and acoustic Doppler velocity profiler (ADVP).

Important Measurement and Operational Issues

The two key measurement issues in the acoustic quantification of fish are target strength and fish behavior. Target strength is defined as a logarithmic measure of backscattering cross section. Target strength depends on species, size, shape, biological condition, orientation, and sonar frequency. Its *in-situ* measurement and modeling present constant challenges to the researcher. Fish behavior, or how the fish is moving and orienting itself, or reacting to the passage of the transducer-bearing platform (e.g., research vessel) is also of concern in acoustic surveys.

Another key issue in measuring groundfish is resolution of fish echoes near to the bottom. These are generally powerful, dominating echoes from the individual fish that are near the bottom, but because of their oblique position relative to the acoustic axis of the sensing transducer, lie at greater range than the bottom.

Other important, operational issues in the acoustic surveying of groundfish stocks are: (1) survey design, including determination of transect spacing and issues of sampling variability; (2) availability of fish to acoustic sensing, with proper allowance made for vertical diurnal migrations, seasonal migrations, other migratory behavior, and vessel-avoidance effects; (3) biological sampling, principally by trawling; (4) calibration of the scientific instruments, but also including standardization of trawling protocols; and (5) acoustic instrument performance, especially as gauged by stability, dynamic range, and signal-to-noise ratio.

Recent Developments

A number of recent developments are addressing outstanding issues. These include special studies of target strength and fish behavior, collection of data at multiple frequencies, removal of noise from echograms, observation of fish near to the bottom with a towed transducer, application of multibeam sonar to fish quantification, and bottom-habitat characterization. Advances in multibeam sonar calibration are rendering this sonar useable in fish surveying. A number of measures are being taken to deal with noise-quieting of vessels, calibration, and stability in performance of the acoustic instruments, and the use of fishing boats as auxiliary sources of echo sounder data. In the case of target strength, measurement methods developed in the late 1970s and 1980s are steadily being applied to improve specification of the characteristic fish size-target strength relationship used to convert echo integrator data to biological-physical measures of fish density.

Future directions under consideration to improve acoustic-trawl survey work include: (1) multiple-frequency and broadband acoustic systems use in remote classification of fish, including determinations of both species and size; (2) alternative platforms to extend the overall sampling power of surveys; (3) use of multibeam sonar systems in an exploratory manner in an attempt to increase the acoustic sampling volume; (4) research to evaluate the potential for using other advanced-technology tools, such as light detection and ranging (LIDAR) systems and laser line scan (LLS) systems for survey assessment and, potentially, developing approaches which combine acoustics with these approaches; (5) collection of acoustic data by commercial fishing vessels equipped with uncalibrated echo sounders as well as future plans to include calibration of these systems and incorporation of their collected data in the overall stock assessment of eastern Bering Sea pollock; and (6) opportunistic studies on walleye pollock to determine the geographical distribution of the stock.

National Resources – A number of resources exist that may be drawn upon in developing acoustic methods for surveying groundfish. These include on-going acoustic survey programs at NMFS, research vessels carrying scientific echo sounders, echo-data postprocessing systems that are in routine use, fishing vessels available as platforms of opportunity, research programs engaging fishermen, acoustic calibration techniques and facilities, research and operational expertise, sonar manufacturing businesses, and the Alliance for Coastal Technologies, with its organizational and electronic communication resources.

ACOUSTIC SURVEYING IN GROUNDFISH STOCK MANAGEMENT

Exclusive Economic Zone (EEZ) Acoustic Surveys

While echograms often take very different forms, depending on the fish species, behavior, and location, they are used in the management of many groundfish stocks in Norway for Atlantic cod, haddock, pollock, redfish; in the U.S. for walleye pollock, Pacific hake; in New Zealand for hoki, orange roughy, southern blue whiting; in Australia for orange roughy; and in Canada for Atlantic cod, Pacific hake, rockfishes (*Sebastes* spp.). For example, indices of New Zealand hoki (*Macruronus novaezelandiae*) abundance are derived from acoustic data collected during the spawning period and used with indices derived from catch-per-unit-effort (CPUE) data and trawl surveys conducted outside of the spawning period to estimate the stock biomass. Distributions of raw age and length data derived on the basis of trawl data are used in the interpretation and analysis of acoustic data in order to estimate the overall biomass of the spawning stock.

