Are the 1/3-Octave 63- and 125-Hz Band Noise Levels Predictive of Vessel Activity? The Case in the Cres–Lošinj Archipelago (Northern Adriatic Sea, Croatia)

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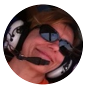

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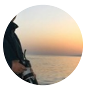

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Chapter 101
Are the 1/3-Octave Band 63- and 125-Hz Noise Levels Predictive of Vessel Activity? The Case in the Cres–Lošinj Archipelago (Northern Adriatic Sea, Croatia)

Marta Picciulin, Linda Sebastianutto, Caterina Maria Fortuna, Peter Mackelworth, Draško Holcer, and Nikolina Rako Gospić

Abstract A 3-years sea ambient-noise (SAN) monitoring was carried out in the Cres–Lošinj Archipelago (Croatia), where a bottlenose dolphin population is threatened by unregulated nautical tourism. A total of 540 5-min SAN samples were collected and analyzed in an Indicator 11.2.1 (Marine Strategy Framework Directive) perspective. The 1/3-octave band center frequencies of 63 and 125 Hz (re 1 μPa·rms) proved to be predictive of local predominant ship type over time. However, the noisiest band level was centered on 200 Hz. We therefore suggest measuring a wider frequency band than those requested in Indicator 11.2.1.

Keywords Noise • Boat • Dolphins

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1 Introduction

Several studies have shown that ambient-noise levels constantly increased over the last decades (Andrew et al. 2002; Ross 2005; Slabbekoorn et al. 2010). Sea background noise comes from a variety of sound sources of both natural (physical and biological) and anthropogenic origin (Richardson et al. 1995; Hildebrand 2009). Anthropogenic sounds may be of short duration (e.g., impulsive such as from seismic surveys and piling for wind farms and platforms as well as explosions) or be long lasting (e.g., continuous such as dredging, shipping, and energy installations), affecting organisms in different ways ranging from nil to severe (Tyack 2008; Slabbekoorn et al. 2010; van der Sluijs et al. 2011). As a result, underwater noise became an important aspect of the Marine Strategy Framework Directive (MSFD) adopted by the European Union in July 2008 (European Commission 2008), which aims to achieve a good environmental status (GES) of the European marine environment by 2020. The MSFD considered both the distribution in time and place of loud-, low-, and midfrequency impulsive sounds (Criterion 11.1.1) and the trends in time of continuous low-frequency sound (Criterion 11.2.1). Here we are interested in Indicator 11.2.1 that requests monitoring of the trend in the ambient-noise level within the 1/3-octave bands of 63 and 125 Hz (center frequency; re 1 μPa root-mean-square [rms]; average noise level in these octave bands over 1 year) measured at observation stations. The choice of these octave bands is based on the scientifically justifiable signatures of anthropogenic noise that avoid most naturally generated sources. The MSFD indicators could help in evaluating the quality of the marine environment affected by the intense boat traffic, especially in the coastal areas where boat noise represents one of the most dominant underwater anthropogenic noise sources. The aims of the present paper are (1) to describe the results of a 3-years sea ambient-noise monitoring (2007–2009) in the Cres-Lošinj Archipelago, where local cetacean and fish communities are threatened by unregulated nautical tourism and coastal construction (Rako et al. 2012), by using the 63- and 125-Hz 1/3-octave bands and (2) to verify if these bands levels are predictive of local boat traffic in these coastal waters.

2 Materials and Methods

The study area of ~545 km^2 is located in the Kvarnerić region (Northeastern Adriatic Sea, Croatia). It includes steep rocky shores and a seabed patched with muddy areas and sea grass flats. Sea depth is on average 70 m (Arko-Pijevac et al. 2003). The sea currents rarely exceed an average speed of 0.5 kn, while the sea temperature ranges between 7 and 15 °C in the winter and 22 and 25 °C in the summer (Favro and Saganić 2007).

From 2007 to 2009, the acoustic surveys were carried out monthly at ten predefined acoustic stations grouped in three areas characterized by different proximities to major tourist and municipal locations on land (high-, medium-, and low-anthropogenic impact areas; for details on recording methods, see Rako et al. 2012).

