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# MASKING EFFECTS OF NOISE;
# THEIR DISTRIBUTION IN TIME AND SPACE

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## 1. INTRODUCTION

Current knowledge of the effects of noise on marine mammals is limited. In fact, very little is known for terrestrial mammals (Janssen 1978), and with regard to our own species, the issue is still subject to large scale research, introduction of new standards and regulations. The effect of noise is also a subject of legal battles (Smith 1980). However, one special effect of noise, masking of the acoustic channel, is quite well understood in marine mammals. Since these creatures rely heavily on acoustic information for orientation and communication, and since these activities are noise limited in a predictable manner, it follows that at least one objective measure of the effect of increased noise can be obtained in terms of masking. Masking is the obscuring of one sound (the signal) by another (the noise). The most common type of noise is random, gaussian amplitude distributed noise, with a negatively sloping spectrum density (1/f- noise). Ocean ambient noise and propeller cavitation noise are basically of this category.

Confronted with the problem of retrieving a signal from the ever-present noise, mammals have been found to comply with the theory of the ideal observer (Swets 1964) in that they base decisions on probability rather than absolute signal power. These mammals possess the equivalent of an adaptive filtering process called the critical band. Also, other sophisticated signal processes such as correlation have been indicated (Simmons 1973; Osman 1973). At high frequencies, directional effects (beam forming) are used to improve the ratio between signal and noise (S/N). The point is that this sophisticated processing is already used to cope with naturally generated noise. Traffic noise can be treated as the addition of one noise level to another, which can be evaluated in terms of masking.

## 2. THE SONAR EQUATION

The S/N ratio depends on the transmitted level of the signal (P), the losses in the transmission process (TL), the noise in the entire system (N), and possibly some receiver properties (Gp), according to the passive sonar equation:

$$(S/N) = P - Tl - N + Gp$$

where all terms to the right of the equal sign are in dB units. It follows that an increase in noise causes a decrease in S/N. This can be compensated for by either an increase in P or a decrease in Tl, while Gp (receiver gain, such as directionality) is likely to be constant. An increase in P in response to an increase in N has been found in echolocating dolphins (Au et al 1974), but without interaction between transmitter and receiver, this is not feasible. A reduction of Tl generally implies a reduction of range. Consider a case in which ambient noise has been raised by 6 dB; assuming spherical radiation, the original S/N can then be restored if the listener halves the distance to the signal source. Thus, a range reduction factor (RRF, numerically 0.5 in this example) can be derived from the change in S/N and used to quantify the impact of added noise to the environment.

In Figures 1a and 1b are shown a set of functions that describe the relationship between the source level of the "polluter" and the distance from this source for various range reduction factors, natural ambient noise, and transmission conditions. No assumptions are required in regard to the numerical value of the original S/N, nor about the distance between the listener and the signal source.

The main feature of the functions is the small slope for distances beyond a few miles. This explains why a noisy ship can ensonify surprisingly large areas and why any increase in source level at values above the steep slope is a matter of concern. The changes in ambient level are equally important as demonstrated when under-ice levels from various sources are used. Figure 1a also shows the consequences of cylindrical versus spherical transmission, with the former generally the case in arctic waters. Figure 1b portrays the effect of different noise levels and different values for range reduction factors. The observation can be made that such manipulations result in a simple translation of the function along the y-axis. The same is true where mammals are using signals propagated in the cylindrical mode. This situation is roughly equivalent to halving the range reduction factors.

Although nothing is assumed with regard to the numerical value of S/N, it is assumed that excessive S/N in the natural situation is likely to be infrequent. The sensory tasks performed by marine mammals on acoustic signals are vastly more demanding than simple detection and require a large S/N ratio. Determination of bearing by interaural phase differences obviously requires a "clean" signal (Mills 1972). The information on size that sperm whales have coded into their multipulse clicks (Norris and Harvey 1972, Møhl et al 1978, Adler-Fenchel 1980) is an example of a system in which any increase in noise reduces the confidence of the classification.

With the estimates of 181 and 196 dB for the LNG source in open water and heavy ice, respectively, it is obvious from Figure 1 that the introduction of this kind of traffic to Davis Strait - Baffin Bay - Northwest Passage areas will drastically reduce the range of acoustic orientation and communication of marine mammals in these waters.

