Midwater Fish Surveys at the AFSC

by Jim Traynor

Introduction

Echosounders, devices which transmit sound waves and "listen" for returning echoes, have been used for fish detection since the 1930s. The use of echo integrators, which sum returning echoes, was first proposed for fish detection by Dragesund and Olsen in 1965, with scientific applications beginning in about 1970. Early applications were subject to considerable error due to the unsophisticated nature of the equipment as well as the unknown acoustic scattering characteristics of the fish being surveyed. The first digital echo integrator, developed in the early 1970s, greatly improved the accuracy of echo integration systems, though the assumption of linearity between echo integrator output and fish density was still under discussion.

The Alaska Fisheries Science Center (AFSC), then part of the Northwest and Alaska Fisheries Center, was one of the first scientific research agencies worldwide to utilize echo integration for obtaining estimates of fish abundance. Quantitative fisheries acoustics (echo integration) has been used by the AFSC to assess the abundance of Pacific whiting (*Merluccius productus*) stocks off the West Coast since 1974 and walleye pollock (*Theragra chalcogramma*) stocks in the Bering Sea and Gulf of Alaska since 1979. As fisheries acoustic methodology has matured, acoustic research at the AFSC has involved refinements in equipment and techniques. Whereas early echosounders and echo integrators were subject to the drifts associated with the use of analogue electronic circuitry and were limited by system dynamic range, modern units utilized by the AFSC employ digital circuitry and are designed to have enormous dynamic range (as much as 160 dB). With the improvement of equipment and general acceptance of the echo integration theory, the use of echo integration has become the standard procedure worldwide for midwater fish stock abundance estimation. Echo integration surveying procedures are especially well suited for abundance estimation of temperate gadoid stocks which tend to occur in large monospecific aggregations.

Fisheries Acoustics at the AFSC

As a leader in the development and improvement of fisheries acoustic techniques, the AFSC has played a key role in developing procedures for fisheries surveys using acoustic instrumentation. Currently, the AFSC uses a SIMRAD EK500 digital echosounder operating at 38 kHz for fish abundance estimation purposes. The system has about 160 dB of dynamic range, which makes it capable of quantifying echoes ranging from those as small as from zooplankton to extremely large echo returns from the bottom.

An echo integrator sums the returning echoes from fish observed beneath the vessel. The output of an echo integrator (the average acoustic backscattering area (SA) in units m^2 / nmi^2) is proportional to fish density (ρ), that is

$$\rho = {}^{SA}/_{<\sigma>} \qquad (1)$$

where $<\sigma>$ is the average acoustic backscatter (m^2) for the fish targets of interest. When referring to acoustic fish size, target strength (TS) in decibels, (a logarithmic representation of acoustic backscatter) is often used and is defined as

$$TS = 10 Log_{10} (\sigma/4\pi) \qquad (2)$$

Equipment Calibration

Acoustic collection systems must be frequently and reliably calibrated in order to improve the accuracy of acoustic equipment performance. Calibration procedures have improved significantly in the last 20 years. Early calibration involved the use of standard

