

A 50 Year comparison of ambient ocean noise near San Clemente Island: A bathymetrically complex coastal region off Southern California

Mark A. McDonald

WhaleAcoustics, 11430 Rist Canyon Road, Bellvue, Colorado 80512

John A. Hildebrand and Sean M. Wiggins

Scripps Institution of Oceanography, 9500 Gilman Drive, La Jolla, California 92093-0205

Donald Ross

8870 Villa La Jolla Drive, La Jolla, California 92037

(Received 31 October 2007; revised 8 July 2008; accepted 8 July 2008)

Repeated ocean ambient noise measurements at a shallow water (110 m) site near San Clemente Island reveal little increase in noise levels in the absence of local ships. Navy reports document ambient noise levels at this site in 1958–1959 and 1963–1964 and a seafloor recorder documents noise during 2005–2006. When noise from local ships was excluded from the 2005–2006 recordings, median sound levels were essentially the same as were observed in 1958 and 1963. Local ship noise, however, was present in 31% of the recordings in 1963 but was present in 89% of the recordings in 2005–2006. Median levels including local ships are 6–9 dB higher than median levels chosen from times when local ship noise was absent. Biological sounds and the sound of wind driven waves controlled ambient noise levels in the absence of local ships. The median noise levels at this site are low for an open water site due to the poor acoustic propagation and low average wind speeds. The quiet nature of this site in the absence of local ships allows correlation of wind speed to wave noise across the 10–220 Hz spectral band of this study.

© 2008 Acoustical Society of America. [DOI: 10.1121/1.2967889]

PACS number(s): 43.30.Nb, 43.80.Ka, 43.80.Nd [WMC]

Pages: 1985–1992

I. INTRODUCTION

A. Background

The noise environment of the ocean is an important aspect of habitat for marine mammals and other organisms, and introduction of human-generated sounds may result in auditory, physiological, or behavioral impacts (National Research Council, 2003 and 2005). Rising levels of ocean noise may negatively impact marine mammals by interfering with their ability to detect sounds, whether these are calls of members of their own species, echoes from prey, or natural sounds that aid in navigation or foraging. Noise may cause generalized stress and affect developmental, reproductive, or immune functions. Noise may exclude animals from areas of critical habitat. Long-term noise measurements in diverse marine environments help to document past changes in noise levels as well as to provide a baseline for future changes. Documenting changes in ocean noise, therefore, is important in understanding the state of the marine environment.

In the deep-water portion of the North Pacific, beyond the continental margins, there has been a steady rise in low frequency ambient noise levels, which is attributed to distant ship traffic corresponding primarily to the increasing propulsion power of the largest commercial ships (Ross, 1993; Andrew *et al.*, 2002; McDonald *et al.*, 2006). It is important to understand whether distant ship traffic also affects ambient noise levels on the continental shelf, an area of critical marine habitat. To study this question changes in ambient noise

levels were examined in the relatively shallow coastal waters off Southern California. Shallow water ambient noise studies were conducted at a site west of San Clemente Island in 1958–1960 (Wenz, 1964) and in 1963 (Wenz *et al.*, 1965). The same site was reoccupied in 2005–2006 with a seafloor acoustic recording package (Wiggins, 2003). The earlier study results were compared to the recent results and re-examined in light of current understanding of wind dependent noise, shipping traffic, and biological sound sources.

To understand geographic differences in low frequency shallow water ambient noise levels the contributions of distant and local noise sources must be teased apart as well as differences in seafloor reverberation and acoustic propagation at each measurement site. The primary distant noise source is ship traffic and the primary local noise source is wind driven surface waves. Differences of greater than 10 dB in ambient noise levels under similar wind conditions at different shallow water sites have been attributed to differences in ocean bottom properties, water depths, and sound speed profiles (Ingenito and Wolf, 1989). Vertical hydrophone arrays have been used to separate ship traffic and other distant noise from wind-wave noise (Kuperman and Ferla, 1985; Kewley *et al.*, 1990; Chapman and Cornish, 1993) and to estimate wave source level which can then be used to model omnidirectional noise spectrum levels for given sound speed profiles and seafloor properties. While it should be possible to model the propagation of distant deep-water ship traffic noise onto the continental margins, the approach taken

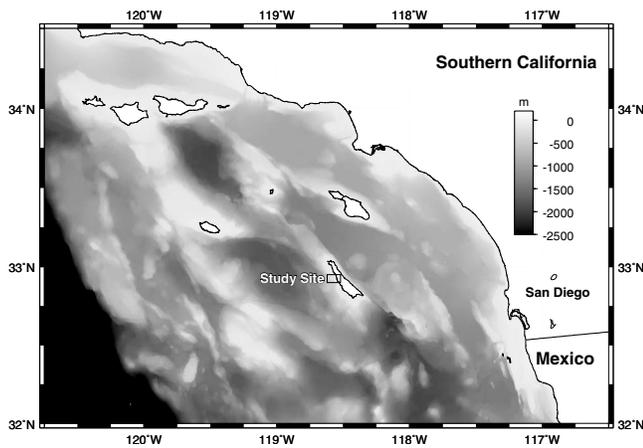


FIG. 1. Bathymetry of the Southern California continental margin showing the ambient noise study site off the west coast of San Clemente Island, CA.

here is to look for any shallow water noise increase at the study site which could be caused by the approximately 15 dB deep-water noise increase over the study time period (McDonald *et al.*, 2006).

