NOAA Protocols for Fisheries Acoustics Surveys and Related Sampling

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Introduction

In response to Vice Admiral Lautenbacher's September 16, 2002 memo that mandated a review of current protocols and a publication of new protocols, NOAA Fisheries began a discussion on developing national and regional protocols for acoustic-based surveys. The objective of the protocols is to "ensure that all aspects of preparation for [trawl] surveys and [trawl] survey procedures are consistent and in keeping with the highest quality standards to provide for survey data accuracy and consistency from one survey to the next". For these protocols, "trawl" is replaced with "fisheries acoustics". Members from the Alaska Fisheries Science Center (AFSC), Northeast Fisheries Science Center (NEFSC), Northwest Fisheries Science Center (NWFSC), and Southwest Fisheries Science Center (SWFSC) participated in a workshop during April 23-24, 2003 to develop a protocol framework that would be consistent among all centers, encompass acoustical aspects of conducting fisheries independent acoustical surveys, and include survey methods as related to acoustical surveys.

The overall goal of fisheries acoustical surveys is to provide age-dependent, fishery independent estimates of species-specific biomass and abundance. These protocols are designed to provide guidelines for collecting, processing, and analyzing acoustical and related biological and physical oceanographic data. These protocols are to be used for existing fisheries acoustics surveys, and to provide guidance for designing new surveys. These protocols are limited to mobile surveys using downward looking transducers of one or more frequencies. In addition, protocols for collecting and processing other data (*e.g.*, biological and physical data) are provided only to the extent that these data are incorporated in acoustical surveys. This document is based on current practices and state-of-the-art knowledge and equipment. Additional protocols will be developed when other types of instrumentation or other types of surveys become routine, and when scientific and technological advancements necessitate modification of these protocols. Efforts have been made to develop a format that will allow efficient additions or modifications of current protocols via quantitative consideration of associated measurement errors.

Acoustic-based biomass and abundance estimates are used in assessments as relative indices or absolute numbers. These protocols are also designed to provide guidelines for supplying assessment scientists with objective information and knowledge of the levels of uncertainty associated with the acoustical estimates.

This document is arranged as follows. Center-specific background is given to provide information on each Center's personnel and general support. A short review of acoustical methods relative to performing surveys is provided. This review sets the foundation for the protocol framework. Lastly, the methods for collecting, processing, and analyzing acoustical and related biological data are given. Center and/or regional protocols are detailed in each region's protocol document.

Center Background

AFSC

AFSC – The Alaska Fisheries Science Center (AFSC) conducts acoustic-trawl surveys in the Bering Sea and Gulf of Alaska. The target species is walleye pollock (*Theragra chalcogramma*). Surveys are conducted aboard the NOAA Ship Miller Freeman and, beginning in 2005, the NOAA Ship Oscar Dyson. Field seasons include approximately six weeks in the winter and three months in the summer. Abundance–at-age estimates from these surveys, along with bottom trawl survey data and fishery catch data, are used to model population size, and, in turn, to establish quotas for the commercial fishing industry under the auspices of the North Pacific Fishery Management Council. The acoustics group within the Midwater Assessment and Conservation Engineering (MACE) Program is comprised of eleven fisheries biologists and three information technology specialists. All employees are full-time and base-funded.

NEFSC

The Northeast Fisheries Science Center (NEFSC) fisheries acoustics group currently has two FTE's affiliated with the Survey Branch and one FTE affiliated with the Population Dynamics Branch. Two FTE's are base funded and the other FTE is funded on a congressional budget "line-item". The NEFSC fisheries acoustics group focuses on estimating Atlantic herring (*Clupea harengus*) spawning stock biomass with an annual six-week survey conducted in the fall.

NWFSC

Scientists from the Northwest Fisheries Science Center (NWFSC) and Canada Department of Fisheries and Oceans (DFO) conduct periodic joint acoustic surveys of Pacific hake, *Merluccius productus*, along the west coasts of both countries. The surveys are a key data source for the joint Canada/US Pacific stock assessments and act as the foundation for advice on harvest levels. Integrated acoustic and trawl surveys, used to assess the distribution, abundance and biology of Pacific hake, have been historically conducted triennially by Alaska Fisheries Science Center (AFSC) since 1977 and annually along the Canadian west coast since 1990 by Pacific Biological Station (PBS) scientists. The triennial surveys in 1995, 1998, and 2001 were carried out jointly by AFSC and DFO. Following 2001, the responsibility of the US portion of the survey was transferred to Fishery Resource Analysis and Monitoring (FRAM) Division scientists at NWFSC. FRAM and PBS scientists conducted a joint survey in 2003, marking not only the change in the US participants but also a change to a newly adopted biennial survey regimen. The FRAM Division acoustics group currently is composed of five full-time, base funded fisheries biologists.

SWFSC

The Southwest Fisheries Science Center (SWFSC) conducts quantitative acoustical surveys for Antarctic krill in support of the U.S. Antarctic Marine Living Resources Program (AMLR) and the fisheries management efforts of the Antarctic Treaty's Commission for the Conservation of Marine Living Resources (CCAMLR). These acoustical surveys are supported by two FTE's in the SWFSC's Antarctic Ecosystems Research Division (AERD) and one FTE in the SWFSC's

Advanced Survey Technologies Program (AST). The AERD and AST each employ contractors to assist with the associated surveys, data processing, and technology development. AERD's FTEs and one-quarter of AST's FTE are funded on a congressional budget "line-item" – AMLR. Three-quarters of the AST FTE are base funded.

Acoustical Background

Acoustical technologies are effective and efficient methods for sampling fish and zooplankton in the water column. Fisheries acoustics methods are analogous to remote sensing techniques and advantageous to other sampling methods as nearly the entire water column can be sampled quickly (sound travels approximately 1500 m s^{-1} in water), areal coverage is continuous, data resolution is on the order of tenths of meters vertically and meters horizontally, and data can be post-processed in a variety of ways. Limitations of acoustical technologies include: near-boundary areas (near surface and seabed) are not well sampled, species identification is difficult, and obtaining biological information (*e.g.*, age, maturity, diet) is very difficult. Optimally, fisheries acoustic surveys integrate acoustical technologies with other sampling methods such as net catch and temperature-salinity data to estimate population abundance.

Underwater acoustical systems used in fisheries consist of an echo sounder that produces a transmit voltage, processes returned signals, and transmits data to computers, and a transducer that converts the transmit voltage to a pressure wave (a "ping") and then converts echoes from targets in the water column back to a voltage. The downward-looking transducer is mounted on the hull or drop keel or in a towbody to sample the water column directly beneath the ship while the ship steams along transects. The SONAR equation defines the sound propagation and interaction with targets in the water column.

SONAR Equation

The RADAR equivalent of the SONAR equation is accurate, easily understood, and therefore useful. The equation detailing volume scattering (S_v [dB]) is:

$$Sv = \frac{P_R 32\pi^2}{P_T G_0^2 r_0^2 \lambda^2 c \tau \psi} r^2 10^{2\alpha r} \qquad (1)$$

where P_R is the received power [Watts], P_T is the transmitted power [Watts], G_0 is the system gain, r_0 is the reference range (r_0=1 m) [no units], c is the speed of sound in water [m s^{-1}], □ is the acoustic wavelength [m] ($\lambda = c/f$, where f is the acoustic frequency [Hz]), □ is the transmit pulse duration [sec], □ is the two-way integrated beam pattern, r is the range [m] from the transducer, and □ is the acoustic attenuation [dB m^{-1}]. Speed of sound is dependent on temperature, salinity, and pressure (depth).

It is important to note that parameters in equation 1 (□, □, □, □, and G_0) are sound speed, frequency, and system (echo sounder and transducer) dependent, and interactions among these parameters affect measurements of Sv in linear and non-linear ways. Analyses of uncertainty associated with these parameters must incorporate these interactions.

The SONAR equation defines the interaction of the pressure wave with the environment, targets, and the echo sounder. The next step is to convert the acoustical measures (Sv) to a population estimate. We define a general equation of this conversion that will provide a framework for the protocols.

Generalized Equation

The general equation used to convert volume backscattering measurements to population biomass estimates is:

$$B_i = \frac{CE_i}{\sigma_i} D_i A_i \tag{2}$$

where C is the calibration parameters/coefficients, E_i is the measured acoustical energy, □ is the estimated backscattering cross-sectional area, D is the numerical density to biomass density conversion, and A is the survey area. Subscript *"i"* denotes the target classification level (*i.e.*, species, age- or length-class, or target type).

Equation 2 provides a framework for this protocol. Based on this equation, five general categories are defined: system calibration and performance (C), volume backscattering measurements (E), target strength (□), acoustical-biological conversions (D), and survey design (A). The Methods section details specific methods for each of these categories. Topics under each category are detailed with a consistent structure:

Definition & Importance: Description of the topic and why it is important to the acoustical survey process.

Techniques: Details on the procedures and methods (how, when, where, and documentation).

Error: Discussion of the random and systematic errors, and accuracy and precision of the measurements.

Considerations: Description of remediation procedures and improvements in techniques or measurements.

Methods

Calibration and System Performance

Calibration

Definition & Importance

Calibrations characterize system parameters relative to expected standard values.

System parameters specific to scientific echo sounders are: gain constants (G_0), pulse duration (□), two-way integrated beam pattern (□), time-varied gain (TVG), the speed of sound in the water (c), sound attenuation (□), and the transmit power. Calibrations are conducted to ensure that the echo sounder and transducer are operating properly, to ensure system stability over time (i.e., among survey periods), and to allow inter-echo sounder comparisons.

Echo sounder calibrations conducted on board NOAA fisheries research vessels use the standard-target method (Foote *et al.*, 1987), which relates acoustical energy to an absolute standard. The standard-target method calibrates the overall acoustical system, which consists of the echo sounder, transducer, and cable. The calibrations consist of two parts: on-axis sensitivity and beam pattern measurements. On-axis target strength and S_A measurements calibrate gain parameters and beam pattern measurements supply beamwidth and angle offset values.

Techniques

Before conducting a calibration important issues to consider are:

1) The calibration should be conducted in the same environmental conditions (water temperature and salinity) as are experienced during the survey.
2) Water depths must be sufficient to exceed near-field limitations and/or system limitations for the echo sounder frequencies to be calibrated (Table 1).
3) Calibrations must be conducted before the survey begins to establish proper echo sounder operation, and after or near the end of the survey to ensure no significant changes have occurred. Additional calibrations during the survey are valuable for maintaining system performance and ensuring high-quality data.
4) Calibrations must be conducted with the same pulse durations, transmit powers, and bandwidths used during the survey.

Software

Echo sounder manufacturers provide detailed instructions and software programs for calibrating their systems. These instructions must be followed to ensure proper calibration and system stability. Because software upgrades occur, software version identification (both calibration software and echo sounder software) should be documented.

Standard values

Table 1 provides a list of common standard values for calibration. The calibration sphere target strength is dependent on the water temperature and salinity (*i.e.*, sound speed dependent). The copper spheres specified for each frequency have been shown to be "optimal" in that the target strengths of the specified spheres vary minimally for a normal range of temperatures and salinities (Foote, 1982; 1983a). However, one should confirm that the theoretical TS is valid for the measured environmental conditions.

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Frequency [kHz]	**Calibration Sphere**	**EK500 Minimum Target Range [m]**	**Nominal TS [dB]***
12	45 mm Cu	35	-40.4
18	64 mm Cu	22	-34.4
38	60 mm Cu	10	-33.6
38	38.1 mm WC	10	-42.2
120	23 mm Cu	10	-40.4
120	38.1 mm WC	10	-39.6
200	13.7 mm Cu	10	-45.0
200	38.1 mm WC	10	-39.5

Table 1. Calibration standard values.

Calibration sphere measurements are the sphere diameter. 'Cu' denotes a copper calibration sphere, and 'WC' denotes a tungsten carbide with 6% cobalt binder calibration sphere. The 'EK500 Minimum Target Range' applies to the SIMRAD EK500 and was derived as a combination of the far field of the transducer and electronic limitations of the echo sounder

On-axis sensitivity

On-axis sensitivity is measured by positioning the calibration sphere on the acoustic axis of the transducer. The target strength gain is derived from the measured on-axis target strengths relative to the target strength of the calibration sphere.

Beam pattern measurements

Beam pattern measurements are acquired by positioning the calibration sphere at many different angular locations within the acoustic beam. For split-beam transducers, echo strength is compensated by the angular location of the target in the acoustic beam. A target's location is derived from electrical phase differences among the quadrants. The transducer manufacturer supplies transducer parameters such as the beamwidth, transmit-receive directivity response, and two-way integrated beam pattern. Calibration software packages may provide beam width and angle offset parameter estimates based on the beam pattern measurements. Use of these parameters is based on the individual center's protocols.

S_v Calibrations

Echo sounder calibrations for S_v measurements involve positioning the calibration sphere on the transducer axis and measuring S_v relative to the theoretical value. The theoretical S_v is based on the target strength and range to the calibration sphere. The primary result of the S_v calibration is the S_v gain.

Oceanographic Data

A vertical temperature and salinity profile should be obtained to calculate sound speed prior to every calibration. The profile must encompass the calibration depths. This profile should be compared to temperature and salinity profiles obtained during the survey to ensure similar physical environmental conditions between the calibration exercise and the survey.

Error

The standard target method for calibrating echo sounders is used to calibrate the overall acoustical system (combined transmit and receive echo sounder components, transducer, transducer cable, and the electrical supply) to an absolute standard. Thus the calibrations reflect an integration of the echo sounder, transducer, and shipboard electrical system. If any component of this system changes (e.g., the shipboard electrical system, transducer cable length) during the survey, the echo sounder must be recalibrated.

Errors and tolerances associated with calibrations are relative to the system precision. Angular target locations derived from split-beam systems are dependent on the A/D sampling rate and the ability to measure electrical phase differences among the quadrants. Target strength measurements are dependent on the dynamic range and the A/D sampling rate. Thus tolerances for calibration results are relative to the system precision. For example, Foote (1983a) and MacLennan and Simmonds (1992) suggest a tolerance in on-axis target strength measurements of $\pm$ 0.2 dB (TS $G_0 \pm$ 0.1 dB) for the SIMRAD EK500.

Variability in system parameters due to environmental conditions, primarily temperature, has been observed in the EK500. The temperature effect appears to influence the 120- and 200-kHz transducers more than other frequencies, and is observed even when attenuation and sound speed are properly established. This effect is believed to be a transducer design issue.

Considerations

Remediation

Echo sounder manufacturers should provide detailed diagnostic and evaluation routines. General diagnoses for the EK500 are:

The ‘test’ values for the EK500 are a measure of the transducer performance and are acquired for each transducer. A ‘test’ value not within the specified tolerance (refer to the Simrad EK500 manual for values and tolerances) is an indication of a broken connection in one or more of the wires to the transducer. Impedance and continuity tests should be performed to determine which wires are severed, and the connections must be repaired. The cause of the broken connection should be determined and rectified.

If the TS and/or Sv gains (G_0) are not within tolerance, ‘test’ values (for the EK500) may indicate a problem with the transducer or transducer cable. If this is not the problem, then a full set of diagnostics must be completed on the echo sounder to determine the cause of the problem. The survey should not continue until the problem is rectified.

Improvements

Improvements in calibrations include the ability to measure the angular location of the target independent of the echo sounder.

<u>System Performance</u>

Definition & Importance

System performance is the evaluation of echo sounder and transducer performance during a survey.

Periodic monitoring and evaluating of system performance is necessary for ensuring high-quality acoustical data during surveys. System performance deals with the internal electronics and processors and transducer and cable, not with interference introduced from external sources (System Degradation section).

Techniques

Error

Reduced or variable system performance will affect target strength and volume scattering measurements, and ultimately population estimates. Systematic errors in system performance include a change in transducer sensitivity over time or with other shipboard operations. Random errors can be very difficult to diagnose, but every effort should be made to diagnose the problems. If systematic and/or random errors are found, evaluation of the effects of these errors should be done during or after the survey.

Considerations

Remediation

Echo sounder manufacturers should provide detailed diagnostic and evaluation routines. These routines should be used to identify and evaluate the problem.

For the EK500, survey operations should be suspended if the ‘Test’ values are out of tolerance (refer to the Remediation section under Calibrations). After the problem is resolved, the survey can continue.

If individual targets do not appear in all quadrants, survey operations should be suspended and the problem diagnosed.

Improvements

Improvements in monitoring system performance include continuous monitoring of the output echo sounder power or voltage to the transducer. The ability to monitor voltage to the transducer would provide real-time evaluation of the echo sounder performance.

Data Management

Documenting and archiving calibration data and supporting information is critical. In addition to data and derived values acquired from the calibration software, data should be collected directly from the echo sounder. Echo sounder data include high-resolution sample, individual target strength, and volume scattering data. These data should be archived immediately after conclusion of the calibration. Supporting information should be documented and archived with the calibration data.

Calibration data, such as the data collected by the calibration software and the echo sounder, and associated meta-data should be archived on-board upon completion of each calibration exercise. These data are downloaded to shore-based computers and permanently archived for each calibration.

Volume Backscattering Measurements (E_i)

Data Collection

Definition & Importance

Volume backscattering (S_v, m^2/m^3) is the summation of echo energy (E_i) within a sampling volume.

S_v is a measure of the relative density of organisms and the primary measurement for acoustically estimating fish densities and abundance. Equation 1 (Acoustical Background section) details the dependency of S_v on sound speed (c), acoustical frequency (f) and wavelength (□), pulse duration (□), two-way integrated beam pattern (□), S_v gain (G_0), and attenuation (□).

Techniques

Echo Sounder Parameters

Scientific echo sounders allow the user to input the parameters: G_0, c, □, □, and □ and to choose the ping interval. The acoustic frequency (f) is defined by the echo sounder. Choosing echo sounder settings should be done with the understanding of the interdependency of these parameters and how they affect S_v measurements (Furusawa, 1991).

The S_v gain (G_0) is obtained from the echo sounder calibration (Calibration section). Choice of the pulse duration (□) is dependent on the objectives and conditions of the survey. For higher resolution of individual targets, a shorter pulse duration is desirable, whereas a longer pulse duration is desirable for greater ranges because of a higher signal-to-noise (SNR) ratio. The echo sounder must be calibrated at the pulse duration used during a survey. Sound speed (c) is dependent on water temperature and salinity, so setting the sound speed requires *a priori* knowledge of the environmental conditions expected during the survey. The two-way integrated beam pattern (□) or beam width is defined by the transducer specifications supplied by the manufacturer. Sound attenuation (□) and acoustic spreading combine for the total acoustical transmission loss. To correct for spreading and attenuation losses, a $20\log_{10}(R)$ time-varied gain, where R is range, is applied to the S_v data. Sound attenuation is dependent on the acoustic frequency and water temperature and salinity. Similar to the sound speed, setting □ requires *a priori* knowledge of the environmental conditions. If significant environmental changes occur, the attenuation parameter and sound speed should be recalculated and set for those conditions. It is essential to document all initial echo sounder parameter settings and any changes made to them, either during data collection or during post-processing.

Software

Upgrades to echo sounder firmware versions and post-processing software versions are developed by manufacturers to correct software errors and to improve performance. When software is changed significantly, output for the two versions should be compared to ensure that the results are as expected. If not, analysis is needed to determine the source of the unexpected difference. Documenting firmware and software versions aids in interpreting any observed differences in results between old and new versions, and in making corrections, if necessary.

GPS

Integrating Global Positioning System (GPS) data with S_v measurements is critical for population estimates. GPS data are required for scaling S_v measurements to the survey area (Sampling section). Choices of positioning instrumentation and data are dependent on the availability of the on-board GPS systems, performance of the GPS over the survey area, compatibility of the GPS system with the echo sounder, and the desired accuracy and precision of the GPS data. Proper practice requires monitoring GPS output during data collection, documenting the type of GPS data used, and documenting data storage and retrieval procedures.

Oceanographic Data

Sea-surface profiles of temperature and salinity may be collected continuously during a survey. Vertical profiles may be collected routinely and at regular intervals during the survey and in close temporal and spatial proximity to trawl sets. Temperature and salinity data can also be useful for measuring the physical environment for ecological studies.

Oceanographic sensor manufacturers provide calibration, operational, and diagnostic instructions. These instructions should be followed.

Error

Because S_v data are the primary measurements used for acoustical estimates of species density and abundance, an understanding of the uncertainty associated with S_v measurements is invaluable. Linear and non-linear relationships among the parameters and environmental conditions can make understanding and quantifying uncertainty in S_v measurements difficult. Additionally, random and systematic errors in parameter settings relative to true values increase the uncertainty in density and abundance estimates.

Considerations

Remediation

If a parameter is incorrectly set during the survey, correct the parameter value, and document the change. Record the old and new values, date and time of modification, and other data indices so that the data collected prior to the modification can be reprocessed using a software package such as Echoview (SonarData, Tasmania, Australia).

Improvements

A single sound speed is currently used to describe the vertical sound speed profile, which is appropriate when the water column is mixed from surface to bottom. However, thermoclines (temperature gradients) and haloclines (salinity gradients) often exist, potentially with 10^{o} or more temperature and $1\text{-}3^{o}/oo$ salinity changes. Simulations should be conducted to determine the effect of using a single sound speed value in the presence of pycnoclines or over large geographical areas. An error analysis should be completed to assess the effects of variable environmental conditions (expected and observed) on S_v measurements.

Detection Probability

Definition & Importance

Detection probability refers to the likelihood of detecting the target organism.

Fisheries acoustics surveys are conducted to estimate species-specific density and abundance. Density and abundance estimates can be further categorized into age or length classes. Anatomical characteristics (e.g., the presence or absence of a gas-bearing structure), behavior (diel vertical migration, affinity for the seabed, active swimming), spatial and temporal distribution, ontogenetic changes, and frequency dependent backscattering affect Sv measurements and the interpretation of Sv to estimates of fish numbers or biomass.

Data collection parameters are set to acquire data that can be used for a variety of purposes, whereas post-processing parameters and techniques are optimized for single species. In other words, data collection attempts to maximize the detection probability for a wide variety of organisms, while post-processing attempts to maximize the detection probability for the species of interest while minimizing the detection probability for all other organisms. Techniques for enhancing target species detection probability and reducing non-target species S_v include applying a threshold, selecting optimal survey sites and times (Survey Design section) and employing multiple acoustic frequencies (Classification sub-section).

The underwater, radiated vessel noise can potentially cause behavioral changes in organisms. Behavioral changes include a change in the spatial orientation of the organism, changes in activity such as swimming, changes in the vertical distribution, and/or avoidance of the vessel (horizontal distribution). Modification of orientation and activity affect the backscattering strength of the individual organisms. Changes in vertical distribution can affect the backscattering strength of individuals and whether the organism is located in the acoustic beam. Changes in horizontal distribution, such as vessel avoidance, influence whether the organism is located in the acoustic beam (i.e., whether the organism is sampled or not).

Techniques

Thresholding

Acoustical backscatter by organisms with a gas-bearing structure such as a swimbladder is significantly greater than for organisms without a gas-bearing structure. This attribute can be used to reduce or eliminate the S_v from non-gas-bearing organisms by setting a volume backscattering threshold greater than the detection probability for these organisms while retaining S_v for the gas-bearing organisms. No setting can discriminate between fish and plankton or other non-target species with 100% accuracy. Some small fish targets are unavoidably discarded, just as some small amount of acoustic return from unwanted sources is included. The goal in choosing an S_v threshold setting is to find an optimal balance between eliminating non-target species S_v and preserving the target species S_v. Because some error is involved in applying a threshold, it is important to maintain consistency between surveys, i.e. the data collection threshold choices should be the same for all surveys in a time series.

It is important to distinguish between Sv threshold and TS threshold. The target strength threshold applies to backscattering by individuals. Sv threshold applies to the accumulation of backscattering by multiple individuals.

Range

The detection probability is a function of range: targets farther from the transducer have a lower probability of detection. The decrease with range is related to the dynamic range of the echo sounder, the noise level of the signal, and transmission loss of the acoustical signal. As range increases, the signal to noise ratio (SNR) decreases (signal decreases and noise increases) and echo amplitudes from targets in the water column drop below the noise level or S_v threshold. This effect is a particular concern when surveying deep water species or species without a gas-bearing structure. It is also necessary to take into account the SNR for the target species as a function of depth in order to plan a survey or to interpret the results.

Acoustic Dead Zones: Near surface and near bottom

Although acoustical methods are efficient for water column measurements, they are less effective at measuring backscattering by organisms near boundaries such as the sea surface or sea floor. Vessel-mounted or surface towed downward-looking transducers do not sample the water column above the depth of the transducer. Additionally, data within the transducer near field are not valid for survey estimates. For post-processing, a surface exclusion zone is selected, accounting for both transducer depth and the near field.

Echoes from fish close to the bottom may merge with the much stronger echoes from the bottom itself. Because the bottom echo is so much larger than that from fish, quantitative survey estimates of fish abundance depend strongly on properly distinguishing between the bottom and fish targets (MacLennan and Simmonds 1998). The problem of discriminating between fish and the bottom is further complicated because for each sound pulse transmitted by the echo sounder, there exists a zone near the seabed that is not sampled, the acoustic ‘deadzone’ (Ona and Mitson 1996). In addition, the bottom-tracking algorithm in use on modern echo sounders (e.g. SIMRAD) includes a ‘backstep’, a user-selected distance from the echo sounder bottom-detected depth, where the energy contribution of the bottom echo is considered negligible. In rough topography or rough seas, the bottom detection algorithm fails more frequently, resulting in the intrusion of bottom echoes into the water column, even with an increase in the backstep value. These bottom-tracking failures must be corrected manually during post-processing. Corrections for unsampled fish in the dead zone and in the zone above the bottom within the backstep interval must also be made in post-processing, to generate a more representative abundance estimate for fish in the water column.

Animal Behavior

For acoustical measurements, organism behavior is a combination of activity and spatial orientation of the organism. For targets that are non-spherical in shape, acoustic backscattering strength in the geometric scattering region is strongly dependent on the angle of the organism relative to the transducer. In general, backscatter in the geometric scattering region is strongest when the major axis of the organism is perpendicular to the transducer's acoustic axis and weakest when the organism's major axis is parallel to the acoustic axis. Activities such as swimming, feeding, or vertical migrations potentially affect Sv measurements by increasing or decreasing detection probabilities. Variability in backscattering strength as a function of organism orientation and behavior combined with Sv thresholding may affect the detection probability. For example, when the distribution of organism orientations is centered near perpendicular to the transducer, the detection probability may be high. When these organisms orient at angles near parallel to the acoustic axis, the S_v decreases and potentially below the S_v threshold.

Vertical and horizontal migrations can affect detection probabilities. Migration into or out of the near-surface or bottom zones during the survey will nearly eliminate the detection probability for these organisms. Horizontal migrations may take the organisms out of the survey area or outside of the acoustic beam.

