NOAA Protocols for Fisheries Acoustics Surveys and Related Sampling

Alaska Fisheries Science Center

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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 *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 two information technology specialists – all full-time and base-funded. Also part of the team are two full-time contract employees – an information technology specialist and a survey scientist.

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.

<u>Calibration</u>

Further details about AFSC calibration can be found in the following operating manuals - MACE (2009a), 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. A standard sphere (in a monofilament bag) for the frequencies to be calibrated is suspended below the transducer(s) on a monofilament line. Positioning of the sphere in the acoustic beam is (remote) controlled with a 3-point downrigger system (Simrad, 1997).

Software

The echo sounder used by AFSC is Simrad's EK60. Myriax Echoview software (Sonardata, 2009) is used to process on-axis data for gain and SA correction parameters. Simrad's Lobe program is used to estimate beam pattern parameters - i.e. 3 dB beam width, 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, 70, 120 and 200 kHz systems.

Data archive

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 data are all recorded to files. Echo sounder system parameters are recorded in the EK60 .raw 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 gain parameter. On-axis measurements of the sphere S_A (compared to the theoretical S_A) are used to estimate the system's SA correction parameter. (Note: in the EK60, integration gain = gain + SA correction.) With the sphere unmoving and few scatterers near the sphere, approximately 5 minutes of data collection at maximum ping rate 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 gain and SA correction 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 adjusts the nominal value supplied by Simrad upon delivery of the transducer based on sound speed differences between Simrad tank conditions and survey conditions. 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 gain, 3dB beam widths and offset angles. Gain as estimated from this model fit is used as a further check of the on-axis derived value. Measured beam widths and offset angles are used in the acoustic system for collection and processing of TS data.

Oceanographic data

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 (frequency-specific) attenuation coefficients between the transducer and the appropriate sphere. Values of sound speed and attenuation coefficients for survey conditions are derived from averages of historical oceanographic data from the survey regions.

Update guidelines

Gain, SA correction and beam pattern parameters are established for data collection at the start of each field season (e.g. winter or summer). Final abundance results are scaled with averaged values from the set of sphere calibrations conducted during the field season.. The 38 kHz EK60 system (and its predecessor EK500) has demonstrated remarkable stability through time. For a given field season (i.e. winter or summer), gain estimates do not vary more than 0.2 dB. Gain estimates for the higher frequencies are a bit less precise.

System Performance

Further details about AFSC system performance checks can be found in the following operating manuals - MACE (2009a), Simrad (1997), and Simrad (2001).

To ensure system stability, the following check is conducted routinely. Collected data files are checked to confirm there has been no large change to the integration output from the transmit pulse.

Underway self-noise noise levels aboard the NOAA Ships *Oscar Dyson* are monitored with ship-mounted hydrophones during survey operations, in order to help identify sources of noise affecting acoustic instruments, and to monitor sounds produced by the vessel. Noise sources include damage to the propeller, objects entangled in the propeller (e.g. rope, kelp), or noise from shipboard machinery (e.g. generators, compressors, interference from other acoustic equipment).

Volume Backscattering Measurements

Data Collection

Echo Sounder Parameters

The AFSC uses a Simrad EK60 echo sounder. Abundance estimation is based on data collected at a frequency of 38 kHz. See Calibration section for the calculation of gain and SA correction. Other 38 kHz frequency settings are as follows:

pulse duration (τ) = 1.024 or 0.512 ms
two-way integrated beam pattern (ψ) adjusted as described earlier
attenuation (α) is approximately 10 dB/km

sound speed (c) = 1470 m/s in summer and 1466 m/s in winter

Echo sounder parameter values are recorded in the .raw EK60 files.

Software

The echo sounder firmware version is Simrad ER60 Version 2.2.1. Acoustic data are logged with Myriax EchoLog 500 Version 5.3. Both EK60 .raw and Echoview .ek5 files are routinely recorded. Acoustic data are logged on two separate PCs. Both logging PCs are backed up every day.

The post-processing software is Myriax Echoview. The post-processing version is included as a field in the Integration Settings table in the survey database MACEBASE. Current version is 5.3.

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 Ships' Scientific Computing Systems. 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.

<u>Detection Probability</u>

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 1, 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 2). 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 1B. The post-processing s_v threshold is included as a field in the survey database MACEBASE.