B. Study setting

The site for this study is located in the continental borderland region offshore Southern California, along the western flank of San Clemente Island (Fig. 1). The Southern California continental borderland is not a typical continental margin in that the bathymetry is complex and alternates between relatively deep troughs (greater than 1 km) and shallow banks. The distance between the mainland-shore and the oceanic-crustal margin, where full ocean depths (>4000 m) occur, is more than 100 miles for this region. A zone of extended continental crust creates a broad shelf, with alternating banks and troughs created by normal faulting.

The region being studied is important with respect to marine mammals, shipping, and military operations. The study site (Figs. 1 and 2) was chosen because ambient noise was previously characterized at this site. The study site is adjacent to a Navy sonar test range; thus local ship traffic in this region is not necessarily typical of a random sampling off Southern California, as commercial ships may be excluded from the range at times of active naval operations and more Navy ships are expected to operate near this site than at other sites in this region.

II. METHODS

A. Wenz recordings, 1958–1959 and 1963–1964

During 1958–1959 a shore connected cabled hydrophone was deployed near Eel Point, on the western flank of San Clemente Island. The hydrophone was located several meters above the seafloor in 110 m of water over a relatively flat sandy bottom (Wenz, 1964; Wenz *et al.*, 1965). Rockfish and flatfish were observed in seafloor photos taken during the deployment. The location of the hydrophone deployment was determined using bearing angles from the island. The 1958–1959 hydrophone location is estimated to be 32°55.45' N

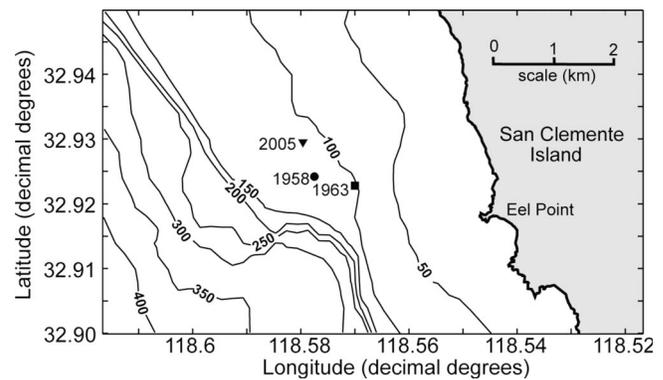


FIG. 2. The locations of the sites occupied in 1958 (circle), 1963 (square), and 2005 (triangle) are shown with bathymetric contours in meters.

118°34.65' W. A recording anemometer was located onshore approximately 2 miles (3.7 km) from the study site.

During the 1958–1959 time period, four data sets were collected with saved noise spectra being chosen to avoid interference from local ship noise. The data windows were 30 June–31 July (525 spectra), 8 September–19 October (658 spectra), 17 November–22 December (515 spectra), and 3 March–21 May (580 spectra). The first three data groups were analyzed using six one-third octave band filters, where the band level was chosen visually from a strip chart recorder, to avoid transient noises and ship noise. Each spectra sample averaged over 165 s and represented a sample from a different hour. The March–May 1959 data set was analyzed with a more complex system allowing for more one-third octave band levels, the details of which are described by Wenz (1964), but the goal was to have similar data for comparison.

The 1963–1964 data were collected with a different hydrophone system, again deployed near Eel Point, with an estimated location of 32°55.37' N 118°34.20' W. The hydrophone was approximately 2 m above the seafloor and an onshore anemometer was again recorded. Several methods, including magnetic tape were used to collect data during this period, but the data used for spectrum comparison were collected with one-third octave filters and strip chart recorders, again discriminating against local ships by eye (Wenz *et al.*, 1965). The magnetic tape records were further analyzed, particularly with regard to blue whale songs (20 Hz longs), although these sounds were not recognized as being from blue whales at that time (Thompson, 1965).

B. Autonomous seafloor recorder, 2005–2006

Recordings were made with an autonomous recording package (ARP) of the same design as that described by Wiggins (2003), and used in previous ambient noise studies (McDonald *et al.*, 2006). Continuous acoustic recordings were collected from 16 August 2005 to 9 February 2006 (179 days) at a sampling rate of 500 Hz. The recorder was deployed at 32°55.768' N, 118°34.777' W in a water depth of 110 m, with the hydrophone suspended 10 m above the seafloor. Review of the data revealed no evidence of instrumental problems throughout the recording period. When this same instrument design has been deployed in high current

areas, flow noise and cable strum can be recognized by significant energy below 10 Hz, but during this deployment there was no evidence of current induced flow noise. Wind data relevant to the study site were obtained from the naval air station on San Clemente Island, 10.3 km to the north of the study site.

C. Calibration

Calibration of a similar seafloor acoustic recording package was conducted using reference hydrophones at the U.S. Navy's Transducer Evaluation Center facility in San Diego (TRANSDEC) to verify the theoretical calibration which was based on nominal component specifications. Calibration was conducted from 10 to 250 Hz. Differences between the actual instrument used for measurements at the Eel Point site and the one tested at TRANSDEC are expected to be less than 1 dB, due to slight differences in hydrophone sensitivity and circuitry.

