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Spatial and temporal variability of sea ambient noise as an anthropogenic pressure index: the case of the Cres-Lošinj archipelago, Croatia

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*This study monitors the spatial and temporal variability of sea ambient noise (SAN) in the Cres-Lošinj archipelago from 2007 to 2009 (north-eastern Adriatic Sea, Croatia). The archipelago is an important marine habitat for many protected species, including the bottlenose dolphin (*Tursiops truncatus*) that is considered as vulnerable to disturbance from intense local vessel traffic. Systematic monthly sampling of SAN was carried out at ten predefined acoustic stations. Data on the presence, type and distance of vessels from these stations was also collected during sampling and vessels were allocated into four main classes. A sample of noise produced by a representative vessel of each vessel class was collected and the noise levels were extracted on the 1/3 octave band standard centre frequencies. All the recordings were analysed in terms of instantaneous sound pressure level (L_{LSP}, L-weighted, 63 Hz–20 kHz, root mean square fast). The equivalent continuous sound pressure levels (L_{Leq}) for vessel and SAN were calculated averaging the L_{LSP} of vessel and SAN samples. Results indicate an increase of SAN levels particularly in the range of low frequencies (63 Hz–1 kHz) during the tourist season. A positive relationship was found between the spatial and temporal distribution of SAN and seasonal changes in anthropogenic pressure, in terms of vessel traffic. Potential implications for local marine life, with particular reference to bottlenose dolphins, are discussed.*

Keywords: anthropogenic noise, sea ambient noise, vessel traffic, sound pressure level, coastal area, Adriatic Sea, bottlenose dolphin

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INTRODUCTION

Background noise in the sea comes from a variety of sound sources including those of natural (physical and biological) and anthropogenic origin (Richardson *et al.*, 1995; Hildebrand, 2009; Popper & Hastings, 2009). In many coastal areas, anthropogenic noise is generated as a by-product of increasing urbanization, industrialization and expanding tourism. Recreational boating represents a growing sector of the tourism industry and often results in alterations of the coastal marine ecosystem (Davenport & Davenport, 2006; Lloret *et al.*, 2008). The wide distribution and mobility of motorized vessels represents the dominant source of underwater anthropogenic noise (Haviland-Howell *et al.*, 2007). Vessel noise causes an increase of the background noise in the sea, particularly over low frequencies (below 1 kHz: e.g. Richardson *et al.*, 1995; Richardson & Würsig, 1997; Erbe, 2002). This anthropogenic noise has already been found to adversely affect the behaviour and communication between marine animals (Tyack, 2008; Clark *et al.*, 2009; Slabbekoorn *et al.*, 2010). An inventory of the acoustic conditions of the regional seas has been highlighted as a priority for the maintenance of good environmental status for the European Union Marine Strategy Framework Directive (MSFD) (Tasker *et al.*, 2010). Monitoring sea ambient noise (SAN) is therefore essential in assessing environmental conditions, especially in the sensitive coastal areas subject to strong human exploitation. Defining the acoustic conditions of this area provides a baseline in accordance with the MSFD objectives, which is particularly pertinent considering Croatia's EU candidate status.

The Cres and Lošinj archipelago represents a popular tourist destination in the northern part of the Croatian Adriatic Sea. Since the 1960s tourism has developed to become the dominant economic sector in this region (Mikačić, 1994). Activities related to tourism are particularly intense during the summer season (Town of Mali Lošinj Tourist Board, 2011, personal communication) resulting in a rapid increase in the number of motorized vessels frequenting the area (Karpouzli, 1996). The extreme seasonal variation in the vessel presence is reflected in the ambient underwater noise level (Rako, 2006). This has possible consequences to the structure and functioning of this sensitive marine area. Of particular consequence is that the Cres and Lošinj waters are an important feeding and nursing ground for the locally

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resident bottlenose dolphin (*Tursiops truncatus*, Montagu, 1821) putative population (Bearzi *et al.*, 1997; Fortuna, 2006). This population has been studied for more than two decades and changes in dolphin habitat use have been identified as a reaction to increased anthropogenic pressure in the area, particularly in relation to the number of recreational vessels (Fortuna, 2006). Disturbance related to vessel presence implies not only physical intrusion but also acoustic harassment of dolphins (Erbe & Farmer, 2000; Mattson *et al.*, 2005; Morisaka *et al.*, 2005; Bejder *et al.*, 2006; Jensen *et al.*, 2009).

Reactions of dolphins to elevated ambient noise levels include short-term changes in surface behaviour, diving intervals, group formation and orientation as well as modifications to their acoustic behaviour (Hastie *et al.*, 2003; Morisaka *et al.*, 2005; Ribeiro *et al.*, 2005; Lemon *et al.*, 2006). Long lasting effects also include migration from important habitats (Bejder *et al.*, 2006).

Quantifying changes in underwater noise levels provides fundamental information for development of future marine conservation strategies that would be beneficial for the local bottlenose dolphin population and the overall status of this coastal habitat. This paper presents results from the implementation of passive bio-acoustic monitoring along the Croatian Adriatic coastline to assess the contribution of anthropogenic noise to SAN. The specific aims of this study were: (i) the identification and characterization of major sources of noise in the Cres and Lošinj coastal waters; and (ii) the long-term monitoring of both spatial and temporal variability of SAN levels in this habitat.

MATERIALS AND METHODS

Monitoring of SAN was undertaken in an area of approximately 545 km^2 extending along the eastern coast of the islands of Cres and Lošinj (Figure 1). The study area is characterized by the numerous small uninhabited islands and islets, steep rocky shores, muddy sea bottoms, limestone reefs and sea depths that do not exceed beyond 120 m (Arko-Pijevac *et al.*, 2003). The average sea current speed is approximately 0.5 knots while the sea temperature varies between the winter 7–15°C to 22–25°C in the summer (Favro & Saganić, 2007). The main urban area is the city of Mali Lošinj, the largest city of all of the Adriatic islands, with a permanent population of about 8000 persons (Croatian Bureau of Statistics, 2011). Other settlements in the archipelago also attract a significant number of tourists; in total the islands host about 1.5 million overnight stays during the summer tourist season (Mali Lošinj Tourist Board, 2011, personal communication).

Over the three-year period from 2007–2009, monitoring of SAN was carried out on ten predefined acoustic stations with bottom depth ranging from 40 m to 90 m (Figure 1).

All the recordings were made in the conditions of sea state <2 (Beaufort scale) to minimize the wave motion that can be transferred to the hydrophone cable. Temporal variability of SAN was assessed focusing on seasonal changes in its levels. In total 418 SAN samples were taken over ten acoustic stations with the mean of about 42 samples per observation station (SD ± 2.8). The overall monitoring yielded a vast data set with 220 SAN recordings made in tourist season (TS) and 198 samples made in non-tourist season (NTS). The definition of what constituted the TS and NTS was based on the official unpublished statistics of tourist stays (Mali Lošinj Tourist Board, 2011, personal communication). The local Tourist Board classifies the period June–September as TS, while NTS corresponds to the period October–May.