Vessel Noise and Avoidance

All vessels radiate underwater noise (Urick 1983). Fish species are able to detect this vessel noise over a range of frequencies from tens to at least several hundred Hz (Mitson 1995). Whether the fish react to the vessel noise, thereby altering their behavior and detection probability has been the subject of much research (Ona and Godo 1990, Mitson 1995, Handegard et al. 2003). Vessel avoidance is defined as a zero detection probability resulting from a change in behavior due to the vessel noise, but even less severe changes in behavior may affect S_v measurements and the detection probability. The ICES Cooperative Research Report No. 209 (Mitson 1995) provides guidelines for making noise range measurements and gives recommendations for dealing with vessel noise and avoidance, including, in particular, proposed standards for underwater radiated noise levels in the design of new vessels. Underwater noise levels should be determined for vessels to be used in fishery research that do not conform to the ICES standard. Mitson (1995) recommends that 'observations should be carried out whenever possible to relate the known (measured) characteristics of a vessel to any observed avoidance behavior of fish, or to noise affecting acoustic survey equipment.'

Multiple scattering and shadowing

The theory of the linear summation of individual echo strengths within a sampling volume is valid for a wide range of organism densities (Foote, 1983b). However, when organism densities are high, multiple scattering (echoes have scattered off multiple individuals before returning to the transducer) and shadowing (similar to bubble attenuation, the pressure wave amplitude decreases at a greater rate than explained by transmission loss) have non-linear affects on the summation of echoes within a sampling volume (MacLennan 1990, Toresen 1991).

Error

Uncertainty in detection probabilities of target and non-target species affects interpretation of S_v measurements and the efficacy of post-processing techniques. Systematic and random changes in detection probabilities during the survey will have linear and non-linear effects on S_v measurements. A systematic change in fish orientation, for example, from a horizontal to a more vertical position during vertical migration, will cause a decrease in the volume backscattering. If factors such as orientation are not taken into account, it might appear that there are fewer or smaller fish. Thresholding the S_v data could compound the error in abundance estimates.

Considerations

Remediation

The survey design (timing and location) should consider potential systematic changes in detection probability. If systematic changes in detection probability are discovered, either a change in the survey design is required or analyses should be conducted to determine a correction factor. If significant changes are made to the survey vessel that are expected to affect vessel-generated noise (e.g. major modifications to propeller, generators, or main engine), noise-range measurements should be conducted.

Improvements

The first of four low-noise NOAA survey vessels is currently under construction and will begin survey work for the AFSC in 2005. The NEFSC, NWFSC, and SWFSC will each receive one of the other vessels. All four vessels will meet ICES noise standards, which will greatly reduce the potential for vessel noise affecting fish behavior.

Classification

Definition & Importance

Classification is the discrimination and identification of organism type or species during an acoustic survey. Discrimination refers to the process of separating targets of interest from other targets and noise.

Fisheries acoustics surveys are designed to provide density and abundance estimates, usually age or length-based, for one or more target species. A critical requirement, therefore, is to separate backscatter of the target species from all other backscatter. This is done in two steps. First, noise from unwanted sources such as plankton (if not the object of the survey), air bubbles, bottom echoes, and electrical interference is removed. Then, the remaining targets are apportioned between species or groups of species of fish or plankton. The main technique used for this purpose is inspection of echograms. Partitioning of echo integration data is aided by application of an appropriate S_v threshold (S_v Detection Probability section) and a survey design chosen so that the target species is favorably distributed away from boundaries and in schools or layers that are mono-specific and easily identified. The main source of information used to validate interpretation of echograms is net catches. Other potential sources of validation data are underwater video and use of multiple frequency acoustic data.

Techniques

Single Frequency

The standard frequency for estimating density and abundance of marine fish species is 38 kHz; and for krill, 120 kHz. Echo sounders operating at 38 kHz are able to detect fish with swimbladders, and aggregations of macrozooplankton such as krill. Fish without swim bladders are more difficult to detect with either of these two frequencies. However, the ability to measure backscatter from a diversity of species at reasonable ranges make both of these frequencies useful. A disadvantage is that separating backscatter from target species can be difficult. Thus, multiple frequency data are often utilized in conjunction with biological sampling as an aid in classification of the acoustic returns (Reid 2000).

Multiple Frequency

Multiple frequency data include multiple narrow-band (single frequency) echo sounders and broadband sonars. Currently, broadband systems are not routinely used for surveys. The efficacy of multiple narrow-band frequencies in classification of acoustical backscatter is based on the frequency-dependent scattering by different types of organisms. In the simplest application, echograms from several frequencies are visually compared, and qualitative differences are noted and used to help classify targets or layers. Multi-frequency algorithms have been developed for some applications to make quantitative comparisons, but they are not in use at NOAA in routine surveys of fish

Biological Sampling

Trawls

Pelagic trawls are the primary tools for validating the species composition of acoustic backscatter and for obtaining length frequency distribution, age, and other biological information. Trawls provide the best available method of obtaining relatively unbiased estimates of species and size composition (Simmonds *et al*. 1992). Appropriate trawl gear should be chosen with full consideration of its size in relation to the towing power of the vessel. The number, locations, and timing of trawl sets are dependent on the objectives of the survey, but the main idea is to obtain catches that are representative of the species composition and the length-frequency distribution of organisms detected acoustically. This is a difficult to accomplish because nearly all biological sampling methods are species and size selective.

Different parts of a school or layer may have different length-frequency distributions or even different species compositions, and a single school may not be representative of the cluster of schools in an area. For this reason, hauls should include more than one small school and more than one part of a large school or layer if this can be done without taking a sample that cannot be handled by the vessel.

Trawls in acoustical surveys are targeted on schools or layers detected by the echo sounder. Such aimed trawling requires effective net mensuration instrumentation. Net mensuration instrumentation choices include door and wing sensors, third-wire sensors, depth sensors, and head- and footrope sensors. Although net catches for hauls made during acoustical surveys are not used for estimating fish biomass, it is still important that trawl procedures are consistent between and within surveys. Net mensuration information is essential for maintaining consistency and evaluating performance in trawl procedures.

In many cases trawl catches are too large to sample in their entirety, and must be sub-sampled. Even when an entire trawl catch is processed for species composition by weight and number, additional information such as age, fish length and sex cannot, in most cases, be taken from all captured specimens. Thus, random sub-samples of the catch should be taken to obtain the biological information. Determination of the sub-sample size should be guided by statistical principles.

Protocols for setting and retrieving the net should be based on the type of net and vessel. Vessel personnel play a key role in maintaining repeatability in net deployment, and should be briefed on the importance of adhering to protocols. They should have a copy of the protocols and should be consulted in the development of the trawl field manual. Routine inspections of the gear should be made to confirm that it conforms to design specifications. This is especially important after nets have been damaged and repaired in the field.

A schedule for calibration and maintenance of net mensuration equipment should follow the manufacturer's recommendations. If possible, spare parts or complete backup systems should be available for all critical net mensuration instruments.

Underwater video.

Underwater video and still-camera systems provide visual identification of species and has the potential to document behavior. Limitations of underwater video include small detection ranges and volumes (order of meters) and potential disruption of behavior. Because of the limited light penetration in water, cameras must be positioned near the targets of interest and often, artificial lighting must be used. These two factors complicate acquisition of visual data for species identification and potentially alter the behavior of the organisms. Additional sensors, such as altimeters or depth sensors and towbody orientation sensors (tilt, roll, and pitch) are also required to quantify the data for behavioral measurements.

Bottom Tracking

Echo sounders and post-processing software use algorithms to detect the seabed. Performance of these algorithms depends on bottom type and topography. On hard, flat substrate, the algorithms perform well. On soft substrate, or rugged topography, the ability to accurately detect the water-seabed interface is reduced. The echo return from the seabed is typically orders of magnitude greater than that from organisms, so it is critical to eliminate seabed echoes from the water column data. Improper bottom detections are found and corrected manually through inspection of the echograms. Bottom detection parameters used during data collection and in post-processing should be documented.

Error

Uncertainty in classifying and separating acoustic backscatter by target species from non-target species is a potential source of error in acoustic estimates of density and abundance. Possible errors include misclassification (either incorporating volume backscatter by non-target species or eliminating volume backscatter by target species), scaling acoustic data with trawl catch data that are not representative of species composition or length- and age-frequency distributions, incorporating seabed echoes in water column data, use of an inappropriate attenuation coefficient, and improper calibration of echo sounder systems and temperature and salinity sensors.

Considerations

Remediation

Determining whether trawl catch data are representative of species composition and length- and age-frequency distributions is complex. Comparison of data from different gear types used from the same vessel as close in time and space as possible could be useful in evaluating potential errors and designing corrections to be applied.

Improvements

Improvements in bottom tracking algorithms will greatly increase the efficiency of post-processing acoustic data and improve accuracy of the estimates. A bottom tracking algorithm failure in real-time might be corrected with a post-processing algorithm (such as that available in

Echoview) or by comparison with or substitution by bottom detect data from a second echo sounder or frequency.

Introduction of new opening-closing nets with multiple cod ends attached to the end of a standard trawl will allow more discrete sampling. Trawls currently in use sample mid-water layers and schools of fish continuously throughout a deployment. Thus, samples of deeper layers contain fish caught in shallow layers, because the net is open on descent and ascent. Use of opening-closing gear will result in better characterization of targeted schools and layers, and will result more accurate length-frequency distributions.

Multiple frequency data include multiple narrow-band (single frequency) echo sounders and broadband sonars. Currently, broadband systems are not routinely used for surveys. Both broadband and multiple frequency systems are undergoing intensive development and testing, and may be introduced soon, at least on an experimental basis. Although some success has been achieved, especially for zooplankton (e.g., Martin *et al.* 1996), problems such as differences in the insonified volume between frequencies, short ranges associated with high frequencies, and change in noise levels with frequency must be overcome (see Reid (2000) for a brief review and bibliography). Such methods seem promising, and although multi-frequency studies of fish are still in their infancy, they are likely to be part of routine surveys in the future. Protocols for their use will be developed along with the systems themselves.

Underwater video and low ambient light level still-camera systems provide visual identification of species and have the potential to document behavior. Limitations of underwater video include small detection ranges and volumes (order of meters) and potential disruption of behavior. Because of the limited light penetration in water, cameras must be positioned near the targets of interest and often, artificial lighting must be used. These two factors complicate acquisition of visual data for species identification and potentially alter the behavior of the organisms. Additional sensors, such as altimeters or depth sensors and towed body orientation sensors (tilt, roll, and pitch) are also needed to quantify the data for behavioral measurements. Underwater video methods and techniques are currently under development. If these methods and techniques become routine part of a survey, protocols should be developed for video maintenance, data collection and archiving, and data analysis.

Performance Degradation

Definition & Importance

Performance degradation is the reduction in echo sounder performance due to mechanical, biological, or electrical processes.

Degradation in echo sounder performance can be caused by acoustical, vessel, and electrical noise, bio-fouling of the transducer face, excessive transducer motion, and bubble attenuation. Performance degradation differs from system performance in that the causes of performance degradation are external to the echo sounder, where as ‘system performance’ concerns the echo sounder electronics.

Routine monitoring of data by scientific personnel during data collection is necessary to ensure a high standard of data quality.

Techniques

Noise

Acoustical

A common type of acoustic noise is a discreet spike caused by another echo sounder or sonar operating within the frequency bandwidth or a harmonic of the scientific echo sounder. The solution is to identify the source of the interference and shut it down. A list of all acoustic systems with associated operating frequencies can aid in identifying the interfering system. Interference can be eliminated if acoustical instrumentation essential for safe ship operation is synchronized with the survey echo sounder. Removal of acoustic noise during post-processing is sometimes possible, but difficult, so eliminating it during the survey is always preferable.

Electrical

Electrical noise can be of many types. Electrical interference caused by improper grounding or other electrical systems can cause low-level voltage interference, spikes, or cyclical interference. A low level voltage introduced to the echo sounder can be amplified with range by the TVG function, and may pose a problem only in the deeper parts of the survey area. Problems can be reduced or eliminated by ensuring proper grounding of the scientific echo sounder, by using an uninterruptible power supply (UPS) for the scientific echo sounder, and by eliminating electrical interference during data collection. Electrical interference not eliminated during data collection should be removed during post-processing, either manually or with signal processing techniques. If signal processing techniques are used, care should be taken to ensure that target data is not modified, or correction factors may be required.

Bubble Attenuation

Bubbles can have a strong effect on propagation and transmission of sound. Due to the high acoustic impedance between air and water, bubbles are efficient scatterers of sound. Bubbles can increase attenuation (loss of signal strength) and potentially increase the probability of misclassification of gas-bearing organisms. Bubbles near the sea surface are generally associated with increased sea state and/or the position of the transducer relative to the vessel's hull. The transducer location on the hull must be chosen to minimize potential problems caused by bubbles. To prevent degradation of survey data, it is necessary to slow vessel speed or suspend acoustic survey operations when sea state causes unacceptable bubble attenuation. Currently, this decision is based on the judgment of the scientific field party chief, but explicit criteria need to be developed. In some cases, bubble backscattering can be removed from S_v data during post-processing, but this will not correct signal loss from targets of interest.

Transducer Motion

Excessive transducer motion is associated with increased sea state. Transducer motion affects bottom tracking, target strength and volume backscattering measurements. 'Dropouts' (i.e., reduction or elimination of S_v values over one or more pings) observed on the echogram are a clear indication of excessive transducer motion. If the vessel is outfitted with a motion sensor, these data should be recorded. Motion sensor data may be used for objective decisions on acoustic data quality or for making corrections to the acoustic data. Such corrections may be as high as 30% (MacLennan and Simmonds 1992). When sea state or vessel motion is excessive, as judged by the field party chief, survey speed must be slowed or operations must be suspended.

Bio-fouling

Bio-fouling can occur on hull-mounted transducers or protective coverings that stay in the water for long periods of time. Accumulation of material on the transducer will reduce the transmitted and received sensitivity, and this reduction may not be recognized by system performance procedures, although it should be detected by calibration. Hull-mounted transducers and protective coverings should be checked and cleaned regularly, and at a minimum before each field season.

Error

Bio-fouling will cause a systematic degradation in echo sounder performance as the bio-fouling increases. Transducer motion effects increase with increasing sea states, but the overall effect on abundance estimates requires investigation. Near-surface bubbles can be removed from the data during post-processing, however the resulting effects of bubble attenuation on S_v and acoustical estimates need to be studied. Most types of electrical and acoustical noise can be eliminated during data collection or post-processing. Noise that cannot be removed will increase S_v measurements and lead to overestimates of fish biomass.

Considerations

Remediation

If noise issues are found to be a problem, then analyses are required to determine the effects on S_v measurements. In most cases, noise can be removed from the data set by eliminating the problematic pings, but if the noise persists for long periods, removal is more difficult.

If motion sensor data are available, corrections can be made to the acoustic measurements (Dunford 2002).

Improvements

Better understanding of the effects of transducer motion and bubble attenuation will improve our ability to make adjustments to the S_v data or make objective decisions on when conditions preclude collecting useful data. The timing of pulses emitted by the echo sounder can be adjusted (adaptive pulse timing) so that the necessary correction is minimized. (Dunford 2002).

Systematic analyses are recommended to determine the effects of performance degradation on data quality. Results of these analyses will improve (or at least make possible) objective decisions during data collection.

<u>Data Management</u>

Volume backscattering data, post-processed data, biological, and associated meta-data should be routinely archived during the survey. These data are downloaded to shore-based computers and permanently archived for each survey. In addition to data, post-processing and other software should be archived.

Target Strength ($_i$)

Target strength and backscattering cross sectional area are the ability of a target to scatter sound back to the receiver. Target strength (TS) is defined as the base 10 logarithm of an intensity ratio:

$$TS \equiv 10\log_{10}\left(\frac{I_r}{I_i}\right)\text{dB re }1\,\mu\text{Pa} \tag{3}$$

where I_r is the received intensity, and I_i is the incident intensity at a distance of 1 m. The linear form of target strength is the backscattering cross sectional area ($\square_{bs}$):

$$\sigma_{bs} \equiv \left(\frac{I_{bs}}{I_i}\right)\quad [\text{m}^2] \tag{4}$$

$$\sigma_{bs} = 10^{\left(TS/10\right)} \tag{5}$$

The term ‘target strength’ is often used as a generic reference to the backscattering characteristics of the target. One must be very careful to recognize that TS is a logarithmic value and not to confuse TS with the linear $\square_{bs}$ when performing calculations.

When converting volume backscattering measurements (S_v) to numeric densities (# m^{-3}), the calibrated echo energy (CE_i in equation 2) is scaled by the backscattering cross sectional area ($\square_i$ in equation 2). Thus, an accurate $\square_{bs}$ is critical for accurate density and abundance estimates.

Two general methods are available for obtaining an estimate of $\square_{bs}$. When organisms are acoustically resolvable, the *in situ* TS values from individuals can be used to scale S_v. When organisms are not acoustically resolvable, the $\square_{bs}$ must be estimated by other means. A common method to estimate $\square_{bs}$ is to use trawl catch length-frequency distributions and convert organism length (or some other metric of size) to target strength. This method requires a conversion from organism size to target strength. An empirically derived regression of the form TS = $\square\log_{10}(L)+\square$, where L is fish length, is commonly used where □ is traditionally set equal to 20 (Foote, 1987). Deriving this regression for surveyed species is not trivial. The regression requires a combination of *in situ* (if available) and *ex situ* measurements, and if possible, theoretical predictions of individual backscatter. Additionally, this equation is frequency dependent and should incorporate organism behavior and vertical distribution of target species encountered during the survey.

The treatment of target strength for abundance estimates depends on the objectives and use of acoustical estimates in fisheries assessments. Acoustic-based estimates as relative indices require a constant target strength over time and among surveys. If acoustical abundance estimates are to be used as absolute values, accurate TS measurements must be obtained for every survey. Due to the complexity involved with deriving an accurate TS-length equation, acoustical estimates are often treated as relative abundances.

Models

Definition & Importance

Acoustical models used in fisheries acoustics are mathematical constructs derived to describe a relationship between acoustical energy and biological metrics.

Acoustical backscattering models include numerical and analytical derivations based on acoustical theory, and empirically derived relationships between acoustical energy and biological metrics. These models are used to predict acoustical backscattering by the species being surveyed.

Techniques

Theoretical

Numerical and analytical models have been developed to predict acoustical backscatter as a function of organism size, shape, anatomical characteristics, orientation, and acoustic frequency for zooplankton and fish. These models have advantages and limitations when applied to different organism types. The models range in complexity from approximating organism anatomy and morphometry as simple shapes to utilizing three-dimensional digital images of organism internal structures. Advantages to theoretical models are that once verified, predictions over a wide range of conditions (*i.e.*, acoustic frequency, behavior, biological state) can be tabulated. Difficulties with applying models to survey data are obtaining accurate representations of *in situ* organism anatomy, morphometry and orientation, and verifying the predictions. Currently for fish, model results have only been used to develop a TS-length equation for Atlantic herring in the North Sea.

Empirical

Empirical methods relating target strength to organism size include *in situ* measurements and *ex situ* laboratory experiments. *In situ* methods are advantageous because the target strengths incorporate behaviors and vertical distributions observed during the survey. Limitations are obtaining representative length-frequency distributions of the insonified organisms, the organisms must be acoustically resolved, and predictions are limited to the range of organism size and behavior observed. *Ex situ* measurements are controlled or semi-controlled experiments where individuals or groups of known sizes are insonified. Disadvantages to *ex situ* measurements are difficulties in replicating *in situ* conditions and uncertainty in applying *ex situ* measurements to survey conditions.

Validation

Validating target strength measurements relative to organism size, behavior, and biological conditions encountered during surveys is difficult. Empirical methods are limited to the range of measurements. Numerical and analytical models can predict acoustical scattering over a wide range of conditions, but verifying model predictions is difficult.

Error

If volume backscattering measurements are to be converted from relative indices to absolute values, accuracy and precision of target strength measurements are critical. Assuming correctly calibrated echo sounders, target strength is the sole scalar for calculating absolute density. A 3 dB error in target strength leads to a factor of two in uncertainty for density and abundance estimates. Due to the complex nature of organism anatomy and behavior, acoustical backscattering by biological targets is complicated. Uncertainty in target strength measurements and predictions is a combination of systematic and random errors, which can be difficult to separate.

Considerations

Remediation

If a TS-length regression is found to be incorrect or numerical and analytical model predictions are found to be erroneous, and these results were incorporated in survey estimates, then analyses must be performed to determine the effect of these errors in population estimates.

Improvements

Significant effort improving and verifying target strength predictions by numerical and analytical models is required. Improved understanding and characterization of target strength relative to organism size and behavior is required. Even if TS measurements are not directly used in survey estimates, target strengths can be useful for evaluating changes in S_v.

<u>Data Collection</u>

Definition & Importance

Target strength data collection is the operational procedures used to acoustically resolve individuals.

Target strength is an important scalar for converting S_v measurements to absolute values. Organisms must be acoustically resolvable for valid target strength measurements. Acoustic resolution is defined as the ability to separate echoes among individuals and is based on the pulse duration (□) and sound speed (c):

$$R_2 - R_1 > \frac{c\tau}{2} \qquad (6)$$

where the R's are the ranges for two targets (subscript 1 and 2) (MacLennan and Simmonds, 1992).

Techniques

Echo sounder Parameters

A generic method to separate echoes by individuals involves selecting peak amplitudes above a threshold, measuring the echo width (either time- or range-based), and comparing the echo width to the pulse duration. Different echo sounder manufacturers apply this single target detection method differently. It is important to understand the specific method the echo sounder uses and the parameter settings employed.

Software

As with echo sounder manufacturers, different post-processing software packages apply single target detection algorithms differently. It is important to understand the specific method and parameters used by post-processing software, and to document the algorithms, parameters, and software versions.

In situ data

Collecting *in situ* target strength data should be a routine operation during surveys and is as important as collecting biological data regardless of the ultimate use of target strength data in survey estimates. Target strength data can be collected while transecting and/or at selected sites. Numbers, locations, and timing of target strength operations are dependent on the objectives of the survey.

GPS

Integrating Global Positioning System (GPS) data with TS measurements are imperative for using target strength data in survey estimates. Choice of positioning data is dependent on the availability of the GPS systems on-board, performance of the GPS over the survey area, compatibility of the GPS system with the echo sounder, and the desired accuracy and precision of the GPS data.

Oceanographic Data

Sea-surface and vertical profiles of temperature and salinity are required for ensuring that the sound speed is calculated correctly. Sea-surface and vertical profiles of temperature and salinity should be collected in conjunction with target strength data. Temperature and salinity data can also be useful for measuring the physical environment for ecological studies

Oceanographic sensor manufacturers provide calibration, operational, and diagnostic instructions. These instructions should be followed.

Error

Uncertainty in single target detection parameters and data collection procedures affects the accuracy and precision of target strength data. Systematic or random errors in selecting and relating target strength data to S_v measurements will influence population estimates by introducing errors in the scaling of S_v data to estimates of density and abundance.

Considerations

Remediation

Application of target strength data to S_v measurements is completed after the survey has been completed and is a component of deriving abundance and biomass estimates. Collecting *in situ* target strength measurements requires calibrated echo sounders, and remediation protocols equivalent to those used for S_v measurements should be maintained.

Improvements

Improvements in single target detection, such as multiple frequency techniques (Demer et al., 1999), will increase the accuracy and precision of target strength measurements and ultimately survey estimates.

<u>Detection Probability</u>

Definition & Importance

Target strength detection probability is the likelihood of detecting echoes from individual organisms.

Single target detection probability is dependent on the TS threshold and other parameter settings ('Target Strength Data Collection' section) and the behavior of the organisms. Organism orientation strongly affects target strength, as does the vertical distribution. Organisms on the edge of the beam will have lower detection probabilities due to the acoustic beam pattern. Organisms near the surface and seabed will also have lower detection probabilities.

Techniques

Beam Pattern

Transducers used in fisheries acoustics are used to transmit and receive sound. These transducers are directional where the sensitivity decreases as a function of angular distance from the acoustic axis. Relevant transducer parameters for target strength measurements are the beam width and the directivity response function. Beam width is measured as the total angular distance at the half-power points (i.e., 3 dB ‘down-points’). The directivity response is measured as the two-way (transmit and receive) sensitivity as a function of angular location in the acoustic beam. The two-way integrated beam pattern (□) used in S_v measurements is the surface integration of the directivity response function. Due to the directivity of a transducer, the echo strength of an organism will be greater on-axis than off-axis. To measure the target strength of the organism, the echo strength must be compensated for location in the acoustic beam. Split-beam transducers measure the angular location of a target and compensate echo strength by the directivity response.

Thresholding

The first criterion for single target detection is the TS threshold, where peak echo amplitudes greater than the threshold are further evaluated as single targets. Thresholding is useful for eliminating target strength measurements from non-target organisms. However, applying a TS threshold can eliminate target strengths from desired species. Thus selecting an optimal threshold should incorporate knowledge of targets strengths from the species of interest and non-target species and the behavior of the targets.

Acoustic Dead Zones: Near Bottom and Near Surface

Similar to S_v measurements, organisms located above the transducer and within a few meters of the transducer are not measured. In addition, organisms must be in the far field of the transducer for valid target strength measurements. Resolving organisms near the seabed is dependent on the range resolution of the echo sounder (pulse length dependent) and the topography of the bottom. Single target detection probabilities near the seabed are reduced over rough bottom topography.

Animal Behavior

Organism behavior includes activities such as vertical migration, swimming, and feeding and the orientation of the organism relative to the transducer. In general, for acoustic frequencies in the geometric scattering region, target strength is greatest when the major axis of the organism is aligned perpendicular to the transducer. In the case of fish with swimbladders, maximum TS occurs when the major axis of the swimbladder is aligned perpendicular to the transducer. Target strength decreases significantly as the major axis of the organism aligns parallel to the acoustic axis. The detection probability may be dependent on organism orientation if the target strength at low aspect angles is below the TS threshold.

Vessel Noise

Vessels radiate underwater noise. Depending on the characteristics of the noise spectrum, a number of fish species are able to detect the vessel noise. An issue is whether the fish react to the vessel noise, thereby altering their behavior and detection probability. Vessel avoidance is defined as a zero detection probability resulting from a change in behavior due to the vessel noise. Less severe changes in behavior may affect the TS measurements and the detection probability. Urick (1983) details radiated vessel noise. The ICES Cooperative Report (Mitson 1995) provides an overview of the issues relating to acoustical surveys of fish.

Avoidance of fisheries vessels is a complex issue. A number of fish species have the ability to detect vessel noise, but whether avoidance or other behavioral changes occur is difficult to document. Physical environmental conditions such as the presence of a thermocline or halocline, animal vertical distribution, and biological factors such as spawning or feeding combine to influence organism behavior. Fundamental methods for investigating vessel avoidance are to obtain a vessel noise spectrum and to monitor the vessel noise during a survey.