A total of 540 5-min sea ambient-noise (SAN) samples (frequency range: 25–40,000 Hz) were collected: 300 were made during the "tourist season" (TS; June to September; 30 ± 3 [mean ± SD] per acoustic station) and 240 samples were made in the "nontourist season" (NTS; October to May; 24 ± 2 per acoustic station). Data were analyzed for the 1/3-octave band standard center frequencies in terms of instantaneous sound pressure level (SPL; L-weighted; 63–20 kHz rms fast) by using SPECTRA RTA software calibrated with a signal of 100 mV rms at 1 kHz (sensitivity: −170 dB re 1 μPa). Subsequently, the equivalent continuous SPLs (SPL_{Leq}) for vessels and SAN were calculated by averaging the SPLs over 60 s. In an Indicator 11.2.1 perspective of the "continuous low-frequency sound," 1/3-octave bands of 63 and 125 Hz (re 1 μPa·rms) were considered.

During the acoustic sampling, data on vessel presence, type, and distance from the monitoring location were collected visually using FUJINON 7 × 50 marine binoculars. Seven vessel types were defined depending on size, type of movement, and engine power (HP): motor yacht (MY), speed boat (SB), motor boat (MB), sailing boat on engine (SailB), trawler (TW), gillnetter (GN), and tour boat (TB), according to Rako et al. (2012).

For statistical analysis, when the assumptions for normality and homogeneity of variances were met, data were analyzed with ANOVA, whereas when assumptions were not met, data were analyzed using nonparametric tests: Mann–Whitney *U*-test (for two groups) and Kruskal-Wallis test (for more than two groups), with an α level of 0.05. A Spearman rank correlation test was used to correlate the 63- and 125-Hz noise levels with the boat presence.

3 Results

3.1 1/3-Octave Band Levels

Figure 101.1 shows the average 1/3-octave band levels recorded during the monitoring period. It is possible to notice that the highest average decibel value (re 1 V/μPa) refers to the 200-Hz band (123.9 ± 6 [SD] dB re 1 μPa; min = 96 dB and max = 142 dB). The average levels for the 63- and 125-Hz bands recorded in the area during the monitoring period were 115.3 ± 7 (SD) dB re 1 μPa (min = 96 dB and max = 142 dB) and 116.3 ± 6.6 dB re 1 μPa (min = 92 dB and max = 136 dB), respectively (Table 101.1).

3.2 Temporal and Spatial Variability of 1/3-Octave Bands of 63 and 125 Hz

A significant year-to-year decrease was found during the monitoring period for both band levels [ANOVA; $F(2,537) = 7.7$, $P < 0.001$ and $F(2,537) = 3.8$, $P = 0.02$, respectively].

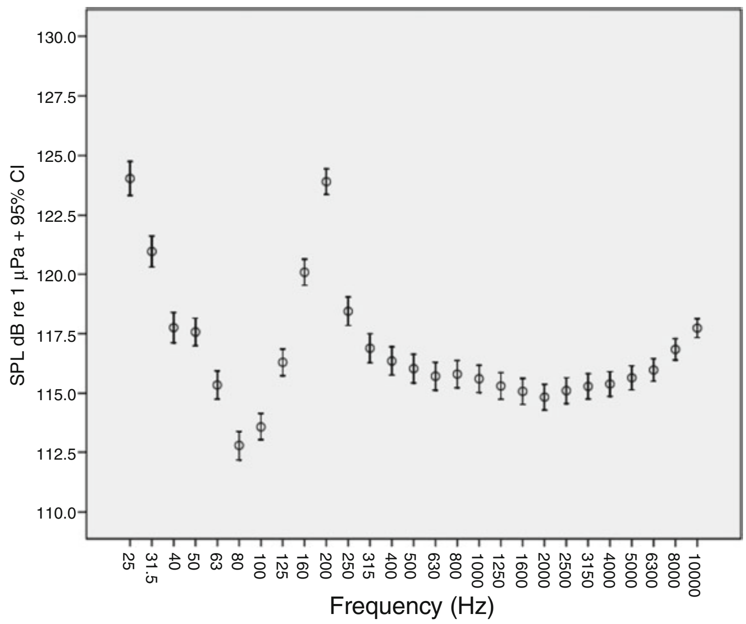

Fig. 101.1 Sound pressure levels (SPLs) of the sea ambient noise recorded in the Cres-Lošinj Archipelago from 2007 to 2009. Values are averages ± SD of the 1/3-octave band; $N = 540$ samples

