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Fish reaction to trawling noise: the significance for trawl sampling

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The reactions of fish during trawling were observed with a stationary echo sounder as a trawling vessel passed close to the transducer. Several strong, downward avoidance reactions of haddock (*Melanogrammus aeglefinus*) were recorded. At depths greater than 100 m, however, the reaction pattern was weak and irregular. A comparative analysis of echo-integrator data at random bottom-trawl sampling sites indicates that fish avoidance occurs between the surface and 200-m depth, even before the vessel arrives. At greater depths, such pre-vessel avoidance reactions are not significant.

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Introduction

Improvements in trawl sampling techniques and the precision of abundance estimates developed using these techniques are dependent on a thorough understanding of the selective behaviour of fishing gear. Various methods, including the use of divers, remote-operated vehicles, and photographic techniques have been used to observe patterns of fish behaviour in the vicinity of an active fishing trawl between the doors and the codend. Much of this work has been reviewed by Ben Tuvia and Dickson (1969) and Wardle (1984, 1986). The reaction of fish to vessel noise has been studied extensively by Olsen (1969, 1971, 1979, 1980) and Olsen *et al.* (1982a, 1982b). This should be taken into account when the study requires collection of a representative sample of the fish community with a single-vessel trawl. Despite measurements indicating that vessel noise levels increase during trawling (Chapman and Hawkins, 1969; Buerkle, 1977), only a few observations of trawling avoidance have been reported and most of these address problems associated with catching pelagic fish in commercial quantities (Sharfe, 1955; Okonski, 1969).

Since cod (*Gadus morhua*) and other demersal fish are very sensitive to low-frequency noise (Hawkins, 1973; Sand and Karlsen, 1986), they can discriminate and localize engine and propeller noise above the background noise level at distances greater than 2.0 km. Avoidance reactions should therefore be expected, especially when fish experience the highest vessel noise intensity during a trawling operation. This paper presents evidence for such avoidance behaviour in demersal fish and discusses the significance of this behaviour for trawl selectivity.

Materials and methods

Direct observations of fish behaviour were made using a stationary echo sounder on board a launch. Two portable echo-sounder systems have been used: the 70 kHz Simrad EY-M scientific sounder with a 20-degree (nominal) full-beamwidth transducer, and the 50 kHz Furuno FE-881, with a 12-degree (nominal) full-beamwidth transducer. The calibrated output and trigger signals from both sounders were recorded on a Nakamichi 550 portable tape recorder for subsequent analysis. Measurements were conducted with the transducer lowered to 5 m below the surface to avoid the wake of the fishing vessel.

During periods of observation the engine in the launch was turned off. For each experiment, the fishing vessel approached the launch at a specific speed from a distance of about 2.0 km, passing as close as possible to the launch, generally within 5 m, while allowing for safe clearance of the warps (Fig. 1).

A 60-m combined purse seiner/trawler was used as the source of vessel noise. The vessel's main engine developed 3400 hp at 600 rpm. During trawling operations at 1.5 m/s (3 knots), the engine was operated at 460 rpm and generated approximately 1000 hp.

To compare fish reactions under different noise conditions, the vessel was first operated without the net at trawling, 1.5 m/s (3 knots), and surveying, 4.6 m/s (9 knots), speeds. For the trawling experiments, two trawls were used: the Campelen 1800 bottom trawl and the 16×16 fathom square opening capelin trawl. Both nets are used to sample cod and haddock in the Northeast Arctic. Most observations were made on haddock with a mean length of 40 cm, s.d.=5.6 cm. A few experi-