A series of echo registrations can illustrate fish behavior like those from the 1992 big school of northern cod in Canada (Fig. 1), which show the aggregation evolving from a school-like form to one of increasing dispersion, where individuals are migrating 20-25 miles per day. Some acoustic discrimination of size is possible to within a doubling in length, but not to the desired 4-cm resolution for mature animals. Scientists are now studying characteristic formations labeled "spawning columns" (Fig. 2), where details of a single column in high resolution can show individual fish.

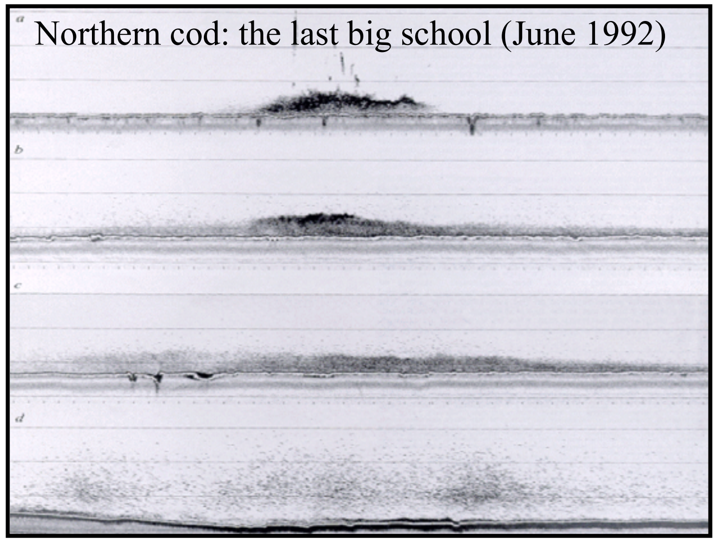

Figure 1. Echogram of northern cod on Grand Bank: the last big school

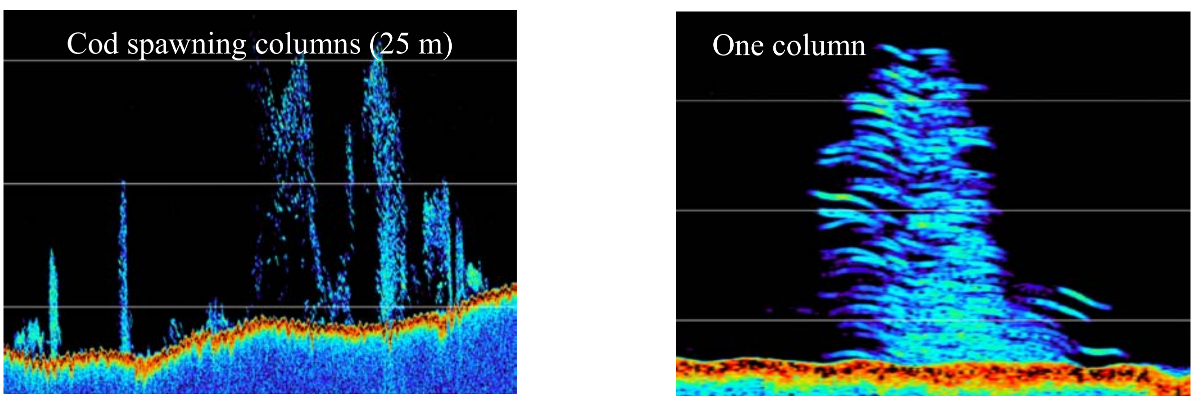

Figure 2. Cod spawning columns (25 m) & high resolution detail of one column

<u>Northwest and Alaska U.S. EEZ Acoustic Surveys</u>

Two major groundfish species in the northeast Pacific, walleye pollock (*Theragra chalcogramma*) and Pacific hake (*Meluccius productus*), are being assessed in part by means of combined acoustic-trawl surveys that sense the pelagic components. Throughout the year, the water-column distribution of walleye pollock is semi-pelagic, rendering the pelagic portion accessible to acoustics. Combined acoustic-trawl surveys of walleye pollock are performed in Shelikof Strait with 7.5-nautical-mile (n.mi.) spacing and in the eastern Bering Sea with 20-n.mi. spacing. The latter surveys were formerly performed triennially; they are currently performed on a biennial cycle. Surveys of the eastern Bering Sea within the US EEZ are performed during a two-month period in the summer; bottom trawl surveys are carried out in the same region to assess the demersal portion of the pollock stock and several other commercially important species. The Bogoslof area is also surveyed each winter. Combined acoustic-trawl assessments of the pelagic portion of this Pacific hake population have been performed triennially by the U.S. since 1977 in conjunction with triennial bottom trawl surveys.

