Underwater Radiated Noise Levels along the California Coast for Participating Vessels in the 2024 Protecting Blue Whales and Blue Skies Program

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1. Introduction

The Scripps Machine Listening Lab was contracted by the Protecting Blue Whales and Blue Skies program to analyze acoustic data for the 2024 vessel speed reduction (VSR) effort along the California coast. This study involves the analysis of underwater radiated noise metrics (source level and noise level) at three sites, the Santa Barbara Channel (Site B), Monterey Bay (Site MB) and San Francisco (Site SF). The VSR program was active during the 2024 season from May 1, 2025 through the end of the year.

The specific goals of this study were to:

- Quantify differences in source levels at Site B while the VSR program was active versus inactive,
- Estimate differences in source levels at Sites MB and SF while the program was active versus inactive based on historical source level measurements at Site B,
- Quantify differences in noise levels at Site B while the VSR program was active versus inactive.

The key results of this study are:

- Mean source levels were reduced during the VSR program active period at each site by 5.4 dB (Site B), 4.6 dB (Site SF), 2.3 dB (Site MB), equating to a percent reduction in sound pressure of 46%, 41%, and 23%, respectively.
- Across all sites, there was a 36% mean reduction in sound pressure.
- Noise level reduction at Site B was 3.94 dB (36%).

2. Background

Reducing underwater radiated noise (URN) pollution generated by ships has become an international priority for ocean conservation (Chou et al., 2021; IMO, 2018, 2023; IWC, 2014). URN reduction techniques are beginning to be explored and implemented around the world (MacGillivray et al., 2019; Malinka et al., 2023; ZoBell et al., 2021b; ZoBell et al., 2023a). Critical habitats, marine sanctuaries, and marine monuments are of high priority for protection from noise pollution. In 2014, the Channel Islands National Marine Sanctuary (CINMS) partnered with the Santa Barbara County Air Pollution Control District, Ventura County Air Pollution Control District, National Marine Sanctuary Foundation, and the Environmental Defense Center to implement a voluntary, incentive-based vessel speed reduction (VSR) initiative known as the Protecting Blue Whales and Blue Skies Program (hereafter BWBS program). Enrollment was made available to companies operating container ships or vehicle carriers within the vessel speed reduction zone. In addition to its original goals of reducing the risk of ship strikes on endangered whales and decreasing air pollution emissions, the BWBS program also recognized the opportunity to address underwater noise pollution from vessels. During the 2024 season, vessel speed reduction zones were expanded along the California coast to encompass much of Northern and Central California. Participating vessels were asked to travel

10 knots or less during May 1, 2024 through December 31, 2024 through the expanded VSR zone.

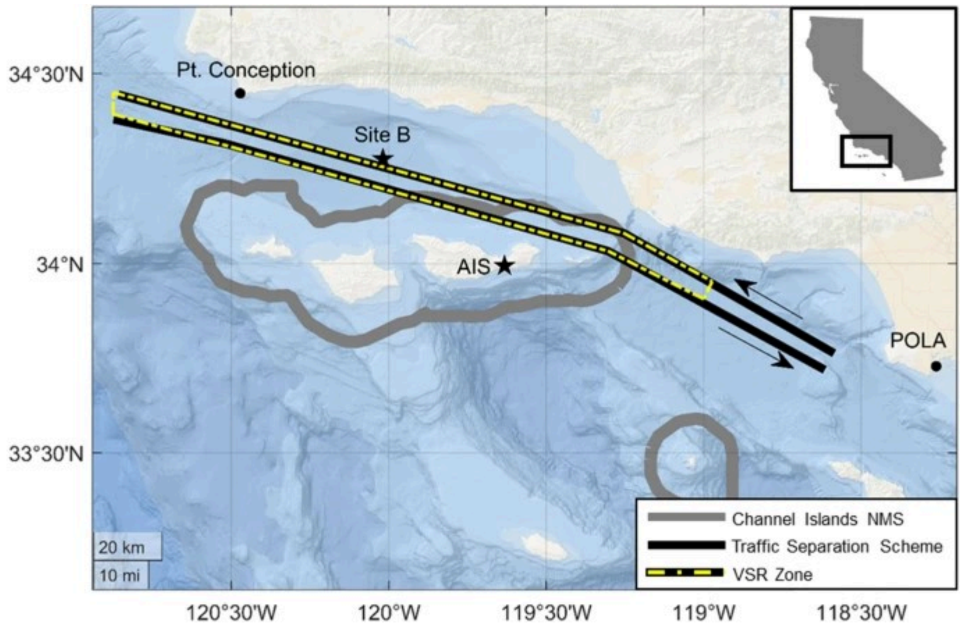

Figure 1: Vessel speed reduction zone from the 2014 Protecting Blue Whales and Blue Skies Program in relation to the traffic separation scheme and Channel Islands National Marine Sanctuary.

