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Can Hydroacoustic Survey Approaches Yield Abundance Indices of Pollock on the Scotian Shelf?

Peut-on obtenir des indices d'abondance de la goberge sur le plateau néo-écossais par des relevés hydroacoustiques?

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ABSTRACT

The feasibility of using hydroacoustic techniques to obtain indices of abundance of pollock (*Pollachius virens*) was investigated using both a research vessel and a commercial fishing vessel. The constancy of the spatial distribution of the resource (both seasonally and on a 24-h basis) is documented, and the process of collection and editing of the hydroacoustic data is described. The vertical distribution of pollock is documented in related to the near-bottom zone where the acoustic signals are occluded. The density of fish indicated from the hydroacoustic studies is compared with the net catches, and the co-occurrence of other species is described. Considerations such as these are summarized in conclusions concerning the effectiveness of hydroacoustic approaches for describing the abundance of pollock.

RÉSUMÉ

À l'aide d'un navire de recherche et d'un bateau de pêche commerciale, nous avons étudié la faisabilité de techniques hydroacoustiques pour obtenir des indices d'abondance de la goberge (*Pollachius virens*). Nous présentons des données sur la constance de la répartition spatiale de la ressource (saisonnière et quotidienne) et décrivons le processus de collecte et de traitement des données hydroacoustiques. La répartition verticale de la goberge est mise en évidence en relation avec la zone près du fond où les signaux acoustiques sont masqués. Nous comparons la densité de poisson indiquée par les études hydroacoustiques avec les captures au filet et nous décrivons aussi la présence d'autres espèces. Nous résumons des considérations de ce type dans des conclusions concernant l'efficacité de méthodes hydroacoustiques pour décrire l'abondance de la goberge.

INTRODUCTION

The life history of pollock in the Northwest Atlantic involves an offshore spawning and larval phase, recruitment to the coastal environment for a period of one to two years, followed by an offshore migration (Clay *et al.* 1989). As adults in the Northwest Atlantic offshore environment, they are generally found in schools of fish of about the same size. For example, within the Bay of Fundy, smaller (45-60 cm) fish were found off Brier Island (south-west Nova Scotia) and larger (65-85 cm) fish were found off the western side of the Bay of Fundy (Steele 1963). Such a pattern of aggregation by size persisted over several years in the 1960s and was consistent with observations made several decades earlier. On the basis of such characteristics, pollock were considered to be strong facultative schoolers (Partridge *et al*. 1980). Pollock are also known to spend less time on bottom and more time moving freely through the water column (Scott and Scott 1988) compared with other gadids.

The life history characteristics of schooling and relative lack of affinity with the ocean bottom imply that standard research vessel surveys that employ bottom fishing gear may not yield useful indices of abundance for this species. As an alternative to research vessel survey data, stock assessments for pollock have therefore included catch rate series from the commercial fishery as indicators of abundance (Neilson *et al* 1999). Catch rates, however, are subject to criticism as an index of abundance due to factors such as changes in technology (Kimura 1981), management measures (Worthington *et al.* 1998) or environmental conditions (Perry and Boutillier 2000) that can potentially influence the proportionality between catch rates and stock abundance. For schooling species such as tunas, catch rate analysis has been shown to sometimes provide misleading and optimistic interpretations of stock abundance (Clark and Mangel 1979).

Thus, there has been interest in developing alternative indicators of the abundance of pollock. Elsewhere in the Atlantic range of the species, countries such as Norway have employed acoustic techniques for the evaluation of pollock abundance (Nedreaas 1997). The same semi-pelagic, schooling life history characteristics that make pollock ill-suited for bottom trawl surveys may enhance the prospects of using hydroacoustic approaches that have been more typically used for pelagic species such as herring. Prior to the implementation of such approaches, however, it was considered desirable to investigate the biological characteristics of pollock aggregations in the Northwest Atlantic that might influence the survey design, and evaluate the potential utility of hydroacoustic methods for assessing pollock abundance. In this paper, we document factors that could influence the potential success of the hydroacoustic approach for pollock on the Scotian Shelf.

METHODS

For the purposes of this study, we used data from special purpose research vessel surveys, annual DFO bottom trawl surveys and information from the commercial fishery, as well as the Observer Program and a cooperative study undertaken with National Sea Products. Details of the special-purpose research activities that were undertaken are provided below.

Cooperative Work with the Fishing Industry

To provide year-round information on the vertical distribution of pollock on the Scotian Shelf, an automated acoustic data logging system was placed onboard the *Cape John*, a vessel specializing in the pollock fishery. The acoustic data were collected by a Femto Model DE9320 digital echosounder connected to a Furuno 50B12 50 kHz, 12-degree transducer mounted in the keel of the *Cape John*. The pulse duration and pulse repetition rate was set at 1.0 msec and 60 pings/minute respectively. The power output was 2 kW, and the sample rate was 15 kHz with a nominal sample interval of 5 cm. Data were collected from October 1999 to March 2001.

The DE9320 was connected to a desktop computer with a 6-gigabyte removable hard drive for porting the logged data to the shore-based processing/archival computer after each fishing trip. A monitor was installed at the electronics console of the bridge so the skipper could monitor the data collection process and report any concerns. Data collection typically occurred continuously throughout the fishing trip.

The hydroacoustic data logging system was calibrated in 1999 and 2000 by use of a TVG (time varied gain), standard target, and beam angle calibration. The TVG calibration is used to compensate for the differences between the nominal TVG of the DE9320 and the ideal TVG in consideration of the frequency and anticipated marine conditions of temperature, working depth, salinity, and pH. Currently, only nominal values for these conditions are used since the current project goals are to determine target behavior over extended periods. As the focus of the project changes to biomass estimation, more effort will be required toward refining those parameters. Since a directly coupled digital echosounder is used and assuming that the conditions are accurately known, there is little error associated with this calibration.

A standard target calibration is used to provide the final calibration factor used to standardize the received echo amplitudes into target strength (TS) after the TVG corrections have been applied. The standard target was suspended under the vessel using the procedure described in Clay and Claytor (1998). The resolution of this type of calibration is within 0.2dB.

The main logging, editing, and analysis software used was the Hydroacoustics Data Processing System (HDPS) developed by Femto Electronics Ltd (Dartmouth, Nova Scotia). The software provides several ways of reviewing the data and an interactive data editor for removing noise and the bottom layer prior to interpreting the acoustic signal. The processing software also provides a mechanism for post-collection partitioning of the data into discrete depth layers.

Each raw data file underwent a consistent process for quality control before editing. First, the data files were checked for navigation and speed errors and corrected as necessary. Data files were then combined into set files that ran from the beginning to the end of a fishing set (obtained from log records and captain's information). For the purposes of this paper, only those sets that included at least 95% pollock by weight were included, and where length-frequency samples from the catch were available.

The acoustic files corresponding to fishing sets were then edited using the HDPS interactive editor to eliminate backscatter that was considered non-pollock (i.e. plankton, acoustic interference, feed, and bottom reverberation). The subsequent analysis applied the time-varied-gain and standard target calibrations to the raw volume backscatter. For each 25 navigation fixes, an average area backscattering coefficient (S_a) was calculated for each of 30 bottom referenced layers at 1-m increments to 30 meters above the bottom. These averages were then distance weighted and summed for the duration of the set file to produce a single average S_a per depth layer per set. Using an average target strength for the set, the biomass area density was determined for each layer and presented as kilograms per square meter of sea surface area. An average target strength was computed for each set using the method of Foote (1987) from the size distribution of pollock sampled and an estimated length weight regression for pollock.

Describing the vertical distribution of pollock in relation to the near-bottom integrator dead zone (Ona and Mitson, 1996) was also of interest. In defining this area, Ona and Mitson noted that some targets are unavailable to the acoustic beam due to the integration parameters and beam geometry. This can significantly affect biomass estimates as the beam angle increases or as relative near-bottom densities become large compared to off-bottom densities. For the work, the beam angle was 12 degrees and bottom depths were typically between 150 to 200 meters. A similar approach to that of Ona and Mitson (1996) was used to identify the effect of the integrator dead zone on the estimates. It was assumed that the density of pollock within the integrator dead zone was the same as that observed in the one meter layer immediately above the integrator dead zone.

Special Purpose Research Vessel Surveys

Data presented here were collected onboard the CCGS *Teleost*, from September 30 to October 4, 1999. Two additional surveys have been conducted (September 2000 and February 2002), but these data are not yet fully edited and are unavailable at this time.

The acoustic equipment included a calibrated, Simrad EK 500 echosounder with a hull-mounted split beam 38 kHz transducer and a personal computer. The performance of the EK500 was measured prior to the start of the trip while the vessel was moored in a deep-water cove by two bow and two stern anchors. A 38-mm tungsten carbide sphere was suspended under the vessel by three monofilament lines at a range of approximately 27-m below the transducer. A vertical cast was made with a CTD to acquire data for calculation of the sound speed at the depth of the sphere. This value was used to determine a TS value for the sphere. Also, the CTD data were used to compute the average sound speed for the range from the transducer face to the sphere. This value was entered into the EK500 via the Sound Speed Menu. The calibration was completed using the TS-measurement, S_A-measurement and LOBE software procedures described in the Calibration of the EK500 / EY500 Section of the Simrad EK500 Manual. The TS and Sv Transducer Gains were estimated to be 26.13 dB and 26.11 dB respectively. The values for beamwidth provided by the "FIT" procedure of the LOBE program were: 6.8˚ for the athwartships direction and 7.0˚ for the alongships direction. Using these beamwidth estimates, the Equivalent 2-Way Beam Angle was computed to be -20.9 dB.