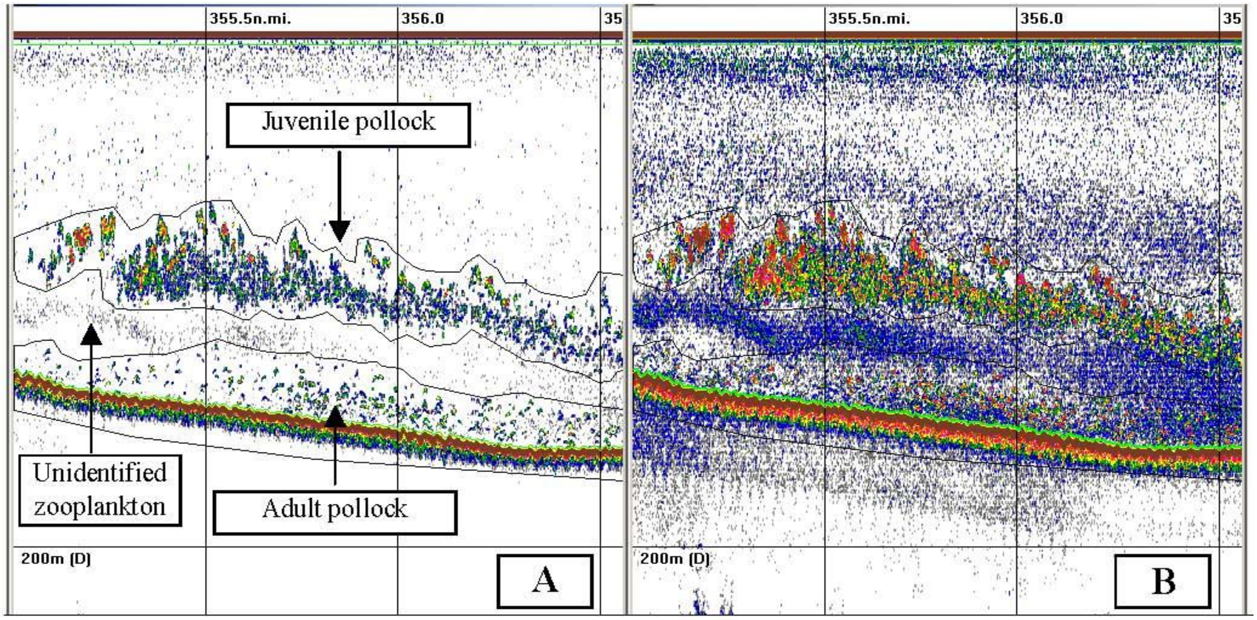

Figure 1.--Example of thresholding on pollock echo sign using (A) the standard s_v threshold of –70 dB and (B) a decreased s_v threshold of –80 dB. Data were collected during August 2001 off Kodiak Island, Alaska.

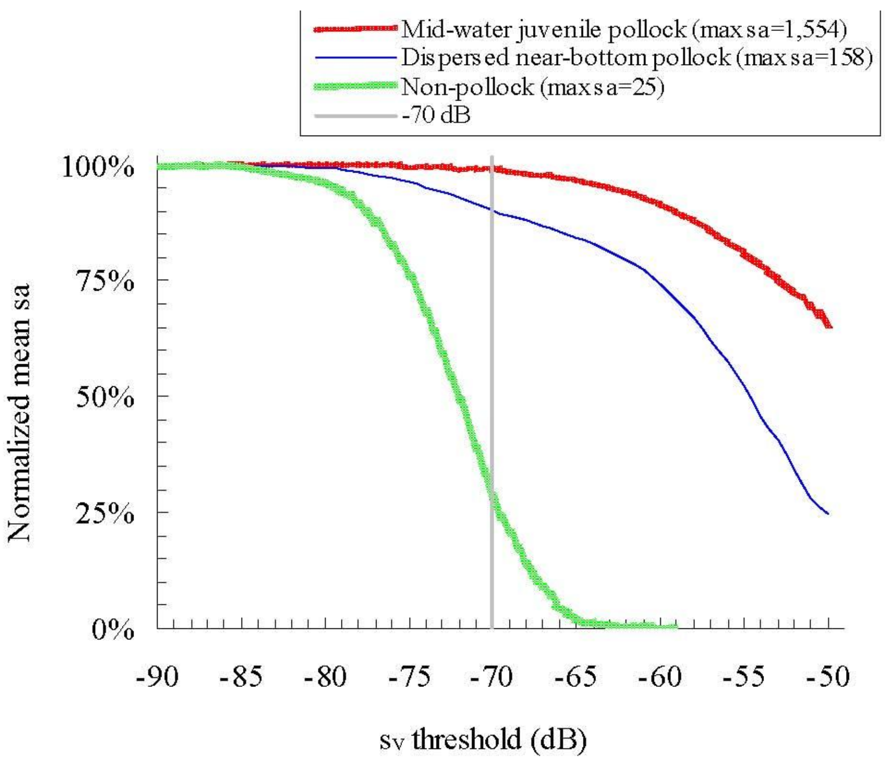

Figure 2.--Contrast in s_A as a function of s_v threshold for a dense juvenile pollock mid-water layer, dispersed near-bottom adult pollock, and non-pollock echo sign. Data were collected during August 2001 off Kodiak Island, Alaska

