Report on forms of vocalisation at sites characterised by different levels of noise

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Summary

1. Introduction

Most of what we know about animal communication and cognition was from studies of terrestrial species such as nonhumane primates (Arbib et al., 2008) and birds (Hurford, 2007). Much less attention has been paid to communication systems of species in an aquatic environment although it was probable that cetacean communication networks are among the largest in the world (Payne and Webb, 1971). This was certainly partly due to difficulties in recording communication signals and observing related behavioural patterns in a world very different to ours. With current and future advances in monitoring technology, bottlenose dolphins (*Tursiops truncatus*) can provide an interesting opportunity to study the complex communication systems of species in an aquatic environment. Identifying specific acoustic parameters of bottlenose dolphin vocalisations was fundamental for further research. Sound types can then be put into a behavioural context to better understand their functionality and to gain insights into the complex acoustic communication system of this species. Furthermore, identifying specific parameters of dolphin vocalisations will enable the investigation of the potential influence of man-made acoustic pollution on their vocal communication systems.

Leisure boating noise has been identified as the major contributor to the overall sea ambient noise (SAN; Rako et al., 2013) in the Cres-Lošinj archipelago (Croatia). The east side of the archipelago was of high relevance for the resident bottlenose dolphin community as their important feeding and nursing ground (Bearzi et al., 1999) and was designated as the Cres-Lošinj Natura 2000 Site of Community Importance (SCI) (HR3000161). The channel area between the islands (HR3000161) is subject to intense recreational boating between June and September (the Tourist Season – TS; Rako et al., 2013). Previous studies have shown that leisure boating noise on the east side of the Cres-Lošinj archipelago was a trigger for the displacement of the bottlenose dolphins in the TS (Rako et al., 2013).

Moreover, Rako and Picciulin (2016) also showed that there were changes in whistle structure of bottlenose dolphins in relation to underwater noise and boat traffic on the east side of the Cres-Lošinj archipelago.

1.1 Target species

The conservation status of bottlenose dolphins (*Tursiops truncatus*) was of least concern (LC) at a global level according to the IUCN Red List of Threatened Species, vulnerable (VU) in a subpopulation in the Mediterranean (Bearzi et al., 2012) and endangered (EN) in Croatia according to the Red Book of Mammals (Holcer, 2006). Bottlenose dolphins were protected under the Nature Protection Act (NN 162/03) and were included in the II and IV Annex of the EU Habitats Directive. The resident bottlenose dolphin population in the Cres-Lošinj archipelago (Figure 1) has been monitored consistently since 1987, with about 200 individuals living in this area throughout the year (Bearzi et al., 1997; Fortuna, 2007; Pleslić et al., 2015).

Figure 1: Resident bottlenose dolphins in front of the island Oruda where the MS6 Lošinj monitoring station was located.

1.2 Bottlenose dolphin vocalisations

The acoustic behaviour of wild bottlenose dolphins has been observed in multiple studies (dos Santos et al., 1995; Janik, 2000a&b; Boisseau, 2005). However, in most of these studies, the focus has been on whistles and echolocation clicks and not on the entire repertoire of vocal production (Au et al., 1982; Quick and Janik, 2008). Frequency modulated whistles were narrowband sounds and the most analysed communication signal, ranging between 0.8 and 28.5 kHz in frequency for bottlenose dolphins (May-Collado and Wartzok, 2008). A study by Hiley et al. (2016) found signature whistles to have an ultrasonic fundamental frequency component of > 30 kHz. Between 39% and 52% of whistles produced by dolphins in the wild were signature whistles (Quick and Janik, 2008). However, the function of the remaining percentage of whistles was unknown (Quick and Janik, 2008). The contour shape of these signature whistles carried identity information (Janik et al. 2006) which allows conspecifics to copy this whistle to address each other (King and Janik 2013). Previous studies (Janik and Slater, 1998) have shown that signature whistles were used to maintain group cohesion. Echolocation clicks were short and intense broadband sounds with ultrasonic frequencies, generated in rapid succession (click trains) by dolphins listening to the echoes returning from the object to estimate its range, direction and location (Au, 1993). The signal functionality of echolocation clicks thus differs from that in communication because the use of sound for communication enables dolphins to encode information in their signals which can then be decoded by a receiver (Janik, 2009). Most studies (Herzing, 1996; Boisseau, 2005) acknowledged the presence of other sounds within the acoustic repertoire of bottlenose dolphins and yet these sounds have received less attention. Burst-pulsed (BP) sounds, for example, are discrete aural packets of closely spaced broadband clicks (Herzing, 2014) that appear as harmonic bands in the spectrogram due to their high repetition rates which are perceived as continuous for human observers (Watkins, 1967; Herzing, 2000). Even though BP sounds took up a large proportion of the acoustic repertoire of bottlenose dolphins (Herzing, 2000), comparisons of BP sounds between populations was difficult due to the non-standardised analysis methods used to classify sounds and how humans aurally perceive sounds (Herzing, 2000; Boisseau, 2005). The exact signal functionality of BP sounds remains unclear (Janik, 2009). However, previous studies have shown that BP sounds play a major role in communication rather than echolocation (Lammers et al., 2003; Vaughn-Hirshorn et al., 2012). According to Ivanov (2004), the inter-click interval (ICI) or inter-pulse interval (IPI) of less than 10 milliseconds exceeds the two-way propagation time which is thought to be required to receive echoes of the individual clicks. Chirps have not been well described in previous literature. Griffin (1959, cited in Caldwell et al. 1990) have described chirps as sounds that occur over a large frequency range in a fraction of a second. Janik et al. (2013, Figure 3B) described chirps as short, stereotyped tonal upsweeps. Low frequency narrow-band (LFN) sounds (Schultz et al. 1995; Simard et al. 2011) are short tonal signals (< 1 seconds) with the frequency range usually being under 1 kHz (Schultz et al., 1995; Simard et al., 2011). Due to the LFN sounds occurring at low frequencies, it is not easy to detect these sounds when masked by low frequency noise (Gridley et al., 2015). The function of LFN sounds within a dolphin's acoustic repertoire has yet to be discovered. Beside individual signal components, dolphins have also been observed to combine sound types to produce distinct vocal units such as bray vocalisations (Janik, 2000a; Blomqvist et al., 2005). Based on dos Santos et al. (1995) and Janik (2000a), brays are distinct vocal units consisting of two sound types such as a BP sound followed by a short downsweep (Janik 2000a). According to Simead et al. (2011), the downsweep is similar in structure of an LFN sound. A study by Janik (2000a) has shown that bray sounds are correlated with feeding on salmonids.

1.3 Aims

This study focused on the identification and description of sounds produced by a well-documented group of bottlenose dolphins (*Tursiops truncatus*) which were frequently present at two sites characterised by their distinct ecological settings and their exposure to different levels of anthropogenic noise in the Cres-Lošinj archipelago (northeast Adriatic Sea), Croatia. It was assessed if there was a difference in the whistle parameters measured in March/April 2020, the Non-Tourist Season (NTS), and in July/August 2020, the Tourist Season (TS). Additionally, it was tested if whistle parameters differed during the day and night.

2. Methods

Acoustic recordings for this study were collected with autonomous passive underwater acoustic recorders (APUARs) at two monitoring stations that were characterised by their distinct ecological settings and their exposure to different levels of anthropogenic noise. Acoustic data from March/April 2020, the Non-Tourist Season (NTS), and July/August 2020, the Tourist Season (TS) were analysed. The APUAR's had a Sono.Vault housing from Develogic and a hydrophone from Neptune Sonar. The APUARs were programmed to record continuously at a sampling rate of 48 kHz (providing a recording bandwidth of 24 kHz), 16 bit and gain 6.

