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Underwater noise assessment outside harbor areas: The case of Port of Civitavecchia, northern Tyrrhenian Sea, Italy

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ABSTRACT

Underwater noise assessment is particularly important in coastal areas where a wide range of natural and anthropogenic sounds generate complex and variable soundscapes. In the last century, the number and size of noise sources has increased significantly, thereby increasing the ocean's background noise. Shipping is the main source of lower-frequency underwater noises (< 500 Hz). This research aimed to provide an initial assessment of underwater noise levels in a coastal area of the northern Tyrrhenian Sea (Italy) using short-term recordings. Spatial and temporal variations in the noise level, and the type and number of ships sailing through the port were recorded. A significant correlation was found between ferry boats and sound pressure levels, indicating their role as a prevalent source of low frequency underwater noise in the project area. This research could provide the baseline for implementation of distribution and point-source underwater noise models that are required for sustainable coastal management.

1. Introduction

Anthropogenic noise pervades a range of marine environments and sound energy input can be highly variable in both time and location (Tasker et al., 2010), becoming an important part of the overall ocean acoustic background. Waves, wind, rainfall, and earthquakes are some of the natural sources of noise in the ocean while anthropogenic sources include shipping, hydrocarbon exploration, seabed mining, coastal development, sonar sensing, electricity generation, fishing, research (e.g. air guns, sonars, telemetry, and navigation), and recreational boating (Wenz, 1962; Hildebrand, 2009).

Underwater sound plays an ecologically important role for many marine species and includes settlement cues in larvae, orientation, communication, predator avoidance, and prey location and capture (Myrberg Jr, 1997; Simpson et al., 2005; Montgomery et al., 2006; Radford et al., 2008; Fay, 2009; Stanley et al., 2012; Lillis et al., 2013). Most of the research on the effects of underwater noise has been performed on megafauna, such as marine mammals and certain commercially important species of fish (Engås and Løkkeborg, 2002; Madsen et al., 2006; Weilgart, 2007; Popper and Hastings, 2009). Several authors have shown the influence of temporal and spatial variations of underwater noise on the distribution and behavior of different animals groups (Amoser and Ladich, 2010; Slabbekoorn et al., 2010; Rako et al., 2013), alteration of vocalization, disruption of orientation, and acoustic masking (Lesage et al., 1999; Finneran et al., 2002; Holles et al., 2013), and also its interference with foraging activities (Wisniewska et al., 2018). Recently, the effects of anthropogenic noise have also been shown for a variety of marine invertebrates mainly causing a delay in the development and settlement rates of larvae and body malformations, and increasing settlement and growth rates of invasive species in non-native habitats (Wilkens et al., 2012; Aguilar De Soto et al., 2013). Overall, many studies have described how noise can lead to increased stress and risk of mortality (Southall et al., 2007; Codarin et al., 2009; Popper and Hastings, 2009; Erbe et al., 2016), but the severity of noise effects on marine organisms depends on the characteristics of the source, such as intensity, frequency, duration, direction, and temporality (Weilgart, 2007; Kight and Swaddle, 2011).

Thus, the underwater noise assessment is particularly important especially in coastal areas where a wide range of natural sounds and anthropogenic noise generate complex and variable soundscapes (Urick, 1983). The increase in the anthropogenic noise level resulting from urbanization growth, shipping, and expanding tourism is significant and has become a form of chronic and constant pollution, especially in shallow coastal environments (Popper and Hastings, 2009; Codarin and Picciulin, 2015). Shipping is considered to be the main source of underwater noise at frequencies lower than 500 Hz (Wenz,

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1962; Ross, 1976; Andrew et al., 2002; Hildebrand, 2009; CSA Ocean Sciences Inc., 2013). However, there is substantial variability in the sound emitted by individual vessels because of characteristics such as the type and size (increasing size usually decreases frequency), method of propulsion, and operation of additional machinery onboard a vessel (Hildebrand, 2009). The International Maritime Organization (IMO) has recognized the negative impact of shipping on underwater noise levels and has recently introduced voluntary guidelines for ship designers, builders, and operators, aiming to reduce the contribution of commercial shipping to the underwater noise levels (International Maritime Organization, 2013).

In the last century, there has been a large increase in the number and size of noise sources, which resulted in a large increase in the background noise in oceans (Andrew et al., 2002; Buscaino et al., 2010; Johansson et al., 2016; Slotte et al., 2004; Tyack, 2008; Kastelein et al., 2008; Peng et al., 2015). However, underwater noise in coastal waters has been poorly described (Samuel et al., 2005; Radford et al., 2010; Bittencourt et al., 2014; Lillis et al., 2014), and there are few data regarding the Italian coastal waters (Codarin and Picciulin, 2015; Azzellino et al., 2011).