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

For all surveys, a fixed depth of 16 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 7 m buffer zone for the transducers' near field. An offset of 0.5 m above the sounder-detected bottom is used as the bottom offset for all regions except the eastern Bering Sea shelf where the offset can be safely reduced to 0.25 m because of the relatively flat bottom. Dead zone corrections are not currently 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

Underwater radiated noise by research vessels is a concern during acoustic surveys because low-frequency radiated noise is a likely stimulus for fish avoidance reactions, and because high-frequency radiated noise affects the performance of acoustic instruments (Mitson, 1995). The NOAA ships used to conduct acoustic surveys by AFSC have been designed or modified to minimize radiated noise.

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 the U.S. Navy's Southeast Alaska Acoustic Measurement Facility, following the repair work. Range results showed that the NOAA Ship *Miller Freeman*'s underway noise signatures at high frequency were reduced considerably, with underwater radiated vessel noise levels less than 2 kHz exceeding the ICES specification. Although this has resulted in increased performance of acoustic instruments, this is unlikely to have much impact on fish avoidance as fish do not have sensate hearing at > 1 kHz (Mitson, 1995). The vessel's low-frequency noise signature is dominated by propulsion-related sources, primarily the main engine and propulsion shafting related sources.

The noise-reduced NOAA Ship *Oscar Dyson* was first used for AFSC acoustic survey assessment in summer 2005. The ship was designed to meet the ICES noise recommendation for survey vessels (Mitson 1995), which is primarily an attempt to reduce avoidance reactions of fish to the survey vessel. *Oscar Dyson* has been noise-ranged multiple times and been shown to be substantially quieter than the *Miller Freeman* over a typical range of fish hearing frequencies (e.g. De Robertis et al, 2008).

Because the *Oscar Dyson* is a noise-reduced vessel designed to minimize vessel avoidance by fish, whereas the *Miller Freeman* is not, there is concern that biomass indices derived from the two vessels will differ due to differential reactions to the vessel. To ensure consistent results as the acoustic surveys transition to the *Oscar Dyson*, the Alaska Fisheries Science Center's (AFSC) Midwater Assessment and Conservation Engineering (MACE) program has undertaken a series of field experiments designed to establish if walleye pollock differentially avoid the two ships. Four different acoustic surveys of walleye pollock are routinely conducted by the AFSC: a summer survey of the eastern Bering Sea (2006, 2008), and winter surveys of pre-spawning fish in the vicinity of Bogoslof Island in the Bering Sea (2007), and Shelikof Strait (2007) and the Shumagin Islands (2008) in the Gulf of Alaska. The potential for differential vessel avoidance has been evaluated separately in each survey area as the walleye pollock in these surveys differ markedly in their depth distribution, age-structure, reproductive state, and environmental conditions.

The experiments (reported in De Robertis et al., 2008, De Robertis et al., in press, De Robertis et al.,, in prep) followed a two-part design where the vessels 1) were arranged side by side during the survey transects, or 2) conducted a series of transects in which one vessel led and the other followed behind the leading vessel. During the side-by-side transects, one vessel conducted an acoustic survey using standard protocols along equally spaced transects. The accompanying vessel was laterally displaced by 0.5 -0.7 nautical miles (nmi) to the side of the survey vessel. The side-by-side transects were periodically interrupted to conduct a series of 5-nmi-long follow-the-leader transects oriented in an east/west direction and spaced 0.5 nmi apart. The other vessel followed at a distance of 1 nmi and was offset to starboard by 0.1 nmi. The paired acoustic data from both the side-by-side and follow-the-leader transects were analyzed in 5 nmi segments. During the Shumagin Islands survey, a dedicated experiment using an echosounder mounted in a free-floating buoy was conducted to characterize the behavioural responses of walleye pollock as they were approached and then passed by the *Oscar Dyson* and the *Miller Freeman*.

