

Fish are attracted to vessels

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Fish rapidly accumulated below research vessels (RVs) at anchor, kept stationary by dynamic satellite positioning, or freely drifting. This happened by day and night, beneath vessels with different noise levels, in fjords and the open ocean, comprised different species assemblages of fish, and spanned depths of several hundred metres. Acoustic backscatter (fish abundance) increased by more than an order of magnitude in less than an hour. One of the study sites was characterized by much ship traffic, and intermittent, strong decreases in the local fish aggregation beneath the RV were caused by fish swimming towards passing commercial vessels, before returning to the stationary RV. The study suggests more complex relationships between fish, vessels, and noise than previously anticipated. If fish are commonly attracted to vessels, this has implications for fish abundance estimates and basic ecological research.

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Introduction

It is widely believed that fish avoid steaming research vessels (RVs) because of the noise they make. Such behaviour will bias abundance estimates (Mitson, 1995; Vabø *et al.*, 2002; Mitson and Knudsen, 2003), and extensive measures are now taken to lessen ship noise (Mitson, 1995; Fernandes *et al.*, 2000a, b). On the contrary, fish are attracted to floating objects, and this has been exploited by use of so-called fish aggregation devices (FADs; e.g. Castro *et al.*, 2001). While the avoidance responses of fish to steaming RVs have received much attention, the possible functioning of stationary or slow-moving RVs as FADs has to our knowledge not been addressed.

This investigation was originally initiated to study ship avoidance, because we invariably observed that fish abundance decreased dramatically beneath our RV during the passages of commercial vessels at a study site in Oslofjord, Norway. Such observations of reduced fish abundance corresponded to reports from experiments carried out to assess fish avoidance from RVs passing a reference site, often a buoy with acoustic equipment (Olsen *et al.*, 1983; Vabø *et al.*, 2002). However, the initial results compelled us to change focus because it became evident that fish were

attracted to our vessel, so that fish abundance beneath the RV (our “reference site”) appeared to be artificially high in periods between ship passages, rather than, or as well as, artificially low during ship passages (Onsrud *et al.*, 2004).

If fish are commonly attracted to vessels, this has implications for both management and basic ecological research. In changing the scope of the study from avoidance to attraction, we included additional study sites and vessels. Here we report that fish became attracted to vessels at different noise levels, in various habitats comprising different species assemblages, and we estimate the rates and magnitude of the accumulation.

Material and methods

We studied the effect exerted on the fish fauna by (i) a research vessel (RV) at anchor, (ii) passing commercial vessels, (iii) an RV kept stationary using automatic satellite navigation (dynamic positioning; DP), and (iv) a freely drifting RV. Three RVs were used at three locations; records spanned different periods of the year (Table 1) and involved different species compositions of fish. Acoustic records were obtained by SIMRAD EK500 and EK60,

Table 1. Dates, research vessels, locations, and acoustic set-ups used during the study.

Date	Research vessel	Location	Ship positioning	Echosounder	Transducers	Transducer configuration
20 February 2003	“Trygve Braarud”	Oslofjord	Anchored	SIMRAD EK60 and EK500	ES120–7 (7°)	Hull
06 November 2003		(59°08'N			ES38DD (7°)	Buoy
04 December 2003		10°06'E)			ES38–12 (12°)	Horizontal
09 March 2004						Bottom-mounted
5–6 November 2004	“Håkon Mosby”	Masfjord	Dynamic positioning	EK500	ES38B (7°)	Hull
		(60°05'N				
		05°02'E)				
24 May 2004	“G.O. Sars”	Norwegian Sea	Drifting	EK60	ES38B (7°)	Hull
		(~70°N 4°E)			ES18–11 (11°)	

18-kHz and 120-kHz scientific echosounders, using hull-mounted transducers in various combinations with portable (submersible) transducers (Table 1). Acoustic targets were sampled by trawling, but we also relied on knowledge of the faunal composition revealed by earlier studies.

