FISH BEHAVIOUR DURING SAMPLING AS OBSERVED FROM FREE FLOATING BUOYS - APPLICATION FOR BOTTOM TRAWL SURVEY ASSESSMENT

by

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ABSTRACT

Varying fish distribution and behaviour during bottom trawl surveys has long been considered important for the reliability of survey abundance estimates. Size and species dependent behaviour may bias the estimates and the problem may be augmented by within and between survey variation in the natural conditions. Qualitative descriptions of behavioural effects are numerous, but a quantitative methodology driven by observations is still lacking. In this paper we look into the application of data from a newly developed acoustic buoy based on experiments from saithe (*Pollachius virens*) off northern Norway. Time series plots of collective as well as individual fish behaviour during vessel passage show avoidance reaction. Time series plots of vertical fish velocity vectors show periods in which both speed and direction appear to be random alternating with periods with clear synchronous co-ordinated movement even when the fish are not simulated by vessel noise. The data uncover substantial variability in natural fish behaviour which is an obstacle for drawing firm conclusion as well as for modelling vessel/trawl affected behaviour for use in survey stock assessment. Bergen Acoustic Buoy (BAB) is an improved sampling tool, which has the potential to supply the data needed for resolving these problems.

Keywords: Fish behaviour, acoustic buoy, saithe, modeling, survey assessment

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INTRODUCTION

Absolute abundance estimates of semi-pelagic species such as north-east Arctic gadoids require that hydroacoustic estimates of the pelagic portion of the stock and bottom trawl estimates of the benthic portion be combined in some way (see e.g. Godø 1994). A simple summation has been used, but such an approach will lead to biased estimates if fish dive substantially between the time they are censused acoustically by the survey vessel and the time they are censused by the trawl (Aglen 1996). Diving results in a positive bias when fish counted acoustically descend into the trawl path and are counted again in the catch. This bias could be eliminated, however, if it were possible to estimate the proportion of the fish density measured acoustically that still remains in the water column at the time of trawl passage. This proportion, which we will refer to as the diving correction coefficient (DCC), could then be used multiplicatively to scale the pelagic estimate of abundance, integrated from the surface to the depth of the trawl headrope, to the abundance above the trawl and therefore allow absolute abundance to be calculated as the summation of the benthic and scaled pelagic estimates.

To help quantify the effects of diving and estimate this proportion, Godø and Totland (1999) developed a buoyed hydroacoustic system designed to continuously record the apparent fish density, expressed as the back scattering coefficient per unit of sea surface (s_A), from a near-stationary reference point. When a survey vessel closely passes this buoy it provides a time series of s_A and other types of information through the entire sampling process from vessel approach to trawl passage. More simple studies of vessel effects have earlier been made with portable single beam sounders from small skiffs (Ona and Godø 1990, Nunnalle 1992) and with split beam sounders operated from small drifting vessels (Vabø 1999).

In the simplest case, an estimate of DCC could be calculated as the quotient of the s_A measured by the buoy at trawl passage divided by the s_A measured at vessel passage. However, there are a variety of additional effects that may accompany fish diving that complicate this process. The target strength of fish change because their tilt angles and therefore their acoustic crossectional areas change. The target strength also changes because hydrostatic pressure and therefore swimbladder volume changes. Such variation in target strength produces variation in s_A that is unrelated to fish density. In addition, fish may swim horizontally out of the acoustic beam between vessel and trawl passage resulting in a decrease in pelagic fish density that is not associated with a corresponding increase in benthic density. Finally, the s_A measured by the buoy varies for reasons that are unrelated to the passage of the vessel and trawl (e.g. buoy drift and natural fish movement) and any measure of change in s_A must be assessed in terms of this variability.

The importance of these effects can be assessed with an additional type of data collected by the hydroacoustic buoy, using an analytical method known as target tracking (Ona and Hansen 1992). In this procedure, the targets identified as individual fish by the echosounder at each ping are linked together over successive pings to create three-dimensional trajectories of individual fish. These trajectories can then be used to compute

changes in swimming speed, direction or target strength associated with the passage of the vessel and trawl.

In this paper we examine the use of data collected with the Bergen Acoustic Buoy (BAB, Godø and Totland 1999) for saithe (*Pollachius virens*) to demonstrate these techniques.

MATERIAL and METHODS

The experiment was conducted with the R/V Johan Hjort in August 1998 off the coast of northern Norway in an area with strong tidal currents and depths varying from 70 m to 130 m. The site was ideal for the study because, as shown by fishing trials, nearly all of the fish were saithe in sufficiently low concentrations that they could be acoustically resolved into single targets.