The ten acoustic stations were distributed between three areas classified as: high anthropogenic impact (stations 1, 2, 3 and 10), medium anthropogenic impact (stations 4, 5, 6 and 7) and low anthropogenic impact (stations 8 and 9). The criterion for these *a priori* classifications was the proximity of important urban centres, tourist destinations and/or popular boating routes implying probable strong physical exploitation (Fortuna, 2006).

All the acoustic samples were taken using a RESON TC 4032 omni-directional hydrophone (sensitivity −170 dB re 1V/Pa) connected to a calibrated Pioneer DC-88 DAT recorder (sampling rate 44.1 kHz, 16-bit) operating on batteries. The hydrophone was lowered underwater to a depth of approximately 4 m from a 5.7 m inflatable research vessel. Recordings were made above the seasonal thermocline depth (Artegiani *et al.*, 1997). Each recording lasted for 5 minutes.

General boat traffic for the archipelago was accessed from the annual official unpublished statistics of boats present or passing through the area (Mali Lošinj Harbour Master Office, 2010, personal communication). At each acoustic station, during sampling, data on vessel presence, type and distance from the station was collected using FUJINON 7 × 50 marine binoculars. Each observed vessel was allocated to one of the four main vessel classes (see Table 1). Vessels class is defined based on size, type of movement and engine horsepower (HP): class 1, motor yacht and speed boat (MY_SB); class 2, motor boat and sailing boat on engine (MB_SailB); class 3, trawler and gillnetter (TW_GN); and class 4, tour boat (TB). The presence of a vessel was recorded if it was within a 2 km radius from the acoustic station. This distance was chosen to avoid replication in vessel count and to allow the correct visual estimation of the boat type and size.

For each of the defined vessel classes a sample of noise produced by a representative vessel was made and included recordings of motor yacht (MY), speed boat (SB), trawler (TW), gillnetter (GN), motor boat (MB) and sailing boat moving on engine (SailB). The recordings of the representative vessels were made from approximately 25 m distance defined based on the reference length of the research vessel. Vessels' emissions were all recorded in the conditions of sea state 0, without the presence of other vessels within sight. A single representative vessel for the class TB was not defined as the class consists in many different types of vessels ranging from former fishing boats (such as TW/GN) to standard motor yachts of the approximate size up to 20 m.

This work focuses on ordering the boat's relative contribution to the local sea ambient noise. Measurement of the absolute source level of each boat type was beyond the aim of the present paper, as well as the definition of sound propagation in the study area.

Both SAN and vessel noise were analysed in terms of instantaneous sound pressure level (L_{LSP}, L-weighted, 63 Hz–20 kHz, root mean square (rms) fast) using SPECTRA RTA software previously calibrated with a signal of 100 mV rms @1 kHz and hydrophone sensitivity. Acoustic samples were analysed for the 1/3 octave band standard centre frequencies. The equivalent continuous sound pressure levels (L_{Leq}) for vessel and SAN were calculated

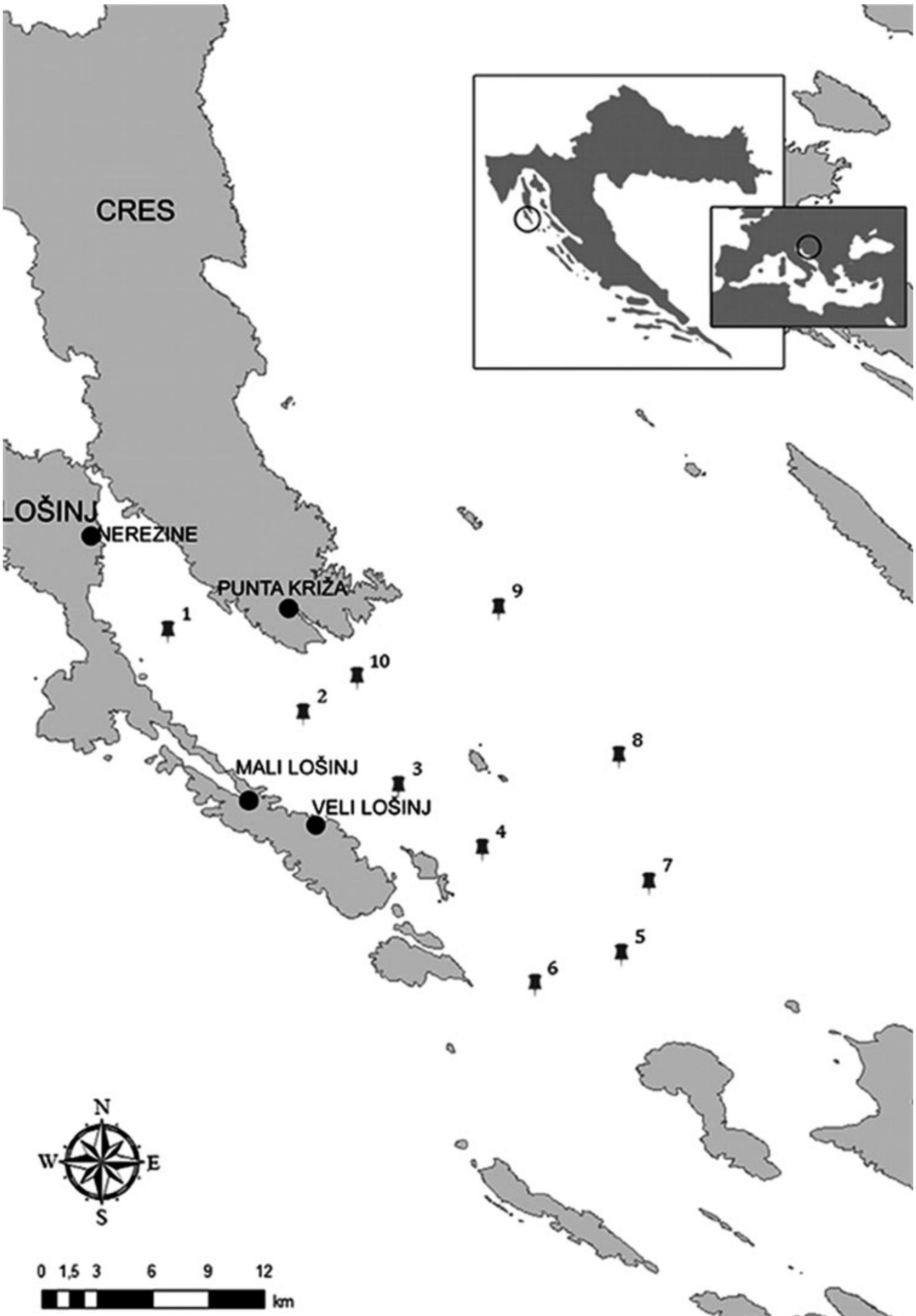

Fig. 1. Geographical position of the study area, with acoustic stations indicated.

averaging the L_{LSP} over 60 seconds (vessels samples) and 300 seconds (SAN samples), respectively—$L_{Leq\ vess}$ and $L_{Leq\ SAN}$. Considering that most underwater anthropogenic noise is generated below 1 kHz and the wideband frequencies may be affected by the variety of natural sound sources (Richardson *et al.*, 1995; Richardson & Würsig, 1997; Hildebrand, 2009), the L_{Leq} (hereafter 'SPL') for frequencies range 63 Hz–1 kHz was calculated along with the wideband SPLs (63 Hz–20 kHz). The given wideband and <1 kHz SPLs represent a logarithmic summation of the recorded sound extracted on the 1/3 octave band frequencies.