The calibration testing showed the theoretical response of the instrument to be within about 1 dB of the measured response. The seafloor recorder is not expected to have a meaningful response below 2 Hz and absolute calibration is questionable below 10 Hz. The high frequency rolloff of the recorder used begins at 220 Hz and provides -36 dB/octave of protection from aliasing. The noise floor of the instrument is calculated to be near the lowest values observed in this study. Because of possible differences in the antialias filtering between instruments, these data are plotted only to 220 Hz, the start of the antialiasing rolloff.

D. Spectral averaging

The analysis of Wenz (1964) used either 165 or 200 s of data for each spectral average. Wenz (1964) used only three averages per hour, presumably because of data processing limitations, while the 2005–2006 recordings were analyzed using continuous data with no overlap between 200 s spectral averages, processed with a Hann window. The 2005–2006 spectra were calculated as 1 Hz bins, which is a standard procedure for noise spectra, providing more detailed information than one-third octave bands to help identify sound sources. The 2005–2006 spectrum which includes local shipping noise is an average computed continuously over all data from the 179 day deployment using a 200 s average for a total of 62 504 spectra.

To estimate noise levels when local ship noise is not apparent in the data, time intervals of 30 min each were chosen, as near as possible to sunrise, local noon, sunset, and local midnight for each day. When a 30 min time interval free of ship noise was not available a lesser interval of not less than 10 min was used. Sometimes there were no intervals of 10 min or more free of ship noise for as long as several days. The presence of ship noise was determined by examining spectrogram views of the data with 1 Hz spectral bins for either strong tonals associated with ships or for strong cavitation noise. In total, 319 spectra free of local ship noise, averaging near 30 min each in duration, were chosen in this manner.

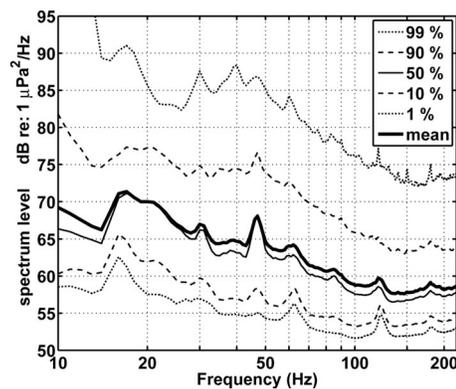


FIG. 3. The 2005–2006 pressure spectrum level distribution at the San Clemente site including local shipping. A total of 62 504 spectra, each 200 s in duration, spanning 179 days was used.

III. RESULTS

The 2005–2006 pressure spectra that include local ship noise reveal average noise levels to be about 70 dB re $1 \mu\text{Pa}^2/\text{Hz}$ at 20 Hz, decreasing to about 58 dB re $1 \mu\text{Pa}^2/\text{Hz}$ at 200 Hz (Fig. 3). Spectral level cumulative distributions for 2005–2006 are long tailed for higher values, with the ambient noise cumulative 99 percentile about 20 dB above the mean, whereas the 1 percentile is about 10 dB below the mean (Fig. 3). Since Wenz (1964, 1965) did not report 1958 or 1963 spectral levels in the presence of ships, a direct comparison with 2005–2006 spectra including local ship noise is not possible.

Pressure spectrum average levels excluding local ships in 2005–2006 are as much as 10 dB lower than the long-term average including ships (Fig. 4). The differences between

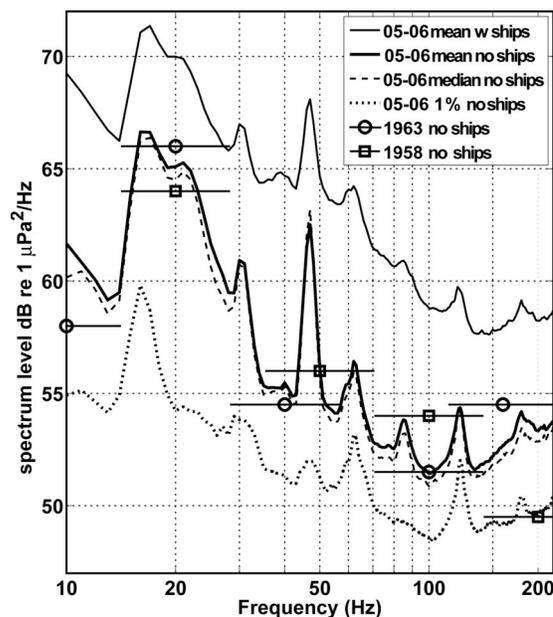


FIG. 4. The 2005–2006 pressure spectrum levels at the San Clemente site excluding local shipping are compared to the spectrum levels from representative one-third octave averages of November–December 1958 (\square) and 1963 (\circ) at 0800 h for the same site with local ship noise excluded and the 2005–2006 mean values with ships included. The horizontal bars on the 1958 and 1963 values indicate the frequency ranges of the one-third octave bands used to compute the values.

noise levels with and without ships are slightly larger at 10–80 Hz (8–10 dB) than for frequencies >100 Hz (5–6 dB). The median and mean spectral levels excluding local ships are essentially the same, as illustrated by the heavy dashed line and heavy solid lines in Fig. 4. The ambient spectrum cumulative 1 percentile distribution without local ship noise (dotted line in Fig. 4) is 3–5 dB below the mean, with levels of 54 dB re $1 \mu\text{Pa}^2/\text{Hz}$ at 20 Hz, decreasing to about 48 dB re $1 \mu\text{Pa}^2/\text{Hz}$ at 100 Hz.