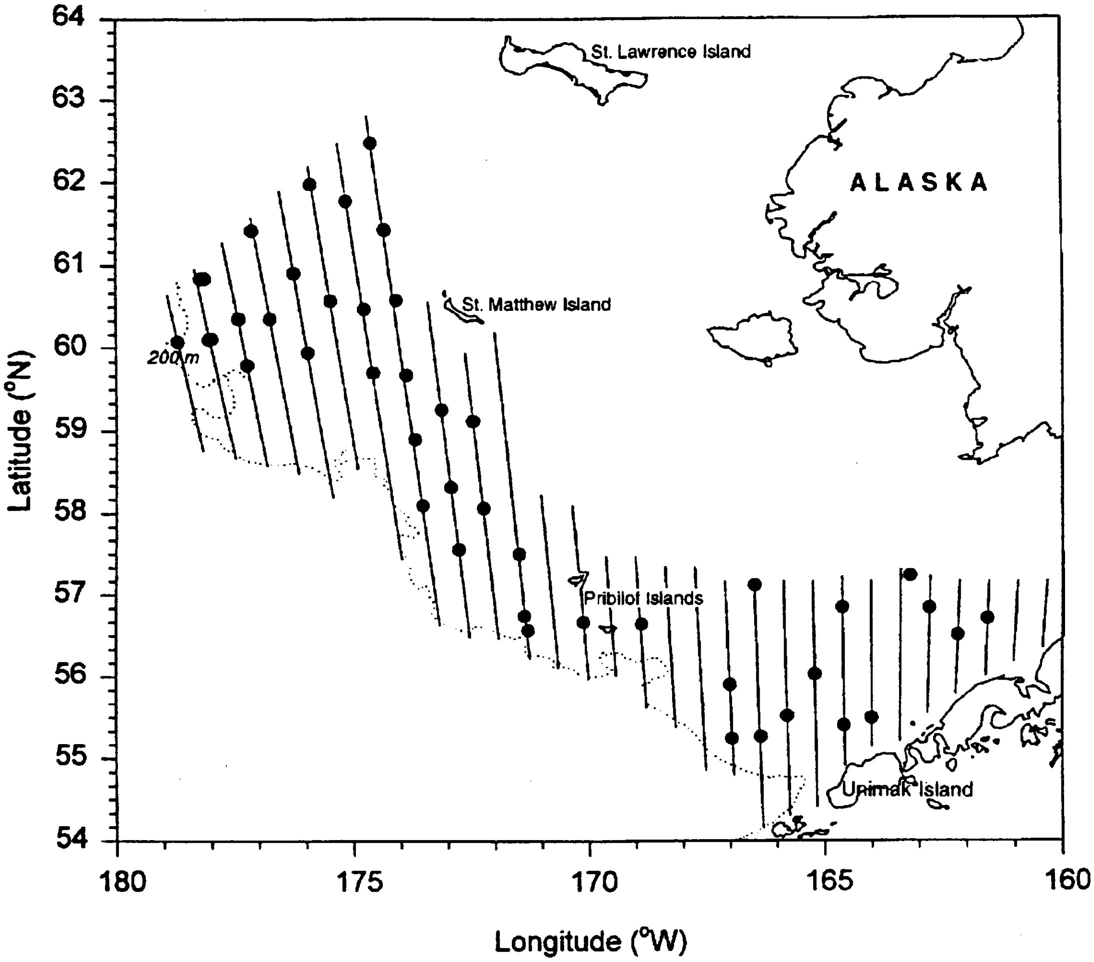


Figure 1. Transect lines and haul locations during the summer 1996 pollock echo integration-trawl survey of the Bering Sea shelf and slope, MF96-12.

calibration transducers to measure the transmitting and receiving characteristics of the acoustic system under test. Accuracy of such calibrations is on the order of ±30%. Standard sphere calibrations, in which a metal sphere of known acoustic characteristics (the "standard sphere") is lowered beneath the echosounder transducer, if carried out properly, may have an accuracy on the order of ±5%. Standard calibration spheres, used intermittently since about 1985 and routinely since 1990, have greatly simplified the procedures for calibrating acoustic systems. The use of standard spheres, now the primary method of system calibration, along with the advent of more accurate equipment using digital electronics has removed a significant portion of the uncertainty associated with acoustic equipment performance and, therefore, with fish abundance estimates obtained using that equipment.

Survey Design

Echo integration-trawl (EIT) surveys are typically designed to consist of parallel, equally spaced transects across an area, as in the 1996 eastern Bering Sea shelf pollock survey (Fig. 1). In this survey, the NOAA research vessel *Miller Freeman* was used to collect acoustic data along north-south transects spaced at 20 nautical mile (nmi) intervals. Opportunistic trawl samples were collected when significant echosign was observed in order to identify the echosign and provide biological information about the target species, in this case walleye pollock. EIT surveys are carried out when the target fish are expected to be relatively stationary. The Bering Sea shelf pollock EIT surveys are typically carried out in the summer when little directional movement (migration) is expected. For other surveys such as