The first part of the study was carried out at a location ~150 m deep in Oslofjord, Norway (59°8'N 10°6'E). The 22-m RV “Trygve Braarud” was kept at a fixed position by means of three anchors, during acoustic data collection. All deck lights were turned off. As we initially believed that sounds from the ship might frighten the fish, the main engine was turned off, and a smaller auxiliary engine provided the necessary electrical power. Subsequent trials were made with the main engine running, to test for any effect of this local noise source. The studies were carried out near the main shipping lane into the busy port of Oslo, and the distance and the speed of passing ships were recorded by radar. Portable transducers were hooked up with the echosounders onboard “Trygve Braarud” by 300 m and 100 m of cable for 38 kHz and 120 kHz, respectively. The portable transducers were applied in three different ways: first, an upward-looking mode, situated on the bottom ~140 m away from the RV; second, horizontally-looking, attached to a ~30° anchor wire, so that fish could be monitored immediately below and adjacent to the vessel; and third, attached to a floating buoy, which enabled acoustic registrations to be made at varying distances away from the ship. Beam widths were 7°, apart from the hull-mounted 38-kHz transducer, which had a beam width of 12°. Swimming speed of schooling fish was assessed by measuring school displacement against time in records from the horizontally directed transducer.

A second fjord study was carried out with the RV “Håkon Mosby” in the ~500-m deep Masfjord of western Norway (60°5'N 05°02'E). This 47-m long RV was kept stationary in the deepest part of the fjord by dynamic positioning (DP), which involved operation of both the main propeller and the bow-thrusters. All unnecessary lights were turned off during registrations. Owing to the mountains surrounding the fjord, satellite communication was lost on several occasions, leading to repeated changes in

position. We also intentionally relocated the ship to assess its impact on fish abundance beneath the vessel.

To test the response of fish to vessels in the open ocean, we measured fish abundance beneath the 78-m RV “G.O. Sars” while it was drifting freely in the Norwegian Sea (~70°N 04°E). This vessel was built according to the ICES specifications for noise reduction (Mitson, 1995). During the drift experiment, the position of the ship was assessed by GPS. Swimming speed of individual fish relative to the RV was assessed using acoustic target tracking (TT) at 38 kHz. Split-beam echosounders can locate a target in the acoustic beam (Ehrenberg and Torkelson, 1996). By applying software allocating subsequent echoes to the same target (Balk and Lindem, 2002), TT provides data on size (target strength; TS) and swimming speed of resolved individuals. Swimming speed was estimated on the basis of start and stop positions of each track. Each track contained a minimum of ten echoes, with a maximum of one echo missing between each echo.

Fish were sampled by pelagic trawling. Sampling depths were monitored during trawling using SCANMAR depth sensors. In Oslofjord, we applied a small, pelagic trawl with a vertical opening of ~10 m. In Masfjord, we used a Harstad trawl (vertical opening of 20 m) with a so-called multisampler codend (permitting depth-stratified sampling), although the trawl with the multisampler did not function properly. Therefore, the sampling in Masfjord only gave an indication of faunal composition. In the Norwegian Sea, fish were captured by a pelagic trawl with a vertical opening of ~30 m (an Åkra trawl).

Results

In Oslofjord we invariably observed greater fish abundance below than just adjacent to the RV “Trygve Braarud” (Figure 1). This effect of the vessel functioning as a FAD was revealed by locally elevated acoustic backscattering (fish biomass). The build-up of fish beneath the ship caused a ~10 fold increase in backscatter (fish biomass) in the course of an hour. This was recorded by all three acoustic