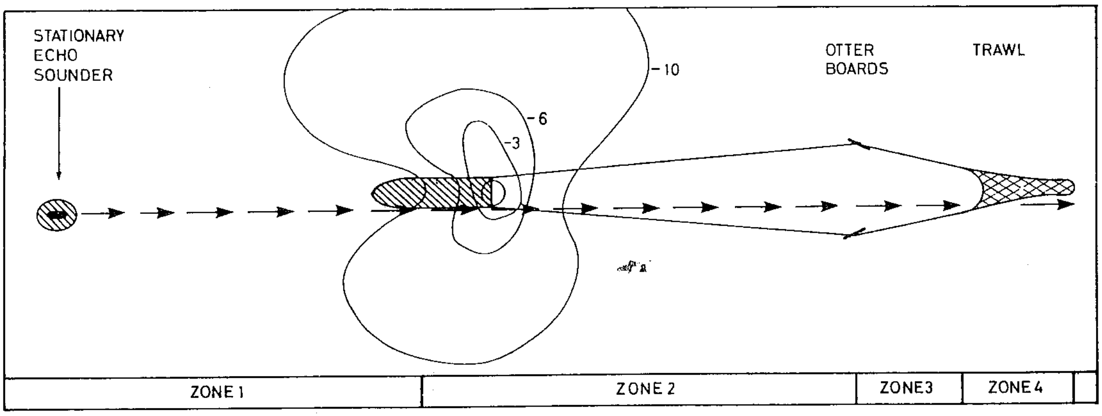

Figure 1. General set-up during passage of the stationary echo sounder with the referred selection zones indicated. Assumed –3, –6, and –10 dB contours of the propeller noise directivity pattern, measured 12 m below the vessel, are shown (from Urick, 1975).

ments were also made on a mixture of this haddock and cod of 8 to 35 cm.

Based on the observations made during the study, four zones were defined with respect to the approach and passage of the vessel and trawl (Fig. 1). These were: (1) the pre-vessel avoidance zone (the volume in front of the hull-mounted vessel transducer), (2) the propeller noise and warp avoidance zone (the volume between the acoustic axis of the vessel's transducer and the trawl doors), (3) the herding zone (the sweep volume from the trawl doors to the trawl), and (4) the mesh selection zone (the part of the trawl where the fish that have entered are subjected to mesh selection).

In addition to the general set-up for avoidance measurements as described, a statistical analysis of data from the 1985 and 1986 bottom-trawl surveys in the Barents Sea (Fig. 2), was made in order to evaluate the significance of pre-vessel avoidance. A systematically lower

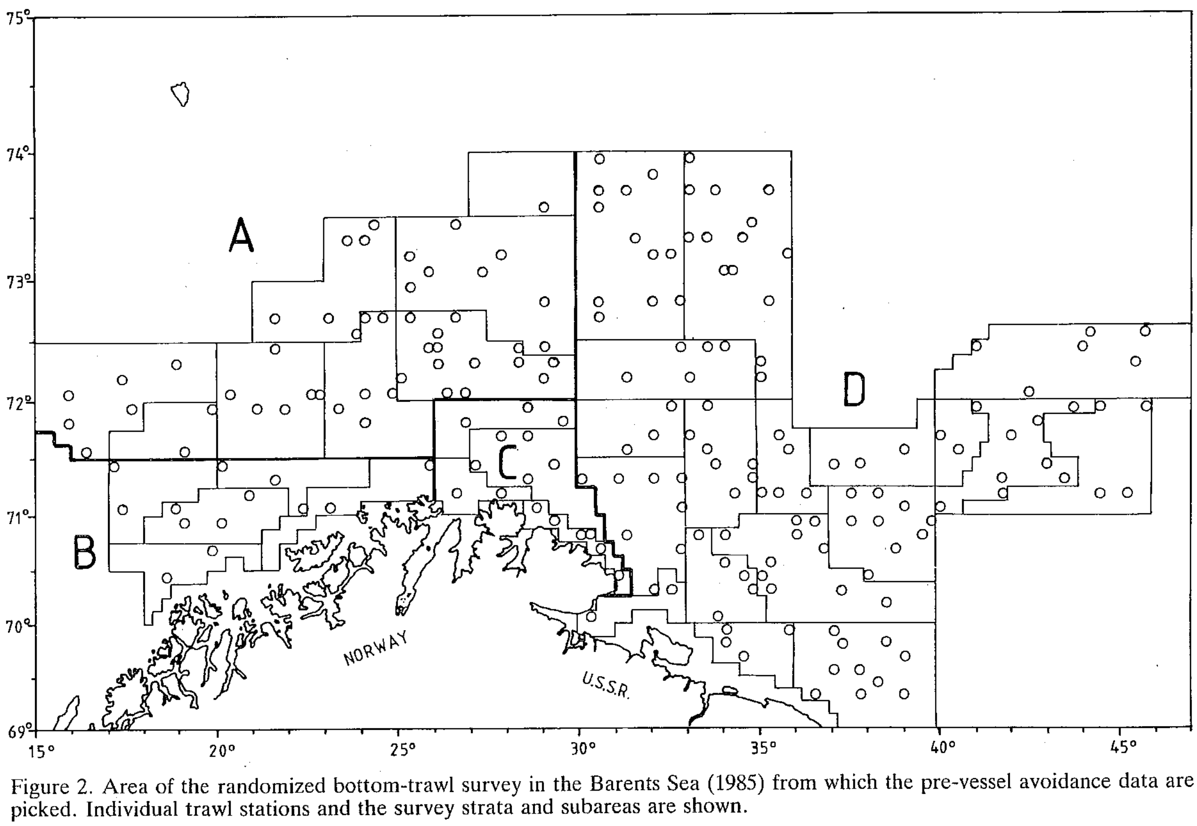

Figure 2. Area of the randomized bottom-trawl survey in the Barents Sea (1985) from which the pre-vessel avoidance data are picked. Individual trawl stations and the survey strata and subareas are shown.

