Shipping noise impacts on marine life

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ABSTRACT

Concerns about the impact of noise of shipping on marine life, has led to the recent publication by the International Maritime Organisation of guidelines for the reduction of noise from commercial shipping. This paper puts the noise from shipping in context with other sounds in the ocean, addresses the potential impact of noise from shipping, the difficulties of assessing the impact and the likely effectiveness of mitigation measures. It draws on underwater noise studies around Australia that included areas of low shipping densities, allowing reliable characterisation of natural ambient noise at frequencies of shipping noise. This low frequency ambient noise has been difficult to determine in the high shipping areas where most ambient noise studies have been made. The paper also draws on studies of the effects of noise on marine mammals. Noise from many distant ships across an ocean basin produces a general nondescript background noise known as "traffic noise" where the contribution of any single ship is not detectable. Noise from a nearby ship reaches higher levels than traffic noise but is present for short times and close distances. Noise from a close ship can be positive if it causes an animal to move away and avoid collision.

Keywords: Ship noise, noise impact, marine animals
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1. INTRODUCTION

There has been concern about the effects of anthropogenic noise on marine life for many years, particularly for impacts on marine mammals (1, 2), although impacts on fish and invertebrates have also been considered. There are many sources of anthropogenic noise in the ocean. Some have high source levels and may be audible for considerable distances but are generally intermittent, examples being various forms of sonar, seismic air guns and pile driving. Noise from shipping is more pervasive and produces a prevailing low frequency (below a few hundred hertz) background noise over large parts of the world's oceans. There is concern that shipping noise is adversely affecting marine animals by limiting the distances over which they can use sound effectively. While all ships have one or more sonars, these are usually considered separately, and in this paper and the references cited, shipping noise does not include any contribution from sonars. There have been many research projects on the effects of noise on marine life and recently plans to address this at an international level through the concept of a Quiet Ocean Experiment by the Scientific Committee on Oceanic Research and the Partnership for Observation of the Global Oceans (3). The aim is to coordinate the international research community to both quantify the ocean soundscape and examine the functional relationship between sound and the viability of key marine organisms, including systematic shut down of anthropogenic sources. While this is aimed at all sources of noise, a recent report by the Marine Environment Protection Committee of the International Maritime Organisation (IMO) provides guidelines for reducing underwater noise from commercial shipping to address possible adverse effects of noise on marine life (4). This paper considers what is known about the effects of shipping noise on marine life and puts the noise into context with other sources and components of noise in the ocean. It does not consider shipping noise source processes or methods of reducing the noise radiated.

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2. OCEAN NOISE AND MARINE LIFE

2.1 Ocean ambient noise

The most effective way of describing ocean ambient noise is in terms of the main components. Each component is generated by a particular type of source and the temporal and geographical variation depends on the source behaviour. Early studies of ambient noise (5) established the main components of ambient noise as:

(a) sea surface noise: the noise of wind and wave action at the surface, usually referred to as wind-dependent noise, and rain noise. These provide a prevailing background noise over a wide frequency range (< 1 Hz to tens of kHz).

(b) biological noise, the noise of fish, whales and invertebrates.

(c) traffic noise, the noise of distant shipping.

These may be considered to be the prevailing components, i.e. the ones that are usually present, though there may be times or locations where one or other are insignificant. Figure 1 shows a summary of the components in the Indo-Pacific region around Australia (6, 7).

Wind-dependent noise results from oscillation of bubbles in breaking waves across the sea surface and is better correlated with wind speed than any measure of the wave conditions. Traffic noise is the background rumble from the many ships in an ocean basin and does not include contributions from ships close enough to be identified individually (5). Ships at long distances can contribute to traffic noise if the propagation of sound is good, and many ships in an ocean basin produce high traffic noise levels. This is the most widespread and prevailing anthropogenic ambient noise, though traffic noise levels are much lower than those of a close source.

2.2 The acoustic environment of marine animals

Marine animals live in an environment where light penetrates only short distances but sound travels to great distances and much further than it does in air because of the much lower absorption. Hence marine animals make extensive use of sound for many purposes, such as communication, obtaining information about their environment, finding prey and avoiding predators. Their sounds form a widespread and variable background noise. Together, the biological and non-biological components form the highly variable ambient noise of the ocean. This noise provides the basic limitation on the use of sound in the ocean, whether by the marine animals or in human activity. The variation in ambient noise causes significant variation in the distance that any source is audible. Anthropogenic noise adds to the natural ambient noise.

