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Extensive gas bubble release in Norwegian spring spawning herring (*Clupea harengus*) during predator avoidance

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Abstract

Events of extensive gas bubble releases in overwintering Norwegian spring spawning herring (*Clupea harengus*) were repeatedly observed acoustically and visually in Vestfjorden, northern Norway, during attacks from killer whales (*Orcinus orca*) and saithe (*Pollachius virens*). Gas bubble production was so extensive that large areas of the sea surface were sometimes covered with white foam after an event. Gas bubbles were visually observed to come from the swimbladder of individual herring swimming very close to the surface. Acoustically, gas bubbles could be identified on the echosounder as strong echoes covering the upper 0-30 m of the water column. Schools of herring were forced from 30-100 m depth up to the surface by predatory killer whales and saithe. I suggest that herring expel gas near the surface as a concequence of the rapid change in depth, and that gas bubble release may confuse and deflect both visually and acoustically oriented predators due to increased scattering of light, reduced range of vision, and confusing effects of the reflection energy of the bubbles and the fish. Such events may have considerable effect on the target strength and estimated stock sizes during acoustic surveys.

Key words: gas bubbles, herring, killer whales, target strength, saithe

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Introduction

Pacific herring *(Clupea pallasi)* have been observed to release gas bubbles during diel vertical migration (Thorne and Thomas, 1990). Also, gas bubble release has been reported in herring (*Clupea harengus*) in the Baltic in response to midwater trawling (Suuronen *et al.*, 1997). Although fishermen along the coast of Norway have seen this feature in Norwegian spring spawning herring (*Clupea harengus*) and even use the word 'mesking' for this type of behaviour, documentation has so far been limited for this stock.

Clupeoids are physostomous fish with an open swimbladder, i.e. have a pneumatic duct leading from the posterior end of the stomach to the swimbladder in addition to an anal duct from the swimbladder to the vent (Blaxter *et al.*, 1979). The lack of a buoyancy function is presumably linked to the advantages of making rapid vertical movements in response to predators (Blaxter, 1985). The hydrostatic function of the gas bladder is limited to the near-surface in clupeoids according to Blaxter and Hunter (1982). Herring may swallow air at the surface and pass it into the swimbladder via the pneumatic duct (Brawn, 1962; Blaxter and Batty, 1984). The volume of gas in the swimbladder is likely to vary in response to the changes in ambient pressure (depth) according to Boyle's law (Ona, 1984; 1990). Laboratory studies by Blaxter and Batty (1984) indicate that herring may not be able to secrete gas into the swimbladder like physoclist fish and may always be negatively buoyant (Brawn 1962; Blaxter and Batty, 1984; Ona, 1984; 1990).

Overwintering Norwegian spring spawning herring in northern Norway make diel vertical migrations between 400 m depth during daytime up to 50 m depth at night (Huse and Ona, 1996). During this period they hardly eat (Slotte, 1996) and stay normally in deep schools or dense layers during daytime presumably to avoid visually oriented predators (Huse and Ona, 1996). Despite the fact that herring prefer to stay in deep waters during daytime, predators are capable of herding schools of herring into dense balls (Similä and Ugarte, 1993; Similä *et al.*, 1996) and forcing them into shallower areas and sometimes all the way to the surface (Similä and Ugarte, 1993). During such events the release of bubbles has been noticed. Inshore, their main predators are killer whales (*Orcinus orca*), saithe (*Pollachius virens*) and cod (*Gadus morhua*) (Huse and Ona, 1996; Similä 1997).

The aim of this study was to collect direct observations on gas bubble production in herring and to reveal the physiological and behavioural significance and implications of this behaviour. Alternative hypothesis to existing theory are presented.

Material and Methods

Herring schools in Vestfjorden, Ofotfjorden and Tysfjorden were observed acoustically by the 16 m long (20 BRT) R/V "Fjordfangst" during daytime (07:00 -

18:00) in the period 7-20 November. Due to its small size, the vessel is very convenient to study herring school dynamics within the Vestfjorden system.