acoustic abundance during the process of trawling, compared with the abundance when surveying at full speed in the area adjacent to the trawl station, is interpreted as pre-vessel avoidance when trawling.

From the randomized trawl survey for cod and haddock, echo-integrator data giving the average area backscattering coefficient over intervals of 9.3 km (5 nautical miles) were selected for particular trawl stations and neighbouring areas when the following criteria were met:

i. the trawl was towed in the survey steaming direction (not reversed trawling),
ii. the depth variations within the analysed five adjacent integrated cells of 9.3 km (5 nautical miles) were less than 10%.

The index to be tested is then simply:

$$I = S_A(t) / S_A(n).$$

$S_A(t)$ = average area backscattering coefficient, identified from the echogram as cod and haddock during the trawl haul.

$S_A(n)$ = average area backscattering coefficient in the four adjacent integrator cells, two before and two after the haul.

When no avoidance occurs in front of the vessel transducer, the probability of observing an index below and above $I=1$ should be equal, and a straight binomial test (Zar, 1974) can be used to establish the probability levels of the observed frequencies.

Results

Moderate avoidance reactions were observed when the vessel operated under low-noise conditions at 1.5 m/s (3 knots), without the net (Fig. 3), and slight avoidance reactions were observed during full survey speed (4.6 m/s, 9 knots) (Fig. 4). In the pre-vessel avoidance zone, minimal reactions were observed: the uppermost fish traces disappeared during the slower speed operation. At the time of propeller passage and through zone 2, a slight density reduction and general downward flux of fish was observed at the higher speed, while only a compression of the fish occurred in this zone at the lower speed.

During trawling, however, a slight reaction was seen even in the pre-vessel zone, and a substantial diving reaction occurred just after propeller passage (Fig. 5). The fish were also concentrated during the dive, with the fish in the upper layer escaping at a steeper angle than those deeper in the water. The original pattern of distribution was re-established by the time the vessel was 400 m away, after 4 or 5 minutes. Shallow night-time recordings of young haddock, as presented here, are typical near the east coast of Finmark. Classical patterns of vertical migration were not observed during this study (February–April 1986), but fish did aggregate during daytime.

Avoidance during bottom trawling in shallow water was also observed (Fig. 6). The fish in the upper layer were small cod and Norway pout (*Trisopterus esmarkii*), and the larger fish near the bottom were 40-cm haddock and a few larger cod. There was almost no avoidance in

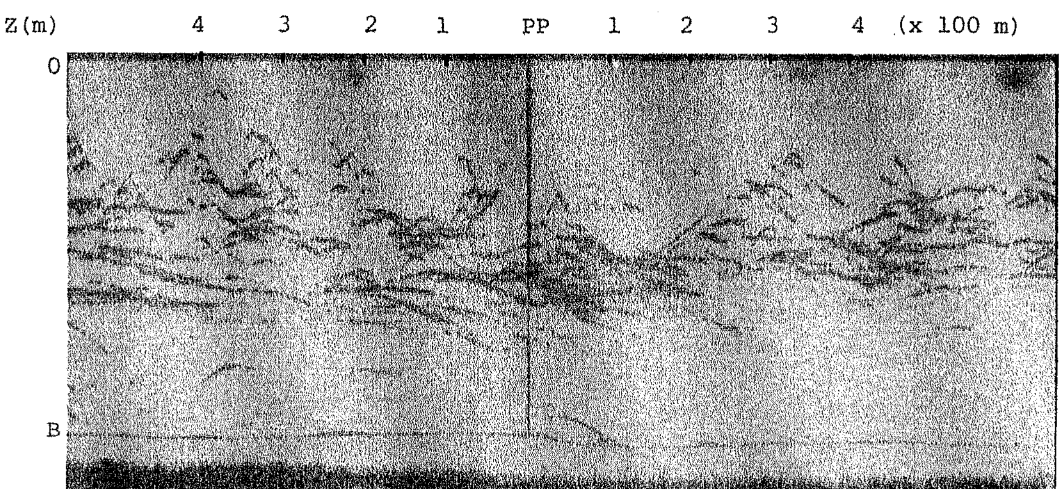

Figure 3. Moderate avoidance reaction when the vessel passes without a trawl at a speed of 3 knots. Approximate distance between the launch and the vessel is indicated above. PP – propeller passage.