Natural ambient noise varies typically by 20 dB or so over relatively short time scales and variations of 30 dB can occur. Such variation is evident in Figure 1. Wind-dependent noise varies by about 20 dB variation over a wide frequency band for a range of wind speeds typical of normal variation in ocean weather conditions. The biological choruses shown are regular events that increase noise levels by 20 to 30 dB above typical quiet conditions. Rain also causes high levels of noise.

Propagation of sound in the ocean is complex and varies substantially between environments and with changing oceanographic conditions, causing substantial variation in distance for a particular value of propagation loss. This variation substantially affects the distance over which animals can communicate. The sonar equation (8) relates the amount by which the received signal exceeds its threshold of detection to the other terms, including the propagation loss, background noise and source characteristics. Hence the sonar equation provides a trade-off between components in terms of the effect on the detection of a source. An increase in background noise, for example, can be offset by a corresponding decrease in the propagation (transmission) loss to maintain the same threshold of detection. A variation of 20 dB in background noise therefore can be traded with a variation in propagation loss of the same amount. In the ocean, a 20 dB variation in propagation loss occurs for a change in propagation distance of typically a factor of 10 in distance, though different areas and ocean conditions cause this amount to vary significantly. Hence, an increase in ambient noise by 20 dB, as is common from natural sources, would typically lead to a decrease in detection range of about a factor of 10. In addition to this, there is the variation in detection range caused by the variability in propagation loss itself as ocean conditions change. This simple comparison shows that marine animals live in a very dynamic acoustic environment and must be able to cope with wide variations in noise levels and the distances at which sources are audible.

2.3 The effects of noise on marine life

In discussing the effects of noise on marine life, it is useful to separate effects that result from high received levels, such as temporary threshold shift (TTS) in hearing sensitivity from those that cause behavioural changes or mask signals of interest. TTS is reversible and generally considered to be a fatiguing effect. The hearing threshold returns to the level before exposure over some time period. It occurs at high received sound levels and the animal would need to be within distances of typically hundreds of metres for high intensity sources. Avoiding TTS is a convenient way of ensuring that a permanent hearing threshold shift does not occur since a permanent change requires substantially higher noise exposure or substantially longer term noise exposure (1). The mitigation measure usually adopted for minimising the chance of TTS for whales is to avoid operating the source when whales are within a certain distance of the source, allowing for a suitable safety factor. For example, the Australian Government policy on seismic operations (9) requires the seismic array to be shut down when a whale is within 500 m of the source, and to operate at lower power when the whale is within 1 or 2 km (depending on other factors). Behavioural changes or masking can occur at much lower received levels and thus at much greater distances, so are more difficult to manage.

