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# Ocean ambient sound: Comparing the 1960s with the 1990s for a receiver off the California coast

**Rex K. Andrew, Bruce M. Howe, and James A. Mercer**

Applied Physics Laboratory, University of Washington, Seattle, Washington 98105
*randrew@apl.washington.edu, howe@apl.washington.edu, and mercer@apl.washington.edu*

**Matthew A. Dzieciuch**

Scripps Institution of Oceanography, University of California San Diego, La Jolla, California 92093
*mdzieciuch@ucsd.edu*

**Abstract:** Ocean ambient sound data from 1994 to 2001 have been collected using a receiver on the continental slope off Point Sur, California. A temporary, nearby receiving array was used for calibration purposes. The resulting data set is compared with long-term averages of earlier measurements made with the identical receiver over the period from 1963 to 1965. This comparison shows that the 1994 to 2001 levels exceed the 1963 to 1965 levels by about 10 dB between 20 and 80 Hz and between 200 and 300 Hz, and about 3 dB at 100 Hz. Increases in (distant) shipping sound levels may account for this.

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## 1. Introduction

The Heard Island Feasibility Test and the Acoustic Thermometry of Ocean Climate (ATOC) projects awakened interest and concern about the effects of man-produced sound on marine mammals[1]. This prompted several questions: How does the ATOC signal, used for measuring ocean temperature changes, compare with other sources of man-produced ocean sound? How does it compare with “background" ambient sound levels, which are known to fluctuate significantly depending on time and location? More fundamentally, what are the fluctuation characteristics of the background? Some historical data were available in the open literature, but this raised a further question: were the historical data still applicable?

Curtis et al.[2] started to address these questions by using data collected on 13 U.S. Navy receivers around the North Pacific. The main results were a description of the variability, described by cumulative probability functions versus frequency, crude attempts at determining the probability of detecting ships and marine mammals (specifically blue and fin whales), and comparisons of measured noise levels at higher frequencies (200–400 Hz) with wind speed. Unfortunately, the absolute sound levels could not be determined. New information now allows us to estimate the absolute sound levels for one of these receivers off Point Sur, California, and compare them with data that were collected on the same receiver in the 1960s.

We are aware of only a few published reports of trends in ambient sound level over long periods, all by Ross[3,4,5]. He presented data that indicated sound levels had increased by 15 dB between 1950 and 1975 because of shipping. He further predicted that shipping noise levels would increase by only about 5 dB over the balance of the century, projecting that the pace of shipbuilding would slow and that improvements to propulsion power plants would be incremental at best[3].

In this brief note, the data collected on the Point Sur receiver and on a calibrated receiving array nearby are discussed first (Section 2). The procedure used to calibrate the Point Sur data is described in Section 3 and is fundamental to the conclusions. The calibrated Point Sur results are presented and compared with the 1960s data. This comparison shows an increase in observed levels (Section 4). Possible causes (whales, shipping, and increased wind speed) for

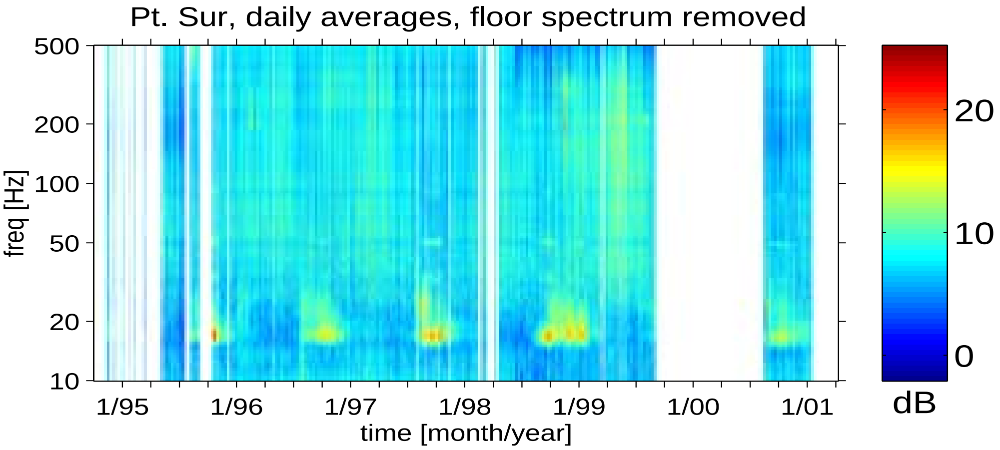

Fig. 1. Spectrogram from Point Sur from January 1995 to January 2001, using 1-day averages. The spectrogram is relative to the “floor spectrum" shown in Fig. 3.

this increase are discussed. Concluding remarks are given in Section 5.