The comparison of acoustic backscatter observed by the vessels revealed strong contrasts among survey areas (Fig. 3). In daytime surveys in the eastern Bering Sea where the fish were the shallowest (< 120 m), there was no significant difference in acoustic backscatter strength in 2006 and 2008. This indicates that acoustic estimates from the *Oscar Dyson* and the *Miller Freeman* were not different in this area during the daytime survey. There was no difference in backscatter between vessels for the Bogoslof survey area, where walleye pollock were distributed between 400 and 700 m. However, significant differences were observed in the Shumagin Islands and Shelikof Strait. On average, acoustic abundance estimates from the *Oscar Dyson* were 31% higher than those from the *Miller Freeman* in the Shumagin Islands and 13% higher in Shelikof Strait. The discrepancies in vessel ratio were greater for shallower fish, which is consistent with the expectation of a stronger response for fish closer to the vessels.

The differential vessel avoidance observed during the Shumagin experiment was independently confirmed by the experiment conducted using the buoy-mounted echosounder (De Robertis and Wilson, in press). When the *Miller Freeman* passed the buoy, larger decreases in backscatter intensity and an increased diving response were observed compared to when the *Oscar Dyson* passed. The reaction was observed to begin ~45 seconds prior to the time the vessels passed over the buoy, which corresponds to a separation distance of ~270 m.

These studies demonstrate, for the first time, that a noise-reduced vessel designed to minimize fish avoidance detected more fish than a conventional (i.e. non-noise reduced) vessel under some survey conditions. In the case of the Shumagin Islands and Shelikof Strait abundance surveys, the acoustic estimates of abundance from the *Oscar Dyson* are expected to be higher than those conducted by the *Miller Freeman*. This result illustrates that there may be a 'vessel effect' , and that differential biases can be introduced into a time series by switching vessels, particularly in the case where the change involves a noise-reduced vessel designed to minimize avoidance such as the newest generation of NOAA fisheries research ships. The vessel comparison results have been considered explicitly in the stock assessment process (Dorn et al., 2008). The differences in pollock abundance detected by the vessels are likely due to the difference in radiated noise, which highlights the importance of maintaining low radiated noise over a vessel's life in order to ensure consistent survey results.

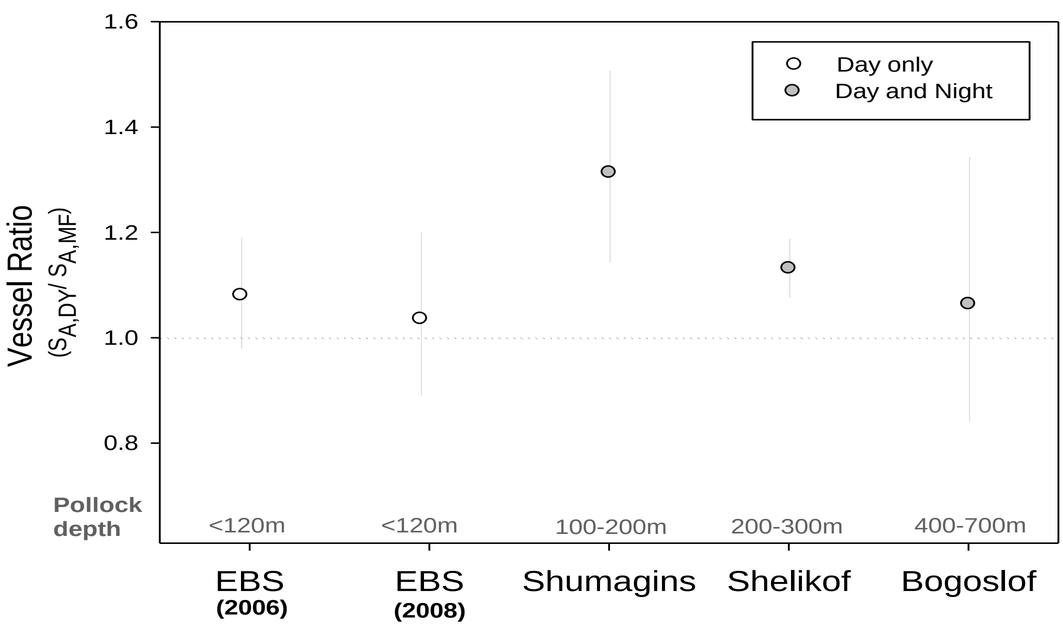

Figure 3**.** Estimated vessel ratios (*Oscar Dyson / Miller Freeman*) with 95% confidence intervals for the side-by-side transects from each experiment. A vessel ratio >1 indicates that the *Oscar Dyson* detected more walleye pollock backscatter than the *Miller Freeman*. Cases in which the 95% confidence interval does not include 1 imply a significant difference between vessels. Daytime measurements are shown for the eastern Bering Sea (EBS) survey, which is conducted during daytime hours only, whereas the other surveys are conducted both day and night. The approximate depth range of most of the walleye pollock in each study area is noted

in gray.