The stock assessment process involves integrating fishery-dependent data from observers, logbooks, and other sources with fishery-independent data derived from bottom trawl surveys, and combined acoustic-trawl surveys, in order to assess the size and age-size composition of the stock. The combined acoustic-trawl surveys may also be viewed as a process (Fig. 3). The method of echo integration is applied to echo sounder data collected along survey-vessel tracklines that are typically regularly spaced, parallel, oriented orthogonally to the isobaths, and span the limits of the distribution from inshore to offshore waters. The combined echo sounder and echo integrator system is calibrated in an absolute sense by the standard-target method. Echo integrator data are judged, or allocated to particular species and size compositions within species, on the basis of trawl data. The age-length key is similarly derived from trawl data. The weighted size composition and standard target strength-fish length relationship is used to convert the measurements of acoustic density to numerical estimates of fish density and mass.

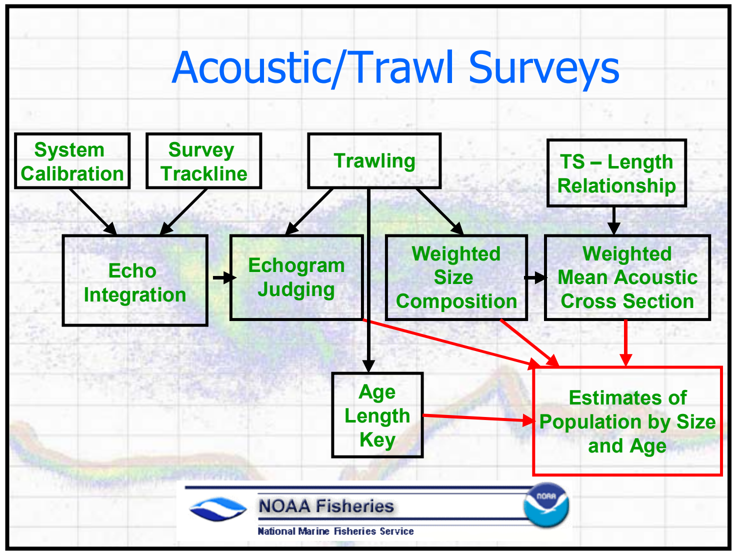

Figure 3. Acoustic/trawl surveys flow diagram

Northeast U.S. EEZ Acoustic Surveys

The Northeast Fisheries Science Center (NEFSC) is currently performing acoustic surveys on Atlantic herring in the Georges Bank and Gulf of Maine region. For acoustic quantification, the Simrad EK500 scientific echo sounder system is used with transducers operating at 12 (pre-2002), 18 (2002 and current), 38, and 120 kHz (Fig. 4)

Transducer specifications for the NEFSC Simrad EK500 echo sounder

Transducer model	12-16	ES38-12	ES120-7
Transducer depth (m)	3.2	3.2	3.2
Absorption coef. (dB/km)	1.0	10.0	38.0
Pulse length	Short	Medium	Long
Bandwidth	Auto	Auto	Auto
Max power (W)	4000	1000	1000
2-Way beam angle (dB)	-15.8	-15.8	-20.6
Sv transducer gain (dB)	18.50	23.00	25.20
TS transducer gain (dB)	18.50	23.02	25.30
Angle sensitivity along (dg)	0.0	12.5	21.0
Angle sensitivity athw (dg)	0.0	12.5	21.0
3 dB beam along (dg)	16.0	11.8	7.3
3 dB beam athw (dg)	16.0	11.7	7.2
Along offset (dg)	0.00	0.25	-0.21
Athw offset (dg)	0.00	0.02	-0.15

Figure 4. NEFSC Transducer Specifications

Other acoustic systems are used to measure current velocity profiles in the water column and to monitor trawl performance during fishing operations. During periodic research bottom trawl surveys of groundfish, acoustic data are collected with the same echo sounder system operating at 38 and 120 kHz (Fig. 5). These data are incidental to the primary trawl samples for redfish. When the EK500 is replaced with the EK60 on the R/V Albatross in 2003, the operating frequencies will be 18, 38, and 120 kHz.