Acoustic data were collected onboard the "*Teleost*" while the ship was steaming along transects at 6.0 knots, and during bottom trawls, typically conducted at 3.5 knots. The EK500 was configured with a ping interval of 1.0 seconds/pulse, a pulse length of 1.0 msec and a bandwidth setting of "Auto". The data acquisition software known as CH1 (Simard et al. 1998) was used to record volume backscattering strength (S_v) data. Upon return to the laboratory, the S_v data were edited and integrated using the hydroacoustic data analysis software known as CH2 (Simard et al. 2000). The editing procedure involved removing ambient noise associated with the operation of the ship's acoustic net mensuration system, and identifying the bottom relative to fish concentrations. Backscattering area coefficients (S_a, a unitless parameter (m2/m2), Anon. (2000)) were obtained by integrating S_v data for six layers (1-5, 6-10, 11-15, 16-20, 21-25, and 26-30 m off bottom). The first meter off bottom was excluded from the integration, as fish targets close to the bottom are generally undetectable using standard hydroacoustic techniques (Ona and Mitson 1996).

The S_a values were obtained by averaging over six pings, which at a vessel speed of 6 knots, corresponded with a distance of about 18.5 m. To provide a graphic representation of the density of the fish as indicated by the hydroacoustic data, these S_a values were contoured using kriging software (Anon. 2001). This approach takes irregularly spaced and geo-referenced data and interpolates such data into an evenly spaced grid.

To confirm species identification, periodic sets were made with a Campellen bottom trawl equipped with a 13 mm cod end liner. The average tow speed was 3.5 knots, and the tow duration varied between 3 and 15 min. The average vertical opening of the trawl was 4.1 m, as indicated by an electronic net monitoring system, and thus included the near-bottom (up to one m off bottom) zone where fish were not detectable using hydroacoustic systems. The catch weights shown here were standardized to a towed distance of 0.75 nautical miles, equaling about 15 min at 3.5 knots. The catch was sorted by species and total weight, and a length frequency sample was obtained in all cases. The bottom trawl information was used to confirm the identity of the fish species comprising the aggregations located by the hydroacoustic system, and also to provide a qualitative comparison of the net catch to the acoustic signal.

RESULTS

Constancy of the spatial distribution of the resource

A key consideration from the perspective of survey design is the distribution of the resource, and its consistency from year to year. Distribution information presented in Neilson et al. 2003(a) and reproduced in Fig. 1 show that in general, the locations of aggregations did not change appreciably from month to month. An important exception is the occurrence of aggregations on the western Shelf edge (along the 200-m depth contour) during the January to April period, but not during the rest of the year. The association of Northeast Atlantic saithe with particular depth contours has also been noted. For example, Reinsch (1994) noted that saithe migrate to spawning areas on the northern border of the North Sea along the 200-m contour.

There are also significant portions of the Scotian Shelf where pollock were absent or rare, such as Western and Sable Island Banks, the area inshore of Banquereau Bank (Fig. 2), and the Bay of Fundy during the spring. Knowledge of such areas will assist with survey design, as it will be possible to direct the survey to those areas that have been associated with pollock aggregations in the past.

The Editing of Hydroacoustic Data

Using the in-house Departmental hydroacoustic program known as CH2 (Simard et al. 2000), it was possible to obtain interpretations of echograms that were replicable between individuals (Fig.3) and by the same reader over time. The software provides capability to display and interpret CH1 files recorded in the HAC format. The software contains several editing tools to eliminate, ignore, threshold, filter or correct the raw HAC data, without loss of the original information. The user has the capability of editing the data on a ping by ping basis, and can choose to manually or automatically relocate the bottom. The user can track the processing steps, and the software has multiple undo levels. Integrated output are exported as ASCII text files that can be input into analyses software such as Excel or Surfer (for kriging and visual representation of data).

However, in some cases, problematic situations arose when it was difficult to differentiate the aggregations of fish from the bottom. Dense aggregations of fish sometimes caused the echo-sounder to misplace the bottom and operator judgement was required to manually correct the problem. In areas of considerable vertical contrast, multiple echoes from the rough ocean floor can produce a signal that looks like a fish concentration, but is an artifact. Such situations require skill and judgement to provide the correct interpretation, but even then, some guesswork is involved for those situations. Examples of such difficult edits are provided in Fig. 4.

The "Dead Zone"

In consideration of the acoustic dead zone (Ona and Mitson 1996), some targets are unavailable to the acoustic beam due to the beam geometry. Figure 5 shows that a target in position "ADZ" is unavailable to the acoustic beam because by the time the pulse wave-front reaches that target it has already reached the bottom on the acoustic axis.

As an indication of the potential undetected biomass, Fig. 6 shows the percentage of biomass lost for various thicknesses of uniformly distributed targets at the bottom, calculated for a beam angle corresponding with the 12-degree transducer used on the *Cape John*. It is seen that for a two-meter layer, approximately 15% of the biomass is lost at a bottom depth of 100 meters. Less than 5% of the biomass is lost assuming a 20 meter thick layer at the same depth. As depth increases, the percentage of lost biomass also increases. Note that this calculation depends on the assumption that the density of fish within the ADZ is the same throughout depth h.

Vertical Distribution of Pollock Biomass Inferred from Hydroacoustics

Year-round data collected from the *Cape John* provide insight into the vertical distribution of pollock with respect to the bottom and help give perspective to the magnitude of the possible impact of the "dead zone" (Fig. 7). Peak biomasses of pollock were observed during the December and January period. During that time, aggregations of pollock ranged up to 30 m off bottom, but 75% of the biomass occurred within 10 m of the bottom. These vertical distributions imply a potential loss of about 5% to the ADZ, with the assumptions stated in the previous section and at an average depth of 150 m. Since this work was not repeated over several years, it is not possible to comment on possible interannual variations in the proportion of the acoustic signal that might be occluded by the ADZ. These results imply that December and January are suitable months to conduct a survey of pollock, since the fish are highly aggregated and detectable by the hydroacoustics.

Fine-scale Aspects of Pollock Aggregations that Could Influence Survey Design

A special purpose RV survey conducted in 1999 located two large aggregations of pollock that were studied on a 24-h basis (Fig. 8). The aggregations demonstrated diel variability, become larger and denser at night but daytime aggregations persist, albeit more scattered than those at night (Fig. 9 shows data from the Banana, a sea-mound located on the Central Scotian Shelf, and Fig. 10 shows information from the Shelf Edge). Such differences appear more pronounced at the Shelf Edge site than at the Banana site. Knowledge of these day/night differences in aggregations of pollock has important implications for design of a survey of abundance. It may be necessary to include considerations of the day/night changes in the availability of pollock into the survey design and analyses of the data. Aglen *et al*. (1999) also observed diel variations for demersal species in the Barents Sea, with different patterns of vertical migrations for small and large redfish (*Sebastes* spp.) and haddock (*Melanogrammus aeglefinus*). In our case, we found no differences in the size composition of the bottom trawl catches of pollock at night or day.

Samples taken at the two sites indicate the length frequencies of pollock differed significantly, with larger pollock found in the deeper water at the shelf edge (Fig. 11). This is consistent with the observations of Steele (1963) that pollock generally form size specific aggregations. Very few pollock were found at the shelf edge that were less than 45 cm, the size at 50% sexual maturity (Trippel *et al*. 1997), while most pollock at the Banana site were <45 cm.

Detailed sampling at the Banana site indicated size-segregation within the aggregation as well. Larger fish dominated the size composition in the core area, while smaller pollock were more abundant outside this area. Age-length keys developed from sampling the commercial fishery in the area indicate that the smaller mode in Fig. 12 corresponds with the 1997 year-class (two year olds), while the second mode of larger fish is comprised of the 1995 and 1996 year-classes (three and four year-olds). Segregation by size has been described for a number of fish species (Ward and Kraus, 2001; Ranta et al 1992). Smaller fish in an aggregation have been shown to be at a competitive disadvantage in feeding (Ward and Krause, 2001; Seppa et al, 1999) and at higher risk of predation due to conspicuousness (Landeau and Terborgh, 1986). Joining the dense aggregation of larger pollock may, therefore, be disadvantageous for these smaller pollock. This has implications for sampling pollock for characterizing the length composition of acoustic records. Samples taken from outside the area of high aggregation may not be representative of the size composition of the aggregation.

Comparison with net catches

We compared the standardized catch of pollock to the integrated acoustic signal through increasing range off bottom (Fig. 13). The best correlations of net catch and the acoustic signal occurred when the signal was integrated up to 30 m off bottom. Norwegian workers (Aglen *et al*. (1999) have described a similar result with saithe, and they attributed this to diving behaviour of pollock as they react to the passage of the ship. An alternative explanation might be the noise of the approaching trawl.

Mixing of other species

During the targeted pollock survey onboard the *Teleost* in 1999, the total catch weight of pollock was 59,241 kg during the study period, which represented about 88% of the total fish catch of 67,228 kg for the 28 sets made at the two sites. Other species co-occurring with pollock included scorpaenids (5% of the catch weight, mostly *Sebastes* sp. and blackbelly rosefish *Helicolenus dactylopterus*), silver hake *Merluccius bilinearis* and haddock *Melannogrammus aeglefinus* (each comprising 3% of the catch weight). The remaining 2% of the catch weight was comprised of more than 30 unique taxa. Typically, when the catch weight in a set exceeded 1000 kg, the proportion of pollock in the catch exceeded 95% (Fig.14).

Difficulty of validation with net trawls for species and size composition

We earlier illustrated the need for bottom trawl sampling to characterize the size composition of the fish, and we indicated how the size composition information can vary from site to site and even within site. For hydroacoustic applications, periodic net sampling is required to characterize the size composition of the aggregation for use in the relationship converting fish length to target strength and to confirm species composition.

