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CHARACTERIZATION OF THE NOISE PRODUCED BY CLASS 1 POWERBOAT RACE IN PIRAN BAY (SLOVENIA) AND POTENTIAL IMPACT ON THE MARINE FAUNA

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ABSTRACT

Underwater noise produced during a Class 1 powerboat race was measured in the Bay of Piran (Slovenia) in September 2006. The calculated $L_{Leq\ 30\,sec}$ *of a single powerboat passing 300 m away from the hydrophone was equal to 120 dB re 1 µPa, exceeding the local sea ambient noise by an average of 8.5 dB within the considered frequency range (40–22100 Hz). The same powerboat, passing 670 m away, allowed the estimation of the source level, which is 145 dB re 1 µPa at 1 m. Comparisons with the hearing abilities of a crustacean, a fish species, a marine mammal, and indications from previous studies lead us to conclude that noise of such intensity can elicit behavioural responses as well as mask and impair acoustic communication in the considered animals. We also noticed that some 200–300 spectator's boats moving across the race field simultaneously at the end of the race brought an increment in the sea ambient noise exceeding the powerboat noise in the frequency range below 500 Hz.*

Key words: noise pollution, anthropogenic impact, power boat race, Adriatic Sea

CARATTERIZZAZIONE DEL RUMORE IRRADIATO IN ACQUA DA MOTOSCAFI TIPO *OFFSHORE* CLASSE 1 IN COMPETIZIONE NELLA BAIA DI PIRANO (SLOVENIA) E POTENZIALI IMPATTI SULLA FAUNA MARINA

SINTESI

Il rumore subacqueo prodotto da motoscafi tipo offshore Classe 1 è stato misurato nel corso di un Gran Premio del campionato mondiale, tenutosi nel settembre 2006 nella baia di Pirano (Slovenia). L'$L_{Leq\ 30\,sec}$ *calcolato per un singolo motoscafo che transitava a 300 m di distanza dall'idrofono era uguale a 120 dB re 1 µPa, superando mediamente il sea ambient noise locale di 8,5 dB nel range di frequenze considerato (40–22100 Hz). Tenuto conto del livello di pressione sonora generato dalla stessa imbarcazione che passava ad una distanza di 670 m, si è potuto stimare il source level, che è di 145 dB re 1 µPa a 1 m. La comparazione della sensibilità acustica di diverse specie marine – un crostaceo, un pesce ed un mammifero – assieme ad indicazioni tratte da studi precedenti, permette di concludere che rumori di tale intensità possono determinare variazioni di tipo comportamentale, nonché mascherare e rendere difficoltosa la comunicazione acustica negli animali considerati. Inoltre, è stato rilevato che circa 200–300 barche con a bordo spettatori, le quali si muovevano simultaneamente lungo il confine del campo di gara alla fine della competizione, portano ad un incremento del rumore ambiente subacqueo locale, superando il rumore prodotto da un motoscafo nel range di frequenze al di sotto dei 500 Hz.*

Parole chiave: inquinamento acustico, impatto antropico, gara di motoscafi tipo offshore, mare Adriatico

INTRODUCTION

A constant increase of the human activities in many diverse natural environments has pointed out the necessity of monitoring and evaluating the potential effects that human presence may cause. Among others, noise pollution is a serious threat to marine animals whose effects, compared to more visible pollutants like oil spills and marine debris, are not as easy to notice. Even if they are noticed, they cannot be easily stopped and confined out of sensitive or protected areas. Noise pollution is particularly relevant in coastal areas due to the high number of anthropogenic sources as, for example, the motorised vessels (Allen & Read, 2000; Buckstaff, 2004). Several studies showed that boat noise elicit different types of avoidance behavior both in small cetaceans and in fish *(e.g.*, Avecedo, 1991; Nestler *et al.*, 1992; Janik & Thompson, 1996; Gregory & Rowden, 2001; Mitson & Knudsen, 2003; Sarà *et al.*, 2007). Temporary hearing loss (Scholik & Yan, 2001; Amoser & Ladich, 2003; Smith *et al.*, 2004), impaired temporal resolution ability (Wysocki & Ladich, 2005), damages to the sensory epithelia of the inner ear (Hastings *et al.*, 1996; McCauley *et al.*, 2003) and endocrinological stress responses (Santulli *et al.*, 1999; Smith *et al.*, 2004) caused by exposure to different anthropogenic noise types have been also demonstrated in these taxa.

