# THE INFLUENCE OF CHANGING SEA CONDITIONS ON SHIPPING NOISE, INCLUDING EFFECTS OF WIND, FISH AND CLIMATE CHANGE

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## 1 INTRODUCTION

Early human interest in ambient noise in the sea, especially during and after the Second World War, resulted from its effect on limiting the performance of military search sonar [Urick 1983]. While that interest continues, it is now accompanied by non-military uses of underwater sound, such as navigation, fisheries, oceanography and seismic surveys [Ainslie 2010]. But humans are novice users of underwater sound: many marine animals are equipped with sophisticated biological sonars that have evolved over millions of years. Use of these sonars include foraging, navigation and communication [Au & Hastings 2008], and increasing awareness of these uses has resulted in attempts to monitor and mitigate possible detrimental effects of anthropogenic sources of sound [EC 2008, EC 2010].

A review of underwater sound sources in the North Sea ranked them according to the annual average 'free-field energy' attributed to each source, a measure of the contribution from that source to the annual average low frequency sound field. That review, published in 2009, identified airgun arrays, shipping, pile driving and explosions as the anthropogenic sources making the largest contributions to free-field energy in the Dutch part of the North sea, averaged over a year [Ainslie et al 2009]. For this reason, the same four sources are considered likely to be responsible for the main contributions to the annual average anthropogenic contribution to low frequency ambient noise in the North Sea. For the present purpose we focus on shipping, as it is the only source of the four that has a continuous rather than intermittent nature, and is therefore most likely to be the prevalent noise source at an arbitrary moment in time. The meaning of the term "shipping noise" is discussed first, followed by descriptions of ships as sources of underwater sound and of the sea as propagation medium for shipping noise. Illustrations of the dependence on environmental conditions are included in the form of measurements in the north-east Pacific Ocean [Andrew et al 2002] and in the North Sea [Ainslie et al 2011a, Ainslie et al 2011c].

## 2 WHAT IS SHIPPING NOISE?

Underwater noise can be defined as the part of underwater sound that is not part of the useful "signal". In the absence of a signal (the type of which must be specified) then the terms 'noise' and 'sound' are synonymous in an acoustical context. Ambient noise is that part of the total noise that would have been there in the absence of any attempt to measure it, or activities associated with those attempts. Thus, a formal definition of ambient noise associated with underwater sound might be: "In the absence of a specified signal, all contributions to the sound pressure field except those caused by the presence or use of measurement equipment and platform or any other activity associated with the equipment and platform, such as installation, maintenance or dismantling".

This definition excludes all self-noise of the equipment such as flow noise and electrical noise, as well as radiated sound from the platform from which the equipment is deployed. It also might exclude noise from nearby vessels if their presence is a direct result of the measurement, such as supply ships or curious passers by, whether human or biological, coming for a closer look. Shipping noise, then, is that part of the ambient noise that originates from those ships not associated with the acoustic measurement.

## 3 SHIPS AS SOURCES OF SOUND

According to [Wenz 1962], for Beaufort wind force 5 or less, distant shipping is the main source of deep water noise between 10 Hz and 200 Hz, being exceeded at higher frequencies by wind noise. In shallow water, shipping noise shifts to higher frequencies. Close to a shipping lane or a major port the shipping noise can extend in frequency up to tens of kilohertz [Ainslie et al 2011a].

Ship underwater radiated noise generally consists of broadband propeller cavitation noise in combination with low frequency tonal noise generated by propeller cavitation and by on board machinery. The sound radiated from a surface ship is influenced by interaction with the water surface. If the source of the radiated noise is represented by a monopole at a certain depth below the water surface, this monopole and its image above the water surface can act as a dipole. Consequently, the radiated sound field depends on the elevation angle, and its spectral density decreases with decreasing frequency, with a cut-off frequency that depends on the monopole depth. Existing data on ship radiated noise are often difficult to interpret due to the confusion caused by the absence of a widely accepted definition of the term "source level". Existing standards (e.g. [ANSI 2009]) for measuring ship noise produce a value for the radiated noise level, referred to by the standard as "affected source level" because its value depends on the measurement and propagation conditions. Before they can be used as input for estimations of the contribution of the measured vessel to the ambient underwater noise, the resulting data must be converted to a true (monopole or dipole) source level. [de Jong et al 2011]

## 4 WHAT ELSE DOES SHIPPING NOISE DEPEND ON?

The amount of shipping noise depends in part on the number of contributing sources (i.e., the number of large vessels in the vicinity of the receiver) and on the radiated noise characteristics of each source. Measurements at a fixed location in the north-east Pacific Ocean exhibit an increase in level of between 5 dB and 10 dB in the frequency range 10 Hz to a few hundred hertz (Figure 1), of which 5 dB can be explained by an increase in the number of ships and their size. It also depends on the distance travelled by the sound from these sources and the propagation conditions in between, as discussed below.