In some instances, however, we found that because of the affinity of pollock with the Shelf edge, aggregations were often found in areas that were difficult to sample with standard bottom trawl procedures. For example, one of the special purpose surveys (February 2002) located a very large concentration of pollock on the north-east edge of Georges Bank. A combination of strong tidal conditions and rough bottom conditions made it very difficult to obtain bottom trawl samples to confirm the species composition of what was assumed to be a concentration of pollock.

Associations with Sea-Mounds and Shelf Edges

Previous DFO investigations and fishermen's comments indicate that pollock tend to aggregate in association with "sea-mounds" (submarine rises of slight differences from the adjacent sea-floor) or along the Shelf edge. Our observations support this conclusion. An example of an aggregation of pollock in association with a sea-mound is shown in Fig. 15, which is the information from the Banana site, redrawn to shown the vertical contrast in bottom depth.

CONCLUSIONS AND RECOMMENDATIONS

The factors supporting hydroacoustic methods as an indicator of abundance include the ability to operate the vessel in a relatively high-speed search mode covering areas of known pollock aggregations. Given the propensity of pollock to aggregate in areas of particular bathymetric features, it is possible to describe an efficient survey track that would cover the newly-defined 4X5 management unit. Pollock appear to be somewhat predictable in their year to year occurrence in a given area, but not to the same extent as other schooling species such as herring. Considering the technical feasibility, Departmental and third-party software tools are available that facilitate the acquisition and editing of hydroacoustic data. Several Maritimes Region staff now have expertise with such tools, and have links with DFO staff in other regions using such software on a routine basis. The editing of the hydroacoustic signals, including separation of the fish from the bottom, appears feasible (but time consuming and sometimes difficult). Comparable results have been obtained when echograms have been re-examined by either the same scientist, or a second scientist reviewing the data independently. Using funds from the Strategic Science initiative, the pollock program has purchased three data loggers of the type deployed in the *Cape John*, and these hardware systems are available for use on other platforms.

On the negative side, experience with the *Teleost* surveys suggest that the aggregations are not always easily found. During the three surveys undertaken to date, considerable vessel time was spent in scouting mode, following outline surveys in areas thought by industry to be productive for pollock during the time of surveys, but often such locales proved to have no pollock. Once the aggregations were found, we have shown that bottom trawling will be required to characterize the species and size composition. The locations of these aggregations are sometimes on bottom conditions that are difficult for bottom trawling, thus obtaining biological samples can be problematic. Our results also show a tendency for the aggregations to become more available to the hydroacoustic system during the night. Other scientists and fishermen have noted that tidal influences near the mouth of the Bay of Fundy (Cruise Report NO82, 1987) strongly influence the nature of the aggregations there, but this relationship is not well understood. The technical expertise to manage and maintain the hydroacoustic software and hardware is not available in DFO Maritimes Region, but is available from local private companies and in other Regions. To produce useful and consistent results, the acoustic systems must be calibrated each year, at a cost of about $3 K per system if these services are procured from private companies. The editing and analysis of hydroacoustic information is labor-intensive and requires skilled individuals.

In summary, while there are significant benefits in undertaking a hydroacoustic approach to generate an index of abundance for pollock, there are also very significant risks and costs. A combined acoustic/trawl survey in conjunction with industry support could be feasible. Presently, however, the resource base in scientific and technical expertise is not available within the region to undertake routine acoustic surveys, even with industry support. At a minimum, one additional professional staff member (acoustic, statistics, biology background) and one technical person (biological, computer hardware/software background) would be required. These staff members could provide hydroacoustic support to the Region (i.e. provide support for other scientists wishing to develop and integrate acoustic techniques into their stock assessment work). A long-term funding commitment is essential to ensure success.

As a final point, the correlation between the acoustics and trawl catches observed here and by other workers (Boudreau and Dickie 1988) suggest that a specially designed trawl survey could perhaps accomplish the goal of providing an index of abundance. However, the issue of feasibility of using trawling investigations in the shelf edge environments often frequented by pollock would of course still apply.

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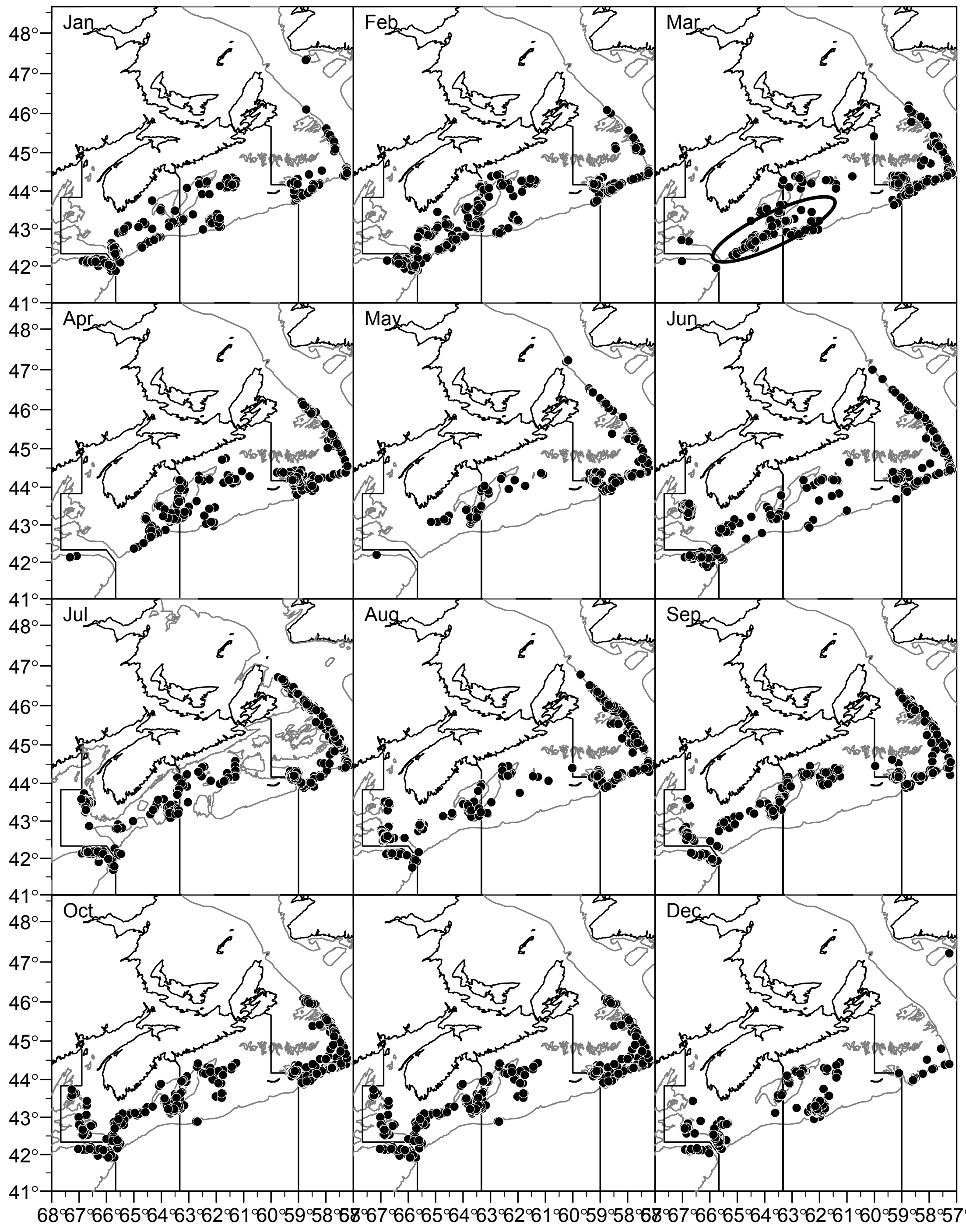

Fig. 1. Locations of pollock catches (by trawl catch) in the fishery, summarized by month from 1981 to 1990. Vessels were Tonnage Class 4 and larger, and the data source is the Observer Program. The depth contours shown are the 100 and 200-m contours. The ellipse superimposed on the March panel highlights aggregations of pollock found along the Scotian Shelf edge from January through April.