A Class 1 Powerboat Race, part of the world offshore championship, took place out of Piran Bay (Slovenia) between 1st and 3rd September 2006. About 10 offshore powerboats participated in the competition; these are boats with a high power to weight ratio and a hull with twin inboard engines designed for easy planning, high speed (up to 270 km/h; Amoser *et al.* 2004) and improved handling. Although the offshore competitions are raced every year on three different continents, only few environmental impact assessments have been made on them. Despite being limited in number, these assessments pointed our a particular concern about hydrological forces and turbidity in view of the blue mussels, about potential collisions between powerboats and marine mammals and about fish disturbance due to the high noise levels emanating from the vessels (Morgenroth, 2002, 2003; Amoser *et al.*, 2004).

The aims of the present study are (1) to describe underwater noise emissions and noise levels produced by the powerboats and (2) to compare them with the local sea ambient noise recorded both in quiet and boat traffic condition. The hearing abilities of a crustacean, a fish species and a marine mammal, whose home ranges include the competition area, are taken into account in order to discuss the potential impacts of the powerboat noise.

MATERIALS AND METHODS

The race was run in Slovenian waters of the Trieste Gulf (North Adriatic Sea), 2 km outside the town of Piran. Data were collected from a rubber boat from 10 to 11.30 a.m. on 2 September 2006 (pole position) and from 14 to 16 p.m. on 3 September 2006 (race). The rubber boat was anchored during both days at a distance of approximately 300 meters from the longest straight leg of the race (Fig. 1; 45°31′48.54″ N, 13°33′14.84″ E), where powerboats passed at highest speed. This was the place closest to the race, due to an official security zone. The weather was sunny on both days (sea state 0), with water temperature ranging from 23°C (surface) to 20°C (at 15 meters depth).

The noise emission of the powerboats was recorded at a depth of 10 m (muddy bottom; depth 20 m) using a calibrated Reson TC4032 hydrophone (Slangerup, Denmark; sensitivity –170 dB re 1 V/μPa) and a Pioneer D-C88 DAT recorder (Pioneer Electronics, U.S.A.; sample rate 44.1 kHz, 16-bit) battery operated. These settings were used also for recording the sea ambient noise before the pole, when no powerboats were running and a limited number of motor boats (< 10) were visible in Piran Bay (quiet condition, QC), and after the race, when about 200–300 boats of public viewers were moving along the race circuit (traffic condition, TC).

All the recordings were analysed in terms of instantaneous sound pressure levels (SPL, *L*-weighted, 20 Hz to 20 kHz, RMS fast) using Spectra RTA (Sound Technology) spectral analyser calibrated with a signal of 100 mV rms @1 kHz and hydrophone sensitivity. For the analysis, ten 30 sec-samples were chosen from the race noise recordings; all of them include the background noise recorded while single powerboats were passing at the minimum distance (300 ±10 m; powerboat close, PC) or at the maximum distance (670 ±10 m; powerboat far, PF) from the hydrophone. Distances were measured trough a hand-hold GPS navigator, by crossing the race ground right after the competition, while the buoys setting the lanes were still in place. Their L_{Leq} values (30 sec) were calculated as well as their power spectra and the loudest and weakest samples (corresponding to the minimum and maximum distance of the powerboat) were considered for comparative analysis with the sea ambient noise. 30 sec-samples of ambient noise were also randomly chosen both for quiet and traffic condition and their L_{Leq} (30 sec) calculated. The loudest and weakest samples were considered for comparative analysis: the instantaneous sound pressure level (L_{LSP}, *L*-weighted, 10 Hz to 20 kHz, RMS fast) was calculated over a 30 sec sample (n=30 for each sample) per each of the four conditions (PF, PC, QC, TC) and a multivariate ANOVA based on two within-subjects factors (frequency and condition) with a Bonferroni post-hoc test was applied on the data using the computer package Statistica 6.0 for Windows (StatSoft, Inc.). Assumptions of normality and homogeneity of variances were met. The sonogram and the waveform of the powerboat noise