## 3. EXPOSURE OVER TIME

It is important also to evaluate the noise impact over time. The number of variables is large and the outcome is quite dependent on the conditions chosen. Figure 2 illustrates outputs from a simple model describing the rise in noise level experienced by observers during 30 days at distances of 100 and 10 nautical miles from the shipping lane, under various assumptions about ship noise level, speed and spacing of ships, ambient noise, and the position of the observer along the route. Two ships are in operation, the round trip is set at 11.0 km and average speed is maintained throughout the period. The ships spend one day at each terminal. Sound barriers to limit the propagation are introduced at ± 1100 km (Figures 2a, 2b, 2c) and +600, -1200 km (Figures 2d, 2e, 2f). Transmission loss is according to the DREA report.

Figure 2a shows an average situation where speed is limited to 11 knots because of ice, sound level is only 180 dB as less than full power is used, and ambient noise is taken to be 70 dB, which is a compromise between levels from Milne and Ganton (1964), Kibblewhite and Jones (1976), Diachok and Winokur 1974 and the DREA report. It is evident that under these conditions and at a distance of 100 nautical miles, the change from natural conditions will be very large and noise in the environment will be entirely dominated by the LNG traffic.

With the assumptions adopted in the DREA report (low noise from the ships, open water and relatively high ambient noise), the impact is still of a magnitude that will significantly raise the background level throughout the area. Range reduction factors down to 0.1 will occur at distances of 100 nautical miles.

If a low natural, under-ice ambient noise level of 50 dB (which is 12 dB above the Milne and Ganton 1964 "low") and noisy ship operation occurs, the outcome is shown in Figure 2c. The obvious question is whether this is, in fact, physically possible? The main factor is the low ambient under-ice level which has repeatedly been reported (Milne and Ganton 1964, Kibblewhite and Jones 1976). The noise level of the ship can be argued to be too high, but this is a relatively minor factor; DREA's estimate is 6 dB lower. More important is the possibility of increased absorption due to scattering of the sound by a rough under-ice surface. Allowing for a 15 dB further loss on this account does not change the picture radically. Simplifications of such basic assumptions as the constancy of ambient noise throughout the period, a constant ship speed and noise generation are unrealistic but also do not bias the functions, either. Thus, the actual distribution may be different but a load this high could indeed occur. Let us recall that the area thus ensonified is more than 100,000 $km^2$ and that the levels are only that "low" at the rim of this area.

The time course of the exposure will depend on the actual position of the observer along the route, any sound barriers, and the spacing in time of the ships. Figure 2e illustrates how the noise could be experienced by observers 10 nautical miles from the route. Finally, the spacing of the ships can reduce the average load, as indicated in Figure 2f. In fact, if the ships are in convoy, the total noise load over time would be minimized. Two ships are obviously able to cause a substantial change in the acoustic environment over time. If the Arctic Pilot Project is indeed the forerunner of more intense traffic, such as predicted by the Canadian Arctic Resources Committee, this deterioration of the environment would change from being intermittent to continuous.

## 4. CONCLUSION

The estimated quantitative impact of LNG ship noise depends entirely on the assumed levels of ship and ambient noise. However, even allowing for optimistic deviations, the conclusion is that virtually the entire area of Baffin Bay would be significantly affected by noise from LNG carriers. For restricted passages such as Lancaster Sound and the Parry Channel, the impact is expected to be even larger.