2.1 Study area

The monitoring station MS5 Susak (E 14.28821, N 44.49241) was located on the west side of the Cres-Lošinj archipelago, away from the shore and islands, in the open sea area near the island of Susak (Figure 2). The location was relatively close to one of the main shipping lanes to Rijeka and thus exposed to higher commercial shipping by bigger vessels. There was also some recreational boating but the location is far away from the recreational boating hot spots. The anthropogenic underwater noise pressure was expected to be low to moderate. The water depth at the monitoring station MS5 Susak was 40 metres and the area was of importance for sea turtles and a potential open water Natura 2000 site.

The monitoring station MS6 Lošinj (E 14.57469, N 44.54597) was located within the coastal area of the Cres-Lošinj Natura 2000 Site of Community Importance (SCI) (HR3000161) near the island of Oruda (Figure 2). The channel area between the islands (HR3000161) is subject to intense recreational boating between June and September (the Tourist Season – TS; Rako et al., 2013) but was isolated from major shipping lanes. There were also some commercial fishing activities in the area. The anthropogenic underwater noise pressure was expected to be low but moderate to high during the Touristic Season in summer. The water depth at the monitoring station MS6 Lošinj was 37 metres and the area was of high relevance for the resident bottlenose dolphin community as their important feeding and nursing ground (Bearzi et al., 1999).

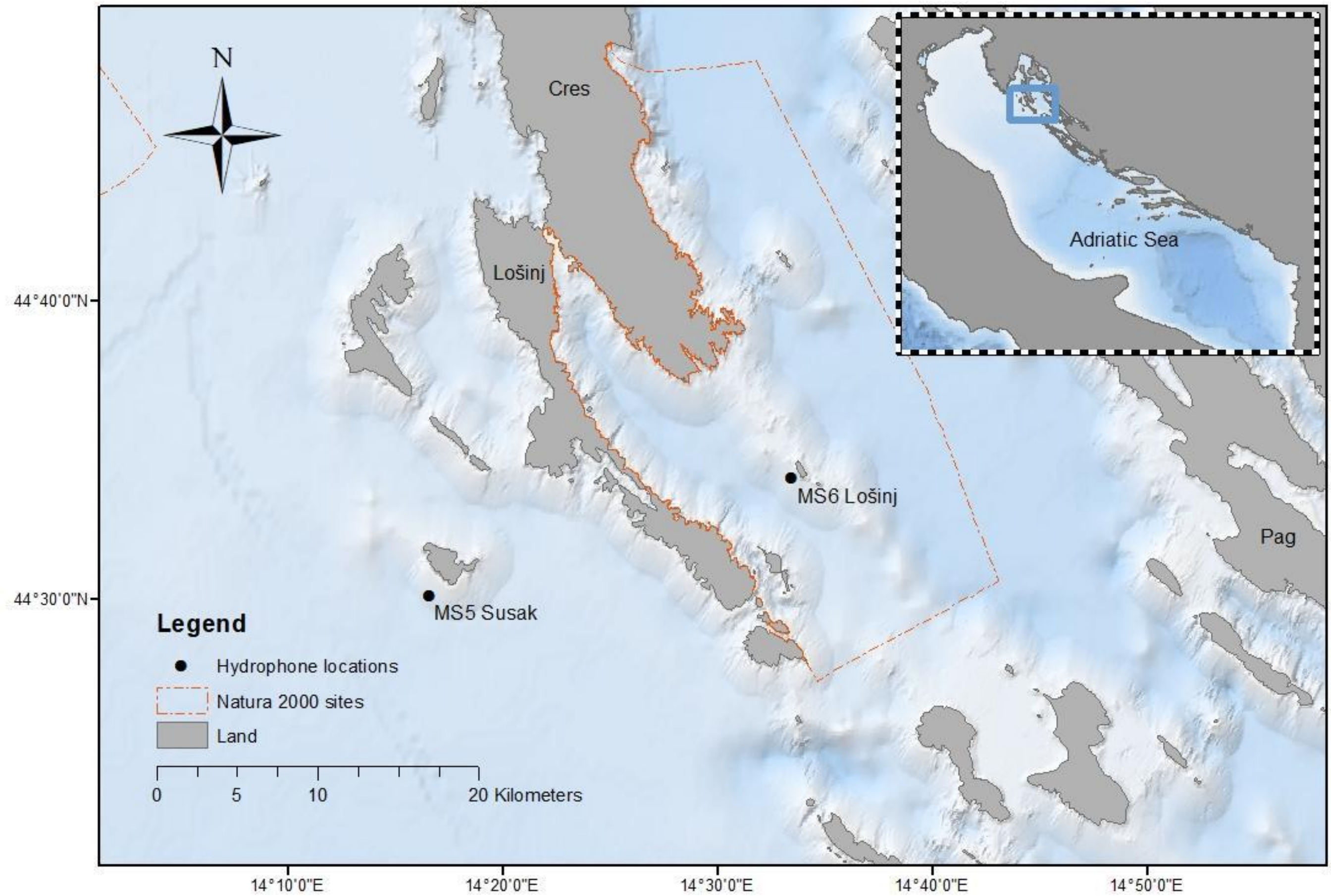

Figure 2: Map showing the location of the MS5 Susak and MS6 Lošinj monitoring station.

2.2 Acoustic analysis

The analysis focused on the identification and description of sounds produced by bottlenose dolphins at the MS5 Susak and MS6 Lošinj monitoring station. Sound types were identified in the spectrogram display of Adobe Audition (Ver. 3.0) by visually and aurally scanning through the recordings. For a more detailed analysis of whistles, Raven Pro (Ver. 1.6) was used. Spectrogram displays were generated using a Hanning window with an FFT of 512 for tonal sounds and an FFT of 1024 for burst pulse sounds. The recordings from the two monitoring stations, MS5 Susak and MS6 Lošinj, were analysed separately to assess if there was a difference in whistle parameters measured in March/April 2020, the Non-Tourist Season (NTS), and in July/August 2020, the Tourist Season (TS). In total, 1029 hours of recordings were visually and aurally inspected to look for the presence of dolphin vocalisations (Table 1).

Table 1: Summary of dates and hours that were analysed from the MS5 Susak and MS6 Lošinj monitoring station in the NTS and TS.

MS5 Susak - NTS		MS6 Lošinj - NTS	
Date	Hours analysed	Date	Hours analysed
		07.03.2020	24
10.03.2020	24	10.03.2020	24
11.03.2020	24	11.03.2020	24
12.03.2020	24	12.03.2020	24
13.03.2020	24	13.03.2020	24
14.03.2020	24	14.03.2020	24
15.03.2020	24	15.03.2020	24
16.03.2020	24	16.03.2020	24
01.04.2020	24	02.04.2020	24

MS5 Susak - TS		MS6 Lošinj - TS	
Date	Hours analysed	Date	Hours analysed
13.07.2020	24	02.07.2020	24
14.07.2020	24	08.07.2020	24
15.07.2020	23	15.07.2020	24
16.07.2020	24	16.07.2020	24
21.07.2020	24	21.07.2020	24
25.07.2020	24	25.07.2020	24
26.07.2020	24	26.07.2020	24
27.07.2020	24	27.07.2020	23
28.07.2020	24	28.07.2020	24
29.07.2020	24	29.07.2020	24
30.07.2020	24	30.07.2020	24
31.07.2020	24	31.07.2020	23
01.08.2020	24	01.08.2020	24

The acoustic recordings were scanned through, to look for the occurrence of all sound types produced by bottlenose dolphins such as whistles, chirps, low frequency narrow-band (LFN) sounds, burst pulse (BP) sounds, echolocation clicks, as well as the combined sounds, the bray, which have been described in other regions (Table 2).

