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NOAA Protocols for Fisheries Acoustics Surveys and Related Sampling

Alaska Fisheries Science Center

Prepared by:

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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.

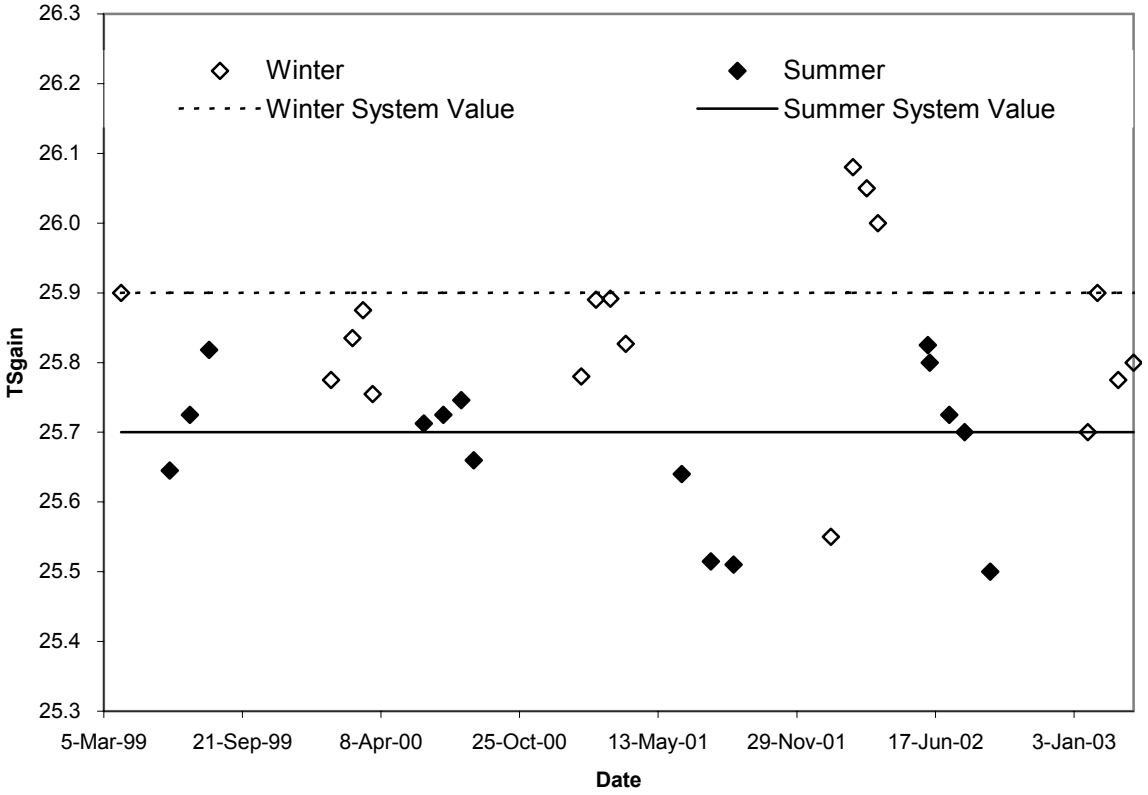

Figure 1. Winter and summer TS gain measurements from calibration of the AFSC 38 kHz Simrad EK500 system.

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.