Bergen Acoustic Buoy (BAB)
The acoustic buoy contains a Simrad ES-60 38 kHz echo sounder controlled by a computer running Windows NT. A splitbeam tranducer is attached to the buoy with a 20 m cable balanced with floats to minimize the effect of surface movements on the transducer orientation. Speed and position are measured with a GPS mounted in the buoy and geographical orientation is measured with a compass mounted on the transducer. Echogram data (back scattering volume by depth) are collected with a 20 log R gain and target strength data, with depth and angle information, are collected with a 40 log R gain. All data (echogram, target position, GPS, compass) are stored on a buoy-mounted PC but are transmitted simultaneously with a radio link (data transfer rate of 115.2 Kbs) to the research vessel and displayed on the steering and monitoring computer. Elements of the display include buoy track, transducer orientation, and echogram (Figure 1). The radio link is bi-directional so that all echosounder facilities on the buoy can be operated from the research vessel. Communication with the buoy is conducted with a user interface developed at IMR in conjunction with a commercial software product (PcAnywhere). More extensive description of function and technical specification of BAB is given by Godø and Totland (1999).

Integration
Vertical displacement of fish was monitored by changes in the total amount and vertical distribution of biomass. Area back-scattering cross section per square nautical mile (s_A) was calculated from the echo gram data using the following relationship:

$$s_A = \sum_{i=i1}^{i2} 10^{(S_{vi}/10)} \cdot 1852^2 \cdot 4\Pi$$

where Sv_i is the volume backscattering within the ith depth interval and i1 and i2 are the minimum and maximum depths for summation. The weighted mean depth at each ping (*Drec*) was calculated as:

$$Drec = \sum_{i=i1}^{i2} d_i \cdot S_{vi} / S_{vsum}$$

where d_i is the ith depth interval and S_{Vsum} is the total integrated Sv for each ping. To reduce the effects of a large ping to ping variation, s_A and $Drec$ values were averaged over one minute intervals.

Target tracking.
Assessment of the movement and changes in target strength of individual fish was accomplished with target tracking, a procedure described in Brede *et al.* 1990, Ona and Hansen (1992) and Zhao (1996). Some of the important features of this procedure are as follows. The SIMRAD split beam echosounder used aboard the acoustic buoy has the ability to distinguish peaks in the returning echo energy. When such peaks meet a variety of conditions they are considered to be echoes from individual fish targets. For each of these targets, the echosounder calculates its location in the acoustic beam (i.e. depth and the angle relative to each horizontal axis) and its target strength. The target tracking procedure developed by Ona and Hansen (1992) utilizes this target identification information to construct 3 dimensional trajectories of individual fish by linking the identified targets on one acoustic ping with those on the next ping based on the assumption that the closest targets on successive pings are the same fish. As with target identification, track identification is controlled by a number of parameters including the minimum number of peaks needed to define a single-fish-track and the maximum allowable vertical movement between successive pings. Tracks considered in the following analysis were required to have at least 10 peaks.

Target track data was first used in an attempt to determine whether there was a significant horizontal movement of fish from within the acoustic beam to outside the beam between the time of vessel passage and trawl passage. Initially we examined the question of whether or not fish changed either swimming speed or direction near the time of vessel passage in a manner consistent with vessel avoidance. This was done by computing fish trajectories relative to the trajectory of the research vessel. These trajectories were developed in several stages. First, trajectory plots displayed considerable variability, which, upon subsequent analysis, was attributable to an angular oscillation of the buoy transducer. To remove this error, the trajectories in both the x (alongship, with positive toward the top of the transducer) and y (athwartship, with positive toward right hand side of the transducer) dimensions were smoothed by fitting straight lines to the position and time data. Second, trajectory direction, relative to the top of the transducer, was next computed. Third, swimming speed was then computed as the distance between the ends of the trajectory divided by the elapsed time. Fourth, trajectory angles were then corrected for transducer heading by adding orientation angle from buoy compass data, indicating the orientation of the transducer relative to true north. Finally, the heading of the ship was determined from the nearest GPS fixes immediately proceeding and following passage of the buoy. Rather than correcting all fish trajectories for vessel heading at the time of passage, the ships heading was simply indicated on time series plots of the fish trajectory vectors.

Target track data was then used to examine the changes in tilt angle that occur as fish are approached by a vessel and the relationship between tilt angle and target strength. Average tilt angle was computed for each track based on the difference in depth and

horizontal position between successive pings then averaged over all pings. This computation is based on the assumption that as a fish swims from one location to another its body will be orientated along the straight-line vector between the two positions (Zhao 1996). Average tilt angle was then plotted against time to determine whether obvious changes occurred at the times of vessel passage. A functional relationship between tilt angle and target strength was determined nonparametrically by fitting a cubic spline to track-averaged tilt angle and track-averaged target strength.

RESULTS

The fish
Fishing stations (line and hook) showed a very homogenous fish size with average length of 60.5 cm (sd= 5.7, n=21). Saithe normally school by size and although the fishing method used is rather selective, we are quite confident that the observed species and size distribution is fairly correct. The fish at this size are capable of swimming fast (Wardle 1977), and vessel and trawl avoidance represent a problem for both commercial fishing and survey sampling.