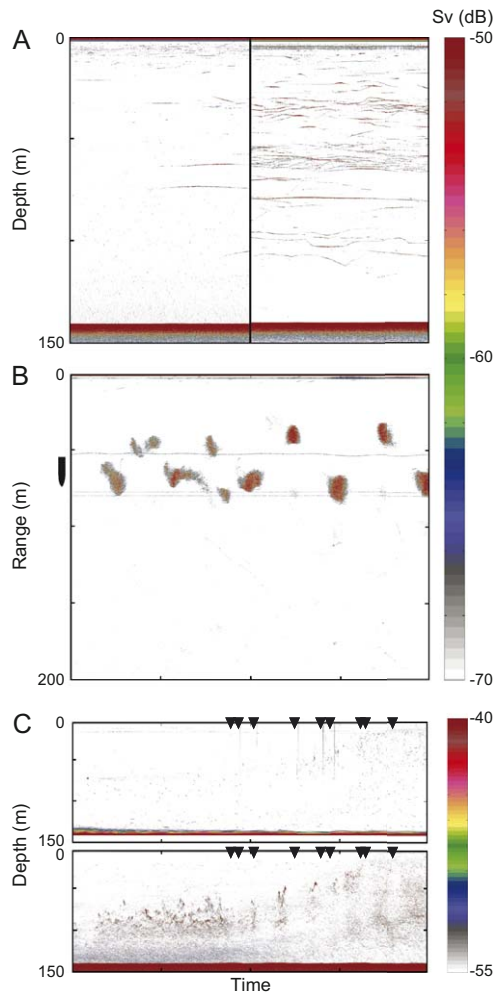


Figure 1. Fish abundance (acoustic backscatter) beneath, and adjacent to the research vessel (RV) “Trygve Braarud” at anchor in Oslofjord. The colour scale refers to fish abundance (echo intensity, Sv), grey showing the weakest and brown the strongest echoes. The seabed is shown by a thick, brown line. (A) Records at night (06 November 2003) from a vertically directed transducer (120 kHz) attached to a floating buoy located ~ 50 m away from the RV (left; 19:20–19:25), and at the stern (right; 19:35–19:40). Fish abundance is ~ 10 times higher close to the RV; (B) records by day (08:10–08:40; 09 March 2004) from a horizontally directed transducer (120 kHz) attached to an anchor wire ~ 55 m deep and ~ 50 m away from the ship, showing a section of the water mass beneath and beyond the RV. Schools of clupeids are accumulating beneath the vessel (location of RV indicated); (C) concurrent records from day and night (13:30–19:40; 20 February 2003) made by a bottom-mounted, upward-looking transducer (38 kHz; upper), located ~ 140 m away from the RV, and a hull-mounted, downward-looking transducer (120 kHz; lower). Fish abundance is higher beneath the RV. Voids in the acoustic backscatter are explained by disappearance of fish underneath the RV during the passage nearby of other ships (marked with triangles).