The research vessel was equipped with a FURUNO CH-12 multibeam sonar (150 kHz) and a PC based SIMRAD EY-500 echosounder (38 kHz) connected to an echo-integrator. The echosounder has similar functions to the SIMRAD EK-500 with the Bergen Echo Integrator system (Knutsen, 1990). Instruments were calibrated according to the standard target method (Foote *et al.*, 1987). Echosounder signal were printed and ping-to-ping data were regularly stored on optical disk. Herring schools were first recorded on the sonar, and lengthwise and crosswise extent (Misund, 1990) of the school projection were measured by a ruler directly on the monitor screen. School area, vertical extent, school volume, transect length, fish density and school biomass were calculated using equations from Johannesson and Losse (1977) and Misund (1990; 1991; 1993).

Calculations were corrected for beam width and pulse length (Misund, 1993). Horizontal dimensions were corrected by taking into account the school depth and the nominal beam angle of the transducer (McLennan and Simmonds, 1992).

The sonar which is commenly used in commercial fisheries may operate as an omni-sonar sending and receiving acoustic signals from 360°, although ping interval is then quite low. We applied a 90° sector width during operation. The vessel passed over the school with an average speed of 5 knots and the echosounder with echo-integrator recorded vertical extension and depth of the school. To record the behaviour and dynamics of a herring school an attampt was made to position the vessel directly above it during behavioural recordings, using the presence and location of gas bubbles, predators (sea birds, killer whales) and of stunned and dead herring as guidance. During daytime visual observations were made by several persons. The behaviour of individual herring at the surface was also noted in the daytime. Vessel avoidance, where natural fish behaviour may be influenced by the presence of a research ship, i.e. sudden change in swimming speed or direction, was not observed in this study (see Olsen 1979). The engine was always put in neutral position during predator-prey interactions as long as the ship were situated above the school. While the observations were made the estimated horizontal movement of the schools was less than 50 m according to the Global Positioning System.

Target strength (TS) were used to distinguish a school from bottom signals and between herring, saithe and killer whales. Echo intensity of the gas bubbles and their contribution from the gas bubbles were calculated by echo-integrating those areas or water layers with extensive gas bubble release, where no herring were present.

Target strength (TS) of herring from fish length (L) was calculated as $TS_{clupeoid} = 20 \log L - 71.9$ after Foote (1987), based on sub-samples from 400 individuals of herring taken from commercial purse seine catches in the same area. Stunned and dead herring near the surface were caught with a landing net. Also, predatory fish were caught when herring were under attack, by using five different baits attached on a 1.0 mm fishing line. Catches consisted entirely of saithe. Length and weight were measured and stomach samples from both herring and saithe were analysed.

Detailed information was collected on some of the schooling events taking place close to surface by day. It was possible to track the school visually by spotting the wake of frightened herring being herded in schools of considerable size.

Results

Three case studies of rapid vertical migration followed by gas bubble release are reported here (figure 1a-c). School A (figure 1a) is placed very densely close to the bottom at 65 to 80 m depth, up to 30 m depth. The bottom is irregular but can easily be distinguished from the school on the echogram. The herring school were attacked by both six killer whales and a shoal of saithe. Gas bubbles are shown in figure 1a from the surface down to 30 m depth with medium density. The school had dived to deeper waters from approximately 10 m down to 40 m after predator attack.

School B (figure 1b) is inseperable from the bottom at 50 m depth and extends up to 27 m depth. Air bubbles are seen as quite strong acoustic signals from the upper left corner at the surface, down to a more scattered and distributed layer at 25 m depth. This situation was recorded when the school had just dived from the surface layers. It was not possible to determine the shoal size and density of saithe. The saithe were too mixed with the herring.