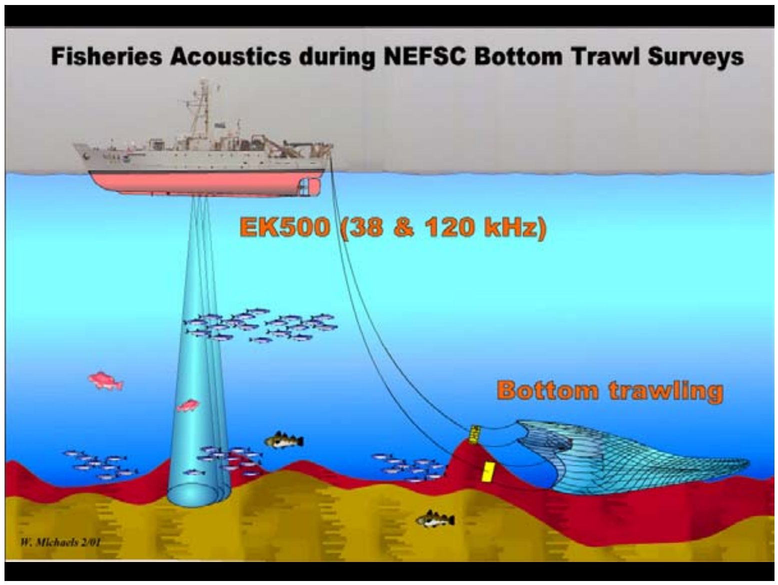

Figure 5. Scientific echo sounding during NEFSC bottom trawl surveys

Survey design is an important consideration when implementing acoustic surveys of groundfish. Systematic survey designs are employed during NEFSC herring acoustic surveys, while random-stratified survey designs are implemented during NEFSC bottom trawl surveys.

A prerequisite for deriving species-specific population abundance estimates from acoustic surveys at NEFSC is the identification of target strength (TS) measurements for selected fish species. Laboratory measurements of TS of single tethered fish are being performed. Representative TS data are shown in the form of histograms at 38 and 120 kHz (Fig. 6). The effect of filtering the data with respect to their multiple-frequency content reduces the number of analyzed data by roughly two orders of magnitude, but increases the quality to a significant degree.

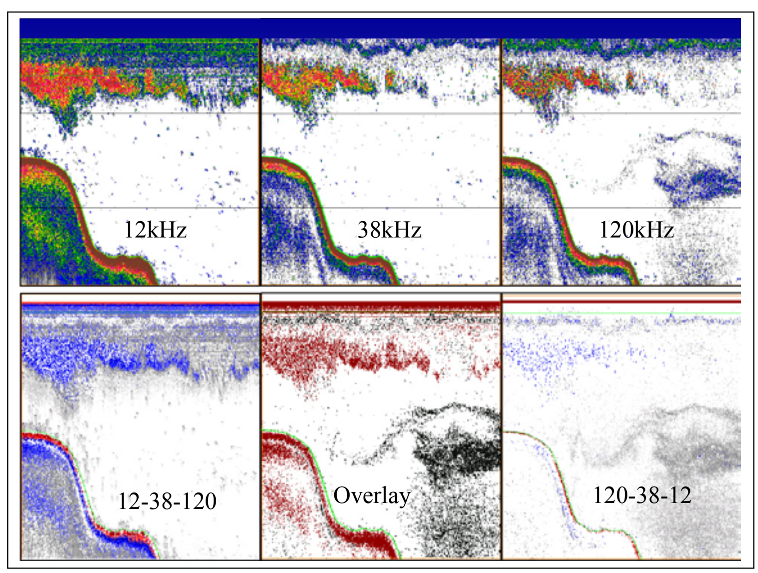

Figure 6. Synthesis of echo data collected at 12, 38, and 120 kHz

Synthesis of echo data collected at three frequencies, 12, 38, and 120 kHz, illustrate differences with each frequency particularly features of the fish in the water column are enhanced or diminished. These are suggestive of differences in species and/or size composition. Analyses of target strength from different regions of the "overlay" echogram can enhance the classification power in the synthesis.