For over a decade, the Scripps Institution of Oceanography has monitored ambient noise levels within the Santa Barbara Channel with High-frequency Acoustic Recording Packages (HARPs; Figure 1). Ambient noise levels within the region largely reflected the volatility and cyclicity of maritime traffic patterns, which are shaped by factors such as holidays and U.S. consumer spending (Figure 2). Historical economic and port events, such as the implementation of the California Air Resources Board Vessel Fuel Rule, anchorage congestion, and dock workers strikes, are reflected within the soundscape (Figure 2).

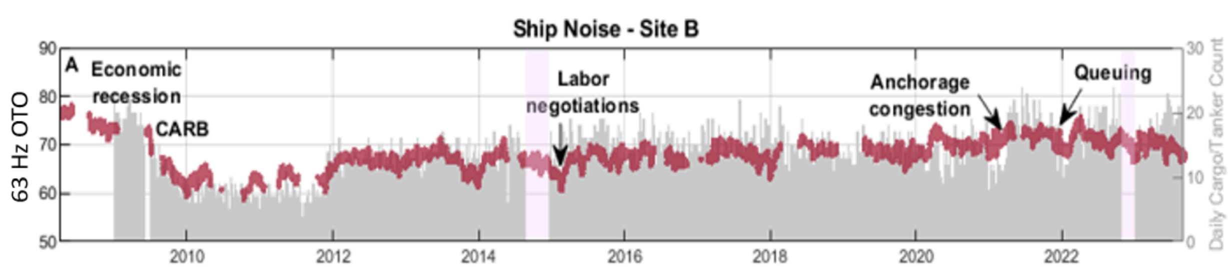

Figure 2: Daily ambient sound levels at a HARP site within the Santa Barbara Channel with associated daily count of unique cargo ships and tankers. Socioeconomic events, such as economic recessions and labor negotiations are defined in the timeseris.

In 2019, the Scripps Whale Acoustics Lab quantified the reduction in source levels and sound exposure levels of participating vessels in the Protecting Blue Whales and Blue Skies program (ZoBell et al. 2021). Annual reporting of source level reductions in the Southern California region has continued annually by the Scripps Machine Listening Lab, with a 5.4 dB mean source level reduction for participating vessels documented for 2023 (ZoBell et al. 2024).

Due to the expansion of the VSR zone in 2024, underwater noise analytics were expanded to the central California and northern California regions (Figure 3). A HARP site in the Monterey Bay area (MB), managed by the Naval Postgraduate School, was proposed to be included in the 2024 noise reduction analysis to monitor changes in source levels of vessels in the Central Coast area. However, the data was contaminated at low-frequencies by noise associated with continuous hydrophone cable strum linked to high currents, and was not usable for this analysis. Instead, the site location of this instrument was used to identify participating vessel activity, and source levels were estimated from AIS data from the same vessels transiting at similar conditions from the historical source level database from Site B. Because there are currently no listening stations in the San Francisco region, AIS data from a location within the shipping lane was used to estimate source levels from the same vessels transiting at similar conditions from the source level database from Site B. An additional noise metric, noise level, was added to the noise reduction analysis for Site B. Noise levels for Site MB and Site SF may be computed for future years with acoustic data (Site MB), addition of an acoustic sensor (Site SF), and ambient noise modeling.