School C was observed at the surface down to approximately 80 m during a predator-prey interaction with a shoal of saithe and eight killer whales (figure 1c). The latter are visible as elongated, strong echoes of variable density encircling the school. Measurements of high density of some visible tracks in combination with parallel visual observation provided an opportunity to test the acoustic signals from killer whales qualitatively. After some experience, they are quite easy to distinguish from other echoes in the water column, because they are large (3-6 m) and killer whales have lungs which reflect very strong echoes. The bottom at 110 m depth was relatively flat. However, at the surface it is more difficult to distinguish herring from gas bubbles. Gas bubbles are seen from 0-10 m. The echogram was taken simultaneously with the photograph of the foam at the surface (figure 2). Some minutes later the school dived to deep water. The killer whales appearently stopped feeding and moved off at high speed.

A common feature of the results is that all schools appears to have been under predator attack either from pods of killer whales and/or shoals of Atlantic saithe. Hundreds of herring were seen releasing gas bubbles close to surface only a few metres from the research vessel. Highly visible foam (figure 2) covered some 50 m^2 of the water surface around the ship. Although not examined chemically, the origin was most probably accumulated gas bubbles released from herring near the surface with a possibly addition of some gas release by attacking killer whales. The predator-prey interactions attracted hundreds of sea gulls such as herring gulls (*Larus fuscus*), common gulls (*Larus canus*), great black back gulls (*Larus marinus*) and lesser black-backed gulls (*Larus argentatus*) and some adult white tailed eagles (*Haliaeetus albicilla*). Stomach samples from saithe (n = 68) showed that 85% of the individuals had recently been eating one or more herring confirming that predator-prey interactions were actually taking place. Herring caught from the observed schools (n = 24) and herring (n = 400) sub-sampled from commercial catches had no prey in their stomachs, confirming that their behaviour was not affected by feeding. Extensive analysis of stomach analysis have previously shown that herring hardly eat during the winter (Slotte 1996), The main prey for herring, *Calanus finmarchicus*, winter at great depths, thus being unavailable for herring. During all three events, gas bubbles in the surface waters were seen from the ship, although with various intensity. Although herring were seen under the surface, there was no evidence of gulping air from the surface. Stunned and dead herring were floating at the surface, and some herring had bite marks that appears to be consistant with the distance between teeth in adult killer whales, suggesting that killer whales were actually chasing herring.

Table 1 provides relevant data on herring school dimension, biomass and gas bubble release. Although average herring densities were not particularly high, densities up to 20-30 fish m^{-3} were measured in some parts of the schools.

Discussion

The study confirmed that on particular occations extensive gas bubbles may be released by herring and the available evidence suggests that this behaviour is strongly related to predator-prey interactions. Thorne and Thomas (1990) put forward two alternative hypotheses to explain the source of the gas, since herring are considered not to have the physiological mechanisms to secrete gas (Brawn, 1962; Blaxter and Batty, 1984; Ona, 1984; 1990). A first hypothesis was that gas is formed during fermentation in the gut, while a second possibility is that herring may gulp air at the surface prior to descent. Neither of these hypotheses is supported by the present observations. Since herring do not feed during the overwintering period (Dommasnes *et al.*, 1994; Huse and Ona, 1996; Slotte, 1996), fermentation in the gut can be rejected as a possible explanation in this study, and visual observations did not indicate that herring came right up to the surface to gulp air, even though herring swallowing air at the surface have been observed in laboratory experiments (Blaxter and Batty, 1984). The fish stay normally deep (> 50 - 100m) during at least some time of the overwintering period (Huse and Ona, 1996), which would provide little opportunity to exchange gas at the surface. Moreover, such behaviour would cause serious risk because of predation by the numerous seabirds in the area.

An alternative hypothesis must be put forward to explain the observations in Norwegian spring spawning herring. I suggest that herring may be able to secrete gas from the blood system into the swimbladder. Although gas for physostome swimbladder inflation or deflation is generally considered to be insignificant (Moyle and Cech, 1988), the situation may be different during rapid upward swimming when an overpressure of gas in the blood may be formed.