STATUS OF ACOUSTIC METHODS FOR STOCK ASSESSMENT

Acoustic data are being used in both pelagic and the pelagic portion of semi-demersal fish stock assessments in many countries and regions of the world: Canada, Norway, New Zealand, South Africa, Pacific Northwest, Japan, Australia, South America, and other regions.

Acoustics is a credible tool to augment stock assessments. Its application is not universal, but there are many important groundfish stocks that are being managed with key contributions from acoustic data. In New England, there is fishing industry interest in advancing use of acoustics for groundfish surveying.

There are three primary reasons that acoustics is not being more widely used:

(1) Lack of awareness of acoustic technology and its potential to provide useful data or information for groundfish research and stock assessment. This is also evidenced by lack of education and training in the field of fisheries acoustics.

(2) Uncertainty in effectiveness because of perceived or actual technical limitations (e.g., species identification, sizing, detection near bottom (dead-zone), target strength, behavior).

(3) Cost, priority, lack of funding.

PROBLEMS ADDRESSED BY ACOUSTICS

Acoustics can be used to address some important problems relating to stock assessment, biology, ecology, distribution, and sampling strategies. Direct sampling may also be necessary for species identification and biological measurements. The implicit applications have potential for groundfish stocks with a semi-pelagic distribution that are not already being surveyed by acoustics.

(1) *Qualitative determination of presence and absence*. Echo sounders and other sonars have long been used to determine the presence or absence of fish in the water column; for example, commercial fishermen routinely use echo sounders to find fish. While echoes may not be detected from fish lying on or very near to the bottom, groundfish in a semi-pelagic state can be readily detected by acoustic means.

(2) *Quantification of many species of fish and some zooplankton*. Echo sounders and other sonar have been used to quantify density and abundance of fish since the 1960s and of Antarctic

krill since the 1970s. The range of applications to both fish and zooplankton has increased steadily since then.

(3) *Geographical distribution*. The geographical limits of a stock can be determined by means of acoustics. In survey situations, transects are designed to span the area of the stock distribution.

(4) *Stock abundance*. As described above in the "Overview of acoustic methods and technology," techniques exist for measuring fish density over an area and expressing the integrated result as an overall estimate of stock abundance.

(5) *Fish behavior*. A variety of fish behaviors can be observed by acoustic means. These include, for example, diurnal vertical migration in the water column, local horizontal movements of individual fish, seasonal migration, and swimming speed and direction of individual fish and fish schools.

(6) *Multiple species ecology*. Groundfish species, as well as other organisms, give echoes. Insofar as these can be distinguished, as by their echogram features, spatial and temporal information on multiple species and their physical relationships can be obtained. Changes in the relative numerical densities and abundances of species by size group can be monitored in some cases. Relationships among different organisms and their environment can thus be quantified.

(7) *Link of distribution to environment*. By providing information on the location and concentration densities of fish in the water column and throughout a region, the fish can be described in terms of their relationship to the environment. In the case of groundfish in a semi-pelagic state, the association of fish echoes with the bathymetry is often immediate.

(8) *Bottom-habitat characterization*. Bottom echoes are generally registered by echo sounders with vertically oriented transducer beams. These provide information both on depth and backscatter. When multiple echoes are assembled, a picture of the topography and backscatter patterns may be formed. This often constitutes a useful characterization of the bottom.

(9) *Tool to assess vessel-avoidance effects*. Fish may react to the passage of vessels or to fishing gear such as trawls. The degree of reaction may depend on the range of the fish from the causative sound source. Experiments have been designed and executed to quantify the degree of reaction by means of echo sounders and sonars. These are sometimes mounted on trawl gear, at other times on platforms external to the primary survey vessel.

(10) *Adaptive sampling*. By means of acoustic observations, decisions can be made about survey operations, for example, whether to continue along or terminate a particular transect or whether to collect biological data. Such adaptive sampling, in which sampling is performed according to observation at the time of data collection, can be very powerful. Particular survey aims, such as defining the limits of distribution of a stock in a local area, can be aided in this way.

(11) *Marine mammal studies*. The behavior of marine mammals is often observed by passive acoustics (i.e., by listening to underwater vocalizations or other sounds made by the animals by means of hydrophones). Active devices can also be used, based on registration and recognition of echoes from these animals.