## 2. Data

### 2.1. Point Sur

The Point Sur hydrophone array, now a decommissioned U.S. Navy Sound Surveillance System (SOSUS) receiver, is located approximately 40 km west of Point Sur, California (36° 17.948’ N, 122° 23.631’ W, 1359 m depth). Between January 1963 and December 1965, data were collected by this system and subsequently analyzed by Wenz [6].

The present data set extends, with some gaps, from June 1994 to January 2001. Three minutes of data were collected every 5 or 6 minutes and used to produce autospectral estimates over 1–500 Hz in 1-Hz bins. The most obvious signals in the 6-year spectrogram from January 1995 to January 2001 (Fig. 1) are the blue and fin whales (17–20 Hz and harmonics, annual period.) Curtis et al.[2] found that ship tonals and whales could be detected 72% and 38% of the time, respectively, in the 2-year data set they analyzed.

These autospectral estimates used a frequency-dependent “terminal sensitivity" transfer function that dates from the 1950s and a frequency-independent wideband gain term. The validity of the terminal sensitivity after 40+ years is unknown. The wideband gain term is suspected of having an error of unknown magnitude. To compare this data set against Wenz [6], an absolute correction must be determined.

### 2.2. North Pacific Acoustic Laboratory arrays

During July 1998 to June 1999, 5 autonomous vertical line receiving arrays (VLAs) were deployed 7 km west of the Point Sur array in 1800 m of water as part of the North Pacific Acoustic Laboratory (NPAL) project[7]. Four arrays had 20 hydrophones, and one had 40; all had a hydrophone spacing of 35 m. The pass band was nominally 9 Hz to 110 Hz. The calibration of each hydrophone was accurate to about 1 dB. The VLA calibrated measurements provided the ground truth for correcting the present Point Sur dataset.

## 3. Calibrating the Point Sur data with ambient sound

One calibration method uses a statistically identical input (the ambient sound) and compares the outputs from calibrated and uncalibrated systems to determine the correction for the uncalibrated system.

During the NPAL experiment, the Point Sur and the VLA receivers collected several hundred simultaneous 20-minute blocks of data. The sound fields at either site were not always identical; instances when this occurred were excluded from analysis. The resulting averaged empirical correction function between incorrect Point Sur levels and VLA ambient levels is shown in Fig. 2. The root-mean-square (rms) error (not shown) at each point is approximately 1 dB. A smoother parametric curve is fitted to the empirical data and used for the correction function.

Above 30 Hz, the parametric correction function is essentially independent of frequency and follows the empirical results with a variability of about 1 or 2 dB. This bolsters the conjecture that an incorrect frequency-independent gain term has been applied here. At low frequencies ($< 15$ Hz), the parametric function becomes frequency-dependent and follows the empirical data more faithfully. This might indicate an aging terminal sensitivity at Point Sur or an incorrect original terminal sensitivity or even a bias introduced by range-dependent propagation—there is no clear explanation here. The VLA data do not extend beyond about 100 Hz, so no ambient sound calibration can be done over the remaining frequency span of Point Sur data. Given the frequency-independent behavior of the empirical correction above 30 Hz, the correction beyond 100 Hz is assumed to also be frequency-independent and assigned the asymptotic parametric value.

## 4. Results

### *4.1. Point Sur*

The entire Point Sur data set was corrected using the parametric correction function in Fig. 2. The cumulative distribution functions for each frequency spectra are shown in Fig. 3. This is very similar to Fig. 3d in Curtis et al.[2], except Fig. 3 here has absolute units and covers a 6-year record.

### *4.2. Comparisons: 1963–1965 and 1994–2001*

Concerned that the statistics would be upwardly biased by “noise transients" presumably due to nearby ships, Wenz[6] used a simple comparison procedure to edit out transient data: three consecutive levels were estimated over 10 minutes at the top of every hour, and if any of the three-way level comparisons exceeded ±3 dB, the three levels were discarded, otherwise the three levels were averaged and retained. The same processing applied to the present data set determined that the Wenz processing produces a result that is indistinguishable from the median. Thus, Wenz’s average spectrum can be directly compared with the present data set medians.

The comparison, shown in Fig. 4, indicates an approximate 10-dB increase in median sound level between 20 and 80 Hz over the approximately 33-year time period. Around 100 Hz, there is a small increase of approximately 3 dB. From 200 Hz to beyond 300 Hz, the present data are up to 9 dB higher.

An obvious explanation for the increase at low frequency is an overall increase in shipping levels over the time period. This is consistent with the increase in ship number and gross tonnage: from 1972 to 1999 the total number of ships in the world’s merchant fleet has increased from approximately 57,000 to 87,000, and the total gross tonnage from 268 million to 543 million gross tons[8].