Table 2: Description of sound types produced by bottlenose dolphins.

Whistles	Whistles were frequency modulated narrow-band tonal sounds which were longer than 0.1 seconds in duration. Also, whistles had to have at least part of their fundamental frequency above 3 kHz.
Chirps	Chirps were short tonal sounds that occurred over a large frequency range. To distinguish chirps from whistles, a maximum allowable length of 0.1 s was defined.
LFN sounds	low frequency narrow-band (LFN) sounds were defined as tonal signals being less than 1 s in duration and confined to frequencies of less than 1 kHz.
BP sound	burst pulse (BP) sounds were horizontal harmonic banded sounds in which clicks were aurally and visually indiscernible in the spectrogram display to the human observer. Also, BP sounds in this study were based on their ICI (< 10 ms) and not solely on their visual parameters.
Echolocation clicks	Echolocation clicks were short and intense broadband sounds with ultrasonic frequencies, generated in rapid succession (click trains).
Bray	Brays were distinct vocal units consisting of two sound types such as a BP sound followed by a short downsweep/LFN sound.

An index of content for each 1-hour recording was created and all sound types were visually assessed and graded based on their signal-to-noise ratio (SNR). There were three categories: (1) signal was faint but still visible on the spectrogram, (2) signal was clearly visible on the spectrogram, (3) signal was clear with no other sound types in the background. Additionally, for each sound type it was noted how much boat noise there was in the background. There were four categories: (0) no boat noise, (1) idle speed, (2) low speed and (3) high speed. Only sound types of high quality (SNR 2 & 3) and boat noise categories 0 to 2 were included in the vocalisation index. Whistles were then further analysed in Raven. Frequency characteristics of whistles such as the start, end, minimum, maximum and peak frequency as well as frequency range and duration were measured in Raven. Inflection points were counted by visually inspecting the spectrogram in Adobe Audition. Inflection points were the points at which a change in slope (+/-) occurred.

2.3 Statistical analysis

It was tested for differences in whistle parameters measured between NTS and TS as well as between day and night. The parameters for whistles were start, end, minimum, maximum and peak frequency as well as frequency range, duration and inflection points. All statistical tests were run through SPSS. A Test of Homogeneity of Variances was caried out and if the p-value was > 0.05, which means that the assumption of homogeneity of variance was met, a one-way ANOVA test was conducted. In case the p-value was < 0.05 after testing for the homogeneity of variances, which means that the assumption of homogeneity of variance was violated, a non-parametric Kruskal-Wallis test or Mann-Whitney U test was used. The following combinations were tested.

Differences in whistle parameters: NTS vs TS

- MS5 Susak: NTS vs TS
- MS6 Lošinj: NTS vs TS
- MS5 Susak & MS6 Lošinj: NTS vs TS

Differences in whistle parameters: Day vs Night

- MS5: day vs night during NTS
- MS5: day vs night during TS
- MS5: day vs night (NTS + TS)
- MS6: day vs night during NTS
- MS6: day vs night during TS
- MS6: day vs night (NTS + TS)
- MS5 & MS6: day vs night during NTS
- MS5 & MS6: day vs night during TS
- MS5 & MS6: day vs night (NTS + TS)

It was also tested whether there was a difference in the number of other bottlenose dolphin vocalisations such as chirps and LFN sounds between NTS and TS:

- MS5 Susak: NTS vs TS
- MS6 Lošinj: NTS vs TS
- MS5 Susak & MS6 Lošinj: NTS vs NTS
- MS5 Susak & MS6 Lošinj: TS vs TS
- MS5 Susak & MS6 Lošinj: NTS vs TS

3. Results

Acoustic recordings collected with the autonomous passive underwater acoustic recorders (APUARs) were analysed from the MS5 Susak and MS6 Lošinj monitoring station in the Cres-Lošinj archipelago from March/April 2020, the Non-Tourist Season (NTS), and July 2020, the Tourist Season (TS). Out of the 1029 1-hour recordings inspected, 216 1-hour recordings included dolphin vocalisations (Table 3-6).

Table 3: Presence (1) and absence (0) of dolphin vocalisations at MS5 Susak in the NTS.

	Time of day h (UTC)																							
Date	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
10.03.2020	0	0	0	0	1	1	1	1	1	1	0	0	0	1	1	1	1	1	0	0	0	0	0	0
11.03.2020	0	0	0	0	1	1	1	0	0	1	1	1	1	0	1	1	1	1	1	1	1	1	0	0
12.03.2020	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	0	0	0	1	0	0	0
13.03.2020	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0
14.03.2020	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1	0
15.03.2020	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	1	0	0	0	0
16.03.2020	0	0	0	0	0	0	1	0	0	0	1	0	1	1	1	0	0	0	0	1	0	1	1	1
01.04.2020	0	0	0	1	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1

Table 4: Presence (1) and absence (0) of dolphin vocalisations at MS5 Susak in the TS.

	Time of day h (UTC)																							
Date	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
13.07.2020	0	0	0	0	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1	1	0
14.07.2020	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0
15.07.2020	0	0	0	0	0	0	0	0	0	1	1	1	0	0	0	0	0	x	0	0	0	0	0	0
16.07.2020	0	1	1	1	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0	1	1
21.07.2020	1	0	1	1	1	1	1	0	0	0	0	0	1	1	1	0	1	1	1	1	0	1	0	0
25.07.2020	1	1	1	1	1	0	0	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0	1	0

26.07.2020	1	1	1	0	0	0	0	0	1	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0
27.07.2020	1	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	1
28.07.2020	0	1	1	1	0	1	0	1	0	1	1	1	0	0	0	0	1	1	1	0	1	0	0	0
29.07.2020	1	0	0	0	0	1	1	0	1	1	0	1	0	1	1	0	1	1	1	0	0	0	0	0
30.07.2020	0	0	1	1	1	0	0	0	0	0	0	0	0	1	0	1	0	1	0	0	0	0	0	0
31.07.2020	1	1	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	1	1	0
01.08.2020	1	0	0	1	0	0	0	1	1	1	1	1	1	0	0	0	0	1	1	0	1	1	0	0

Table 5: Presence (1) and absence (0) of dolphin vocalisations at MS6 Lošinj in the NTS.

	Time of day h (UTC)																							
Date	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
07.03.2020	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	1	1	0	0	0	1	1	0
10.03.2020	0	0	0	0	0	0	0	1	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0
11.03.2020	0	0	0	0	0	1	1	0	0	0	1	1	1	1	0	0	1	0	0	0	0	0	0	0
12.03.2020	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0
13.03.2020	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
14.03.2020	1	0	0	0	0	0	0	1	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
15.03.2020	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
16.03.2020	0	0	0	0	0	0	1	0	0	0	0	1	0	0	0	1	0	0	0	1	0	0	0	0
02.04.2020	0	0	0	0	0	1	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0

Table 6: Presence (1) and absence (0) of dolphin vocalisations at MS6 Lošinj in the TS.