Statistical tests were run through SPSS 17.0 for Windows. Since the data failed the Kolmogorov–Smirnov tests for a normal distribution ($P < 0.05$), the relationships between vessel noise, SAN, and boat distribution were assessed using non-parametric tests (Mann–Whitney *U*-test—testing if two groups come from the same distribution, and Kruskal–Wallis test—testing if two or more groups come from data populations with the same median). Relationship between the vessel presence and SAN was obtained on computation of Spearman rank-order correlation for observations made on an approximately continuous scale.

Table 1. Classification of vessels observed in the study area and relative noise levels.

Vessel classes	Size/engine horse power (HP)	$L_{Leq,\ vess}$ (wideband) dB re 1 μPa	Max L_{LSP}, (wideband) dB re 1 μPa
1. MY_SB			
Motor yacht (MY)	4–30 m/40–200 HP	156.2	161.9
Speed boat (SB)	7–15 m/130–320 HP	140.8	147.8
2. MB_SailB			
Motor boat (MB)	1–5 m/maximum 20 HP	133.9	139.0
Sailing boat on engine (SailB)	8–17 m/18–100 HP	133.7	138.3
3. TW_GN			
Trawler (TW)	10–30 m/220–320 HP	143.0	148.5
Gillnetter (GN)	7–9 m/130–220 HP	148.2	153.0
4. TB			
Tour boat (TB)	10–30 m/220–500 HP	—	—

RESULTS

Vessel noise

Table 1 indicates the SPLs of representative vessels emissions recorded in the field at approximately 25 m of distance as well as their maximum recorded L_{LSP}. For the <1 kHz frequency range, maximum SPLs (155.6 ± 5.1 dB re 1 μPa) were measured for motor yacht (MY) followed by trawler (TW; 140.2 ± 6.1 dB re 1 μPa) and speed boat (SB; 136.5 ± 5.9 dB re 1 μPa). In contrast, motor boats (MB) and sailing boats moving on engine (SailB) appeared to be significantly less noisy in this frequency range (124.9 ± 1.9 dB re 1 μPa and 115.4 ± 6.0 dB re 1 μPa).

A comparison between octave band levels of different vessels (Figure 2) indicates peak levels at 125 Hz frequency for MY; TW and SB also had peak levels measured at 125 Hz, GN emitted higher noise levels (>130 dB re 1 μPa) at frequencies >315 Hz while MB and SailB contributed more to the frequencies >2 kHz (>120 dB re 1 μPa).

Temporal and spatial characteristics of SAN

The average SAN recorded in the area for the wideband frequency range (63 Hz–20 kHz) equates to 132.4 ± 5.2 dB re 1 μPa. The SPLs averaged for the <1 kHz (63 Hz–1 kHz) frequency range is similar, with 129.4 ± 6.1 dB re 1 μPa. The average sea ambient noise 1/3 octave band pressure spectra for the period 2007–2009, is presented in Figure 3.

No significant year-to-year changes were found in the overall background noise of the study area (Figure 4) when considering both frequency ranges (<1 kHz and wideband)

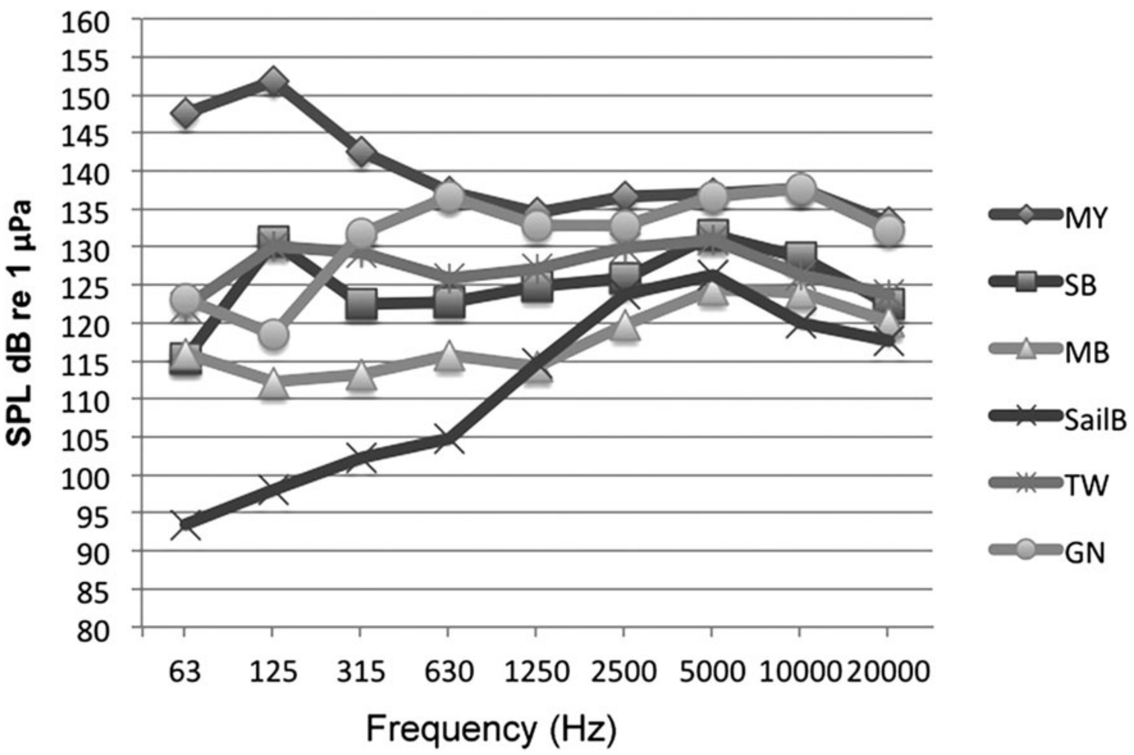

Fig. 2. 1/3 octave band sound pressure levels (SPLs) of representative vessels.