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**Fig. 1a.**

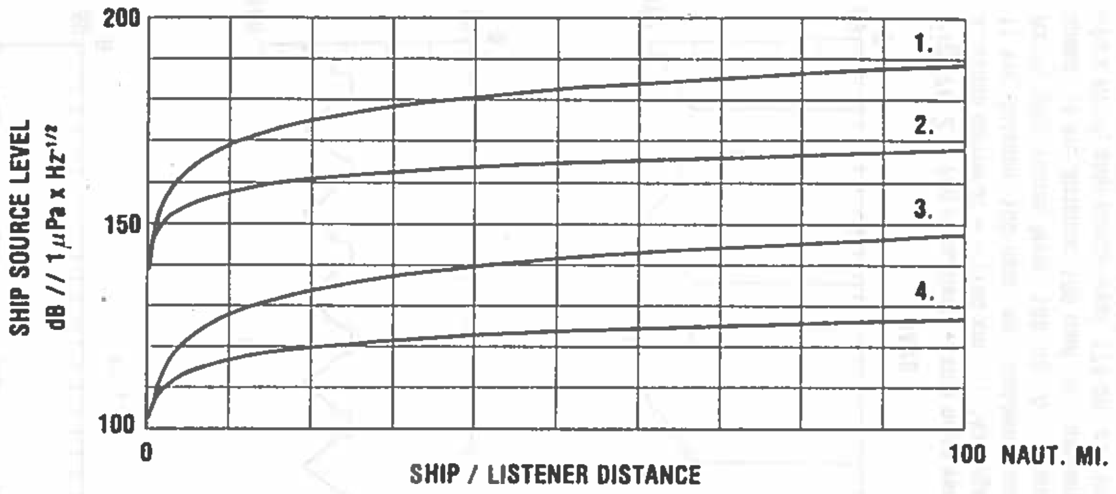


**Figure 1a.**

**Plot of required propeller noise source level as a function of distance from ship to accomplish a 50% reduction in communication/orientation range (RRF = 0.5) at 100 Hz. 1. Ambient noise: 79 dB//1 $\mu$Pa x Hz$^{-1/2}$ (DREA report, cum. probability: 0.5), spherical spreading. 2. As (1), except for spreading assumed to be cylindrical. 3. Ambient noise: 38 dB//1 $\mu$Pa x Hz$^{-1/2}$ (Milne & Ganton 1964), spherical spreading. 4. As (3), except for cylindrical spreading.**

**Fig. 1b.**

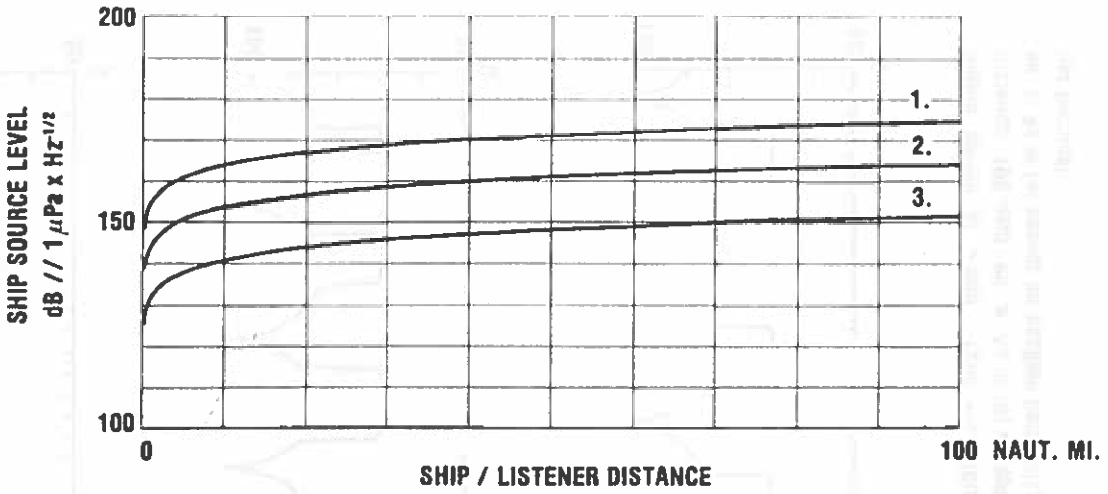


**Figure 1b.**

**1. Ambient noise: 85 dB//1 $\mu$Pa x Hz$^{-1/2}$, Sea State 5, at ice edge (Diachok & Winokur 1974); RRF: 0.5. 2. Ambient noise: 68 dB//1 $\mu$Pa x Hz$^{-1/2}$, SST 1, 100 km from ice edge; RRF: 0.25. 3. As (2), except for RRF: 0.75.**