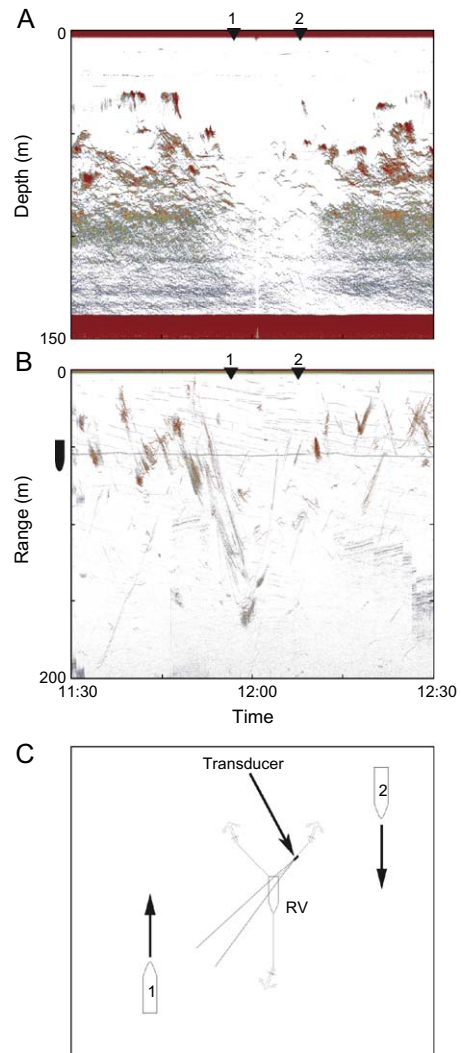


Figure 2. Fish abundance (acoustic backscatter) beneath and adjacent to RV “Trygve Braarud” at anchor in Oslofjord during daylight prior to, during, and after commercial vessels have passed nearby as concurrently recorded by (A), the downward-looking, hull-mounted (38 kHz), and (B), a horizontally directed transducer (120 kHz) located at ~ 50 -m depth and ~ 40 m away from the ship. (C) Sketch of the experimental set-up for the horizontally directed transducer (symbols and units as in Figure 1). The passage of a 12 000-t vessel (vessel 1) in front of the horizontally directed transducer (~ 600 m away from the RV; 04 December 2003) is marked by triangle 1. The passage of a second ship (~ 18 000 t; vessel 2) passing ~ 500 m behind the transducer 10 min later is marked by triangle 2. The horizontal section (B) shows that fish leaving the water column beneath the RV are swimming away from the transducer. This implies that they are swimming towards the approaching ship (1), as outlined in (C), before returning to the RV, which also entails swimming towards vessel 2.

set-ups: by the transducer attached to a floating buoy immediately adjacent to the ship compared with the same set-up ~ 50 m away from it (Figure 1A), by the horizontally directed transducer demonstrating fish schools just beneath, but not away from, the vessel (Figure 1B), and by the downward-looking transducer on the research vessel compared with the upward-looking transducer located on the bottom 140 m away from the RV (Figure 1C). This accumulation took place by both day and night, throughout the ~ 150 -m deep water column. Both schooling and individual fish seemed to accumulate. Schooling species in the location are herring (*Clupea harengus*) and sprat (*Sprattus sprattus*), as evidenced by pelagic trawling. Whiting (*Merlangius merlangus*) dominated the catch of non-schooling species. Detailed results on the fish fauna at this location, based on several years of trawling, are given in Onsrud et al. (2004); most pelagic fish there are apparently actively foraging on krill and copepods at the times of year the present study was conducted.

Some of the fish beneath the ship recurrently disappeared for short periods, resulting in voids in the acoustic backscatter (Figure 1C). This was associated with the passing of commercial vessels 200–600 m away. Surprisingly, this did not appear to be an “avoidance reaction”, but was rather caused by fish swimming towards the approaching vessel. This became evident when simultaneously applying both a down-looking transducer at the research vessel (documenting the void; Figure 2A), and a horizontally looking transducer directed towards (Figure 2B, C), or away from, the passing ships, hence documenting the swimming direction. Fish moved towards the approaching ship, but returned to their original position beneath the stationary research vessel after the ship had passed. The fish did not change their swimming speed in the course of these events, consistently swimming at ~ 20 cm s⁻¹.

These results were obtained when the main engine of “Trygve Braarud” was turned off, with only the auxiliary engine operating. Part of the programme was repeated with the main engine running, and fish accumulated beneath the RV also at this setting (not shown).

In Masfjord, the abundance of large fish in the upper ~ 160 m increased rapidly beneath the vessel when it was kept stationary by DP, both day and night. These fish virtually disappeared when the ship changed position (Figure 3). The TS suggested relatively large fish (TS ~ -30 dB), and three ~ 60 – 70 -cm saithe (*Pollachius virens*) were captured in one trawl tow. Unidentified schooling fish were present in the upper waters (assemblage of red targets in the upper 20 m; Figure 3B). These showed a different response. There was an initial, apparently startling effect when the vessel started relocating and these targets disappeared, but thereafter there was great abundance during the relocation period (speed of ~ 40 cm s⁻¹).