Density Requirements

Single target detections are dependent on the range resolution and the density of organisms. As the organism density increases, the distance between organisms decreases to where single target discrimination is not feasible. At increased ranges, the signal-to-noise ratio (SNR) increases, which decreases the ability to detect single targets. Methods to objectively determine when single target detections are valid (Sawada *et al.* 1993; Gauthier and Rose, 2001) have been developed and should be used when incorporating *in situ* TS measurements.

Single Frequency

Methods using single frequency data have been derived to estimate the density at which valid TS measurements can be obtained (Sawada *et al.* 1993; Gauthier and Rose, 2001). These methods require *a priori* knowledge of the target strength distribution.

Multiple Frequency

A method to increase the accuracy and precision of target strength measurements using multiple frequencies was derived by Demer et al. (1999). Using the geometry of the transducer locations (accurate measurements of the transducer locations are required) and acoustical beam directivities (accurate measurements of the beam directivities are required), improper single-target detections by individual frequency algorithms are greatly reduced, thus increasing confidence in *in situ* TS measurements.

Error

When using a calibrated echo sounder, target strength is the sole scaling factor for converting relative indices to absolute estimates. Thus obtaining a representative target strength for the target species is imperative. Systematic and random changes in detection probabilities during the survey will have linear and non-linear effects on target strength measurements. Uncertainties in target strength detection probabilities will affect *in situ* target strength measurements and ultimately bias scaling S_v measurements to absolute density estimates. Uncertainty in detection probabilities of target and non-target species affects interpretation of target strength measurements and the efficacy of post-processing techniques. Errors in beam pattern measurements and echo sounder gains will contribute to systematic biases of TS measurements. Improper thresholds may unnecessarily eliminate or include measurements of non-target species, which will systematically bias measured target strength distributions. Vessel noise and behavioral attributes may introduce random errors in target strength measurements. A systematic change in fish orientation, for example, from a horizontal to a more vertical position during vertical migration, will cause a decrease in TS. If factors such as orientation are not taken into account, target strength to length regressions will be in error.

Considerations

Remediation

The survey design (timing and location) should consider potential systematic changes in detection probability. If systematic changes in detection probability are discovered, either a change in the survey design is required or analyses should be conducted to determine a correction factor. If significant changes are made to the survey vessel that are expected to affect vessel-generated noise (e.g. major modifications to propeller, generators, or main engine), noise-range measurements should be conducted.

The TS threshold should be modified if organisms on the lower end of the target strength distribution are not detected.

If beam pattern and TS gain calibrations indicate problems with the echo sounder and transducer, these problems need to be evaluated (refer to the Calibration section) before the survey can commence.

Improvements

Incorporating theoretical acoustical backscattering models to determine target strength distributions may improve operational protocols for collecting target strength measurements. Simulations of the effects of detection probability on absolute density and abundance estimates should be conducted to determine the extent of biases in population estimates.

The first of four low-noise NOAA survey vessels is currently under construction and will begin survey work for the AFSC in 2005. The NEFSC, NWFSC, and SWFSC will each receive one of the other vessels. All four vessels will meet ICES noise standards, which will greatly reduce the potential for vessel noise affecting fish behavior.

<u>Classification</u>

Definition & Importance

Classification is the discrimination, categorization, and identification of organism type or species.

Target strength measurements are used to scale S_v measurements to absolute density and abundance. Target strength measurements are classified to species and age- or length-classes based on acoustical and ancillary information. Scaling species and age- or length-based S_v measurements requires that target strength measurements be obtained from the species of interest, which requires classification of target strength measurements.

Techniques

Single Frequency

In mixed-species aggregation or even single-species aggregation conditions, classifying target strength measurements using single frequencies is difficult. The standard frequency for estimating density and abundance of marine fish species is 38 kHz. Echo sounders operating at 38 kHz are able to detect juvenile and adult fish with a swimbladder, juvenile and adult fish without a swimbladder, and macrozooplankton such as euphausiids and krill. The ability to measure backscatter by a wide variety of organisms is advantageous in that 38-kHz echo sounders can be used for a diversity of species. The disadvantage is separating backscatter from target species is difficult. Due to this difficulty, multiple frequency data are utilized in conjunction with biological sampling to classify acoustical data to species.

Multiple Frequency

Multiple frequency data include multiple narrow-band (single frequency) echo sounders and broadband sonars. Currently, broadband systems are not routinely used for surveys. The efficacy of multiple narrow-band frequencies to classify target strength data is based on the frequency dependent scattering by different types of organisms. In general, more frequencies do not necessarily equate to better classification, but a judicious choice of frequencies can improve classification techniques.

Biological Sampling

Trawls

Pelagic trawls are the primary tools for validating the species composition of acoustic backscatter and for obtaining length frequency distribution, age, and other biological information. Trawls provide the best available method of obtaining relatively unbiased estimates of species and size composition (Simmonds *et al*. 1992). Appropriate trawl gear should be chosen with full consideration of its size in relation to the towing power of the vessel. The number, locations, and timing of trawl sets are dependent on the objectives of the survey, but the main idea is to obtain catches that are representative of the species composition and the length-frequency distribution of organisms detected acoustically. This is a difficult to accomplish because nearly all biological sampling methods are species and size selective.

Different parts of a school or layer may have different length-frequency distributions or even different species compositions, and a single school may not be representative of the cluster of schools in an area. For this reason, hauls should include more than one small school and more than one part of a large school or layer if this can be done without taking a sample that cannot be handled by the vessel.

Trawls in acoustical surveys are targeted on schools or layers detected by the echo sounder. Such aimed trawling requires effective net mensuration instrumentation. Net mensuration instrumentation choices include door and wing sensors, third-wire sensors, depth sensors, and head- and footrope sensors. Although net catches for hauls made during acoustical surveys are not used for estimating fish biomass, it is still important that trawl procedures are consistent between and within surveys. Net mensuration information is essential for maintaining consistency and evaluating performance in trawl procedures.

In many cases trawl catches are too large to sample in their entirety, and must be sub-sampled. Even when an entire trawl catch is processed for species composition by weight and number, additional information such as age, fish length and sex cannot, in most cases, be taken from all captured specimens. Thus, random sub-samples of the catch should be taken to obtain the biological information. Determination of the sub-sample size should be guided by statistical principles.

Protocols for setting and retrieving the net should be based on the type of net and vessel. Vessel personnel play a key role in maintaining repeatability in net deployment, and should be briefed on the importance of adhering to protocols. They should have a copy of the protocols and should be consulted in the development of the trawl field manual. Routine inspections of the gear should be made to confirm that it conforms to design specifications. This is especially important after nets have been damaged and repaired in the field.

A schedule for calibration and maintenance of net mensuration equipment should follow the manufacturer's recommendations. If possible, spare parts or complete backup systems should be available for all critical net mensuration instruments.

Underwater video.

Underwater video and still-camera systems provide visual identification of species and potentially can document behavior. Limitations of underwater video include small detection ranges and volumes (order of meters) and potential disruption of behavior. Because of the limited light penetration in water, cameras must be positioned near the targets of interest and often, artificial lighting must be used. These two factors complicate acquisition of visual data for species identification and potentially alter the behavior of the organisms. Additional sensors, such as altimeters or depth sensors and towbody orientation sensors (tilt, roll, and pitch) are also required to quantify the data for behavioral measurements.

Bottom Tracking

Echo sounders and post-processing software use algorithms to detect the seabed. Depending on bottom type and topography, performance of these algorithms varies. On hard, flat substrate, the algorithms perform well. On soft substrate, or rugged topography, the ability to accurately detect the bottom degrades. The echo strength from the seabed is typically orders of magnitude greater than the echo strength from biological organisms, thus eliminating seabed echoes from the water column data is imperative. Improper bottom detections are found and corrected manually through inspection of the echograms. Bottom detection parameters used during data collection and in post-processing should be documented.

Error

When using a calibrated echo sounder, target strength is the sole scaling factor for converting relative indices to absolute estimates. Thus obtaining a representative target strength for the species of interest is imperative. Uncertainty in target strength classification will increase biases when scaling S_v measurements to absolute density and abundance estimates. Uncertainty in classifying and separating acoustic backscatter by target species from non-target species is a potential source of error in acoustical estimates of density and abundance. Possible errors include misclassification (either incorporating target strengths by non-target species or eliminating target strengths by target species), relating target strength measurements to trawl catch data that are not representative of species composition or length- and age-frequency distributions, incorporating seabed echoes in water column data, use of an inappropriate attenuation coefficient, and improper calibration of echo sounder systems and temperature and salinity sensors.

Considerations

Remediation

Determining whether trawl catch data are representative of species composition and length- and age-frequency distributions is complex. Comparison of data from different gear types used from the same vessel as close in time and space as possible could be useful in evaluating potential errors and designing corrections to be applied.

Improvements

Improvements in bottom tracking algorithms will greatly increase the efficiency of post-processing acoustic data and improve accuracy of the target strength distributions for demersal species. A bottom tracking algorithm failure in real-time might be corrected with a post-processing algorithm (such as that available in Echoview) or by comparison with or substitution by bottom detect data from a second echo sounder or frequency.

Introduction of new opening-closing nets with multiple cod ends attached to the end of a standard trawl will allow more discrete sampling. Trawls currently in use sample mid-water layers and schools of fish continuously throughout a deployment. Thus, samples of deeper layers contain fish caught in shallow layers, because the net is open on descent and ascent. Use of opening-closing gear will result in better characterization of targeted schools and layers, and will result more accurate length-frequency distributions and relationships of target strength to length.

Multiple frequency data include multiple narrow-band (single frequency) echo sounders and broadband sonars. Currently, broadband systems are not routinely used for surveys. Both broadband and multiple frequency systems are undergoing intensive development and testing, and may be introduced soon, at least on an experimental basis. Although some success has been achieved, especially for zooplankton (e.g., Martin *et al*. 1996), problems such as differences in the insonified volume between frequencies, short ranges associated with high frequencies, and change in noise levels with frequency must be overcome (see Reid (2000) for a brief review and bibliography). Such methods seem promising, and although multi-frequency studies of fish are still in their infancy, they are likely to be part of routine surveys in the future. Protocols for their use will be developed along with the systems themselves.

Underwater video and low ambient light level still-camera systems provide visual identification of species and have the potential to document behavior. Limitations of underwater video include small detection ranges and volumes (order of meters) and potential disruption of behavior. Because of the limited light penetration in water, cameras must be positioned near the targets of interest and often, artificial lighting must be used. These two factors complicate acquisition of visual data for species identification and potentially alter the behavior of the organisms. Additional sensors, such as altimeters or depth sensors and towed body orientation sensors (tilt, roll, and pitch) are also needed to quantify the data for behavioral measurements. Underwater video methods and techniques are currently under development. If these methods and techniques become routine part of a survey, protocols should be developed for video maintenance, data collection and archiving, and data analysis.

Developing objective classification criteria will require incorporating theoretical acoustical backscattering models and *ex situ* laboratory measurements in classification techniques. The integration of *in situ* and *ex situ* measurements and analytical predictions as routine methods will significantly improve our ability to classify and identify acoustical backscattering and improve the accuracy and precision of population estimates.

Performance Degradation

Definition & Importance

Performance degradation is the reduction in echo sounder performance due to mechanical, biological, or electrical processes and mechanisms.

Degradation in echo sounder performance can be caused by acoustical and electrical noise, bio-fouling of the transducer face or cables, excessive transducer motion, and bubble attenuation. Performance degradation differs from system performance in that the causes of performance degradation are external to the echo sounder, where as system performance accounts for the echo sounder electronics. Additionally, performance degradation is often not observed until the resulting effects are greater than the TS threshold.

Routine monitoring of data by scientific personnel during data collection is necessary to ensure a high standard of data quality.

Techniques

Noise

Acoustical

A common type of acoustic noise is a discreet spike caused by another echo sounder or sonar operating within the frequency bandwidth or a harmonic of the scientific echo sounder. The solution is to identify the source of the interference and shut it down. A list of all acoustic systems with associated operating frequencies can aid in identifying the interfering system. Interference can be eliminated if acoustical instrumentation essential for safe ship operation is synchronized with the survey echo sounder. Removal of acoustic noise during post-processing is sometimes possible, but difficult, so eliminating it during the survey is always preferable.

Electrical

Electrical noise can be of many types. Electrical interference caused by improper grounding or other electrical systems can cause low-level voltage interference, spikes, or cyclical interference. A low level voltage introduced to the echo sounder can be amplified with range by the TVG function, and may pose a problem only in the deeper parts of the survey area. Problems can be reduced or eliminated by ensuring proper grounding of the scientific echo sounder, by using an uninterruptible power supply (UPS) for the scientific echo sounder, and by eliminating electrical interference during data collection. Electrical interference not eliminated during data collection should be removed during post-processing, either manually or with signal processing techniques. If signal processing techniques are used, care should be taken to ensure that target strength distributions are not modified, or correction factors may be required.

Bubble Attenuation

Bubbles can have a strong effect on propagation and transmission of sound. Due to the high acoustic impedance between air and water, bubbles are efficient scatterers of sound. Bubbles can increase attenuation (loss of signal strength) and potentially increase the probability of misclassification of gas-bearing organisms. Bubbles near the sea surface are generally associated with increased sea state and/or the position of the transducer relative to the vessel's hull. The transducer location on the hull must be chosen to minimize potential problems caused by bubbles. To prevent degradation of survey data, it is necessary to slow vessel speed or suspend acoustic survey operations when sea state causes unacceptable bubble attenuation. Currently, this decision is based on the judgment of the scientific field party chief, but explicit criteria need to be developed. In some cases, bubble backscattering can be removed from target strength data during post-processing, but this will not correct signal loss from targets of interest.

Transducer Motion

Excessive transducer motion is associated with increased sea state. Transducer motion affects bottom tracking, target strength and volume backscattering measurements. 'Dropouts' (i.e., reduction or elimination of TS values over one or more pings) observed on the echogram are a clear indication of excessive transducer motion. If the vessel is outfitted with a motion sensor, these data should be recorded. Motion sensor data may be used for objective decisions on acoustic data quality or for making corrections to the acoustic data. When sea state or vessel motion is excessive, as judged by the field party chief, survey speed must be slowed or operations must be suspended.

Bio-fouling

Bio-fouling can occur on hull-mounted transducers or protective coverings that stay in the water for long periods of time. Accumulation of material on the transducer will reduce the transmitted and received sensitivity, and this reduction may not be recognized by system performance procedures, although it should be detected by calibration. Hull-mounted transducers and protective coverings should be checked and cleaned regularly, and at a minimum before each field season.

Error

Bio-fouling will cause a systematic degradation in echo sounder performance as the bio-fouling increases. Transducer motion effects increase with increasing sea states, but the overall effect on abundance estimates requires investigation. Near-surface bubbles can be removed from the data during post-processing, however the resulting effects of bubble attenuation on target strength need to be studied. Most types of electrical and acoustical noise can be eliminated during data collection or post-processing. Noise that cannot be removed will bias target strength measurements and lead to errors in fish biomass estimates.

Considerations

Remediation

If noise issues are found to be a problem, then analyses are required to determine the effects on target strength measurements. In most cases, noise can be removed from the data set by eliminating the problematic pings, but if the noise persists for long periods, removal is more difficult.

If motion sensor data are available, corrections can be made to the acoustic measurements (Dunford 2002).

Improvements

A better understanding of the effects of transducer motion and bubble attenuation will improve our ability to make adjustments to the target strength data or make objective decisions on when conditions preclude collecting useful data. The timing of pulses emitted by the echo sounder can be adjusted (adaptive pulse timing) so that the necessary correction is minimized. (Dunford 2002).

Systematic analyses are recommended to determine the effects of performance degradation on data quality. Results of these analyses will improve (or at least make possible) objective decisions during data collection.

<u>Data Management</u>

Target strength data, post-processed data, biological, and associated meta-data should be routinely archived during the survey. These data are downloaded to shore-based computers and permanently archived for each survey or portion of a survey. In addition to data, post-processing and other software should be archived.

Sampling

Survey Design (A_i)

Definition & Importance

The design of an acoustic survey, as the consideration of the collection methods and analytic processes employed to meet the informational objectives and goals of a particular survey, manifests in the execution of the survey cruise track.

Since fishery acoustic survey results are based on sampling (as opposed to a census), the principal importance of the choice of the area sampled relates directly to the accuracy and precision of the resulting population estimate and, importantly, the ability to understand, manage, control and report on all known sources of error that impact on the quality of the resulting estimate.

In most marine fishery acoustic surveys, and in particular those addressed in this protocol, the echo sounder instrumentation is deployed off ocean-going vessels. In these mobile surveys, acoustic measurements – principally volume or area backscattering – are made along pre-determined transects that encompass an area (A_i) inhabited by the organisms of interest. The placement of transects, their spacing and orientation, and other aspects of sampling time or sampling frequency are not only determined by the population estimation goals of the survey but also by the practical constraints of vessel logistics and other resources available.

Techniques

Transect-based surveys are developed around the knowledge that the measurements made along the survey tracks are samples of the wider distribution of the target species. Since only a portion of the overall area of concern is actually sampled, any survey design consists of choices that need to address specific objectives, which can vary from an overall estimate of abundance for an entire population to simply the identification of locations of fish concentrations. In each instance, the informational demands of the survey need to be fully reflected in the survey design as they pertain to the objectives of the survey, to any *a priori* knowledge of stock distribution, and importantly, to the analytical method to be used for analysis (ICES 1993). Assumptions also need to be recognized and addressed in the design, especially where changes in fish behavior or distribution may impact those assumptions. The general guidelines for planning and conducting an acoustic survey as listed by MacLennan and Simmons (1992) include:

1) Definition of the geographic area to be covered;
2) Estimation of the resources required to adequately sample the area, including all methods;
3) Calculation of the time available to conduct all operations;
4) Decision on the sampling strategy and type of cruise track; and
5) Plot of the cruise tracks on a chart [or navigation plotting software] to check survey design feasibility.

Within the area under consideration, the choice of spacing and track layout (e.g., systematic parallel, random parallel, systematic zig-zag) should reflect an understanding of the serially correlated nature of the acoustic sampling technique and a consideration of the expected patchiness of the population of interest. With an obligation for intra-transect interpolation of the acoustic observations, objectivity is paramount in this decision. Moreover, the confidence in any particular estimate is reflected ultimately in the associated error. Jolly and Hampton (1990) demonstrate the gain in precision based on a stratified random design where practicable. However, where the demands on an acoustical survey by random sampling theory may not be practicable, the application of regularly spaced transects may be used to efficiently ensure adequate coverage. In these situations, the spatial correlation must be modeled and geostatistics may be the best tool for estimates of precision of the total population estimate (Petitgas 1993).

1) Describe and defend choice of survey track layout;
2) Explore acoustic data for spatial, temporal, and multivariate structure of the population of interest for development of appropriate error structure and subsequent improvements in survey design.

Vessel Speed

Vessel speed is a survey aspect that requires consideration. Choosing an operational speed is a balance between coverage, data quality, and vessel limitations. Ten knots is a common vessel speed while conducting fisheries acoustics transects. However, as sea state increases, vessel speed often will need to decrease to maintain data quality owing to increased noise and the influx of bubbles across the face of the transducer due to cavitation – not to mention considerations due to vessel pitch and roll effects on transducer motion (Stanton 1982). At some sea state, data quality cannot be maintained and survey operations must be suspended. Criteria based on sea state and data quality standards need to be developed (refer to the Volume Backscattering Measurements and Target Strength Performance Degradation sections).

GPS

Integrating Global Positioning System (GPS) data with acoustical measurements are critical for population estimates. GPS data are required for measurements of a species spatial distribution and determining vessel location relative to physical oceanographic conditions and topographic features. Choice of positioning data is dependent on the availability of the GPS systems on-board, performance of the GPS over the survey area, compatibility of the GPS system with the echo sounder, and the desired accuracy and precision of the GPS data.

Error

Uncertainty and random and systematic errors in survey design include inadequate sampling of the organism's spatial distribution, incomplete coverage of the population, and incorrect timing of the survey relative to seasonal migrations or other behaviors.

Considerations

Remediation

If intolerable errors or bias in a survey design are either observed directly or inferred from population dynamics modeling, a new survey design must be implemented. However, changes in the design must be considerate of the possible impacts to a time series.

Improvements

Improvements in survey design include the use of vessels designed for conducting acoustic surveys (allowing faster operation at lower radiated noise), and the incorporation of platforms such as buoys and AUV's to augment vessel surveys.

Numerical Density to Biomass Density (D_i)

Definition & Importance

Numerical density to biomass density is the conversion of acoustical energy to organism size (*e.g.*, length, equivalent volume) and biomass. This conversion is done during data analysis, and hence detailed data collection protocols do not apply. Specific data collection protocols for target strength, S_v, and fish lengths are detailed in their respective sections.

Species-specific biomass density and abundance estimates are the end result of fisheries acoustics surveys. Converting acoustical energy to biomass is a multi-step procedure. Sv [m^2 m^{-3}] measurements are scaled to numerical density [# m^{-3}] by target strength. Target strengths are obtained from *in situ* measurements and empirical or numerical and analytical regressions of target strength to organism size. Volume densities are vertically integrated to give areal densities [m^2 m^{-2}] along the cruise track, and areal densities are scaled to the survey area. The marine convention is to scale areal density to square nautical miles [1 $nmi^2 = (1852)^2$ m^2]. Biomass is obtained from organism size to biomass regressions tabulated from net catch data. If age- or length-based estimates are desired, the same steps are done for each age or length class.

Acoustical energy to biomass conversions integrate results from data collection, post-processing, and analysis and as such, incorporate and accumulate errors from all steps. An error budget that includes all sources of error is necessary.

Techniques

Target Strength to Length Regression

The target strength-to-length regression is the conversion of acoustical energy to fish length. Application of the target strength-to-length regression is completed during data analysis. Data collection protocols are detailed in the target strength data collection sections.

Fish length is the standard measure of a fish's size. However, a few measures of fish length are used. Fish lengths are measured as the total length, fork length, or standard length and in units of centimeters or millimeters. Target strength to length regressions are derived for a specific measurement type of fish length and unit of measure. When reporting TS-length regressions, the measurement type and units must be documented. Conversions among length measurement types can be tabulated as regressions, such as fork length to total length, but be aware that these add an additional layer of error and bias.

Length-Weight Regression

A length-weight regression is an empirical relationship between a fish's length and weight (or biomass). Application of the length-to-weight regression is completed during data analysis. Data collection protocols are detailed in the volume backscattering biological data collection sections.

The length-weight relationship is a common measure of fish growth. It is also a necessary regression to convert fish abundance to fish biomass. The length-weight regression is often defined as: $W=aL^b$, where W is fish mass, L is fish length, and a and b are empirically derived coefficients. The coefficients a and b are derived for specific length measurement types (e.g., fork length) and measurement units.

Error

Uncertainty and random and systematic errors in conversions of acoustical energy to species-specific biomass accumulate errors throughout the data collection, post-processing, and analysis steps. An overall error budget should be done.

Considerations

Remediation

If there is an indication of length or weight differences within a survey area, length-weight regressions should be tabulated at multiple stations during a survey.

Improvements

Improvements in *in situ* and *ex situ* target strength measurements and the relationships between target strength and fish lengths will significantly improve conversion of relative indices to absolute indices.

<u>Oceanographic Data</u>

Definition & Importance

Oceanographic data include temperature, salinity, and depth measurements.

Temperature and salinity measurements are required for computing sound speed and are important for calibrations, S_v and TS measurements, species classification, and ecological studies. Temperature and salinity measurements are collected at the sea surface and throughout the water column (CTD profiles).

Techniques

CTD profiles

Conductivity-Temperature-Depth (CTD) sensors measure temperature, salinity (computed from conductivity), and depth. Lowering and raising the CTD at a station provides a vertical temperature and salinity profile. Collecting temperature and salinity data are dependent on the objectives of the survey.

Surface temperature and salinity

Sea surface temperature and salinity data are obtained with hull-mounted sensors. These sensors provide real-time data and can be used to detect surface fronts. Surface temperature and salinity sensor can be placed at multiple depths on the hull. Sea surface temperatures can also be obtained from satellites, although are limited to relatively cloud-free periods.

<u>Scientific Computer System (SCS)</u>

Definition & Importance

The Scientific Computer System (SCS) is a shipboard system that logs data from sensors.

The Scientific Computer System (SCS) continuously collects and electronically records navigational, oceanographic, and meteorological data from shipboard sensors. The SCS system continuously samples data streams from shipboard instrumentation at regular intervals throughout the cruise periods. Approximately 150 data variables are collected, including date and time (GMT), multiple latitude and longitude positions (PCODE, differential, LORAN), water and air temperatures, salinity, fluorometry, wind speed, pitch and roll, and bottom depths and vessel log values from the EK500.

An electronic ‘event log’ can be developed based on the SCS system. The event log is a data management tool for relating echo sounder data with scientific operations. When operational, the event log is routinely completed throughout each cruise to document chronological events of the acoustic sampling, deployments, and other operational details that are important for data processing and management. The event log can be used to register the start and stop of transects, gear deployments, sites and transect series and associated data such as date-time stamps, geographic location, EK500 vessel logs, and comments during survey operations.

Techniques

Event Log

SCS data

Error

Uncertainty in temperature and salinity affect sound speed calculations, which affect all acoustical measurements. Temperature and salinity sensors must be calibrated to ensure high quality oceanographic measurements.

Errors in logging and recording events will reduce the accuracy of survey estimates because acoustical data will be improperly related to transects or deployments. While the information is redundantly entered on a hard copy version of the event log, every effort must be insured to accurately enter information in the electronic event log.

Considerations

Remediation

If temperature and salinity measurements are found to be in error, corrections to the oceanographic data should be implemented and new sound speeds calculated. If a significant change in sound speed is found, acoustical data should be reanalyzed.

If errors in the event logging software or SCS data are observed during the survey, contact the electronics technician on board to rectify the problem.

Improvements

Acoustical data are continuous in two dimensions (vertical and along the ship track). CTD profiles provide vertical measurements at a single point along the cruise track and surface sensors provide one-dimensional measurements along the cruise track. Interpolation and extrapolation of these data are necessary to match the physical environment to the acoustical data. An improvement would be having the ability to collect two-dimensional temperature and salinity measurements.

Data Management

Data, post-processed data, and associated meta-data should be routinely archived during the survey. These data are downloaded to shore-based computers and permanently archived for each survey. In addition to data, post-processing and other software should be archived.

Modifications to Protocols

Changes to operational protocols will be at the discretion of the appropriate Science Director who may approve such changes directly or specify a peer review process to further evaluate the justification and impacts of the proposed changes.

We recommend that a national standing working group be established to coordinate development of national and regional protocols, to share information among the centers, and to improve the techniques of acoustical surveys.

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Regional Protocols

Because of the diversity among NOAA Fisheries acoustic surveys, these protocols are specified in general terms to allow each Science Center survey flexibility in their approach to meeting the standardization criteria. In the following appendices the specific methodology used to implement the standardization requirements of the protocol by each NOAA Fisheries acoustic survey is described.