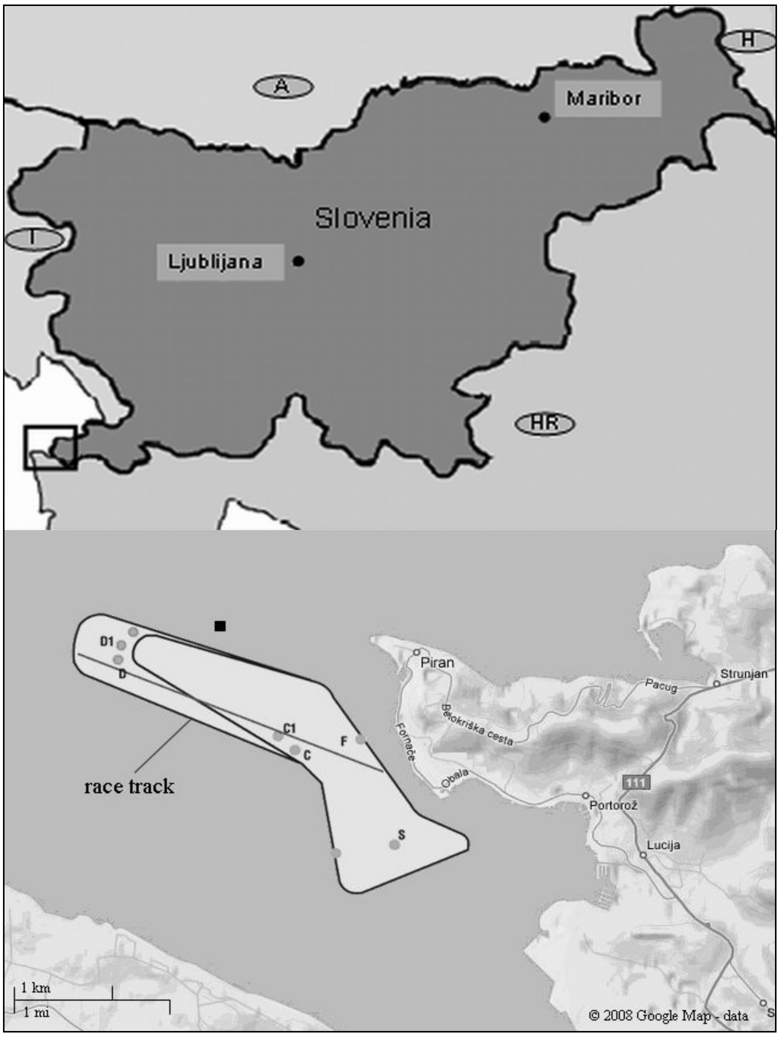

Fig. 1: Race track of the Class 1 powerboat race in Piran Bay. The black square indicates the recording position.
Sl. 1: Tekmovalna proga za motorne čolne razreda 1 v Piranskem zalivu. Črni kvadrat označuje mesto opravljenih meritev.

were displayed using Avisoft SasLab Pro (Avisoft Bioacoustics, Berlin, Germany) signal processing software (Hamming window, frequency bandwidth of 75 Hz, 1024 point FFT, overlap 97%, frame 75%).

RESULTS

One powerboat passing about 300 m from the hydrophone (PC) produces a noise that is concentrated mainly below 5 kHz with a maximum instantaneous sound pressure level (SPL) of 126 dB re 1 μPa. From the sonogram and the power spectra of the noise (Fig. 2) three harmonics are easily detectable. The mean fundamental frequency is equal to 420 ± 4.7 Hz (range 412–426 Hz, n=10), corresponding to the rotational speed of the propeller.

Figure 3 represents the power spectra of the four considered conditions (PF, PC, QC, TC). The harmonic peaks are evident in the spectra of the powerboat noise recorded at 300 m (PC) and at 670 m (PF) of distance. PC spectra levels remain much higher in the upper frequency range than all the other conditions. This is not the case of PF spectra that show a decrement at high frequency similar to QC and TC. This likely occurred because the noise transmission loss is frequency dependent, and attenuation of sound by seawater increases with increasing frequency (Rogers & Cox, 1988). On the opposite, the main energy in the low frequency range (<400 Hz) is produced by the boat traffic present in the area after the race (TC). As predictable, QC has the quietest spectra. Compared to quiet conditions (QC), PC noise shows an almost constant increment of 8.5 ± 3.7 dB along all the frequencies (n=10).