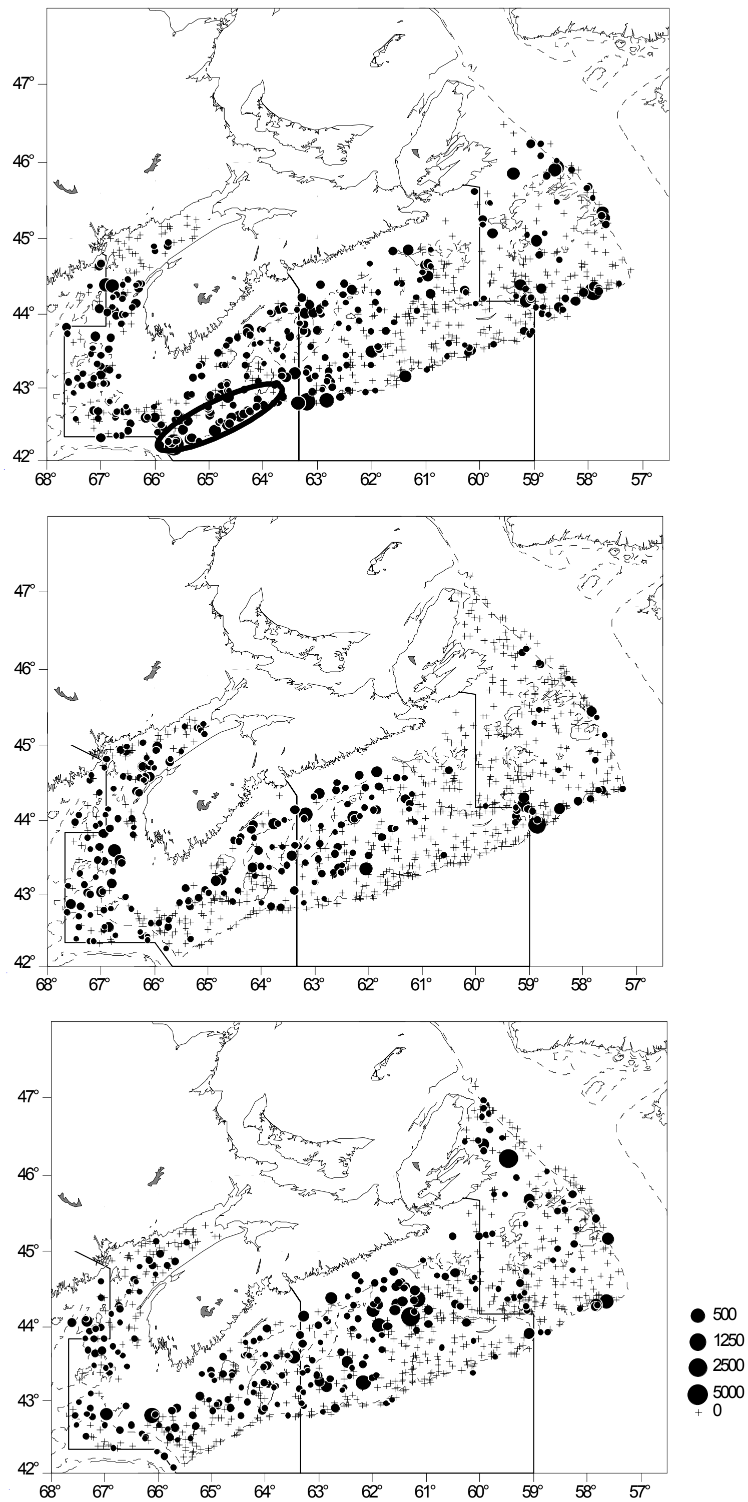

Fig. 2. The distribution of pollock (numbers) caught during depth-stratified random surveys of the Scotian Shelf conducted in the spring (March), summer (July) and fall (October), 1979 to 1984. Sets with null catches are indicated by '+'. The depth contours shown are the 100 and 200-m contours. The ellipse superimposed on the spring survey distribution highlights aggregations of pollock found along the Scotian Shelf edge, not found in the summer and fall surveys.

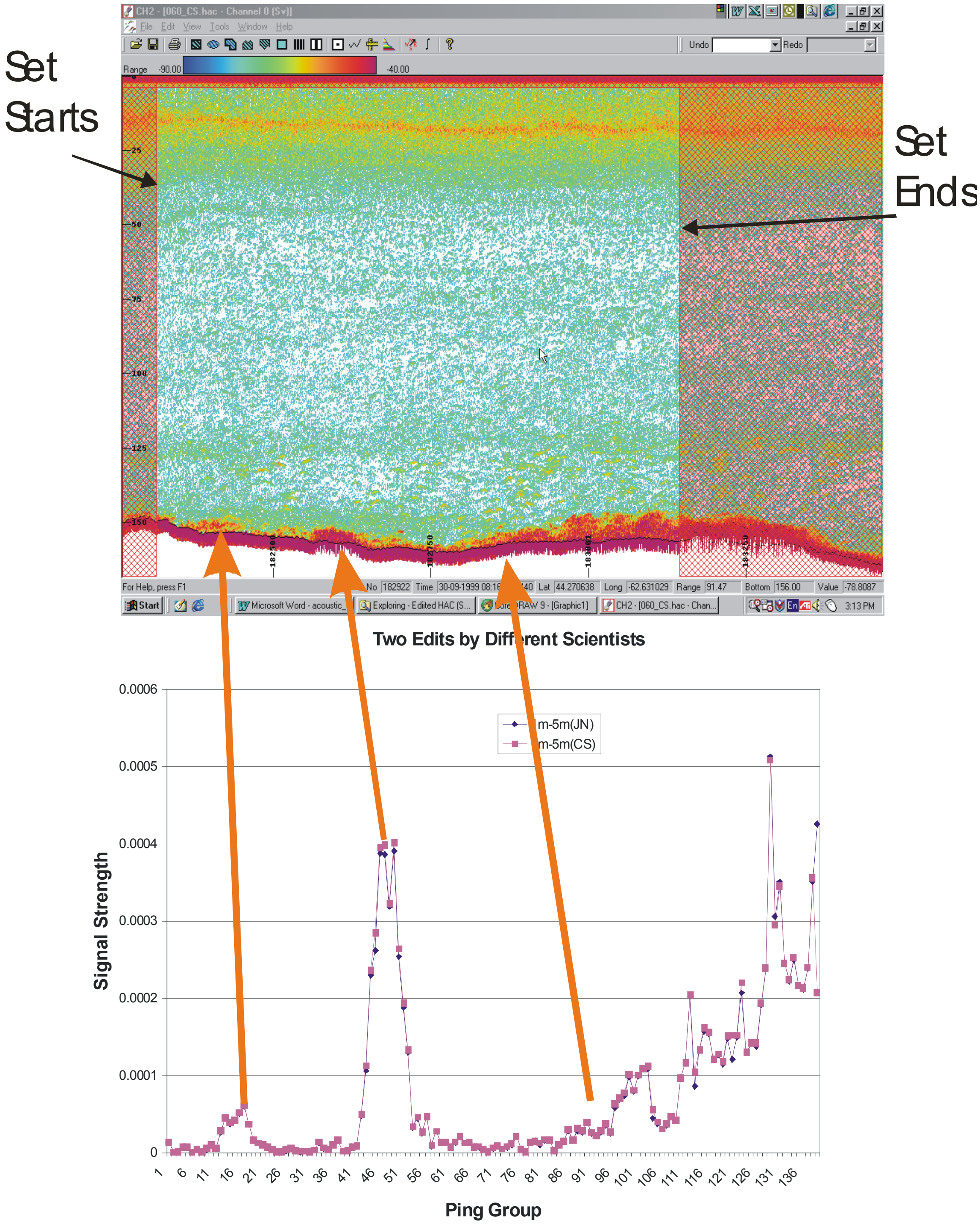

Figure 3. Example echogram from the *Teleost* survey (T083), with pollock aggregations highlighted with the arrows. The bottom panel shows the results of editing and echo-integration undertaken by two scientists independently.

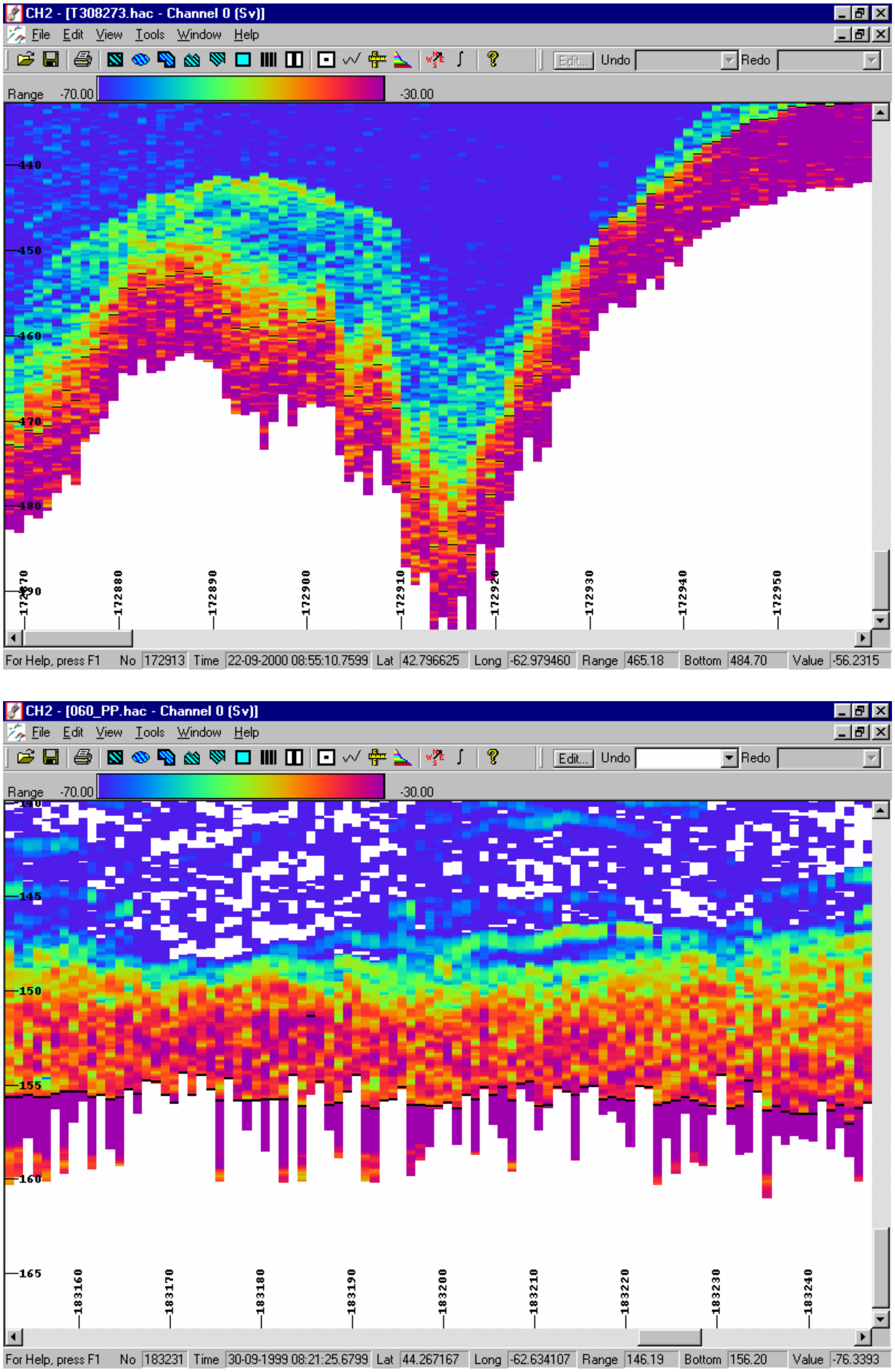

Figure 4. Examples of problematic echograms. The top panel is associated with the Shelf Edge. Bottom detection is difficult, as was trawling to confirm species and size composition. In the bottom case, pollock were densely packed near the bottom, triggering a false bottom identification by the echosounder.