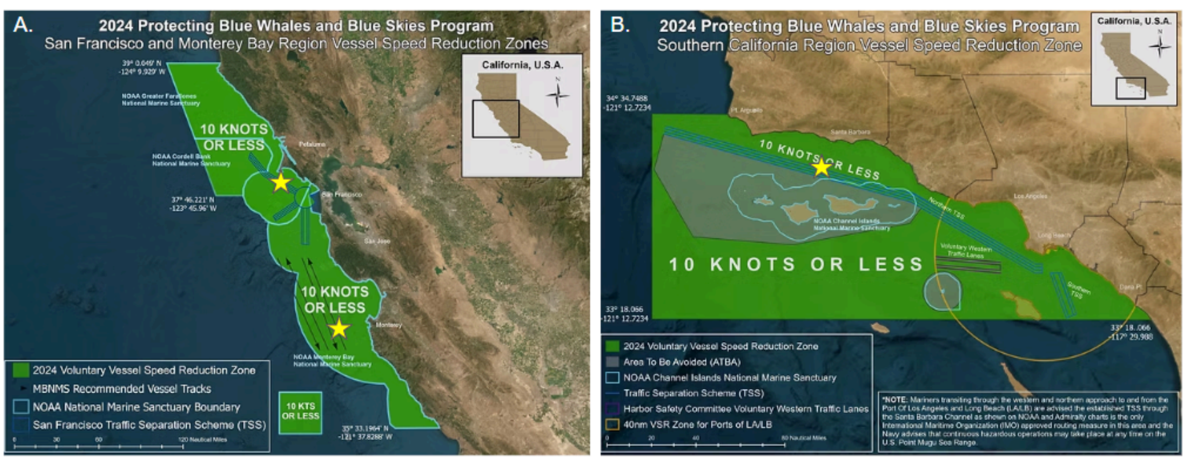

Figure 3: Expanded vessel speed reduction zone along the California coast. Sites where source levels and noise levels were either measured (Southern California) or estimated (Northern / Central California) are denoted by a yellow pentagram.

3. Methods

3.1 Ship Passages

Automatic identification system (AIS) data was received from the United States Coast Guard for 25 - 50 km surrounding each recording site. The ship name, IMO identification, type, speed over ground (SOG), draft, length, and position (latitude and longitude) were retained from the AIS messages.

The High-frequency Acoustic Recording Package (HARP) used in this study has been maintained in the Santa Barbara Channel for over a decade. Site B is moored in the Santa Barbara Channel (34.250°, -120.025°) at ~ 580 m depth. Acoustic recordings were collected at a sampling rate of 200 kHz from January 1 through November 6. The data collected at Site B were decimated by a factor of 20 before source level and noise level calculations for computational efficiency. The data were low pass filtered with an 8th order Chebyshev Type I IIR filter to prevent aliasing during decimation. The acoustic recordings were scanned for data quality, and transits that were contaminated with low-frequency hydrophone cable strumming were excluded. Site MB is located off of Point Sur within the Monterey Bay National Marine Sanctuary (36.37°, -122.32°) at 855 m depth. Data from MB was not used in this year's analysis due to low-frequency noise contamination, but may be included in future year analyses. Source levels of participating vessels transiting by Site MB and Site SF (37.88°, -122.93°) were estimated by identifying the same vessel from the Site B source level database. A vessel from Site MB and Site SF was included only if there was a transit of the same vessel transiting at a similar speed (maximum difference of 1 knot) in the historical source level database.

3.2 Source Levels

For acoustic recordings at Site B, AIS data was pruned to 6 km around the sensor location for efficient batch processing. Sound pressure levels (SPLs) for each vessel transit were averaged over the data window period that equaled the time it took the ship to travel its length, as defined in ANSI/ASA (2009). For the data window period, a fast Fourier transform (FFT) and Hanning window with FFT length of 10,000 samples and 60% overlap provided the power spectral density (PSD) in 1 Hz bins. Ten times the base-10 logarithm of the PSD in 1 Hz bins was used to convert to sound pressure received levels in decibels (dB) referenced to a unit pressure density (1 μPa^2). The frequency-dependent hydrophone calibration was then applied to the PSDs to produce SPL in dB re 1 $\mu Pa^2/Hz$.

Source levels were determined by applying propagation loss (PL) between the recording device and the source at the closest point of approach (CPA) to the SPLs for each vessel transit. A PL model that corrects for the Lloyd's mirror effect was applied to account for sea surface image source interference, in compliance with ISO (2019). The PL model ignores sound refraction in the water column and reflections from the seafloor and solely accounts for reflections from the sea surface. The Lloyd's mirror model incorporates the distance from the source to the receiver, distance from the image source to the receiver, and the wave number in rad/m. A modification of the Lloyd's mirror model was applied to remove mismatched interference lobes identified with ship noise measurements in compliance with ANSI/ASA (2009) and ISO (2019). The modification involves using the Lloyd's mirror model from 5 Hz up to the lowest frequency at which the Lloyd's mirror model and the spherical spreading model intersect, while at the higher frequencies, the spherical spreading model was used (Gassmann et al. 2017). Broadband source levels were computed from 5 Hz to 1 kHz and used for the final source level metric. Source levels of vessel transits were removed from the analysis if another vessel transit occurred within the monitoring area within 30 minutes to ensure that each ship transit was acoustically isolated. To remove any transits that may have source levels affected by bottom interactions, transits with the closest point of approach with less than a 12 degree surface angle (~3 km) were discarded.