Saithe are members of the gadoid family and are therefore as physoclists (Gunderson 1993) not able to release gas. Therefore, they cannot be held responsible for the gas bubble production observed during this study. Still, a fraction of the gas bubbles may have come from killer whales releasing gas from their blowhole. However, the type of gas bubbles produced by killer whales are very different from those coming from herring (Similä and Ugarte, 1993) and can easily be confirmed. Killer whales produce large bubbles with low frequency. Bubbles produced by herring are small (< 1 cm) and they may be released more or less continously as long as individuals in the school may have some gas left in the swimbladder. Since each school was tracked for an extended period of time (25, 32 and 39 min, for schools A, B and C respectively), it seems most likely that the herring schools were forced by predators from deeper areas near the bottom to surface waters, where they expelled the gas, followed by a rapid downward escape.

Rapid downward swimming appears to be a commen and efficient anti-predator reaction in herring schools (Blaxter, 1985). In addition, an active release of gas bubbles may effectively contribute to predator avoidance by scattering the light and thereby reduce the visible range of predators especially near the surface during daytime when light conditions are good. Marine mammals use gas bubbles to increase their hunting efficiency on various schooling fish species (Sharpe and Dill, 1997). However, the results obtained here indicate that pelagic physostomous species may use gas bubbles in the opposite way as part of a tactical anti-predator repertoire. It has been suggested that gas bubbles may also confuse the biological sonar of killer whales (Barrett-Lennard *et al.*, 1997) by dispersion and scattering of the sound.

There were no opportunities to examine stomach samples from killer whales, and we did not obtain direct observations of killer whales actually catching fish. However, herring represent the main prey for the killer whale population in northern Norway and they follow the herring stock all year around (Similä *et al.*, 1996). Therefore it seems likely that they were mainly feeding on herring also during our study, even though saithe may also have been eaten. Density of fish in schools is around one fish per cube of body length (Pitcher and Partridge 1979; Misund 1991). The high density values on adult herring in our study indicate that the herring were under predator attack.

The dimensions of the herring schools attacked suggest that only relatively small sized (4.5 - 18 tonnes) and dense (2.6 - 5.2 ind*m^{-3}) schools in shallow water (50 - 110 m) were pursued. Most herring appears to stay in the deep layers covering huge areas up to several kilometers during overwintering (Vabø and Nøttestad 1997), and the bottom depth within most of the Vestfjorden system which ranges mostly between 300 down to 900 m depth (Røttingen *et al.*, 1994). Thus, it would seem that only a relative small component of the stock suffers from predator attacks.

If herring are able to expel gas over short time intervals then abrupt changes in target strength might be expected. Due to the low specific acoustic impedance of gas compared to fish flesh and bones, the swimbladder is the primary organ responsible for the reflected energy from a fish (Foote, 1980; 1985; Furusawa, 1988) Therefore, any change in its size should affect target strength. Moreover, rapid vertical swimming has a significant effect on the tilt angle, thus reducing the dorsal aspect target strength of the recorded fish (Huse and Ona, 1996). Since acoustic population estimates of herring are made in these wintering areas, ecological interactions as shown in this study may affect in situ acoustic measurements, and should be taken into account during the surveys.

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Figure legends:

Figure 1a.

Echogram taken 15 November 1997 at 11:29 UTC (68°23'27''N, 15°58'65''E) showing herring school, predators (saithe) and gas bubble concentrations from approximately 5 m down to 30 m depth.

Figure 1b.

Echogram taken 17 November 1996 at 10:32 UTC (68°22'11''N, 15°51'01''E) showing herring school, predators (saithe), and gas bubble concentrations close to the surface down to approximately 25 m depth. Note that surface line is drawn as a thick line at the top (SURFACE). The line below indicate start of the echo-integration process. Integration value by layer is indicated on the right side of the echogram, water depth on the left hand side.

Figure 1c.

Echogram taken 17 November 1997 at 13:48 UTC (68°22'05''N, 15°48'40''E) showing herring school, predators (killer whales) and gas bubble concentrations visible at the surface (see figure 2) and down to approximately 10 m depth. Note that gas bubbles and herring are inseperable in some regions. Herring is so high that registrations in the lower region (>80 m) probably represent false echoes. The echosounder had difficulties in detecting the bottom below part of the school.