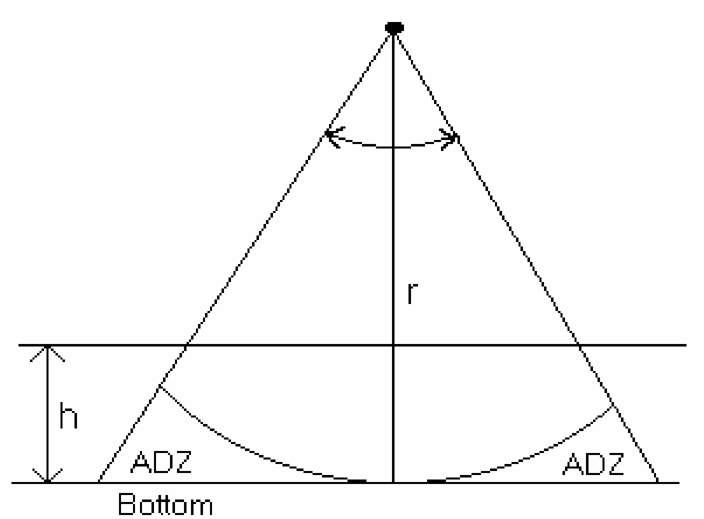

Fig. 5. Representation of an acoustic beam, along with the “Acoustic Dead Zone” (ADZ).

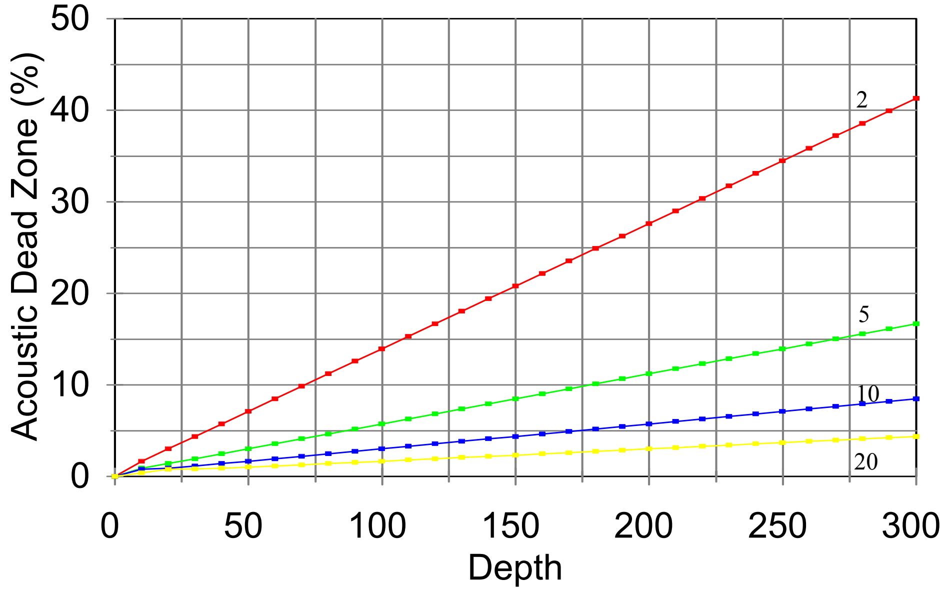

Fig. 6. The percentage of biomass potentially "lost" in the Acoustic Dead Zone, as a function of depth, and assuming aggregations of pollock that extended 2, 5, 10 and 20 m off bottom. The calculations were based on the characteristics of the transducer installed onboard the Cape John, 1999.

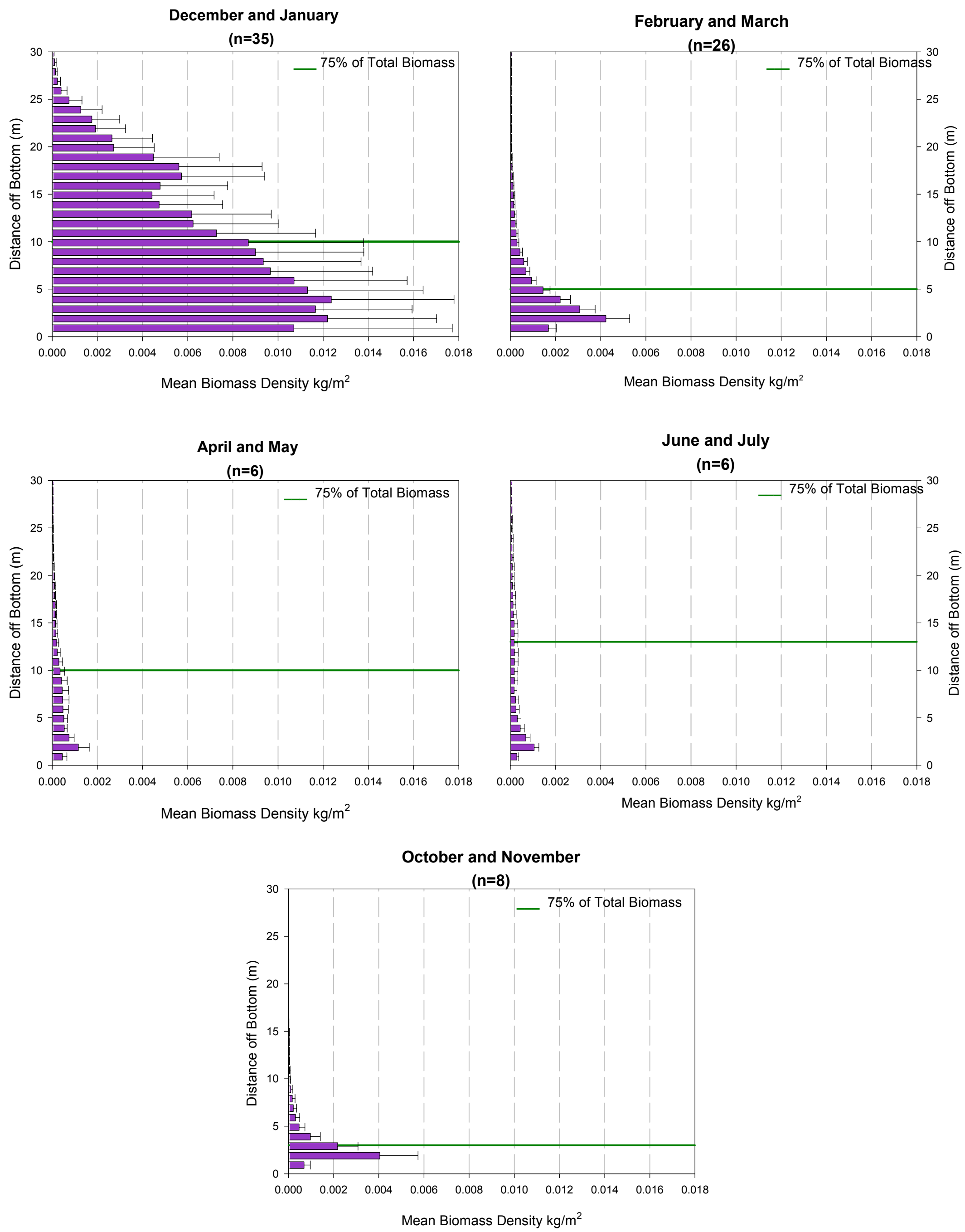

Fig. 7. Biomass density indicated from a hydroacoustic data logger installed onboard the fishing vessel *Cape John*, 1999 to 2000, summarized into bimonthly plots. The data are stratified by one-m intervals with respect to the bottom, and one S.E. is shown. Only sets corresponding to catches of 95% pollock by weight or greater are shown.

