Original scientific article
Received: 2013-10-09

UDK 502.51(262.32):504.6:534.322.3

CHARACTERISATION OF THE NOISE EMITTED BY THE PASSAGE OF A PASSENGER CRUISE LINER IN THE VENICE LAGOON: CONCERN ABOUT POSSIBLE EFFECTS ON THE LOCAL FISH COMMUNITY

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ABSTRACT

Underwater noise emitted by a modern passenger cruise liner in the Venice lagoon under normal operational conditions was recorded in situ and analysed. This boat type causes a maximum increment of 27 dB re 1 µPa on the local background noise at 160 Hz 1/3 octave band frequency. This is of particular concern, considering that we calculated an average of five cruise passages per day in the whole month of August 2013, when this study was carried out. This increase in noise levels can cause temporary adverse responses as well as chronic effects on the typical fish population. We conclude that cruise tourism in the lagoon generates a complex variety of anthropogenic pressures acting synergistically on the aquatic community, which are difficult to predict and estimate, and therefore to mitigate.

Key words: anthropogenic noise, impact, marine ecosystem, fish community

CARATTERIZZAZIONE DEL RUMORE EMESSO DAL PASSAGGIO DI UNA NAVE DA CROCIERA NELLA LAGUNA DI VENEZIA: POSSIBILI EFFETTI SULLA COMUNITÀ ITTICA

SINTESI

È stato qui registrato e analizzato il rumore prodotto dal passaggio di una nave passeggeri durante le normali procedure di transito in laguna di Venezia. Questa imbarcazione determina un incremento di 27 dB re 1 µPa del rumore di fondo locale alla frequenza di 160 Hz (misurato in 1/3 bande d'ottava). Ciò desta particolare preoccupazione se si considera che, nel solo mese di agosto 2013, periodo in cui è stato svolto lo studio, si registra una media di 5 passaggi al giorno da parte di navi da crociera all'interno del bacino. L'aumento del rumore di fondo nell'area di transito può avere effetti temporanei o cronici rilevanti sulla comunità ittica locale. Se ne conclude che il turismo legato alle navi da crociera generi in laguna una complessa varietà di pressioni antropiche che agiscono in maniera sinergica sulla comunità acquatica e i cui effetti sono difficili da valutare e predire e, quindi, da mitigare.

Parole chiave: rumore di origine antropica, impatto, ecosistema marino, comunità ittica

INTRODUCTION

Modern extensive passenger cruise traffic is the result of a globalized tourism market with increased passenger capacity and luxury facilities (Dwyer & Forsyth, 1998). The quantification of the environmental impacts of this type of ship traffic is not an easy task to address (Dwyer *et al.,* 2004). Operational impacts involve air and water pollution and other impacts such as the physical damage of the marine ecosystem. As a result, the International Convention for the Prevention of Pollution from Ships (MARPOL) was introduced in 1973 and since updated; it aims to prevent marine environmental pollution generated from operational or accidental aspects of ships' traffic. Even if ship noise has only recently been recognized as a threat for the marine environment (Jasny *et al.,* 2005; Slabeekoorn *et al.,* 2010), in coastal regions, where ship noise may dominate the low frequency bandwidth of the underwater soundscape (Hildebrand, 2009), it is now evident that it represents a form of chronic and constant pollution (Tasker *et al.,* 2010). Ship noise pollution is considered one of the major factors affecting habitat quality for marine organisms (National Research Council, 2005), having the potential to interfere with the ability of marine animals to communicate and to interpret acoustic cues in their environment (Myberg, 1990; Jasny *et al.,* 2005; Vasconcelos *et al.,* 2007; Slabbekoorn *et al.,* 2010).

This is of particular concern in ecologically important areas, such as the Venice lagoon (Italy), situated in the NW part of the Adriatic Sea. Although the Venice lagoon has been recognized as a Special Protection Area (IT3250046, 79/409/CEE, DGP n. 441/2007) and it has have been established as a World Heritage Site by UNESCO in 1987 thanks to the presence of several different and important ecosystems, the mainland harbour of Marghera in the Venice lagoon is one of the widest and most complex industrial and shipping areas in Europe (Regione Veneto, 2010). More recently, Bolgan *et al.* (2013) have reported for the first time a consistent underwater noise pollution in the Venice lagoon, likely due to the intense merchant and passenger ship traffic characterising this lagoon. The same authors have also suggested that the passenger cruises are one of the major sources of local underwater noise (Bolgan *et al.,* 2013) but this noise source remains undescribed. The aim of the present paper is to describe the spectral characteristics of the noise emitted by a modern passenger cruise liner transiting in the Venice lagoon under normal operational conditions, *i.e.* in the presence of a tug boat and a pilot boat, and recorded *in situ* at the closest distance achievable.

