Underwater noise radiated by research vessels

R. B. Mitson


Levels of radiated noise from ships are such that many fish species are capable of detecting them at long ranges. A ship's noise field is extremely dynamic in terms of discrete frequencies and overall level, and the variation from vessel to vessel is great. The relationship between this noise field and any reaction by fish may be complex, but currently there are insufficient data to correlate specific observations with noise characteristics of the vessels causing the reaction. A selection of data on six research vessels is presented to illustrate the levels of variability encountered under a variety of running and working conditions. An outline is given of the noise measurements required if the problem of fish reaction to noise is to be solved.


Introduction

Adverse effects of ship-radiated noise on fish behaviour have been noted by many authors but there is no clear picture of cause and effect. Fish can detect noise, often at considerable distances. The reason for a specific reaction, which can affect the availability of fish in the vicinity of a trawl, or along the track of an acoustic survey, can be related neither to the pressure level nor to the frequency spectrum of the noise. Many separate pieces of valuable knowledge exist, but for a variety of reasons they are not easily linked together, for example when observations on fish reaction to ship noise do not include a description of the vessel noise, usually because this is not known.

Interest in this subject is currently being revived because greater precision is sought in the assessment of fish stocks, whether by acoustic or by trawling methods, or a combination of the two. Low levels of high-frequency ship-radiated noise are necessary if the recent significant increase in the dynamic range of echo sounders (Bodholt et al., 1989) is to be fully exploited.

An adequate description of underwater radiated noise can only be obtained by measurement under a variety of conditions. This is because of the extreme variability of the frequency spectrum and sound pressure levels in relation to speed, load, pitch angle of propeller, and age of vessel. It is timely to examine available noise data so the information in this paper has been collated from several sources, including the "grey" literature. It serves to emphasize the need for collection of data in greater detail if the questions of fish response and reaction are to be answered.

Fish hearing

Fish hearing varies from species to species so it is likely that there may be different reactions according to: (a) the noise frequency spectrum radiated from vessels; (b) the pressure levels; (c) a combination of the two; (d) the circumstances under which the noise is detected.

Under (d) we might expect complications due to other sensory effects, perhaps lights on a vessel at night, or its shadow during the day and possibly other factors such as seasonal effects. Studies to determine the sensitivity of fish to sound include Buerkle (1967, 1968), Enger (1967), Chapman (1964), Chapman and Hawkins (1969), Chapman and Sand (1974), and a recent review by MacLennan and Simmonds (1992). Figure 1 shows the hearing thresholds for several species of fish taken from some of these sources. Of these fish, herring have the most sensitive hearing and also the broadest frequency response. Other species show a sharper cut-off immediately following their most sensitive hearing region.
Noise detection and reaction by fish

The audiograms in Figure 1 enable the calculation of distances at which the fish can detect noise (Buerkle, 1977; taking into account possible masking effects of the ambient level, Buerkle, 1969) but give no direct clue as to the specific stimulus to which they will respond. Evidence suggests a large difference between the distance at which fish detect sounds and the distance at which they react.

Olsen (1976) observed directional response in herring (Clupea harengus) at more than 80 m and Sorokin et al. (1988) showed that Pacific sardine (Sardinops sagax melanostica) had the ability to determine the direction of a 60 Hz pulsed source at up to 150 m. Ona (1988) detected diving reactions in cod (Gadus morhua) 200 m in front of a vessel moving at 3 knots, the fish spreading horizontally and vertically, but at 10 knots the reaction was less. Assuming a controllable pitch propeller (CPP), a possible explanation is that the overall noise level in the hearing band of the fish was less at 10 knots because cavitation often decreases slightly with speed for a CPP.

Alternatively, a strong tone or tones may have caused a reaction at low speed but have been swamped by cavitation above 3 knots. In this report and another using the same vessel (Ona and Chruickshank, 1986), the propeller was deemed to be the major cause of disturbance to the fish. Without more details of the vessel, or its propeller, it is difficult to speculate; a singing propeller producing a discrete tone seems likely, but even the whine from a gearbox can be radiated into the water. Propeller-induced vibration of the hull can cause very high levels of low-frequency noise.

Engås et al. (1991) observed the reaction of acoustically tagged cod to an approaching research vessel by tracking the detailed movements of individual fish; their results appear to confirm that the fish could sense the bearing of the vessel as it approached. These authors remind us that there is a directional pattern to ship-radiated noise, which in this instance may have had a herding effect when the fish sought minimum intensity of the noise field.