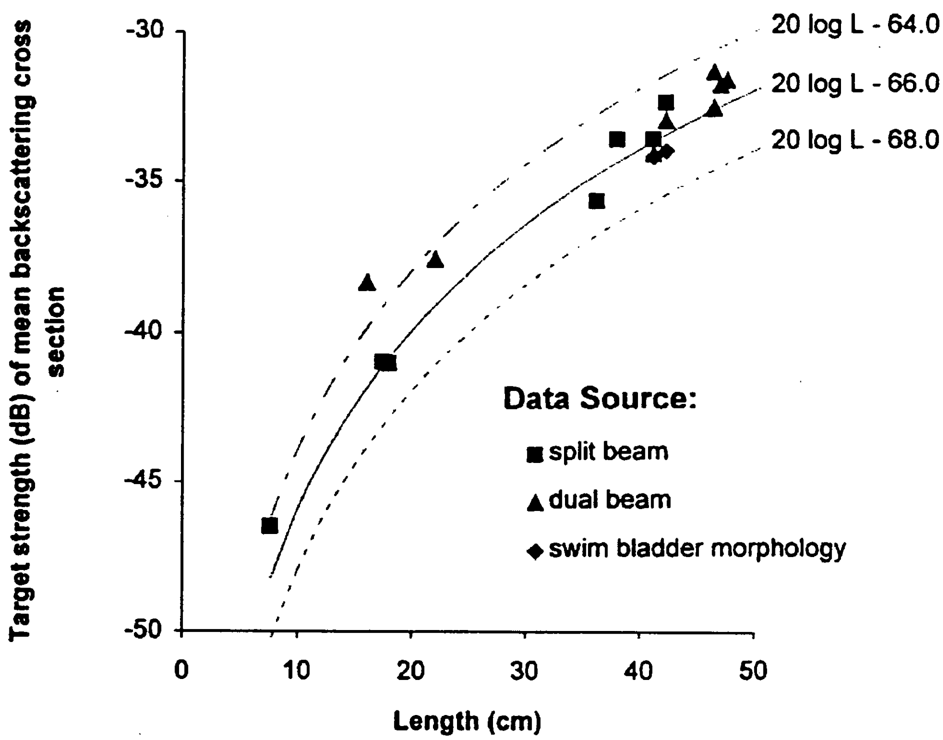


Figure 2. Target strength-to-length relationship for walleye pollock (*Theragra chalcogramma*).

spawning stock surveys carried out annually near Bogoslof Island and in Shelikof Strait, timing to avoid directional fish movement is critical, thus the survey is timed to take place after the fish migrate to the spawning grounds but before they emigrate from the grounds after spawning.

Trawl net sampling is a necessary companion to acoustic survey work. Net catch data are used to determine size and species composition. Proper analysis of acoustic survey data requires accurate assessments of species and size composition in surveyed waters. This analysis is normally achieved by an evaluation of echograms in conjunction with net catch data. Biological data in midwater catches are combined with the echo integration data to provide abundance estimates by size.

Abundance Estimation

In order to accurately assess the abundance of midwater fish stocks, the target strength (TS) characteristics of the fish being surveyed must be known. The SIMRAD EK500 utilizes the split-beam technique, which uses the phase of returns from four half-beams within the transducer to estimate angular position in the beam and, from the position, the beam pattern effect. Subsequently, TS can be calculated from the strength of the observed echo. Because the requirements for TS measurements in the field (single species, shallow depth, and low density) are rarely observed for most species, it is virtually impossible in the marine environment to make simultaneous measurements of TS and echo integration to allow real-time TS measurement for use in scaling simultaneously derived echo integration data to fish density. This necessitates the use of a TS-to-length relationship. The most commonly used model for relating target strength to length for EIT surveys is $TS=20 \log_{10} L - b$, where L is length in centimeters and b is a constant dependent on fish species, ranging from about -65 to -72. Figure 2 shows the currently available measurements of TS for walleye pollock at a variety of fish lengths and the relationship ($TS = 20 \log_{10} L - 66.0$) used to estimate $<\sigma>$ for a particular group of fish based on the size composition in trawl hauls.