Table 101.1 Annual values for 63- and 125-Hz centered bands

	63 Hz	125 Hz
Total	115.3 ± 7.0	116.3 ± 6.6
2007	116.7 ± 6.9	116.7 ± 6.2
2008	115.4 ± 6.6	116.9 ± 6.5
2009	113.8 ± 6.2	115.1 ± 7.0

Values are means ± SD in dB re 1 µPa·rms

In the 63-Hz band, noise level was significantly higher during the TS compared with the NTS [two-way ANOVA: $F(1,534) = 11.44$, $P < 0.001$] but did not change between the three impact areas [$F(2,534) = 0.5$, $P = 0.5$]. The interaction found between season and impact area was not significant [impact × season: $F(2,534) = 1.6$, $P = 0.2$]; however, a Bonferroni post hoc test showed that the noise level in the high-impact area was significantly higher during the TS ($P = 0.002$).

The 125-Hz band level varied significantly between seasons [$F(1,534) = 12.7$, $P < 0.001$] and among the three impact areas [two-way ANOVA: $F(2,534) = 3.2$, $P = 0.04$]; the interaction between season and impact area was not significant [interaction impact × season: $F(2,534) = 2.4$, $P = 0.08$]. Again, a significantly higher level of noise was found during the TS only in the high-impact area (Bonferroni post hoc test: $P < 0.001$).

3.3 Boat Spatial and Temporal Distribution

The total number of boats within the study area did not change significantly during the 3-years monitoring period (Kruskal-Wallis test: H [2, $N=540$ samples] $=2.08$, $P=0.35$), but they were significantly more frequent during the TS compared with the NTS (Mann–Whitney U-test: $U=24{,}689$, $P<0.001$). Within the study area, TBs, MYs, SBs, and SailBs were recorded more often during the TS than during the NTS (Mann–Whitney: $P<0.001$ for all; Fig. 101.2), whereas trawlers (TWs) were more frequently spotted during the NTS ($P<0.001$).

Taking into account the three areas of different anthropogenic impact, during the NTS, the number of boats did not change, whereas significant variations were found during the TS (Kruskal-Wallis test: H [2, $N=300$ samples] $=35.76$, $P<0.001$); multiple comparisons showed that the total number of boats observed in the high-impact area was higher than in the medium-impact area ($P=0.004$) and low-impact area ($P<0.001$) and that the number of boats in the medium-impact area was again higher than in the low-impact area ($P=0.008$). Out of all the boat categories, during the TS, only SBs were present in a significantly higher number in the high-impact area compared with the medium-impact and low-impact areas (Kruskal-Wallis test: H [2; $N=540$ samples] $=36.5$, $P=0.003$; multiple comparison high vs. medium, $P=0.003$ and $P=0.002$, respectively). All together, the SB was the most frequent boat type observed during the 3-years monitoring period (Fig. 101.2).

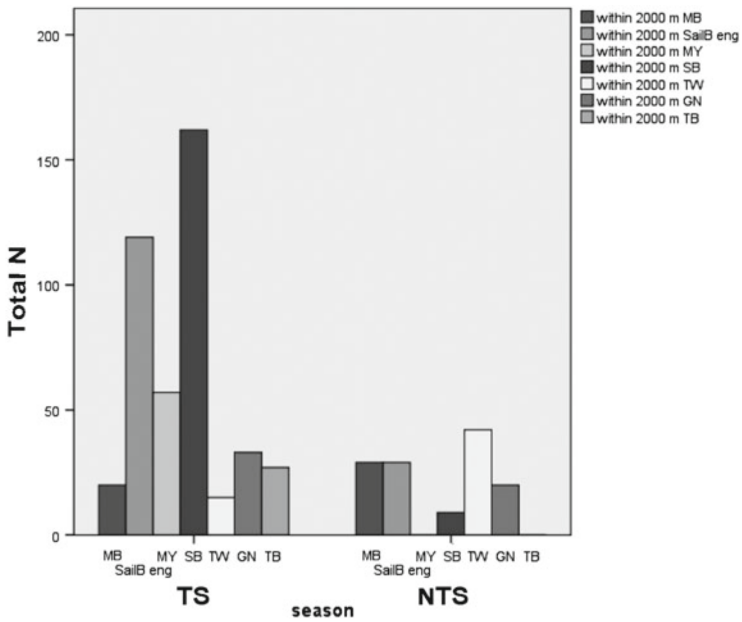

Fig. 101.2 Seasonal intensity of leisure boating during the tourist (TS; June to September) and nontourist (NTS; October to May) seasons. *MB* motor boat, *SailB eng* sailing boat on engine, *MY* motor yacht, *SB* speed boat, *TW* trawler, *GN* gillnetter, *TB* tour boat. *N* number of recorded boats