Natural fish behaviour
As the saithe were resolved in single fish traces, individual fish behaviour could be studied both from the integration and tracking method. Figure 2 shows an echogram with no external stimuli. It is evident that the individual fish perform substantial vertical excursions during the time they are within the acoustic beam. Further, when looking at adjoining fish, these vertical movements appear to be quite synchronous. The motion seems to propagate through the whole vertical extent of the recording, resulting in an undulating movement of the acoustic recordings over time and suggesting some rhythmic behaviour. This is even more apparent in the "undisturbed" periods during the passage experiment presented in Figure 3 and 4. Smoothed average depth per ping (Drec) shows systematic variation over time, substantiating the visual impression from the echograms. Further, the back scattering cross section per ping varies systematically with periods similar to the depth.

Fish response during sampling
The fish response to sampling differed between hydroacoustic trials, in which the vessel passed the buoy at 11 knots in the same manner as used in a hydroacoustic survey, and trawling trials, where the vessel passed the buoy at 3 knots towing a trawl in midwater in a manner similar to that used during trawl sampling. Hydroacoustic trials are typified by Trial 2 (Figure 4) in which the vessel passed within 8 m of the buoy, then approximately 15 minutes later made a second pass traveling in the opposite direction. Fish diving is evident on the echogram at approximately 1 minute before each vessel passage (Figure 4, top panel). However, interpretation of this motion as vessel avoidance is difficult because similar co-ordinated vertical movement also occurs at times other than vessel passage. Other indicators of fish response are also weak. Changes in fish swimming speed or direction were not obvious on the target track time plot near the times of vessel passage (Figure 4, panel 2) nor were changes in target strength and tilt angle (Figure 4, panels 3

and 4). The same impression is underlined by the observation of depth and s_A (Figure 3). Although dips in depth and s_A co-occur with the passages, these dips can not be distinguished form the natural occurring undulating behaviour of the curves. Collectively these measures indicate that the diving response of saithe to an hydroacoustics vessel is weak.

The trawl trials are typified by Trial 8 (Figures 3; lower panel and 5) where the vessel made a single close pass of the buoy while towing a trawl. In contrast to the hydroacoustic trial, the echogram for this trial shows a dramatic diving response which continued after vessel passage and reached a maximum near trawl passage (Figure 5; top panel). After trawl passage, fish rapidly ascended to their former depths which were as much as 60 m shallower (Figure 3 and 5). A possible slight rotation in the swimming direction might have started 2-3 minutes before vessel passage (Figure 5; panel 2), however there were other equally strong directional changes over the trial that were not associated with vessel passage. Target strength decreased before vessel passage, dramatically rose at passage then decreased starting about 5 min after passage (Figure 5; panels 3 and 4). This pattern is clearly attributed to three changes in tilt angle: 1) the initial decrease in TS is due to the tilting associated with diving, 2) the increase in TS is due to the decrease in tilt angle as the diving fish neared the bottom and 3) the subsequent decrease in TS is due to the increase in tilt angle as fish ascended after trawl passage. The drastic reduction in s_A (Figure 3; lower panel) is due to a vertical escape into the acoustic bottom dead zone (Ona and Mitson 1997) possibly with a small component due to horizontal movement out of the acoustic beam. Collectively these measures indicate that saithe initiates a strong diving response to a vessel towing a trawl. However, there was only a weak indication that saithe altered either their swimming speed or direction, therefore it is unlikely that they swam laterally outside of the acoustic beam between the times of vessel and trawl passage.

As a means to correct TS for changes in tilt angle during sampling, we developed target-strength versus tilt-angle functions for each trial. These functions were quite similar for all of the trials. Using the function for Track 8 (Fig. 6) as an example, target strength was maximum at a tilt angle of about –2 degrees (negative indicates a head down position). Target strength decreased with increasing tilt angle, but the decrease was stronger for positive (head up) angles. In this case, a positive tilt of 10 degrees resulted in a decrease in target strength of approximately 8 dB or the equivalent of more than 80% decrease in biomass.

DISCUSSION

Natural variation

In this experiment saithe displayed a weak diving response to a vessel traveling at 11 knots but a dramatic response to a vessel traveling at 3 knots while towing a trawl in mid-water. There are two explanations for this difference. First, fish diving behavior is likely

initiated and perhaps sustained when sound levels exceed some threshold level. If this level is exceeded within some radius of the vessel, then duration of the stimulus is shorter when the vessel is travelling 11 knots than when travelling 3 knots. If diving velocity is independent of vessel speed, then the vertical extent of diving will be greater when the vessel is travelling slower. Second, the warps and trawl produce vibrational noise and therefore likely produce a secondary stimulus to dive. Since the trawl follows the vessel by 5-6 minutes, depending on the length of warp, the duration of the diving stimulus, and extent of the response, is increased further.