During the AFSC's EIT surveys, the usual procedure is to segregate the echosign into categories that the researcher believes have similar biological characteristics. For example, in a typical Shelikof Strait spawning pollock survey, one group (stratum) may include spawning fish within the main spawning aggregation, another group may include smaller fish distributed higher in the water column, and a third group may include smaller, immature fish located near bottom away from the spawning aggregation. During standard EIT surveys, trawl hauls are made to confirm species and size composition for each species/length frequency group (SPLFG). For each group, an estimate of the total backscattering in an area (SM) (units=m^2) is calculated as

$$SM=\Sigma SA_j \cdot T_j \cdot L_j \qquad (3)$$

where SA_j is the average areal backscatter per nmi^2 for transect j, T_j is transect width (nmi) and L_j is transect length (nmi). Figure 3 shows the data flow for abundance and biomass estimation. For each SPLFG, mean scattering cross section $<\sigma_i>$ is estimated for each stratum using weighted length frequency observations and the relationship, $TS= 20\log_{10}(L)-66.0$. An estimate of the number of pollock of Group i, for example, is estimated as

$$N_i=\frac{SM_i}{<\sigma_i>} \qquad (4)$$

Using the weighted length frequency distribution, population estimates by size are derived. Biomass estimates can then be calculated using a length-weight relationship. To obtain population abundance for the total stock in the area, the population estimates by length for each SPLFG are simply summed to provide the estimate of the total abundance in the survey area. Biomass and population by age are also calculated, using an age-length key.

Data Flow

Data from the SIMRAD EK500 consist of a maximum of 500 surface-referenced samples. Depth resolution depends on the maximum range setting for the EK500 (Fig. 4). Also, an additional 150 samples (0.1 m resolution) are available for the interval from 10 m above to 5 m below the detected bottom. The primary reference for all acoustic data is the log value, the cumulated distance traveled by the survey vessel since the start of data collection.

The SIMRAD BI500 is a sophisticated software package that displays high resolution data from the EK500 and allows the operator to segregate echo integration data by species and size group (Fig. 5). It is possible to assign up to 20 species/length frequency groups to echosign with the BI500 software. However, usually two or three groups are used to assign the majority of the echosign observed during a survey.

For typical data collection during AFSC EIT surveys, analyzed data are stored in 0.5- nmi intervals and in 10-m depth bins. Geographic-referenced BI500 data for each SPLFG are initially stored in an Ingres database and are then transferred to an Oracle database for analysis. The BI500 has the important capability of excluding unwanted bottom echoes from the echo integration while including near-bottom fish echoes. Although the algorithm in the EK500 for detecting bottom usually excludes bottom echoes from the echo integration, in instances where it fails, such as very steep bottom slopes or during rough weather, the BI500 allows the operator to easily exclude bottom during the next stage of analysis, while still including most fish echoes.

In the BI500 display screen depicted in Figure 5, the operator has segregated the echo integration in the water column to two SPLFGs. In this case, one group consists of walleye pollock with a mode at 29 cm (age 3) while the other group consists of a wide range of sizes (10-60 cm).

Database Analyses

The basic data initially stored in the Oracle database are SA (backscattering area per nmi^2) and SM (total backscattering area) for each SPLFG in each 0.5-nmi interval and 10-m depth bin (can be 5 or 20 m, depending on the survey objectives and depth extent of fish). During initial analysis, the operator chooses a range of valid log numbers to be included to estimate abundance within the survey area. For example, vessel travel that is not part of the survey transects, such as vessel track completed during trawl hauls or when running between transects (cross