	Time of day h (UTC)																							
Date	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
02.07.2020	0	1	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
08.07.2020	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
15.07.2020	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0
16.07.2020	0	0	1	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
21.07.2020	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
25.07.2020	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
26.07.2020	0	0	1	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
27.07.2020	0	0	x	1	0	0	0	0	0	0	1	1	0	0	1	0	0	0	0	0	0	0	0	0
28.07.2020	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	0	0	0	0	0	0	0
29.07.2020	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0
30.07.2020	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

31.07.2020	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	x	0	0
01.08.2020	0	0	0	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0

Bottlenose dolphins in the Cres-Lošinj archipelago were found to produce whistles (Figure 3), chirps (Figure 4), low frequency narrow-band (LFN) sounds (Figure 5), burst pulse (BP) sounds (Figure 6 & 7) and echolocation clicks (Figure 8), except of the combined sound, the bray, which could not be identified with certainty.

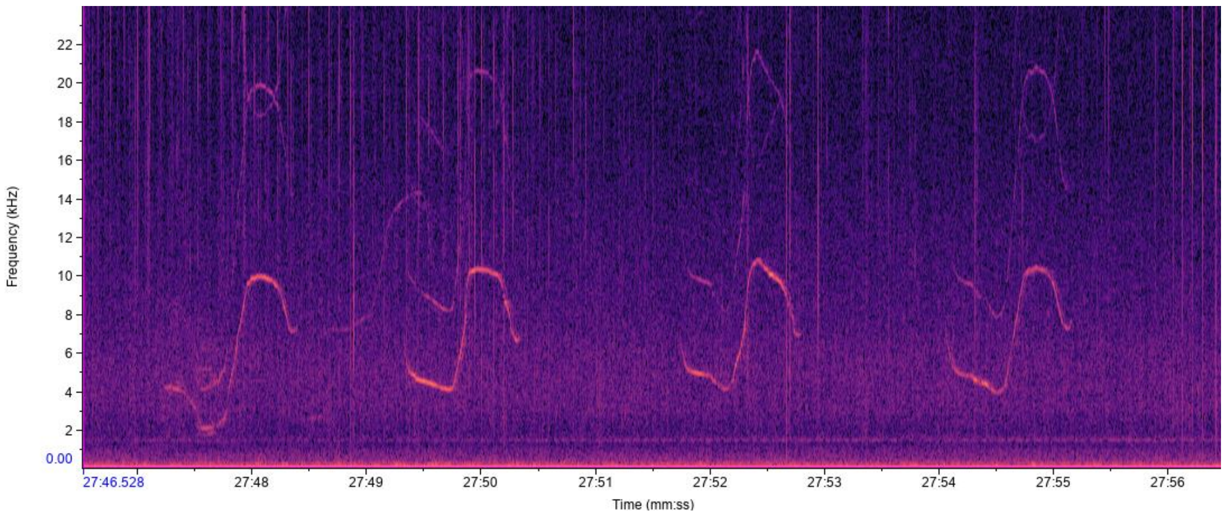

Figure 3: An example of a spectrogram showing whistles with faint echolocation clicks in the background produced by the bottlenose dolphins in the Cres-Lošinj archipelago.

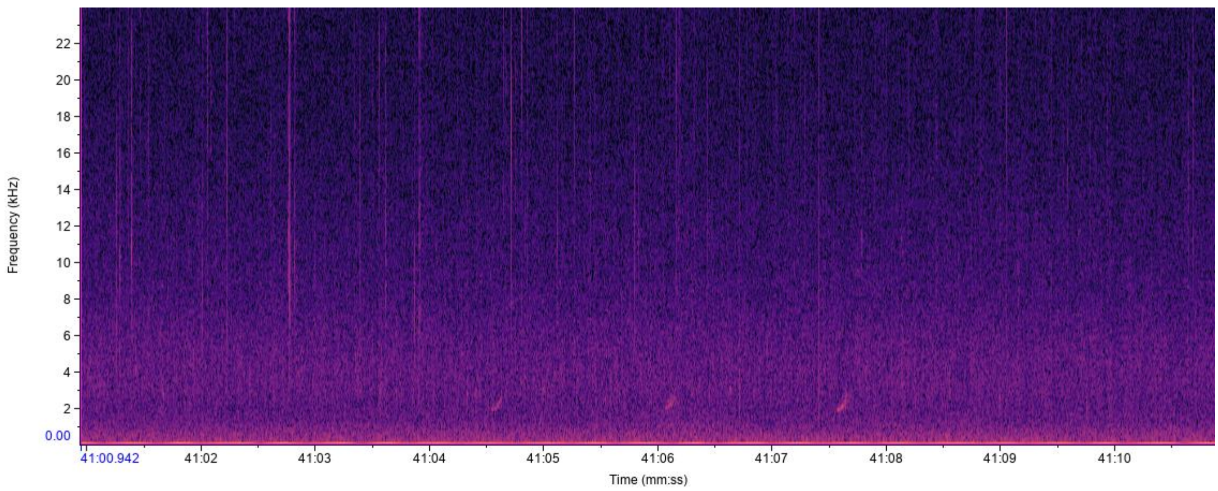

Figure 4: An example of a spectrogram showing chirps produced by the bottlenose dolphins in the Cres-Lošinj archipelago.

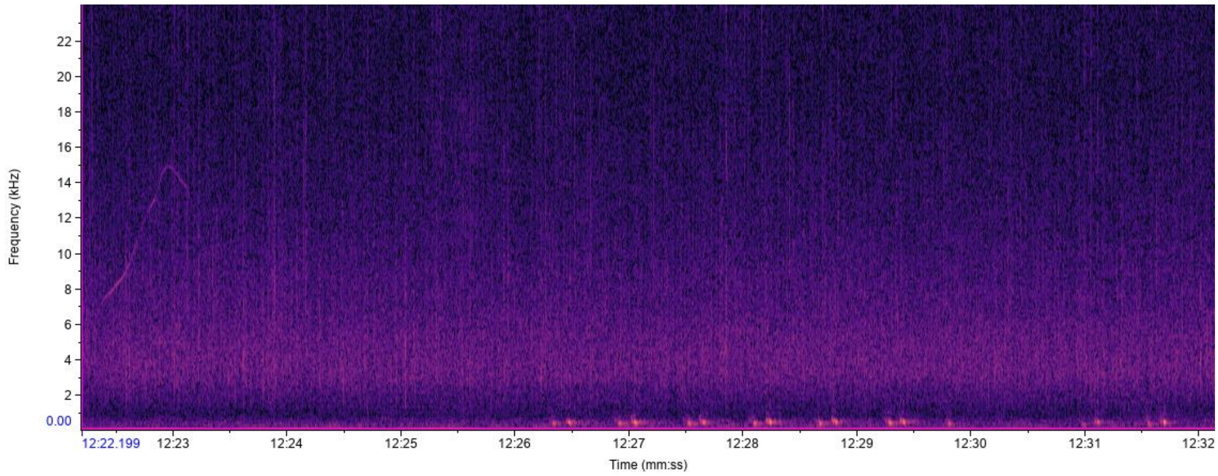

Figure 5: An example of a spectrogram showing a low frequency narrow-band sound train with a faint whistle in the background produced by the bottlenose dolphins in the Cres-Lošinj archipelago. LFN trains often occurred in 2 packs as visible above.