Ambient pressure spectral levels excluding local ship noise were effectively the same in 1958, 1963, and 2005–2006 (see points in Fig. 4). Data from 1958 and 1963 differ from the 2005–2006 data by less than 5 dB, with equal numbers of the early data points below and above the recent data in noise level. Note that it was necessary to selectively choose 1958 and 1963 data that were not biased upward in noise level due to high winds or high biological noise. The 1958 data were chosen to avoid unusually high winds and the 1963 data were chosen from a time of day that did not contain high levels of fish chorusing.

Both early and recent data sets show mean pressure spectrum levels dominated by the calls of fin and blue whales over the 15–30 Hz band (McDonald *et al.*, 1995). When ships are present, blue and fin whale calls rise about 5 dB above the background noise (see peaks at 15–22 and 48 Hz in the top curve in Fig. 4). When ships are absent, these blue and fin whale call levels are 10 dB above the background noise (bold curve in Fig. 4). Note that in absolute terms, the blue and fin whale spectral peaks are about 5 dB lower when ships are absent, suggesting a responsive change in blue and fin whale source levels in the presence of ship noise.

If one excludes the fin and blue whale calls, the average noise level in 2005–2006, in the absence of ships, slopes from about 60 dB re $1 \mu\text{Pa}^2/\text{Hz}$ at 10 Hz to about 53 dB re $1 \mu\text{Pa}^2/\text{Hz}$ at 70 Hz. In the 70–220 Hz range the noise level is about 52.5 dB re $1 \mu\text{Pa}^2/\text{Hz}$. Note that noise peaks near 60, 120, and 180 Hz may be related to seafloor electrical power cables and are not thought to be components of the ambient noise field.

IV. ANALYSIS AND DISCUSSION

A. Shipping noise

Comparisons between 1963 and 2005–2006 at the study site suggest that it has experienced increased exposure to local shipping noise. The analysis by Thompson (1965) of eight days of data from July 1963 at this site reports that 31% of the recordings contained ship propulsion sounds. A ship noise analysis of the 179 days of recordings from 2005–2006 was conducted by examining 200 random times, chosen with a random number generator, from throughout the recording interval. Significant local ship noise was present in 89% of the samples to a degree such that these samples could not be used for the local-ship-excluded noise average. The nearby location of the Navy test range to the west of San Clemente Island may contribute local ship noise. This site is not directly on a commercial shipping transit lane and is shielded from ships near Long Beach/Los Angeles and San

Diego by the presence of Santa Catalina and San Clemente Islands. However, ships transiting from Long Beach to the southwest (e.g., to Hawaii or Australia) pass nearby this site to the north. Likewise, some local ship traffic may result from fishing activity in this area.

The local-ship-included noise levels are presented in Fig. 3 for comparison to other locations and to this same location in the future. Unfortunately, Thompson (1965) did not present a local-ship-included noise average for comparison. Omnidirectional noise levels at a site 7 nautical miles west of San Diego are reported to be 72 dB re $1 \mu\text{Pa}^2/\text{Hz}$ at 62 Hz when local ship noise is included (Heitmeyer *et al.*, 2004). The local shipping included noise level at the site of this study is 64 dB re $1 \mu\text{Pa}^2/\text{Hz}$ at 62 Hz (Fig. 3), suggesting greater local ship noise influence near the port of San Diego.

Deep-water ambient noise levels are generally more predictable than coastal ambient noise levels because distant shipping noise typically dominates deep-water noise levels. Shallow water noise levels are highly variable primarily because of differences in local acoustic propagation and seafloor absorption characteristics. The results of this study suggest that distant shipping traffic does not provide a significant contribution to ambient noise at the study site, leaving wind noise, biological noise, and local shipping to determine noise levels.

At many shallow water coastal sites, where acoustic propagation is more efficient over long ranges than at this site, distant shipping provides the major contribution to ambient noise. Many coastal sites show mean spectrum levels at 50 Hz which are 15–20 dB higher than the San Clemente Island site after exclusion of obvious local shipping noise, examples being from the Norwegian Sea (Walkinshaw, 1966), Eastern Canada (Zakarauskas *et al.*, 1990), and the Mediterranean (Kuperman and Ferla, 1985). Even higher levels have been measured in the North Sea and Baltic Sea (Wille and Geyer, 1984). This difference can be attributed to a relatively constant depth flat seafloor allowing for much better propagation of distant shipping noise at these other sites when compared with the irregular bathymetry of the California continental borderlands. A study by Piggott (1964) off Eastern Canada found relatively low noise levels, although still higher than those recorded at the San Clemente Island site. Piggott's (1964) relatively low spectrum levels have been attributed to poor acoustic propagation near his study site (Zakarauskas *et al.*, 1990).

Sites in the Arafura and Timor Sea (Cato, 1976) are the only published results that have ambient noise levels as low as those found in this study. The San Clemente site is also quiet when compared to North Pacific measurements near the axis of the deep sound channel (Wenz, 1969; Andrew *et al.*, 2002; McDonald *et al.*, 2006). Even including the noise from local ships, which are present 89% of the time at the study site, the mean noise levels at this study site are relatively low when compared to most other shallow water sites worldwide.