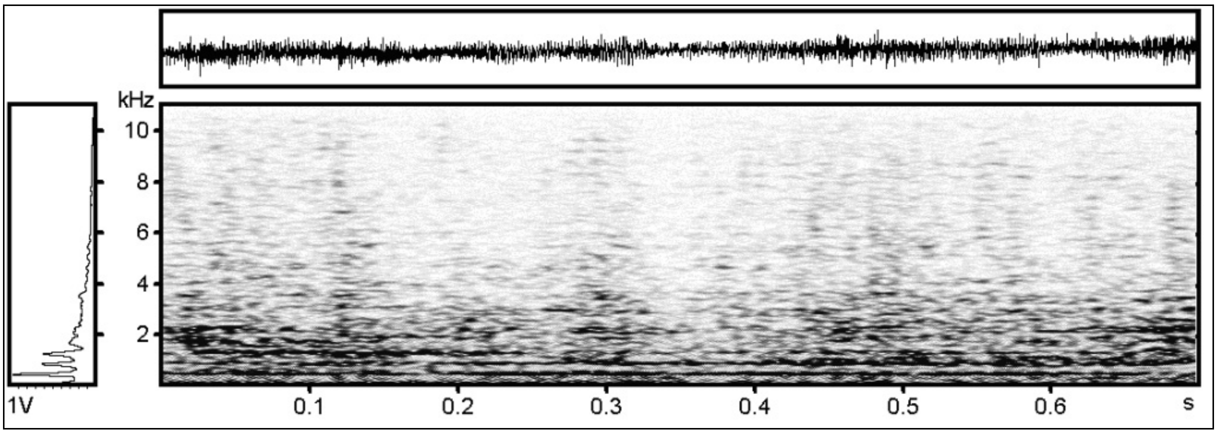

Fig. 2: Sonogram, power spectra (on the left) and oscillogram (above) of the noise produced by a powerboat passing at 300 m from the hydrophone (Hamming window, frequency bandwidth of 75 Hz, 1024 point FFT, overlap 97%, frame 75%).
Sl. 2: Sonogram, spektri moči (na levi) in oscilogram (zgoraj) hrupa, ki ga je povzročil motorni čoln na razdalji 300 m od hidrofona (Hammingovo okno, širina frekvenčnega pasu 75 Hz, 1024 točk FFT, prekrivanje 97%, okvir 75%).

The calculated L_{Leq} (30 sec) for each of the four considered conditions (PF, PC, QC, TC) is equal to 120 dB re 1 μPa (PC), 116 dB re 1 μPa (PF), 111.3 dB re 1 μPa (QC) and 119.8 dB re 1 μPa (TC). Although some values can be considered similar, a multivariate ANOVA revealed a significant effect of the four conditions (PF, PC, QC, TC) on their L_{LSP} calculated over 30 sec (F= 1766; P<0.001) and the post-hoc Bonferroni test indicates that each condition differs significantly from all the others (P<0.001).

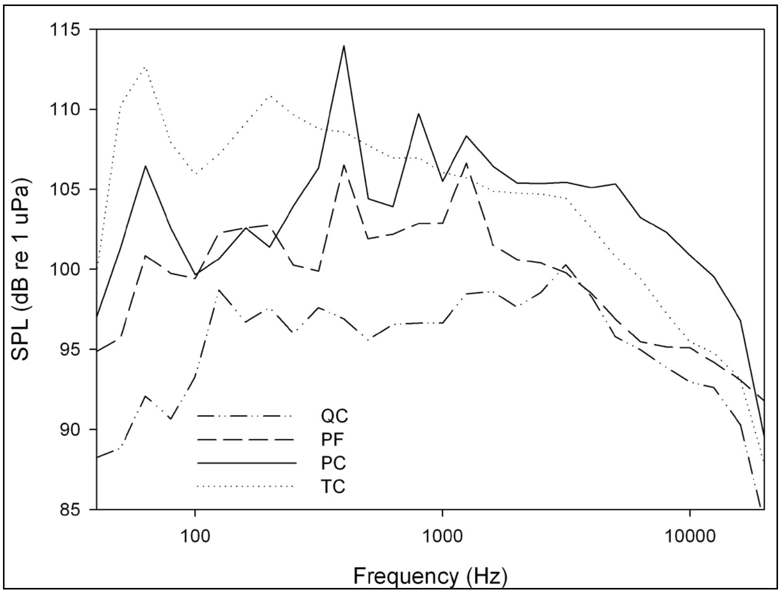

Fig. 3: Power spectra of the different recorded noise. QC = sea ambient noise in quiet condition; TC = sea ambient noise in traffic condition; PC = noise produced by a powerboat passing at a distance of 300 m from the recording point; PF = noise produced by a powerboat passing at 670 m distance from the recording point. See text for details.
Sl. 3: Spektri moči različnega hrupa. QC = hrup lokalnega morskega okolja v mirnih razmerah; TC = hrup lokalnega morskega okolja v razmerah povečanega morskega prometa; PC = hrup, ki ga je povzročil motorni čoln na razdalji 300 m od točke merjenja; PF = hrup, ki ga je povzročil motorni čoln na razdalji 670 m od točke merjenja. Podrobnosti v besedilu samem.