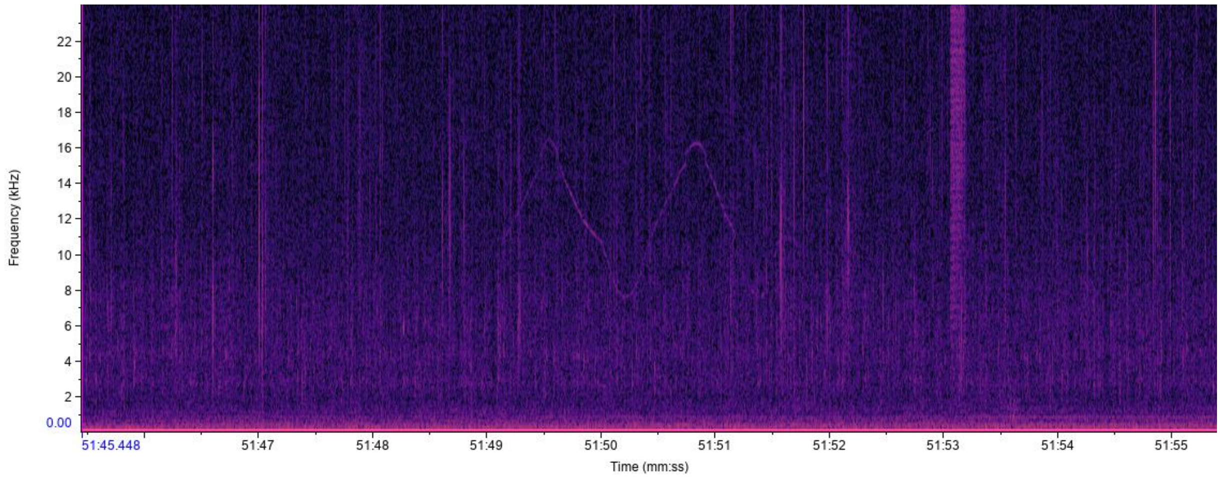

Figure 6: An example of a spectrogram showing a burst pulse sound with faint a whistle and echolocation clicks in the background produced by the bottlenose dolphins in the Cres-Lošinj archipelago.

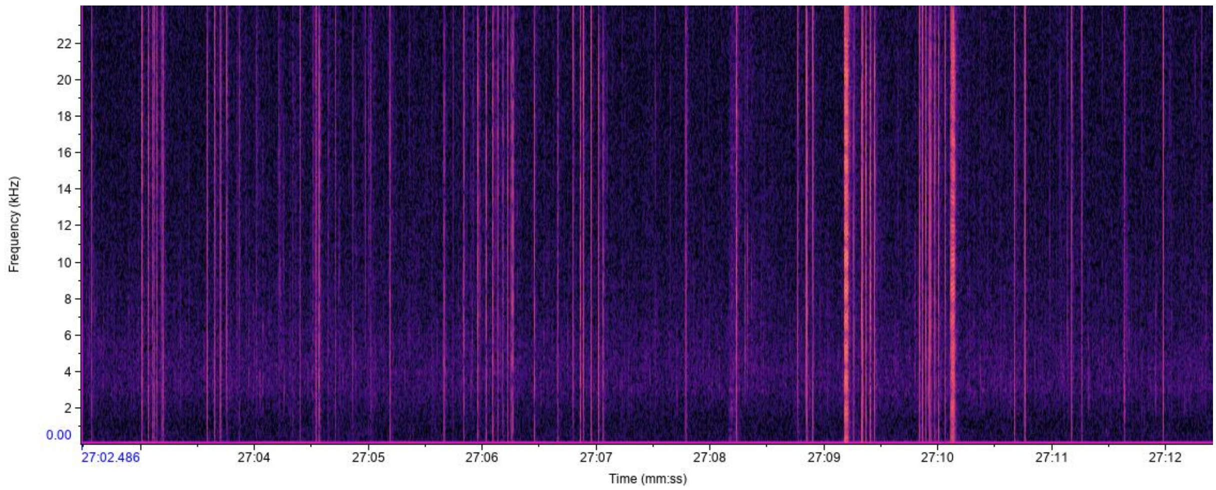

Figure 7: An example of a spectrogram showing two really short burst pulse sounds with echolocation clicks in the background produced by the bottlenose dolphins in the Cres-Lošinj archipelago.

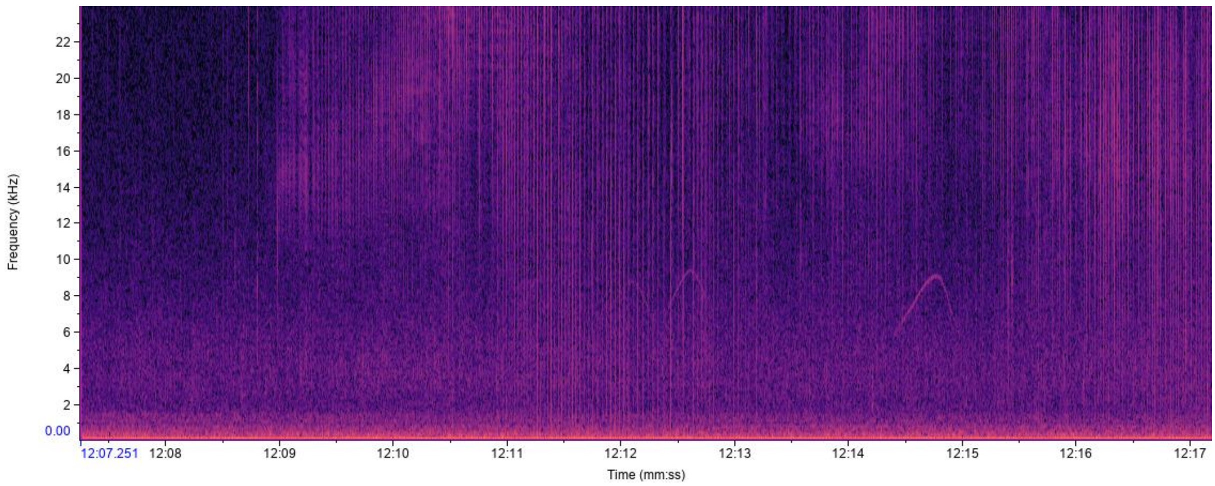

Figure 8: An example of a spectrogram showing echolocation clicks and some faint whistles in the background produced by the bottlenose dolphins in the Cres-Lošinj archipelago.

Further analysis was carried out by characterising whistles. The descriptive statistics for the acoustic parameters of whistles were summarised in Tables 1 to 4, including the number of whistles analysed, mean, standard deviation (SD), range (minimum and maximum) and coefficient of variation (CV = SD/Mean*100).

3.1 MS5 Susak - NTS

In March/April 2020, a total of 301 whistles that had a good signal to noise ratio (SNR 2 & 3) were analysed from the MS5 Susak monitoring station (Table 7). Whistles ranged from 1.66 to 22.46 kHz in frequency, having a mean minimum frequency of 6.35 kHz (± SD = 1.61) and a mean maximum frequency of 12.40 kHz (± SD = 2.49). Start and end frequencies of whistles were very different, having a mean start frequency of 6.98 kHz (± SD = 2.07) and a mean end frequency of 11.17 kHz (± SD = 3.32). The mean frequency range of whistles was 6.05 kHz (± SD = 2.47), the mean peak frequency was 8.66 (± SD = 2.15) and the mean duration of whistles was 0.80 s (± SD = 0.49). The mean number of inflection points was 1.21 (± SD = 1.46) except for a few whistles with many inflection points (maximum 8). The duration and inflection points of whistles were highly variable with CVs of 60.48 and 121.42, respectively.