LIMITATIONS IN ACOUSTIC METHODS AND THEIR REMEDIES

A wide diversity of problems can be addressed by acoustics. Conditions, or limitations, on the use of acoustics and respective remedies are enumerated. The first four touch on fundamental physical limitations. The others concern more operational matters.

(1) *Registering fish echoes near boundary surface.* As an acoustic signal is transmitted into the water column, it radiates or propagates outwards in an expanding spherical surface more or less. As soon as it hits a large reflecting surface, a powerful echo is usually generated. Echoes that are generated after this because of the greater range of targets are generally totally obscured. The "dead-zone" characterizes the acoustically inaccessible region near the bottom (Fig. 7). By changing the transducer bandwidth or pulse duration or by moving the transducer closer to the target organism, for example, the chance of making clean observations may be substantially increased.

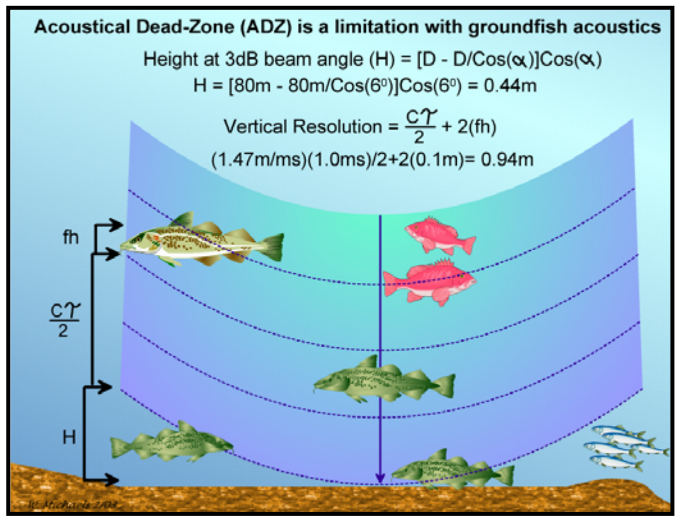

Figure 7. Groundfish acoustic "dead zone" limitation

(2) *Distinguishing species on the basis of echo data.* Interpretation of a single echo due to transmission of an ordinary narrowband signal is generally impossible. Simply not enough information is contained in the transmitted signal to introduce significant spectral content in the echo. However, use of multiple frequencies (Fig. 6) or a genuinely broadband transmitter may increase the information content of the echo signal, enabling this to be interpreted. The relationship of organism size to wavelength is innately complex and needs to be considered, when trying to maximize the potential in echo classification. There are situations that can be addressed by resolving the frequency content of echoes, and there is much productive work being focused on this problem at present.

(3) *Resolving individual scatterers except in a dispersed state.* Direct determination of target strength requires resolution of individual fish echoes. This condition is often unobservable, owing to the numerical density of fish aggregation, its range from the transducer, and/or the

transducer beamwidth. In some case, deploying the transducer nearer to the fish targets may be sufficient to resolve individual fish, but this depends on fish behavior, too.

(4) *Narrow beam and correspondingly small sampling volume.* The transducer beam of many echo sounders is quite narrow, which also accounts for the high system sensitivity. The acoustic sampling volume, however, is relatively small. This may be increased with multibeam sonar by a factor of ten or more, but at the expense of sensitivity. For example, individual fish specimens of a certain size and range may be detected by a scientific echo sounder with narrow transducer beam but missed by a multibeam sonar. However, a large school or aggregation of fish may be much more effectively imaged by means of a multibeam sonar than with a narrow-beam echo sounder.

(5) *Prior knowledge of stock biology.* Survey design begins with knowledge of stock biology. It is a necessary but not sufficient precondition for any successful survey, whether by research bottom trawl or by scientific echo sounder or other sonar system. The remedy is careful examination of existing data. If these data are insufficient or lacking, it is necessary to invest in a program of observation to define the geographical limits of distribution and their changes with time of year.

(6) *Distinguishing age or size on the basis of echo data.* The conventional way of determining age and size is by laboratory investigation of captured fish species. Under certain circumstances, acoustic data can yield information about fish size. If single-fish echoes can be resolved, and target strength measured, then the resulting target strength distribution will contain information about the underlying size distribution. If corresponding data are available at multiple frequencies, this determination may be refined. If continuously broadband data are available, then certain features of the data may be interpreted in terms of physical dimensions of single fish targets.