Transits of participating vessels at Site MB and Site SF, which did not have a recording device or usable data, were estimated from historical source level measurements at Site B. Transits of the same vessel, operating within 1 knot of the operating speed, were used to estimate the source level of the transit passing Site MB and SF. If there were no representative transits in the Site B database, the transit was excluded from the analysis. The difference in estimated source levels between program active and inactive periods was computed by subtracting the mean source level of participating vessels during the active period from the mean source level of participating vessels during the inactive period. Percent change in sound pressure was calculated by dividing the change in decibels by 20, taking 10 to the power of that value, subtracting from 1, and multiplying by 100.

3.3 Noise Levels

Noise levels of participating vessels at Site B were computed by extracting the times in which a participating vessel was both within 10 km of the sensor and the nearest of all AIS-broadcasting vessels to the hydrophone. Only times in which vessels participating in the BWBS program were closest to the acoustic sensor were used for the noise reduction analysis, in an effort to decrease any confounding effects of noise reduction brought about by other factors. During the times in which the criteria were met, a PSD was calculated for 1s and 1 Hz bins. The 63-Hz one-third-octave level (TOL) was computed by summing sound pressure levels (in linear space) from the start to the end frequency of the band. The minute-level median noise levels are defined as the median of the 1 second resolution 63-Hz TOL. Percentiles of the minute-level median noise level distributions during the active and inactive periods were compared. The difference in noise level measurements between program active and inactive periods was computed by subtracting the mean noise level during the active period from the mean noise level during the inactive period.

4. Results

4.1 Source Level Analysis

4.1.1 Southern California

A total of 4,229 total vessels transits in the Santa Barbara Channel with paired AIS and acoustic data were within 6 km of the acoustic sensor. Of these transits, 1,140 total transits (26%) had a larger than 12 degree surface angle and were deemed suitable for source level calculations. When determining acoustic isolation from other vessels, 277 had to be discarded as they were too close to other vessels and could potentially be contaminated, resulting in 904 vessel transits with usable source levels. Of the final usable transits, there were 368 transits from BWBS participating vessels (252 during program active dates, and 116 during program inactive dates). Of the transits from participating vessels with paired AIS and acoustic data, the mean speed over ground during active versus inactive periods was 9.7 and 12.3 knots, respectively (Figure 4). The mean source level of participating vessels while the program was active versus inactive was 179.3 and 184.7 dB re 1μPa^2 @ 1m, respectively (Figure 5).