Appendix 1: Northeast Fisheries Science Center
Northeast Regional Protocol for Fisheries Acoustics Surveys and related Sampling.

Appendix 2: Alaska Fisheries Science Center
Alaska Regional Protocol for Fisheries Acoustics Surveys and related Sampling.

Appendix 1: Northeast Fisheries Science Center
Northeast Regional Protocol for the Joint Canadian and U.S. Hake Acoustics Surveys and related Sampling.

Appendix 1

December 30, 2003

NOAA Protocols for Fisheries Acoustics Surveys and Related Sampling at the
Northeast Fisheries Science Center

Prepared by Personnel from NOAA Fisheries
Northeast Fisheries Science Center

Table of Contents

Introduction

This document provides data collection and operational protocols for acoustical surveys of Atlantic herring (*Clupea harengus*) at the Northeast Fisheries Science Center (NEFSC).

This document is arranged as follows. Center-specific background is given to provide information on NEFSC personnel and general support. Five general categories are defined: system calibration and performance, acoustical backscattering measurements, target strength, acoustical-biological conversions, and sampling (survey) design. Acoustical background and general information for each section and the topics “Definition & Importance”, “Error”, and “Considerations” are given in the acoustics National Protocol and are not repeated here. The Methods section details specific methods for each of these categories.

Center Background

NEFSC

The Northeast Fisheries Science Center (NEFSC) fisheries acoustics group currently has two FTE's affiliated with the Survey Branch and one FTE affiliated with the Population Dynamic's Branch. Two FTE's are base funded and the other FTE is funded on a congressional budget "line-item". The NEFSC fisheries acoustics group focuses on estimating Atlantic herring (*Clupea harengus*) spawning stock biomass with an annual six-week survey conducted in the fall.

The Atlantic herring acoustical survey employs a systematic parallel design, with inter-transect spacing set at 8 or 10 nautical miles (nmi). The transect spacing is consistent within a survey, but has changed among surveys. This is due to logistic constraints, and the fact that a definitive survey design has not been determined at this time. The extent of the survey encompasses the spawning stock biomass in the Georges Bank region. The S_a values along transects are used to derive relative indices of the herring abundance. The S_a values are extrapolated to the surveyed region using geostatistical methods. The Sa values are converted to abundance by calculating mean herring lengths from trawl catches, converting the mean lengths to target strength (TS) using a generic Atlantic herring TS-Length regression. Biomass estimates are derived by scaling the abundance estimates by an empirical length-weight relationship. Age-based estimates are derived from the age composition of the trawl catches.

Methods

Calibration and System Performance

Calibration

Techniques

Software

The NEFSC uses the Simrad Lobe program, version EK/EY500 5.XX (date of last revision: 30 October 1995) to calibrate the EK500 echo sounder. The calibration software version and the echo sounder firmware version are documented for all calibrations.

Standard values

Table 1 provides a list of standard values for calibration.

Table 1. Calibration standard values used at the NEFSC.

Frequency [kHz]	Calibration Sphere	EK500 Minimum Target Range [m]	Nominal TS [dB]*
12	45 mm Cu	35	-40.4
18	64 mm Cu	22	-34.4
18	63 mm Cu	22	-34.4
38	60 mm Cu	10	-33.6
120	23 mm Cu	10	-40.4

Calibration sphere measurements are the sphere diameter. 'Cu' denotes a copper calibration sphere. Note that the 18 kHz has two spheres listed. Simrad originally recommended the 63-mm sphere. However, after consultation with Neal Williamson (NOAA-Fisheries, AFSC) and Ken Foote (WHOI) during the fall of 2003, the 64-mm Cu sphere was determined to be the optimal sphere. The 64-mm Cu will be used from 2004 on. The 12-kHz echo sounder was replaced in 2002 with the 18-kHz echo sounder.

On-axis sensitivity

The NEFSC acoustics manual (NEFSC_aqstx-acoustics_manual.doc) details on-axis calibration protocols. The tolerance of the 38-kHz on-axis calibration is ±0.4 dB (G_0: ±0.2 dB).

Transceiver settings are equivalent to those used during the survey.

Beam pattern measurements

The NEFSC acoustics manual (NEFSC_aqstx-acoustics_manual.doc) details beampattern measurement protocols. The NEFSC does not modify the offset or beamwidth parameters based on the LOBE program. This is due to the concern that the beam pattern parameters derived by the LOBE program are not based on independent measurements of the beam pattern. The LOBE program relies on the angular offsets provided by the EK500 and transducer, which is not an independent measure of the true angular positions.

Transceiver settings are equivalent to those used during the survey.

S_v Calibrations

The NEFSC acoustics manual (NEFSC_aqstx-acoustics_manual.doc) details S_v calibration protocols. The tolerance of the 38-kHz S_v calibration is ±0.4 dB (G_0: ±0.2 dB).

Transceiver settings are equivalent to those used during the survey.

Oceanographic Data

A vertical temperature and salinity (CTD) profile is collected prior to calibrations that are conducted offshore. For inshore calibrations, such as those that are conducted at the Woods Hole Oceanographic Institution's pier, either CTD profiles or the 3-m temperature and salinity hull-mounted sensor are used for the physical data. CTD profiles encompass the calibration depths. Refer to the Sampling->Oceanographic Data section for details on operating the CTD.

Temperature and salinity measurements are compared between the CTD profiler and hull-mounted sensors during the calibrations.

Considerations

Remediation

If the 38-kHz TS or S_v gain values (G_0) are outside of the tolerances defined above, the survey will not commence until the cause of the error is resolved. The Simrad manual (Simrad, 1996) provides diagnostic tests to evaluate the EK500 echo sounder.

If temperature and salinity measurements are not comparable between the CTD profiler and hull-mounted sensors, the Fisheries Oceanography Investigation (FOI) and the ship's electronic technician should be contacted to determine the cause of the discrepancy.

<u>System Performance</u>

Techniques

The 'test' values and passive noise values for the Simrad EK500 echo sounder are documented for every calibration and at the beginning of each survey 'leg' (two-week portion of a survey). Test and passive noise values are documented for the 18, 38, and 120-kHz frequencies.

During the survey, individual target locations in the acoustic beam (EK500 TS Detection Menu) are evaluated to ensure that individual target locations appear in all quadrants.

Considerations

Remediation

Survey operations should be suspended if the 'Test' values are out of tolerance and the cause of the errors diagnosed. The Simrad manual provides diagnostic and evaluation procedures (Simrad, 1996). After the problem is resolved, the survey can continue.

If individual targets do not appear in all quadrants, survey operations should be suspended and the problem diagnosed. After the problem is resolved, the survey can continue.

<u>Data Management</u>

The calibration LOBE data, EK500 telegram data, parameter settings, and associated meta-data are stored on board until such time is appropriate for downloading to a shore-based computer. The LOBE data are stored on the laptop computer that was used for the calibrations. The EK500 telegram data are stored on the backup SCS server, which is RAID configured to minimize potential loss of data. These data are archived by the Data Management Service branch at the NEFSC after the data are downloaded to shore.

Volume Backscattering Measurements (E_i)

<u>Data Collection</u>

Techniques

Echo Sounder Parameters

Echo sounder parameters are set relative to the goals of the survey and in some cases are a compromise between data quality and preferred values, where data quality has paramount priority.

Transceiver settings for the Simrad EK500 echo sounder are provided in Table 2. The S_v gain (G_0) is obtained from the echo sounder calibration (Calibration section). Simrad provides the power and two-way integrated beam pattern and these values are not modified unless a transducer is changed. The sound speed and sound attenuation are not modified from the default values for the fall Atlantic herring survey. The bandwidth value ('auto') is set according to the Simrad recommendations. The pulse durations for the 38-kHz and the 120-kHz systems are set equivalently (*i.e.*, the 'medium' 38-kHz pulse duration is equivalent to the 120-kHz 'long' pulse duration) as per the recommendation of Demer et al. (1999) for improving acoustical discrimination of individual targets using multi-frequency methods. The 1 ms pulse duration was chosen for the 38-kHz echo sounder as the optimal setting for the depth ranges encountered during the fall Atlantic herring survey (maximum range of approximately 500 m) and the vertical resolution of the integrated data (1 m). The 'medium' pulse durations of the 12 and 18-kHz systems were chosen to avoid poor performance detected at the 'short' setting.

Table 2. EK500 echo sounder transceiver parameter settings.

Frequency [kHz]	Sound Speed [m s^{-1}]	Pulse Length	Bandwidth	□	□	Power [Watts]
12	1500	Medium (3.0)	Auto	-15.8	1	4000
18	1500	Medium (2.0)	Auto	-16.9	3	2000
38	1500	Medium (1.0)	Auto	-15.8	10	1000
120	1500	Long (1.0)	Auto	-20.7	38	1000

□ is the two-way integrated beam pattern [dB], and □ is the sound attenuation [dB m^{-1}]. The pulse length is given as the Simrad setting (Medium or Long) and the duration (given in milliseconds). Note the 12-kHz echo sounder was replace by the 18-kHz echo sounder in 2002.

The echo sounder is calibrated with the same transceiver settings used during the survey, and the transceiver settings are not modified during the survey.

Other EK500 echo sounder parameters for S_v data collection are provided in Table 3. These parameter settings are common among all frequencies (12, 18, 38, and 120 kHz). Parameters not listed in Table 3 are left to the discretion of the operator and do not affect data collection.

Table 3. EK500 echo sounder S_v data collection parameters.

Parameter	**Setting**
Operation Menu/Ping Auto Start	Off
Operation Menu/Ping Interval	2.0

Operation Menu/Transmit Power	Normal
Operation Menu/Noise Margin	0
Bottom Detection Menu/Minimum Depth	3.0
Bottom Detection Menu/Maximum Depth	550
Bottom Detection Menu/Minimum Level	-50
Log Menu/Mode	Speed
Log Menu/Dist. Interval	1.0
Layer Menu/Super Layer	1
Layer Menu/Layer-1 Menu/Type	Surface
Layer Menu/Layer-1 Menu/Range	500.0
Layer Menu/Layer-1 Menu/Range Start	0.0
Layer Menu/Layer-1 Menu/Margin	0.0
Layer Menu/Layer-1 Menu/Sv Threshold	-90
Layer Menu/Layer-1 Menu/No. of Sublayers	1
All other 'Layer Menu/…/Type'	Off
Ethernet Com. Menu: Local and Remote ETH and IP addresses are set to the appropriate values depending on the computer network.	
Ethernet Com. Menu/Telegram Menu/Remote Control	On
Ethernet Com. Menu/Telegram Menu/Sample Range	500
Ethernet Com. Menu/Telegram Menu/Status	On
Ethernet Com. Menu/Telegram Menu/Parameter	On
Ethernet Com. Menu/Telegram Menu/Annotation	Off
Ethernet Com. Menu/Telegram Menu/Sound Velocity	Off
Ethernet Com. Menu/Telegram Menu/Navigation	On
Ethernet Com. Menu/Telegram Menu/Motion Sensor	Off
Ethernet Com. Menu/Telegram Menu/Depth	1&2&3
Ethernet Com. Menu/Telegram Menu/Depth NMEA	Off
Ethernet Com. Menu/Telegram Menu/Echogram	1&2&3
Ethernet Com. Menu/Telegram Menu/Echo-Trace	1&2&3
Ethernet Com. Menu/Telegram Menu/Sv	Off
Ethernet Com. Menu/Telegram Menu/Sample Angle	Off
Ethernet Com. Menu/Telegram Menu/Sample Power	Off
Ethernet Com. Menu/Telegram Menu/Sample Sv	Off
Ethernet Com. Menu/Telegram Menu/Sample TS	Off
Ethernet Com. Menu/Telegram Menu/Vessel-Log	On
Ethernet Com. Menu/Telegram Menu/Layer	Off
Ethernet Com. Menu/Telegram Menu/Integrator	Off
Ethernet Com. Menu/Telegram Menu/TS Distribution	Off
Ethernet Com. Menu/Telegram Menu/Towed Fish	Off
Ethernet Com. Menu/UDP Port Menu: All values set to 2000.	
Ethernet Com. Menu/Echogram Menu/Range (all values set equally among transceivers)	500
Ethernet Com. Menu/Echogram Menu/Range Start	0
Ethernet Com. Menu/Echogram Menu/Auto Range	Off
Ethernet Com. Menu/Echogram Menu/Bottom Range	15

Ethernet Com. Menu/Echogram Menu/Bot. Range Start	10
Ethernet Com. Menu/Echogram Menu/No. of Main Val.	500
Ethernet Com. Menu/Echogram Menu/No. of Bot. Val.	150
Ethernet Com. Menu/Echogram Menu/TVG	20 log R
Serial Com. Menu/Telegram Menu/Format	ASCII
Serial Com. Menu/Telegram Menu/Remote Control	On
Serial Com. Menu/Telegram Menu/Navigation	On
Serial Com. Menu/Telegram Menu/Depth	1&2&3
Serial Com. Menu/Telegram Menu/Depth NMEA	2
Serial Com. Menu/Telegram Menu/Vessel-Log	On
Serial Com. Menu/USART Menu/Baudrate	9600
Serial Com. Menu/USART Menu/Bits Per Char.	8
Serial Com. Menu/USART Menu/Stop Bits	1
Serial Com. Menu/USART Menu/Parity	None
Navigation Menu/Navig. Input	Serial
Navigation Menu/Start Sequence	$GPGLL
Navigation Menu/Separation Char.	002C
Navigation Menu/Stop Character	000D
Navigation Menu/First Field No.	2
Navigation Menu/N. of Fields	4
Navigation Menu/Speed Input	Serial
Navigation Menu/Manual Speed	10
Navigation Menu/NMEA Transfer	On
Navigation Menu/Baudrate	4800
Navigation Menu/Bits Per Char.	8
Navigation Menu/Stop Bits	1
Navigation Menu/Parity	None
Utility Menu/Status Messages	On
Utility Menu/FIFO Output	Off
Utility Menu/External Clock	Off
Utility Menu/Password	0
Utility Menu/Default Setting	No

Software

The echo sounder firmware version and the post-processing software (SonarData, Echoview) version are documented for every survey.

GPS

The primary Global Positioning System (GPS) data used for the acoustical surveys are the differential GPS values. PCODE GPS data are used as a secondary source.

Oceanographic Data

Sea-surface temperature and salinity data are collected continuously during the survey. These are a standard set of data regularly collected by the Scientific Computer System (SCS).

Vertical temperature and salinity (CTD) profiles are conducted at the beginning and end of each transect.

Vertical CTD profiles are also conducted immediately prior to or immediately after every deployment or set of deployments. If multiple deployments are to be conducted in the same area and over a short time frame (e.g., less than 12 hours), whether to conduct a single CTD or multiple profiles is left to the discretion of the scientific watch chief.

The Fisheries Oceanography Investigation (FOI) maintains the CTD instrumentation and is responsible for CTD data management. The FOI provides training for CTD operation at the beginning of each survey 'leg'. All scientific personnel participate in the training at least once during the survey.

Detection Probability

Techniques

Thresholding

The S_v data collection threshold for all acoustical frequencies is set at –90 dB for Atlantic herring surveys (this value is set in the 'Layers' menu). The –90 dB value was chosen due to the observation that echo amplitudes for juvenile and adult Atlantic herring are sufficiently (30-50 dB) greater than the –90 dB threshold.

The post-processing S_v threshold was chosen for Atlantic herring by evaluating the relationship of S_A as a function of S_v threshold (Figure 1). An S_v threshold of –66 dB was chosen as the optimal value to retain volume backscattering by Atlantic herring while reducing backscatter by other organisms.

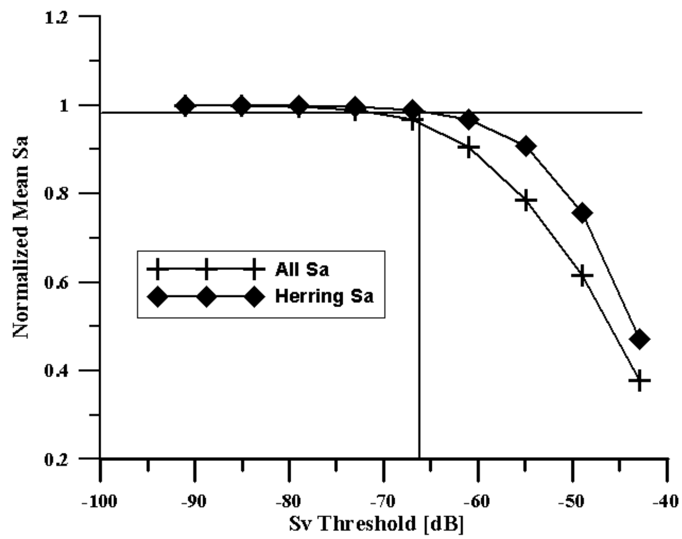

Figure 1. Normalized water column S_A and Atlantic herring S_A as a function of S_v threshold. Data were collected during September 1999 on Georges Bank.

Range

Currently we do not have protocols to account for range or signal to noise affects.

Acoustic Dead Zones: Near surface and near bottom

No S_v data are eliminated during data collection.

When post-processing the S_v data, a constant depth below the surface is chosen where data above this depth (i.e., near-surface data) are eliminated from analyses (this depth is commonly called the ‘bubble layer’). The minimum depth is set to 10 m for the 18, 38, and 120-kHz echo sounders. The minimum depth was set to 32 m for the 12-kHz echo sounder. The depth for the 18, 38, and 120-kHz systems was chosen based on: 1) the hull-mounted transducers are located approximately 3 m below the surface, 2) the near field of the 38 kHz transducer is approximately 7 m, 3) a consistent depth is desired to compare data among the frequencies, and 4) under normal survey conditions, surface noise (*e.g.*, bubbles) do not penetrate deeper than 10 m. The 32 m depth was chosen for the 12 kHz due to significant ‘ring-down’ of the 12-kHz transducer in the top 30 m.

During data collection and post-processing of the S_v data, a constant distance above the bottom where data below this depth are eliminated from analyses (this distance is commonly called the ‘backstep’) is selected. The ‘backstep’ is set to 0.5 m for all frequencies. This distance was chosen based on observations of the S_v data and the EK500 and Echoview bottom-detection algorithms. EK500 bottom-detection parameters are:

i. Minimum Depth: 5.0 m
ii. Maximum Depth: 500 m (dependent on survey area)
iii. Min. and Max. Depth Alarm: 0.0 m
iv. Bottom Lost Alarm: Off
v. Minimum Level: -50 dB

For post-processing the S_v data, we use Echoview’s bottom-detection algorithm to select the echoes from the seabed. Echoview bottom-detection parameters are:

i. Bottom detection algorithm: Maximum Sv with backstep

ii. Minimum Sv for good pick: -50.00 dB
iii. Discrimination Level: -40.00 dB
iv. Backstep range: -0.50 m

The bottom detection is obtained from the 120 kHz data and applied to all frequencies. After the 120-kHz bottom detection has been completed using Echoview's algorithm, all echograms are visually inspected for improper bottom detections. Improper bottom detections are manually corrected using Echoview post-processing software.

As an independent check of the bottom detection algorithm and subsequent visual inspection, a 1 m layer adjacent to and above the bottom detection line (including backstep) is created using Echoview's 'virtual echogram' module. S_v values within this layer greater than an S_v threshold of –40 dB (note this threshold is not equivalent to the post-processing threshold) may indicate improper bottom detections or may indicate backscattering by fish. These Sv values are exported and used to visually inspect echograms for a final determination of improper bottom detection.

Animal Behavior

Currently we do not have protocols to account for animal behavior effects on S_v measurements.

Vessel Noise and Avoidance

Sound range measurements were conducted on the FRV Delaware II in January 2003 at the Canadian Naval Sound Range in Halifax, Nova Scotia. A report from the sound range and a summary of the data were generated and are available from the NEFSC fisheries acoustics group.

Currently we do not have protocols for investigating vessel noise effects on S_v measurements.

Currently we do not have protocols for monitoring vessel noise during surveys.

Multiple scattering and shadowing

Currently we do not have protocols for determining when non-linear scattering effects are significant or for correcting S_v measurements due to multiple scattering and shadowing.

<u>Classification</u>

Techniques

Single Frequency

The NEFSC utilizes multiple frequencies for subjective classification of Atlantic herring (Refer to the next section).

Multiple Frequency

Each echo sounder is calibrated according to the calibration protocols (Calibration Section). The 38-kHz data are the primary data for Atlantic herring density and abundance estimates used in assessments. Data processing and post-processing protocols established for the 38-kHz data apply to all frequencies used for analysis. However this does not imply that all parameter settings are equivalent among echo sounders. Calibration and data collection parameters may differ among systems. For near-bottom data, a common bottom-detection line is applied among all frequencies. For near-surface data, the deepest 'bubble layer' will generally limit application of multi-frequency analyses.

Currently we do not have protocols for quantitative multi-frequency analysis in the NEFSC. Atlantic herring are classified qualitatively using subjective interpretation of the S_v backscatter from all frequencies and trawl catch data.

Biological Sampling

Trawls

For the Fall Atlantic herring survey on Georges Bank, pre-determined trawl locations are defined. These trawl locations were chosen based on spatial distributions of Atlantic herring during acoustical surveys from 1999-2002. Trawl hauls are conducted within ±5 nautical miles (nmi) of these locations. Other trawl locations are determined on an *ad hoc* basis. Selecting *ad hoc* trawl locations is at the discretion of the scientific watch chief, and is based on the experience of the scientific personnel and the goals of the survey.

For other sites in the Gulf of Maine, trawl locations are determined on an *ad hoc* basis. Selecting *ad hoc* trawl locations is at the discretion of the scientific watch chief, and is based on the experience of the scientific personnel and the goals of the survey.

The pelagic trawl used during acoustical surveys is the High Speed Midwater Rope Trawl (HSMRT). The HSMRT used by the NEFSC is modified from Dotson and Griffith (1996). Maintenance details for the HSMRT are given in "NEFSC_midwater_trawl_maintenance.PDF". The chief boatswain is provided a copy of this document before sailing.

Trawl catch data are processed according to the Ecosystems Survey Branch (ESB) protocols (refer to the Bottom Trawl Survey Protocol), with modifications for the acoustical surveys and sampling Atlantic herring. The primary trawl catch processing software is the Fisheries Scientific Computer System (FSCS). The two components of FSCS that are modified for acoustical surveys are the 'Trawl Event' and the sampling station designation.

The 'Trawl Event' electronically documents meta-data information pertinent to the trawl. The FSCS manual provides standard operating procedures for the trawl event and the bridge officers are responsible for operating the trawl event. Five modifications of the trawl event for acoustical surveys are:

i. The "Station Number" and the "Tow Number" are set equivalent to the acoustical deployment number.
ii. The "Start Event" button is clicked when the net begins streaming.
iii. The "Start Trawl" button is clicked when the doors enter the water.
iv. The "Stop Trawl" button is clicked when the doors come out of the water.
v. The "Stop Event" button is clicked when the net is on the deck.

The ESB defines a 'station' as a coordinated set of activities associated with a trawl. The fisheries acoustics group does not follow this convention. During acoustical surveys, a 'deployment' is defined as a single activity or event, deployment numbers are sequential throughout the entire survey, and each deployment receives a sequential number. For example, a CTD conducted prior to a trawl is given a separate deployment number from the trawl. The start of the mid-water trawl is defined as when the doors enter the water, and the end is defined as when the doors exit the water. This start and end distinctions are due to the fact that the net is able to encounter and catch fish and other organisms as soon as the doors are set.

Procedures for setting and retrieving the pelagic trawl are provided in the "NEFSC_aqstx-biology_manual.doc" document. The manual provides procedures for the bridge and scientific staff.

Net mensuration sensors are attached to the net during trawling activities to: provide real-time evaluation of the net performance, ensure proper net configuration, and document net performance. Net mensuration data are collected with Vemco minilog temperature-depth probes, Simrad ITI sensors, and a Simrad FS903 scanning sonar.

Two Vemco minilog temperature-depth probes are attached to the net, one on the headrope and one on the footrope, as the net is being set. The probes record temperature and depth at 2-second intervals. Each probe is initialized immediately prior to the trawl. Upon retrieval of the net, the data are downloaded to a shipboard computer, and downloaded to a shore-based computer at the end of the survey.

Simrad ITI sensors measure door and wing spread, and athwartship location of the net relative to the vessel. The ITI sensors are battery operated, and must be charged prior to sailing and during the survey. Prior to sailing, two ITI sensors are attached to the doors (a 'communication' sensor on one door, and a 'remote' sensor on the other). As the net is being set, two ITI sensors are attached to the wings. Similar to the doors, a communication sensor is placed on one wing, and a remote sensor is placed on the opposite wing. Simrad labels the ITI sensors as '1' and '2'. It is imperative that two sets of '1' or '2' are not used on the same net. Upon retrieval of the net, the wing sensors are removed and stored.

The Simrad FS903 is the primary instrument used for evaluating the real-time performance of the net. A trawl is not to be conducted if the FS903 is inoperable. The FS903 is a 'third-wire' system that contains a scanning sonar and a temperature-depth recorder. The FS903 requires an armored conducting cable and winch. Prior to sailing, the ship's electronic technician will connect the FS903 and ensure that it is operational. As the net is being set, the FS903 is placed in the 'kite' near the headrope, and upon retrieval the FS903 is removed from the kite and stored. Because the FS903 is the primary instrument for determining that the net is properly set, a display is located on the bridge and in the trawl winch operator room.

The ITI and FS903 displays are constantly monitored by scientific and bridge personnel during the trawl to ensure that the net is 'fishing' properly and is not on the bottom. After the net has reached 'fishing' depth, at approximately 5-minute intervals or each time the depth of the net is modified, the data and time (in GMT), vessel speed, shaft RPM, temperature at the net, depth of the headrope, door and wing spreads, vertical mouth opening, and horizontal opening are recorded to a paper form. These data are then entered in a spreadsheet and archived at the conclusion of the survey.

Trawl catch sampling and sub-sampling protocols for length, weight, age, and other biological variables are based on the standard protocols set by the NEFSC – except for Atlantic herring. For more details on the standard protocols refer to the NEFSC Trawl Survey Protocol, and the NEFSC Fisheries Scientific Computing System (FSCS) manual. The catch, including herring, is processed using the FSCS system.

Sampling and sub-sampling Atlantic herring protocols are:

i. Approximately 150 individual Atlantic herring are randomly chosen from the entire herring catch as a sample. If there are fewer than 150 individuals, all herring are sampled.
ii. For all 150 herring, individual lengths and individual weights are measured.
    a. Fish length is recorded as fork length (FL) to the nearest millimeter [mm]. If the electronic board does not measure to the nearest mm, use a manual measuring board.

b. Fish weight (mass) is recorded to the nearest gram [g].

iii. At least once per survey, fork lengths and total lengths (TL) should be measured, in addition to the other measurements, to maintain a time series of the FL-to-TL relationship.

iv. For 'age&growth', food habits, and maturity data the following sub-sampling is conducted:

a. One herring per centimeter [cm] length class below 25 cm is sampled.
b. Three herring per cm length class greater than or equal to 25 cm are sampled.
c. The cm length class is defined as between 5 mm below and 4 mm above the length class designation. For example, the 25 cm length class is bounded by 245 and 254 mm (24.5 to 25.4 cm).
d. Only the herring sub-sampled for age&growth are frozen whole for later otolith extraction by the Age and Growth Branch at the NEFSC.

v. At the conclusion of processing the catch, the data are loaded into Oracle.