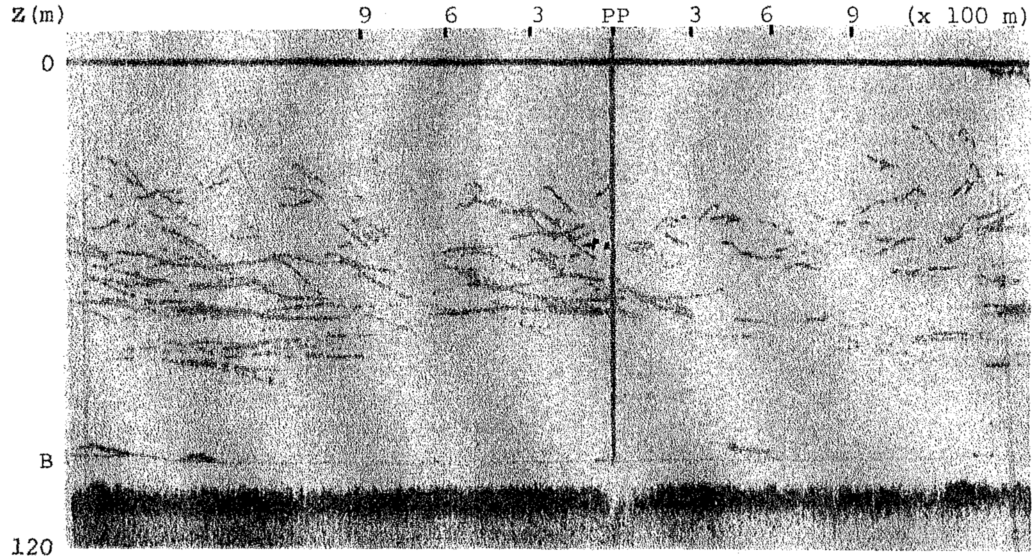

Figure 4. Slight reaction when the vessel passes at surveying speed, 9 knots. PP – propeller passage.

the pre-vessel zone by fish in the bottom layer, but a marked diving and compression effect was observed during passage of the propeller, the trawl warps, and doors. Note that there were no fish above or in front of the trawl as the mouth of the net passed by. The weak trace just above the headline was caused by interference from the net sonde sonar unit. The pattern of behaviour illustrated in Figure 6 indicates that horizontal and vertical movements occurred. If practical considerations had permitted us to locate the stationary transducer directly in the central path of the trawl, more precise observations in the herding zone might have been possible. The original pattern of fish distribution appears to have been restored within six to seven minutes of passage by the trawl.

The patterns of behaviour described above were not as clearly evident in all of the 16 experiments conducted. At several of the deeper stations a weak pattern