DISCUSSION AND CONCLUSIONS

Boat and ships are major contributors to the overall man-made noise in the sea, given their large numbers, wide distribution and mobility. Sea traffic noise characterizes the sea ambient noise of coastal areas mainly in the range below 1 kHz, nevertheless boat noise source level *(i.e.* the amount of radiated sound at a particular frequency measured at 1m from the source) and frequency characteristics are extremely variable in relation to speed, load, pitch angle of propeller and age of the vessel (Mitson, 1993). Levels and frequencies of both tonal and broadband sounds tend to be related to vessel size, but are also strongly affected by vessel design and speed (Richardson *et al.*, 1995). In general, source levels of small boats increased with increasing speed (Erbe, 2002), whereas for large vessels (merchant cargo and passenger ships), the relationship is logarithmic (Ross, 1976). At high speed, propeller cavitation produces most of the broadband noise, with dominant tones arising from the propeller blade rate, whereas at low speeds, wave splashing and engine noise are usually audible as the prime component of the noise (Ross, 1976).

The present paper indicates a L_{Leq} (30 sec) of 120 dB re 1 μPa for a powerboat passing at 300 meter of distance and a maximum instantaneous SPL of 126 dB re 1 μPa, according to Amoser *et al.* (2004), that reported a maximum noise levels of 128 dB re 1 μPa (instantaneous SPL) generated by powerboats running at a distance of 300 m. This noise level is considerably louder than sea ambient noise recorded in the area in quiet condition (111.3 dB re 1 μPa); on the other hand, it is similar to the background noise measured in concomitance of elevated boat traffic (119.8 dB re 1 μPa). The noise produced by boat traffic is mainly concentrated below 500 Hz, whereas the powerboat noise shows harmonic peaks and a high energy component at high frequency. A significant difference between all the considered noise conditions in terms of instantaneous SPL is confirmed by the multivariate ANOVA. The post-hoc Bonferroni test demonstrates frequency-dependent variation of the background noise according to the number and types of vessels present in the area.

Amoser *et al.* (2004) indicate a source level (SL) of the powerboat equals to 180 dB re 1 μPa at 1 m distance, assuming a spherical noise spreading model (20 log R, where R is the distance between noise source and hydrophone). On the other hand, we considered a cylindrical spreading (10 log R) as the best transmission loss model in shallow water (Richardson *et al.*, 1995), obtaining a source level of approximately 145 dB at 1 m. Although it must be considered an estimation, due to several other variables affecting the sound propagation in costal area *(i.e.* bottom morphology, absorption, shadow zones due to refraction, salinity, temperature clines, etc), this SL does not vary a lot from other reported *SL* values for different ships. Following Boussard (1981), cruising barges and high speed boats determine 1/3 octave band levels of up to 140 and 160 dB, Vasconcelos *et al.* (2007) indicate a source level at 1 m of approx 143 dB being produced by a ferry boat, Erbe (2002) reported boat source levels ranging from 145 to 169 dB re 1 μPa at 1m (an average of 162 dB re 1 μPa at 1m for speeds of around 50 km/h), whereas Greene & Moore (1995) recorded a noise of 142 dB being produced by a 70 horsepower outboard motor at a distance of 50 m.

Moreover, we calculated that a *SL* of 145 dB at 1 m at a distance of 600 m generates a sound pressure level equal to 117 dB re 1 μPa according to the cylindrical model; this value fits well with the measured L_{Leq} (30 sec) of a powerboat passing at 670 m distance, confirming the validity of the model. This leads us to conclude that the powerboat noise is theoretically detectable above the local sea ambient noise (quiet condition, *QC,* L_{Leq} (30 sec) = 111.3 dB re 1 μPa) for about 2 km from the source; up to this distance, we calculated a noise to ambient noise ratio larger than one.

Cylindrical spreading equation, however, does not account for variables such as source and receiver depth or complex bottom interactions; therefore we will consider only the noise values recorded in the field for discussing the potential impact of powerboat noise on the local fauna. Since the source level of the powerboat noise is surely higher than the here considered value, it is likely that the impacts are greater than those discussed here.