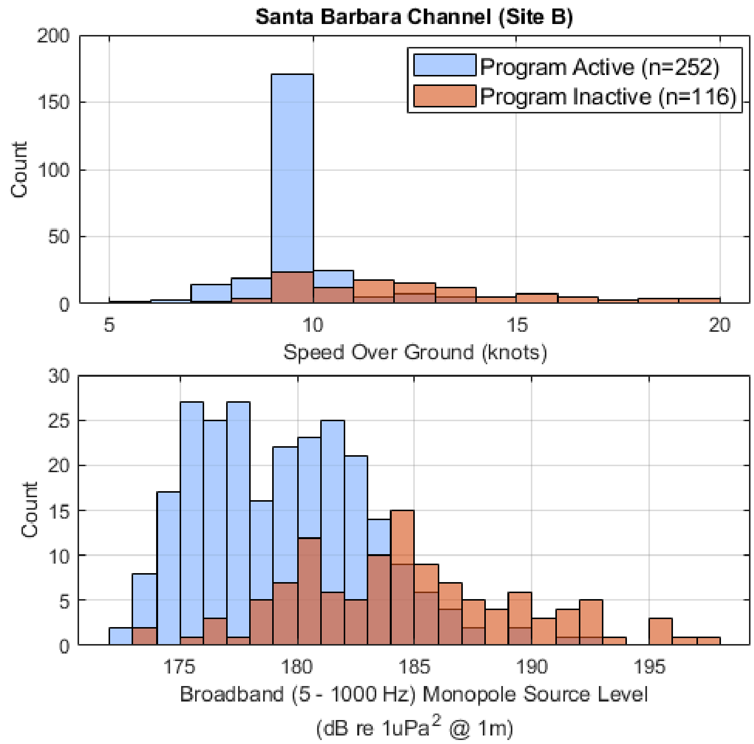

Figure 4: Speed over ground (knots) and broadband (5-1000 Hz) monopole source level (dB re 1uPa²) for participating vessels during active and inactive periods in the Southern California region (Site B).

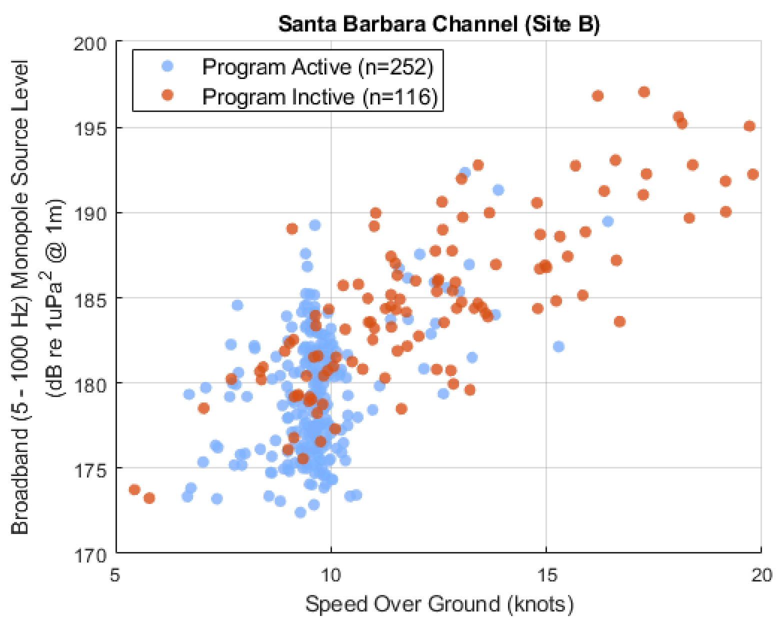

Figure 5: Speed over ground (knots) versus broadband (5-1000 Hz) monopole source level for participating vessels during active and inactive periods in the Southern California region.

4.1.2 Monterey Bay

Source levels for Site MB were estimated by identifying transits from Site B with the same vessels transiting within 1 knot of the operating speed during the transit at Site MB. There were 1,072 transits of participating vessels within 10 km around Site MB. Of these, there were 488 vessels represented in the Site B historical dataset (46%). There were 288 transits (27%) with speeds within 1 knot of a transit of the same vessel in the Site B dataset. There were 168 matching transits of participating vessels during active program months, and 125 transits during inactive program months. Of the transits from participating vessels within the radius of Site MB, the mean speed over ground during active versus inactive periods was 10.6 and 12.4 knots, respectively (Figure 6, 7). The mean source level of participating vessels while the program was active versus inactive was 181.2 and 183.5 dB re 1µPa² @ 1m, respectively.