Moreover, considering the Marine Strategy Framework Directive (MSFD) (2008/56/EC, EU, 2008) and the Commission Decision of September 2010 (2010/477/EU, regarding the criteria and methodological standards on Good Environmental Status, GES), underwater noise has been recognized as pollution and included in the qualitative high level descriptors to achieve GES. As reported in the Monitoring Guidance of Underwater Noise (Dekeling et al., 2014), Indicator 11.2.1 assessed the issue of marine life chronic exposure to low frequency ambient noise, of which the main contributor is commercial shipping noise. This Indicator requests monitoring of the ambient noise level trend within the 1/3 octave bands 63 Hz and 125 Hz (center frequency; re 1 μPa RMS, the average noise level in these octave bands over a year), measured at different observation stations (Monitoring Guidance of Underwater Noise, 2014).

Thus, the aim of this study was to assess the underwater noise in a coastal area located in the Northern Latium (Northern Tyrrhenian Sea, Italy), which hosts one of the largest ports for commercial and cruise traffic in the Mediterranean Sea.

2. Materials and methods

2.1. Study area

The study area consisted of a marine platform section located in the northern part of the Latium region that extended from Capo Linaro (N 42.03014, E 11.83656) to the Tarquinia seaside (N 42.20121, E 11.71483) (Fig. 1). In the Civitavecchia coastal area, there are two Sites of Community Importance (SCIs), which are characterized by the presence of *Posidonia oceanica* meadows and other priority species such as *Corallium rubrum* and *Pinna nobilis*.

The study area receives alluvial contributions mainly from the Marta and Mignone rivers. There are also several smaller rivers, but their contribution to marine sedimentation is limited to strong flood phases (Angelucci et al., 1979; Carboni et al., 1980; Scanu et al., 2015).

Concerning the thermal structures of the water column in the area, a typical seasonal trend characterized by homogeneous temperatures (approximately 14 °C) during winter and pronounced stratification during summer was observed. The water column salinity trend is also linked to the temperature trend, with minimum values of surface salinity during the winter season and maximum values during the summer season (Bonamano et al., 2016).

The Civitavecchia compound has one of the largest energy production sites in Europe, the Torrevaldaliga Nord (TVN) coal-fired power plant, and one of the most important ports in the Mediterranean Sea. The port of Civitavecchia is located on the west coast of Central Italy, about 31 miles north of Rome. Its strategic position, the numerous expansion projects, and construction of new docks in the last few years have helped to make the port of Civitavecchia a leader in cruise transit in the Mediterranean Sea. Currently, the harbor basin covers 1.62 km^2, with an average depth of 15 m.

2.2. Acoustic data recording

Underwater noise monitoring was performed monthly at 14 predefined acoustic stations located between depths of 35 m and 100 m, from May to September 2017. Some of these stations were occasionally sampled throughout the year (six times between October and April 2017; Fig. 1).

Acoustic recordings (60 s long) were taken using a pre-calibrated omnidirectional hydrophone Teledyne Reson TC4013 (receiving sensitivity, −211 dB ± 3 dB re 1 V/μPa; frequency response, 1 Hz to 170 kHz), which was connected to a voltage preamplifier VP1000 and to a Tascam DR05 handy recorder (sampling rate 96 kHz, 24-bit) that was battery-operated.

The hydrophone was lowered to a fixed depth of 20 m at each of the sampling stations to minimize the boundary effect (e.g. water depth, seabed type).

Acoustic measurements were taken from a 5-m long vessel with the engine shut off during the recordings to minimize platform noise, and care was taken by the crew on board.

All acoustic recordings were collected under similar sea state conditions (< 1 Beaufort scale) to minimize the variation in shallow water ambient noise levels that could result from weather conditions (e.g. wind). All the samplings were made in the same hours in order to reduce the effects of marine traffic in different time of the day. All data collected were stored in the WAV file format.

2.3. Acoustic data analysis

Each recording was analyzed and the instantaneous sound pressure level (SPL) was calculated for each 1/3 octave band (frequency range, 12.5–16 kHz). The *pwelch* function (Welch, 1967) was applied (considering the Hamming window, 50% overlap, and 92 kHz sampling frequency) using software R (Ihaka and Gentleman, 1996).

The function uses a fast Fourier transform that was based on time averaging over short modified periodograms to estimate the power spectra. The calculation process also took into account the analogue-to-digital conversion such as the recorder and amplifier gain and the hydrophone sensitivity (Erbe, 2011). A single SPL value was obtained in dB re 1 μPa for each sampling station and for each of the 1/3 octave bands. The acoustic data were used to create a contour map using Surfer® software (Golden Software Incorporation, Golden, Co, USA). The *Natural Neighbor* interpolation method was used because it does not extrapolate contours beyond the convex hull of the data location, while this algorithm uses a weighted average of the neighboring observations (Sibson, 1981).

2.4. Marine traffic

The number and type of vessels present in the area and their status (moving or at anchor) during each recording was obtained by keeping a log of the visible vessels. Additionally, data concerning the entry and exit of ships from the Port were provided by the Port Authority System of the Central Northern Tyrrhenian Sea. Ships were classified as belonging to one of the following categories: cruise ship, ferry boat, or large ship (comprising tanker, container, and cargo ships).

2.5. Statistical analysis

To assess the ambient noise level trend throughout the year and the potential differences across the seasons, data were divided into two periods: S1 (May–September) and S2 (October–April). Because the data