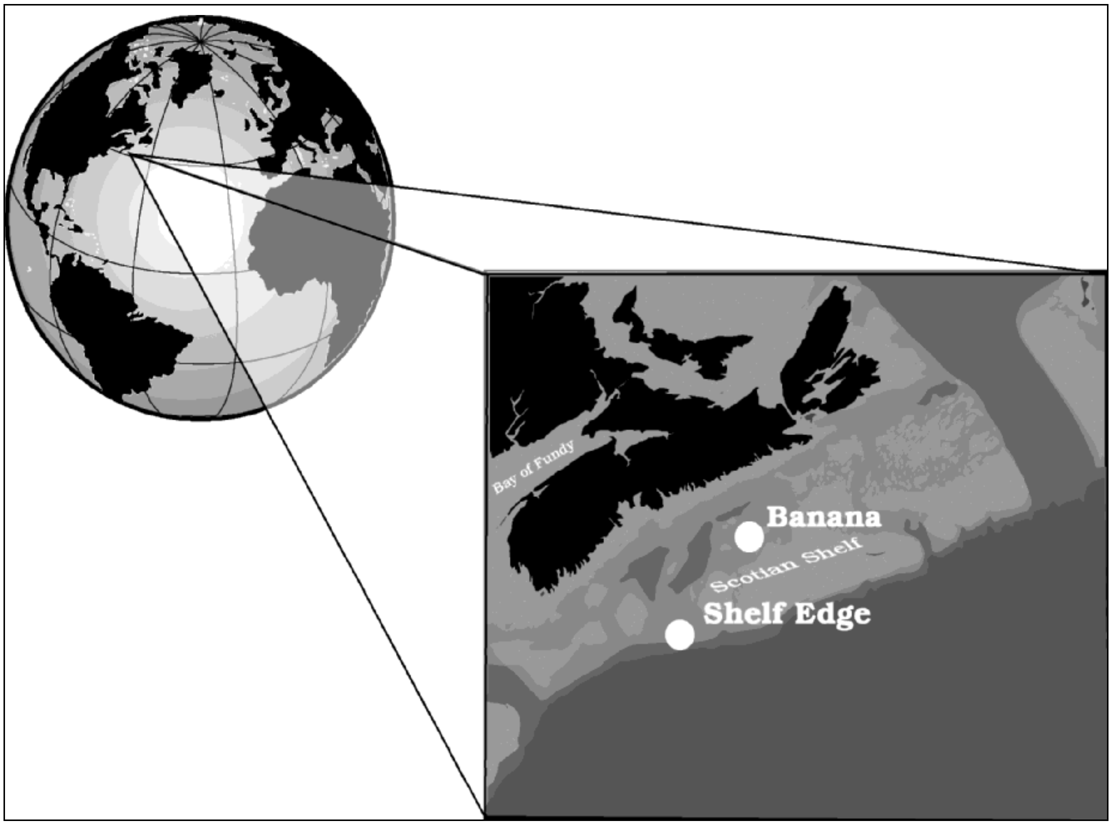

Figure 8. Location of the two study sites on the Scotian Shelf occupied during T083, September/October 1999.

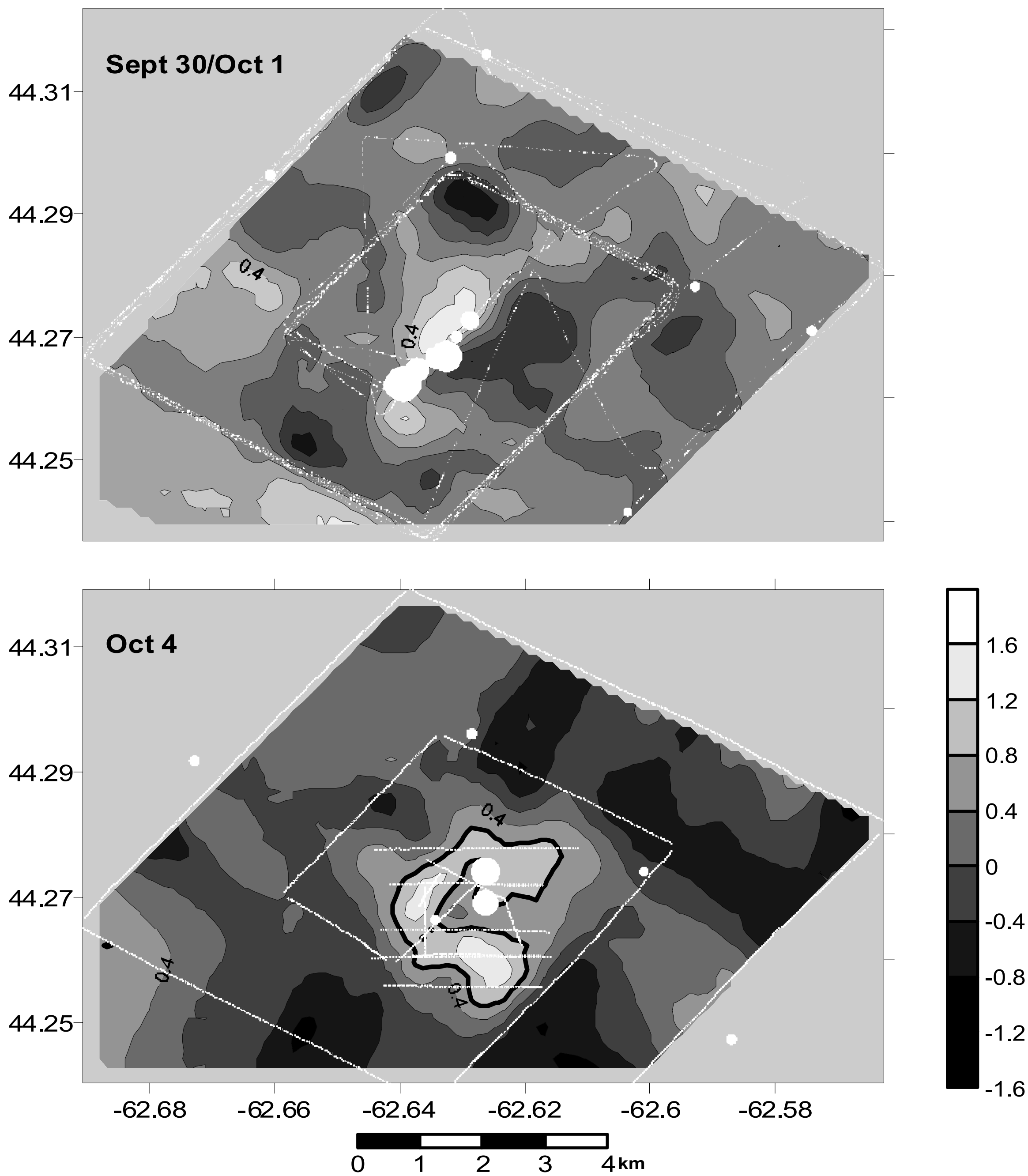

Figure 9 . The distribution of pollock at the Banana during two periods (Sept 30/Oct 1 and Oct 4, 1999). The site was monitored for 48 and 24 hours respectively . The contours represent kriged area backscattering coefficients (S_a), with the lighter shades of grey representing higher values. The expanding white circles represent the standardized net catches by a research vessel, scaled from a minimum of .001 MT to a maximum catch of 16 MT with all other catches between these two values proportionally scaled. The white lines represent the track of the research vessel. The heavy black contour defines the core area referred to in the analyses of length-frequency information.

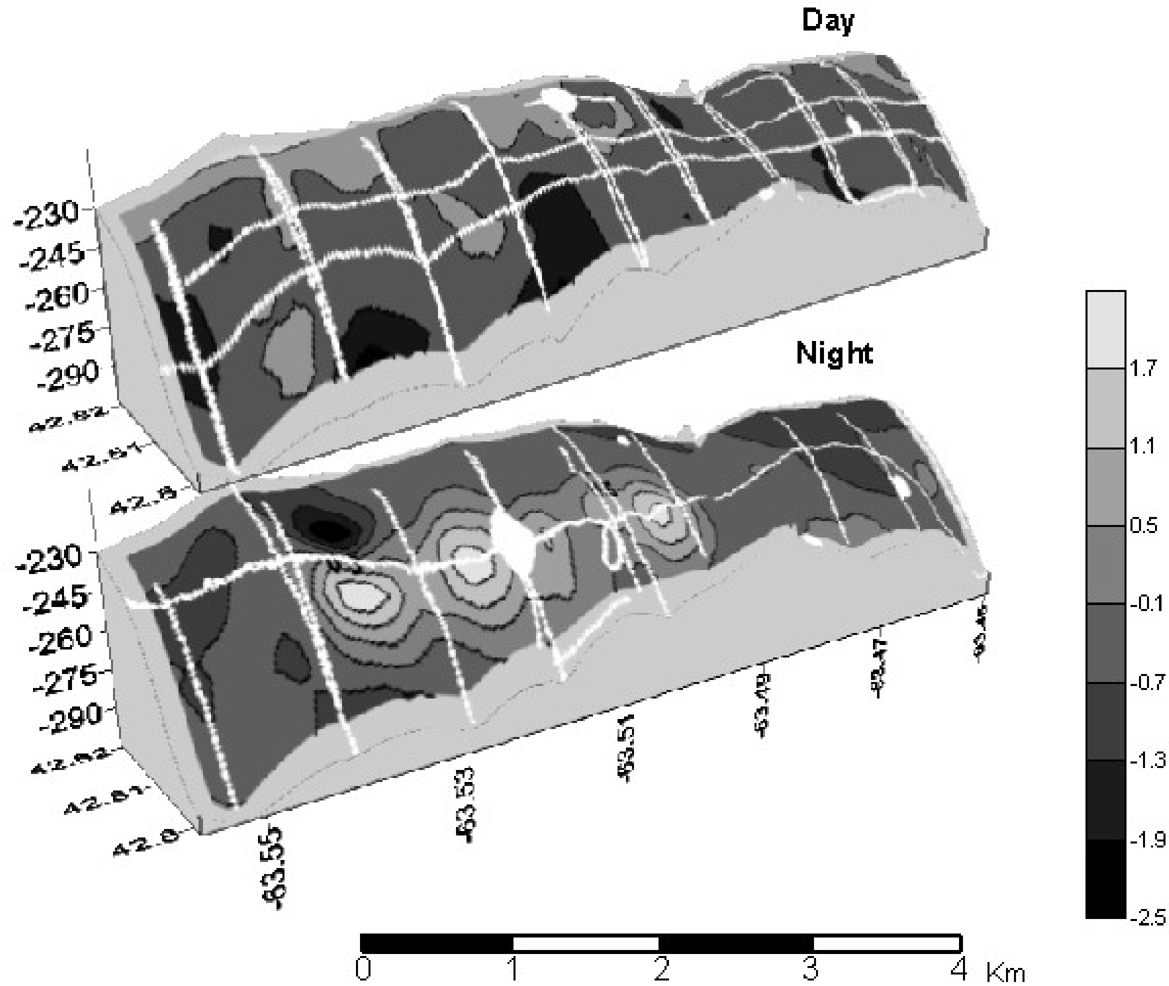

Figure 10. The night and day distribution of pollock at the Shelf Edge (October 2/3, 1999). The contours represent kriged area backscattering coefficients (Sa), with the lightest shades of grey representing higher values. The expanding white circles represent the standardized net catches by a research vessel, scaled from a minimum of .001 MT to a maximum catch of 4 MT with all other catches between these two values proportionally scaled. The white lines represent the track of the research vessel. The bottom panel depicts the bottom depth contours in meters. The z-axis represents depth (m), relative to the surface.