3.4 Correlation between the 63- and 125-Hz Bands and Boat Presence

We found a positive correlation between the 63- and 125-Hz noise levels and the total number of boats (Spearman rank-order correlation: $P<0.05$, $\rho=0.097$ and $\rho=0.121$, respectively). More precisely, a positive correlation was found between the 63-Hz band level and TB and SB presence (Spearman rank-order correlation: $P<0.05$, $\rho=0.107$ and $P<0.05$, $\rho=0.136$, respectively) as well as between the 125-Hz band level and MY, TB, and SB presence (Spearman rank-order correlation: $P<0.05$, $\rho=0.131$; $P<0.05$, $\rho=0.155$; and $P<0.05$, $\rho=0.202$, respectively).

4 Discussion

The Cres-Lošinj Archipelago represents a popular tourist destination in the northern part of the Croatian Adriatic Sea; since the 1960s, tourism has developed and become one of the most dominant economic sectors in this region (Mikačić 1994). Activities related to tourism are particularly intense during the summer, resulting in a rapid increase in the number of motorized vessels frequenting the area (Rako et al. 2012). Nevertheless Cres and Lošinj waters are an important feeding and nursing ground for the locally resident bottlenose dolphin (*Tursiops truncatus*, Montagu, 1821) population (Bearzi et al. 1997; Fortuna 2006). A recent study (Rako et al. 2013) demonstrated that the noise related to the intense leisure boating causes significant seasonal displacements of resident bottlenose dolphins within this marine habitat. Using the 63- and 125-Hz 1/3-octave bands for monitoring boat presence is therefore of particular interest.

Our results highlighted a positive correlation between the 63- and 125-Hz band noise levels and the number of boats observed in the study area (irrespective of boat type). This explains the season-dependent increment in noise levels across both 1/3-octave bands (63 and 125 Hz) found during the TS, which is characterized by the increased number of boats present.

More precisely, the most frequent type of boat observed during this study in the archipelago was the SB; its presence was particularly high at the stations located close to the important urban and tourist centers (high-impact area) than in the others. Because we found a positive correlation between TB and SB number and 63- and 125-Hz band levels and that the recorded noise in these bands was significantly higher in the high-impact area than in the others during summer, we conclude that the 63- and 125-Hz band levels are predictive not only of the total boat traffic, in agreement with the assumption of the MSDF, but also of the most frequent boat type in the area.

It has to be noted that MYs together with SBs represent the primary source of anthropogenic noise in the archipelago, with particular reference to the high-impact area (Rako et al. 2012). In addition, both SB and MY noise peak at 125 Hz (Rako et al. 2012). If this can explain the correlation between MY number and the 125-Hz band, a nonsignificant correlation between MYs and 63 Hz could likely be related to a much smaller number of MYs in comparison to the number of SBs in the area.

Regarding the monitoring trend, it still remains unclear why the 63- and 125-Hz band levels decreased during the period of 2007–2009, although a relatively stable number of boats (total boats as well single boat types) were observed in the archipelago.

Last but not least, it has to be stressed that the noisiest band level recorded in the Cres-Lošinj Archipelago was not centered either on 63 Hz or on 125 Hz but on 200 Hz; this is in agreement with other studies carried in shallow water, such as the Baltic Sea, where ambient noise peaks at higher levels than these two frequency bands (as reported in van der Graaf et al. 2012). When exploring the use of these bands, not only for evaluating trends but also for defining a good environmental status (and therefore, indirectly, for evaluating the local impact of noise on marine fauna), we suggest the consideration of a wider frequency range than that in Indicator 11.2.1. This conclusion supports a similar recommendation expressed by the MSFD Technical Subgroup on Underwater Noise to the European Commission that provided guidance on implementing aspects of the MSFD under Descriptor 11 (van der Graaf et al. 2012).

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