Figure 2

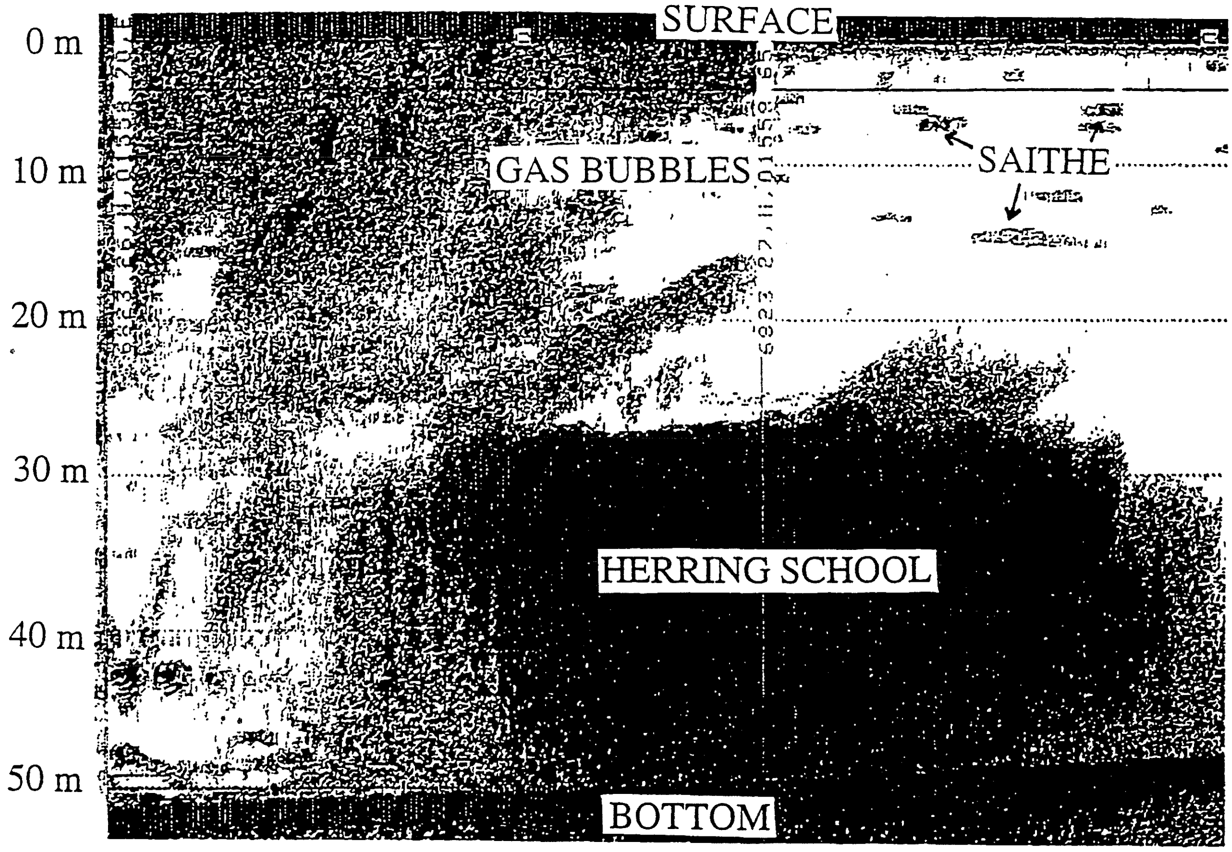
Photograph showing foam at the surface caused by massive gas bubble release from herring, covering an area of up to 50 m^2.

Table legends

Estimated dimensions and other characteristics of three schools of herring reported. Note that vertical swimming distance is measured according to the centre of mass.