The change in target strength that accompanies diving behaviour creates two problems for stock assessment. The first problem concerns the measurement of target strength at the moment a fish is assessed acoustically by a survey vessel. Typically the target-strength versus fish-length functions used for stock assessment were obtained either from drifting vessels or from caged fish. However, when a fish dives in response to an approaching vessel its tilt angle may increase relative to undisturbed conditions and its target strength may become less than that predicted by the target strength function. In such situations, obtaining unbiased biomass estimates will require an estimate of target strength corrected for tilt angle. Although when fish are sufficiently disaggregated to acoustically resolve individuals it is possible to measure target strength during assessment, this is normally not done due to the extreme variability of target strength measurements. Acceptable alternative approaches to obtaining such dynamic estimates of target strength are not clear. However, with the use of the BAB it is possible to estimate tilt angle changes due to diving and target-strength versus tilt-angle functions needed to correct target strength for such changes. From our trials, however, it appears that saithe have a weak diving response to a hydroacoustic vessel and therefore do not substantially change their tilt angle. This implies that the acoustic estimation of saithe abundance is likely unaffected by diving.

The second problem caused by diving induced changes in target strength influences the way in which the Diving Correction Coefficient is calculated. Initially we considered estimating DCC as the value of s_A (integrated from the surface to the headrope depth) measured at the time of trawl passage divided by the s_A at the time of vessel passage. However, saithe appear to have such a strong diving response that their target strength is significantly changed and this change must be accommodated in the estimator. It is not clear how this should be done, but as additional experiments are conducted we will attempt to simply calculate the ratio of the target strength at the moments of trawl and vessel passage.

Although the trials on saithe indicated that diving is unlikely to significantly affect hydroacoustic estimates of abundance, it has a quite pronounced affect on bottom trawl estimates of biomass. This, in turn, indicates that combined estimates of abundance can not be obtained from the addition of hydroacoustic and bottom trawl estimates and that an estimate of a Diving Correction Coefficient is needed. However, the trials also indicate the estimation of the Diving Correction Coefficient will be complicated by the change in

target strength as fish dive and that considerable additional experimentation will be needed to resolve the problems.

Our first experiences with BAB have shown that reliable behaviour models of fish response motion and TS will require more types of data and more replication than we originally anticipated. Not only is it necessary to detect and quantify the 3 dimensional movements of individual fish influenced by a survey vessel and trawl, but it is also essential to have a comprehensive understanding of natural fish behaviour. Natural movements appear to be substantial and represent a major source of variation in TS. In contrast to the strong horizontal avoidance behaviour herring (Egil Ona, per. Comm.), saithe avoidance appears to involve only vertical motion. In addition, the avoidance behaviour does not seem to involve an acceleration (i.e. fleeing) but only a change in direction.

BAB has improved our ability to monitor natural fish behaviour over long periods and has enabled a less laborious and resource demanding set-up for vessel/trawl passage experiments. As such, the buoy might become an important tool for collecting data during monitoring surveys for a direct assessment of behavioural effects on standard survey estimates. One should, however, not underestimate the data demand and the time needed to complete such an approach. In many cases it might be more productive to use BAB in more systematic studies with the aim of producing general behaviour models.

ACKNOWLEDGEMENT

REFERENCES

Aglen, A. 1996. Impact of fish distribution and species composition on the relationship between acoustic and swept-area estimates of fish density. *ICES J. Mar. Sci. 53*: 501-506.

Brede, R., Kristensen, F.H., Sollie, H. and Ona E. 1990. Target tracking with split beam echo sounder. Rapp. P. –v. Reun. Cons. int. Explor. Mer, 189: 254-263.

Godø, O.R. 1994. Factors affecting reliability of groundfish abundance estimates from bottom trawl surveys. *In* A. Fernö and S. Olsen [eds.] pp 166-199. *Marine Fish Behaviour in Capture and Abundance Estimation.* Fishing News Books. Oxford.

Godø, O.R and Totland, A. 1999. Bergen Acoustic Buoy (BAB)- A Tool For Remote Monitoring Of Marine Resources. Joint IASA/EASA meeting Berlin, March 1999. Paper 2pAO10.

Nunnallee, E. 1991. An investigation of the avoidance reaction of Pacific whiting (*Merluccius productus*) for demersal and midwater trawl gear. ICES CM 1991/B:5.

Ona, E. and Godø, O.R. 1990. Fish reaction to trawling noise: the significance for trawl sampling. Rapp. P.-v. Reun. Cons. int. Explor. Mer 189: 159-166.

Ona, E. and Hansen, K. 1991. Software for target tracking with split-beam echo sounders: Users manual. Institute of Marine Research, Bergen, Norway.

Vabø, R. 1999. Measurements and correction models of behaviourally induced biases in acoustic estimates of wintering herring (*Clupea harengus* L.). Dr. scient. dissertation , University of Bergen, Norway.

Wardle, C.S. 1977. Effects of size on the sweeming speed of fish. In: T.J. Pedley(ed.). Scale effects in animal locomotion. Acedemic Press. New York.

Zhao, X. 1996. Target strength of herring (*Clupea harengus* L.) measured by the split-beam tracking method. Mphil Thesis. University of Bergen. 103pp.

