Noiseconomics: The relationship between ambient noise levels in the sea and global economic trends

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In recent years, the topic of noise in the sea and its effects on marine mammals has attracted considerable attention from both the scientific community and the general public. Since marine mammals rely heavily on acoustics as a primary means of communicating, navigating, and foraging in the ocean, any change in their acoustic environment may have an impact on their behavior. Specifically, a growing body of literature suggests that low-frequency, ambient noise levels in the open ocean increased approximately 3.3 dB per decade during the period 1950–2007. Here we show that this increase can be attributed primarily to commercial shipping activity, which in turn, can be linked to global economic growth. As a corollary, we conclude that ambient noise levels can be directly related to global economic conditions. We provide experimental evidence supporting this theory and discuss its implications for predicting future noise levels based on global economic trends.

Ocean ambient noise, or the background din of the sea, is generated by a variety of sources of both natural and anthropogenic origin. While ambient noise cannot be associated with a specific, identifiable source, it can be attributed to general types of sources. Natural causes include geophysical events such as wind-generated waves, earthquakes, precipitation, and cracking ice, as well as biological phenomena such as whale songs, dolphin clicks, and fish vocalizations. Anthropogenic sources include commercial shipping, geophysical surveys, oil drilling, dredging, and sonar systems. The classical work of Wenz showed that ambient noise generated by this myriad of sources extends over a broad range of frequencies (1 to 100,000 Hz), but tends to be dominated by commercial shipping at low frequencies (< several hundred Hz) and wind-generated waves at high frequencies (> several hundred Hz). Although long-term changes in ambient noise levels may have significant impact on marine mammal behavior, our understanding of the trends in noise levels on decadal time scales remains very limited. Only at low frequencies has a body of experimental evidence emerged suggesting a gradual increase in noise levels, from measurements in the open ocean, during the second half of the 20th and early part of the 21st centuries. Theoretical explanations of this trend are even more scarce, with the consequence that predictions of future trends in noise levels are largely of a speculative nature.

Therefore, we propose theoretical underpinnings for the observed long-term trends that are based on the idea that temporal changes in low-frequency noise are primarily due to changes in commercial shipping activity. Furthermore, we show that shipping activity can be directly related to global economic conditions, and as a corollary, that ambient noise levels are correlated with the state of the global economy. First, we present the experimental evidence that led to the development of this theory. Then we derive the quantitative relationship among ambient noise levels, shipping activity, and the global economic condition. Finally, we proffer a prediction of ambient noise levels in 2030 based on the projected state of the global economy.

Results

Figure 1 provides a summary of existing data on trends in low-frequency ambient noise levels. The plot delineates two fundamental categories of noise, namely, that which is of natural or biological origin and that which is of anthropogenic origin, specifically shipping. The natural/biological component was estimated from measurements acquired in areas of the South Pacific with extremely low ship traffic and is corroborated by data acquired in other regions of the world’s oceans. Measurements of the time dependence of this component are unavailable, and it is assumed to remain constant during the period shown in the figure. In fact, temporal variability in the low-frequency, natural/biological contribution may be attributable to several factors, including: (1) depletion of
the whale population due to the burgeoning whaling industry; (2)
increased ice cracking and breaking wave activity associated
with global climate change; and (3) variation in undersea seismic activity.
Nevertheless, actual changes in natural/biological noise levels
would very likely be overshadowed by the anthropogenic contribution from
commercial shipping traffic. The available data on low-frequency
shipping noise12–18 are restricted to the Northeast Pacific Ocean and
show a gradual increase in level of approximately 19 dB (decibels re
1 μPa²/Hz) during the period 1950–2007. Even though the data in
the early part of the 21st century suggest a levelling off (or even a
decrease at some locations) in noise levels17, there appears to be
incontrovertible evidence that noise levels increased at approxi-
mately a rate of 3.3 dB per decade from 1950 to 2007. The key to the theory of noiseomics lies in determining the
relationship among the three exponentially growing quantities shown
in Figs. 1–3. The underlying assumptions associated with this theory are:
Assumption 1: Long-term changes in low-frequency, ambient noise
levels are primarily of anthropogenic origin.
Assumption 2: Commercial shipping activity is the principal anthro-
pogenic source of long-term changes in ambient noise levels at
low frequencies and is concentrated in the northern hemisphere,
which is the location of most of the world’s ship traffic.
Assumption 3: Long-term changes in ambient noise levels due to ship-
ning have occurred since the onset of the Industrial Revolution in
1850, when a major shift from sailing vessels to powered vessels
began to occur. Unfortunately, there appear to be no available data
on ambient noise levels during the period 1850–1950.
With these assumptions, the theory of noiseonomics is summarized below:

**Hypothesis 1:** Low-frequency, ambient noise levels are directly correlated with the gross tonnage of the world fleet.

**Hypothesis 2:** The gross tonnage of the world fleet is directly correlated with the world gross domestic product.

**Corollary:** Ambient noise levels are correlated with the world gross domestic product.

In order to quantify this theory, we define the following decibel quantities:

\[
\text{Ambient Noise Levels in dB } = 20 \log_{10} \left( \frac{\text{World Fleet GT}}{1000 \text{ GT}} \right) \quad (1)
\]

\[
\text{World Fleet Gross Tonnage (dB)} = 20 \log_{10} \left( \frac{\text{World Fleet GT}}{1000 \text{ GT}} \right) \quad (2)
\]

\[
\text{World GDP (dB)} = 20 \log_{10} \left( \frac{\text{World GDP (International 1990 mega $)}}{1 \text{ International 1990 mega $}} \right) \quad (3)
\]

Note that the reference quantity in Eq. (1) is the standard one used in ocean acoustics, while the reference quantities in Eqs. (2) and (3) are chosen for convenience in displaying the results. Figure 4 shows the results of applying Eqs. (1)-(3) to the data in Figs. 1–3 and presenting the results on the same decibel plot. We see that the rate of growth of all three quantities is approximately 3.3 dB per decade, thereby confirming the correlation among low-frequency ambient noise level, world fleet gross tonnage, and world gross domestic product. Examining the relationship among the linear fits in Fig. 4, we can further quantify the noiseonomics theory:

**Hypothesis 1:** Ambient Noise (dB) = World Fleet GT (dB) – 27 dB

**Hypothesis 2:** World Fleet GT (dB) = World GDP (dB) – 36 dB

**Corollary:** Ambient Noise (dB) = World GDP (dB) – 63 dB \quad (4)

### Discussion

Equation (4) provides us with the capability to predict ambient noise levels from knowledge of the world gross domestic product. For example, one economic forecast\(^2^7\) (made in 2005) predicts a world GDP of 89,480,000 international 1990 mega $ in 2030. Substituting this value into Eq. (3) and using Eq. (4), we obtain a predicted ambient noise level of 96 dB in 2030. When compared to a noise level of 91 dB in 2007 (cf. Fig. 1), this corresponds to a rate of increase of 2.2 dB per decade. Since the economic forecast was made prior to the onset of the current global recession, we can speculate that the world GDP in 2030 will in fact be lower than predicted, and therefore the projected ambient noise level will be lower as well. This behavior is also consistent with the more recent ambient noise data\(^2^7\), which are most likely a reflection of the global economic downturn.

Furthermore, we note that mathematical modeling of global economic trends is an active area of research in the economics community and has produced a variety of models to explain and predict the behavior of the dynamic world economy\(^2^8–3^0\). The noiseonomics concept suggests that these models could be used to generate predictions of future ambient noise levels. Conversely, it conjures up the intriguing idea that measurements of low-frequency ambient noise levels could be used as metrics for assessments of global economic growth rates.

Finally, it is important to point out that Eq. (4) is the first attempt to establish a quantitative relationship between ambient noise levels and global economic trends. In the future, this equation may require refinement in order to incorporate: (1) new ambient noise measurements and global economic data; (2) noise mitigation measures, including the use of more energy efficient, quieter propulsion systems in newer ships; and (3) observations of long-term variability in natural/biological noise.
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