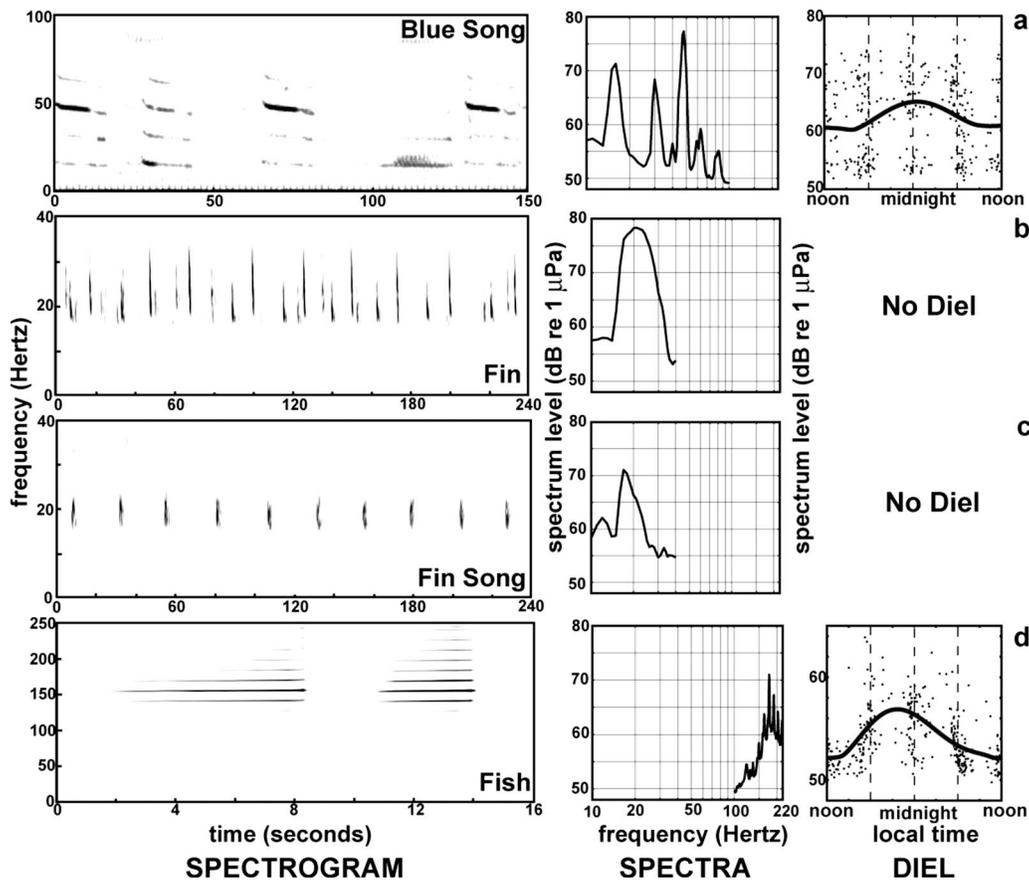


FIG. 5. The four most prominent biological sounds are (a) blue whale song, (b) fin whale countercalling, (c) fin whale song, and (d) a fish chorus referred to as the “motorboat,” each spectrogram computed with a 1 s FFT from the 2005–2006 data. Representative spectra are shown for each sound type, computed as a 30 min average over a time period when the given biological sound dominates. The diel variation shown here is the spectrum level of the most distinctive spectral peaks (a) 47.3 and (d) 181 Hz for each sound for the 319 spectral averages.

B. Biological sounds

The strongest seasonal variations in noise at the San Clemente site are due to blue and fin whale calling which appears as a broad spectral peak near 20 Hz (Fig. 5), most prominently in the fall (Thompson, 1965, Burtenshaw *et al.*, 2004). Blue whales are normally present in this region only from June through January, while fin whales are present year-round (Oleson *et al.*, 2007a). The 20 Hz spectral peak results from patterned song calls of blue whales, which increase in occurrence during the fall (Oleson *et al.*, 2007b). The 2005–2006 study period (179 days) coincided with the seasonal occurrence of blue whale song in this region (Burtenshaw *et al.*, 2004), as did the data from 1958 and 1963 (plotted in Fig. 4). The blue whale population off California has been increasing (Calambokidis and Barlow, 2004) though the blue whale song spectrum levels at this site appear more or less the same in 1958, 1963, and 2005–2006. Blue whale singing appears to increase at nighttime [Fig. 5(a)], based on the spectrum level at 48 Hz, the frequency midpoint of the third harmonic of the blue whale song during 2005–2006 (Oleson *et al.*, 2007b). Subtle diel variations, due to peaks in blue whale calling near sunrise and sunset, may be present in these data (Thompson, 1965; Wiggins *et al.*, 2005). Less prominent blue whale sounds include D calls (countercalling), which are occasionally significant in terms of average spectral levels.

The two dominant sounds produced by fin whales in this region include irregularly spaced pulses of about 0.8 s duration [Fig. 5(b)], which are sometimes used as countercalls between traveling fin whales (McDonald *et al.*, 1995; McDonald and Fox, 1999) and similar pulses used in patterned calls [Fig. 5(c)], often with bimodal temporal spacing (Thompson *et al.*, 1992), produced only by males (Croll *et al.*, 2002). These temporally patterned calls are referred to as song and have a stereotypical character. At this site, the fin whale call type changed from dominantly irregular countercalls to dominantly song type calls about the second week of December. No diel pattern was discerned with these data for either the countercall type or the song type calls.