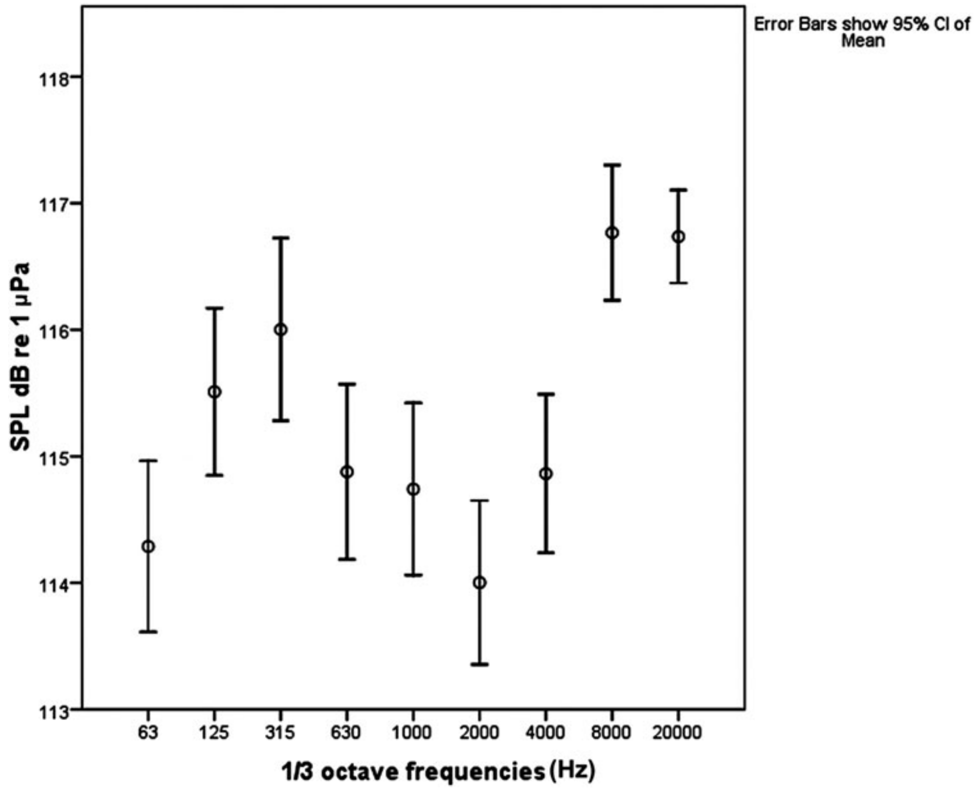

Fig. 3. 1/3 octave band sound pressure level spectra (SPLs) averaged over the period 2007–2009.

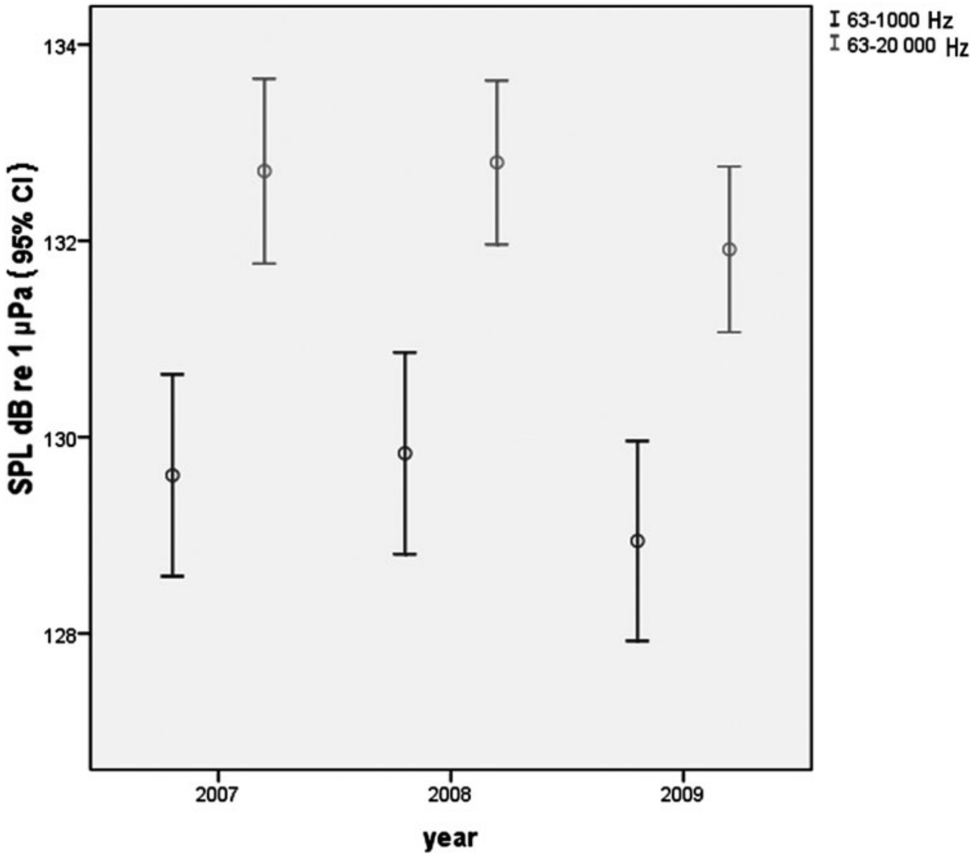

Fig. 4. Year-to-year course of the sea ambient noise levels for <1 kHz frequency range and the wideband.

SPLs (Kruskal–Wallis test, $N = 418$, $df = 2$, $P = 0.371$ (wideband) and $P = 0.264$ (<1 kHz).

Figure 5 represents the seasonal distribution of the SAN (for wideband and <1 kHz frequency range) during the TS and NTS across the ten monitoring stations. During TS, <1 kHz SPLs at acoustic stations located closer to the coast of the islands of Lošinj and Cres (stations 4, 10, 6, 2 and 1 followed by the station 9) had SPLs ≤ 132 dB re 1 μPa with the highest SPLs of approximately 135 dB re 1 μPa measured at the acoustic station 3. Acoustic stations located along the eastern perimeter of the study area (stations 5, 7 and 8) had SPLs around 126 dB re 1 μPa. In the NTS, SPLs were more homogeneous throughout the area with the average SPLs between 127 and 131 dB re 1 μPa.

When clustering all the stations into three spatial areas, i.e. of high (stations 1, 2, 3 and 10), medium (stations 4, 5, 6 and 7) and low (stations 8 and 9) anthropogenic impact, a significant difference was found between TS and NTS for only the high anthropogenic impact area for both wideband (Mann–Whitney test, $N = 173$, $P = 0.005$) and <1 kHz SPLs (Mann–Whitney test, $N = 173$, $P < 0.001$), with TS SPLs higher than NTS SPLs (Figure 6). In addition, for the three impact areas there were heterogeneous results for both wideband and <1 kHz SPLs during TS (Kruskal–Wallis test, $N = 220$, $df = 2$, $P < 0.001$ and $P = 0.001$, respectively), but not during NTS (Kruskal–Wallis test, $N = 198$, $df = 2$, not significant).