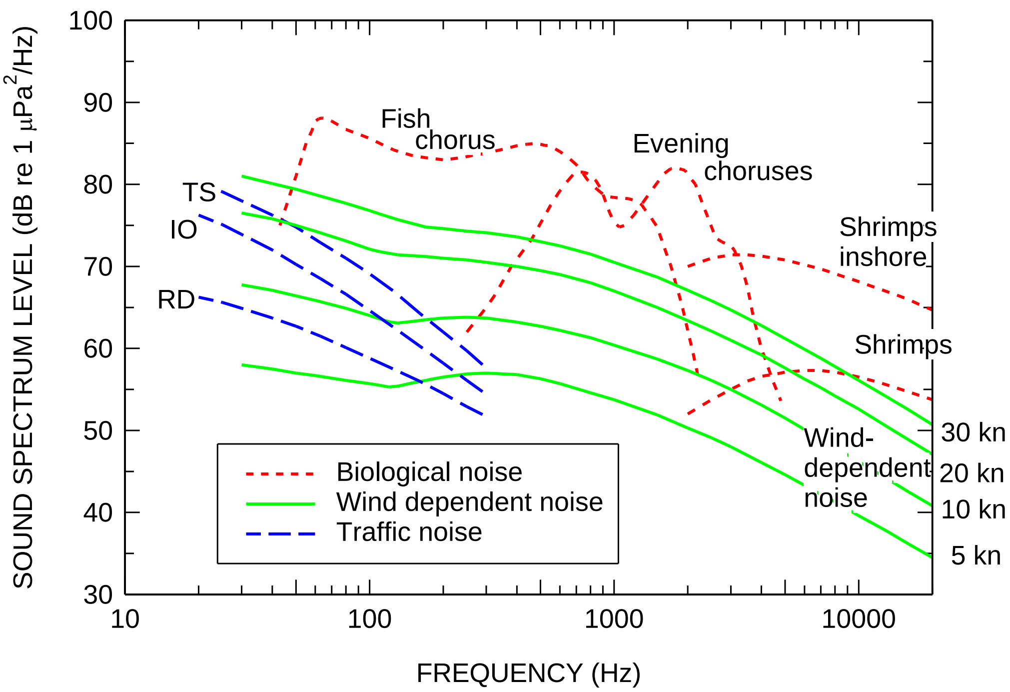

Figure 1 – Ambient ocean noise in the Indo-Pacific region around Australia in terms of the components that make up the noise (6, 7). Wind-dependent noise is an average of measurements in quiet waters (low traffic noise and no biological noise) near Australia. Traffic noise curves are the average of the variation in the regions shown. "TS" is the Tasman Sea (SW Pacific), "IO" the SE Indian Ocean and "RD" is remote (from shipping lanes). Typically the traffic noise level in any region varies around ± 5 dB temporally and by at least that amount spatially. The biological choruses vary with time of day and season (typical maximum levels shown). One evening chorus would have one peak, but more than one chorus may occur at the same time (as shown). "Shrimps" refers to the range of sustained background noise from snapping shrimps in shallow water.

It is generally accepted by scientists and regulators that changes to the behaviour of marine animals or masking of sounds of interest are of concern only if they are likely to have longer term biological consequences. Such responses are usually referred to as being "biologically significant." For example, if a whale showed a reaction that lasted for a short period but then resumed normal activities soon after, this would not be considered to be biologically significant. Some examples of biologically significant effects are a long-term decrease in the size of a population, fragmenting an existing population, adversely affecting habitat critical to the survival of a species, or disruption of the breeding cycle of a population.

The problem lies in determining what responses are biologically significant and this is very difficult and remains a large area of uncertainty (2). A detailed discussion of the difficulties in determining this for whales and an example of how they are being addressed in an experimental study are given in reference (10).

3. NOISE FROM SHIPPING AND ITS POTENTIAL EFFECTS

3.1 Noise from close shipping

Animals within 100 m of a passing ship may experience quite high noise levels but little work has been done on assessing the impacts on the animals. The noise of a passing ship also has a beneficial effect, however, by warning marine animals that it is approaching, allowing them to move out of the way. A significant number of whales are killed by ship strikes and as far as we know, this appears to be a more lethal effect than any adverse effect of shipping noise. The northern right whale population off the north east coast of North America suffers significant losses each year from ship strikes to the extent that it has an impact on the population as a whole (11). On the other hand, whales may get used to the noise from ships in an area and fail to respond, or if whales are resting near the surface and conditions for sound propagation are adverse, they may not hear approaching ships. Various theories have been offered to explain the cause of the ship strikes in terms of the failure of the whales to hear approaching ships (12). The probability of a lethal outcome of a collision between a whale and a ship decreases as the speed of impact decreases (11), so speed restrictions have been imposed in areas of high whale densities near ports, e.g. northern right whales near ports in NE of North America. Ship noise, however, increases as the ship's speed increases (13) so a reduction in speed has to be balanced with a reduction in the likelihood that a whale will hear the approaching ship.

3.2 Traffic noise

Most of our knowledge of ocean ambient noise comes from measurements in waters around North America where shipping densities are high. In these waters, traffic noise tends to obscure the natural components of background noise at low frequencies, such as that generated by the sea surface. In Figure 1 it is evident that the wind-dependent noise curves show a broad peak at around 500 Hz, decreasing in level with decreasing frequency below that, but then increasing for frequencies below 150 – 200 Hz. Most measurements around North America generally were not able to show the wind-dependent noise levels below about 200 Hz, so ambient noise prediction curves generally show only the broad peak at around 500 Hz and no wind-dependent noise below frequencies varying from about 200 Hz at low wind speeds to below 100 Hz at high wind speeds (5). Estimates of the natural ambient noise for the purpose of determining the background noise experienced by whales before powered shipping have usually been made by extrapolating the wind-dependent curves below the broad peak to lower frequencies, resulting in noise levels substantially lower than actually measured in the absence of traffic noise. This has led to the idea that, prior to introduction of powered shipping, there was a "noise notch" at low frequencies which was exploited by whales, but is no longer available. The implication is that traffic noise has substantially limited the ability to communicate for those marine animals that use low frequency sounds, e.g. baleen whales and some fish. Where it has been possible to measure wind-dependent noise at low frequencies (e.g. Australian waters and some studies have been able to do this off North America), the measurements show much higher levels as is evident in Figure 1. Hence the low frequency noise notch prior to powered shipping never existed and increased noise exposure due to shipping is much less than is often reported.