The studies of Wenz (1964), Wenz *et al.* (1965), and Thompson (1965) found at least three different sounds known to be produced by fishes, which at given times and seasons set the ambient noise levels within a frequency band near 150–200 Hz. The 1958 fish sounds differed in frequency and seasonality from the 1963 sounds, suggesting that different species were present. The 2005–2006 data contained only one obvious fish sound [Fig. 5(d)], this showing a strong diel pattern. When a single day of data free of local ship noise is examined the diel pattern is commonly stronger than the mean for all (319) spectral averages as in Fig. 5(d). The diel pattern is asymmetrical within the night, the greatest chorusing occurring shortly after sunset, suggesting a crep-

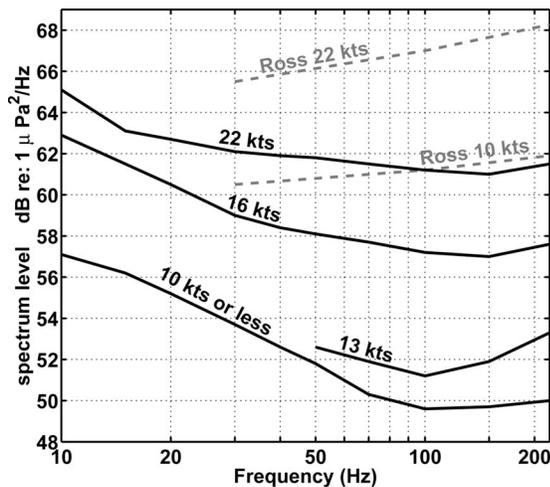


FIG. 6. In the absence of local shipping traffic, surface wind/wave noise is seen across the entire study band when winds exceed about 13 kn. The generalized wind speed/noise curves of Ross (1976) are included for comparison.

uscular pattern. The spectrum presented in Fig. 5(d) shows peaks near 150 Hz, corresponding to what is presumed to be an individual fish near the hydrophone. The precise spectral peaks change from one recording to the next, resulting in an average spectral peak near 180 Hz. The fish sounds in the spectrogram of Fig. 5 are pulsive in nature, a 1 s duration fast Fourier transform (FFT) resulting in 15 Hz sidebands, corresponding to the 15 pulses per second. The presumed fish sounds described by Thompson (1965) were characterized as a “motorboat” sound because of their similarity to the sound of a single piston small boat motor. A detailed review and comparison of these fish sounds with the current data is beyond the scope of this study, but a 10–20 dB diel pattern with higher intensities during the night was found in 1963.

In January and February gray whale and humpback whale calls and song are present in sufficient quantity to increase the average noise levels over periods of hours, but do not contribute substantially to the ambient pressure spectrum level when averaged over monthly or seasonal time periods. Recordings with greater bandwidth would be better suited for the study of these sounds, as most of the sounds produced by these species occur above the frequencies recorded in this study.

C. Wind driven surface wave noise

The relatively low ambient noise levels that occur at the study site when local shipping noise is absent allow correlation of ambient noise levels to wind speed across the entire 10–220 Hz band considered in this study. The average and median wind speed during the study period was 7 kn, with the highest sustained wind speed being 22 kn. Periods with low biological and ship noise were selected to compute hourly averaged spectra as wind speed changed, particularly selecting for intervals with high wind speeds (Fig. 6). These data suggest a minimum surface wind noise at 100–150 Hz, with about a 6 dB/octave increase in noise level at lower frequencies, and a 1–2 dB/octave increase in noise level at higher frequencies. The correlations in Fig. 6 show notably

lower spectral levels than Ross (1976) or Urick (1983). The wind speed noise correlations of Ross (1976) and Urick (1983) peak near 250 Hz and decrease down to where the curves end near 100 Hz (Urick, 1983) or 30 Hz (Ross, 1976). The increase in noise level at the highest frequencies of Fig. 6 corresponds in shape to the plots in Ross (1976) and Urick (1983), but is lower in absolute spectral level.

The 10 km separation between the wind and the ambient noise recording sites for this study may result in some error, although the high winds in this region typically come from the west, with no sheltering effect from the island at this site. While propagation conditions and seafloor absorption characteristics are important to such wind-noise correlations, the data in Fig. 6 are likely better for estimating wind related noise levels in similar water depths in California coastal waters than the deep-water correlations of Ross (1976) or the more generalized correlations of Urick (1983).

Studies of wind noise using vertical hydrophone arrays to separate ship traffic and other distant noise from wind-wave noise (Kewley *et al.*, 1990; Chapman and Cornish, 1993) have estimated source level as opposed to omnidirectional noise spectrum levels versus frequency. The conversion from source level to omnidirectional spectrum level assumes a frequency dependent bottom reflection loss (Burgess and Kewley, 1983). If seafloor reflection loss is large, the conversion is approximately 7 dB, if seafloor reflection loss is 4 dB the conversion is 8.5 dB and for a 2 dB loss the conversion factor is 13.5 dB. The source level at 100 Hz from Kewley *et al.* (1990) and Chapman and Cornish (1993) is 50 dB for a 10 kn wind, predicting a noise level not less than 58 dB at 100 Hz, which is about 8 dB higher than that seen in Fig. 6. This discrepancy might be explained by leakage of near horizontally propagating distant noise into the vertically beamformed noise measurements or it might be that deep-water waves are different than those at this site.