Table 7: Acoustic characteristics of sound types produced by bottlenose dolphins at MS5 Susak monitoring station in March/April 2020.

Statistics	Start freq (kHz)	End freq (kHz)	Min freq (kHz)	Max freq (kHz)	Freq range (kHz)	Peak freq (kHz)	Duration (s)	Inflection points (n)
n	301	301	301	301	301	301	301	301
Mean (±SD)	6.98 (2.07)	11.17 (3.32)	6.35 (1.61)	12.40 (2.49)	6.05 (2.47)	8.66 (2.15)	0.80 (0.49)	1.21 (1.46)
Range	3.54 – 15.35	4.41 – 22.46	1.66 – 11.80	4.81 – 22.46	0.08 – 14.67	2.81 – 17.34	0.01 – 6.10	0.00 – 8.00
CV	29.72	29.69	25.30	20.05	40.83	24.87	60.48	121.42

3.2 MS5 Susak - TS

In July 2020, a total of 36 whistles that had a good signal to noise ratio (SNR 2 & 3) were analysed from the MS5 Susak monitoring station (Table 8). Whistles ranged from 3.84 to 16.04 kHz in frequency and had mean minimum and maximum frequencies of 5.91 kHz (± SD = 1.83) and 10.95 kHz (± SD = 2.48), respectively. The start and end frequencies of whistles were very similar, having a mean start frequency of 8.83 kHz (± SD = 2.39) and a mean end frequency of 7.90 kHz (± SD = 2.59). The mean frequency range of whistles was 5.04 kHz (± SD = 2.55), the mean peak frequency was 7.52 kHz (± SD = 2.24) and the duration of whistles was 0.75 s (± SD = 0.41). The mean number of inflection points was 1.72 (± SD = 1.16) except for a few whistles with many inflection points (maximum 4). The frequency range, duration and inflection points of whistles were highly variable with CVs of 50.50 and over.

Table 8: Acoustic characteristics of sound types produced by bottlenose dolphins at MS5 Susak monitoring station in July 2020.

Statistics	Start freq (kHz)	End freq (kHz)	Min freq (kHz)	Max freq (kHz)	Freq range (kHz)	Peak freq (kHz)	Duration (s)	Inflection points (n)
n	36	36	36	36	36	36	36	36
Mean (±SD)	8.83 (2.39)	7.90 (2.59)	5.91 (1.83)	10.95 (2.48)	5.04 (2.55)	7.52 (2.24)	0.75 (0.41)	1.72 (1.16)
Range	4.98 – 12.79	3.84 – 12.94	3.84 – 9.31	5.04 – 16.04	1.06 – 9.03	4.03 – 11.44	0.20 – 1.62	0.00 – 4.00
CV	27.08	32.75	31.04	22.61	50.50	29.75	53.99	67.45

3.3 MS6 Lošinj - NTS

In March/April 2020, a total of 302 whistles that had a good signal to noise ratio (SNR 2 & 3) were analysed from the MS6 Lošinj monitoring station (Table 9). Whistles ranged from 3.36 to 17.62 kHz in frequency, having a mean minimum frequency of 5.81 kHz (± SD = 2,11) and a mean maximum frequency of 9.81 kHz (± SD = 4.44). The mean start and end frequencies of whistles were 6.91 kHz (± SD = 2.71) and 8.11 kHz (± SD = 4.25), respectively. The mean frequency range of whistles was 4.00 kHz (± SD = 3.05), the mean peak frequency was 7.04 (± SD = 2.97) and the mean duration of whistles was 0.74 s (± SD = 0.36). The mean number of inflection points was 0.85 (± SD = 1.25) except for a few whistles with many inflection points (maximum 10). The end frequency, max frequency, frequency range, duration and inflection points of whistles were highly variable with CVs of 45.24 and over.

Table 9: Acoustic characteristics of sound types produced by bottlenose dolphins at MS6 Lošinj monitoring station in March/April 2020.

Statistics	Start freq (kHz)	End freq (kHz)	Min freq (kHz)	Max freq (kHz)	Freq range (kHz)	Peak freq (kHz)	Duration (s)	Inflection points (n)
n	302	302	302	302	302	302	302	302
Mean (±SD)	6,91 (2,71)	8,11 (4,25)	5,81 (2,11)	9,81 (4,44)	4,00 (3,05)	7,04 (2,97)	0,74 (0,36)	0,85 (1,25)
Range	3,61 - 15,37	3,65 - 17,44	3,36 - 14,84	4,59 - 17,62	0,42 - 11,42	0,38 - 17,06	0,16 - 3,15	0,00 – 10,00
CV	39,24	52,41	36,25	45,24	76,35	42,25	48,77	147,25

3.4 MS6 Lošinj - TS

In July 2020, a total of 139 whistles that had a good signal to noise ratio (SNR 2 & 3) were analysed from the MS6 Lošinj monitoring station (Table 10). Whistles ranged from 0.87 to 20.06 kHz in frequency and had mean minimum and maximum frequencies of 5.74 kHz (± SD = 1.70) and 10.92 kHz (± SD = 4.78), respectively. The start and end frequencies of whistles were very similar, having a mean start frequency of 6.73 kHz (± SD = 2.83) and a mean end frequency of 7.65 kHz (± SD = 3.02). The mean frequency range of whistles was 5.18 kHz (± SD = 3.88), the mean peak frequency was 7.44 kHz (± SD = 3.12) and the duration of whistles was 0.85 s (± SD = 0.34). The mean number of inflection points was 1.01 (± SD = 1.05) except for a few whistles with many inflection points (maximum 7). The frequency range and inflection points of whistles were highly variable with CVs of 74.89 and 104.54, respectively.

Table 10: Acoustic characteristics of sound types produced by bottlenose dolphins at MS6 Lošinj monitoring station in July 2020.

Statistics	Start freq (kHz)	End freq (kHz)	Min freq (kHz)	Max freq (kHz)	Freq range (kHz)	Peak freq (kHz)	Duration (s)	Inflection points (n)
n	139	139	139	139	139	139	139	139
Mean (±SD)	6,73 (2,83)	7,65 (3,02)	5,74 (1,70)	10,92 (4,78)	5,18 (3,88)	7,44 (3,12)	0,85 (0,34)	1,01 (1,05)
Range	0,87 - 18,17	3,66 - 17,49	0,87 - 11,32	4,76 - 20,06	0,29 - 15,09	1,13 - 17,01	0,23 - 2,01	0,00 - 7,00
CV	42,00	39,54	29,66	43,77	74,89	41,94	39,52	104,54

4. Differences in whistle parameters: NTS vs TS

4.1 MS5 Susak: NTS vs TS

The start frequency of whistles was significantly higher in summer (one-way ANOVA, F (1,335) = 24.563, p = 0.000), whereas the end frequency of whistles was significantly lower in summer (one-way ANOVA, F (1,335) = 32.523, p = 0.000). The minimum (Mann-Whitney U, U = 4193.000, p = 0.027) and maximum frequency (one-way ANOVA, F (1,335) = 10.932, p = 0.001) of whistles were significantly lower in summer. The frequency range of whistles was significantly smaller in summer (one-way ANOVA, F (1,335) = 5.363, p = 0.021). The peak frequency of whistles was significantly lower in summer (one-way ANOVA, F (1,335) = 8.905, p = 0.003). There was no statistically significant difference in the duration of whistles between seasons (one-way ANOVA, F (1,335) = 0.364, p = 0.547). Whistles had significantly more inflection points in summer (one-way ANOVA, F (1,335) = 4.158, p = 0.042). It is important to notice that the sample size of whistles was 301 for NTS and 36 for TS.