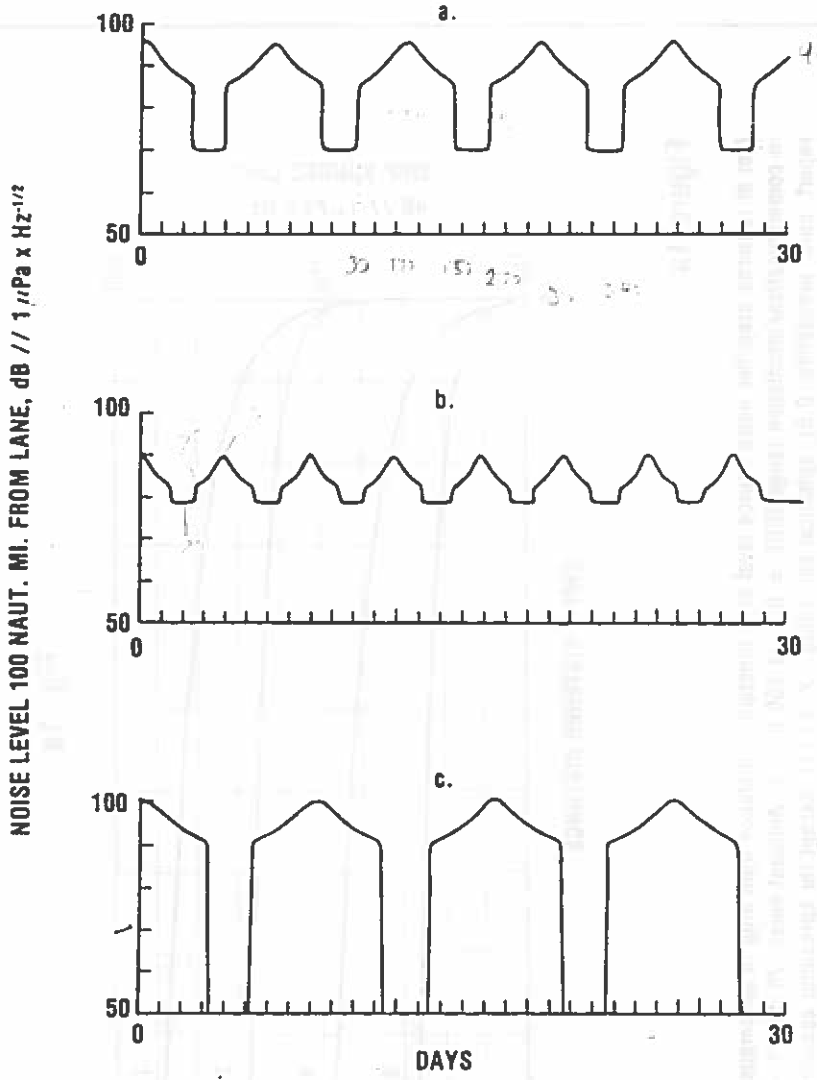
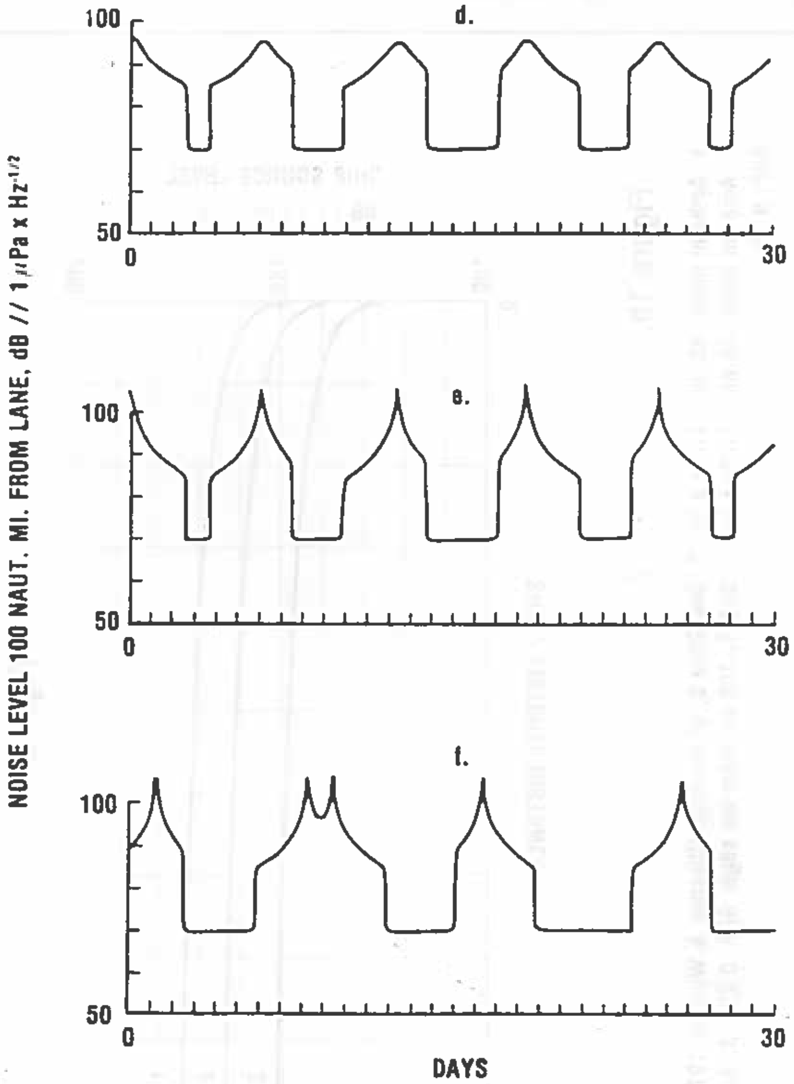