The document "NEFSC_aqstx-biology_manual.doc" details procedures for biological sampling.

Underwater video.

Underwater video methods and techniques are currently experimental and currently we do not have protocols for underwater video measurements.

Bottom Tracking

Refer to the 'Volume Backscattering Measurements->Detection Probability -> Acoustic Dead Zones' section for protocol details.

Performance Degradation

Techniques

Noise

Acoustical

The ship's electronic technician maintains a list of all acoustical systems on board. This list documents operating frequency, manufacturer, model, and serial number. We have established which systems interfere with the scientific EK500 echo sounders. These systems are the bridge Simrad EQ50 echo sounder (dual 50 and 200 kHz), the bridge Raytheon recording depth sounder (38 kHz), and the Acoustic Doppler Current Profiler (ADCP) operating in 'wideband' mode. After the vessel has left port, the Raytheon recording depth sounder is turned off during acoustical surveys. The ADCP is not operated during acoustical surveys. The 50-kHz signal from the EQ50 has been determined to interfere with the EK500 38-kHz echo sounder. The EQ50 operating mode is switched to '200 kHz only' during acoustical surveys.

Electrical

Electrical interference has not been an issue during acoustical surveys.

Bubble Attenuation

Currently we do not have protocols for adjusting S_v measurement due to bubble attenuation during survey operations.

We remove backscattering by surface bubbles that extend below the 'bubble layer' from S_v data during post-processing by encompassing these areas using Echoview regions and defining these regions as 'Bad Data'. The 'bad data' designation eliminates this data from analysis.

Transducer Motion

Currently we do not have protocols for adjusting S_v measurements due to transducer motion.

Currently we do not have protocols for objective decisions for suspending survey operations based on sea state or vessel motion. The decision to slow the vessel or to suspend operations due to sea-state is based on the judgment of the scientific watch chief.

Bio-fouling

Prior to sailing, the bridge officers and deck crew often conduct diving operations on the ships. If feasible, the divers are requested to inspect and, if necessary, clean the hull-mounted transducers before each survey.

Considerations

Remediation

In some cases, we are not able to eliminate acoustical interference during data collection (*e.g.*, the Simrad ITI sensors cause 'spikes' in the 38 kHz data during trawl activities). For these data, the noise is manually removed during post-processing using Echoview regions specified as 'Bad Data'. This designation eliminates those data from analysis.

If results of cavitation, bubble attenuation, or transducer motion are observed on any echo sounder (e.g., blank spots in the echogram), the survey is conducted at a slower speed. If the vessel speed drops below 6 knots, survey operations are suspended. The decision to slow the vessel or suspend operations is at the discretion of the scientific watch chief.

Data Management

During the survey, volume backscattering data are stored on the Scientific Computer System (SCS) backup server. Hard drives on this server are in a RAID configuration to minimize the potential for data loss.

S_v data are downloaded to a shore-based computer at the end of each survey 'leg'. Volume backscattering data are archived by the Data Management Service (DMS).

Target Strength ($_i$***)***

Models

Techniques

Theoretical

The use of theoretical models is experimental. Currently we do not have protocols for integrating theoretical models in survey estimates.

Empirical

Currently we do not have protocols for implementing empirical models of Atlantic herring from the Gulf of Maine in survey estimates.

Validation

Currently we do not have protocols for validating theoretical or empirical models.

Data Collection

Techniques

Echo sounder Parameters

Simrad EK500 single target detection parameters for the Atlantic herring acoustical surveys are given in Table 4. The parameters are set equivalently among all frequencies. The TS threshold is set to –66 dB, which is a compromise between logistic constraints imposed by the EK500 and detecting Atlantic herring or other organisms. The EK500 limits the number of single target detections to 30 targets per ping. This limit restricts the range at which individual targets can be detected (*i.e.*, when the TS threshold is set at a lower value, the number of single detections reaches the limit at depths shallower than the observed depth of the Atlantic herring. Thus Atlantic herring TS measurements are significantly reduced due to this limitation). The maximum phase deviation, and minimum and maximum echo width parameters are set to the EK500 default values. The maximum beam compensation parameter is set to 3 dB, which allows targets from within the full beam width and eliminates targets outside of the acoustic beam.

Table 4. NEFSC EK500 single target detection parameters.

Frequency [kHz]	TS threshold [dB]	Min. Echo Width	Max. Echo Width	Max. Beam Comp. [dB]	Max. Phase Deviation
12	-66	0.8	1.5	3	4
18	-66	0.8	1.5	3	4
38	-66	0.8	1.5	3	4
120	-66	0.8	1.5	3	4

The EK500 echo sounder firmware version and the parameter values are documented for each survey. For standard survey operations, only the ‘Echo Trace telegram’ data are collected for all frequencies. The ‘Echo Trace’ data are individual targets detected by the EK500. For selected site-specific investigations, the ‘Sample Angle’, ‘Sample Power’, and ‘TS’ telegrams are collected. Advantages to collecting these data are that they can be analyzed in other software packages, such as Echoview or other program languages for in-depth studies of TS measurements. The disadvantage is that these data require much greater data storage (approximately an order of magnitude greater data rates).

Software

The Echoview version is documented for every survey. When Simrad Sample Angle, Sample Power, or TS telegrams are recorded, the post-processing parameters for single target detection are documented.

In situ data

Currently we do not have protocols for collecting *in situ* target strength data. The NEFSC is investigating methods and instrumentation for collecting *in situ* target strength data.

GPS

The primary Global Positioning System (GPS) data used for the acoustical surveys are the differential GPS values. PCODE GPS data are used as a secondary source.

Oceanographic Data

Sea-surface temperature and salinity data are collected continuously during the survey. These data are a standard set of data regularly collected by the Scientific Computer System (SCS).

Vertical temperature and salinity (CTD) profiles are conducted at the beginning and end of each transect.

Vertical CTD profiles are also conducted immediately prior to or immediately after every deployment or set of deployments. If multiple deployments are to be conducted in the same area and over a short time frame (e.g., less than 12 hours), whether to conduct a single CTD or multiple casts is left to the discretion of the watch chief.

The Fisheries Oceanography Investigation (FOI) maintains the CTD instrumentation and is responsible for CTD data management. The FOI provides training for CTD operation at the beginning of each survey 'leg'. All scientific personnel participate in the training at least once during the survey.

Detection Probability

Techniques

The beam width and directivity response function for each transducer are provided by the transducer manufacturer (Simrad) and are documented for each survey. During calibration exercises, beam pattern measurements are evaluated for proper echo strength compensation.

Thresholding

The single target discrimination threshold is set at –66 dB. This setting is a compromise between logistic constraints imposed by the EK500 and an optimal threshold to obtain TS measurements of Atlantic herring and other organisms. The 'TS Measurements -> Echo Sounder Parameter Settings' details the justification for this parameter value.

Acoustic Dead Zones: Near Bottom and Near Surface

Near-surface and near-bottom limitations are equivalent for target strength and S_v data. The 'Volume Backscattering Measurement->Detection Probability->Acoustic Dead Zones' section provides detailed protocols.

Animal Behavior

Currently we do not have protocols for incorporating animal behavior in target strength measurements.

Vessel Noise

The 'Volume Backscattering Measurements->Detection Probability->Vessel Noise and Avoidance' section provides details on vessel noise. Currently we do not have protocols for incorporating vessel noise in analysis of TS measurements.

Density Requirements

Currently we do not have protocols for incorporating density dependencies on target strength measurements.

Single Frequency

Currently we do not have protocols for incorporating single frequency methods in analyzing target strength data.

Multiple Frequency

Currently we do not have protocols for incorporating multiple frequency methods in analyzing target strength data. We are investigating the potential for incorporating multi-frequency methods described by Demer et al. (1999) to improve target strength measurements.

<u>Classification</u>

Techniques

Single Frequency

Currently we do not have protocols for classification of individual targets using single frequency target strength data.

Multiple Frequency

Currently we do not have protocols for classification of individual targets using multiple frequency target strength data.

Biological Sampling

Trawls

Verification of the species composition of individual targets is equivalent to methods used for S_v data. The 'Volume Backscattering Measurements->Classification->Biological Sampling->Trawls' section provides detailed protocols for biological sampling.

Underwater video.

The use of underwater video methods and instrumentation are experimental. Currently we do not have protocols for underwater video methods.

Bottom Tracking

Seabed detection protocols are equivalent for target strength and S_v data. Detailed protocols are provided in the 'Volume Backscattering Measurements->Detection Probability->Acoustic Dead Zones' section.

<u>Performance Degradation</u>

Techniques

Noise

Acoustical

Acoustical noise protocols are equivalent for the target strength and S_v data. The 'Volume Backscattering Measurements->Performance Degradation-Noise->Acoustical' section provides detailed methods.

Electrical

Electrical noise protocols are equivalent for the target strength and S_v data. The 'Volume Backscattering Measurements->Performance Degradation->Noise-Electrical' section provides detailed methods.

Bubble Attenuation

Currently we do not have protocols for adjusting or correcting target strength measurements due to bubble attenuation. During post-processing, backscattering by surface bubbles is removed from TS data using Echoview regions defined as 'Bad Data'. This designation eliminates these data from analysis.

Transducer Motion

Currently we do not have protocols for adjusting TS measurements due to transducer motion.

Currently we do not have protocols for objective decisions for suspending survey operations based on sea state or vessel motion. The decision to slow the vessel or suspend operations is at the discretion of the scientific watch chief.

Bio-fouling

Prior to sailing, the bridge officers and deck crew often conduct diving operations on the ships. If feasible, the divers are requested to inspect and, if necessary, clean the hull-mounted transducers before each survey.

Considerations

Remediation

If results of cavitation, bubble attenuation, or transducer motion are observed on any echo sounder (e.g., blank spots in the echogram), the survey is conducted at a slower speed. If the vessel speed drops below 6 knots, survey operations are suspended. The decision to slow the vessel or suspend operations is at the discretion of the scientific watch chief.

Data Management

During the survey, target strength data are stored on the Scientific Computer System (SCS) backup server. Hard drives on this server are in a RAID configuration to minimize the potential for data loss.

Target strength data are downloaded to a shore-based computer at the end of each survey 'leg'. Target strength data are archived by the Data Management Service (DMS).

Sampling

Survey Design (A_i)

Techniques

Vessel Speed

Survey vessel speed while conducting transects is optimally 10 knots. The minimum vessel speed for conducting transects is 6 knots. If excessive vessel motion is observed at six knots, operations should be suspended until the sea state reduces.

Currently we do not have objective criteria for reducing vessel speed or suspending survey operations based on excessive performance degradation.

GPS

The primary Global Positioning System (GPS) data used for the acoustical surveys are the differential GPS values. PCODE GPS data are used as a secondary source.

Numerical Density to Biomass Density (D_i)

Techniques

Target Strength to Length Regression

Interpretation and derivation of target strength to length regressions are beyond the scope of these protocols. Target strength data collection methods are detailed in the 'Target Strength Measurements' section. Fish length measurements and biological data collection methods are detailed in the 'Volume Backscattering Measurements -> Classification->Biological Sampling->Trawls' section.

Length-Weight Regression

Interpretation and derivation of length-weight regressions are beyond the scope of these protocols. Fish length and weight measurements and biological data collection methods are detailed in the 'Volume Backscattering Measurements->Classification -> Biological Sampling->Trawls' section.

Oceanographic Data

Techniques

CTD profiles

Fisheries Oceanography Investigation (FOI) maintains the CTD instrument manufacturer, identification number, firmware version, processing software and version and is responsible for calibrating and maintaining CTD instrumentation.

Water samples are collected once every 24 hours and the water stored for laboratory analysis of salinity. These data are used to ensure data quality throughout the survey.

Vertical temperature and salinity (CTD) profiles are conducted at the beginning and end of each transect.

Vertical CTD profiles are also conducted immediately prior to or immediately after every deployment or set of deployments. If multiple deployments are to be conducted in the same area and over a short time frame (e.g., less than 12 hours), whether to conduct a single CTD or multiple casts is left to the discretion of the watch chief.

Data collection and archiving protocols are established by FOI. Prior to each survey, the FOI conducts training for operating the CTD hardware and software. All scientific personnel involved with collecting CTD data attend training at least once during the survey.

Surface temperature and salinity

Sea-surface temperature and salinity sensors and data are part of the Scientific Computer System (SCS). NOAA Marine and Aviation Operations (NMAO) are responsible for maintaining on-board instrumentation and sensors. The ship's electronic technicians document the manufacturer, model numbers, and identification numbers of temperature and salinity sensors.

For acoustical surveys on the FRV Delaware II, the hull-mounted sensors at 3-m depth provide the primary sea-surface temperature and salinity data.

Scientific Computer System (SCS)

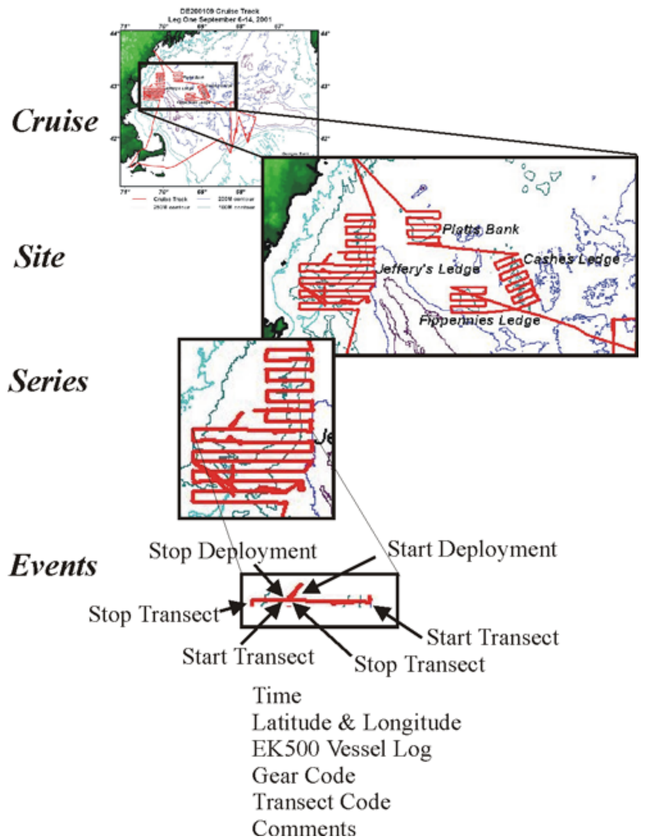

Figure 5. Pictorial overview of the hierarchical NEFSC acoustical event log.

Techniques

Event Log

The Scientific Computer System (SCS) is a shipboard system that logs data from electronic sensors throughout the vessel. Within the SCS framework, SCS event logs are created for specific surveys. The acoustical event log electronically documents events in order to coordinate the acoustical data with other scientific operations, such as CTD and trawl deployments. At the conclusion of a survey, the event log data are audited and entered in an Oracle database. In addition to the electronic log, a ‘hardcopy’ paper form is filled out with equivalent information. This paper log is updated each time the SCS event log is updated.

Prior to sailing, an acoustical SCS event log is created by modifying an existing acoustical event log template. The survey code is set to the current survey, and the event log is saved to a new file. The file name of the SCS acoustical event log is used to define the directory where the data are stored.

During the survey, the acoustical SCS event log is constantly monitored and updated for all events by the scientific personnel. The watch chief is responsible for event log quality and for training personnel in the use of the event log.

SCS data

The following sensor data are pertinent to the acoustical survey and should be collected:

a. Date and time (GMT)
b. GPS (differential and PCODE)
c. Doppler Speed Log (bridge speed log)
d. Motion Sensor

Prior to sailing, the ship's electronic technician is contacted to ensure these data are stored. At the end of the survey, copies of the SCS data are requested from the ship's electronic technician.

Data Management

At the conclusion of each 'leg' of the survey, the SCS and SCS event log data are downloaded to a shore-based computer for storage and archiving. The SCS data are archived by the ship's electronic technician, the NEFSC, and the fisheries acoustics group.

Archival and management of CTD data are the responsibility of the Fisheries Oceanography Investigation.

Modifications to Protocols

Changes to operational protocols will be at the discretion of the NEFSC Science Director who may approve such changes directly or specify a peer review process to further evaluate the justification and impacts of the proposed changes.

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Demer, D.A., M.A. Soule, and R.P. Hewitt. 1999. A multiple-frequency method for potentially improving the accuracy and precision of *in situ* target strength measurements. J. Acoust. Soc. Am. 105: 2359-2377.

Dotson, R. C. and Griffith, D. A. 1996. A high-speed rope trawl for collecting coastal pelagic fishes, CalCOFI Rep., 37: 134-139.

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Appendix 2

March 11, 2005

NOAA Protocols for Fisheries Acoustics Surveys and Related Sampling at the Alaska Fisheries Science Center

Prepared by Personnel from NOAA Fisheries
Alaska Fisheries Science Center

Table of Contents

Introduction

This document provides data collection and operational protocols for acoustical surveys at the Alaska Fisheries Science Center (AFSC). This document is arranged as follows. Center-specific background is given to provide information on AFSC personnel and general support. Four method categories are defined: system calibration and performance, volume backscattering measurements, target strength, and sampling (survey) design. Acoustical background and general information for each category are given in the acoustics National Protocol.

Center Background

AFSC

The Alaska Fisheries Science Center (AFSC) conducts acoustic-trawl surveys in the Bering Sea and Gulf of Alaska. The target species is walleye pollock (*Theragra chalcogramma*). Surveys are conducted aboard the NOAA Ship Miller Freeman and, beginning in 2005, the NOAA Ship Oscar Dyson. Field seasons include approximately six weeks in the winter and three months in the summer. Abundance–at-age estimates from these surveys, along with bottom trawl survey data and fishery catch data, are used to model population size, and, in turn, to establish quotas for the commercial fishing industry under the auspices of the North Pacific Fishery Management Council. The acoustics group within the Midwater Assessment and Conservation Engineering (MACE) Program is comprised of eleven fisheries biologists and three information technology specialists. All employees are full-time and base-funded.

Methods

Calibration and System Performance

A more detailed description of the calibration and system performance techniques presented in the National Protocol document is provided here. For a discussion of the definition and importance of these topics, errors involved and other considerations, the reader is referred to the National Protocol document.

Calibration

Further details about AFSC calibration can be found in the following operating manuals - MACE (2003a), Simrad (1997), and Simrad (2001).

AFSC conducts acoustic-trawl surveys in the winter and summer. To confirm system stability, calibrations are conducted at the start and end of each field season. When possible, additional calibrations may be conducted midway through the field season. The surveys are conducted in Alaska, as are the calibrations, to ensure that environmental conditions are similar.

Calibrations are conducted in the field with the survey vessel anchored (bow and stern) at 50-100 m bottom depth in a sheltered bay. To minimize fish interference with data collection, a site with few or no scatterers in the water column is desired. Standard spheres for the frequencies to be calibrated are suspended below the transducers on a monofilament line. The spheres (each in a monofilament bag) are separated by a distance of 5 m. Positioning of the spheres in the acoustic beam is (remote) controlled with a 3-point downrigger system (Simrad, 1997).

Software

The echo sounders used by AFSC are Simrad's EK500 and EK60. Echoview software (Sonardata, 2003) is used to process on-axis data for Sv and TS gain parameters. Simrad's Lobe program is used to estimate beam pattern parameters - i.e. 3 dB beam width, TS gain and offset angles.

Standard values

AFSC uses the standard spheres listed in Table 1 of the National Protocols document to calibrate its 18, 38, 120 and 200 kHz systems.

Data archive

A snapshot of system parameters is recorded to a file at the start of calibration. All relevant hardware, firmware and software identifiers are recorded on a paper form. For each frequency-echo sounder combination, the internal test oscillator amplitude is recorded and confirmed to be within specification. A measure of passive noise is recorded to ensure conditions are similar among calibrations. Echogram (Q) and echo trace (E) telegrams and "raw" sample power (W) and angular position telegrams (B) data are all recorded to files.

On-axis sensitivity and S_v calibration

Using the echo sounder display of the target in the acoustic beam, the operator moves the sphere to the acoustic axis. On-axis measurements of sphere TS (compared to the standard sphere's known TS) are used to estimate the system's TS gain parameter. On-axis measurements of the sphere S_A (compared to the theoretical S_A) are used to estimate the system's Sv gain parameter. (Note: EK500 defines both TS gain and Sv gain; EK60 uses the terminology TS gain and SA correction, where Sv gain = TS gain + SA correction.) With the sphere unmoving and few scatterers near the sphere, approximately 10 minutes of data collection are sufficient to provide a reasonable sample size for this purpose. Echoview software is used to process these data for estimates of sphere TS and sphere S_A. Estimates of TS gain and Sv gain are required for each frequency-power-pulse length-bandwidth combination to be used during the survey.

Beam pattern measurements

For the two-way integrated beam pattern parameter, AFSC uses the nominal value supplied by Simrad upon delivery of the transducer. The Lobe software program provides a means to check for significant changes to this value. With the remote control downrigger system, the operator swings the sphere through the acoustic beam filling in a circle of data points centered on the acoustic axis. A model of the beam pattern is then fit to these data, providing estimates of TS gain, 3dB beam width and offset angles. TS gain as estimated from this model fit is used as a further check of the on-axis derived value. Results reveal that these two estimates of TS gain differ by no more than 0.1 dB for our 38 kHz EK500 system. Long-term averages of the measured beam width and offset angles are used in the acoustic system for collection and processing of TS data.

Oceanographic data

A fixed sound speed of 1470 m/sec is used for calibration (and survey data collection) of the EK500. For the 38 kHz EK500 system, a fixed attenuation coefficient of 10 dB/km is used for calibration (and survey data collection). For calibration (and survey data collection) with the 120 kHz EK500 system, the attenuation coefficient is set to 38 dB/km in the summer field season and 29 dB/km in the winter field season. These fixed values of sound speed and attenuation coefficient were derived from averages of historical oceanographic data from the survey regions. A CTD is deployed at the calibration site to provide a temperature-salinity-depth profile. For calibration of the EK60, the temperature-salinity-depth profile data are used to provide an averaged value for sound speed and attenuation coefficient between the transducer and the appropriate sphere.

Update guidelines

For the 38 kHz EK500 system, AFSC uses a slightly different set of gain parameters for the summer and winter field season. This system has demonstrated remarkable stability through time and for a wide range of environmental conditions. Gain estimates have not varied more than 0.2 dB from the current system values (Fig. 1). Gain estimates for the 120 kHz EK500 system are much less stable and system parameters are assigned on a survey-by-survey basis.

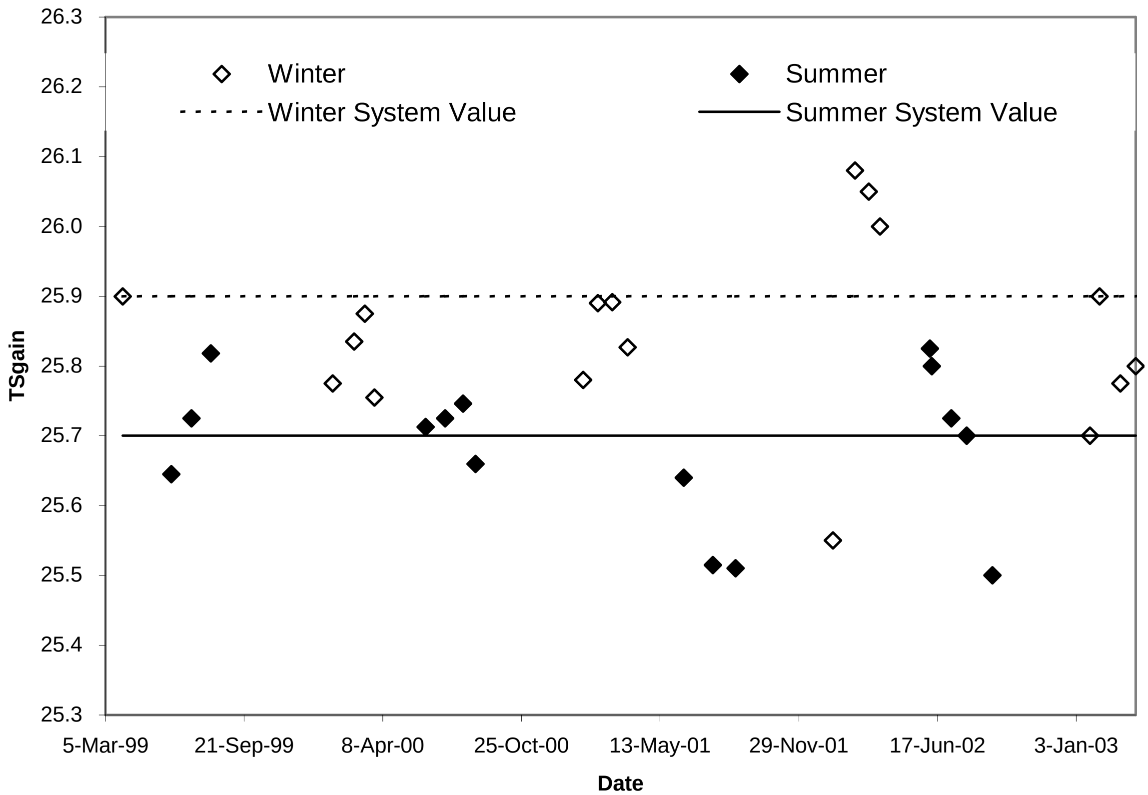

Figure 1. Winter and summer TS gain measurements from calibration of the AFSC 38 kHz Simrad EK500 system.

System Performance

Further details about AFSC system performance checks can be found in the following operating manuals - MACE (2003a), Simrad (1997), and Simrad (2001).

To ensure system stability, the following checks are conducted daily. A snapshot of system parameters is recorded to a file. With the transmitter disabled, the internal test oscillator amplitude is confirmed to be within specification. With the transmitter enabled and the aid of an oscilloscope, transmit current for each of the four transducer quadrants is checked for any significant change. Should a problem exist, these two checks can help isolate the offending component. If both the test tone and current are bad, it is most likely the transducer. If the test tone is bad and the current is good, it is most likely the receiver. If the test tone is good and the current is bad, it is most likely the transmitter (Dan Twohig, pers. comm.).

Volume Backscattering Measurements

Data Collection

Echo Sounder Parameters

The AFSC uses a Simrad EK500 echo sounder. Abundance estimation is based on data collected at a frequency of 38 kHz. See Calibration section for the calculation of G_0. Other 38 kHz frequency settings are as follows:

pulse duration (τ) = 1 ms (Simrad's recommended value, which is considered a "medium" pulse length)
two-way integrated beam pattern (ψ) = -20.7 dB (supplied by the manufacturer)
attenuation (α) = 10 dB/km
sound speed (c) = 1471 m/s

All echo sounder parameter values are exported from the echo sounder to a text file ("EK500 settings") daily during a survey as well as before and after a survey.