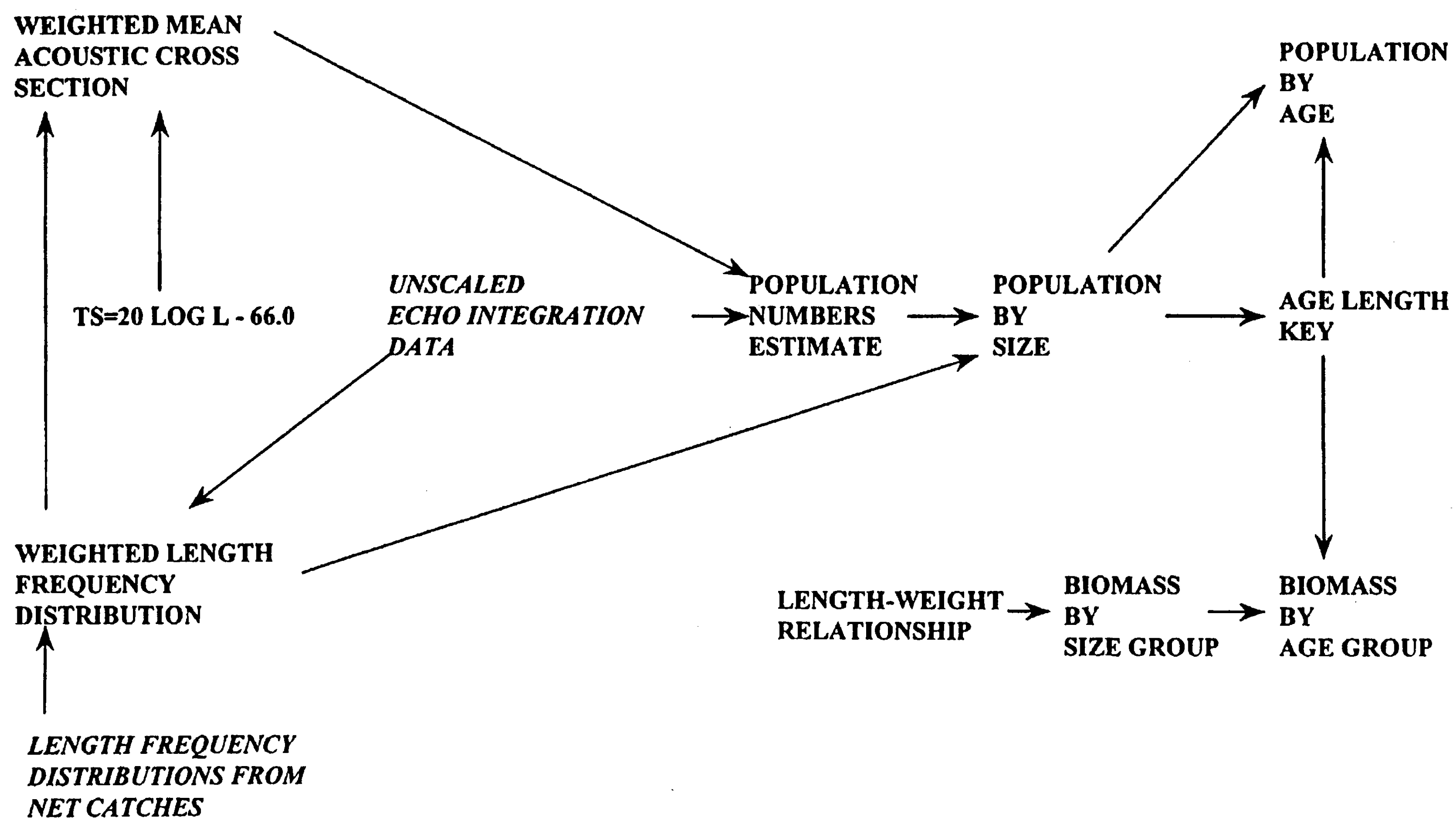
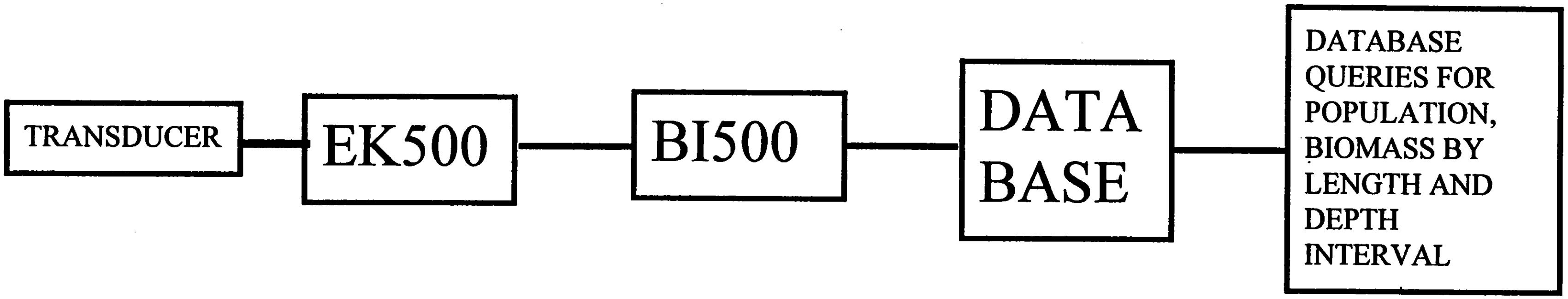


Figure 3. Schematic representation of procedure for estimating walleye pollock abundance using echo integration and net catch data. Italicized blocks are data that are measured during the survey. The remaining blocks are calculated.