Figures 4 and 5 compare the sea ambient noise in the four conditions, *i.e.* sea ambient noise in quiet and traffic conditions (QC, TC) and noise produced by a powerboat when passing close and far from the hydrophone (about 300 and 670 m respectively; PC, PF), with the audiograms of a teleost fish, the sea bass *(Dicentrarchus labrax),* a crustacean, the prawn *(Palaemon serratus)* and a marine mammal, the bottlenose dolphin *(Tursiops truncatus),* which are present in the area of interest (Genov & Furlan, 2006). The sea bass is a hearing generalist fish (Lovell, 2003; Lovell *et al.*, 2005a) that lacks accessory hearing structures (air-filled cavities connected to the inner ear) and it is therefore mainly sensitive to particle motion components of low frequency sounds at relatively high sound intensities (Hawkins & Myrberg, 1983; Ladich & Popper, 2004). Its sound pressure audiogram reveals a maximum sensitivity of 98 dB re 1 μPa around 100 Hz and a hearing range up to about 1 kHz. The crustacean *P. serratus* has a perception of sound similar to hearing generalist fish, being responsive to signals ranging in frequency from 100 to 3000 Hz and having a peak sensitivity at about 100 Hz (Lovell *et al.*, 2005b). The comparison of the hearing sensitivities of these species with absolute powerboat spectra (Fig. 4) shows that they are not affected

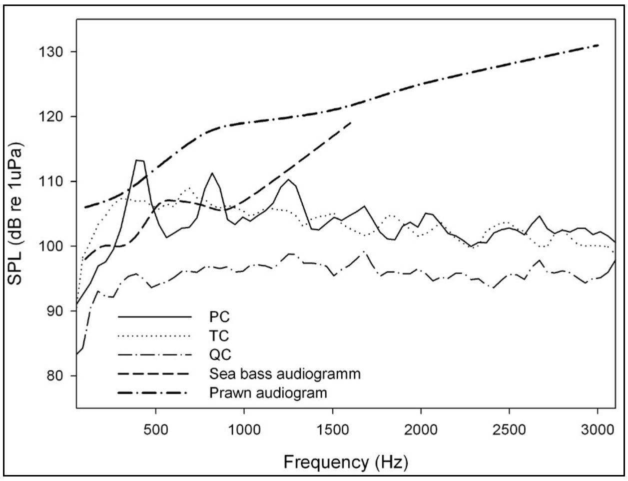

Fig. 4: Audiograms of a hearing generalist fish, the sea bass** (Dicentrarchus labrax; **from Lovell, 2003), and a crustacean, the prawn** (Palaemon serratus; **from Lovell** et al., **2005b), compared with different noise spectra. QC = sea ambient noise in quiet condition; TC = sea ambient noise in traffic condition; PC = noise produced by a powerboat passing at 300 m of distance from the recording point. See text for details.

Fig. 4: Avdiogrami morskih vrst – slušnih generalistov, brancina** (Dicentrarchus labrax; **po Lovellu, 2003) in žagaste kozice** (Palaemon serratus; **po Lovellu** et al., **2005b), primerjani z različnimi spektri hrupa. QC = hrup lokalnega morskega okolja v mirnih razmerah; TC = hrup lokalnega morskega okolja v razmerah povečanega morskega prometa; PC = hrup, ki ga je povzročil motorni čoln na razdalji 300 m od točke merjenja. Podrobnosti v besedilu samem.

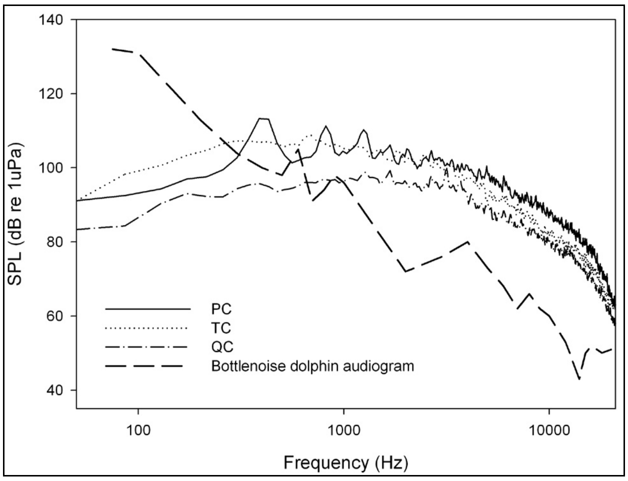

Fig. 5: Audiograms of the bottlenose dolphin** (Tursiops truncatus; **from Johnson, 1968) compared with different noise spectra (x-axes in logarithmic scale). QC = sea ambient noise in quiet condition; TC = sea ambient noise in traffic condition; PC = noise produced by a powerboat passing at 300 m of distance from the recording point. See text for details.