We interpret the rapid increase of large fish below the stationary RV in Masfjord as an effect of attraction, like that unambiguously and repeatedly shown for similar

patterns in Oslofjord. In Masfjord this explanation was not confirmed by echosounders that could concurrently establish fish abundance away from the ship. The alternative explanation would be avoidance when moving. In that case, any avoidance would not likely relate to engine or propeller noise. The ship was kept stationary by DP, which meant intermittent running of the same engine and propellers that were running continuously when the ship relocated. Intermittent noise would be expected to be more alarming for fish than continuous noise (Wysocki et al., 2005).

As in the studies from the fjord environments, fish abundance rapidly increased beneath the RV “G.O. Sars” drifting freely in the Norwegian Sea. While drifting at ~ 34 cm s⁻¹, there was a steep increase in the numbers of fish ~ 200 m below the moving vessel (Figure 4). The level of acoustic backscatter suggested that the abundance of these targets, saithe, as identified by trawling, increased by a factor of ~ 30 in course of the 60-min registration period. These fish were actively following the drifting vessel, confirming its role as a FAD. This was substantiated by acoustic target tracking (TT). The average swimming speed of these large fish (TS > -30 dB; $n = 105$) was virtually zero (2 cm s⁻¹) relative to the direction of the drifting ship, in contrast to smaller organisms tracked in the upper 250 m (TS < -50 ; $n = 122$), which on average showed a displacement velocity of 21 cm s⁻¹ relative to the direction of drift.

Discussion

Contrary to our initial expectation, fish were attracted to vessels rather than being repelled by them. This was true for both stationary and drifting RVs in different environments and for ships with different noise levels (see also Onsrud et al., 2004). Accumulation of various fish assemblages beneath RVs was recorded during autumn, winter, and early summer, by both day and night. Fish even appeared to be attracted to noisy, commercial vessels that passed one of our study sites. In that case, recorded swimming velocities of the schools (likely herring) corresponded to normal (unagitated) cruising speeds of ~ 1 body length s⁻¹ (Gibson and Ezzi, 1985; Nøttestad et al., 2002), in accord with an interpretation that the fish did not become scared by noisy, passing ships. Alternatively, Soria et al. (1996) argued that fish could be herded towards a silent cone in front of a vessel where propeller noise likely was less owing to screening by the hull.

Voids in the acoustic backscatter turned out to be caused by fish swimming towards passing vessels (cf. Figure 2B). Previous studies have suggested that corresponding voids can largely be ascribed to diving, explained by reduced backscatter as the fish change their tilt-angle (Olsen, 1990; Vabø et al., 2002), or horizontal swimming away from approaching ships (Vabø et al., 2002). Although diving appears to be a common escape response among fish, which is also recorded upon approach of an RV (Pitcher et al., 1996; Handegard et al., 2003), this can be refuted