Table 1

School number	A	B	C
Density (N/m^3)	2.6	5.2	3.1
Biomass (tonnes)	4.3	23	18.6
Height of school (m)	23	58	44
Vert. swim. dist. (m)	10-40	25-60	30-70
Gas bubble depth (m)	0-20	5-30	0-10
Bottom depth (m)	50	65-90	110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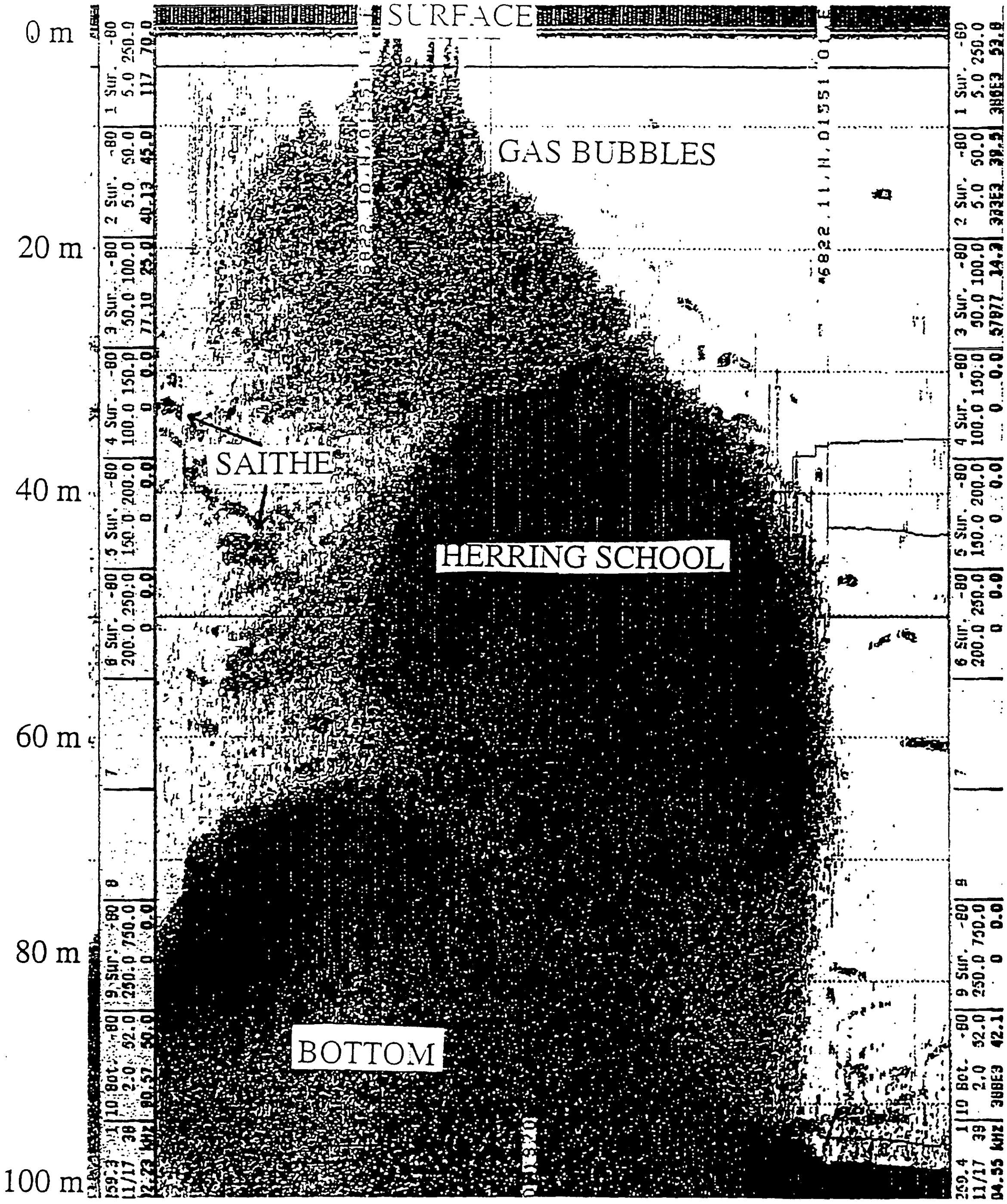
30 m