MATERIALS AND METHODS

In order to estimate the intensity of the passenger cruises traffic in the lagoon, the number of passenger cruise passages along the whole month of August was counted (the data have been obtained from http://www.vtp.it/), calculating the average number of passages per day.

The noise of a passenger cruise of 250 meters (MSC Armonia; MMSI: 357281000), as well as the local background noise, were recorded on August, 23th, 2013 at 19 p.m. in the Lido tide inlet (Fig. 1). The recording was performed from a 7.5 m open boat for a total of 5 minutes. Ships positions were located using the Automatic Identification System (AIS; obtained from http://marinetraffic.com). The ship was moving at about 6 knots along the inlet, at the same speed used inside the Venice lagoon; a pilot and a tug boats were moving close to the ship, as well a speed boat. The inlet consists into a channel that connects the North Adriatic Sea with the Venice lagoon: it is about 900 m wide, about 3.5 km long and it is characterized by a maximum depth of 20 m.

The noise was recorded at a distance of 50 meters, which is the closest safe distance achievable, by lowering a pre-amplified Reson TC4032 hydrophone (sensitivity -170 dB re 1 V/μPa, frequency range 5 Hz - 120 kHz) to four metres depth (bottom depth eight metres), connected to a portable micro recorder (Zoom H1) generating WAV files (sampling rate 44.1 kHz, 16 bit). Pri-

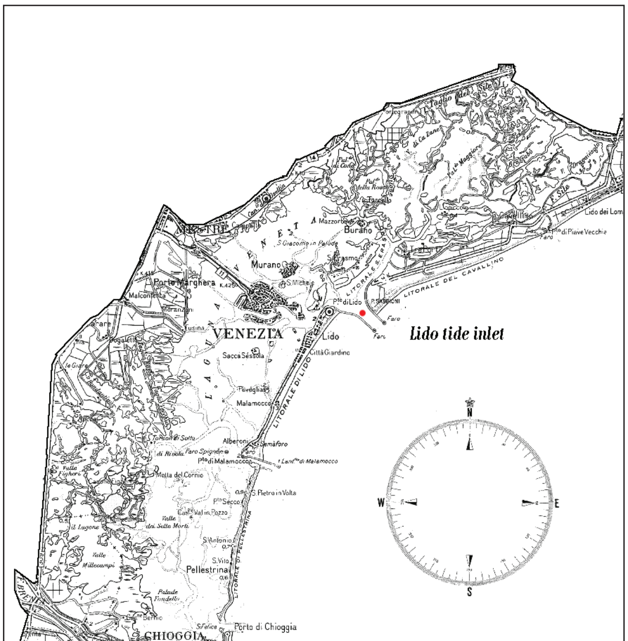

Fig. 1: Map showing the Venice lagoon with particular reference to the recording position (dot) in the Lido tidal inlet.
Sl. 1: Zemljevid Beneške lagune s posebej prikazano merilno lokacijo (pika) v dostopni ožini ob Lidu

or to the recording the signal was calibrated using a generator of pure waves of known voltage. Sampling was carried out with a sea state of less than 2 on Douglas scale and wind speed less than one metre per second; water temperature was 24.5 °C.

Data were analysed using Adobe Audition 3.0 software by auditory and visual assessment of the spectrograms (sampling rate 44.1 kHz, 16 bit). They were subsequently analysed for the 1/3 octave band standard centre frequencies in terms of instantaneous Sound Pressure Level (SPL, L-weighted, 10 Hz - 20 kHz, RMS fast) by using SPECTRA Plus 5.0 software calibrated with a signal of 100 mV RMS @1 kHz (sensitivity -170 dB re 1V/ μPa); the equivalent continuous sound pressure levels (hereafter 'L_{Leq}') were further calculated averaging the SPL over the sample period of five minutes. One assumption of this calculation is that the source is moving away at a given speed and the receiver remains stationary over the integration time.