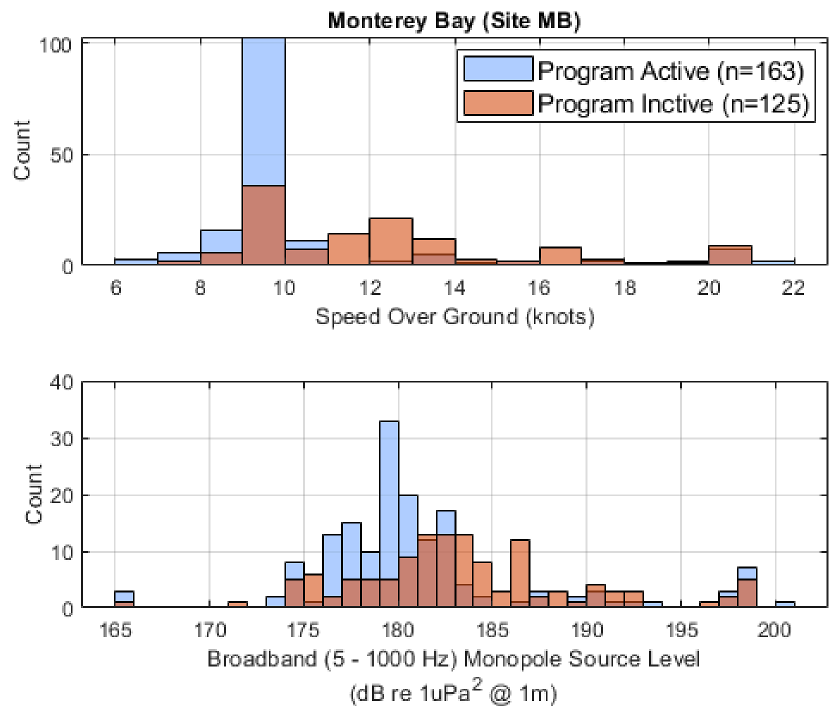

Figure 6: Speed over ground (knots) and broadband (5-1000 Hz) monopole source level (dB re 1uPa²) for participating vessels during active and inactive periods in the Monterey Bay region (Site MB)

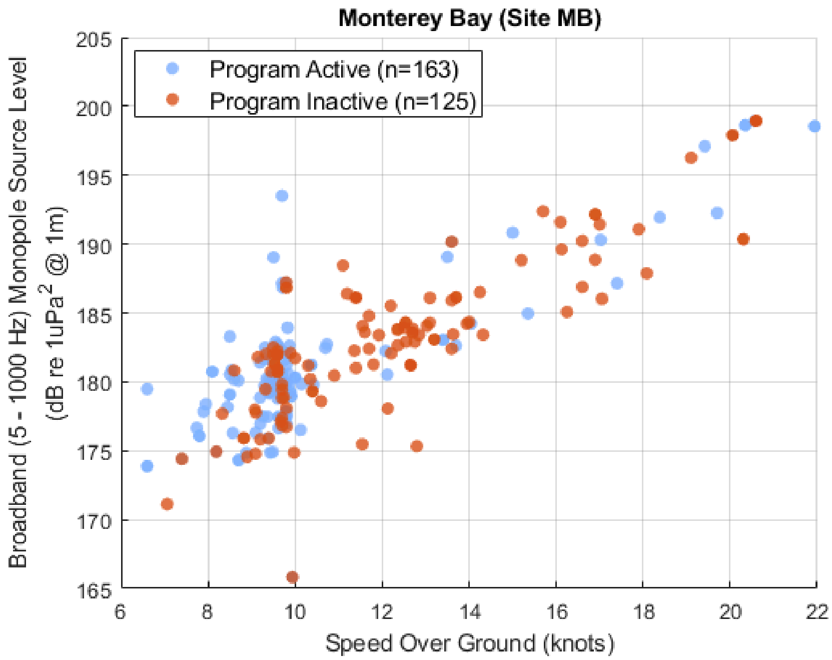

Figure 7: Speed over ground (knots) versus broadband (5-1000 Hz) monopole source level for participating vessels during active and inactive periods in the Monterey Bay region.

4.1.3 San Francisco

Source levels for Site SF were estimated by identifying transits from Site B with the same vessels transiting within 1 knot of the operating speed during the transit at Site SF. There were 2,146 transits of participating vessels within 10 km around Site SF. Of these, there were only 572 vessels represented in the Site B historical dataset (27%). There were 357 transits (17%) transiting within 1 knot of a historical observation of the same vessel at Site B. There were 257 matched transits during active program months, and 100 transits during inactive program months. Of the transits from participating vessels within the radius of Site SF, the mean speed over ground during active versus inactive periods was 9.6 and 12.6 knots, respectively (Figure 8, Figure 9). The mean source level of participating vessels while the program was active versus inactive was 180.1 and 184.7 dB re 1μPa^2 @ 1m, respectively.