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 other frequencies (e.g. 18 and 120, in particular) can also assist in the process. A multi-frequency algorithm is used to isolate euphausid echosign in summer EBS shelf data sets.

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 third wire netsounder system attached to the trawl headrope. On the *Oscar Dyson*, this is a Simrad FS-70 system. For the bottom trawls or as back-up for the third wire systems, 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 (2009b). 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. The maximum depth for bottom detection is set as needed.

The first step during the editing of acoustic data is to zoom in on the bottom echo and inspect for bottom integration An average of the 5 (frequency) sounder-detected bottoms is used to represent the sea floor. Corrections, if necessary, are made to the 0.5 m sea floor offset line.

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 temperature-depth probe 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 sound speed and attenuation coefficient are derived from an analysis of our historical data set of CTD profiles of temperature and salinity. For some surveys, XBT (expendable bathythermograph) casts and additional CTD deployments are conducted to better understand the physical oceanography of the surveyed area.

Performance Degradation

Acoustic noise

Video echogram displays are constantly monitored for the appearance of noise. The most common source of this noise is vessel sounding equipment being powered up inadvertently. 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.

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

Transducers are inspected (and cleaned, if necessary) at the start of of the winter and summer field seasons.

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. Of the other organisms detected acoustically during AFSC acoustic-trawl surveys (e.g., Sebastes spp., Myctophidae, Osmeridae, Euphausidae), capelin (*Mallotus villosus*) is the only species for which there is a published TS-to-length relationship from the Gulf of Alaska or Bering Sea (Guttormsen and Wilson 2008).

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 at 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

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 ES120-7C), which are located on the vessel centerboard (Ona and Traynor 1999). In the past, an oil-filled 38 kHz transducer (Simrad model ES38-D) was connected to the EK500 transceiver and lowered over the side of the vessel to various depths (Traynor 1996, Ona 2003). Currently, AFSC is using a new lowered TS system, which uses an EK60 operating at 38 kHz with a self leveling transducer apparatus. This new system was built in collaboration with SWFSC using ASTWG funds. This system allows one to bring the transducer closer to the targets of interest and would greatly improve the ability to resolve single targets. The system has undergone preliminary testing and several initial collections of deep water targets have been conducted.

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 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). This last constraint has been revisited and subsequently determined to not be mandatory for a new approach to TS estimation (under development).
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 position over suitable fish echosign during the TS measurement period. This usually involves reciprocal transects across the fish aggregation.
6) 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.

7) 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.

8) 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 default Simrad EK60 instrument settings (Simrad 2001) for accepting echoes as valid single targets are listed below. These parameters can be adjusted to suit the specific data collection situation. Pulse length is typically 1 ms and ping rate is set to maximum.

i. TS minimum threshold -70 dB
ii. Minimum echo length 0.6
iii. Maximum echo length 1.8
iv. Maximum gain or beam compensation 6.0 dB
v. Maximum phase deviation 8.0
vi. Minimum echo spacing 1.0

Software

In situ TS data are post-processed using Myriax Echoview software (SonarData 2013). The analysis of TS data can be conducted using the Simrad trace output data string (i.e., E data telegram) or if more flexibility regarding single target detection parameters is desired, the raw data (i.e., sample angle and power data telegrams) can be used.

Several data filtering procedures are used to edit the EK60 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 –3 dB.

Improvements

Improvements in single target detection, such as multiple frequency techniques (Demer et al., 1999), can be implemented to increase the accuracy of 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

In addition to the new lowered TS system mentioned previously, 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 completing development of 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 (Ai)

Techniques – AFSC acoustic surveys are conducted from the NOAA Ship *Oscar Dyson*. 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 750 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, 2005 and 2011, summer surveys of the GOA were conducted, including additional areas not surveyed during the winter. In the future, a GOA summer survey will be conducted 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 are extended northward across this artificial border whenever Russian authorities grant permission. In recent years permission has been granted routinely, allowing the survey to cover the northernmost extent of the distribution.

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 starting point of the transect grid is randomized, so that every point in the survey area has an equal chance of being sampled. AFSC EBS bottom trawl surveys are conducted at approximately the same 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 *Oscar Dyson* 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 11-12 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.

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. CI's estimated using geostatistical simulation have been found to be about equal to twice the relative estimation error obtained from the 1-D analysis (Walline 2007).

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. 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

No 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 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 could be biased high, since transects proceed in the same direction as the migration (MacLennan and Simmonds 1991). 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. In recent years permission to enter Russian waters has been granted routinely, and it is expected that Russian authorities will continue to give permission, so this may no longer be a serious problem. 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 weighted against the 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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