Vessel temporal and spatial distribution

The monthly trend of the average number of different vessel classes observed throughout the three years (Figure 7) highlighted the summer months (July and August followed by June and September) as those characterized by the strongest nautical traffic. Specifically, the most frequent vessels during the TS period were found to belong to the class of fast moving recreational vessels such as motor yachts and speed boats (MY_SB). Tour boats (TB) were found during the TS only, with a peak in July. Although motor boats and sailing boats on engine (MB_SailB) were present throughout the whole year, we found a significant increase in their number over the TS. Only vessels related to professional fishing activities (TW_GN) were more frequent than others during NTS, but with no significant maximum in a particular month. As a result, a significant difference between NTS and TS was found in the number of all the observed vessels with

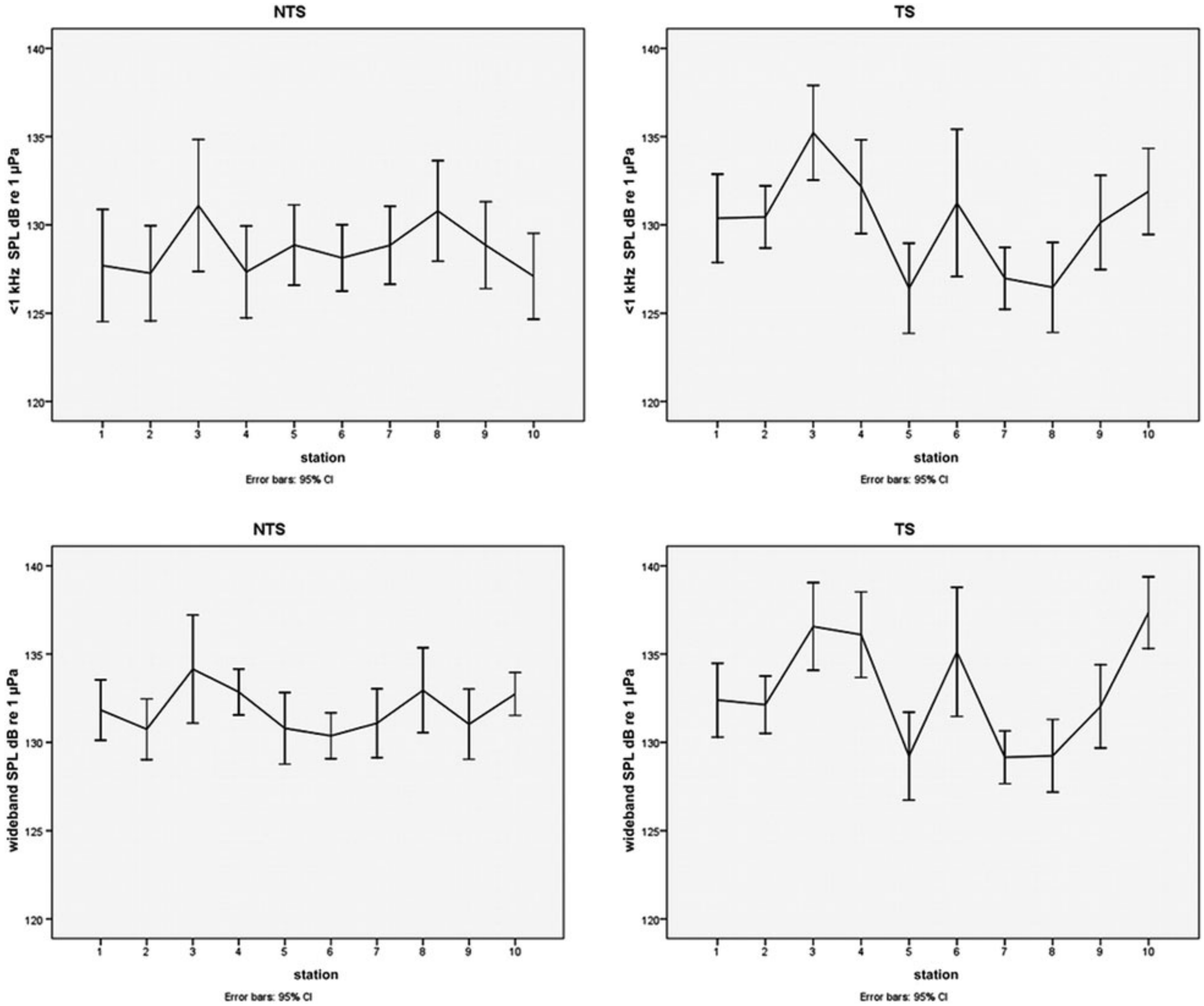

Fig. 5. Spatial distribution of wideband and <1 kHz sea ambient noise sound pressure levels (SPLs) averaged over the non-tourist season (NTS) and tourist season (TS).

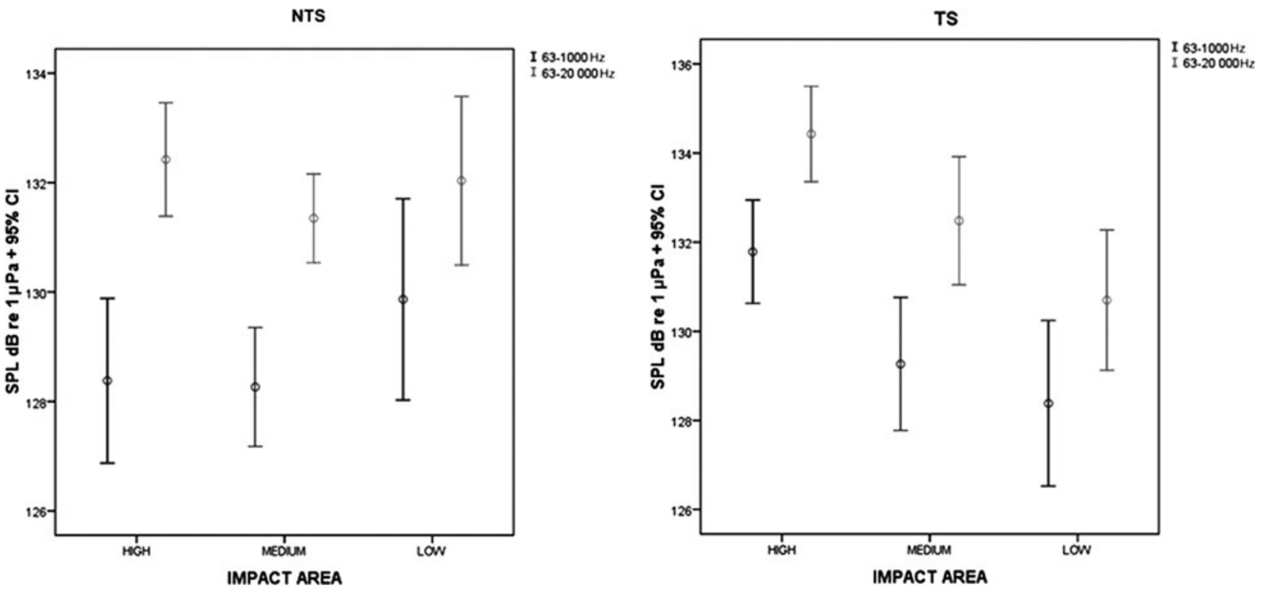

Fig. 6. Averaged <1 kHz and wideband sound pressure levels (SPLs; mean ± 95% confidence interval (CI)) of three impact areas during non-tourist season (NTS) and tourist season (TS).