Another factor may be the increasing North Pacific whale stock. Blue (*Balaenoptera musculus*) and fin (*B. physalus*) whale calls have fundamental frequencies around 17–20 Hz [10]. Whale calls can dominate the received ambient sound during certain times of each year (Fig. 1). These whales were nearly hunted to extinction during the first half of the last century: in 1986, the International Whaling Commission[11] declared a moratorium on commercial whaling of these (and other) whales. At the time Wenz made his measurments, the ambient noise was known to contain whale calls, but the population of blue and fin whales was very likely near its all-time minimum. The blue and fin whale populations had rebounded slightly [12,13] by the end of the century. Although stock assessments are somewhat uncertain, this could imply that at

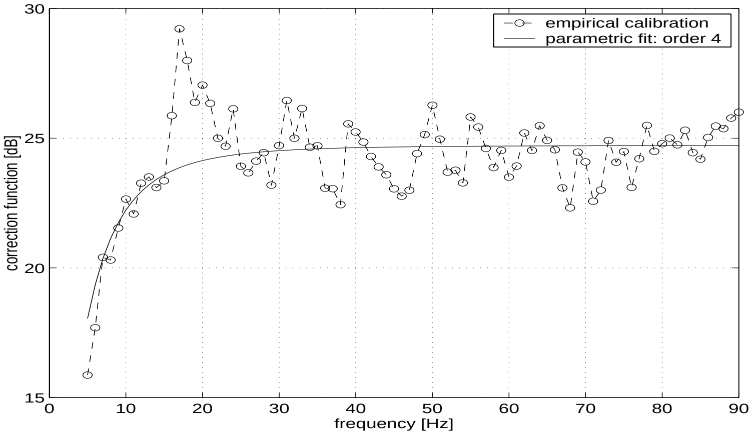

Fig. 2. The correction function for Point Sur autospectra. The circles are raw empirical estimates from the ambient noise calibration procedure. The smooth curve is a parametric fit and is the function used for correction.

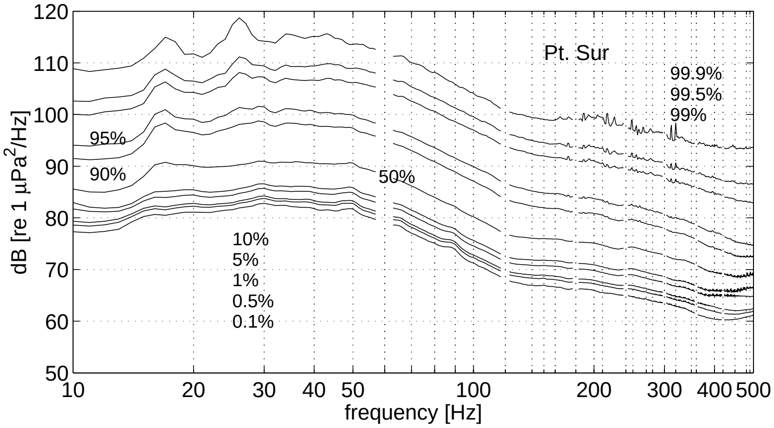

Fig. 3. Point Sur ambient sound level cumulative distribution function, 1994–2001. Shown are several quantiles in absolute sound level (dB re 1 $\mu Pa^2$/Hz.) The first percentile, labeled “1%", is called the “floor spectrum" in Fig. 1. The 50% curve is the median.

appropriate times of year there might be more callers in the Point Sur neighborhood now than in the 1960s.

To investigate this conjecture, the median of the current data was compared to the median of a subset that excluded months when whale calls were evident in the associated spectrogram. The difference between the two curves was only significant below 30 Hz; the difference was at most 3 dB. Thus, although there are more blue and fin whales reported now than in the 1960s, nonwhale contributions to the ambient noise still predominate.

A satisfactory explanation for the increase in the higher frequency band (120–250 Hz) cannot be advanced. A possible cause could be a long-term increase in wind speed. However, Wenz’s “law of fives" stipulates[14] that a doubling in surface wind speed produces an increase in ambient noise of approximately 5 dB. Thus, a 10-dB increase would require a quadrupling of average wind speeds, and such a change has not been reported.

It may even be that the response differences between the VLA and Point Sur systems are not frequency-independent beyond 100 Hz as assumed, but this cannot be resolved with the available data.