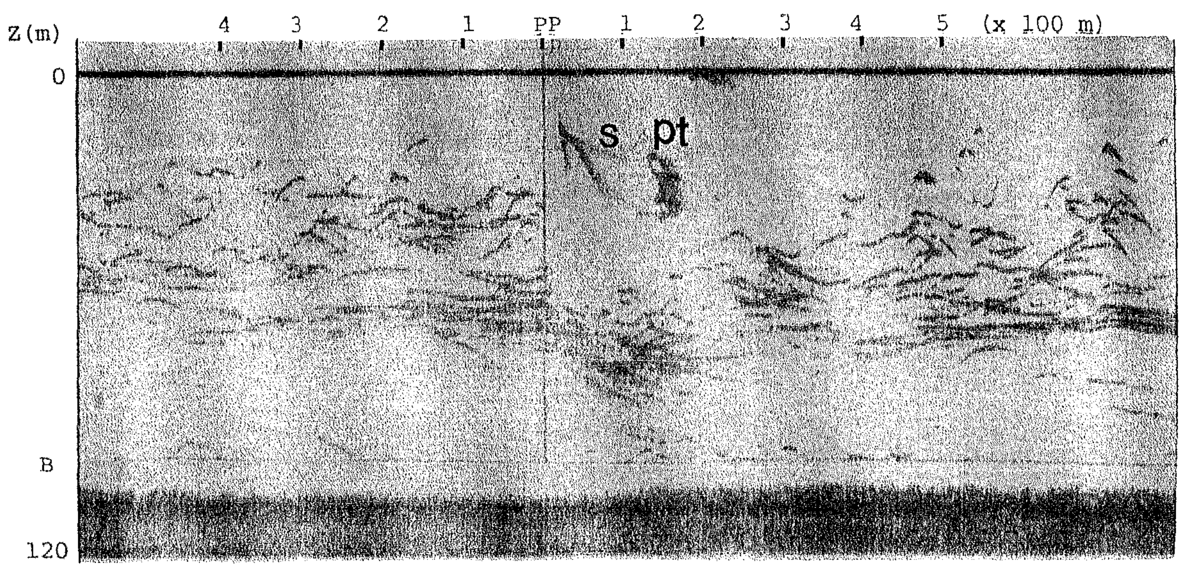

Figure 5. Strong vertical avoidance during trawling. Note the sudden response to the propeller noise. Distance between the launch and the vessel and the different parts of the trawl appearing on the echogram are indicated above. PP – propeller passage, s – sweeps, pt – pelagic trawl.

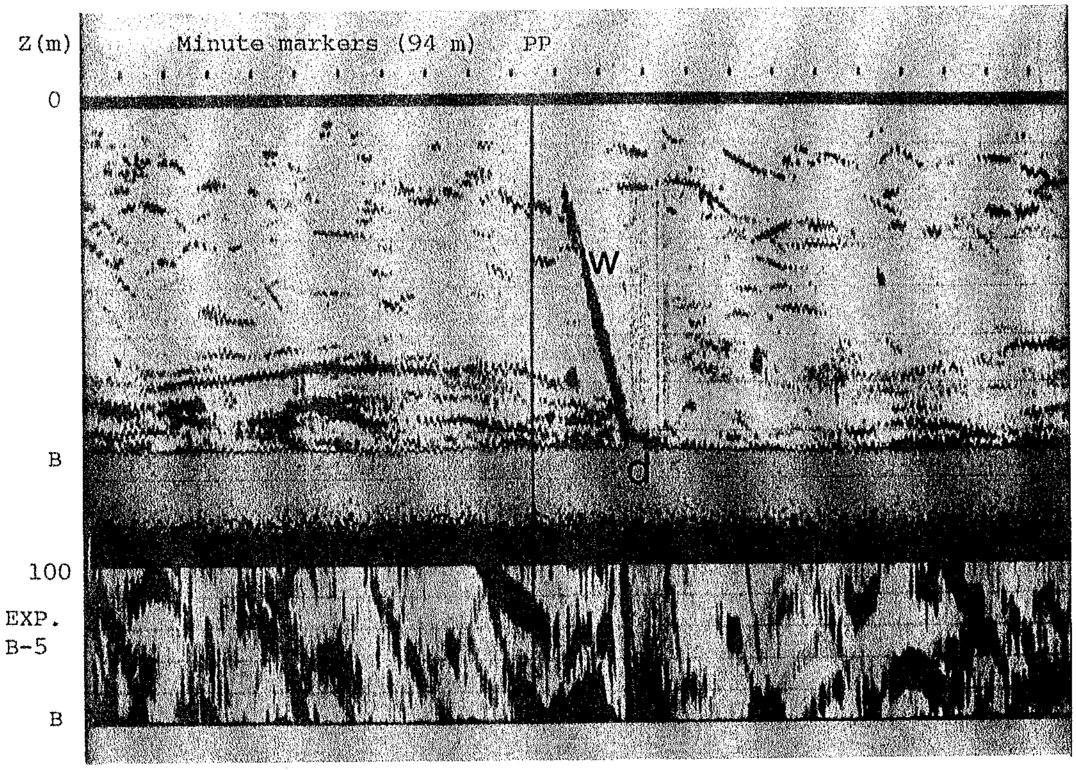

Figure 6. Significant reaction during bottom trawling at 75-m depth, with downward movement of fish from the point of propeller passage towards the trawl doors. d – trawl door, PP – propeller passage, w – warp wire.