EK500	BI500	Database
High Resolution echogram data Sv (volume backscattering strength) High dynamic range (160 dB). 500 samples for water column Resolution - function of range: 100 m range - 0.2 m 250 m range - 0.5 m 500 m range - 1.0 m 1000 m range - 2.0 m. Repetition rate 0.5 to 1 per second. An additional 150 samples with 0.1 m resolution are provided for the region from 10 m above to 5 m below the detected bottom.	Selects one ping each 0.005 nmi (9 m horizontal resolution). Scrutinizing window allows segregation by species/length frequency group (SPLFG) and removal of returns from noise, plankton, scattering layers and bottom echoes. Output at user selectable intervals from 0.1 to 5.0, usually 0.5 nmi (926 m).	Data from BI500 scrutinizing program include SA, SM, population and biomass by length for each 0.5 nmi interval for each depth interval from 5-20 m in extent (usually 10 m). Operator specifies log numbers to include in particular analysis. Operator specifies length frequency stratum for each SPLFG based on log number.

Figure 4. Block diagram of echo integration and acoustic fish abundance estimation system.

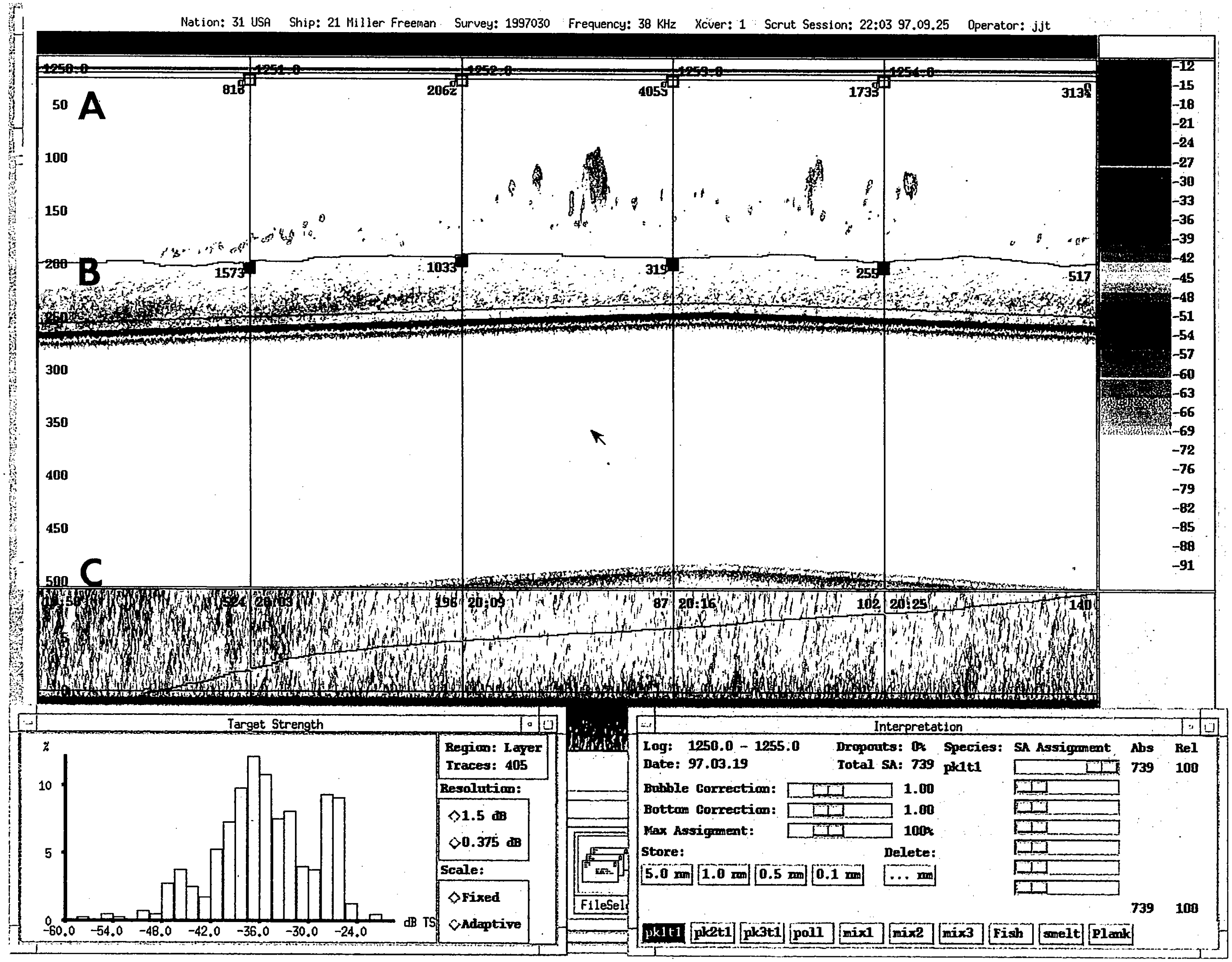


Figure 5. Echogram display on the SIMRAD BI500 echo integration analysis system showing echosign for two species/length frequency groups (SPLFG). The upper echosign (A) is composed of juvenile pollock. The lower, near-bottom sign (B) is a mixture of juvenile and adult pollock. The echosign displayed at the bottom of the window (C) is an enlarged presentation of the layer from 0 to 10 m off bottom.