Figure 1. Monitoring and operational interface as appearing on the mother vessel computer.
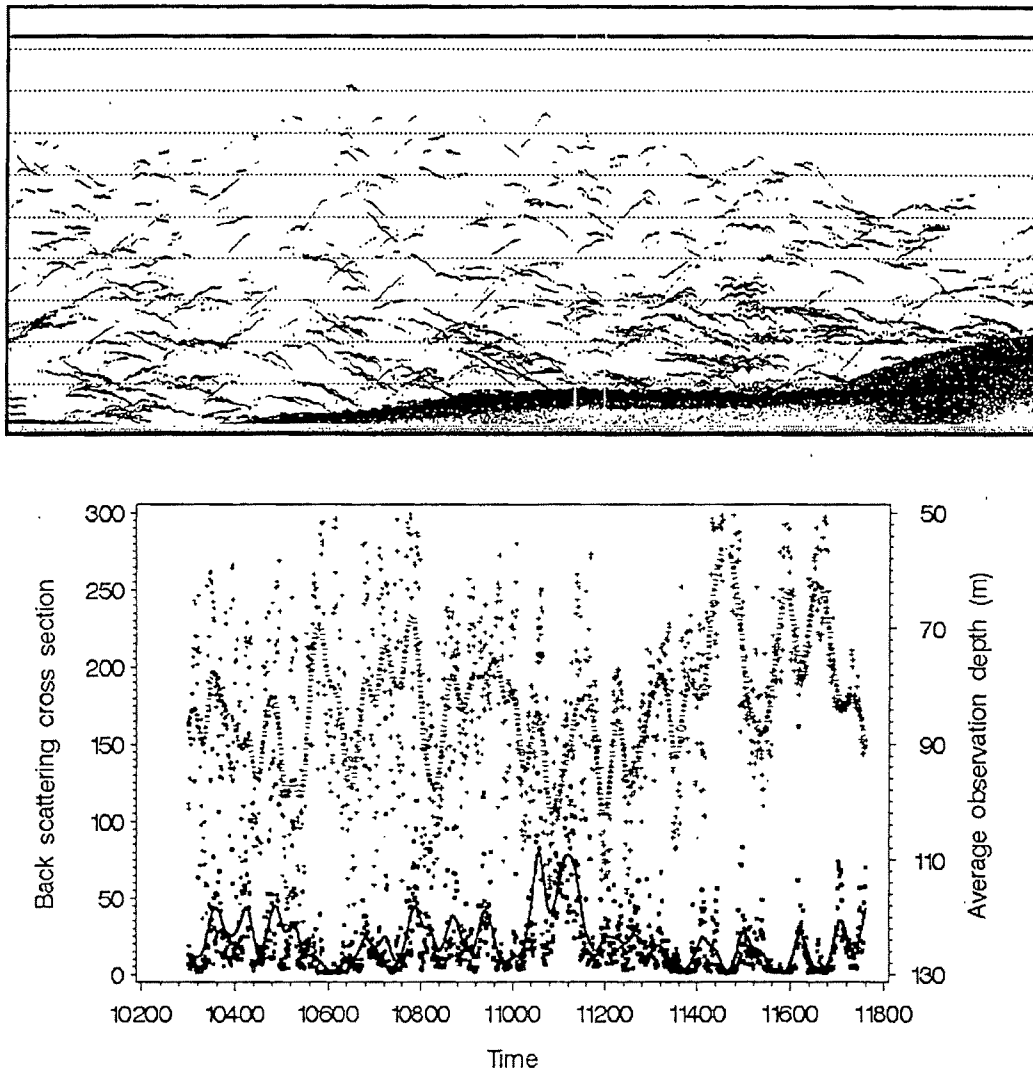
Figure 2. Typical echograms of saithe illustrating natural fish distribution and behaviour as observed from the buoy - upper panel. By means of the integration method, the back scattering cross section per square n. mile (dots) and depth of recordings (+) per ping smoothed with a cubic spline (dotted and continuos line respectively) are presented in lower panel.
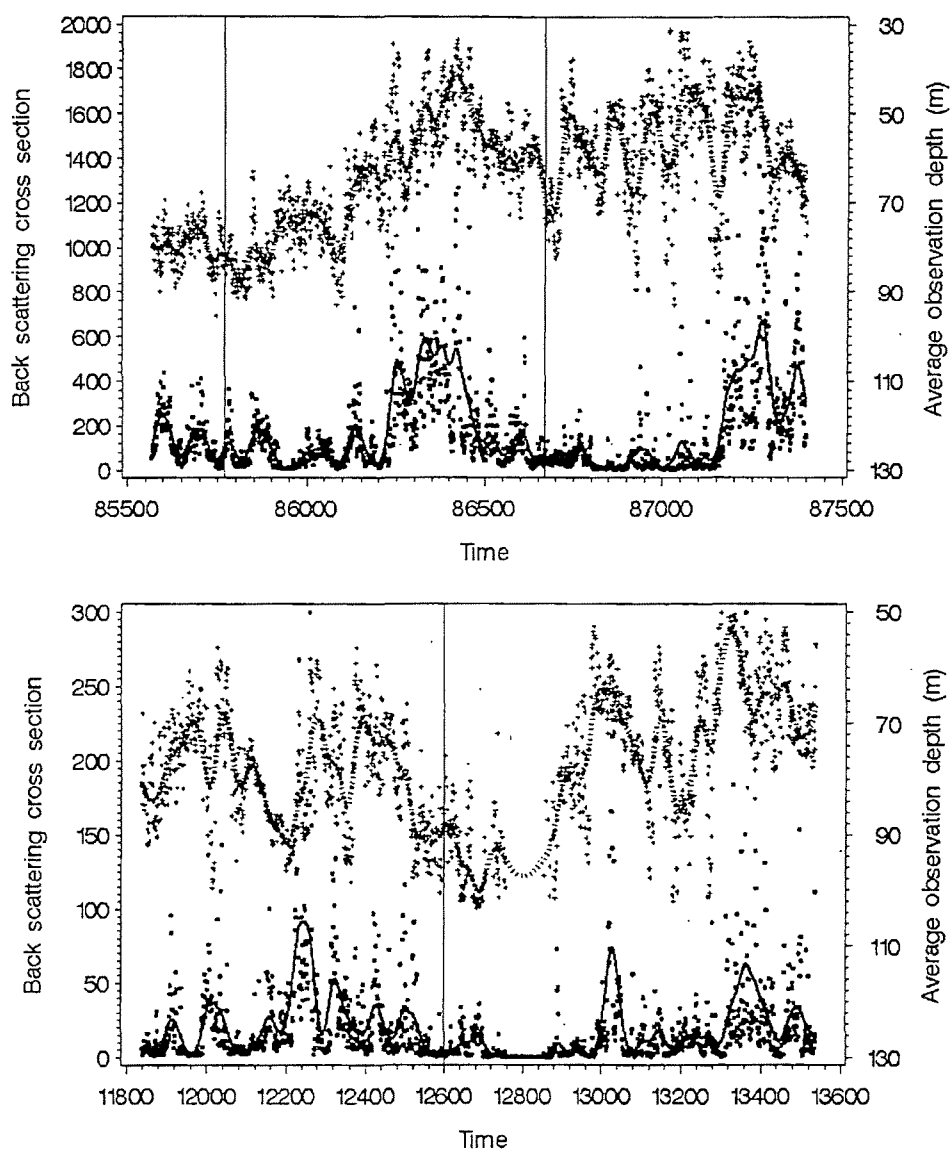
Figure 3. Observed back scattering cross section per square n. mile (dots) and average depth of recordings (+) per ping smoothed with a cubic spline (dotted and continuous line respectively) – A. during