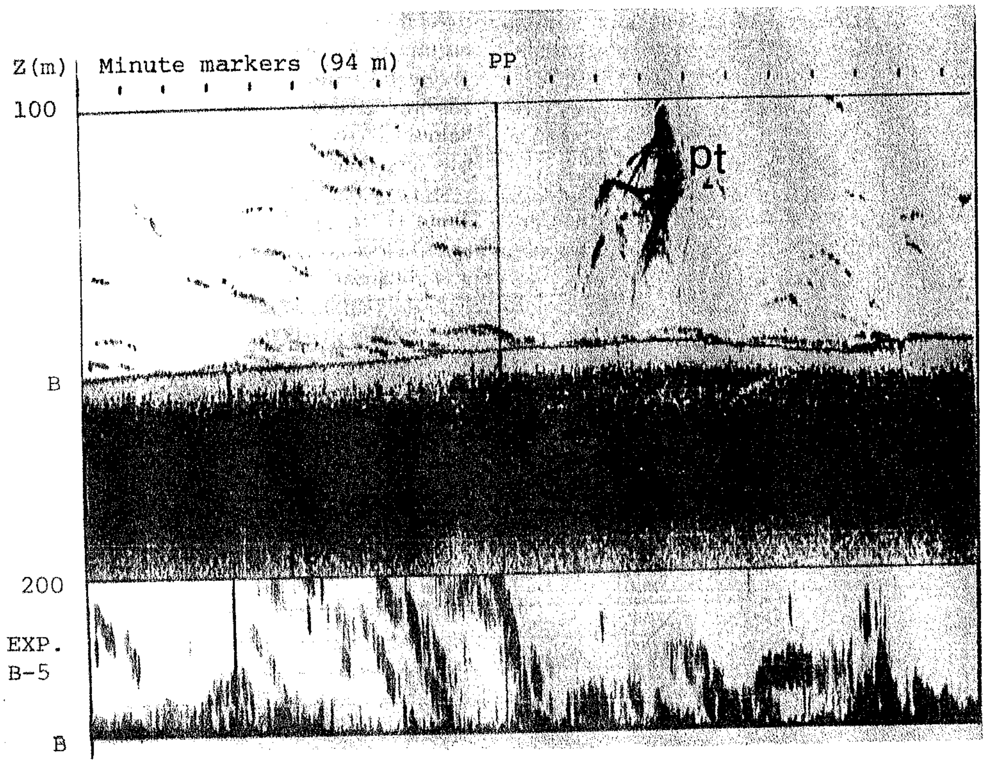

Figure 7. Fish pressing down below the pelagic trawl at 130-m depth. Note the swimming pattern in the expanded display. Phased recording, 100–200 m, is shown. pt – pelagic trawl, PP – propeller passage.

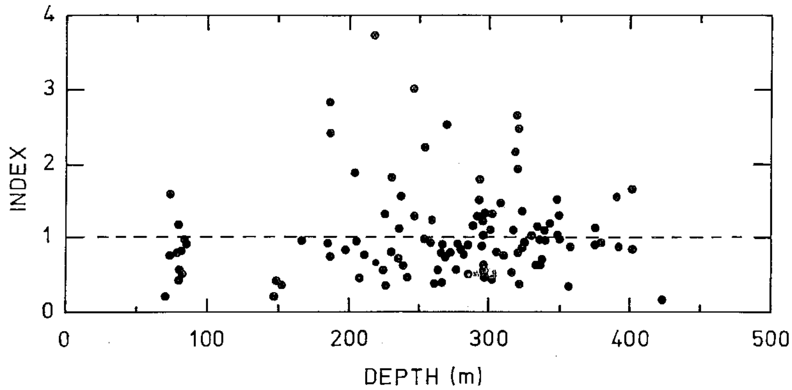

Figure 8. Pre-vessel avoidance index from standard bottom-trawl stations as a function of depth.

of descent was observed before the vessel arrived, persisting during passage of the vessel. Figure 7 illustrates an example of a weak reaction, with fish moving close to the bottom, avoiding the pelagic trawl at 140 m. Note the swimming pattern in the bottom 5 m of the water column in the expanded display.

Discussion

These observations clearly indicate that noise produced by a fishing vessel causes fish behaviour that influences the efficiency and selectivity of pelagic and bottom trawls. Since swimming capabilities vary substantially among individuals and size groups of a given species of fish (Blaxter, 1969; Wardle, 1975, 1977), selectivity is of major concern when horizontal and vertical avoidance occurs, especially in shallow water.

With the evidence for long-range detection (Buerkle, 1977; Sand and Karlsen, 1986) and directional hearing (Schuijf, 1975) among gadoids, pre-vessel avoidance was expected to be even greater than actually observed during this study. This work supports the suggestion that the principal stimulus for an avoidance reaction is the rate of change of sound pressure rather than the sound pressure level.

Analysis of the components of trawling noise indicates that the dominant element is caused by propeller cavitation (Urick, 1975; Buerkle, 1977). Cavitation noise is pulsed by the beats of the propeller blades and is also directional (Pomeranz and Swanson, 1945). The expected directivity pattern of propeller noise during the trawling experiments is indicated in Figure 1.