Wenz (1964) plotted wind speed versus spectrum level, but he found as much as 10 dB of unexplained discrepancy in the wind speed to spectrum level correlations from one data set to the next, perhaps due to noise from nonwind related sources, which caused a coincidental correlation in his small data set. Wenz (1964) did not have the technology to readily examine his data in modern spectrogram form to help identify known noise sources.

D. Minimum noise levels

The biological and other-noise lines can be identified and removed from the minimum noise level plot to estimate the background noise level when winds are calm (Fig. 7). The minimum noise level is 55 dB re $1 \mu\text{Pa}^2/\text{Hz}$ at 10 Hz, decreasing at about 6 dB/octave at higher frequencies. Above the minimum spectral level are seen three spectral lines at multiples of 60 Hz. These lines vary slightly in frequency and time, but they are not impulsive or diel as may be expected for biological sounds. In addition, the seafloor recorder does not use 60 Hz power, and if these peaks were electronic noise lines associated with the recorder, such broad peaks would not be expected. Their origin remains undetermined, but we speculate that they may be associated

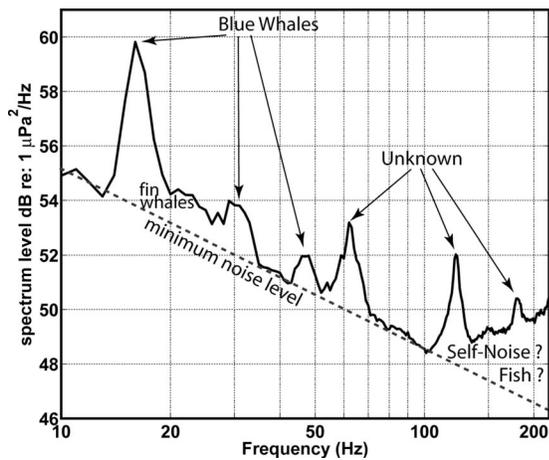


FIG. 7. The lowest one percentile ambient noise curve is shown with noise sources identified. The dashed line is suggested as the minimum noise level in the absence of biological sources. The wind is presumed to be calm at this site for the lowest 1% of noise levels.

with seafloor cables passing near this site, which terminate at San Clemente Island. Above 100 Hz the increased ambient noise seen in Fig. 7 may be due to instrumental self-noise or to the presence of fish chorusing. After removing the biological and other-noise lines, the ambient noise level is 10–15 dB lower than the ambient noise in deep-water offshore of the continental shelf, and as mentioned previously, it has not been increasing over the past 50 years as the deep-water noise levels have.

V. RECOMMENDATIONS

New and better metrics for ship noise should be developed to better examine the question of how local ship noise may be affecting marine mammals. Such metrics would ideally integrate hearing perception curves for each species of interest and percentile plots of noise levels at multiple sites using various averaging intervals appropriate to the hearing integration times of the particular species. For the species which use the frequency band of this study (e.g., blue and fin whales), hearing perception curves have not been measured.

The reoccupations of additional early shallow water ambient noise study sites such as those of Piggott (1964) off Eastern Canada, Walkinshaw (1966) in the Norwegian Sea, and Wenz (1961) in the Bering Sea are needed to better judge long-term changes in ambient sound on continental shelves. These earlier studies also often report the percentage of time local shipping noise was apparent in the data allowing for comparison with more recent recordings.

ACKNOWLEDGMENTS

This work was supported by the US Navy CNO N45 and ONR, and we thank Frank Stone, Ernie Young, Jeff Simmons, and Bob Gisiner.

- Andrew, R. K., Howe, B. M., Mercer, J. A., and Dzieciuch, M. A. (2002). "Ocean ambient sound: Comparing the 1960's with the 1990s for a receiver off the California coast," *ARLO* **3**, 65–70.
- Burgess, A. S., and Kewley, D. J. (1983). "Wind-generated surface noise source levels in deep water east of Australia," *J. Acoust. Soc. Am.* **73**, 201–210.