MY_SB, TB and MB_SailB (Mann–Whitney test, N = 418, *P* < 0.001) being significantly more present during TS, and TW_GN during NTS (Mann–Whitney test, N = 418, *P* = 0.018) particularly across the area of low anthropogenic impact (Figure 8).

It is evident that the highest concentration of particularly noisy vessels affects the high impact area (MY_SB and MB_SailB, differently distributed over the three areas along the TS, Kruskal–Wallis test, N = 220, df = 2, *P* = 0.003 and *P* < 0.001 respectively).

SAN and vessel presence

During the period 2007–2009 a significant positive correlation was found between the number of vessels present during the SAN recordings and the noise levels measured

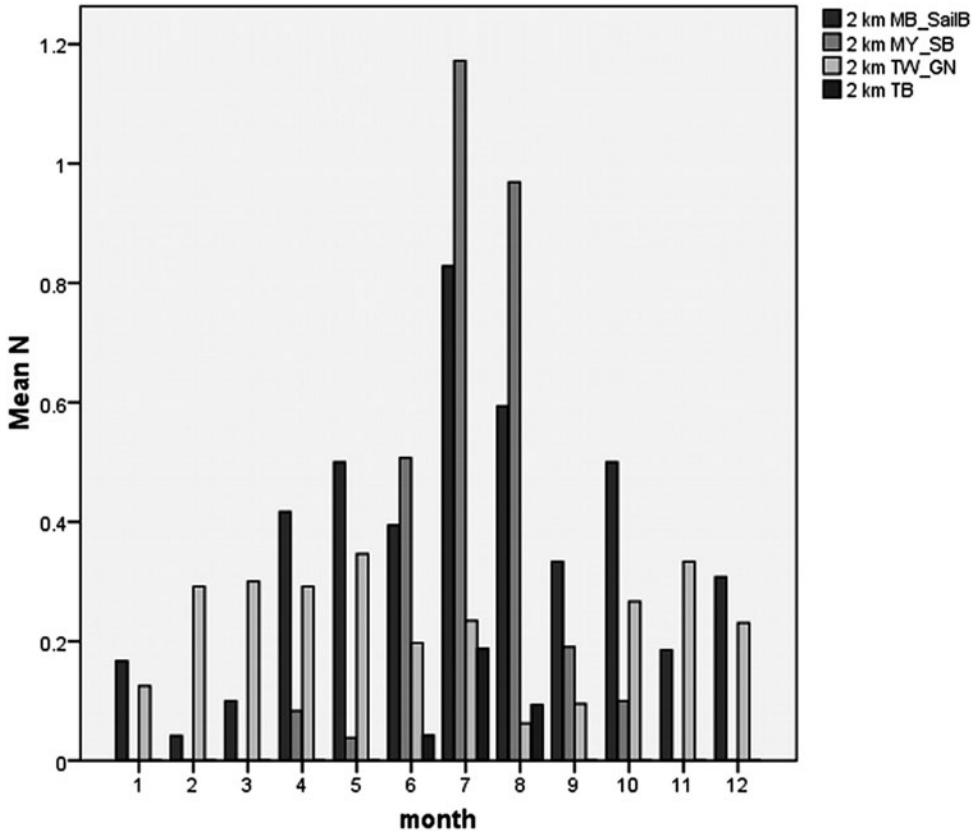

Fig. 7. Monthly trend in the number of different classes of observed vessels averaged over different years (2007–2009) in the study area at distances <2 km.

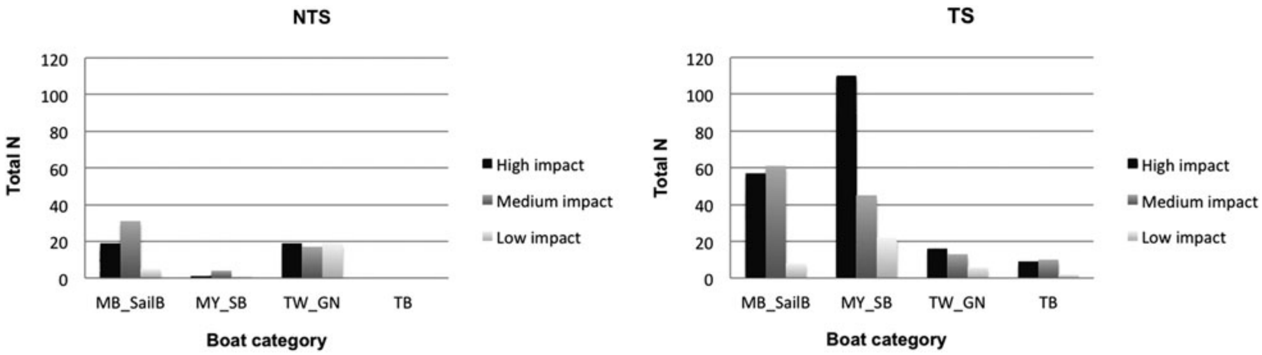

Fig. 8. Spatial distribution of different classes of vessels observed at distances <2 km averaged over the tourist season (TS) and non-tourist season (NTS).

for both <1 kHz frequency range (Spearman rank-order correlation, $P = 0.000$, rho = 0.295) and the wideband (Spearman rank-order correlation, $P = 0.000$, rho = 0.340). The seasonal analysis showed a significant positive correlation only during the TS (Spearman rank-order correlation, <1 kHz: $P = 0.000$, rho = 0.423 and wideband: $P = 0.000$, rho = 0.450). Conversely, this correlation was not found during the NTS (Figure 9, Spearman rank correlation, <1 kHz and wideband, not significant).

DISCUSSION

This study is the first long-term investigation of the changes in SAN in one coastal marine habitat in the Adriatic Sea. The vast dataset provides fundamental, new knowledge on the temporal and spatial variability of SAN in these coastal waters.

The background noise here results to be relatively high, in accordance to similar values reported for the Italian northern Adriatic coastline (Gulf of Trieste: Picciulin *et al.*, 2010). Despite this, clear differences in the wideband and low frequency noise levels (<1 kHz) are present in the SAN noise within the study area. These differences appear to be particularly pronounced between seasons and attributable to the intense nautical tourism within this coastal area as generally higher SPLs reflected the seasonal intensity of the vessel traffic across the study area.