Deep water is considered first, where "deep" here means deep enough for the sound speed at the seabed, which increases with increasing water depth, to exceed that at the sea surface. In this situation any sound radiated close to the horizontal (grazing angle not exceeding a certain critical angle) from the ship is trapped in the deep sound channel. This critical angle is the grazing angle at the sea surface of the steepest ray that is trapped by refraction in the deep sound channel. It depends primarily on the water depth and the sea surface temperature. Average temperature, average salinity and average pH, though less important, are also relevant through their effect on absorption. Surface roughness (and therefore wind speed) might have an influence on shipping noise for the higher end of the shipping noise frequency range. ***Deep water shipping noise depends on the mean absorption coefficient and sea surface temperature***. [Ainslie 2011a]

In shallow water the seabed plays a central role in the propagation of shipping noise. Any sound coming into contact with seabed is only partially reflected. The resulting cumulative losses are important and depend on bottom type. ***Shallow water shipping noise depends on water depth and on bottom type***. [Chapman 1987, Harrison 1996, Ainslie et al 2011b]

Another effect of the seabed is to shift the dominant shipping noise to higher frequencies (only frequencies above the cut-off frequency can propagate effectively). A knock-on effect of this shift to higher frequencies is a greater influence of surface roughness for the same wind speed. ***Shallow water shipping noise depends on wind speed***. [Ainslie et al 2011a]

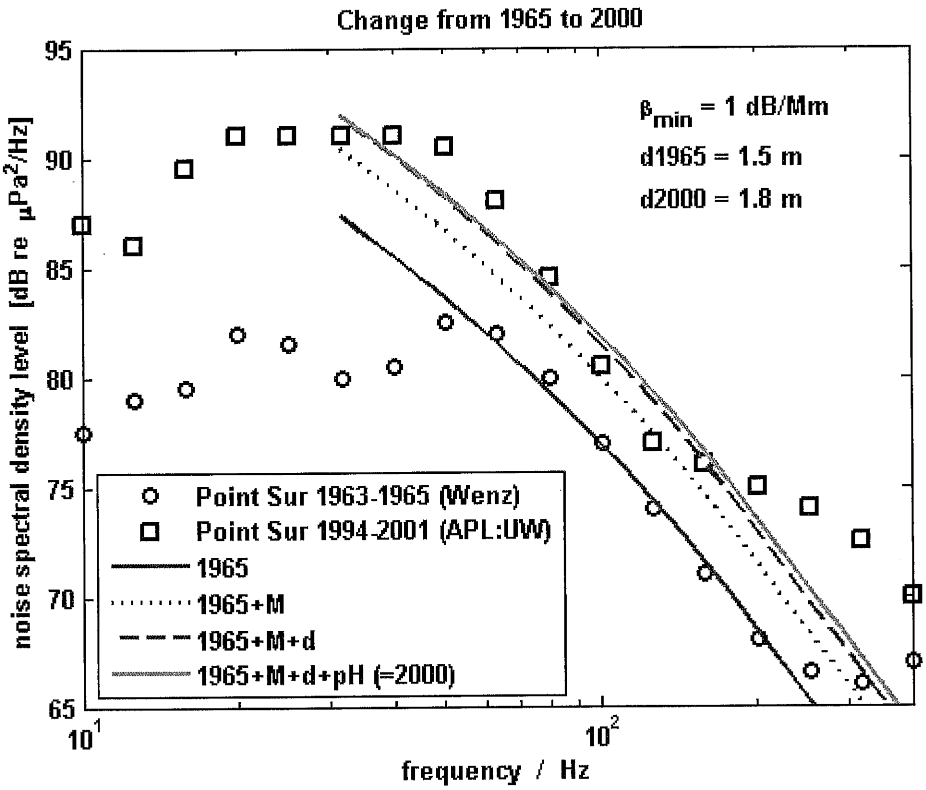


**Figure 1: Modern deep water measurements of ambient noise at Point Sur (California, USA) are up to 10 dB higher than measurements made in the 1960s [Andrew et al 2002]. The predicted increase, taking into account changes in the number of ships, their size and in ocean acidity, is about half this amount [Ainslie 2011a]. The graph shows noise spectral density [dB re 1 μPa$^2$/Hz] vs frequency from 10 Hz to 400 Hz on a logarithmic scale.**