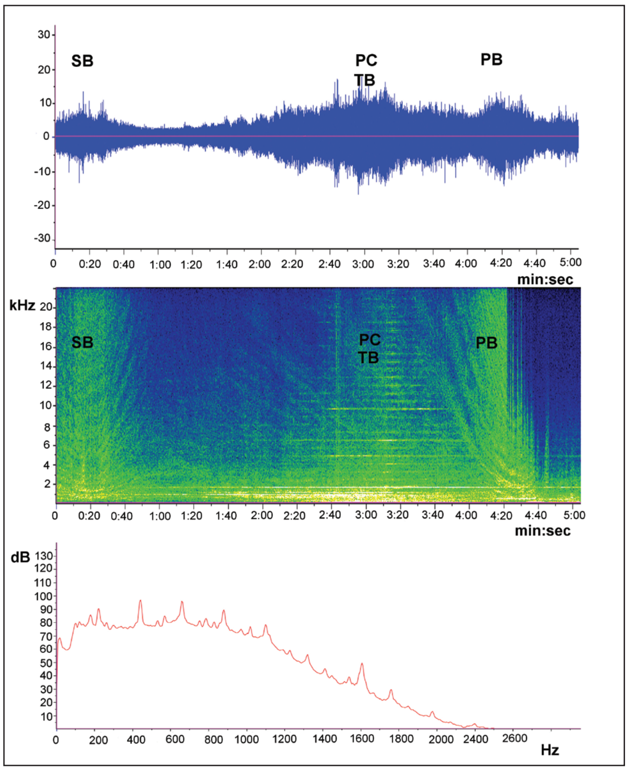

Fig. 2: Oscillogram (top), spectrogram (centre) and power spectrum (bottom) of the noise emitted from a passenger cruise liner crossing the Lido tidal inlet. A five second time period has been chosen for calculating the noise spectra (from 2:45 to 2:50 of the recording). Filter bandwidth 10 Hz, sampling frequency 44.1 KHz, 50% overlap, window Blackman Harris. SB - speed boat, PC - passenger cruise, TB - tug boat, PB - pilot boat.

Sl. 2: Oscilogram (zgoraj), spektrogram (v sredini) in spekter moči (spodaj) hrupa, ki ga oddaja potniška križarka pri prečkanju dostopne ožine pri Lidu. Za računanje spektra hrupa smo izbrali 5-sekundni interval (od 2:45 do 2:50 posnetka). Pasovna širina filtra 10 Hz, frekvenca vzorčenja 44,1 KHz, 50% prekrivanje, okno Blackman Harris. SB – gliser, PC - potniška križarka, TB – vlačilec, PB - pilotski čoln

RESULTS

During August 2013 a total of 98 passenger cruise ships have crossed the Venice lagoon (for a mean of three ships per day, min = 0, max = 7, SD = 2) for a total of 148 passages through the Lido tide inlet (for a mean of five passages per day, min = 0, max = 11, SD = 3).

The passage of the recorded passenger cruise ship produces an underwater noise with peak acoustic energy below 1600 Hz and with two peak frequencies at about 450 and 645 Hz. Also it should be noted that at 200 Hz the amplitude is around 8 dB below the peaks (Fig. 2).

From the spectrogram and the oscillogram represented in the Figure 2, the presence of different noise sources can be identified, *e.g.* a speed boat with outboard motor (around 0.20 min in the figures), followed by the passenger cruise liner and the tug boats and at the end the pilot boat; in addition, five harmonics are detectable when the passenger cruise liner was closest to the hydrophone, about 3:20 min into the recording. Figure 3 shows the mean 1/3 octave bands levels of the noise made by the passenger cruise liner's passage compared to the local background level.

The calculated L_{Leq} (five min) related to the passenger cruise liner's passage under normal operation conditions is 143 dB re 1 μPa whereas the L_{Leq} for the local background noise is 136 dB re 1 uPa; the maximum increment due to the cruise passage is located at 160 Hz and it is equal to 27 dB re 1 uPa.