From the evidence put forward by Ona, and Ona and Chruickshank, using a 60 m, 1000 HP vessel and by Engås et al. with a 30 m ship of 165 HP, cod and haddock perceived noise from these vessels and reacted to it. The effect of the larger vessel appeared to be threatening at a range of about 200 m and fish made immediate movements towards a noise field of lower intensity, moving horizontally and vertically. At the same range the small ship caused the fish to “swim calmly along in front of the vessel”. Around 100 m the swimming pattern became restless until the fish suddenly increased its swimming speed, giving a rapid diagonal burst forward and out of the track of the vessel. Taking a simplistic view we might consider a 25 Hz tone of 160 dB for the big vessel. At 200 m this is likely to be reduced to 114 dB, =15 dB above the hearing threshold. The ratio of engine power of the two ships is about 16 dB, so the level of a similar tone from the small ship might be 144 dB, which at 200 m is

Figure 2. The noise spectrum pressure levels of five research vessels at a nominal speed of 11 knots with curves averaged over one-third octaves. Three of the vessels, “Thalassa”, “Johan Hjort”, and “Tangaroa”, have controllable-pitch propellers whose noise level can change markedly for constant ship speed but with different pitch of the blades and/or the shaft speed.
Radiated noise levels

A band of pressure levels against frequency was proposed wherein the noise signatures of fishery research vessels should be contained (Mitson, 1989). This implied that no tonal levels should exceed the top line of the graph shown in the paper. More detail is given in Mitson (1991) where the importance of narrowband measurements is also stressed. Normal presentation of radiated noise levels is referred to a 1 Hz bandwidth but shown in an averaged form because of the difficulty of displaying narrowband levels over four decades of frequency. The smoothing effect of averaging can disguise very strong tones present in the true signature occurring within the hearing spectrum of fish. Figure 2 compares several research vessel signatures at a nominal free-running speed of 11 knots (+0.5, -1), typical for acoustic surveys. It becomes clear that this type of graph has limited significance when the following data are examined. The vessels are discussed in turn below.

FRV “Thalassa”

After being re-engined in 1984 there was a significant drop in catches of certain fish species (see Sparholt, 1990), so in 1991 a noise ranging trial was carried out. FRV “Thalassa” noise levels are typically 20 dB greater than the next three vessels on the graph. Peaks represent regions where line frequencies (tones) have sufficiently high levels to raise the overall noise level. For some of these the amplitude is known, e.g. the tone at 25 Hz has a peak of 174 dB, and another at 480 Hz is 176 dB, 4 dB and 20 dB above the mean levels, respectively. Diner and Masse (1987) made many observations of fish behaviour with the vessel’s omni-directional sonar and found 200 m was a typical range for fish schools to take avoidance action.
A series of measurements was made when “Thalassa” simulated trawling conditions by towing a loaded barge on the surface. Figure 3 shows four graphs with the vessel moving at speeds of between 3 and 4 knots, each representing a different operating condition, i.e., free-running, then loads of 4.5, 8, and 11 tonnes. Considering these in turn: (a) Free-running: peaks are evident within the band of fish hearing but are not pronounced. The noise falls off sharply beyond 1 kHz. (b) 4.5 tonne load: peaks at 25 and 65 Hz are high but the rest of the spectrum falls away fairly smoothly, albeit at a higher level than any of the other conditions. (c) 8 tonne load: the 25 Hz peak is of a similar level to (b) but sharper, with a rise in the spectrum at 50 Hz but the peak at 65 Hz has disappeared. Another is seen at 480 Hz after which the spectrum falls away with a similar but lower slope to (b). (d) 11 tonne load: here the 25 Hz peak is identical to (c), there is a rise centred at 55 Hz and the peak at 480 Hz becomes very prominent, thereafter the slope is lower than (c).

The increase in high-frequency noise level during the simulated trawling appears to be related to the propeller pitch which was set at 6, 10, and 13 degrees for the loads of 4.5, 8, and 11 tonnes, respectively.

FRV “Explorer”
This steam-powered vessel radiated a high level of underwater noise. When in free-running mode the propeller “sang” at 830 Hz, hence the marked peak at that frequency in Figure 4. The noise ranging included some runs when towing an Aberdeen bottom trawl at different speeds, as shown in Figure 4. These results show a distinct contrast with the FRV “Thalassa”, where a loaded barge was towed on the surface to simulate a trawl. This produced an increase in high-frequency noise but a decrease at low frequencies. In Figure 4 it is clear that “Explorer” produced a very significant 10-20 dB increase in low-frequency noise (20 to 150 Hz) for just over 1 knot increase in towing speed. Another feature of Figure 4 is that the propeller singing tone, clearly seen at 11 knots, is lost in the increased cavitation tone due to the loading effect of the trawl on the vessel. Noise was recorded from the trawl as it passed close to the hydrophone but at 3.75 knots it was not distinguishable from the vessel noise. At 4.9 knots the trawl noise was distinctive in the band 700 Hz to just over 10 kHz.

FRV “Johan Hjort”
Over much of the frequency range for the speed of 11 knots this modern diesel-engined vessel has a lower noise level than FRV “Explorer”. No special noise-reduction features were incorporated but the low-frequency levels of 20-40 Hz are particularly low at 11 knots. As with all CP propellers, noise levels can alter dramatically for a slight alteration of blade pitch and shaft rate although the resulting change in ship speed may be small. In Figure 5, at 10 Hz and 65 Hz, there is an increase of 20 dB for a 0.5 knot reduction in speed. Narrowband analyses are not available so the frequency and intensity of discrete tones giving rise to the increase are not known.