A final consideration in shallow water is the possibility of high concentrations of bladdered fish. A fish bladder is a gas enclosure that resonates at predictable frequency that depends on the size of the bladder and the static pressure at the fish swimming depth. A sound wave close to the bladder's resonance frequency generates high amplitude pulsations of the bladder. The incoming sound is partly absorbed and partly scattered, resulting in less sound reaching the receiver at the resonance frequency than would otherwise have been the case, and therefore less shipping noise at that frequency. Another consequence is a diurnal time dependence, with higher noise expected during daylight hours when the fish are more likely to aggregate in shoals and attenuate the sound less effectively. Such a diurnal variation is observed in the measurements of Figure 2. ***Shallow water shipping noise depends on population density of small bladdered fish***. [Ainslie et al 2011c]

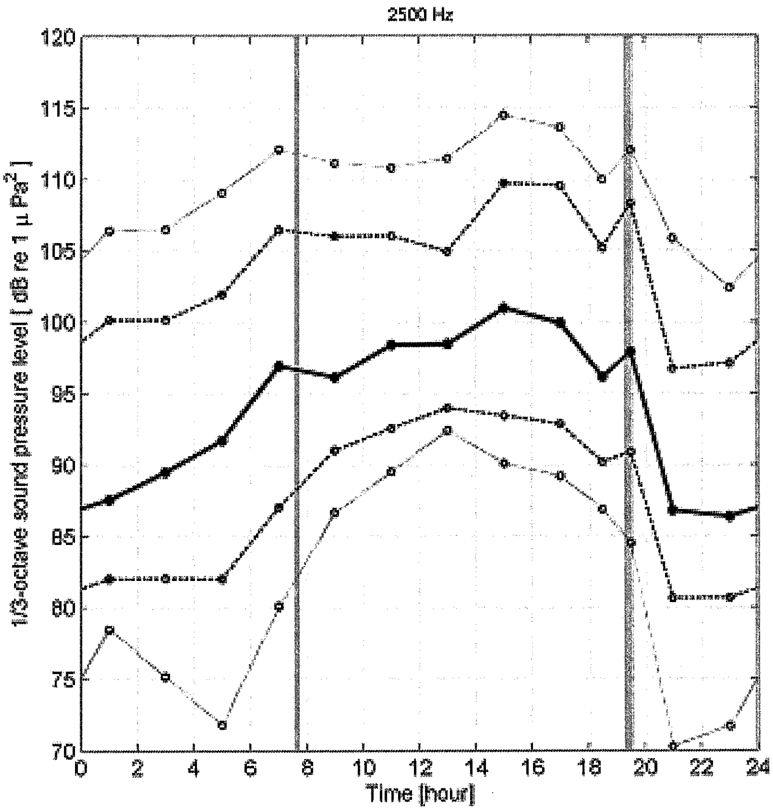


**Figure 2: Shallow water measurements can exhibit diurnal dependence due to fish [Ainslie et al 2011c]. The graph shows sound pressure level [dB re 1 μPa$^2$] in a third-octave band centred at 2500 Hz (close to the bladder resonance frequency), vs time in hours relative to midnight. The solid line shows the median spectral density, with higher and lower percentiles plotted as dashed (16$^{th}$ and 84$^{th}$ percentiles) and dotted lines (5$^{th}$ and 95$^{th}$). The vertical lines indicate the position of dawn (left) and dusk (right).**

## 5 MEASUREMENTS

Measurements are described that illustrate the theoretical effects described above. Examples are taken from deep water measurements in the Pacific Ocean [Andrew et al 2002, see Figure 1; McDonald et al 2006; Andrew et al 2011; Chapman & Price 2011] and from shallow water measurements in the North Sea [Ainslie et al 2011a; Ainslie et al 2011c (see Figure 2)].

Because shipping noise depends on properties of both the ships responsible for the sound and of the propagation medium, in principle a measurement of shipping noise provides information about these properties. For example, the global average source level of all shipping vessels, or the globally averaged sea surface temperature, might be inferred from a measurement of the global average noise field in a frequency range attributable to shipping [Ainslie 2011b].

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