4.2 MS6 Lošinj: NTS vs TS

There was no statistically significant difference in the start (one-way ANOVA, F (1,439) = 0.385, p = 0.535) and end frequency (Mann-Whitney U, U = 19853.000, p = 0.361) of whistles. The minimum frequency of whistles was significantly lower in summer (Mann-Whitney U, U = 18187.000, p = 0.024), whereas the maximum frequency of whistles was significantly higher in summer (Mann-Whitney U, U = 16694.000, p = 0.001). The frequency range of whistles was significantly wider in summer (Mann-Whitney U, U = 17245.000, p = 0.003). The peak frequency of whistles was significantly higher in summer (one-way ANOVA, F (1,439) = 1.702, p = 0.193). The duration of whistles was significantly longer in summer (Mann-Whitney U, U = 17646.000, p = 0.004). Whistles had significantly more inflection points in summer (one-way ANOVA, F (1,439) = 1.709, p = 0.192). The sample size of whistles was 302 for NTS and 139 for TS.

4.3 MS5 Susak & MS6 Lošinj: NTS vs TS

There was no statistically significant difference in the start frequency of whistles between seasons (one-way ANOVA, F (1,776) = 1.020, p = 0.313), however the end frequency of whistles was significantly lower in summer (Mann-Whitney U, U = 39337.000, p = 0.000). There was no statistically significant difference in the minimum frequency (one-way ANOVA, F (1,776) = 3.604, p = 0.058), maximum frequency (Mann-Whitney U, U = 52164.500, p = 0.819), frequency range (Mann-Whitney U, U = 51883.000, p = 0.737), peak frequency (one-way ANOVA, F (1,776) = 2.679, p = 0.102) and duration (one-way ANOVA, F (1,776) = 3.049, p = 0.081) of whistles between seasons. Whistles had significantly more inflection points in summer (Mann-Whitney U, U = 45975.000, p = 0.006). The sample size of whistles was 603 for NTS and 175 for TS.

5. Differences in whistle parameters: Day vs Night

5.1 MS5: day vs night (only NTS)

The start frequency of whistles was significantly lower during the day (Kruskal Wallis, H (1) = 6.278, p = 0.012), however there was no statistically significant difference in the end frequency of whistles between day and night (one-way ANOVA, F (1,34) = 6.645, p = 0.014). The minimum frequency was significantly lower during the day (Kruskal Wallis, H (1) = 6.294, p = 0.012), however there was no statistically significant difference in the maximum frequency of whistles between day and night (one-way ANOVA, F (1,299) = 0.852, p = 0.357). There was no statistically significant difference in the frequency range (one-way ANOVA, F (1,299) = 1.346, p = 0.247), peak frequency (one-way ANOVA, F (1,299) = 0.739, p = 0.391), duration (one-way ANOVA, F (1,299) = 0.066, p = 0.798) and inflection points (one-way ANOVA, F (1,299) = 0.023, p = 0.880) of whistles between day and night. The sample size of whistles was 268 during the day and 33 during the night.

5.2 MS5: day vs night (only TS)

There was no statistically significant difference in the start frequency of whistles between day and night (Mann-Whitney U, U = 102.000, p = 0.476), however the end frequency of whistles was significantly higher during the day (one-way ANOVA, F (1,34) = 6.645, p = 0.014). There was no statistically significant difference in the minimum frequency (one-way ANOVA, F (1,34) = 1.389, p = 0.247), maximum frequency (one-way ANOVA, F (1,34) = 0.027, p = 0.871), frequency range (one-way ANOVA, F (1,34) = 0.460, p = 0.502), peak frequency (one-way ANOVA, F (1,34) = 0.172, p = 0.681), duration (one-way ANOVA, F (1,34) = 2.618, p = 0.115) and inflection points (one-way ANOVA, F (1,34) = 0.027, p = 0.871) of whistles between day and night. The sample size of whistles was 27 during the day and 9 during the night.

5.3 MS5: day vs night (NTS + TS)

The start frequency of whistles was significantly lower during the day (Kruskal Wallis, H (1) = 6.366, p = 0.012), however there was no statistically significant difference in the end frequency between day and night (Kruskal Wallis, H (1) = 0.020, p = 0.887). The minimum frequency of whistles was significantly lower during the day (one-way ANOVA, F (1,335) = 4.200, p = 0.041), however there was no statistically significant difference in the maximum frequency of whistles between day and night (one-way ANOVA, F (1,335) = 0.100, p = 0.752). There was no statistically significant difference in the frequency range (one-way ANOVA, F (1,335) = 1.061, p = 0.304), peak frequency (one-way ANOVA, F (1,335) = 0.034, p = 0.853), duration (one-way ANOVA, F (1,335) = 0.069, p = 0.792) and inflection points of whistles between day and night (one-way ANOVA, F (1,335) = 0.120, p = 0.729). The sample size of whistles was 295 during the day and 42 during the night.

5.4 MS6: day vs night (only NTS)

The start frequency of whistles was significantly higher during the day (one-way ANOVA, F (1,300) = 4.865, p = 0.028, however there was no statistically significant difference in the end frequency of whistles between day and night (one-way ANOVA, F (1,300) = 0.054, p = 0.816). There was no statistically significant difference in the minimum (one-way ANOVA, F (1,300) = 0.245, p = 0.621) and maximum frequency (one-way ANOVA, F (1,300) = 2.038, p = 0.154) of whistles between day and night. The frequency range of whistles was significantly wider during the day (Kruskal Wallis, H (1) = 4.021, p = 0.045). There was no statistically significant difference in the peak frequency of whistles (Kruskal Wallis, H (1) = 2.271, p = 0.132). The duration of whistles was significantly longer during the day (Kruskal Wallis, H (1) = 4.931, p = 0.026). Whistles had more inflection points during the day (Kruskal Wallis, H (1) = 7.284, p = 0.007). The sample size of whistles was 50 during the day and 252 during the night.

5.5 MS6: day vs night (only TS)

The start frequency (Kruskal Wallis, H (1) = 66.924, p = 0.000), end frequency (one-way ANOVA, F (1,137) = 16.838, p = 0.000), minimum frequency (Kruskal Wallis, H (1) = 52.670, p = 0.000) and maximum frequency (one-way ANOVA, F (1,137) = 59.604, p = 0.000) of whistles was significantly higher during the day. The frequency range of whistles was significantly wider during the day (one-way ANOVA, F (1,137) = 33.540, p = 0.000). The peak frequency of whistles was significantly higher during the day (Kruskal Wallis, H (1) = 61.810, p = 0.000). There was no statistically significant difference in the duration of whistles between day and night (Kruskal Wallis, H (1) = 0.716, p = 0.398). Whistles had significantly more inflection points during the day (one-way ANOVA, F (1,137) = 6.662, p = 0.011). The sample size of whistles was 83 during the day and 56 during the night.