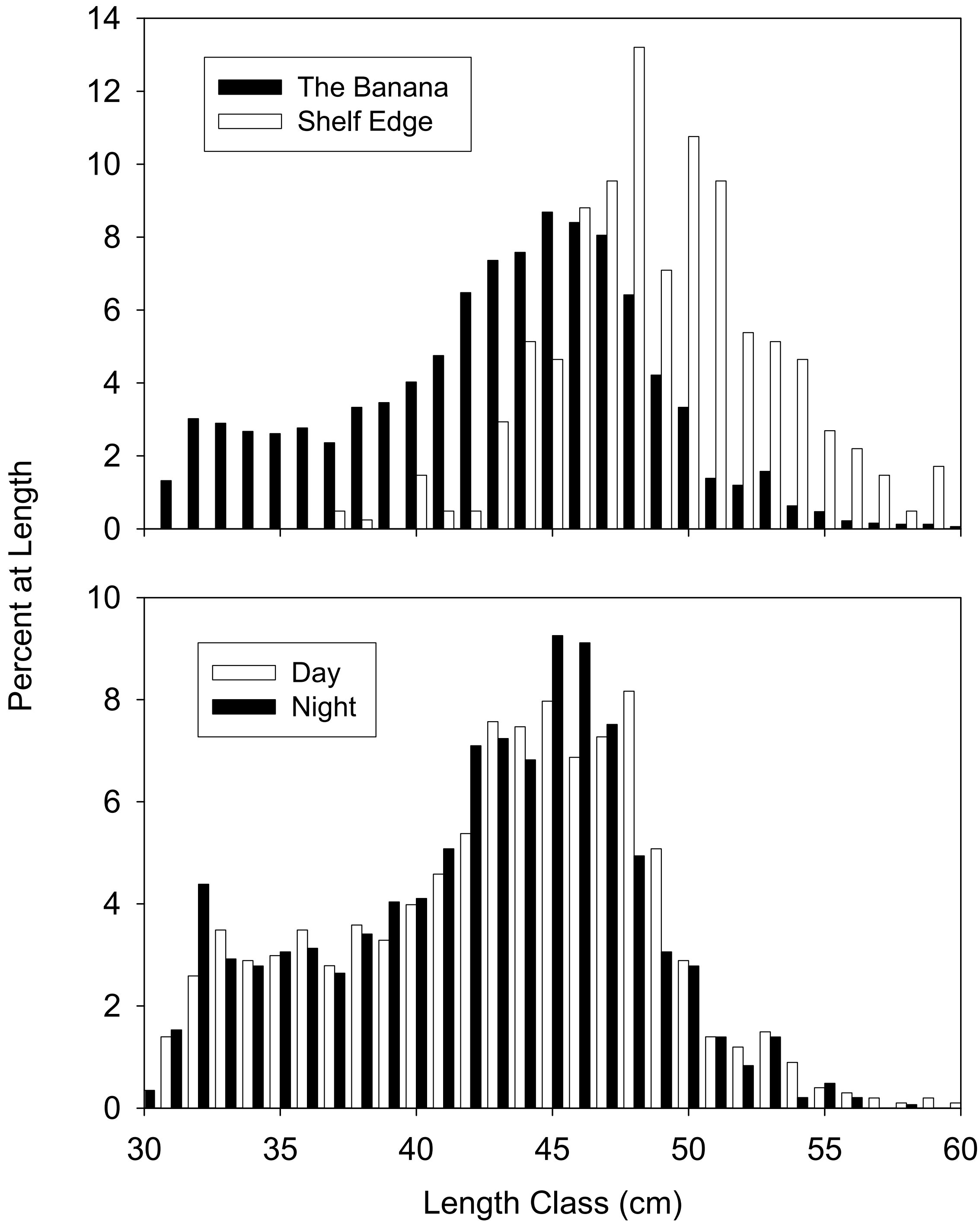

Figure 11. Comparison of length-frequency distributions of pollock caught at the Banana and Shelf Edge sites (top). The lower panel shows the length-frequency distribution of pollock caught during day and night sets on the Banana. Sampling was completed at the Banana September 30/October 1, and October 4, 1999. The sampling was completed at the Shelf Edge October 2/3, 1999.

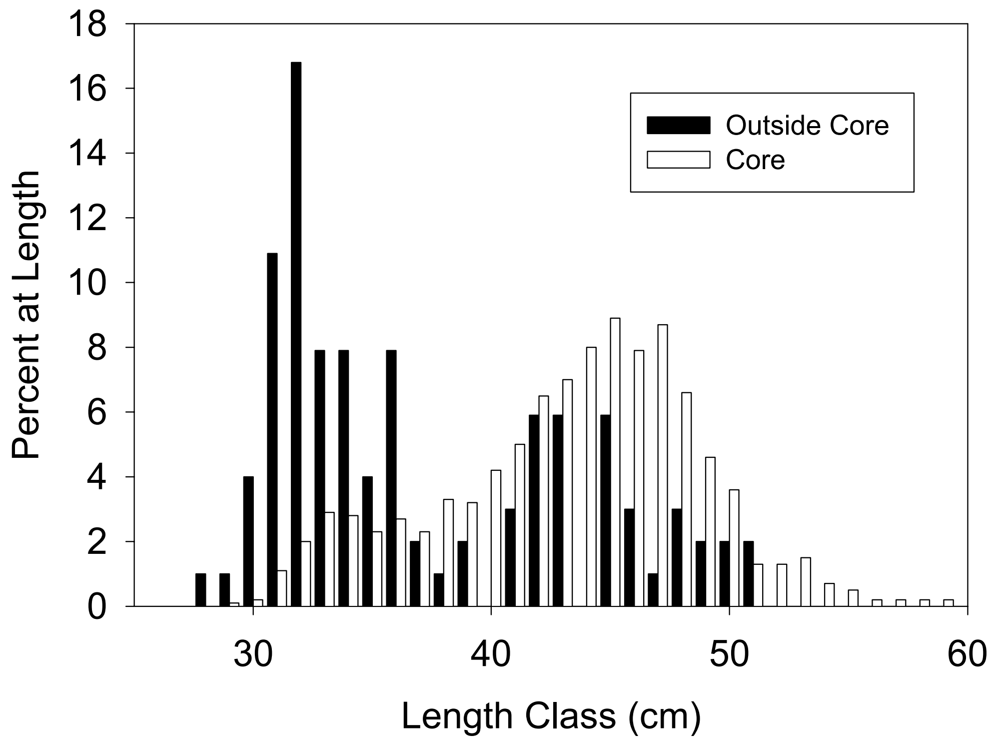

Figure 12 . Length frequency distributions of pollock taken from the core of the pollock aggregation at the Banana site (see Fig. 7 for the boundary definition) compared with the length frequency distribution of pollock outside of the core area. Sampling was completed at the Banana September 30/October 1, and October 4, 1999.

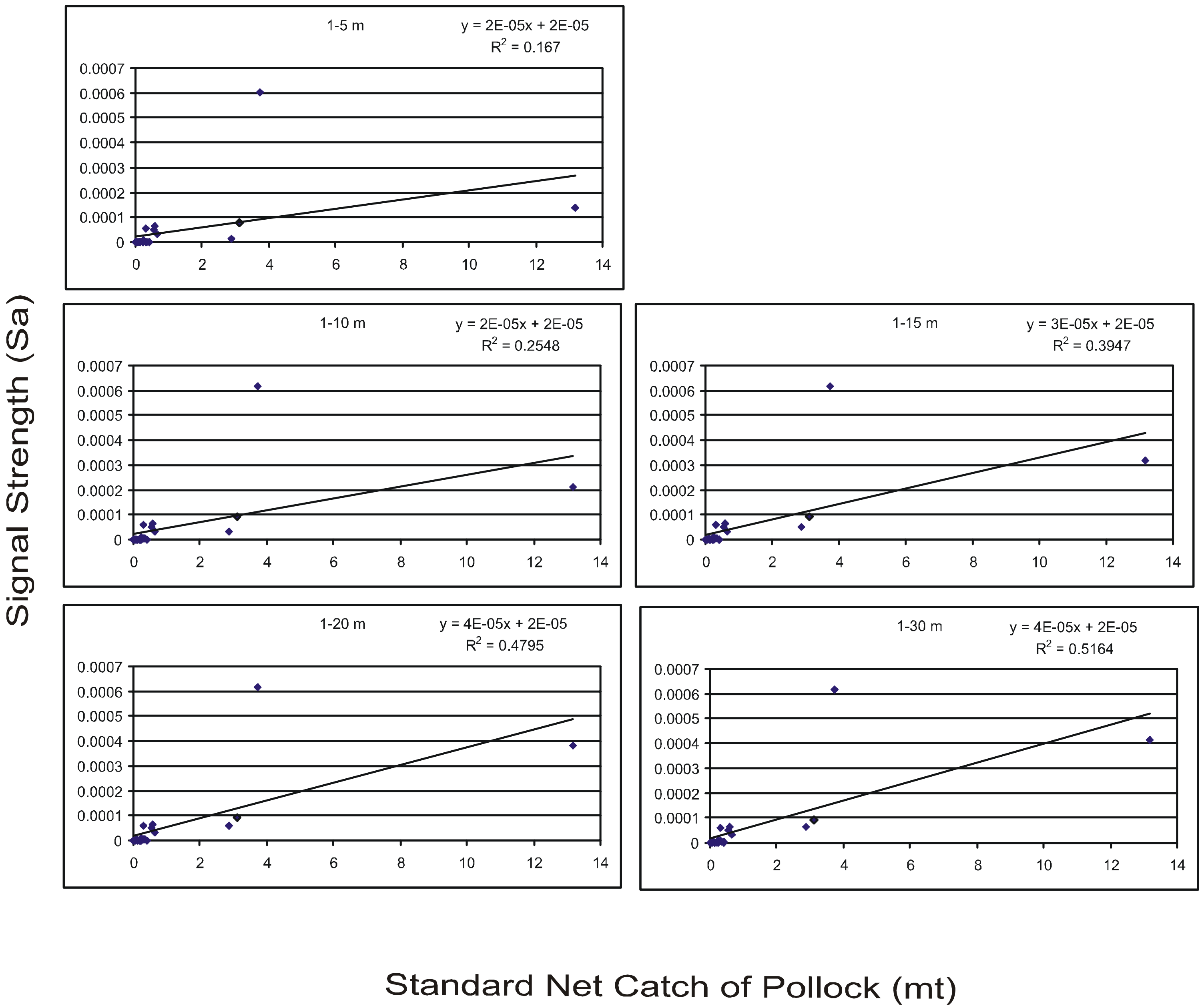

Fig. 13. Standardized catch of pollock at a site on the Scotian Shelf (September, 1999) compared with cumulative signal strength integrated through progressively greater depth ranges, reference to bottom.