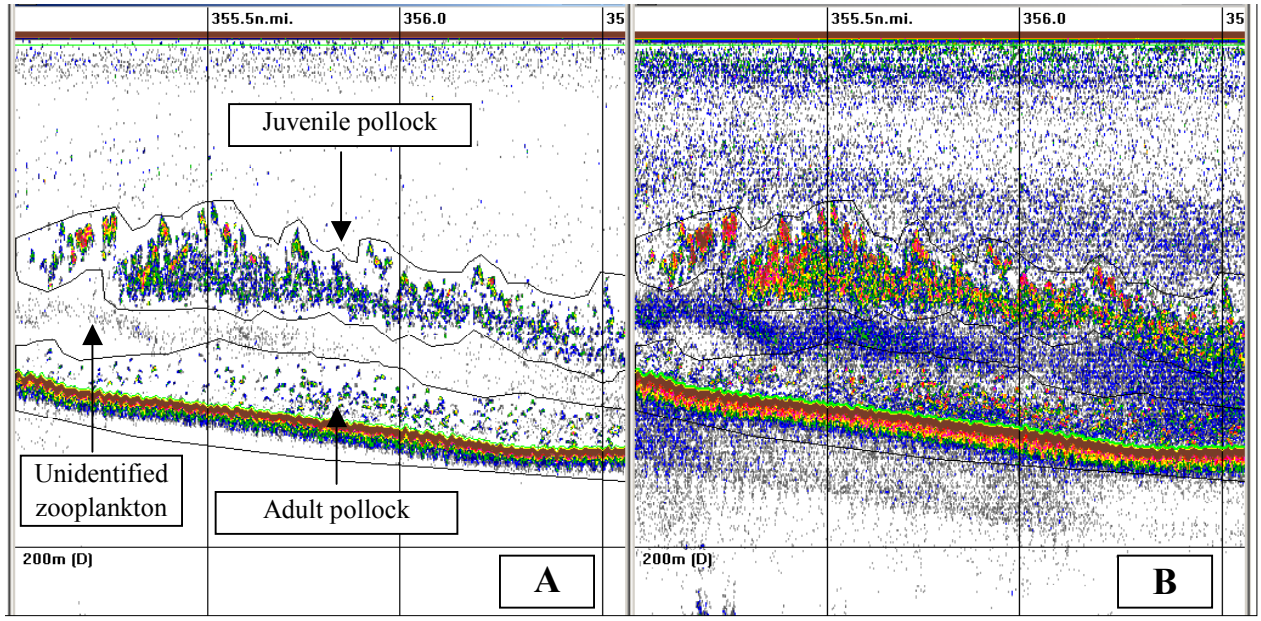

Figure 2.--Example of thresholding on pollock echo sign using (A) the standard s_V threshold of -70 dB and (B) a decreased s_V threshold of -80 dB. Data were collected during August 2001 off Kodiak Island, Alaska.

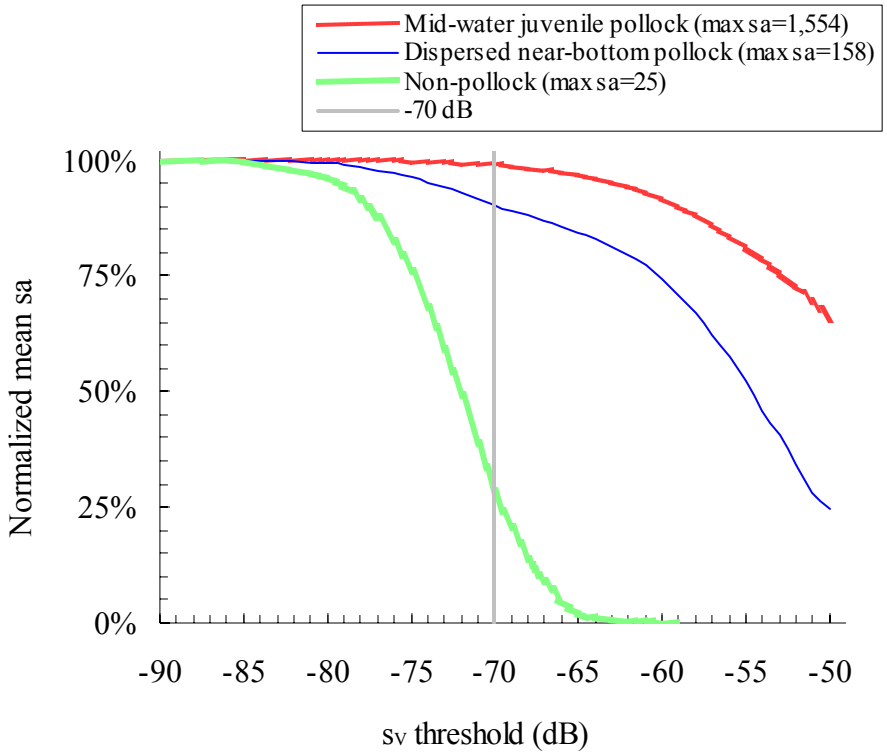

Figure 3. Contrast in s_A as a function of s_V threshold for a dense juvenile pollock mid-water layer, dispersed near-bottom adult pollock, and non-pollock echo sign. Data were collected during August 2001 off Kodiak Island, Alaska.

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.

<u>Classification</u>

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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