- Burtenshaw, J. C., Oleson, E. M., Hildebrand, J. A., McDonald, M. A., Andrew, R. K., Howe, B. M., and Mercer, J. A. (2004). "Acoustic and satellite remote sensing of blue whale seasonality and habitat in the Northeast Pacific," *Deep-Sea Res., Part II* **51**, 967–986.
- Calambokidis, J., and Barlow, J. (2004). "Abundance of blue and humpback whales in the eastern north Pacific estimated by capture-recapture and line-transect methods," *Marine Mammal Sci.* **20**, 63–85.
- Cato, D. H. (1976). "Ambient sea noise in waters near Australia," *J. Acoust. Soc. Am.* **60**, 320–328.
- Chapman, N. R., and Cornish, J. W. (1993). "Wind dependence of deep ocean ambient noise at low frequencies," *J. Acoust. Soc. Am.* **93**, 782–789.
- Croll, D. A., Clark, C. W., Acevedo, A., Tershy, B., Flores, S., Gedamke, J., and Urbán-Ramírez, J. (2002). "Only male fin whales sing loud songs," *Nature (London)* **417**, 809–810.
- Heitmeier, R. M., Wales, S. C., and Pflug, L. A. (2004). "Shipping noise predictions: capabilities and limitations," *Mar. Technol. Soc. J.* **37**, 54–65.
- Ingenito, F., and Wolf, S. N. (1989). "Site dependence of wind-dominated ambient noise in shallow water," *J. Acoust. Soc. Am.* **85**, 141–145.
- Kewley, D. J., Browning, D. G., and Carey, W. M. (1990). "Low-frequency wind-generated ambient noise source levels," *J. Acoust. Soc. Am.* **88**, 1894–1902.
- Kuperman, W. A., and Ferla, M. C. (1985). "A shallow water experiment to determine the source spectrum level of wind generated noise," *J. Acoust. Soc. Am.* **77**, 2067–2073.
- McDonald, M. A., and Fox, C. G. (1999). "Passive acoustic methods for fin whale population density estimation," *J. Acoust. Soc. Am.* **105**, 2643–2651.
- McDonald, M. A., Hildebrand, J. A., and Wiggins, S. M. (2006). "Increases in deep ocean ambient noise in the Northeast Pacific west of San Nicolas Island, California," *J. Acoust. Soc. Am.* **120**, 711–718.
- McDonald, M. A., Webb, S. C., and Hildebrand, J. A. (1995). "Blue and fin whales observed on a seafloor array in the Northeast Pacific," *J. Acoust. Soc. Am.* **98**, 712–721.
- National Research Council (2003). *Ocean Noise and Marine Mammals* (National Academies Press, Washington, DC).
- National Research Council (2005). *Marine Mammal Populations and Ocean Noise: Determining When Noise Causes Biologically Significant Effects* (National Academies Press, Washington, DC).
- Oleson, E. M., Calambokidis, J., Barlow, J., and Hildebrand, J. A. (2007a). "Blue whale visual and acoustic encounter rates in the Southern California Bight," *Marine Mammal Sci.* **23**, 574–597.
- Oleson, E. M., Calambokidis, J., Burgess, W. C., McDonald, M. A., and Hildebrand, J. A. (2007b). "Behavioral context of call production by Eastern North Pacific blue whales," *Mar. Ecol.: Prog. Ser.* **330**, 269–284.
- Piggott, C. L. (1964). "Ambient sea noise at low frequencies in shallow water of the Scotian shelf," *J. Acoust. Soc. Am.* **36**, 2152–2163.
- Ross, D. (1976). *Mechanics of Underwater Noise* (Pergamon, New York).
- Ross, D. (1993). "On ocean underwater ambient noise," *Institute of Acoustics Bulletin* **18**, 5–8.
- Thompson, P. O. (1965). "Marine biological sound west of San Clemente island," U.S. Navy Electronics Laboratory Report No. 1290, San Diego, CA, p. 42.
- Thompson, P. O., Findley, L. T., and Vidal, O. (1992). "20-Hz pulses and other vocalizations of fin whales, *Balaenoptera physalus*, in the Gulf of California, Mexico," *J. Acoust. Soc. Am.* **92**, 3051–3057.
- Urick, R. J. (1983). *Principles of Underwater Sound*, 3rd ed. (McGraw-Hill, New York), pp. 202–236.
- Walkinshaw, H. M. (1966). "Measurements of ambient noise spectra in the south Norwegian Sea," originally published in U. S. Navy J. Underwater Acoust.; reprinted in (2005). *IEEE J. Ocean. Eng.* **30**, 262–266.
- Wenz, G. M. (1961). "Periodic variations in underwater low-frequency ambient noise levels," U.S. Navy Electronics Laboratory Report No. 1014, declassified 1973.
- Wenz, G. M. (1964). "Ambient noise measurements west of San Clemente Island," U.S. Navy Electronics Laboratory Report No. 1235, declassified 1970.
- Wenz, G. M. (1969). "Low-frequency deep-water ambient noise along the Pacific Coast of the United States," U. S. Navy J. Underwater Acoust. **19**, 423–444, declassified 1997.
- Wenz, G. M., Calderon, M. A., and Scanlan, T. F. (1965). "Underwater acoustic ambient-noise and transmission tests west of San Clemente Island, July 1963," U.S. Navy Electronics Laboratory Report No. 1260, declassified 1994.

- Wiggins, S. M. (2003). "Autonomous Acoustic Recording Packages (ARPs) for long-term monitoring of whale sounds," *Mar. Technol. Soc. J.* **37**, 13–22.
- Wiggins, S. M., Oleson, E. M., McDonald, M. A., and Hildebrand, J. A. (2005). "Blue whale (*Balaenoptera musculus*) diel call patterns offshore of Southern California," *Aquat. Mamm.* **31**, 161–168.
- Wille, P. C., and Geyer, D. (1984). "Measurements on the origin of the wind-dependent ambient noise variability in shallow water," *J. Acoust. Soc. Am.* **75**, 173–195.
- Zakaras, P., Chapman, D. M. F., and Staal, P. R. (1990). "Underwater acoustic ambient noise levels on the eastern Canadian continental shelf," *J. Acoust. Soc. Am.* **87**, 2064–2071.