Software

The echo sounder firmware version is Simrad EK500 Version 5.3. Acoustic data are logged with SonarData EchoLog 500 Version 3.0. Acoustic data are logged on two separate PCs. Both logging PCs are backed up every day. The echo sounder firmware version is recorded on the calibration sheets and is included in "EK500 settings".

The current post-processing version is Echoview Version 3.00. The post-processing version is included as a field in the *Integration Settings* table in the survey database MACEBASE. When the post-processing software is upgraded, s_A values are compared for a reference set of transects with both high and low densities of walleye pollock to ensure no significant change has occurred to the echo integration algorithm. Results of these analyses are documented on the AFSC computer network.

GPS

Available GPS receivers are a Leica model MX412 (12 channel differential), Trimble Centurion (P-code), Northstar model 2201 (WAAS compatible), and a TSS (Applanix) position orienting system for marine vessels (POS MV) model 320. GPS data are logged at 1-second intervals by the acoustic system and the NOAA Ship *Miller Freeman*'s Scientific Computing System. At the end of the cruise, GPS data are copied to CD. One copy is stored at the AFSC and the other remains aboard the vessel. Mapping of the planned vessel route and recording of the actual vessel track are accomplished with a navigational software package (Electronic Charts Company, Inc., 4039 21st Ave. West #302, Seattle WA 98199). Vessel speed and direction are also available with this software. Position data and vessel speed for available GPS receivers are monitored in real time. When errors are detected, a different navigational device is selected. If the error has affected on-transect data where walleye pollock echo sign was detected, the survey is halted. The position is determined where the erroneous GPS data began to be collected, and the survey is re-started prior to this position.

Detection Probability

Thresholding

The AFSC does not set a data collection S_v threshold. The post-processing s_v threshold is –70 dB. This threshold eliminates most of the backscattering attributed to smaller non-walleye pollock organisms while accounting for most of the echo sign in regions identified as walleye pollock. When decreasing the s_v threshold from –70 dB to –80 dB for the echo sign shown in Figure 2, the s_A of the dense schools of juvenile walleye pollock increased by 1% and the s_A of the dispersed individual adult walleye pollock increased by 9%, whereas the s_A of the unidentified zooplankton increased by 68% (Figure 3). Most of the increase in s_A within the pollock regions can be attributed to the increased detection of smaller non-walleye pollock scatterers, seen as amorphous stippling throughout the water column seen in Figure 2B. The post-processing s_v threshold is included as a field in the survey database MACEBASE.

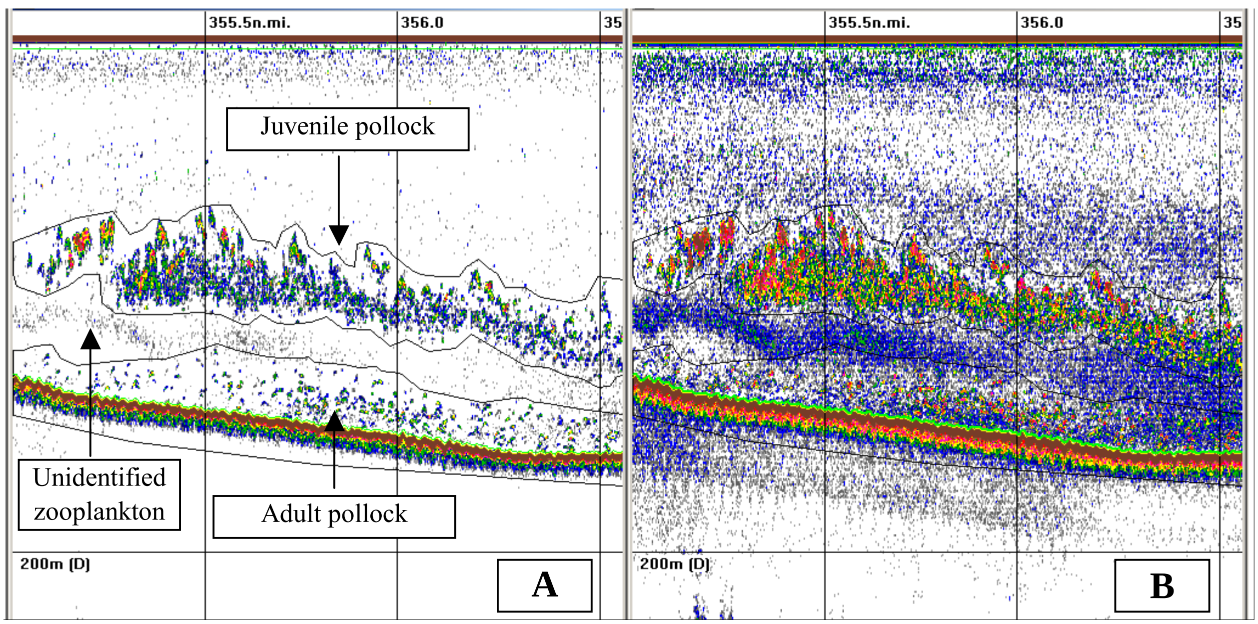

Figure 2.--Example of thresholding on pollock echo sign using (A) the standard s_V threshold of -70 dB and (B) a decreased s_V threshold of -80 dB. Data were collected during August 2001 off Kodiak Island, Alaska.

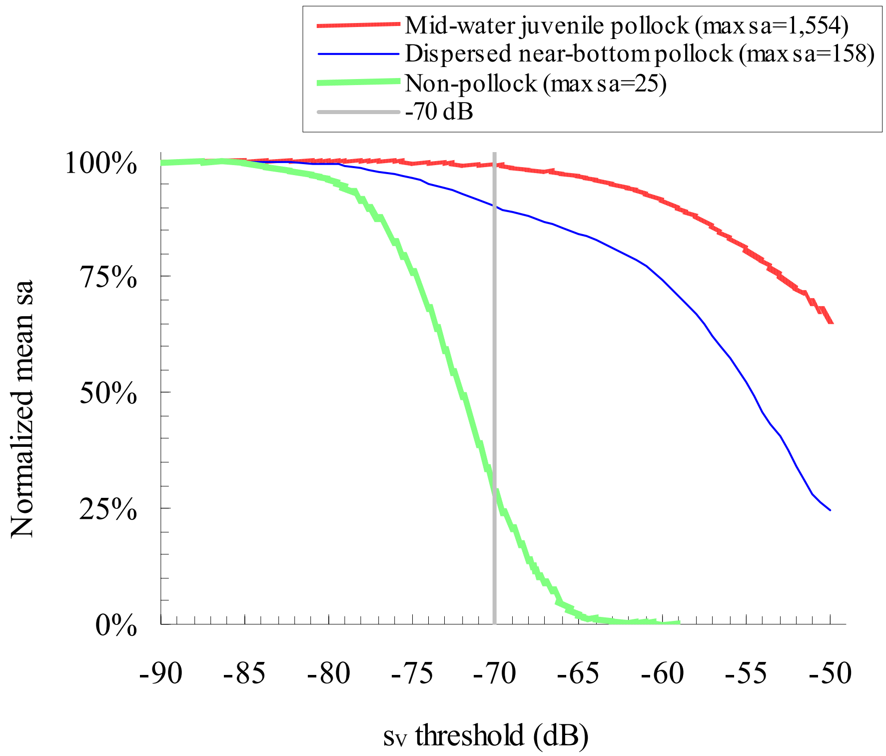

Figure 3. Contrast in s_A as a function of s_V threshold for a dense juvenile pollock mid-water layer, dispersed near-bottom adult pollock, and non-pollock echo sign. Data were collected during August 2001 off Kodiak Island, Alaska.

Range

The vast majority of the areas surveyed by the AFSC are located over the continental shelf (i.e. bottom depth 200 m) although some effort occurs over the shelf break and upper continental shelf break slope where depths can exceed 1500 m. In these latter situations, EIT data to describe pollock distribution and biomass are generally restricted to depths less than 750 m below the ocean surface.

The theoretical return from a 50-cm walleye pollock (based on the 20Log L–66 target strength to length relationship) can be detected to a depth of 550 m before falling beneath the noise threshold.

Acoustic Dead Zones

A fixed depth of 14 m from the surface is used as the surface offset. This value is derived from the location of the transducer on the centerboard 9 m below the water surface plus a 5 m buffer zone for the transducer's near field. An offset of 0.5 m above the sounder-detected bottom is used as the bottom offset. Dead zone corrections are not applied to echo integration data.

Animal Behavior

The effect of vertical and horizontal migration of the target species and efforts to minimize the problem are discussed in the "Sampling" section.

Vessel Noise and Avoidance

The NOAA Ship *Miller Freeman* underwent a major rebuild during winter 1998-99, including installation of a new propeller and major modifications to the main engine. Vessel noise levels for the NOAA Ship *Miller Freeman* were determined during trials at an acoustic range in Behm Canal, Alaska following the repair work. Range results showed that the NOAA Ship *Miller Freeman*'s underway noise signatures were dominated by propulsion-related sources, primarily the main engine and propulsion shafting related sources, and that the underwater radiated vessel noise levels less than 2 kHz exceed the ICES noise recommendation for survey vessels (Mitson 1995). The effect of the vessel noise levels on walleye pollock is currently under investigation.

Fieldwork with a free-drifting acoustic-buoy containing an echo sounder and split-beam transducer operating at 38 kHz has been conducted since 1998 to investigate whether walleye pollock exhibit an avoidance response to underwater-radiated vessel noise. Analysis of the data does not show a consistent, strong avoidance response to noises generated by the NOAA Ship *Miller Freeman* when free running by the buoy at the standard survey speed of 11-12 knots.

Underway system noise levels are routinely measured along offshore cross-transects over deep water (>1,000 m). Calculated noise levels are based on procedures found in the Simrad EK500 Operator Manual (section P2260E/C, pages 16-19). Increased noise may be a result of damage to the propeller, objects entangled in the propeller (e.g. rope, kelp), or noise from shipboard machinery (e.g. generators, compressors).

Multiple Scattering and Shadowing

Furusawa et al. (1992) examined the effect of attenuation caused by dense walleye pollock schools using data collected during a 1990 survey of the eastern Bering Sea. Based on their results, they found the effect of attenuation caused by walleye pollock to be small. Based on this work, the AFSC does not correct for attenuation for high fish densities.

Classification

Single and Multiple Frequency

As mentioned previously, AFSC uses a 38 kHz system in its survey assessment of walleye pollock. Experienced operators use the visual characteristics of these 38 kHz echograms together with catch composition data from trawl hauls to classify echo sign. A qualitative comparison of the 38 kHz echograms with those at higher frequencies (e.g. 120 and 200 kHz) can also assist in the process. At present, no quantitative analysis of multi-frequency data is used to partition echo sign.

Biological Sampling

Mid-water and near-bottom echo sign are sampled with an Aleutian Wing (AWT) 30/26 mid-water trawl (net plan available upon request). On-bottom echo sign is sampled with a 4-panel, high-rise poly nor'eastern bottom trawl (PNE) with roller gear except for Bering Sea shelf summer surveys, where echo sign is sampled with a 2-panel 83-112 bottom trawl without roller gear.

Echo sign is sampled with the AWT unless the echo sign is close enough to the sea floor that the trawl is not able to capture most fish in its path without risking damage to the net. In these cases, a bottom trawl is used. Because of its smaller dimensions, the PNE is occasionally used to sample extremely dense walleye pollock mid-water echo sign when it is impossible to sample the echo sign without over-filling (and thus potentially damaging) the AWT.

Vertical net opening and fishing depth for the AWT are monitored with a WESMAR third wire netsounder system attached to the trawl headrope. For the bottom trawls, a Furuno acoustic link netsounder system is used. Vertical opening for the AWT ranges from 15 to 30 m depending on the size of the tom weights used, the depth fished, and currents. Bottom trawl vertical openings range from 4 to 8 m for the PNE and 2-3 m for the 83-112. Values outside these ranges are indicative of a problem such as a twisted headrope. In these cases, the gear is retrieved and inspected, then reset.

The Chief Boatswain is supplied with diagrams for all trawl gear. The fishing crew immediately repairs minor damage such as broken meshes. When the net is severely damaged, the Chief Boatswain and Chief Scientist examine the damage to decide if the net can be repaired in the field or if the net should be replaced with the spare net carried aboard the vessel. The AFSC maintains a Survey Gear and Support Program, which operates a net shed staffed and equipped to construct and maintain fishing gear used for all RACE Division resource assessment surveys. At the end of each field season, all trawl gear is returned to the net shed, where the gear is stretched out and examined. Repairs are made to meet the standards specified in the trawl diagrams.

Catch rates are visually monitored using the net sounder attached to the head rope. The trawl is retrieved when the scientist in charge feels that a sufficient amount (approximately 1,000 kg) of the target species has been captured. Catches less than about 1,000 kg are sorted completely, while larger catches are subsampled. Details of the catch processing procedures are described in MACE (2003b). To scale backscatter data to estimates of abundance, length data from the target species are aggregated into analytical strata based on echo sign type, geographic proximity of hauls, and similarity in size composition. Age structure (i.e. otolith) samples from the trawl catches are grouped into age-length keys for conversion of abundance-at-length estimates to abundance-at-age.

Length composition data is not used from tows conducted during darkness if during daylight there were two echo sign types (e.g. juvenile mid-water layers and diffuse near-bottom echo sign) in the area but during darkness the two sign types were indistinguishable from each other. Length data are not used when more than one walleye pollock sign type is caught during a trawl haul (e.g. if a mid-water walleye pollock school was captured during gear retrieval when the target echo sign was near-bottom echo sign). Length data from trawl hauls with insignificant catches of the target species (<50 fish) are not included in the analysis of survey data. When the target species is captured along with significant quantities of non-target fish species, the echo sign is partitioned based on catch weight proportions of the two species.

Underwater Video

AFSC does not currently use underwater video to classify echo sign.

Bottom Tracking

The minimum bottom detection level is set at –36 dB. This value is written to "EK500 settings". The maximum depth for bottom detection is set at 1,500 m.

The first step during the editing of acoustic data is to zoom in on the bottom echo and inspect for bottom integration Corrections, if necessary, are made to the 0.5 m bottom offset line. In areas where the bottom has not been tracked well and cannot be easily edited, bottom detection data from another frequency is imported during post processing and applied to the data if it provides an improvement.

A second bottom occasionally appears above the sea floor when in deep water (>1,000 m). When this happens and is noticed in real-time, a slight adjustment is made to the ping rate (0.1 seconds) until the problem clears up. The ping rate is reset to 1.0 seconds as soon as possible. False bottoms are edited out of the data during post-processing.

Oceanographic Data

Temperature profiles are collected at all trawl sites with a micro-bathythermograph affixed to the headrope of the trawl. These profiles are primarily used to compare with vertical and horizontal distribution of the target species. Our survey values of 1471 m/s sound speed and 10 dB/km attenuation coefficient are derived from an analysis of our historical data set of CTD profiles of temperature and salinity.

Performance Degradation

Acoustic noise

Video displays and paper echograms are constantly monitored for the appearance of noise. The most common source of this noise is a result of the bridge sounder or ADCP being out of sync with the EK500. Small amounts of noise are edited during post processing. For severe noise occurrences, the position is determined where the noise began to affect the data, and the survey is re-started prior to this position. Another source of electrical noise is caused by changing the range on the echo sounder.

Electrical noise

An increase in underway system noise levels (See Vessel Noise and Avoidance sub-section) may be indicative of electrical interference caused by another computer system in the Acoustic Lab. When detected the noise is identified and steps taken to reduce or remove it.

Bubble Attenuation

Vessel speed is reduced when heavy seas cause substantial bubble sweep down along the hull and across the transducer face (although slowing the vessel reduces bubbles caused by the pounding of the hull but not by the waves themselves). In extreme weather, survey operations are suspended. However, if surveying in areas where landmasses can offer protection from severe weather, operations are moved into protected areas, and survey operations in the exposed areas are resumed when the weather subsides.

Most noise caused by bubble sweep down is excluded during post processing. No attempt is made to correct for bubble attenuation.

Transducer Motion

Vessel speed is reduced when transducer motion becomes excessive, which helps during extreme pitching but not during extreme rolling. In severe weather, survey operations are suspended. If land masses can offer protection from severe weather, operations are moved into protected areas, and survey operations in the exposed areas are resumed when the weather subsides.

Bio-fouling

The NOAA Ship *Miller Freeman* is moored in fresh water between field seasons, which suppresses the growth of any saltwater organisms (e.g. barnacles) on the transducer face. Transducers are inspected (and cleaned, if necessary) during most sphere calibrations before a survey is started.

Target Strength (σ_i)

Target strength (TS) describes the acoustic reflectivity of a single target. The measurement is needed to scale acoustic estimates (e.g., volume backscattering) into numbers or weight of the target species per unit area. A more detailed description of target strength is presented in the National TS Protocol section. Dedicated efforts at AFSC to collect TS measurements have been directed at fishes. Thus, the following AFSC Regional TS sampling protocols refer to situations where fishes not invertebrates are the target species.

As discussed in the National TS Protocols section, TS measurements can be collected on either immobile fish, fish confined to a cage (*ex situ*), or free-swimming fish in their natural habitat (*in situ*). The focus at AFSC has been to collect *in situ* TS measurements, and attempts to do this are routinely made during AFSC acoustic – trawl surveys. The measurements are used to assess whether modifications should be made to the currently accepted model, which describes the TS to fish length relationship for walleye pollock (Traynor 1996).

<u>Models</u>

Definition & Importance

The model that is currently used to describe the relationship between walleye pollock fork length (L) and TS is TS = 20 log L – 66 (Traynor 1996). The data used to generate the model were in situ TS data collected at 38 kHz from dual-beam and split-beam systems as well as estimates from swimbladder morphology studies. Several other species, besides walleye pollock, are often detected acoustically during AFSC acoustic-trawl surveys (e.g., Sebastes spp., Myctophidae, Osmeridae). Few TS to length relationships have been described for these other species (e.g., Stanley et al. 2000; Benoit-Bird et al. 2001). With the exception of eulachon (Thaleichthys pacificus (Osmeridae)), however, these other species can be discriminated acoustically from the target species, walleye pollock, based on echosign morphology. Research is currently underway to describe the TS to length relationship for eulachon. This information will enable the echo integration data to be more accurately partitioned between pollock and eulachon based on the catch composition of these species and following methods described in MacLennan and Simmonds (1992).

Techniques

Validation

Additional *in situ* TS observations at fish lengths where data are sparse or non-existent (i.e., <35 cm FL) would help justify that the 20 log L – 66 regression model is appropriate to describe the relationship between TS and fish size. Other independent observations for walleye pollock are needed to validate the current TS-length relationship for walleye pollock (Traynor 1996). Horne (2003) reported TS estimates for walleye pollock based on a Kirchhoff-ray mode model and radiographs of anaesthetized fish. His estimates agreed well with the current TS-length regression relationship for fish between about 20-50 cm FL.

Error

Considerations

Several assumptions are made when collecting in situ TS measurements. It is assumed that the measurements are based on single targets, and that the associated trawl catches provide representative size and species compositions of the organisms responsible for the backscattering. These assumptions are often difficult to test (McClatchie et al. 2000, Ermolchev and Zaferman 2003). If they are violated, the current TS-length regression relationship for walleye pollock could be in error. The TS-length regression model that is currently used for walleye pollock is largely based on in situ data that were collected during the day and night. Studies on other gadids have demonstrated that TS estimates may exhibit diel trends (McQuinn and Winger 2003). If this is the case for walleye pollock, the current TS-length regression may be inappropriate.

Remediation

It is important that the currently accepted TS-length regression model for walleye pollock, or any other species, is continuously reassessed using new *in situ* data to evaluate whether the model is appropriate. If additional data lead to revisions in the model, modifications to the survey estimates may be necessary. An illustrative example that documents the evolution of a TS model as a function of fish size at AFSC exists for Pacific hake (*Merluccius productus).* In this case, the TS for hake was revised from –35dB/kg of fish to TS = 20 log L – 68 based on new data (Traynor 1996). This necessitated changes in the abundance estimates for the entire time series (Wilson and Guttormsen 1997; Dorn 1996).

Data Collection

Since 1990 to the present, all *in situ* TS measurements have been taken from the NOAA research vessel, Miller Freeman (http://www.moc.noaa.gov/mf/index.html) using the Simrad EK500 echosounder operating at 38 kHz and, since 1995, at 120 kHz as well. Two different split-beam transducer configurations are used. The most common configuration uses the 38 kHz transducer (Simrad model ES38-B) and 120 kHz transducer (Simrad model ES120-7), which are located on the vessel centerboard (Ona and Traynor 1999). Occasionally, an oil-filled 38 kHz transducer (Simrad model ES38-D) is connected to the EK500 transceiver and lowered over the side of the vessel to various depths (Traynor 1996, Ona 2003).

A decision to collect in situ TS measurements is based on visual assessment of the echogram display. The criteria that are used to make the decision that distributional patterns of the target species (e.g., walleye pollock) are suitable for collecting TS measurements include the following:

1) The range between the transducer and target species is less than about 150 m (Traynor 1996).
2) A cursory visual assessment of the echogram indicates that individual scatterer density is less than about 1 fish per acoustic resolution volume (Ona 1999). To better estimate the number of targets per pulse resolution volume, a simple Excel spreadsheet is sometimes used at this stage to estimate the target density per pulse resolution volume following methods outlined in Ona (1999).
3) The areal extent of the target species having a TS distribution is quickly mapped following an appropriate survey transect pattern (see Sampling section) to verify that an adequate area is available for the work.
4) A midwater haul is conducted to verify that the size and species compositions are adequate to continue TS collection procedures in the area (catch sampling procedures are described in AFSC Regional Sampling section. TS measurements are not considered useable if the presence of another species, by numbers, in the catch exceeds about 5%. The size composition of the target species should be unimodal and cover a fairly narrow size range as recommended by MacLennan and Simmonds (1992).
5) If the above conditions are met, vessel speed is reduced to the point where steering can just be maintained, TS data collection begins, and the details of the event are noted. The vessel course is altered to maintain positions over suitable fish echosign during the TS measurement period. This usually involves reciprocal transects across the fish aggregation.
6) TS data collection proceeds until several thousand measurements have been collected. This typically requires several hours.
7) In situ TS measurements have traditionally been collected at night to minimize the occurrence of multiple targets (Ona 1999). The collection of nighttime TS data should terminate well before dawn while the fish are still within a stable nighttime distributional pattern.
8) A second haul should be made following completion of the acoustic data collection to verify that the conditions such as the species composition and the target species size

composition remained constant during the collection period. If the TS measurements were taken during the night, the second haul should also be conducted well before dawn.

9) The above data collection procedures are generally followed when the lowered transducer is used. However, the vessel speed is reduced to a level needed to simply maintain a transducer wire angle of less than about 10°. A standard copper calibration sphere (60 mm diameter) is suspended about 25 m below the transducer during the entire deployment.

Echo Sounder Parameters

The following Simrad EK500 instrument settings (Simrad 1997) are used to determine the criteria levels for accepting echoes as valid single targets when the equipment is operated at 38 kHz or 120 kHz. Pulse length is 1 ms. The echo sounder firmware version is 5.30.

i. TS minimum threshold -70 dB
ii. Minimum echo length 0.6
iii. Maximum echo length 1.8
iv. Maximum gain or beam compensation 4.0 dB
v. Maximum phase deviation 2.0

Software

In situ TS data are post-processed using Echoview software (SonarData 2003). The analysis of TS data is currently conducted using the Simrad trace output data string (i.e., E data telegram) rather than the raw data (i.e., sample angle and power data telegrams).

Several data filtering procedures are used to edit the EK500 TS data during post-processing. Regions are excluded from further analysis where densities of targets likely result in more than about 1 fish per acoustic resolution volume (Ona 1999). Also excluded are split beam TS measurements with a beam pattern threshold of greater than –1 dB.

Improvements

Improvements in single target detection, such as multiple frequency techniques (Demer et al., 1999), can be implemented to increase the accuracy target strength measurements. Target tracking analyses of the single target data can also be examined to determine if this approach can also be used to improve the data quality of TS data (Ona 2003).

Error

Uncertainty in target strength classification will affect scaling Sv measurements to absolute density and abundance. Systematic errors include using individual targets on the periphery of an aggregation when these individuals are not representative of the species or behavior of organisms within the aggregation.

Considerations

Remediation

Several new methodological approaches could be used to provide information to determine whether organisms from various parts of an aggregation or scattering layer exhibit different physical or behavioral characteristics that impact *in situ* TS measurements. Scientists at AFSC are developing an opening and closing codend device for large trawls that will allow much finer sampling resolution of scattering layers to better characterize the patterns in species and size compositions that may occur within the aggregations and layers. In addition, technologically advanced video systems (Ermolchev and Zaferman 2003) could be integrated with acoustic sensors aboard AUVs to provide new methods of better characterizing fine-scale patterns in scattering layers. These sources of information would be invaluable for interpreting *in situ* TS measurements.

Sampling

Survey Design (A_i)

Techniques – AFSC acoustic surveys are conducted from the NOAA Ship Miller Freeman exclusively. The principle organism of interest is walleye pollock in the Eastern Bering Sea (EBS) and the Gulf of Alaska (GOA). In these mobile surveys, acoustic measurements – principally volume or area backscattering – are made along pre-determined transects that encompass the area (A_i) inhabited by the walleye pollock at the time of the survey. Walleye pollock have been the subject of a long-standing fishery, both in the EBS and in the GOA, so the distribution is well known from fishery catch statistics and from previous scientific surveys. In the Bering Sea in summer, walleye pollock are found primarily along the middle and outer shelf in waters from 200 m to 50 m. In winter, aggregations of spawning walleye pollock are found in the area close to Bogoslof Island at depths of up to 500 m. In the south the Alaska Peninsula and the Aleutian Islands limit the distribution. In the GOA the winter spawning aggregations surveyed are found primarily in Shelikof Strait and in the Shumagin Islands. In recent years substantial aggregations of walleye pollock have also been encountered off the shelf break near Chirikof Island and in Sanak Trough. In 2003 an exploratory summer survey of the GOA was made, including additional areas not surveyed during the winter. This GOA summer survey will be continued on a biennial basis.

Although the earliest AFSC surveys used zigzag patterns, current surveys are made with parallel transect spacing. This design was chosen for the reasons outlined in the ICES report on survey design (Simmonds et al. 1992). The zigzag design was rejected because of the problems caused by uneven sampling at the turns when using this design. The major AFSC surveys are in open seas or areas without major features. Shelikof Strait is 25-30 miles wide, so a parallel design is not markedly less efficient than a zigzag one, nor are there any navigational concerns favoring a zigzag plan. A design utilizing random spacing or stratified random spacing (Jolly and Hampton 1990) was rejected in favor of a systematic parallel design because it was deemed more important to obtain population assessments with high precision than to have good estimates of the precision itself. Analyses have shown that the walleye pollock distribution at the time of the surveys is spatially correlated, so the systematic surveys provide higher precision than random designs (Matheron 1971).