passage with research vessel at 11 knots and B. during passage with a trawl. Vertical lines indicate time of passage.
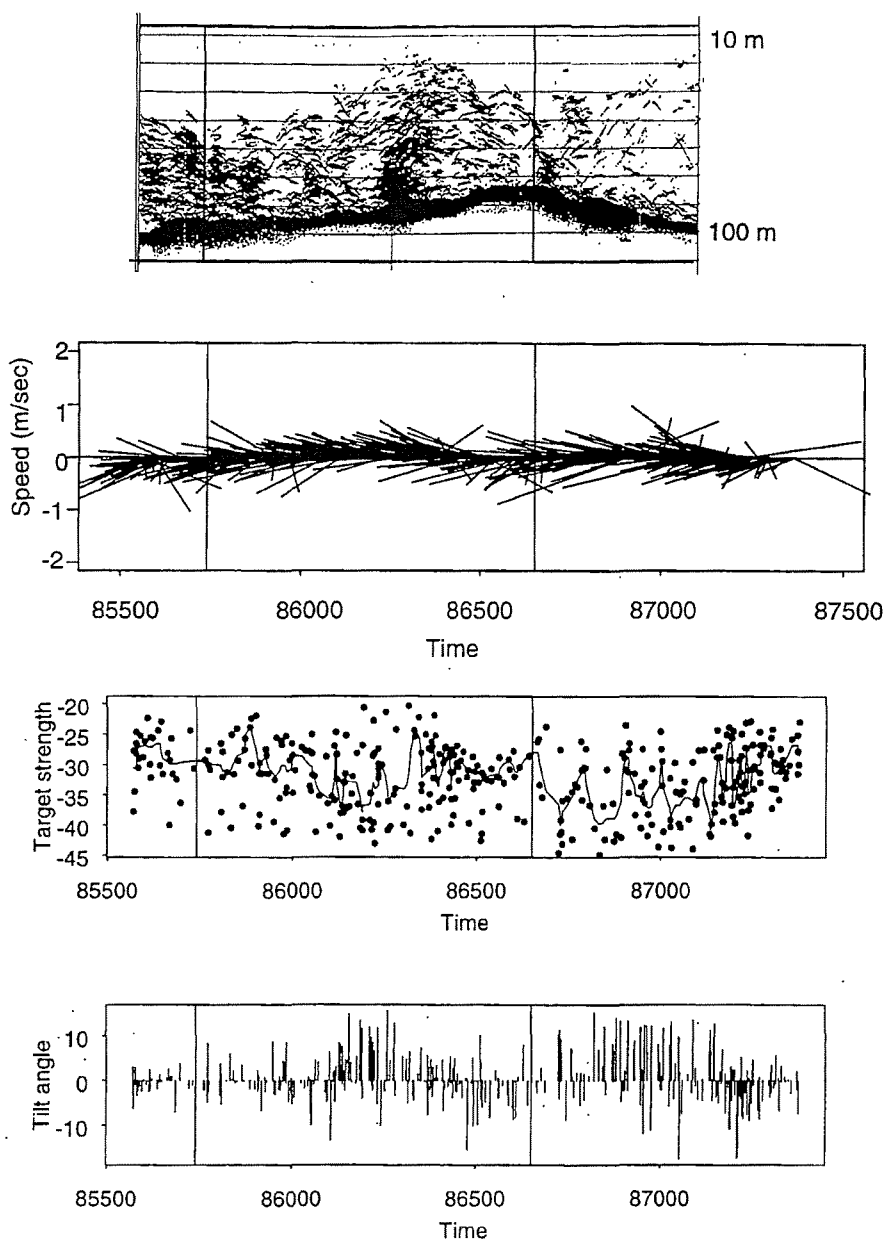
Figure 4. A typical pass from a hydroacoustic vessel. All plots are on the same time axes, with time represented in seconds from midnight. Times of closest approach of the vessel to the buoy are shown with vertical lines. The first (upper) panel shows the echogram from the buoy. The second panel shows a speed and direction time plot of the tracked fish. Speed is represented by the length of each vector using the scale provided on the y axis. Direction is represented by the angle of each vector relative to the 0 on the y axis (i.e. 90 degrees or due east