DISCUSSION

The Venice lagoon stretches along the Adriatic Sea coastline and is separated from the sea by two long islands with three main tide inlets, through which the water exchange is driven by wind and tidal currents (Regione Veneto, 2010). Different shipping pressures characterize the tide inlets. Most ships transiting through the Lido inlet are passenger ships (86% of the total), and this type of marine traffic is strongly affected by seasonality, with the highest pressure during summer (Ministero delle Infrastrutture e dei Trasporti Magistrato alle Acque di Venezia 2007; Bolgan *et al.*, 2013). The average five cruise passages per day calculated in the whole month of August is of particular concern when considering that the cruise tourism, according to the present paper, encompasses a significant portion of the local background noise. Although these *in situ* recordings don't satisfy all ANSI/ASA measurement of underwater ship noise guidelines (S12.64-2009/Part, American National Standard Institute, 2009), mainly due to the intrinsic characteristics of the recording site, the L_{Leq} value presented here provides a good estimation of the noise levels produced by the passage of the passenger cruise liners during operational conditions (*i.e.* in presence of tug and pilot boats) in the inlet. In addition, the fact that noise recordings were carried out in the tide inlet and not inside the lagoon could raise possible concern about the generalization of the present measurements. The tidal inlet has different topography and depth from the lagoon (14-15 m *vs.* an average of 1 m depth; Guerzoni & Tagliapietra, 2006) and sound propagation in shallow water is determined by many factors, such as the type of substratum, the surface boundary condition, the relationship between depth and frequency, the bottom slope, and the temperature and salinity gradient (Forrest *et al.*, 1993). Although differences are possible due to the variability of such factors, it's important to stress that the passenger liners move into the lagoon exclusively via appropriate navigation channels with similar depth and substrate (ranging from sand to muddy bottom) to the tidal inlets (Guerzoni & Tagliapietra, 2006). As result the spectral (frequency) and intensity (amplitude) content of the sounds recorded in the tidal inlet can be a good estimate of the noise created by the passenger cruise liner; this conclusion is supported by the data recorded by Bolgan *et al.* (in press) in the city of Venice.

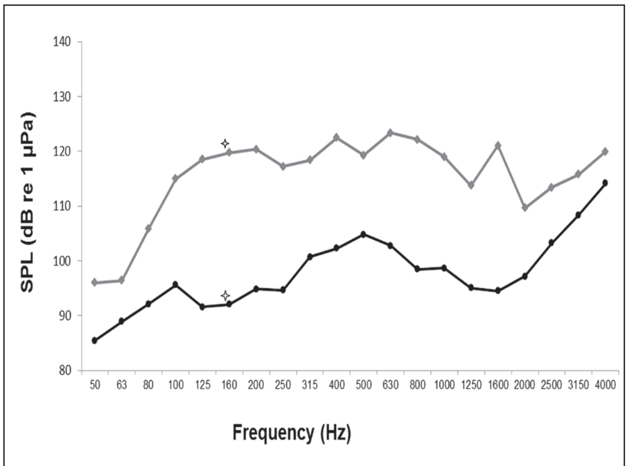

Fig. 3: 1/3 octave band Sound Pressure Level spectra (x-axis in logarithmic scale, 10 Hz – 4 kHz) of the noise produced by a passenger cruise liner under normal operational conditions (line with diamonds) compared to the local background noise level (line with dots) (sampling frequency 44.1 kHz). The frequency in which the passenger cruise causes the maximum increase in the background SPL level is depicted with stars.
Sl. 3: Frekvenčni pas 1/3 oktave ravni zvočnega tlaka (os x na logaritemski lestvici, 10 Hz – 4 kHz) hrupa, ki ga pri normalnih pogojih obratovanja povzroča potniška križarka (črta z rombi) v primerjavi z ravnijo okoljskega hrupa (črta s krogci) (frekvenca vzorčenja 44,1 kHz). Prikazana je frekvenca (zvezdici), pri kateri potniška križarka povzroči največje povišanje ravni zvočnega tlaka v okolici.