The spacing of transects has been established over time and is now constant between surveys: 20 n.m. spacing in the EBS summer surveys, 5 n.m. in the Bogoslof surveys and 7.5 n.m. spacing in the Shelikof Strait surveys. Spacing is closer in other areas of the GOA (5 n.m. in Shumagin Trough; 3 n.m. in Sanak Trough, Stepovak Bay and West Nagai Strait; and as close as 1 n.m. in smaller bays and inlets.) Originally, logistics played a major role in determining transect spacing: as many transects as possible were surveyed in the time allotted. The much larger area to be surveyed in the EBS dictated a large inter-transect spacing. Geostatistical analyses made since the original cruise tracks were chosen have shown that transects are spaced close enough to adequately sample the major structures in the spatial distribution.

Except in the EBS transect orientation was chosen so that transects cross aggregations in the direction of the maximum density gradient. In Shelikof Strait this means that transects cross the strait. In the EBS the situation is more complicated because the shelf break is oriented in different directions in the southern and northern parts of the survey area. The orientation of the transects has changed through time. Since 1991 transects have been oriented in a north-south direction. Near the Alaska Peninsula transects are in the direction of the depth gradient, but in the far north, are nearly parallel to it. This situation is considered to be less important than it might be in other locations because the depth gradients are so small on the Bering Sea Shelf that fish are unlikely to be oriented in relation to it. Results from previous surveys are consistent with this supposition.

The length and position of transects is planned in advance so that the entire walleye pollock distribution is sampled. Walleye pollock abundance varies within the area between years, so that in some years they are farther inshore, and in other years farther offshore. In general, there are no walleye pollock observed at the ends of transects. When they are seen there, transects are extended until none are present. In the EBS surveys some transects are ended early if no walleye pollock are present and it is concluded that the full extent of the distribution has been encompassed.

As mentioned, logistic considerations play a role in survey design. A further limitation is caused by political considerations. The EBS sampling area is constrained by the international boundary on the north. Walleye pollock abundance is usually relatively high in this area, so transects often must be ended despite significant echosign. Surveys would be extended northward across this artificial border were Russian authorities ever to grant permission.

Timing of surveys was chosen based on fishery data and initial surveys. In Shelikof Strait repeated surveys were made to determine the timing of spawning. Current surveys are made on the basis of results from those surveys, which concluded that maximum abundance of walleye pollock in the survey area occurred when most mature females were in a pre-spawning condition. This takes place in the last two weeks in March. Sampling of abundance together with maturity index during subsequent surveys confirmed this period as the best for walleye pollock abundance in Shelikof Strait, and this is the timing used for current surveys.

Spawning populations are not routinely targeted in the EBS surveys. Much of the Bering Sea is ice-covered during the time when walleye pollock are spawning, so a comprehensive assessment is not possible. During the summer walleye pollock are found in feeding aggregations along the outer portion of the continental shelf. Because the area is so large, the survey takes approximately 2 months. The transects are located so that stations occupied during AFSC EBS Groundfish Surveys are on the acoustic transects, although the two surveys are not synchronized in time.

A decision must be made as to whether surveying can be done over 24 h or must be restricted to either day or night. Summer surveys are made only during daylight hours. This restriction is not overly burdensome at these latitudes where daylight lasts 14-18 h during the summer. The reason for the limitation is that walleye pollock schools and layers, especially those composed of juveniles, disperse at night so that it becomes difficult to distinguish walleye pollock from other targets (see Classification section). Spawning aggregations do not disperse at night, however, so surveying during winter surveys continues day and night.

Because survey areas and transect spacing are not changed from year to year for the major AFSC acoustic surveys, the time needed for running the transects is determined by ship speed alone. The NOAA Ship Miller Freeman cruises generally at between 10 and 12 kts in calm conditions without currents. This speed range is dictated by the need to conserve fuel, although higher speeds are possible and desirable to minimize the time needed for making the survey transects. Cruise planning is made assuming a speed of 11 kts. Actual speeds can vary widely, reaching up to 14 kts with favorable winds or currents, and falling to 5 or 6 kts in rough conditions. In rough seas data quality cannot be maintained and survey operations must be suspended at the discretion of the scientific cruise leader. Although rough conditions can preclude the use of the trawl gear for safety reasons, the suspension of acoustic operations is a relatively rare occurrence in AFSC surveys. Extra time for bad weather conditions is included in the survey plan to make up for reduced speed during poor weather. If this allowance is used up, the number of trawls made during the survey is reduced to keep the number of days allotted for the survey constant despite the time lost or gained by variations in speed. If good weather results in availability of extra time, it is used to conduct exploratory surveys or on research to improve surveys.

No statistical method or criteria are used during planning to determine the number of trawls needed for a survey. Instead, a judgment is made on the basis of experience and results from recent surveys in the time series. Surveys with little variation in size and species composition require fewer trawl hauls than do those with more variability. Because some transects in the Shelikof winter survey are without walleye pollock, in recent years the total number of hauls taken has been about equal to or slightly fewer than the number of transects. There is no underlying model of the fish distribution in the EBS survey, so each large aggregation or school is sampled and only a few trawls are pooled between transects. The number of separate length strata in the resulting analysis is large, and can be as high as 30 or more. Because the transects are long, on average 3 or 4 trawls are made on each. In recent years the number of trawls has exceeded 100 during the two- month long EBS survey.

The time needed to run the transects is relatively inflexible, so the total number of days needed to complete a survey is highly dependent on the number of trawls made. The need to share vessel time with other users at AFSC makes it important to make only as many trawls as are necessary to characterize the population, but as described above, there are no clear criteria for determining how many hauls that is. Choosing the number and location of trawl hauls in an acoustic survey is the subject of ongoing research at AFSC (see Improvements section).

At the present time, a geostatistical one-dimensional (1-D) analysis is used to estimate survey precision (Williamson and Traynor 1996). Results show that in both the Bering Sea and the GOA acoustic data are serially correlated, so traditional methods for estimating precision are not applicable. The 1-D method does not provide an estimate of the size of confidence intervals (CI) about the estimate of total population biomass or numbers (Rivoirard et al 2000). Alternative methods for obtaining CI's are being investigated at AFSC (see Improvements section).

Geographic Positioning System (GPS) data are required for measurements of a species spatial distribution and for determining vessel locations. (See Volume Backscattering section for a description of GPS systems used at AFSC.)

Error

Potential errors in survey design include incomplete areal coverage of the population and incorrect timing of the survey relative to seasonal migrations or other behaviors. The problem of incomplete areal coverage is especially acute for the EBS surveys because of the necessity to avoid crossing the international boundary line. Because population densities are significant in this area, slight changes in the timing of walleye pollock migration patterns can result in significant differences in population estimates, even if the population size is unchanged. If walleye pollock are migrating to the north throughout the two months of the EBS survey, the survey design may not sample all the walleye pollock because transecting proceeds from southeast to northwest.

Remediation

If permission is granted to work across the international boundary, the survey will be re-designed. No other problems requiring remediation have been identified.

Improvements

Some of the improved methods discussed in the Classification section may eventually allow the identification of walleye pollock during the night when they are dispersed and mixed with other species. In that case the EBS and GOA summer surveys might be shortened with no loss in precision.

The introduction of the new NOAA Ship Oscar Dyson will probably not impact survey design, because surveying speeds are expected to be similar to those of the NOAA Ship Miller Freeman. However, any improvement in speed will result directly in the saving of time in the survey. Shorter surveys are likely to be more effective because the effect of fish movements will be reduced.

The assumption that walleye pollock do not move into or out of the EBS survey area during the survey is untested. If they migrate from the southern portion of the EBS to the north as is suspected, the present survey design would minimize bias, since transects would alternately be with and against the direction of migration (MacLennan and Simmonds 1991). However, reversing the order of the transects might be a way to deal with the problem at the international boundary. If fish are migrating northward and if the survey vessel arrives at the boundary early enough, fish that would not have been encountered with the present survey design will be surveyed before they have a chance to move across the boundary. Fish may also move between the GOA and the EBS, however. Concentrations of fish are low in the SE Bering Sea near Unimak Pass during the time this area is surveyed, so the problem is minimal with the current design. If fish abundance in this area is higher in late July at the end of the 2 month survey period, benefits gained on the northern border of the survey area might be lost if the survey is changed so that it proceeds from the northwest to the southeast. In any case, benefits expected from a change must be weighed against potential disruption of the time series

Improvements in the methods used to locate trawl hauls and pool them objectively might result in greater efficiency and an associated reduction in the number of trawls needed to scale echo integration data. This could reduce the time needed for a survey. Reductions in the time needed for a survey should also improve precision, as problems with movements of fish into and out of the area would be reduced.

Modifications to Protocols

Changes to operational protocols will be at the discretion of the AFSC Science Director who may approve such changes directly or specify a peer review process to further evaluate the justification and impacts of the proposed changes.

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NWFSC Regional Protocols
For the
Joint Canadian and U.S. Pacific Hake Acoustic Survey

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Introduction

Scientists from the United States (NOAA Fisheries) and Canada (Department of Fisheries and Oceans) jointly conduct periodic acoustic surveys of Pacific hake, *Merluccius productus*, along the west coasts of both countries. The age-specific estimates of total population abundance derived from the surveys are a key data source for the joint US-Canada Pacific hake stock assessments and ultimately act as the foundation for advice on international harvest levels. These integrated acoustic and trawl surveys, used to assess the distribution and biology, in addition to the status and trends in abundance of Pacific hake, were historically conducted triennially by the Alaska Fisheries Science Center (AFSC) beginning in 1977 and annually along the Canadian west coast since 1990 by Pacific Biological Station (PBS) scientists. The triennial surveys in 1995, 1998, and 2001 were carried out jointly by AFSC and DFO.

Following 2001, the responsibility of the US portion of the survey was transferred to Fishery Resource Analysis and Monitoring (FRAM) Division scientists at the Northwest Fisheries Science Center (NWFSC). A joint survey was conducted by FRAM and PBS scientists in 2003, marking not only the change in the US participants but also a change to a newly-adopted biennial survey regimen. As in past efforts, this survey was performed in the summer months (June-September) targeting aggregations of Pacific hake along the continental shelf and break with a geographic coverage that ranged from central California to north of Queen Charlotte Sound (36°30'N - 54°30'N).

The equipment and survey techniques have evolved over the 26-year history of this survey. Improvements in both, especially the rapid and continuous technological advances in the echo sounding systems, have advanced the capabilities of the survey. The NWFSC inherited this current state of survey operations from the AFSC with the transfer of the survey responsibility. For the purposes of these regional protocols, only the most recent operational and procedural elements of the joint Pacific hake survey are considered. The reader should note that the protocols detailed below pertain to acoustic data collected with SIMRAD EK500 quantitative echo sounding systems (Simrad, 1996) (updates to this protocol are anticipated in the near future with the replacement of the SIMRAD EK/ER 60 echo sounding system.) 38 kHz and 120 kHz split-beam transducers are deployed off all participating survey vessels (currently the NOAA Ship *Miller Freeman* and the CCGS *W.E. Ricker*), with the 38 kHz system the primary data source for quantitative Pacific hake backscatter measurements.

The NOAA mandate to develop national and regional protocols for acoustic-based surveys did not consider joint international programs such as the Pacific hake acoustic survey. The protocols listed below pertain strictly to the US portion of the survey. Our Canadian collaborators are aware of the protocol mandate and will be party to the results for their consideration. However, the procedures and standards adopted for the joint Pacific hake survey and listed herein are not to be construed as applicable for the survey practices beyond NOAA and do not necessary signify acceptance and approval by the sovereign of Canada. Details of the procedures and practices by the DFO are listed in Kieser et al. (1998, 1999).

The equation below describes the conversion of measured acoustical energy (E_i,) to a biomass estimate (B_i) for a given class of fish *i*, using calibration parameters (C_i), the estimated backscattering cross-section (σ_i), the conversion from numerical to biomass density (D_i), and the survey area (A_i). This equation providing a conceptual framework for the following protocols, with each component addressed in turn.

$$B_i = \frac{CE_i}{\sigma_i} D_i A_i$$

The national acoustic survey protocol document, NOAA Protocols for Fisheries Acoustics Surveys and Related Sampling, contains more detailed background material and additional information.

Protocol 1 – Calibration and System Performance (C)

<u>Calibration</u>

The calibration process characterizes system parameters relative to expected standard values and is conducted to (1) ensure that the echosounder and transducer components are operating properly, to (2) document the system performance over time (i.e., among survey periods), and to (3) allow inter-echosounder comparisons. The practice of calibration is essential to ensure accurate quantitative surveys.

Techniques

Issues to consider for the calibration procedure include that (1) the calibration should be conducted in as near the range of environmental conditions (e.g., water temperature and salinity) as are expected during the ensuing survey, (2) water depths must be sufficient to exceed near-field limitations and system limitations for the sounder frequencies to be calibrated, (3) the vessel needs to be anchored a) in a location that is calm and sheltered, avoiding areas with inclement weather or strong tidal currents to minimize the effects of surge that can hamper the ability to properly locate the suspended sphere in the sound beam, and b) in an area with few or no fish. Given the above considerations, which collectively are all difficult to fully satisfy, past experience indicates the calibrations for the west coast survey should be conducted at the following locations:

- Port Susan, Puget Sound, Washington (48□9□ N, 122□7□ W)
- Departure Bay, near Nanaimo, British Columbia, Canada (49□12□N, 123□58□ W)
- Barkley Sound, near Ucluelet, British Columbia, Canada (48□55□ N, 125□30.5□ W)
- Prince Rupert, British Columbia, Canada (54□19□ N, 130□19□ W)

Another site that may be used, but is less favorable due to depth limitations and protection from surge, is:

- Monterey Bay, Monterey, California (36°37′ N, 121°53′ W)

A successful calibration must be completed prior to embarking on the survey. An additional calibration immediately after the survey is also strongly encouraged, but is not required if and only if the initial calibration indicated a continued history of acceptable system performance, and regular in situ performance measures did not indicate any system irregularities (see System Performance section below). Calibrations during the survey are helpful for ensuring the system performance, but may be difficult to complete due to the combination of lack of suitable sites on the west coast and time constraints.

The method of calibration used for all acoustic assessment surveys by the NWFSC employs a standard target whose acoustic scattering properties are known following the procedure of Foote et al. (1987). The target is a solid metal copper or tungsten carbide sphere which is suspended below the transducer. The appropriate sphere is suspended on 3 monofilament (fishing) guy lines below the transducer – either manual or mechanical adjustments are made to the individual lines to move the sphere relative to the transducer. Details are listed in the FRAM Hake Acoustic Survey Manual (FRAM Division, Northwest Fisheries Science Center, 2725 Montlake Blvd E., Seattle, WA 98112).

- A 60-mm copper sphere, usually supplied by the manufacturer, is to be used as the primary reference target for the 38 kHz system.
  - Spheres machined to the appropriate diameter matched to other frequencies may be employed (see manufacturer's guidelines for each additional frequency).
  - Tungsten carbide of appropriate diameter can also be used as reference target for 38 kHz and other frequencies.
- The manufacturer recommends a 15 m minimum distance between the transducer and sphere for the 38 kHz system.
- Conduct calibrations at each unique set of sounder settings to be used in the survey.
- Soak spheres in ultrasonic cleaner for approximately 1 hour to ensure clean surface.
- Conduct calibration for each frequency separately.
- Log the calibration results and all supporting information into cruise log as specified in FRAM Hake Acoustic Survey Manual.

Each calibration will follow the manufacturer's operational procedures. Refer to the manufacturer's manual (Simrad, 1996) for details on preparations and transducer maintenance, specific reference target to use, system settings, data recording, data editing, and updating the transducer parameters.

- Collect calibration backscatter data on the acoustic axis.
- To measure beam pattern, move the sphere slowly throughout the beam to collect calibration backscatter data evenly in all quadrants of the beam.
- Record the raw backscatter for both the on- and off-axis sessions for archive.
- Include correction (reduction) of range between transducer and sphere as detailed by manufacturer (Simrad, 1996).

- For the 38 kHz transducer operating at a 1 ms pulse width and a 3.8 kHz bandwidth, the range correction is 0.30 m (Simrad, 1996).

The decision to use the current calibration information to update the system parameters is based on both the guidance provided by the manufacturer and the level of confidence in the calibration values as judged by the scientist. *Failure to update at this point is not critical to the success of the survey as any corrections to these values can be implemented in the post survey analysis.* The judgment by the chief scientist is to be based on the degree the full suite of conditions listed initially in this section were met during the calibration.

Prior to each calibration session, a measurement of the physical environmental conditions needs be made to document temperature and salinity conditions. These variables are necessary to calculate the ambient sound speed. If the duration of the calibration is greater than several (4-5) hours, it is recommended that at least one other measure of temperature and salinity be made to ensure consistency in sound speed during the session. If found different, update values as appropriate.

- Speed of sound will be calculated from the ambient water temperature, salinity and depth as per Mackenzie (1981).
- Apply those measures from the depth stratum immediately surrounding the sphere.
    - The use of the immediate area, the standard practice, rather than consideration of the entire water column for this calculation has been criticized. With this issue unresolved, we recommend avoiding areas with severe clines in temperature or salinity for the calibration.

Error

Errors associated with calibrations are indicative of the overall system precision.

- Tolerance for error in the 38 kHz system calibration should be ± 0.2 dB for on-axis target strength measurements (Foote, 1983; MacLennan and Simmonds, 1992).

Considerations

Measured values should fall within the above tolerance. If not, the source of the error should be identified and corrected. System performance tests (see below) should be performed in an attempt to determine if the problem is with the transducer or transducer cable. If this does not reveal the source of the problem, then a full set of diagnostics must be completed on the echo sounder to determine the source of the problem.

- The survey should not continue until the problem is rectified.

<u>System Performance</u>

System performance procedures are used to evaluate the echo sounder and transducer performance during a survey. These procedures are intended to provide periodic monitoring and evaluation of the system performance to ensure continued data quality during the survey. System performance addresses the internal electronics and processors, transducer, and cable. It does not consider interference introduced from external sources (see Performance Degradation section).

Techniques

Since calibrations cannot be practically performed on a daily basis, measurements of test values and passive noise values need to be completed once a day.

- Test (internal oscillator) values and passive noise values will be documented once every 24 hours. Refer to manufacturers manual (Simrad, 1996) for details on procedures. Logistically, these procedures can only be completed when data collection is not critical, as the echo transmissions need to be turned off.
- Log all results and supporting information into cruise log as specified in FRAM Hake Acoustic Survey Manual.
- During periods of data collection, inspect individual target locations on TS Menu. Individual echoes should appear in all quadrants.

Error

Degraded system performance will directly affect backscattering measurements. Systematic errors include a change in transducer sensitivity that can be tracked by periodic and regular tests as described above. Random errors may also be present, but are more difficult to detect. Every effort should be made to monitor whether system performance is found to change consistently, or vary considerably, over time.

Considerations

Follow the manufacturer's detailed guidelines for system performance.

- Survey operations must be suspended until system performance is rectified if test values range out of manufacturer's tolerances.
- To minimize the potential loss of survey time from failed or failing systems, backup components (e.g., echo sounder unit, cables, and processors) should be kept in stock and ready for deployment. Failed transducers are less likely, but pose a serious logistical problem that will usually require time in dry dock to replace.

Protocol 2 -- Volume Backscattering Measurements (E_i)

Data Collection

The NWFSC has in the past used a Simrad EK500 echo sounder, but will be moving to a Simrad EK/ER60 echo sounder system in the future (using the same transducers). Abundance estimation is based on data collected at a frequency of 38 kHz. See Calibration section for settings derived from calibration of the sounder and transducer. Other 38 kHz frequency settings are as follows:

- Pulse duration (τ) = 1 ms (Simrad's recommended value, which is considered a "medium" value)

- Two-way integrated beam pattern (ψ) = -20.7 dB (supplied by Simrad; value is specific to individual 38 kHz transducers)
- Absorption (α) = 10 dB/km
- Sound speed (c) = 1480 m/s

The sound speed and absorption settings are based on a compromise between previous AFSC survey sound speed settings and DFO Canada sound speed settings. All echo sounder parameter values are exported from the echo sounder to a text file (e.g., "EK500 settings") daily during a survey as well as before and after a survey.

Software –Acoustic data have been logged with SonarData EchoLog 500 (SonarData Pty Ltd, GPO Box 1387, Hobart TAS 7001, Australia) and in the future may be logged with SonarData Echolog60. Acoustic data are logged onto a PC and are backed up at the end of each transect. The echo sounder firmware version is recorded on the calibration sheets and is included in the daily export file of echo sounder parameters.

The post-processing version used to analyze the data should be the most recent validated (non beta) version of SonarData Echoview. The post-processing version is included as a field in the *Integration Settings* table in the survey database. When upgrading versions, a reference set of data should be analyzed with both versions and the s_A values (see definition of s_A in Protocol 3) compared to ensure that no significant change has occurred to the echo integration algorithm.

GPS – A GPS receiver(s) on the vessel sends navigation data to the echosounder where the data are logged with each ping. Mapping of the planned vessel route and recording of the actual vessel track are accomplished with a navigational software package (e.g. Seaplot or Simrad CM-60). Vessel speed and direction are also available with this software. Position data and vessel speed are monitored in real time.

Oceanographic Data – Conductivity-temperature-depth (CTD) profiles may be conducted regularly during cruises, according to standard oceanographic procedures (Emery and Thomson, 1997) and relevant manufacturer guidelines. In general, these salinity and temperature profiles are not used to perform in-cruise updates of sound speed and sound absorption. Rather, single representative sound speed and absorption values are used for the entire survey. As sound speed and absorption may vary rapidly within a transect both in horizontal and vertical distance in the water column, updating sound speed based upon a local profile may generate more variability than it would reduce. Our survey values of 1480 m/s sound speed and 10 dB/km attenuation coefficient are a compromise between values obtained from DFO Canada and the AFSC historical oceanographic data.

Detection Probability

The NWFSC does not set a data collection S_v threshold. The post-processing S_v threshold is -58.5 or –69 dB, depending on the geographic area. Transects south of 47.3° N are analyzed with a threshold of -58.5, and those north of 47.3° N are analyzed with a threshold of -69 dB. This is based upon historical precedent from before the survey was transferred from the AFSC to the NWFSC.

The areas surveyed by the NWFSC range from shallow water through the shelf break to deeper water, covering depths from <50 m to greater than 1500 m. However, the data are only analyzed to a depth of 500 m, as the vast majority of hake are believed to be distributed at depths of less than 500 m. The assumption is made that at this depth hake are above the noise threshold for their entire geographic range.

Acoustic Dead Zones: Near surface and near bottom

A fixed depth of 11 m for the *CCGS Ricker* and 14 m for the NOAA vessel Miller Freeman are used as the surface offsets. These values are derived from the location of the transducer on the centerboard below the water surface plus a 5 m buffer zone for the transducer's near field. The surface offset may vary from ship to ship based upon the depth of the transducer; of greatest importance is to leave a buffer zone for the transducer's near field. An offset of 0.5 m above the sounder-detected bottom is used as the bottom offset. Near bottom dead zone corrections are not applied to echo integration data.

Vessel Noise and Avoidance

According to measured underway noise signatures of the *Miller Freeman* and the *Ricker* (Ken Cooke, DFO, Alex De Robertis, AFSC, personal communication), both vessels exceed the ICES radiated noise recommendations for fisheries survey vessels given by Mitson (1995). However, it is assumed that the radiated noise of these vessels does not significantly affect hake detection probability.

Passive noise levels are routinely measured while underway during surveys as a measure of internal system performance, ideally during offshore cross-transects in deep water (> 1,000 m; see Protocol 1, Calibration and System Performance). Unusual noise levels can also indicate problems external to the system, such as noise from damaged propeller or an object entangled in the propeller (e.g., rope, kelp) or noise from other shipboard equipment (e.g., generators, compressors, other acoustic gear).

Multiple scattering and shadowing

The NWFSC has not observed the conditions that would indicate the need to correct for attenuation at high fish densities.

Considerations

Remediation – Under ideal circumstances, a volume backscattering threshold would not need to be used, as a threshold is a purposeful bias of the backscatter. This bias usually implemented to provide an improved signal to noise ratio, but can also have unintended consequences. Consideration should be given to the possibility that using a consistent threshold may not always yield consistent survey results.

See also Protocol 4, Sampling.

Improvements – Four new fisheries research vessels are currently being built for NOAA, one for each fisheries science center. The first will begin work for the AFSC in 2005. Each will meet ICES recommended noise standards (Mitson, 1995), reducing the potential for vessel noise to affect fish behavior and bias survey results.

Classification

Techniques

Single Frequency – As described previously, the NWFSC uses a 38 kHz system in its survey assessment of hake. Experienced operators use the visual characteristics of these 38 kHz echograms together with catch composition data from trawl hauls to classify the backscattering layers. A qualitative comparison of the 38 kHz echograms with those at higher frequencies (e.g. 120 and 200 kHz) can also assist in the process. At present, no quantitative analysis of multi-frequency data is used to aid in judging the presence of Pacific hake.

Multiple Frequency – Multiple discrete frequency and broadband acoustical data offer potential ways of classifying backscatter from targets of interest, since the scattering from different kinds of fish, for example, may have a different acoustical signature across multiple frequencies. This is an active area of research, and the success of the technique depends heavily on the kinds of organisms present, the frequencies available, and the goals of the survey. Multifrequency techniques have been used to classify fish and plankton, but these techniques have not yet become reliable enough to be a part of regular NWFSC surveys.

Biological Sampling – Mid-water and near-bottom scattering layers are sampled with appropriate trawl gear. Net openings and fishing depth are monitored with a net sounder system. Catch rates are visually monitored with the net sounder and the trawl is retrieved when the chief scientist determines that an appropriate amount of fish has been sampled. Catches are completely sampled, unless the chief scientist determines they are too large; then they are sub-sampled. Details of the catch sampling procedures are in the FRAM Hake Acoustic Survey Manual. To scale backscatter data to estimates of abundance, length data from the target species are aggregated into analytical strata based on patterns of the backscattering layers, geographic proximity of hauls, and similarity in size composition of associated catch data. Age structure (i.e. otolith) samples from the trawl catches are grouped into age-length keys for conversion of abundance-at-length estimates to abundance-at-age. When Pacific hake are captured along with significant quantities of non-target fish species, the backscattering is partitioned based on catch weight proportions of the two species. See Numerical to Biomass Density in Protocol 4, Sampling.

Underwater video and camera systems are a potential alternative to trawling for the purposes of identifying backscattering organisms, collecting size data, and documenting behavior. Potential drawbacks are the relatively short range of view and the possible behavioral reaction of fish to the artificial lights necessary for the operation of the cameras. Also, video or still camera sampling does not provide a direct means of collecting age data. NWFSC does not currently use underwater video to classify echo sign.