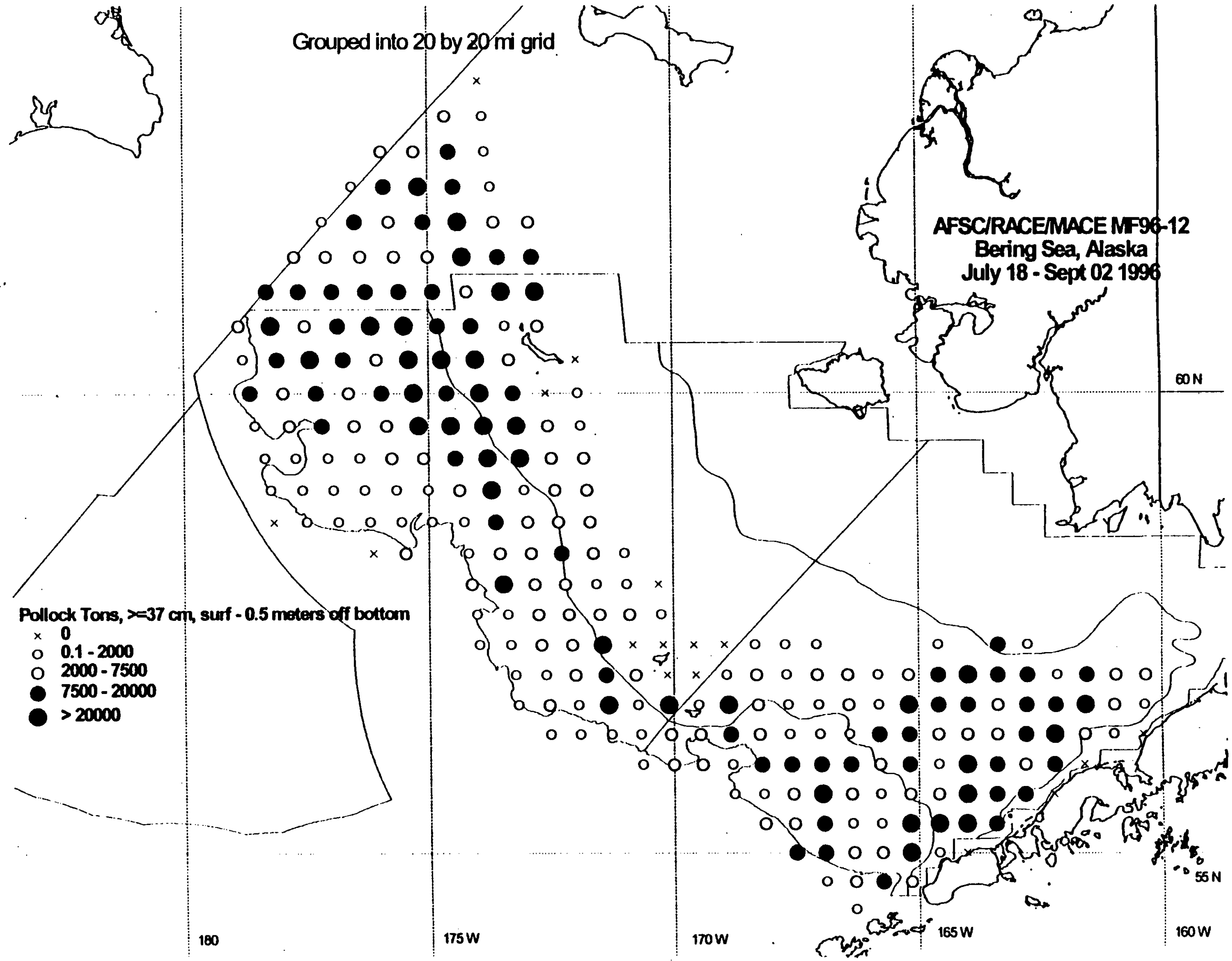


Figure 6. Example of ArcView output using midwater pollock abundance data contained in an Oracle database.

transects), is excluded from analysis based on log number. The database analysis procedures for abundance estimation, written in SQL (Standard Query Language) allow the operator to specify size composition and length-weight parameters based on trawl catch data for each SPLFG within a particular geographic stratum. The geographic stratum is defined within the database by the range of log numbers accepted for that stratum. Within each stratum, population and biomass estimates by length are derived using Equation 4 and a length-weight relationship for each SPLFG. By combining the estimates for all SPLFGs for a species, total abundance and biomass by length for each 0.5-nmi interval can be estimated. Using the appropriate SQL queries or scripts, length-specific estimates can be obtained for any geographic region within a survey area. For example, it is a relatively simple query to obtain the number of walleye pollock that are less than 40 cm that occurred in a particular management area and at water depths greater than 100 m or to obtain a population estimate for fish greater than 38 cm in order to examine the abundance of exploitable fish in a particular region.

The geographic referenced data are displayed using the geographic information system (GIS) package ArcView, with covers created using ARC/INFO. The display capability of ArcView is used to review data to ensure the proper information is included for analysis. The GIS display capability is useful in visualizing the distribution of a stock by size and abundance within the survey area. Figure 6 provides an example of the type of GIS displays generated during EIT surveys. The database analysis and display procedures allow for detailed error checking and rapid interpretation of abundance and distribution information.

Summary and Current Research Priorities