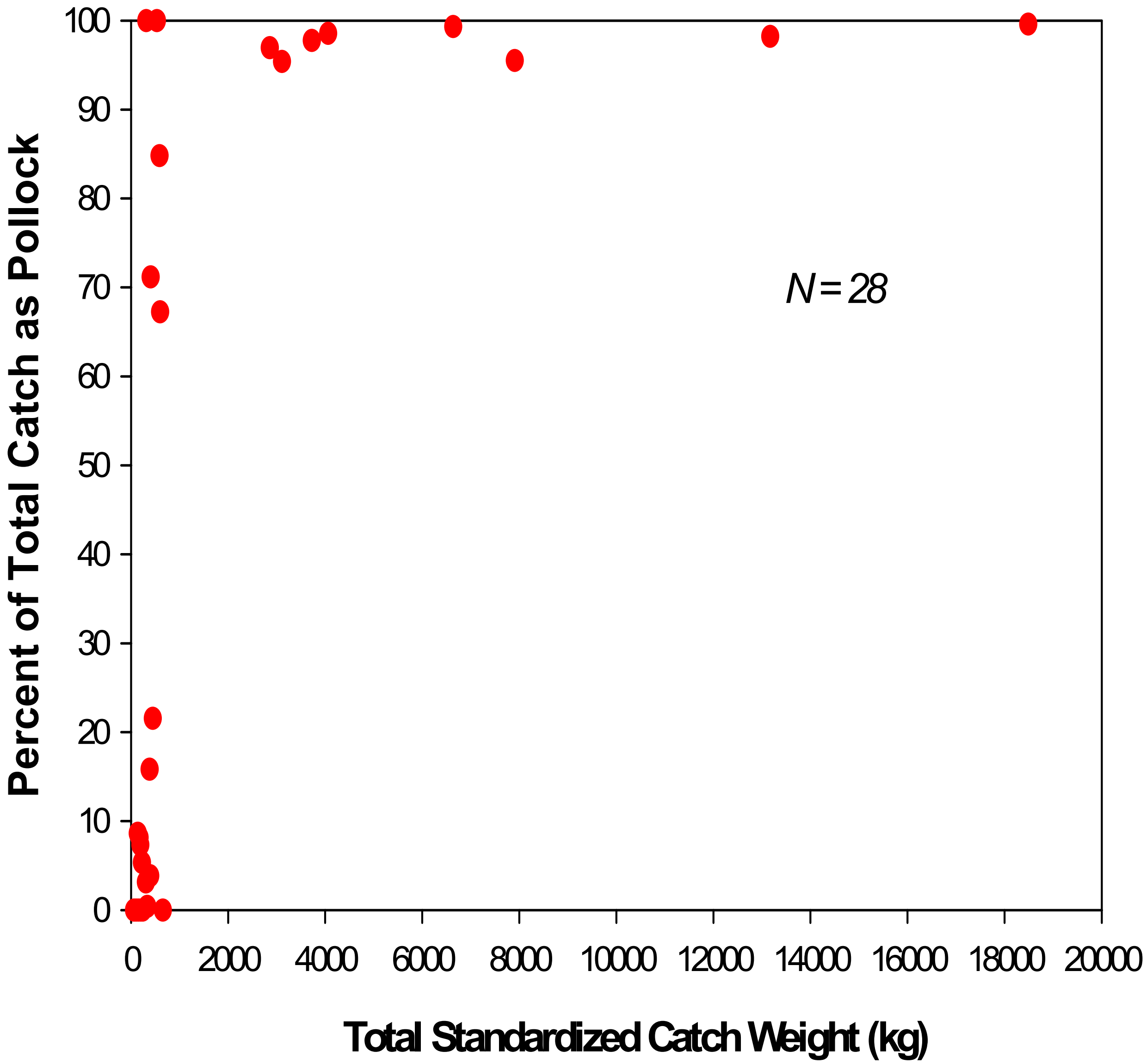

Figure 14. Relationship between total catch weight standardized to a distance towed of 0.75 nautical miles, and the proportion of pollock comprising the total catch weight. Scotian Shelf, September/October 1999.

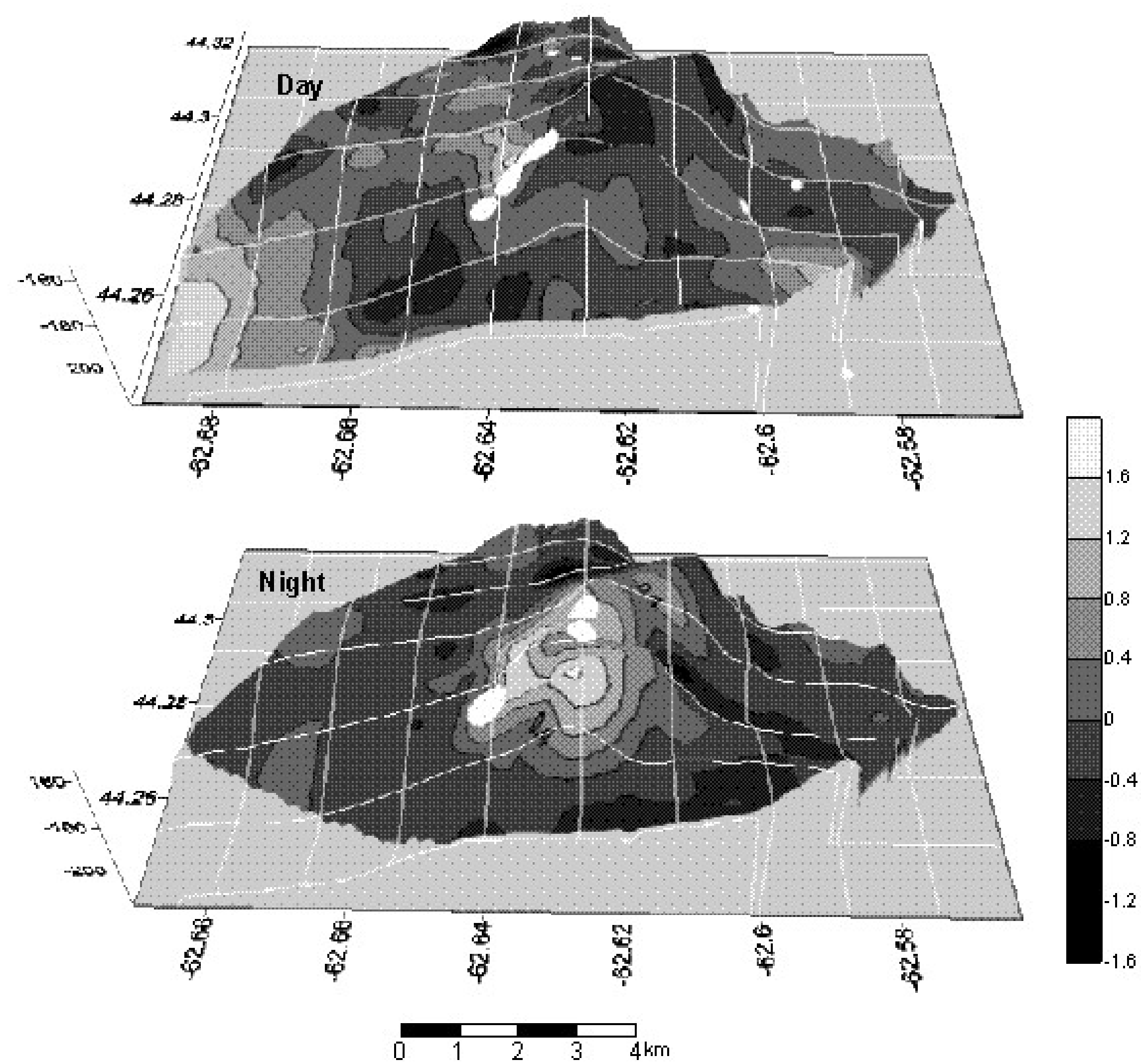

Figure 15. The night and day distribution of pollock at the Banana during two periods (Sept 30/Oct 1 and Oct 4, 1999). The contours represent kriged area backscattering coefficients (Sa), with the lightest shades of grey representing higher values. The expanding white circles represent the standardized net catches by a research vessel scaled from a minimum of .001 MT to a maximum catch of 16 MT with all other catches between these two values proportionally scaled. The z-axis represents depth (m), relative to the surface.