Sl. 5: Avdiogrami velike pliskavke** (Tursiops truncatus; **po Johnsonu, 1968), primerjani z različnimi spektri hrupa (x-osi na logaritmični lestvici). QC = hrup lokalnega morskega okolja v mirnih razmerah; TC = hrup lokalnega morskega okolja v razmerah povečanega morskega prometa; PC = hrup, ki ga je povzročil motorni čoln na razdalji 300 m od točke merjenja. Podrobnosti v besedilu samem.

by the QC. On the opposite, the increase in prevailing sea noise due to a powerboat passing at 300 m distance (PC) results in the signal detection being impaired. If masking is assumed to occur when the noise band levels are equal to or higher than the band levels of a signal, following Fletcher's equal-power-assumption (Fletcher, 1940), the sea bass and the prawn are likely to be masked mainly in the frequencies concomitant with the harmonics, which contain the peak energy of the noise generated by powerboat. The same effect has been demonstrated in other generalist fish by Amoser *et al.* (2004).

At low frequency range (below 500 Hz), however, the boat traffic seems to have an impact on the fish species, due to an increment of the ambient noise up to a maximum of about 8 dB above their hearing thresholds. A masking effect can be hypothesized in the best hearing range of the sea bass; boat noise negative impacts on hearing and acoustic communication have been already demonstrated in the Lusitanian toadfish *(Halobatrachus didactylus)* (Vasconcelos *et al.*, 2007), the brown meagre *(Sciaena umbra)* and the Mediterranean damselfish *(Chromis chromis*; Codarin *et al.*, 2008).

The dolphin's audiogram (Johnson, 1967) showed a frequency range that extends from 75 Hz to 150 kHz with hearing sensitivity improving gradually with frequency up to a maximum sensitivity in the range between 15 kHz and 110 kHz, where acoustic communication takes place. According to figure 5, the bottlenose dolphin, *T. truncatus*, perceives all the here considered sea background noise conditions (QC, TC, PC, PF). Erbe & Farmer (1998) indicated that a propeller cavitation noise may completely mask a typical beluga *(Delphinapterus leucas)* localization for noise-to-signal ratios greater than 18 dB. Although it appears likely that the noise produced by a powerboat passing at 300 as well as 600 m distance can affect the bottlenose dolphin communication ability, a more accurate research should be done, exceeding the aim of the present paper. It must be considered, for example, that contrary to fishes, marine mammals are able to produce more calls, louder calls and shifting the frequency of their vocalization as a consequence of elevated background noise (Au, 1993; Foote *et al.*, 2004). From a behavioural point of view, a broadband sound pressure level of 120 dB re 1 µPa, as the one produced by a powerboat passing at a distance of 300 m, is used in marine mammals as a threshold of responsiveness (Richardson *et al.*, 1995). Following Erbe's models (Erbe, 2002), boat source levels that range from 145 to 169 dB re 1 µPa at 1m are audible to killer whales over 16 km, mask killer whale calls over 14 km, elicit a behavioral response over 200 m, and cause a temporary threshold shift (TTS) in hearing of 5 dB after 30–50 min within 450 m. More in details, the playback of speedboats noise on bottlenose dolphins induced shorter surface periods, longer dives and movement away from vessels at ranges of 150–300 m (Evans *et al.*, 1992). Following Genov (2006), no apparent change in behaviour of bottlenose dolphin (either in terms of behavioural state, dive times, travel direction or sudden startle reaction) was observed during the training phase of the race in Piran Bay. Despite it, possible subtle reactions might not be visible at the surface and no data were available on the possible changes in the animals' acoustic behaviour (Genov, 2006). If we consider that the physical presence of boats impact the marine mammal behaviour (Blane & Jaakson, 1995; Janik & Thompson, 1996; Nowacek, 1999; Hastie *et al.*, 2003; Mattson *et al.*, 2005; Ribeiro *et al.*, 2005), a concern over the potential impacts of the powerboat race on this species can be expressed here.