The systems used to collect and analyze EIT survey data have developed significantly during the last decade. New procedures and equipment utilized by the AFSC for data collection, management, and analysis allow more accurate and timely collection and analysis of EIT survey information for use in determining estimates of the abundance of walleye pollock and Pacific whiting stocks.

Current quantitative fisheries acoustic research at the AFSC centers on three areas. An acoustic buoy, recently constructed and scheduled for testing in fall '97, is designed to be placed in front of a survey vessel for observing changes in fish behavior and distribution as the vessel approaches. The buoy will be used to observe both EIT and bottom trawl survey vessels. By observing the changes that occur as the survey vessel approaches, we hope to be able to estimate the impact of vessel avoidance on estimates of fish abundance. A second research area involves improving our ability to measure the acoustic target strength of fish in a variety of behavioral situations. Historically, the measurement of TS has been possible only in shallow depths and in low-density situations, usually necessitating that measurements be made only at night when the fish have separated and moved up in the water column. We are currently developing a lowered transducer system that will allow us to measure TS at greater depths in a wider range of behavioral situations such as spawning and feeding, thereby allowing for more representative TS measurements for use in scaling acoustic results for echo integration surveys. We also are exploring the possibility of obtaining an opening and closing device for use in a large midwater trawl. The ability to segregate echosign into SPLFGs depends on the ability to obtain representative samples of the species and size composition within each group. Often, it is difficult to obtain unbiased samples of a SPLFG if it is located below another SPLFG. For example, the size composition observed for the deeper echosign in Figure 5 may include some fish captured from the upper layer. Scientists in Norway have developed a prototype device for opening and closing the cod end of a large midwater trawl. We are examining the feasibility of adapting this design for trawls used by the AFSC to sample midwater echosign.