HERRING SCHOOL
40 m
50 m
BOTTOM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SAITHE
HERRING SCHOOL
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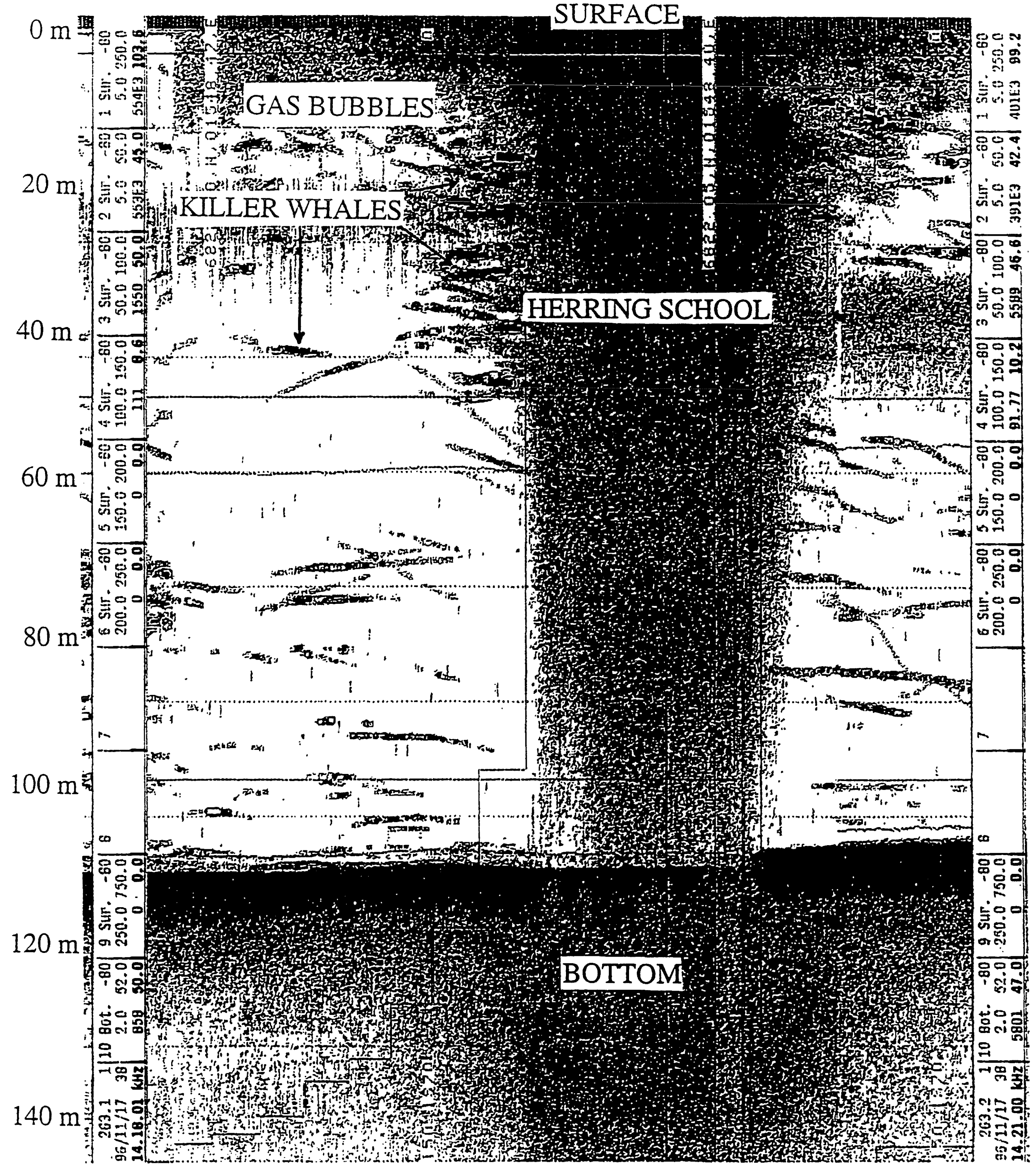
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100 m
120 m
140 m
SURFACE
GAS BUBBLES
KILLER WHALES
HERRING SCHOOL
BOTTOM