The sudden response observed when the vessel passed was probably due to the extreme noise gradient experienced when the fish entered the "main lobe" of the propeller noise. In shallow waters, noise intensity increases by a factor of 100 at this transition. This is comparable to the supersonic boom caused by an aircraft exceeding the speed of sound. Abeam of the vessel, horizontal escapement of fish is to be expected because the noise lobes are transversely directed. During pair trawling, directional propeller noise will tend to move the fish into the path of the trawl; this helps to explain the higher catch rates observed with this type of gear.

Pre-vessel avoidance during trawling influences the density of fish available to the net and the apparent density observed with acoustic instruments. Consequently, evaluation of trawl efficiency must take into account how far fish swim away from the path of the vessel. If this distance is relatively small, it may be partially compensated for by the herding effect of the trawl doors. In the statistical analysis of the randomized bottom-trawl data, a significant depth dependence in pre-vessel avoidance was found. At stations deeper than 200 m, there was no significant trend for values of I below 1.0 ($p=0.38$). For shallower stations, however, I was less than 1.0 for 21 out of 25 observations. Pre-vessel avoidance was significant at these depths (Fig. 8, Table 1). At shallow stations, fish were more concentrated close to the bottom, and a reduction in density was apparent in all echo-integrator depth channels. A typical example of such a density reduction before vessel arrival is illustrated in Figure 9. A pelagic trawl was towed through a fairly dense aggregation of fish close to the bottom; a general horizontal movement of fish oc-

Table 1. Statistics related to the observations of pre-vessel avoidance. Mean avoidance index = 1.06, s.e. = 0.06. Binomial probability when p = 0.5 is indicated as P.

Depth (m)	I<1	I>1	P
0–100	11	2	0.027
100–200	10	2	0.044
200–300	34	28	>0.5
300–400	23	20	>0.5
400–500	3	1	0.375
0–200	21	4	0.0004
200–500	60	49	0.380

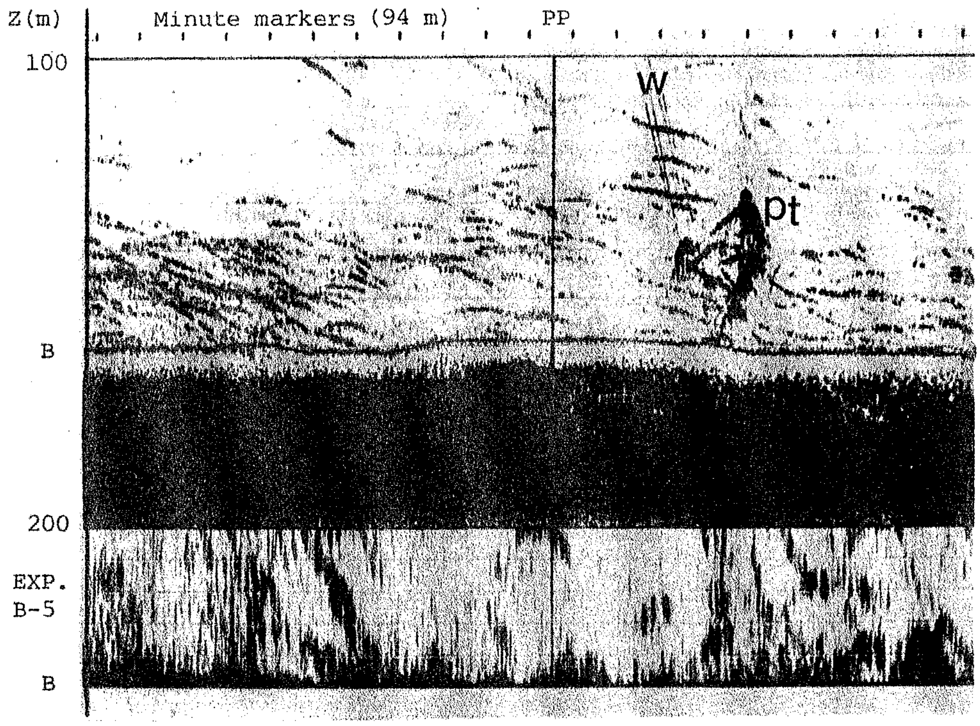

Figure 9. Distinct pre-vessel avoidance from 300 m before vessel arrival, lasting throughout the passage. Phased recording, 100–200 m, is shown. PP – propeller passage, pt – pelagic trawl, w – warp wire.

curred 200 m in front of the vessel, reducing the density of fish available both for the acoustic system on board the trawler, and the trawl itself.