The present study indicates that powerboats generated noise levels of a minimum of 145 dB re 1 µPa at 1 m distance during the first Class 1 powerboat race in Piran Bay, whose main energies are within the best hearing range of fish and crustacean species and are detectable by the bottlenose dolphin. Various authors in earlier studies indicate a behavioural response elicited by noise of such an intensity as well as masking and impaired acoustic communication. A cumulative effect of disturbance due to the simultaneous passages of many powerboats can also be hypothesized, whose implications are difficult to predict. We conclude that the noise produced by these vessels does disturb the local fauna. The extent of this disturbance needs a set of behavioural experiments to be assessed. At the end, it has to be noticed that some 200–300 spectator's boats moving simultaneously randomly across the race field determined an increment in the sea ambient noise exceeding the powerboat noise in the frequency range below 500 Hz. The impact of this noise should also be taken into account when running environmental impact assessments on powerboat races.

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OZNAČITEV HRUPA, KI GA POVZROČAJO TEKMOVALNI ČOLNI RAZREDA 1 V PIRANSKEM ZALIVU, IN POTENCIALNI VPLIV HRUPA NA ŽIVLJENJE V MORJU

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POVZETEK

V začetku septembra 2006 so avtorji članka opravljali podvodne meritve hrupa, ki so ga povzročali čolni razreda 1 med motonavtično dirko v Piranskem zalivu. Namen meritev je bil: 1) opisati podvodne emisije hrupa in ravni hrupa, ki ga povzročajo tekmovalni čolni, in 2) primerjati emisije hrupa s hrupom lokalnega morskega okolja, ki je *bil zabeležen tako v mirnih razmerah kot v razmerah s povečanim vodnim prometom. Hrup so merili z baterijsko napravo Pioneer D-C88 DAT in hidrofonom Reson TC4032, nameščenim v globini 10 m (pri tamkajšnji globini morja 20 m). Dan pred tekmo je bil izmerjen hrup lokalnega morskega okolja v mirnih razmerah, po koncu dirke pa v razmerah s povečanim vodnim prometom. Med dirko je bil izračunani* $L_{Leq\ 30\ sek}$ *enega čolna na razdalji 300 m od hidrofona enak 120 dB re 1 µPa, kar pomeni, da je presegel hrup lokalnega morskega okolja v mirnih razmerah s povprečno 8,5 dB znotraj frekvenčnega območja 40–22100 Hz. Hrup je skoncentriran predvsem pod 5000 Hz, srednja vrednost osnovne frekvence pa je 420 ± 4,7 Hz, kar se ujema z vrtilno hitrostjo vijaka. Hrup istega tekmovalnega čolna na razdalji 670 m se je zmanjšal za 4 dB, s precejšnjim upadom v visokem frekvenčnem območju.*

Izračunani nivo vira hrupa tekmovalnega čolna je torej enak 145 dB re 1 µPa pri 1 m. Pri tem lahko domnevamo, da je hrup tekmovalnega čolna v podobnih okoljskih razmerah teoretično mogoče zabeležiti nad hrupom lokalnega morskega okolja za približno 2 km od vira. To vrednost moramo tu upoštevati kot minimalno razdaljo, pri kateri je treba vir nemira obdržati proč od okoljsko občutljivih lokalitet (na primer morska zaščitena območja).

Primerjave s slušnimi sposobnostmi raka (žagasta kozice Palaemon serratus), *ribe (brancina* Dicentrarchus labrax) *in morskega sesalca (velike pliskavke* Tursiops truncatus), *so hkrati z ugotovitvami iz prejšnjih študij vodile do sklepa, da hrup takšne jakosti lahko izsili določene vedenjske odzive pa tudi zastre in oslabi akustično komunikacijo pri treh izbranih živalih. Zaradi tako velikega nemira bi bilo treba nujno opraviti in oceniti niz vedenjskih eksperimentov.*

Na koncu je bilo ugotovljeno, da je kakih 200 ali 300 čolnov zbranih gledalcev, ki so se takoj po dirki hkrati zapeljali prek tekmovalne proge, povzročilo hrup lokalnega morskega okolja, ki je v frekvenčnem območju pod 500 Hz presegal hrup, povzročen med dirko. In tudi ta hrup bi bilo treba upoštevati med ocenjevanjem vpliva motonavtičnih dirk na okolje.

Ključne besede: zvočno onesnaževanje, antropogeni vpliv, dirka tekmovalnih čolnov, Jadransko morje

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