(7) *Lack of synopticity of data collected by a single vessel.* The most advanced ocean-going vessel can only be in one place at one time, whether its business is trawl surveying, hydrographic measurement, acoustic measurement, or any other scientific observation. While the quality of data derived from well-equipped research vessels is often unsurpassed, more synoptic coverage would be highly advantageous in a number of situations. Some examples are surveys designed to define the geographical extent of a fish stock or to observe its movements, as under seasonal migration, over large distances. In the case of acoustic data collection, a degree of synopticity could be achieved by equipping a fleet of fishing vessels with echo sounders providing a calibrated output signal and data logger. Ideally, each fishing boat would contribute to a synoptic survey by collecting data along specified transects at agreed times according to prior agreement. With coordination, a genuinely synoptic survey could be performed.

(8) *Lack of a digital calibrated output signal.* While some commercial fishery echo sounders do provide a calibrated output signal, the majority do not. In addition, the usual alternative video output consists of data designed for visual display, which cannot be used for ordinary quantitative work. Sonar manufacturers can remedy this situation by providing a calibrated output signal on a serial port.

(9) *Lack of a data storage device linked to commercial fishery echo sounders.* Data loggers can be procured and coupled to commercial fishery echo sounders with a calibrated output signal. However, sonar manufacturers would be providing a very useful service by offering data loggers configured for the logging of calibrated output signals from their echo sounders.

(10) *Lack of dynamic range in acoustic Doppler profilers (ADPs).* ADPs measure the current velocity structure through the water column, assuming that water movements are generally occurring by layers sliding or shearing over one another. The devices are so well engineered and so sophisticated that they could be adapted for scientific echo sounding. An essential ingredient is the dynamic range. This is unimportant in many measurements of velocity, hence the dynamic range is often extremely limited. By preserving more information on the signal magnitude, manufacturers of ADPs could add much functionality to their devices. This would substantially increase the potential number of platforms available for echo sounding observations, while also providing a dual capability for the particular instrument.

(11) *Cost.* The issue of the cost of acoustic surveying can be addressed systematically by means of a decision matrix showing function versus cost. Examples of the function elements are management needs, availability of acoustic instruments, adequacy of the transducer-bearing platform, among other things.

(12) *Near-surface effects.* A major obstacle in acoustic surveying with hull-mounted transducers is the occasional presence of air bubbles in the surface layer. The straightforward remedy is to lower the transducer beneath the bubble layer. This may be done by means of a transducer mounted on a retractable keel or centerboard, which is possible on some research vessels, or by towing the transducer at a sufficient depth. Effects of wave action on the transducer orientation can be reduced in the same way.

(13) *Towing obstacles.* While towing a transducer may be advantageous to avoid near-surface effects, it has associated risks, for example, fouling stationary fishing gear such a traplines and gillnets. The remedy is to use hull-mounted transducers when operating in areas populated with stationary gear.

WORKSHOP RECOMMENDATIONS

Four general recommendations were made:

(1) Further develop acoustic methods for application to groundfish surveying.

Clearly, acoustic methods are being applied in the assessment of a number of major groundfish stocks that have a semi-pelagic state. New applications can be entertained, for example, to stocks of cod, haddock, pollock, and redfish in the Gulf of Maine and on Georges Bank. In other coastal areas, such as the Pacific waters along the West Coast, including Alaska, current applications would benefit from better knowledge of target strength and behavior. A widespread development need is thus defined.

(2) *Encourage education and training in fisheries acoustic methods*.

It was recognized at the workshop that lack of knowledge and competence in the methods of fisheries acoustics has hindered both developments and applications. By spreading knowledge about the methods, as through education and training, the community will be much better prepared to pursue and improve these. This includes training of fisheries scientists in acoustics methodologies and building awareness among fishermen and fisheries managers about the benefits of acoustic techniques.

(3) *Examine existing data including acoustic, physical capture and fishery derived data for new or changing applications of acoustic surveying to groundfish*.

An essential first step in designing a proper acoustic survey of a stock is knowledge of its whereabouts and habits. The easiest, least expensive way to get such knowledge is to refer to historical records when these exist. Data derived from acoustic observations, physical capture, and/or the fisheries themselves are extremely valuable and should be scrutinized for their distributional information.