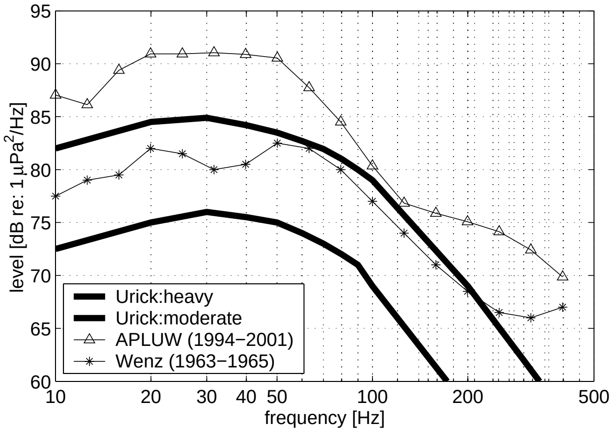

Fig. 4. The present Point Sur autospectra compared with the Wenz (1969) results. Point Sur data have been converted into one-third octave levels for direct comparison. Shown for reference are the “heavy" and “moderate" shipping average deep-water curves presented by Urick[9].

The appearance of a minimum at 100 Hz in the overall increase is unexpected. If the increase were due to shipping noise alone, one might suppose the Urick curves would simply be translated upward uniformly in frequency. The minimum might be explained if there is actually a distinct gap between shipping noise and wind-generated noise. Further characterization would be necessary to substantiate this, and, for now, the minimum remains a puzzle.

## 5. Concluding remarks

The data show an increase in ambient noise over the 33-year period. In the frequency range 20–80 Hz, this increase is approximately 10 dB. The primary explanation is an increase in commercial shipping; increases in whale stocks can account for at best only a minor portion of this increase. The cause of the increase beyond 100 Hz up to 400 Hz and beyond (which is as large as 9 dB) is less obvious; this is generally the regime dominated by the ocean surface wind contribution, but no large changes in average surface wind speeds have been noted. There is no satisfactory explanation for why the increase should have a minimum near 100 Hz.

Other coastal arrays for which recent data as well as “Wenz" data exist should be calibrated in the same way. Then similar analyses can be performed to determine whether the results reported here can be generalized. The authors recommend that no far-reaching conclusions be drawn until this is done. In addition, the cable to the Point Sur system should be repaired so future measurements can be made to augment this unique data set.

## Acknowledgments

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## References and links

[1] W.J. Richardson, C.R. Greene, Jr., C.I. Malme, and D.H. Thompson, *Marine Mammals and Noise* (Academic Press, San Diego, 2001).

[2] K.R. Curtis, B.M. Howe, and J.A. Mercer, “Low-frequency ambient sound in the North Pacific: Long time series observations," J. Acoust. Soc. Am. **106**, 3189-3200 (1999).

[3] D. Ross, *Mechanics of Underwater Noise* (Pergamon Press, New York, 1976).

[4] D. Ross, "Role of propagation in ambient noise," in *Underwater ambient noise: Proceedings of a conference held at SACLANTCEN on 11-14 May 1982*, edited by R. Wagstaff and O.Z. Bluy (SACLANT ASW Research Center, La Spezia, Italy, 1982).

[5] D. Ross, "On ocean underwater ambient noise," Acoust. Bull. **18**, 5-8 (1993).

[6] G.M. Wenz, "Low-frequency deep-water ambient noise along the Pacific Coast of the United States," U.S. Navy J. Underwater Acoust. **19**, 423-444, recently declassified (1969).

[7] The NPAL Group (J A. Colosi, B.D. Cornuelle, B.D. Dushaw, M.A. Dzieciuch, B.M. Howe, J.A. Mercer, R.C. Spindel, and P.F. Worcester) "The North Pacific Acoustic Laboratory (NPAL) Experiment," J. Acoust. Soc. Am. **109**, 2384 (2001).

[8] L.L. Mazzuca, "Potential Effects of Low Frequency Sound (LFS) from Commercial Vessels on Large Whales," Master's Thesis, School of Marine Affairs, University of Washington, Seattle, WA (2001).

[9] R.J. Urick, *Principles of Underwater Sound* (McGraw-Hill, New York, 1983).

[10] M.A. McDonald, J.A. Hildebrand, and S.C. Webb, "Blue and fin whales observed on a seafloor array in the Northeast Pacific," J. Acoust. Soc. Am. **98**, 712-721 (1995).

[11] International Whaling Commission (IWC), http://www.iwcoffice.demon.co.uk/iwc.htm.

[12] J. Calambokidis, G.H. Steiger, J.C. Cubbage, K.C. Balcomb, C. Ewald, S. Kruse, R. Wells, and R. Sears, "Sightings and movements of blue whales off central California 1986–88 from photo-identification of individuals," Rep. Int. Whal. Commn. **12**, 343-348 (1990).

[13] J. Barlow, "Abundance of cetaceans in California waters: I. Ship surveys in summer/fall 1991," Fish. Bull. **93**, 1-14 (1995).

[14] G.M. Wenz, "Acoustic ambient noise in the ocean: spectra and sources," J. Acoust. Soc. Am. **34**, 1936-1956 (1962).