**Figure 2.** Plot of ambient + ship noise versus time (100 Hz). *a.* Sound barrier at + - 1100 km. 1. ''Average'' situation; speed: 11 kn; distance: 100 naut. mi.; ambient noise: 70 dB//1 $\mu$Pa x Hz$^{-1/2}$; ship source level: 180 dB. *b.* ''Open water'' situation; speed: 18 kn; distance: 100 naut. mi.; ambient noise: 79 dB//1 $\mu$Pa x Hz$^{-1/2}$; ship source level: 174 dB. *c.* ''Heavy ice'' situation; speed: 8 kn; distance: 100 naut. mi.; ambient noise: 50 dB//1 $\mu$Pa x Hz$^{-1/2}$; ship source level: 185 dB.



Sound barrier at +600, -1200 km. Situations as in (a). *d.* Distance: 100 naut. mi. *e.* As in (d) except for distance: 10 naut. mi. *f.* As in (e) except for position being displaced 2/3 towards upper terminal.

## FIFTH SESSION

## DISCUSSION ON NOISE PROPAGATION

The discussion opened with the chairman's question whether cylindrical spreading of noise propagation could be assumed in Baffin Bay. Dr. Merklinger suggested that cylindrical spreading could be assumed if noise sources were in the centre of the bay but a higher absorption term would apply in shallow water areas. Dr. Møhl pointed out that, as a rough estimate from the map area, shallow water (less than 200 m) constituted less than 10% of the total marine area of Baffin Bay. When asked his opinion, Dr. Verrall said that cylindrical spreading would apply in summer when an ice cover was a minor feature; however, when ice was both present and rough, he expected propagation loss to be greater than cylindrical spreading, especially at the higher frequencies. In his opinion, cylindrical spreading would underestimate the propagation loss in winter, at which time there is need for a variable absorption term.

The data for summertime ambient noise in Baffin Bay presented by Dr. Merklinger (Leggat et al 1981) were acknowledged by workshop participants to be acceptable, although surprising. Dr. Merklinger added that the source of noise recorded in summer in Baffin Bay was icebergs which rolled and broke up. He calculated that if there were about 2,000 icebergs in Baffin Bay and each rolled over twice a day, the resultant noise would explain the noise levels he recorded there in summer. Dr. Merklinger thought that in winter the activity of icebergs would not likely be present. However, Dr. Buch indicated that iceberg movement commenced in June and that localized movement did occur in winter. Dr. Haller, who had lived in Greenland for a year, stated that he expected a lot of noise near grounded icebergs or those moving with the tide. Dr. Merklinger agreed that the feature which made Baffin Bay different from other arctic marine areas is the superimposed summer noise generated by icebergs and he acknowledged that icebergs could contribute to winter noise. Later in the discussion, Dr. Davis affirmed that icebergs occur in the pack ice of Baffin Bay and that they move virtually all winter, often at different rates than the surrounding pack ice because they are driven by wind or deeper-than-surface currents.

Dr. Møhl enquired of Dr. Greene if the year-round noise level in the Arctic Ocean is higher than the summer noise levels reported by Dr. Merklinger for Baffin Bay, and if there were any other water bodies as noisy as Baffin Bay. Although there did not appear to be information to allow these questions to be answered directly, Dr. Greene indicated that, discounting ship noise, the arctic winter noise levels are low compared to the stormy wind-generated open-water noise levels where classical sea state conditions apply. He also indicated that, in Baffin Bay, ice dynamics from counter-clockwise circulation would contribute noise in addition to any open-ocean noise. It was evident from the discussion that winter ambient noise levels could not be estimated; a figure of 80 to 90 dB ambient noise level was suggested as an average level, without iceberg noise, which could be a point of comparison relative to added LNG ship noise. It was agreed that there would be large variations in ambient noise levels in Baffin Bay.

To Dr. Terhune's question regarding the source of ice noise, Dr. Verrall explained that noise from ice cracking due to cooling is minor in Baffin Bay because the ice there is quite saline and therefore quite plastic, unlike ice in some of the shallower channels of the arctic archipelago. In Baffin Bay, the chief sources of noise in winter are motion of the pack and motion of icebergs through the pack; however, it would be difficult to quantify the proportion of noise resulting from each of these two motions.

Much of the discussion in this session centred around the question of whether Baffin Bay was most noisy in winter or in summer. However, this question was never directly answered.