(4) Prepare specifications for the sonar and sonar-related manufacturers to adapt or develop commercial fishery echo sounder systems to enable commercial fishing vessels to contribute useful quantitative data on groundfish.

The fishing fleet has a significant, generally ignored or depreciated potential to contribute valuable acoustic data on groundfish distribution. Such collections would benefit from fishery echo sounders or other acoustic systems that provide a simple calibrated output signal with a useful dynamic range. While some fishery echo sounders produce such a signal, many do not, nor do acoustic Doppler profilers. Manufacturers of sonars and related systems can help create the capacity for fishermen to add quantitative information about groundfish stocks, ultimately for their better management.

SPECIFIC RECOMMENDATIONS FOR ACT IN DEVELOPING ACOUSTIC TECHNOLOGY AND METHODS

Three additional recommendations were directed to ACT with its command of both organizational and technological resources:

(1) Increase awareness of the potential of acoustic methods for groundfish surveying.

(2) Disseminate current information on acoustic methods for surveying groundfish and keep the community informed through a website.

(3) Help identify, through the formation of a subcommittee, if necessary, performance specifications for acoustic systems to be used in groundfish surveying.

CONCLUSIONS

The overall conclusions of the workshop are the following:

- Acoustic techniques are successful for assessing some groundfish stocks. These require frequent trawling or other physical capture for identification of species and determination of size-age composition.

- Acoustic techniques are not effective for species that reside entirely on the bottom, but the techniques can be used in conjunction with other survey methods applied to semi-pelagic groundfish stocks.

- A good survey design requires extensive knowledge of the spatial and temporal characteristics of the target stock.

- Important technical issues that should be addressed in applications of acoustic surveying include for example calibration of acoustic systems, participation by experienced personnel, knowledge of the acoustic properties of fish (i.e., target strength) and fish behavior, and sometimes use of quiet survey vessels or towed transducers.

- There is recognized potential and interest in collecting useful acoustic and trawl data from commercial fishing vessels.

The myth that acoustic abundance surveying can be performed only for pelagic fish stocks has been dispelled. Acoustic surveying may be no less applicable to groundfish stocks. Issues of delectability of groundfish in the semi-pelagic state, target strength, and species identification, among others, may be approached successfully in ways analogous to those used for the more familiar pelagic case

In summary, acoustic methods are credible sources of information for groundfish stock assessments that can provide much new information about groundfish biology: geographical distribution, behavior, movements, and association with bottom habitat types and other organisms. The resources available for developing acoustic methods include on-going acoustic survey programs at NMFS, research vessels carrying scientific echo sounders, echo-data postprocessing systems in routine use, fishing vessels that can serve as platforms of opportunity, formal programs for engaging fishermen in research, acoustic calibration techniques and facilities, research and operational expertise, sonar manufacturers, and the Alliance for Coastal Technologies. It is clear that acoustic methods can be refined and adapted for much wider use in surveying groundfish resources through partnerships of the research community, fishery managers, fishermen and sonar and sonar-related manufacturers.

ACKNOWLEDGEMENTS

The conveners wish to thank the participants for engaging in a very constructive discussion on developing acoustic methods for surveying groundfish. W. A. Karp, W. Michaels, and G. A. Rose are thanked particularly for their illuminating talks on the practice of groundfish acoustic surveying, and J. Boreman, for his evening talk on future plans for developing acoustic methods, given in behalf of the National Marine Fisheries Service. J. Condiotty, H. Lobe, R. McClure, and T. Mudge are also thanked for their informative impromptu talks on the state of acoustic technology. P. Bogden and J. Quintrell are both thanked for their effective efforts as facilitators. J. Clark and M. Parmenter are thanked for providing logistical and other support. J. Quintrell and M. Tamburri aided in developing workshop theme and in edited this report in substantive ways.

The workshop was supported by the Gulf of Maine Ocean Observing System (GoMOOS), an ACT partner, as well as the Alliance for Coastal Technologies. The Alfred P. Sloan Foundation is thanked for providing travel support to one of the participants under the aegis of the Census of Marine Life Gulf of Maine Program. Discussions with M. Tamburri are gratefully acknowledged.

Photograph of ACT Acoustic Workshop Participants
Samoset Resort, Rockport, Maine
26-28 February 2003

APPENDIX 1

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