is represented by a vector pointing straight up). The third panel shows a time plot of the mean target strength in dB of tracked targets (dots) and a smoothed interpretation of the data (line). The fourth panel shows a time plot of tilt angle in degrees from horizontal with positive representing a head-up body position.
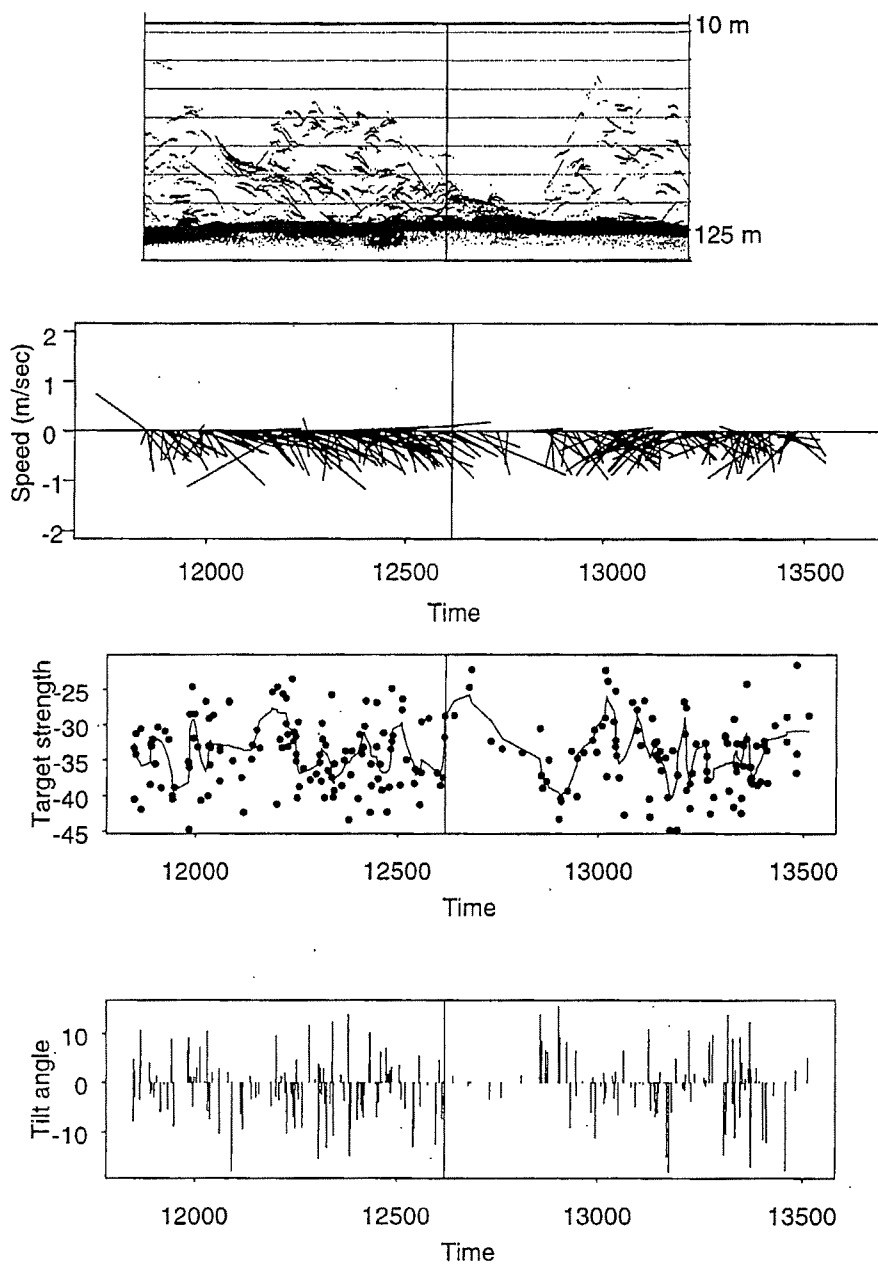
Figure 5. A typical pass from a hydroacoustic vessel towing a trawl. All plots are on the same time axes, with time represented in seconds from midnight. Times of closest approach of the vessel to the buoy are shown with vertical lines. The first (upper) panel shows the echogram from the buoy. The second panel shows a speed and direction time plot of the tracked