The potential impact of traffic noise lies in masking sounds of interest to marine animals. Baleen whales use sound at similar frequencies to traffic noise, so are likely to be most affected. Traffic noise levels generally vary with locality over a range that is comparable to natural ambient noise (Figure 1). An inference from this is that in areas of medium to low traffic noise levels, the traffic noise provides masking but of an amount often experienced from natural ambient noise. Whales have evolved to cope with this. On the other hand, the highest levels of traffic noise provide consistent masking of amounts that would occur only occasionally from natural ambient noise. There appear to be no experimental studies that have investigated effects of such masking and it would be very difficult to do such studies.

3.3 Long term trends in traffic noise/biological noise

Increases in the amount of shipping over the years would be expected to result in increases in traffic noise (14). There have been a few studies off California that appear to support this by making comparisons between recent measurements of ambient noise and those from the 1960s (15, 16). These studies found increases varying from 5 to 10 dB (between studies and frequencies) compared to the earlier measurements, although the rate of increase seems to have slowed since 1980 (16). The authors noted that there were contributions from whales at the same frequencies but, it seems likely that the measurements are predominantly of traffic noise and that the increase is due to increases in the amount of shipping. In the 1960s, traffic noise spectrum levels around North America typically reached highest levels of about 80 dB re 1 $\mu Pa^2/Hz$ (5) from frequencies of 10 to 100 Hz. These studies have shown that recent (late 1990s) maximum levels are closer to 90 dB re 1 $\mu Pa^2/Hz$. So far, there have been no studies to test if traffic noise has increased in other areas of the world.

4. DISCUSSION

There has been little in the way of experimental studies on the effects of the noise of shipping on marine animals. Most of the effort has been with more intense anthropogenic sources of underwater noise. There may be adverse effects of the noise of a passing ship but it is also beneficial in that it warns marine animals that it is approaching, allowing them to move out of the way. Such a beneficial effect may be limited in areas where passing ships are frequent such as near ports if the animals either get used to the sounds of the ships and ignore them as has been suggested for the northern right whales off NE of North America, where ship strikes have significant impact.

Traffic noise has added significantly to the ambient background noise and so has the potential to mask sounds of interest to marine animals. Traffic noise levels are generally within the range of natural ambient noise (Figure 1), except in areas with the highest shipping densities where it may exceed the highest levels of natural ambient noise in the frequency band of 20 Hz to 100 Hz. Some baleen whales communicate in this band. The levels of natural ambient noise in this band are often underestimated substantially by extrapolating of wind-dependent noise spectra at higher frequencies obtained in studies in areas where traffic noise makes it difficult to unambiguously measure wind-dependent noise at these frequencies. Measurements of wind-dependent noise in areas of low shipping densities, and thus low traffic noise (e.g. Figure 1) show that wind-dependent noise is much higher than the extrapolated values. Consequently, the impact of traffic noise is likely to be significantly less than many speculate.

Improving ship design to reduce the radiated noise will take some time to feed through to the world's shipping. This needs to be considered in terms of how it will affect the ability of whales to hear an approaching ship and move out of its way. Noise reduction may or may not be significant and in areas of high whale and ship densities, special acoustic devices may be more effective.

Until most ships have these improvements, the reduction in traffic noise is likely to be small. Traffic noise is the incoherent addition of the contribution from a large number of ships and few noisy ships will contribute disproportionally to the traffic noise. Improvements may be overshadowed by the large variation in ship noise source levels (at least 25 dB – reference 17) and by the variation in ocean ambient noise levels of more than 20 dB.

While there is little experimental information about the effects of shipping noise on marine mammals, there is one example where it appears to have had no significant effect. The humpback population that migrates along the east coast of Australia are baleen whales and they travel along the busiest shipping lane near Australia. This species is one of the most vocal of baleen whales and the frequencies of their sounds overlap with those of shipping noise. Traffic noise off this coast is high (curve marked "TS" in Figure 1) and is comparable to that in some but not all of the high shipping areas elsewhere in the world. In spite of this, this whale population has increased at more than 10.5% pa (18), about the highest possible for this species, indicating that exposure to shipping noise has had no effect at the population level.

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