Conclusions

(a) Vessel noise during trawling can cause avoidance reactions in demersal fish.

(b) Propeller cavitation is the primary source of the noise that causes horizontal and vertical movement of fish in front of the trawl.

(c) Pre-vessel avoidance during trawling was observed at depths shallower than 200 m. No such avoidance was observed at depths from 200 to 500 m.

(d) The observed escapement will reduce the availability of fish to pelagic trawls but may increase availability to demersal trawls if horizontal avoidance is moderate.

(e) Vessel avoidance at the levels observed during this study will influence trawl selectivity to a substantial degree, especially in situations where a mix of species and size classes with different swimming capacity and behaviour are being sampled.

References

Ben Tuvia, A., and Dickson, W. (Eds.). Proceedings of the FAO Conference on Fish Behaviour in Relation to Fishing Techniques and Tactics. Bergen, Norway, 19–27 October 1967. FAO Fish. Rep., 62(1,2,3): 884 pp.

Blaxter, J. H. S. 1969. Swimming speeds of fish. FAO Fish. Rep., 62(2): 69–100.

Buerkle, U. 1977. Detection of trawling noise by Atlantic cod (*Gadus morhua* L.). Mar. behav. Physiol., 4(3): 233–242.

Chapman, C. J., and Hawkins, A. A. 1969. The importance of sound in fish behaviour in relation to capture by trawls. FAO Fish. Rep., 62(3): 717–719.

Hawkins, A. D. 1973. The sensitivity of fish to sounds. Oceanography and mar. Biol. ann. Rev., 11: 291–340.

Okonski, S. 1969. Echosounding observations of fish behaviour in the proximity of the trawl. FAO Fish. Rep., 62(2): 377–388.

Olsen, K. 1969. A comparison of acoustic threshold in cod with recordings of ship noise. FAO Fish. Rep., 62(2): 431–438.

Olsen, K. 1971. Influence of vessel noise on behaviour of herring. *In* Modern fishing gear of the world, 3: 291–294. Ed. by H. Kristjonsson. Fishing News Books Ltd., for FAO.

Olsen, K. 1979. Observed avoidance behaviour in herring in relation to passage of an echo survey vessel. ICES CM 1979/B: 18: 1–21.

Olsen, K. 1980. Echo surveying and fish behaviour. Fish Reaction Working Group, Reykjavik, May 1980: 1–20.

Olsen, K., Angell, J., and Løvik, A. 1982a. Quantitative estimation of the influence of fish behaviour on acoustically determined fish abundance. FAO Fish. Rep., 300: 139–149.

Olsen, K., Angell, J., Pettersen, F., and Løvik, A. 1982b. Observed fish reaction to a surveying vessel with special

reference to herring, cod, capelin and polar cod. FAO Fish. Rep., 300: 131–138.
Pomerantz, J., and Swanson, G. F. 1945. Underwater pressure fields of small naval vessels in the 2–17 and 7–35 cps bands at the Puget Sound acoustic ranges. U.S. Nav. Ord. Lab. Rep., 1022.
Sand, O., and Karlsen, H. E. 1986. Detection of infrasound by the Atlantic cod. J. exp. Biol., 125: 197–204.
Schuijf, A. 1975. Directional hearing of cod (*Gadus morhua*) under appropriate free field conditions. J. comp. Physiol., 98: 307–332.
Sharfe, J. 1955. Observation with echosounding the behaviour of a herring shoal towards a bottom trawl. ICES CM 1955/ No. 42.
Urick, R. J. 1975. Principles of underwater sound for engineers. 2nd ed. McGraw Hill, New York. 384 pp.
Wardle, C. S. 1975. Limits of fish swimming speed. Nature, Lond., 225: 725–727.
Wardle, C. S. 1977. Effects of size on swimming speeds of fish. *In* Scale effects in animal locomotion, pp. 299–313. Ed. by Academic Press, New York.
Wardle, C. S. 1984. Fish behaviour. Trawl efficiency and energy saving strategies. FIIT Working Paper. FAO, Fishing Technology Service, Rome, September 1984. 42 pp.
Wardle, C. S. 1986. Fish behaviour and fishing gear. *In* The behaviour of teleost fishes, pp. 463–495. Ed. by T. J. Pitcher. Croome Helm, London.
Zar, J. H. 1974. Biostatistical analysis. Prentice-Hall, New York. 620 pp.