fish. Speed is represented by the length of each vector using the scale provided on the y axis. Direction is represented by the angle of each vector relative to the 0 on the y axis (i.e. 90 degrees or due east is represented by a vector pointing straight up). The third panel shows a time plot of the mean target strength in dB of tracked targets (dots) and a smoothed interpretation of the data (line). The fourth panel shows a time plot of tilt angle in degrees from horizontal with positive representing a head-up body position.
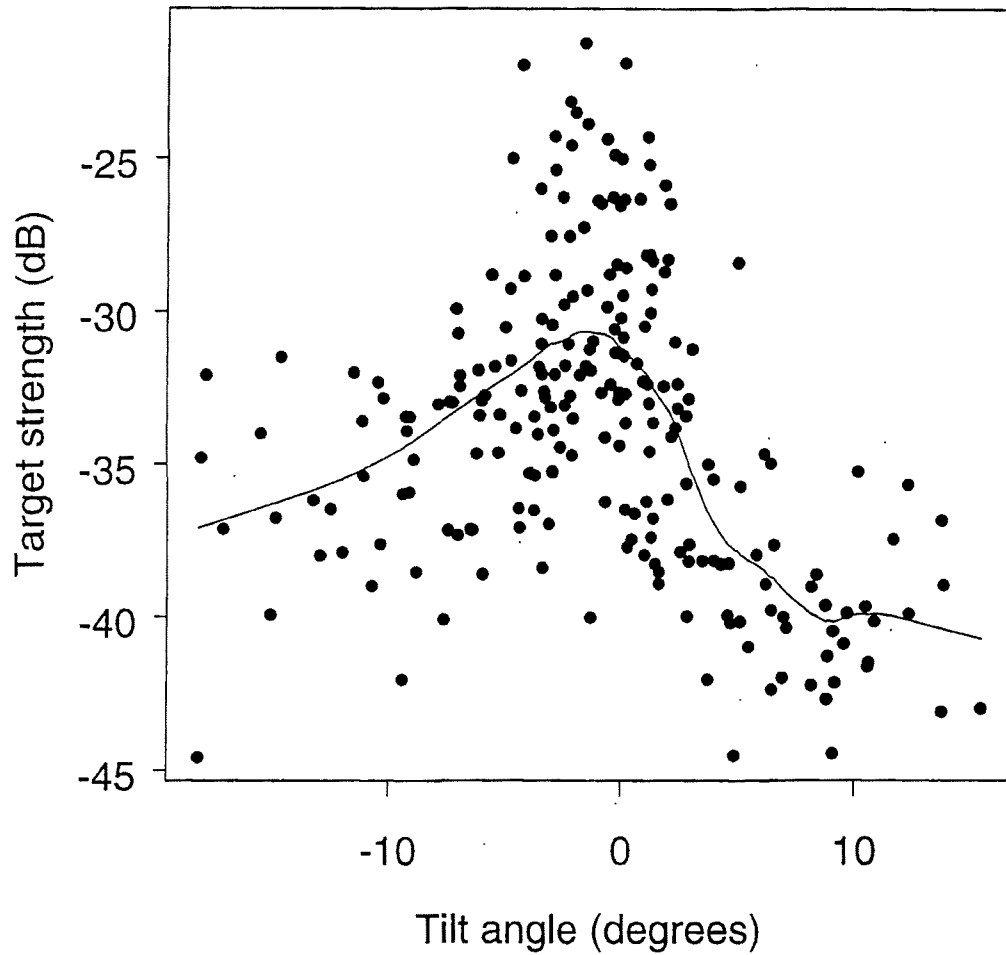
Figure 6. Mean target strength plotted against mean tilt-angle for individual targets during Trial 8. The solid line is a non-parametric estimate of the mean