Bottom Tracking – Echosounders and post processing software have algorithms to identify and track the seabed in the echogram display. This function is very important because non-biological scattering associated with the bottom return must be completely excluded. The performance of these algorithms varies with bottom type, slope, and ship motion. The minimum bottom detection level is set at – 45 dB. This value is written to the sounder settings file. The maximum depth for bottom detection is at least 1000 m, and can be changed by the user depending on conditions.

The NWFSC uses a 0.5 m offset above the sounder-detected bottom to exclude scattering from the seafloor. This 0.5 m offset must be manually checked during post processing. Useful techniques for efficiently completing this bottom checking are detailed in FRAM Hake Acoustic Survey Manual.

Oceanographic Data – Temperature profiles are routinely collected during trawl sites using a temperature depth profiler attached to the headrope of the trawl. These profilers are calibrated by the manufacturer and also compared to the data gathered with the ship's CTD.

Error

Sources of error include departure from the assumption of the representation of the size distribution of the source of backscatter and the selectivity of the trawl gear, which could produce unrepresentative catch proportions, age-length data, and misidentification of acoustic scattering.

Incorrect bottom tracking could result in the inclusion of bottom energy or exclusion of near bottom fish backscatter, depending on where the bottom detection is drawn.

Considerations

Remediation – Proper gear maintenance, deployment, and processing procedures should be followed to maximize the quality of the trawl data for classification of the acoustic data.

Bottom tracking settings should be optimized and the resulting traces checked for accuracy.

Oceanographic equipment should be maintained and calibrated according to the manufacturers specifications. It is good practice to compare the performance of trawl mounted sensors to those on oceanographic CTD packages.

Improvements – Bottom tracking algorithms and post-processing software continue to improve.

Alternative techniques, such as underwater video, still cameras, acoustic cameras (e.g. DIDSON), may be used to judge the performance of traditional trawling techniques or to augment the data gathered by trawling. Other techniques usually have potential drawbacks and biases, however; there is no panacea for the problem of correctly classifying the acoustic data.

Multifrequency and broadband acoustics provide another future means of improving classification and acoustic biomass estimates. These techniques are currently under development.

Performance Degradation

Definition & Importance

"Performance degradation is the reduction in echo sounder performance due to mechanical, biological, or electrical processes.

Degradation in echo sounder performance can be caused by acoustical, vessel, and electrical noise, bio-fouling of the transducer face, excessive transducer motion, and bubble attenuation. Performance degradation differs from system performance in that the causes of performance degradation are external to the echo sounder, where as 'system performance' concerns the echo sounder electronics.

Routine monitoring of data by scientific personnel during data collection is necessary to ensure a high standard of data quality." (NOAA Protocols for Fisheries Acoustics Surveys and Related Sampling)

Techniques

Noise –Video displays of echograms are constantly monitored for the appearance of acoustical noise. Examining the display while the sounder is in passive mode may also be useful in identifying external sources of acoustical noise. A common source of acoustical noise is a result of the bridge sounder or ADCP being out of sync with the EK500. If the source of the noise can be identified as another piece of shipboard gear, the offending gear should be either shut down (preferably) or synchronized with the EK500.

Small amounts of noise are edited during post processing. In the event of serious noise, the position is determined where the noise began to affect the data. The chief scientist will decide either to continue or lose those data, or to re-start the survey prior to the position of the noise. The choice will depend on whether the data loss appeared to be significant. If data loss is determined not to be significant and the survey is continued, the area of noise will be designated as "bad data," and will yield a zero data point at the position.

Electrical noise can result from grounding problems or other pieces of electrical equipment. As with acoustical noise, electrical noise is often manifested in the data display or in unusual system diagnostic values (see Protocol 1, Calibration and System Performance). To resolve, ensure proper grounding of the sounder, use an uninterruptible power supply and/or "clean" ship's power, and shut off offending equipment if it can be identified. Additional remediation methods during the cruise and in post-processing are the same as those given above for acoustical noise.

Bubble Attenuation – Bubbles are strong sources of scattering. Bubbles can both lead to increased signal attenuation and also be a source of misclassified backscattered energy on an echogram (scattering from bubbles could be confused with scattering from fish). Bubbles near the sea surface are often associated both with vessel speed and sea state. Transducers should be located so as to minimize the effects of 'bubble sweep down'. In rough seas, vessel speed may have to be reduced or operations suspended to preserve data quality (see Protocol 4, Sampling). If scattering from bubbles can be reliably identified on the echogram, it can be identified and disregarded in post-processing. This will not correct for attenuation of the transmitted signal, however. The NWFSC does not apply a post-processing correction for signal attenuation due to bubbles.

Transducer Motion – As with bubble attenuation, transducer motion is associated with vessel motion, placement of the transducer, and sea state, thus many of the same considerations and remediation methods apply. “Dropouts” on an echogram are a typical manifestation of transducer motion. As with bubble attenuation, if transducer motions become excessive, vessel speed or suspension of operations may be considered to preserve the quality of the data (see Protocol 4, Sampling).

Bio-fouling – Bio-fouling refers to biological growth (e.g. barnacles) on the face of the transducers. The effects of biofouling can be identified by unusual calibration results or system performance measures (see Protocol 1, Calibration and System Performance). Transducer faces should be inspected and cleaned if necessary before the beginning of a survey or field season.

Error

Noise, bubble attenuation, excessive transducer motion, and biofouling will degrade system performance and lower the signal to noise ratio of the data and any resulting biomass estimates.

Considerations

Remediation – If possible, the above sources of reduced performance should be avoided by proper planning and setup, troubleshooting and elimination of noise problems encountered during the survey, or post-cruise processing to remove or otherwise account for the problem, as described in each section above. The error resulting from issues that reduce sounder performance should be well understood.

Improvements – If applicable, motion sensor data may be used to correct acoustic measurements.

<u>Data Management</u>

Acoustic Data

Raw data files and .ev files are logged, written to an external hard drive, and live viewed with Echoview software. File size is limited to 10 MB to facilitate file handling and data transfer. Raw data files are copied to a second external hard drive at the end of each transect or at the end of a day’s operation to ensure that two shipboard copies of the raw data exist. This copy of the raw data is judged with Echoview and saved on both external hard drives. Raw data, .ev files, and judged data are burned to a DVD when enough data to fill the DVD (approximately 4.75 GB) have been accumulated. A total of three copies of the data are thus created.

Upon completion of the survey all data are uploaded to a server in the Seattle FRAM facility. Duplicate DVD copies are archived to the Newport FRAM and Nanaimo DFO facilities such that, overall, raw data from the survey reside in three separate physical locations.

Biological Data

Data from catch processing and haul operations are recorded to PCs during a survey. Catch, haul, length, and specimen files should be backed up routinely onto external hard drives or networked servers. Files can also be burned onto CD or DVD for added redundancy. Upon survey completion, these files are permanently archived onto an Oracle server at the Seattle FRAM facility after undergoing a battery of error checks.

Oceanographic Data

Vertical profiles of temperature and salinity collected with conductivity-temperature-depth (CTD) systems and temperature and depth profile data collected from portable, micro-bathythermographs are recorded to PCs during a survey. Ocean current velocity profile data from Acoustic Doppler Current Profilers (ADCP) are also written to a PC. Oceanographic data should be backed up routinely onto external hard drives or networked servers during a survey. Data can also be burned onto CD or DVD for added redundancy. Upon survey completion, all files are downloaded to a server in the Seattle FRAM facility. An Oracle-based adatabase for oceanographic data has yet to be developed. Currently, post-cruise quality control/quality assurance procedures and analysis of these data are done in collaboration with partners in the oceanographic field, e.g. at Oregon State University and/or DFO, Institute of Oceanographic Sciences.

Protocol 3 – Target Strength (σ_i)

Models

The backscattering characteristics of detected Pacific hake, required to scale the measured volume backscattering (see Protocol 4), are predicted by applying an empirically derived TS-length relation to the appropriate size distribution of sampled fish. *In situ* measurements are not used owing to the combination of depth (distance from the transducer) and the rather high densities Pacific hake aggregations typically exhibit during survey conditions (see Techniques section and Improvements section, below).

- The Traynor (1996) relation of backscattering to fish size for Pacific hake at 38 kHz is given as

$$TS_{dB} = 20 \log L - 68 \;,$$

where TS_{dB} is target strength in decibels and L is fish length in centimeters.

The following are conventions to be followed:

- Target strength (TS), the logarithmic form of the measured backscattering cross section (σ_{bs}), is given as:

$$TS \equiv 10\log_{10}(\sigma_{bs})\,\mathrm{dB\ re}\,1\,\mu\mathrm{Pa}$$

in Maclennan et al. (2002).

- Backscattering cross section is further distinguished from omni directional or spherical scattering cross-section by:

$$\sigma_{sp} = 4\pi\sigma_{bs}$$

where the 4π term must be included in the scaling of volume backscattering by σ_{bs} when applied to nautical area scattering coefficient (m^2/nm^2), denoted as s_A (Maclennan et al., 2002).

Techniques

The expected backscattering cross section (σ_{bs}) for a given assemblage of Pacific hake is based on the empirical relation suggested by Traynor (1996) as:

$$\sigma_{bs} = \sum_{j} f_{ij} 10^{\{[-68+20\log L_{ij}]/10\}}$$

for the frequency *f* of length *L* of the length class *i* in composite catch sample *j* .

Validation – To date, the empirical equation reported by Traynor (1996) represents the best understanding of *in situ* backscattering properties of Pacific hake that relates target strength to fish length at 38 kHz. This work represents an extension of initial *in situ* measurements on Pacific hake made by (Williamson and Traynor, 1984). These and other studies that attempt to define the *in situ* target strength characteristics of Pacific hake (e.g. Hamano et al., 1996) all suffer from the ability to find appropriate day and nighttime concentrations of hake at moderate depths. Collectively, these studies are consistent within their results, though variability in their measurements suggests further refinements are in order.

Error

Error in the predicted TS values will affect the overall uncertainty in the derived abundance estimates. While this error will never be eliminated, the degree that variability in backscattering characteristics that occurs should be recognized in view of the resulting level of tolerance of error based on survey goals. Under typical survey conditions, MacLennan and Simmonds (1992) suggest error in TS may range 0 – 50%, which at the upper end, may contribute extensively to the overall error budget.

One source of potential error in predicted TS from application of the Traynor (1996) equation is the inability to incorporate effects on backscattering from changes in behavior and vertical distribution of Pacific hake. The conditions that characterized the hake during the acquisition of the *in situ* measurements and used to develop the relation must necessarily be assumed to be the same for subsequent application in any given survey – deviations from those behaviors present in the fish used in developing the relation (e.g., tilt angle distributions) and those encountered during a survey will induce errors in the length-specific predicted TS values. Moreover, this relation also assumes that backscattering cross section is proportional to the square of the fish length (Foote, 1987), which may not necessarily be a viable assumption (McClatchie et al., 1996). The latter feature of the TS-length model has implications for the accuracy to which the relation can predict TS, especially beyond the narrow size range of hake used in the Traynor (1996) equation.

Another consideration regarding bias in the derived TS from fish size distribution is the assumption of representativeness across all length classes for sampled Pacific hake. Net selectivity is typically asymptotic, with smaller fish proportionately less represented in the trawl catches. If the younger fish are indeed a significant proportion of the backscatter, but are not represented in the catch, appropriate compensation by weighting in the size distributions will be needed. There is evidence of variable catchability of Pacific hake acoustic survey (Helser et al., 2004), but this pattern incorporates other features of the survey (e.g., availability, sampling bias) beyond simple net selectivity.

Considerations

Remediation – In the event that the currently accepted TS-fish length relation for Pacific hake is deemed incorrect or not as accurate as a successor, an analysis will be undertaken to determine the effects of the past practices on Pacific hake population estimates.

Improvements – A combination of *in situ*, *ex situ,* and modeling experiments are currently underway and are designed to investigate and compare measured and predicted target strength measurements from a wide range of sizes of Pacific hake. The results of this work will shed additional light on the reliability of the currently accepted TS-length relation, including hake target strength variation as a function of tilt. If needed, the problem of remotely determining the *in situ* orientation distribution of fish may be assessed by an inferential method (Foote and Traynor, 1988). This method, which couples an understanding of swimbladder morphology and fish TS values measured at multiple frequencies, may provide a general method for determining the parameters of the tilt angle distribution *in situ*. Key to advancing this research is the capability to place transducers of different frequencies closer to the hake, either through drop transducer systems or autonomous underwater vehicles.

<u>Data Collection</u>

Not Applicable

<u>Detection Probability</u>

Not Applicable

<u>Classification</u>

See Protocol 2

<u>Performance Degradation</u>

See Protocol 2

Protocol 4 – Sampling (A_i, D_i)

<u>Survey Design (A_i)</u>

Definition & Importance

The design of any acoustic fisheries survey is critical to the accuracy and precision of the resulting estimate of abundance and distribution. There is no single optimum design to achieve all possible survey objectives, so a given design becomes the result of a series of strategic choices (MacLennan and Simmonds, 1992; Simmonds et al., 1992; Rivoirard et al., 2000). The goal of the joint US-Canadian survey for Pacific hake is to "determine the distribution, biomass, and length-at-age composition of the exploitable portion of the [hake] population" (Nelson and Dark, 1985) in support of analysis and management of the stock. The current design of the survey is based upon knowledge of the biology of the fish and the historical distribution of the stock, past survey coverage, statistical considerations, and logistical constraints. The sampling design includes the assumption that the survey area (A_i) encompasses the entire range of the recruited stock and that the stock is available to the survey techniques at the time of the survey.

Techniques

Broadly speaking, the survey measures S_v at 38 kHz along east-west oriented transects spaced at 10 nautical miles (nmi) along the U.S. and Canadian west coasts. S_v is averaged into 0.5 nmi long intervals by 10 m thick depth strata. Backscatter attributed to hake is integrated into units of backscatter per unit area (s_A; see definition in Protocol 3), expanded to a distance of 5 nmi on either side of a transect, and then converted into length- and age-specific estimates of hake biomass using information from midwater and bottom trawls (see Numerical Density to Biomass Density, below). Estimates of age-specific biomass for individual cells are summed for each interval, transect, International North Pacific Fisheries Commission (INPFC) area, and ultimately into a total coast-wide estimate. Basic oceanographic information is also collected during the survey, including regular CTD profiles.

The survey takes place in the summer months (between June and September), when adult hake are found at the northern extent of their annual coastal migration along the continental shelf and slope (Alverson and Larkins, 1969; Bailey et al., 1982). Typically, the survey stretches from near Monterey, CA (36°30'N) to Queen Charlotte Sound, B.C. (54°30'N), extends from about 50 m of water nearshore to water depths of 1500 m or more, and requires about 65-75 days to complete, including coverage of both U.S. and Canadian waters. The survey had been a triennial effort until 2003, when a biennial schedule was implemented (see Introduction).

In terms of transect layout, the Pacific hake survey has employed both zig-zag and parallel transect designs in the past. Currently, a systematic design using parallel transects traversed in a boustrophedonic fashion with a random start location is employed. The transits between lines are not used in the analysis. This design is recommended for "the most precise estimate of abundance," particularly if it is important to determine the geographical distribution of the stock as well as the abundance (MacLennan and Simmonds, 1992; Simmonds et al., 1992; Rivoirard et al., 2000). For each survey, a preliminary transect layout is constructed based upon historical transect locations and recent reports from commercial boats. The first transect of the survey is randomly located within a zone at the southern end of the survey area, and then subsequent transects are subsequently positioned at the standard 10 nmi spacing. The 10 nmi spacing is finer than the 13.5-18.9 nmi (25-35 km) decorrelation distance estimated for Pacific hake using geostatistical techniques (Dorn 1997). A time budget for the survey plan is developed using a conservative survey speed along the preplanned route, allowing extra time for a typical amount of trawling effort, port calls and crew changes, and possible delays for bad weather or mechanical problems.

As a matter of procedure, the northward extent and turn points of these preplanned transects may be adjusted during the survey. If hake are observed on the most northerly planned transect, the survey is extended northward with more transects until no more hake are seen. Transects have extended as far north as Cape Spencer, AK, 58° N (Wilson et al., 2000). Similarly, if hake are observed at the preplanned inshore end of the transect, the ship will proceed inshore as far as safety allows to find the beginning of the detected hake shoal before starting the transect, while at the offshore end, the ship will extend the transect as far offshore as necessary to find the end of the detected shoal (Fleischer et al., in review). The preceding extensions of survey area and transects are not attempts to adaptively allocate survey effort, but rather a procedure to locate the boundaries of the population and ensure that the assumption of complete survey coverage is met (Simmonds et al., 1992; Rivoirard et al., 2000) and are made only in order to find the boundaries of hake shoals already detected on the preplanned transects. It should be noted that adaptive surveys are not recommended for surveys of distribution and abundance, unless the goal is locating commercially fishable aggregations, because the approach may result in a biased stock estimate (MacLennan and Simmonds, 1992; Rivoirard et al., 2000).

Due the diel migratory behavior of Pacific hake (Alverson and Larkins, 1969; Stauffer, 1985), only daytime S_v data are used for the hake biomass estimate: during the daytime, the animals form distinct, mostly isotypic, shoals in midwater, while at night hake disperse and migrate to the surface, along with many other species of fish and plankton. This dispersed and mixed nighttime condition makes accurate classification of the hake S_v and trawl sampling of candidate shoals difficult. Nighttime hours have been used instead to conduct other research, including *in situ* target strength research, or to make oceanographic or other ancillary scientific measurements (see Oceanographic Data, below)

Midwater or bottom trawls are made during survey operations in order to classify the observed S_v and to gather the length and age data needed to scale the acoustic data into units of biomass (see Numerical Density to Biomass Density, below). The locations of these trawl deployments are not systematic, but rather depend on the local acoustic observations, recent and anticipated trawl effort, and other logistical constraints (time available for trawling, time required to process the catch, weather and sea conditions, etc.). Due primarily to logistic and time constraints, not all scattering aggregations can be sampled. Typically, two or three trawl sets are made per day during the survey.

Survey speed along transects ranges from 9-12 knots, depending on the vessel and prevailing sea conditions. Consistent vessel speed and heading are maintained while on transect. When sounding is interrupted for trawling or at the end of the daytime survey effort, the position of this break is recorded and data collection is later resumed at that point with the vessel underway at normal survey speed.

Vessel position is determined by using Global Positioning System (GPS) fixes. These fixes serve as the primary geographic reference for all data and events.

In rough seas, survey speed may need to be reduced to maintain data quality and safe shipboard operations. The field party chief, in consultation with the master of the vessel, must balance the need to maintain data quality, the need to make progress on completing the survey, and safety considerations when deciding whether to alter or suspend survey operations.

Error

Uncertainty, random, systematic – The national protocol document notes that

> "[t]he survey design (timing and location) should consider potential systematic changes in detection probability. If systematic changes in detection probability are discovered, either a change in the survey design is required or analyses should be conducted to determine a correction factor." (NOAA Protocols for Fisheries Acoustics Surveys and Related Sampling)

As mentioned previously, a major assumption made in this survey is that the entire stock is available to the survey effort. Potential bias includes incomplete coverage of the population.

The technique of linear interpolation at each cell area and subsequent summing to desired area does not allow for propagation of error in the estimates of abundance, meaning the level of uncertainty in biomass estimate is not known.

The reader should note that this section addresses potential sources of error in the acoustic survey design and sampling, not in the stock assessment modeling process.

Considerations

Remediation – If it is found that the survey design is in some facet inappropriate (e.g., ill timed, deficient in geographic coverage, or the acoustic technique used is found not to be robust across full range of conditions employed) a new survey design must be considered. However, changes in design must include a strategy for considering the potential impacts on the complete survey time series as on future surveys. As an example, the survey design by the Pacific hake survey underwent changes in 1992 and 1995: the survey was expanded offshore and further northward, and previous data points in the survey time series were back-corrected for this expansion in the assessment (Dorn et al., 1994; Dorn, 1996; Wilson and Guttormsen, 1997). The revision of the design was done based on an accumulation of new information about stock distribution (more northerly and offshore) to ensure more complete coverage of the population.

Understanding the uncertainty associated with the coast wide Pacific hake biomass estimate is an area of current research. One initial approach that has already been attempted is to apply the technique of Jolly and Hampton (1990) in a post survey stratification scheme that treats each transect as a sampling unit (Fleischer et al., in review). In this way, a mean and variance for biomass in each stratum and for the total biomass was estimated, however the error associated with the point estimate propagated by this technique did not consider observation errors.

Improvements – The annual hake migration is known to be sensitive to oceanic phenomena such as the El Niño southern oscillation, with adult hake migrating much further north during warmer years (Dorn, 1995). This implies that environmental data might help model the distribution of the stock during a given year or reveal that survey selectivity is related to environmental conditions. Currently, efforts are underway to determine if oceanographic variables can help improve the design of the survey. Also, the potential impact of changes in survey design will be explored through simulation modeling.

A stratifying the sampling design is advantageous if there are predictable patterns in hake concentrations. Since the variance in fisheries data often increases with the mean, a stratified sampling effort can reduce the variance in the final estimate (MacLennan and Simmonds, 1992). A geostatistical analysis of spatial variability may suggest ways to stratify the survey effort accordingly, thereby reducing the variance of the total population estimate (Simmonds et al., 1992; Rivoirard et al., 2000).

In the future, autonomous underwater vehicles (AUVs) may be used to augment sampling conducted by the acoustic survey vessel.

Numerical Density to Biomass Density (D_i)

Definition & Importance

The age-specific population number and biomass estimates of Pacific hake used for stock assessment modeling are ultimately based on the measured acoustical energy (E_i in the above equation) for each cell. The conversion from calibrated echosounder output to units of biomass relies upon data obtained from trawl sampling during the survey. More specifically, the needed information (encompassed in parameters D_i and σ_i in the equation above) includes the distribution of fish lengths and ages in trawl samples and relationships between fish length, target strength, weight, and age (MacLennan and Simmonds, 1992). The technical memorandum describing the most recent Pacific hake survey (Fleischer et al., in review) gives more equations and further details. See also Protocol 3, Target Strength.

Techniques

The survey area is stratified into sections to determine which trawl samples will be used to classify and analyze a particular portion of the acoustic data. This is done by considering the geographic proximity of the hauls, inspection of the length distributions from trawl catches, and/or by using paired Kolmogorov-Smirnov comparisons (Campbell, 1974) to find hauls with statistically similar distributions of fish length. For each length stratum, a composite average length distribution is generated from trawl data using Equation 8.9 in MacLennan and Simmonds (1992). Equal weight assigned to each haul, taking no account of differences in the total catch. See also Protocol 2, Volume Backscattering Strength.

The relation used to relate target strength to length for Pacific hake is TS=20*log(length)-68 as given by Traynor (1996) (see protocol 3, Target Strength). The form of the equation implies a dependence of target strength on the square of fish length and is the same as that used for many fishes; *in situ* target strength data have been used to determine the intercept value for Pacific hake and validate the equation (Traynor, 1996). Previous to the 1995 survey, a TS-to-biomass conversion value of –35 dB/kg was used, but after this a TS-length relation was used instead and the survey time series was back-corrected for this change in the stock assessment analysis (Dorn et al., 1994; Dorn, 1996; Wilson and Guttormsen, 1997).

An allometric equation, used to convert length to weight, is established for each survey using measurements of individual fish lengths and weights of subsamples from the fish collected during the survey (see Protocol 2, Volume Backscattering Measurements). Typically the equation used is of the transformed form log weight = log a + b * (log fork length). The 'a' and 'b' parameters are determined by linear regression.

The areal backscatter used for generating numbers and biomass of hake has been judged to be essentially 100% hake during the classification process (see section on Classification in Protocol 2). If the acoustic data cannot be classified in this way, the total energy can be partitioned amongst contributing scattering organisms. If the organisms are equally vulnerable to capture in the trawl and have identical backscattering properties, the total backscatter is apportioned based on the biomass catch proportion of acoustically detectable species (i.e., not including bladderless or bottom dwelling fish). If the species have different catchability or scattering properties, some assumptions need to be made and a more complicated calculation is required, using the target strength of each scatterer type (Nakken and Dommasnes, 1975; MacLennan and Simmonds, 1992, Equation 8.8).

Error

Uncertainty, random, systematic – The TS-length relation is a major source of uncertainty.

Considerations

Remediation – Efforts are ongoing to collect and analyze *in situ* measurements of Pacific hake target strength and length in order to evaluate the currently used TS-length relation. This includes a nearly completed analysis of data collected during the last 10 years by the AFSC and a recent joint U.S.-Canadian target strength cruise on the CCGS Ricker. See Protocol 3, Target Strength.

Improvements –De Robertis et al. (2004) suggested that when developing a weight-length relation from a relatively large set of data from an acoustic survey (ca. 100 – 1000 fish), use of the empirical mean weight for each 1 cm length class was less biased than reliance on predicted values from the fitted exponential regression to untransformed data or a linear regression to log-transformed data. Both types of regression analysis tended to not fully capture variations in the changes in weight-at-age and in this particular case overestimated the weight of larger fish and underestimated the weight of smaller fish in a reanalysis of AFSC acoustic survey data.

Oceanographic Data

Definition & Importance

These data are secondary in importance to the acoustic data. Oceanographic data are needed to constrain hydrographic conditions encountered in the survey (e.g., sound speed and sound absorption). They also represent fundamental environmental measurements characterizing the dynamic habitat of the Pacific hake.

Techniques

The primary source of these data is conductivity-temperature-depth (CTD) profiles. Also, acoustic Doppler current profilers (ADCPs) are used to collect data on ocean currents while underway. Expendable bathythermographs (XBTs), underway flow-through collection of temperature and salinity near the surface, and satellite measurements of ocean properties represent additional sources of near-surface environmental data.

The number and location of oceanographic samples should be chosen to provide assurance that proper sound speed and absorption values have been used and to support research on the environmental factors affecting Pacific hake distribution and abundance, taking into account available ship time.

Sampling should follow ship-specific procedures, instrument-specific instruction from the manufacturers of the oceanographic equipment, and protocols developed to facilitate post-cruise processing and analysis of the data to accepted oceanographic standards (Emery and Thomson, 1997). For data management procedures for oceanographic data, see Data Management under Protocol 2.

Error

Uncertainty, random, systematic – While useful information is immediately available from these oceanographic instruments, post-cruise calibration QA/QC procedures by a trained analyst (Emery and Thomson, 1997) are usually required for quantitative work.

Considerations

Remediation – Oceanographic data should be processed post-cruise by a trained analyst if they are to be used for quantitative work.

Improvements – AUV and satellite remote sensing technologies offer major routes of future expansion of the collection of concomitant oceanographic data.

Further details of sampling procedures are given in the technical memoranda describing the 2003 hake survey (Fleischer et al., in review) and in the FRAM Hake Acoustic Survey Manual.

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