Changes in the intensity and types of vessels frequenting the area contribute to creation of two significantly different seasonal underwater soundscapes. The NTS, characterized by the low vessel presence, generally exhibits lower noise levels, in particular over the low range of frequencies (<1 kHz). Conversely, the TS brings increased noise levels especially in recreational boats within the area. The high number of fast moving, recreational vessels significantly affected the SAN levels in the study area. As expected, the highest SPLs were measured on locations close to urban centres and affected both wideband and the <1 kHz frequency range while the points more distant from the usual navigation routes appear to be less noisy. This heterogeneous distribution of noise found during the TS, became even more pronounced when considering the three pre-defined areas of different anthropogenic impact. The high impact area, in

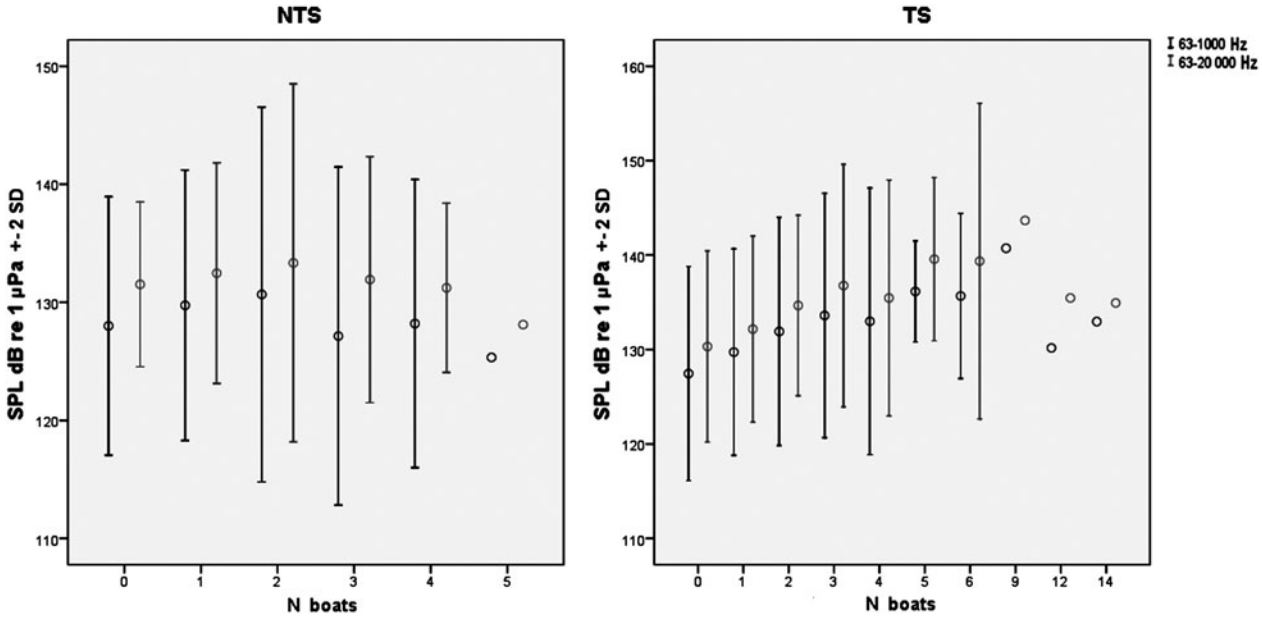

Fig. 9. Correlations between the intensity of vessel traffic and the sea ambient temperature noise levels

the close proximity to the main urban centres, well-known tourist destinations and main marine routes, was the only area showing statistically significant seasonal noise variability, particularly pronounced for the <1 kHz frequency range. Moreover, compared to the other two impact areas ('medium' and 'low'), the SPLs were significantly higher during the TS considering both <1 kHz frequency range and the wideband. In addition, the spatial distribution of vessels indicated significantly higher number of motor yachts and speedboats (MY_SB) only in the high impact area during the TS. From our results it is apparent that these fast moving, recreational boats are the noisiest vessels among all those tested, with maximum energy concentrated in the low frequency range (<1 kHz). It is therefore reasonable to suggest that this particular vessel class (MY_SB) represents the primary source of anthropogenic noise causing the significant seasonal and spatial changes in the underwater soundscape in the study area.

Fortuna (2006) argues that the distribution of the Cres and Lošinj dolphin population is negatively correlated to the distance from the main urban centres, possibly due to the physical presence of recreational vessels. Moreover, the abundance of the resident bottlenose dolphins in Cres–Lošinj waters suffered a significant decline of about 40% within the period 1995–2003 (Fortuna, 2006). This decline was hypothesized to be related to substantial humanly induced environmental changes, particularly the sudden increase of recreational vessels after the Croatian War of Independence (1991–1995) and the following period of political instability in the region (Fortuna, 2006). The evaluation of the intensity of vessel traffic and quantification of the noise derived from different vessel types hence represents an important step towards the assessment of this marine habitat fitness (Jensen *et al.*, 2009).

This study quantifies for the first time the background noise levels in these coastal waters and its seasonal and spatial changes suggesting that anthropogenic noise may explain bottlenose dolphin distribution. The presence of vessels may represent both a source of physical harassment and acoustic disturbance for the resident dolphin population (Erbe & Farmer, 2000). As suggested elsewhere, the physical presence of numerous unpredictable and fast vessels may have induced animals to deviate from their usual behavioural patterns including short-term displacement in the affected area or long-term exclusions from their habitats (Bowles, 1995; Allen & Read, 2000; Bejder *et al.*, 2006). In addition, bottlenose dolphins use sound to communicate and gather information about their environment (Richardson *et al.*, 1995; Au *et al.*, 2000; Jensen *et al.*, 2009). The increased ambient noise reduces the distance at which they perceive biologically important sounds and negatively affects their communication range by masking their signals (Jensen *et al.*, 2009). This particularly regards their low-frequency communication sounds especially in the close proximity to noisy vessels (Perrin *et al.*, 2008; Jensen *et al.*, 2009).

The present study indicates a positive relationship between the spatial and temporal distribution of SAN and the seasonal variations of vessel traffic in one coastal area. Moreover, it provides the first long-term quantification of SAN within the Adriatic Sea helping to fulfil future Croatian commitments to the MSFD (Tasker *et al.*, 2010). The overall results of this study indicate the critical areas within Cres–Lošinj waters where human activities are becoming incompatible with the habitat welfare and where development of the appropriate conservation measures should be prioritized.

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Supplementary Materials

The supplementary material refered to in this paper can be found online at journals.cambridge.org/mbi.

REFERENCES

Allen M.C. and Read A.J. (2000) Habitat selection of foraging bottlenose dolphins in relation to boat density near Clearwater, Florida. *Marine Mammal Science* 16, 815–824.

Arko-Pijevac M., Benac Č., Kovačić M., Kirinčić M. and Gržančić Ž. (2003) Ecological and geological valorisation of the coastal line and submarine area of the islands Ćutin mail and Ćutin veli aiming to establish a protected area. In Besendorfer V. (ed.) *Zbornik sažetaka priopćenja Osmog hrvatskog biološkog kongresa*. Zagreb: Hrvatsko biološko društvo, pp. 407–408.

Artegiani A., Bregant D., Paschini E., Pinardi N., Raicich F. and Russo A. (1997) The Adriatic Sea general circulation. Part I: air–sea interactions and water mass structure. *Journal of Physical Oceanography* 27, 1492–1514.