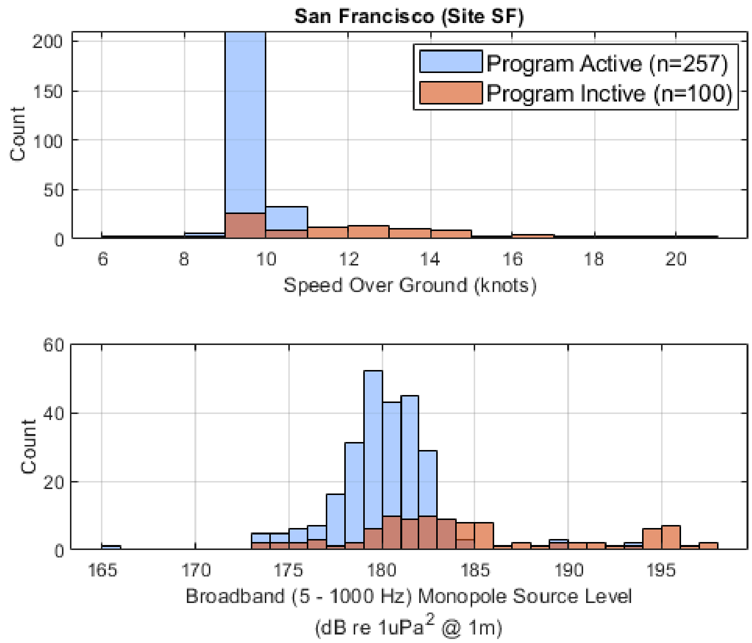

Figure 8: Speed over ground (knots) and broadband (5-1000 Hz) monopole source level (dB re 1uPa²) for participating vessels during active and inactive periods in the San Francisco region (Site SF).

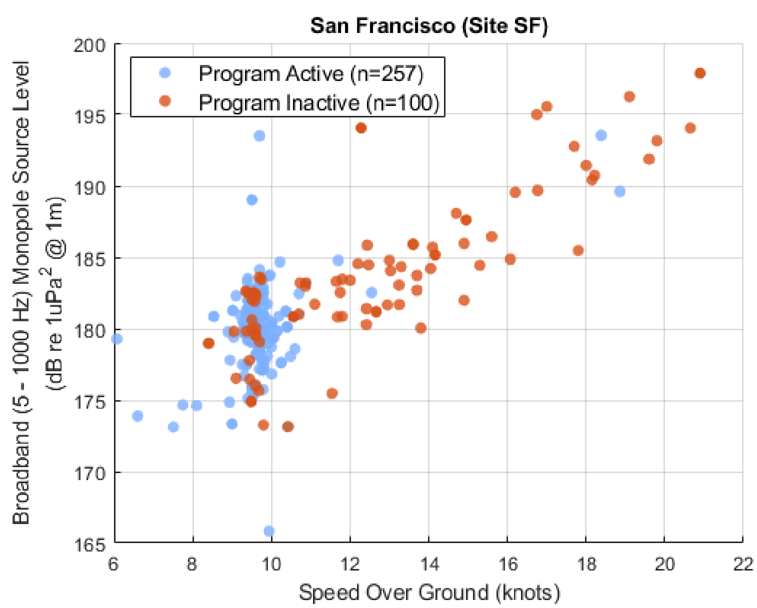

Figure 9: Speed over ground (knots) versus broadband (5-1000 Hz) monopole source level for participating vessels during active and inactive periods in the San Francisco region.

	2018	2019	2020	2021	2022	2023	2024
Southern California	1.0 dB (11%)	-	2.3 dB (23%)	4.1 dB (38%)	4.6 dB (41%)	5.4 dB (46%)	5.4 dB (46%)
San Francisco	-	-	-	-	-	-	4.6 dB (41%)
Monterey Bay	-	-	-	-	-	-	2.3 dB (23%)
All Program	-	-	-	-	-	-	4.1 dB (38%)

Table 1: Reduction in broadband (5-1000 Hz) monopole source levels in decibels per transit (dB) and percent sound pressure from 2018 through 2024.

4.2 Noise Level Analysis

A total of 42,209 one minute SPL medians met criteria for noise level analysis at Site B. Of these, 15,856 minutes were during the program inactive period and 26,353 were during the program active period (Figure 10). Percentiles of the noise levels (minute-level 63 Hz TOL) during the program active versus inactive periods were compared for the 10th, 50th, and 90th percentiles. The 50th percentile had a 3.9 dB reduction while the program was active versus inactive (Table 2).

Percentile	Program Inactive	Program Active	Difference
10	80.94 dB	78.86 dB	2.10 dB
50	89.95 dB	86.01 dB	3.94 dB
90	103.07 dB	98.34 dB	4.74 dB

Table 2: Noise level reduction analysis for 1 minute resolution 63-Hz one-third-octave levels represented in dB re 1uPa^2 (dB).