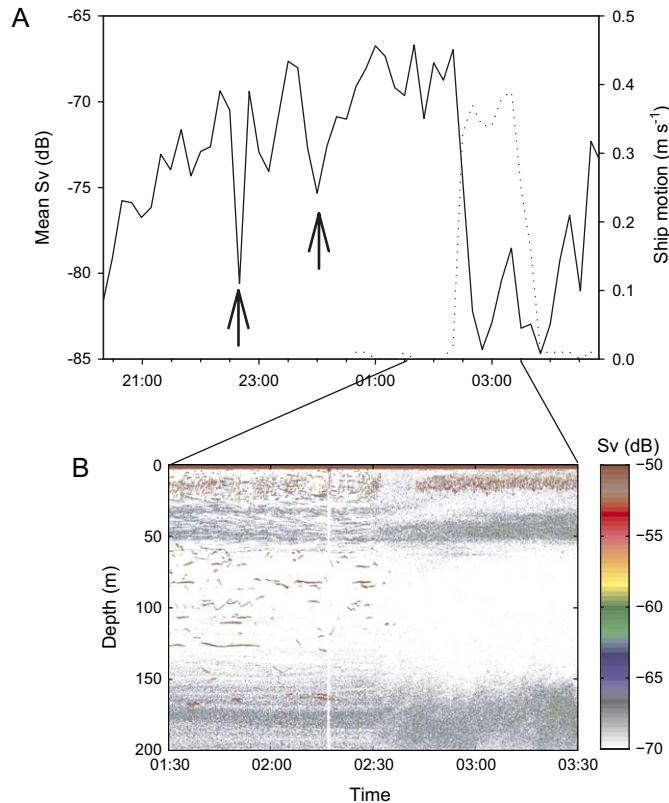


Figure 3. (A) Average acoustic backscatter (Sv) plotted against time at 38 kHz between 160 m and 60 m at night beneath the RV “Håkon Mosby” kept stationary by dynamic satellite positioning in Masfjord, Norway (5–6 November 2004). Arrows indicate short relocations, when the DP lost contact with satellites in the mountainous fjord area. A larger relocation was made in the later part of the registration period; ship speed is then annotated by a dotted line. Similar build-up of fish beneath the vessel when stationary was recorded during the day. (B) An echogram showing fish abundance in the upper 200 m during a selected part of the registration period. The colour scale refers to fish abundance (echo intensity, Sv), grey showing the weakest and brown the strongest echoes.

in our case. We definitively observed horizontal swimming, and even steeply diving fish would be detected by lowering the acoustic thresholds (< -95 dB), as we did as part of the acoustic analyses. In related studies in Oslofjord, we have shown that TS among this fish assemblage may indeed depend strongly on tilt-angle, yet would not account for complete disappearance of targets when using low thresholds (manuscript in draft). It follows that erroneous conclusions on ship avoidance may be drawn if reference sites function as FADs, as in our original experimental design.

We acknowledge the different operation of a surveying RV from that of a ship at a sampling station, and that habituation may play a role for fish that frequently encounter noisy commercial vessels, as in Oslofjord. Even so, the behaviour of fish in relation to vessels is evidently more complex than normally believed. Corresponding to our conclusions, Dagorn *et al.* (2001) showed that yellowtail tuna carrying transmitters developed a strong association with the tracking vessel, following it at speeds up to 5 knots. Those authors suggest that the vessel is not following the

fish but that the fish are following the vessel! Moreover, although it has been generally accepted that fish avoid vessels because of the noise they make (Mitson and Knudsen, 2003), recent studies suggest variable patterns of avoidance. There is no real agreement about the magnitude of the avoidance effect (Gerlotto *et al.*, 2004), and there have been observations of fish swimming towards vessel paths (Handegard and Tjøstheim, 2005). Evidently, the response of fish to vessels is not a simple mechanical avoidance reaction to auditory stimuli.

The mechanisms causing the attraction of fish to vessels are not clear. However, the accumulation of large saithe beneath the drifting “G.O. Sars” in the Norwegian Sea had a striking parallel in accumulations of similar targets beneath krill swarms in the same region (Kaartvedt *et al.*, 2005). In the latter case, it was concluded that large piscivorous fish kept their position beneath the shadow generated by the swarming krill, to prey on planktivorous fish drawn towards the swarms. Registrations in the Norwegian Sea were made in daylight. In Masfjord, saithe also accumulated beneath the vessel at night.