FRV “Cirolana”
Experimental noise reduction methods were used when this vessel was built in 1970. At 11 knots the underwater radiated noise signature is raised significantly by a high level centred on 100 Hz; for lower frequencies the noise-reduction measures were effective but the lack of a noise-reduced propeller gives about average results at high frequencies. Moving mechanical parts become worn as vessels age and the levels of noise and vibration might be expected to increase. There is a lack of noise-ranging reports taken throughout the life of vessels to

![Figure 5](image-url)
allow comparison of the noise signatures over a number of years. FRV “Cirolana” was ranged in 1971, soon after coming into service and again in 1984. Because of differences in recorded speed of the vessel between the two noise rangings the most valid comparison is at 6 knots (Figure 6). There are two data series for 1971, one with the engine raft resiliently mounted, giving significantly lower levels than when it is solidly mounted. The flexibility of the design allowed changing from one state to the other in a few minutes. By 1984 the low-frequency noise level had increased by about 10–20 dB between 30 Hz and 4 kHz but was less than the level when solidly mounted in 1971. This may indicate an increase in engine noise and lower efficiency in the mounting. Above 500 Hz to 2 kHz there is little change but the peak at 4 kHz and another at 7 kHz may have resulted from a change of propeller in the interim period.

FRV “Tangaroa”
The overall level at 11 knots is similar to FRV “Johan Hjort” and FRV “Cirolana” but there are more peaks in the low frequencies, indicating high-level tones. In the absence of complete narrowband data these peaks cannot be classified precisely. From limited narrowband data available (not contained in this paper) it is clear that the propeller “sings” at 825 Hz with a level that varies up to a maximum of 164 dB, according to the rpm and pitch of the blades. Cavitation is quite severe and is present at most operating speeds; in common with CPPs it tends to decrease slightly at higher rpm, i.e. the performance is worse at slower speeds.

FRV “Corystes”
Comprehensive noise-reduction measures were taken to meet the specification at 11 knots. Although the aim was lower, the maximum acceptable overall level was 150–10 log $F_{1kHz}$. At frequencies above 10 kHz the maximum level was set on the basis of single fish detection in shallow water against reflected noise. Below 1 kHz it was largely determined by the requirement for low internal noise levels and a desire to avoid scaring fish. Apart from a minor excursion between 400 and 800 Hz the results were good and well below the maximum acceptable level.

During the first series of trials a number of problems occurred which were later rectified and are detailed in Kay et al. (1991). Two, though, warrant a brief mention here. The first concerns a strong tone at 300 Hz, about 33 dB above the general level, due to ripple on the electrical supply to the propulsion motors at six times the supply frequency, resulting in a vibration at that frequency which was transmitted into the water. As this was within the hearing range of some fish species, it was necessary to reduce this to the general noise level, and chokes were fitted in the circuit of each propulsion motor. These chokes can be switched in and out of circuit and an experiment has been conducted to judge their effect during bottom trawling (Nicholson et al., 1992). The second problem was an unexpected increase in the level above 500 Hz when even a fraction of helm was applied. An intense, piercing squeal was emitted, owing to the rudder bearing being too tight. This might well have had a scaring effect on some species of fish.

Noise ranging of research vessels
Current methods of assessing and comparing noise levels are not fully adequate for fishery research vessels. The facilities designed for naval purposes are excellent in themselves, with standardized techniques and procedures common to many parts of the world. Difficulties arise when measurements of a trawler in action are necessary, because the bottom-mounted hydrophones are normally close to one another and on the course of the vessel. Risk of damage by towing a trawl through the
hydrophone configuration is too great to allow such an exercise, so few results are available for vessels in a loaded or trawling condition. This is unfortunate because the free-running results are normally quite different, as seen in the examples above. The pattern to the radiated noise in the horizontal plane is difficult to measure, but for the future such a method needs to be devised. This should be part of the noise-ranging procedure, which at present takes a measurement on either side of the vessel but the results are often combined.

Discussion

Fish can detect noise from considerable distances but their reaction, if any, to a vessel cannot yet be linked to any particular aspect of ship-radiated noise. The extreme variability of the noise frequency spectrum and levels for six fishery research vessels has been demonstrated at different speeds and loadings where data are available. It is clear from the figures that there is a need to obtain a wider variety of measurements on all vessels than is the present practice. With such information it should be possible to devise and run experiments to determine what stimuli cause fish to react. The benefits would be twofold. First, operational procedures when trawling or surveying acoustically could be modified to cause the least disturbance to fish and the instrumentation. Second, it would be possible to provide a shipbuilding specification for the minimum effective noise reduction, thus keeping costs low.

Acknowledgements

The author is grateful to: Centre de Brest, IFREMER (France); Marine Laboratory, Scottish Office Agriculture and Fisheries Department; Ministry of Fisheries (New Zealand); Institute of Marine Research (Norway); and the Ministry of Agriculture, Fisheries and Food (England and Wales) for permission to publish noise characteristics of their research vessels, and to a number of colleagues who commented on the draft.

References