Specifically, the noise increase caused by the liner is particularly relevant (higher than 10 dB re 1 µPa) between 80 and 2500 Hz 1/3 octave band level, matching the hearing frequency range of most fish (Nedwell *et al.*, 2004) as well as of other marine vertebrates, as the loggerhead turtle *Caretta caretta* (Ketten, 2008) or invertebrates, as squids (Mooney *et al.,* 2010).

The here reported noise levels are particularly critical for marine animals that have limited mobility, considering that they will be affected by noise for about 20 min for each liner's passage (the inlets are about 3.5 km long and the ship speed is about six knots). The same is true for highly mobile animals that show site fidelity during reproduction *e.g. Sciaena umbra*, a protected vocal fish species that has been detected in the Lido tide inlet during its reproductive season (Picciulin *et al.,* 2013). The same consideration is also applicable to the other typical Mediterranean rocky reef communities that colonise the rocky substrate of the Venetian littoral zone (Cecconi *et al.,* 2008; Fiorin *et al.,* 2008; Rismondo *et al.,* 2008; Ministero delle Infrastrutture e dei Trasporti Magistrato alle Acque di Venezia, 2009; Riccato *et al.,* 2009).

Although the temporary adverse responses to vessel noise (*i.e.* changes in behaviour, displacement, decreasing in hearing sensitivity, enhancing of stress hormones) and the masking effect of this type of pollution on acoustic communication have been widely reported for several vertebrate species (Świerzowski, 1999; Scholik & Yan, 2002; Amoser *et al.,* 2004; De Robertis *et al.,* 2010; Engas *et al.,* 2011), the chronic effects of vessel noise on fish have received less attention to date; Picciulin *et al.* (2012) demonstrated that *S. umbra* mean pulse rate increased over multiple boat passages, likely as a form of vocal compensation. On the other hand Spiga *et al.* (2012a, b) did not find any influence of long-term vessel noise exposure on the growth and nutrition of other Sciaenidae species, but behavioural changes have been noticed. Despite this, there may be further long-term consequences due to chronic exposure to vessel noise. Vessel noise pollution can also indirectly affect animals through changes in the accessibility to prey, which may suffer the adverse effects of acoustic pollution: a detrimental effect on marine fish larvae exposed to underwater noise pollution has been recently demonstrated by Aguilar de Soto *et al.* (2013) and Bolle *et al.* (in press). This effect can be important considering that the lagoon is the ideal place for the growth of juveniles of many marine species (Regione Veneto, 2010).

Considering that ship traffic has also been demonstrated to affect both the hydro-morphology and the re-suspension of sediments (Regione Veneto, 2010), we can conclude that the presence of cruise tourism in the lagoon generates a complex variety of anthropogenic pressures acting synergistically on the aquatic community, which are difficult to predict and estimate, and therefore to mitigate.

ACKNOWLEDGEMENTS

We are grateful to Dr. Maurizio Spoto, director of the WWF Miramare Natural Marine Reserve (Trieste, Italy) for the technical support to this research, and Simon Dedman, for valuable comments on the present manuscript and the revision of the English.

OPREDELITEV HRUPA, KI GA POVZROČA PREHOD POTNIŠKE KRIŽARKE V BENEŠKI LAGUNI: ZASKRBLJENOST ZARADI MOŽNIH VPLIVOV NA LOKALNO RIBJO ZDRUŽBO

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POVZETEK

Na mestu izvora smo posneli in kasneje analizirali podvodni hrup, ki ga v Beneški laguni pri normalnih obratovalnih pogojih odda moderna potniška ladja za križarjenje. Ta vrsta plovila za maksimalno 27 dB re 1 µPa poviša okoljski hrup pri 160 Hz frekvenčnega pasu 1/3 oktave. To je še posebej zaskrbljujoče, saj smo za avgust 2013, ko smo izvajali to raziskavo, izračunali povprečje petih prehodov tovrstnih ladij na dan. Zvišana raven hrupa lahko povzroči začasne negativne odzive, lahko pa tudi kronično vpliva na tipično ribjo populacijo. Iz tega lahko sklenemo, da križarski turizem v laguni povzroča zapleten sklop antropogenih pritiskov, ki v sinergiji učinkujejo na vodne združbe in jih je težko predvideti ter oceniti, posledično pa tudi težko omiliti.

Ključne besede: antropogeni hrup, vpliv, morski ekosistem, ribje združbe

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