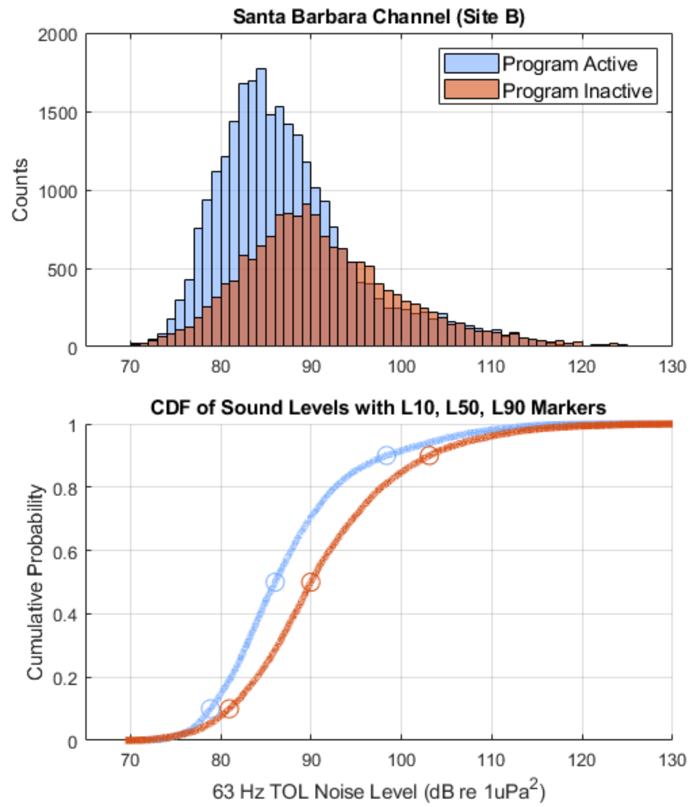

Figure 10: One minute resolution 63-Hz one-third-octave sound pressure levels and cumulative probability distribution. 10th, 50th, and 90th percentiles are marked with a circle.

5. Discussion

Source levels of participating vessels for all three sites, Sites B, MB, and SF, were compared, and noise metric differences during transits of participating vessels while the program was active versus inactive were calculated. Northern California sites only had 17% (SF) and 27% (MB) representation within the Southern California source level database. Source levels were estimated to have been reduced on average at all sites for participating vessels while the program was active. The source level reduction for Site B was the highest while the reduction was lowest for Site MB. The difference is attributed to a higher average speed (~1 knot faster) at Site MB during the program active period compared with the two other sites. The implementation of a queuing program was initiated from Northern California ports to Southern California ports at the end of 2021. This led to a decrease in vessel speed when transiting past the Monterey Bay region, regardless of active or inactive VSR efforts. This may be a contributing factor to the low source level reduction value estimated at this site. The noise level analysis, conducted for the first time in this report, supports prior assumptions that source level reductions likely lead to reductions in noise at Site B. The highest magnitude reductions were achieved at the high end of the noise distribution during the program active period, relative to the program inactive period. Investigating additional baseline time periods, such as historical years when there was little participation in VSR efforts, may be considered to understand noise reduction from baseline levels. Coordination on baseline years with air pollution reduction analyses will be considered in future analyses.

Source levels for the Southern California region have been analyzed annually for the past 7 years. Source levels for additional regions may be measured with the use of acoustic data from additional sites. Site MB and the Monterey Bay Aquarium Research Institute (MBARI) Monterey Accelerated Research System (MARS) hydrophone could be considered for future source level analysis, to gain a greater understanding of the URN of vessels that do not transit to Southern California. In addition, a short-term sensor in the San Francisco region would support a better understanding of the source levels and noise levels in the highly trafficked shipping lanes. In addition to source levels, additional metrics may be considered for future analyses. It is critical to understand the URN from the perspective of the species that are aiming to be protected. Source levels are modeled at a distance 1 meter away from the source, and noise levels are computed from the perspective of a bottom moored sensor, neither of which fully capture the perspective of an animal that is transiting and diving throughout the water column. Modeling ambient noise levels at a variety of depths will aid in understanding the sound pressure levels from the perspective of not only blue whales, but a variety of species that utilize the California Coast Ecosystem. All of these ideas may be considered in future URN analyses for the Protecting Blue Whales and Blue Skies program.

Citations

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