Au W.W.L., Popper A.N. and Fay R.R. (2000) *Hearing by whales and dolphins*. New York: Springer-Verlag, Inc.

Bearzi G., Notarbartolo di Sciara G. and Politi E. (1997) Social ecology of bottlenose dolphins in the Kvarnerić (Northern Adriatic Sea). *Marine Mammal Science* 13, 650–668.

Bejder L., Samuels A., Whitehead H., Gales N., Mann J., Connor R., Heithaus M., Watson-Capps J., Flaherty C. and Krützen M. (2006) Decline in relative abundance of bottlenose dolphins exposed to long-term disturbance. *Conservation Biology* 20, 1791–1798.

Bowles A.E. (1995) Responses of wildlife to noise. In Knight R.L. and Gutzwiller K.J. (eds) *Wildlife and recreationists: coexistence through management and research*. Washington, DC: Island Press, pp. 109–156.

Clark C.W., Ellison W.T., Southall B.L., Hatch L., Van Parijs S.M., Frankel A. and Ponirakis D. (2009) Acoustic masking in marine ecosystems: intuitions, analysis, and implication. *Marine Ecology Progress Series* 395, 201–222.

Croatian Bureau of Statistics (2011) Popis stanovništva, kućanstava i stanova 2011. Prvi rezultati po naseljima. *Statistička izvješća 1441* [Census of Population, Households and Dwellings 2011, First Results by Settlements]. Statistical Reports 1441. ISSN 1332-0297, 208 pp.

Davenport J. and Davenport J.L. (2006) The impact of tourism and personal leisure transport on coastal environments: a review. *Estuarine, Coastal and Shelf Science* 67, 280–292.

Erbe C. (2002) Underwater noise of whale-watching boats and potential effects on killer whales, *Orcinus orca*, based on an acoustic impact model. *Marine Mammal Science* 18, 394–418.

Erbe C. and Farmer D.M. (2000) A software model to estimate zones of impact on marine mammals around anthropogenic noise. *Journal of the Acoustical Society of America* 108, 1327–1331.

Favro S. and Saganić I. (2007) Natural characteristics of Croatian littoral area as a comparative advantage for nautical tourism development. *Geoadria* 12, 59–81.

Fortuna C.M. (2006) *Ecology and conservation of bottlenose dolphins,* Tursiops truncatus, *in the north-eastern Adriatic Sea.* PhD thesis. University of St Andrews, UK.

Hastie G.D., Wilson B., Tufft L.H. and Thompson P.M. (2003) Bottlenose dolphins increase breathing synchrony in response to boat traffic. *Marine Mammal Science* 19, 74–84.

Haviland-Howell G., Frankel A.S., Powell C.M., Bocconcelli A., Herman R.L. and Sayigh L.S. (2007) Recreational boating traffic: a chronic source of anthropogenic noise in the Wilmington, North Carolina Intracoastal Waterway. *Journal of the Acoustical Society of America* 122, 151–160.

Hildebrand J.A. (2009) Anthropogenic and natural sources of ambient noise in the ocean. *Marine Ecology Progress Series* 395, 5–20.

Jensen F.H., Bejder L., Wahlberg M., Aguilar Soto N., Johnson M. and Madsen P.T. (2009) Vessel noise effects on delphinid communication. *Marine Ecology Progress Series* 395, 161–175.

Karpouzli E. (1996) *An assessment of the status of a bottlenose dolphin community,* Tursiops truncatus, *in the Southern Kvarneric Sea (Northern Adriatic).* MSc thesis. Heriot-Watt University, Edinburgh, Scotland.

Lemon M., Lynch T.P., Cato D.H. and Harcourt R.G. (2006) Response of travelling bottlenose dolphins, *Tursiops aduncus*, to experimental approaches by a powerboat in Jervis Bay, New South Wales, Australia. *Biological Conservation* 127, 363–327.

Lloret J., Zaragoza N., Caballero D. and Riera V. (2008) Impacts of recreational boating on the marine environment of Cap de Creus (Mediterranean Sea). *Ocean and Coastal Management* 51, 749–754.

Mattson M., Thomas J. and Aubin D. (2005) Effects of boat activity on the behaviour of bottlenose dolphins, *Tursiops truncatus*, in waters surrounding Hilton Head Island, South Carolina. *Aquatic Mammals* 31, 133–140.

Mikačić V. (1994) Otočni turizam Hrvatske [Island Tourism in Croatia]. *Društvena istraživanja* 3, 517–529.

Morisaka T., Masanori S., Nakahara F. and Akamatsu T. (2005) Effects of ambient noise on the whistles of Indo-Pacific bottlenose dolphin populations. *Journal of Mammalogy* 86, 541–546.

Perrin W.F., Würsig B. and Thewissen J.G.M. (2008) *Encyclopedia of marine mammals.* San Diego, CA: Academic Press.

Picciulin M., Sebastianutto L., Codarin A., Farina A. and Ferrero E.A. (2010) *In-situ* behavioral responses to boat noise exposure of *Gobius cruentatus* (Gmelin, 1789; fam. Gobiidae) and *Chromis chromis* (Linnaeus, 1758; fam. Pomacentridae) living in a Marine Protected Area. *Journal of Experimental Marine Biology and Ecology* 386, 125–132.

Popper A.N. and Hastings M.C. (2009) The effects of human-generated sound on fish. *Integrative Zoology* 4, 43–52.

Rako N. (2006) *Annual characterization of the sea ambient noise (S.A.N.) in Lošinj-Cres archipelago (Croatia) as a potential source of bottlenose dolphin behavioural disturbance.* MSc thesis. University of Trieste, Italy.

Ribeiro S., Viddi F.A. and Freitas T.R.O. (2005) Behavioural responses of Chilean dolphins, *Cephalorhynchus entropia*, to boats in Yaldad Bay, Southern Chile. *Aquatic Mammals* 31, 234–242.

Richardson W.J. and Würsig B. (1997) Influences of man-made noise and other human actions on cetacean behaviour. *Marine and Freshwater Behaviour and Physiology* 29, 183–209.

Richardson W.J., Green C.R. Jr, Malme C.I. and Thompson D.H. (1995) *Marine mammals and noise*. San Diego, CA: Academic Press.

Slabbekoorn H., Bouton N., van Opzeeland I., Coers A., ten Cate C. and Popper A. (2010) A noisy spring: the impact of globally rising underwater sound levels on fish. *Trends in Ecology and Evolution* 25, 419–427.

Tasker M.L., Amundin M., Andre M., Hawkins A., Lang W., Merck T., Scholik- Schlomer A., Teilmann J., Thomsen F., Werner S. and Zakharia M. (2010) *Marine Strategy Framework Directive.* Task Group 11 Report, Underwater noise and other forms of energy (JRC Scientific and Technical Reports), EUR 24341 EN, 55 pp.

and

Tyack P.L. (2008) Implications for marine mammals of large-scale changes in the marine acoustic environment. *Journal of Mammalogy* 89, 549–558.

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