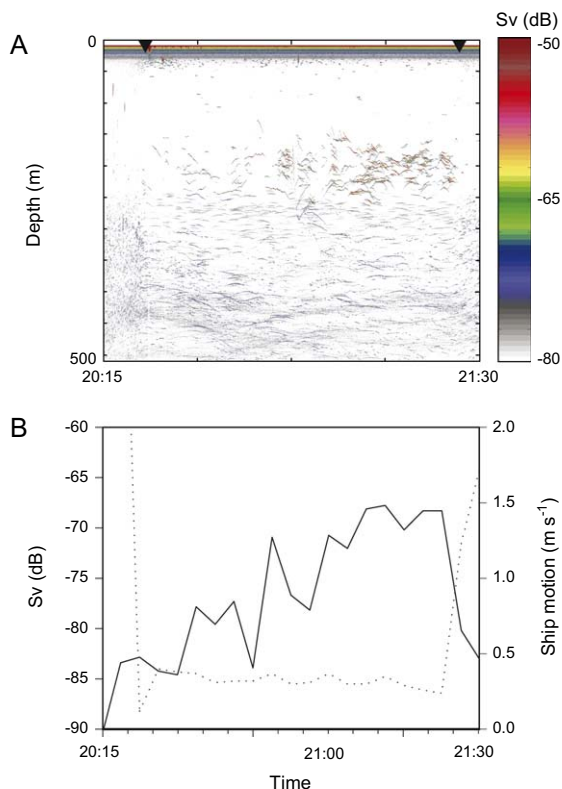


Figure 4. (A) An echogram showing fish abundance during daylight (acoustic backscatter at 18 kHz) against time beneath RV “G.O. Sars” while drifting freely in the Norwegian Sea (at 70.1°N 4.1°E) on 24 May 2004. Triangles depict times for initiation and stop of the drifting period. The colour scale refers to fish abundance (echo intensity, Sv), grey showing the weakest and brown the strongest echoes. (B) Average acoustic backscatter (Sv) between 150 m and 225 m plotted against time at 38 kHz during the same registration period as in (A). Ship speed is annotated by a dotted line. Fish abundance increased by a factor of 30 in the course of the 60-min drift period, immediately dropping when steaming resumed.

In assessing the possible roles of various sensory cues in the homing behaviour of pelagic fish to FADs, moored weather buoys in their case, Dempster and Kingsford (2003) suggested that sound from the FADs produced by, for example, the vibration of wires or associated fish were important cues. This was because the FADs were detected at long range, so chemical and visual stimuli might be excluded as explanation. The sounds produced by FADs are much weaker than those generated by vessels. We note that fish responded to passing vessels at relatively long range (200–600 m), yet so far the role of sound is unknown in our experimental settings.

The responses of fish to vessels may vary between species with different motivations (e.g. depending on trophic level), and motivation may vary with time, e.g. being related to spawning (Skaret *et al.*, 2005). We have observed

that layers of fish in shallow water that are attracted to our vessel apparently become scared and disappear during working activity on deck (unpublished results). We do not refute the possibility that fish may indeed avoid vessels, but if RVs or buoys used as reference sites in fish avoidance experiments commonly function as FADs, it is of significance to both the potential corruption of fish avoidance experiments, and for ecological and behavioural studies. Accumulation of fish as well as avoidance implies incorrect abundance estimates. The enhanced abundance of organisms at one trophic level beneath a vessel at a study site may in turn impact other trophic levels. For example, many plankton studies have demonstrated instantaneous changes in behaviour and the distribution of plankton in response to presence of fish (Hays, 2003). Further, new acoustic techniques have encouraged studies of individual fish behaviour *in situ* beneath research vessels (Huse and Ona, 1996; Torgersen and Kaartvedt, 2001; Onsrud *et al.*, 2005), and if fish swim to keep station beneath a FAD, this may involve studies of biased behaviour.

Work on FADs has normally been carried out in warm water, often related to the commercial exploitation of tuna (Fréon and Misund, 1999; Dempster and Kingsford, 2003), but according to our results seem as relevant at high latitudes where the water is cooler. “Ship avoidance” has been studied in the tropics (Gerlotto and Fréon, 1992) and at high latitudes (Olsen *et al.*, 1983), in the Atlantic (Vabø *et al.*, 2002) and Pacific (Gerlotto *et al.*, 2004). Fish responses to FADs and vessels are therefore of universal interest. It appears necessary to combine knowledge gained from these separate, but at the same time apparently strongly related, themes to obtain a correct assessment of how fish respond to vessels, with subsequent implications for stock assessment and ecological research.

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