5.6 MS6: day vs night (NTS + TS)

The start frequency of whistles was significantly higher during the day (Kruskal Wallis, H (1) = 33.302, p = 0.000), however there was no statistically significant difference in the end frequency of whistles between day and night (one-way ANOVA, F (1,439) = 2.154, p = 0.143). The minimum (one-way ANOVA, F (1,439) = 12.168, p = 0.001) and maximum frequency (one-way ANOVA, F (1,439) = 39.519, p = 0.000) of whistles was significantly higher during the day. The frequency range of whistles was significantly wider during the day (one-way ANOVA, F (1,439) = 40.933, p = 0.000). The peak frequency of whistles was significantly higher during the day (Kruskal Wallis, H (1) = 40.275, p = 0.000). The duration of whistles was significantly longer during the day (Kruskal Wallis, H (1) = 11.661, p = 0.001). Whistles had significantly more inflection points during the day (Kruskal Wallis, H (1) = 19.108, p = 0.000). The sample size of whistles was 133 during the day and 308 during the night.

5.7 MS5 & MS6: day vs night (only NTS)

The start frequency (Kruskal Wallis, H (1) = 5.682, p = 0.017), end frequency (Kruskal Wallis, H (1) = 40.246, p = 0.000), minimum frequency (Kruskal Wallis, H (1) = 9.630, p = 0.002) and maximum frequency (Kruskal Wallis, H (1) = 26.571, p = 0.000) of whistles was significantly higher during the day. The frequency range of whistles was significantly wider during the day (Kruskal Wallis, H (1) = 53.499, p = 0.000). The peak frequency of whistles was significantly higher during the day (Kruskal Wallis, H (1) = 51.827, p = 0.000). The duration of whistles was significantly longer during the day (one-way ANOVA, F (1,601) = 9.833, p = 0.002). Whistles had significantly more inflection points during the day (Kruskal Wallis, H (1) = 17.921, p = 0.000). The sample size of whistles was 318 during the day and 285 during the night.

5.8 MS5 & MS6: day vs night (only TS)

The start frequency (Kruskal Wallis, H (1) = 62.446, p = 0.000), end frequency (one-way ANOVA, F (1,173) = 23.261, p = 0.000), minimum frequency (Kruskal Wallis, H (1) = 44.699, p = 0.000) and maximum frequency (one-way ANOVA, F (1,173) = 53.253, p = 0.000) of whistles was significantly higher during the day. The frequency range of whistles was significantly wider during the day (one-way ANOVA, F (1,173) = 26.448, p = 0.000). The peak frequency of whistles was significantly higher during the day (Kruskal Wallis, H (1) = 56.836, p = 0.000). There was no statistically significant difference in the duration of whistles between day and night (Kruskal Wallis, H (1) = 0.217, p = 0.641). Whistles had significantly more inflection points during the day (Kruskal Wallis, H (1) = 6.246, p = 0.012). The sample size of whistles was 110 during the day and 65 during the night.

5.9 MS5 & MS6: day vs night (NTS + TS)

The start frequency (one-way ANOVA, F (1,776) = 9.155, p = 0.003), end frequency (Kruskal Wallis, H (1) = 55.583, p = 0.000), minimum frequency (Kruskal Wallis, H (1) = 55.583, p = 0.000) and maximum frequency (Kruskal Wallis, H (1) = 55.583, p = 0.000) of whistles was significantly higher during the day. The frequency range of whistles was significantly wider during the day (Kruskal Wallis, H (1) = 85.585, p = 0.000). The peak frequency of whistles was significantly higher during the day (Kruskal Wallis, H (1) = 100.397, p = 0.000). There was no statistically significant difference in the duration of whistles between day and night (Kruskal Wallis, H (1) = 2.734, p = 0.098). Whistles had significantly more inflection points during the day (Kruskal Wallis, H (1) = 26.428, p = 0.000). The sample size of whistles was 428 during the day and 350 during the night.

5. Other bottlenose dolphin vocalisations: NTS vs TS

Other than whistles, bottlenose dolphins also produced chirps, burst pulse (BP) sounds, echolocation clicks and low frequency narrow-band (LFN) sounds except of the combined sound, the bray, which could not be identified with certainty. The percentage of echolocation clicks was noted for each 1-hour recording but not used for further analysis. The number of burst pulse sounds was really low (MS5: 20 BPs in NTS & 5 BPs in TS; MS6: 10 BPs in NTS & 11 BPs in TS) and thus excluded from further analysis. However, it was tested for differences in the presence of chirps and LFN sounds between the NTS and TS.

5.1 MS5 Susak: NTS vs TS

The number of chirps was significantly higher in the NTS (Kruskal Wallis, $H(1) = 8.923$, $p = 0.003$), however there was no statistically significant difference in the number of LFN sounds (one-way ANOVA, $F(1,110) = 0.935$, $p = 0.336$) produced between NTS and TS. The frequency of chirps and LFN sounds present between seasons was as follows: 93 cases in NTS & 25 cases in TS for chirps; 26 cases in NTS & 86 cases in TS for LFN sounds.

5.2 MS6 Lošinj: NTS vs TS

There was no statistically significant difference in the number of chirps (Kruskal Wallis, $H(1) = 2.480$, $p = 0.115$) and LFN sounds (one-way ANOVA, $F(1,110) = 1.553$, $p = 0.215$) produced between NTS and TS. The frequency of chirps and LFN sounds present between seasons was as follows: 19 cases in NTS & 23 cases in TS for chirps; 55 cases in NTS & 57 cases in TS for LFN sounds.

5.3 MS5 Susak & MS6 Lošinj: NTS vs NTS

There was no statistically significant difference in the number of chirps (one-way ANOVA, $F(1,158) = 0.275$, $p = 0.601$) and LFN sounds (one-way ANOVA, $F(1,79) = 0.330$, $p = 0.567$) produced between MS5 Susak NTS and the MS6 Lošinj NTS. The frequency of chirps and LFN sounds present between stations was as follows: 93 cases in MS5 & 19 cases in MS6 for chirps; 26 cases in MS5 & 55 cases in MS6 for LFN sounds.

5.4 MS5 Susak & MS6 Lošinj: TS vs TS

The number of chirps was significantly higher in the TS at the MS5 Susak station (Kruskal Wallis, $H(1) = 7.333$, $p = 0.007$), however there was no statistically significant difference in the number of LFN sounds (Kruskal Wallis, $H(1) = 3.253$, $p = 0.071$) produced between MS5 Susak TS and the MS6 Lošinj TS. The frequency of chirps and LFN sounds present between stations was as follows: 25 cases in MS5 & 23 cases in MS6 for chirps; 86 cases in MS5 & 57 cases in MS6 for LFN sounds.

5.5 MS5 Susak & MS6 Lošinj: NTS vs TS

There was no statistically significant difference in the number of chirps (one-way ANOVA, $F(1,158) = 0.275$, $p = 0.601$) and LFN sounds (one-way ANOVA, $F(1,222) = 0.178$, $p = 0.674$) produced between NTS and TS. The frequency of chirps and LFN sounds present between seasons was as follows: 112 cases in NTS & 48 cases in TS for chirps; 81 cases in NTS & 143 cases in TS for LFN sounds.

6. Summary and conclusion

6.1 MS5 Susak & MS6 Lošinj

Overall, whistle parameters did not differ significantly between NTS and TS. The end frequency was lower in the TS and whistles had more inflection points in the TS. When looking at the whole data set, whistle parameters differed significantly between day and night. In the NTS: the start, end, minimum, maximum and peak frequency were higher, the frequency range wider, duration longer and whistles had more inflection points during the day. In the TS: the exact same parameters differed as in the NTS, except there was no difference in the duration of whistles. Looking at the NTS and TS combined: the exact same parameters differed as in the NTS, except there was no difference in the duration of whistles. Regarding other dolphin vocalisations, there was no difference in the number of chirps and LFN sounds produced between NTS and NTS, TS and TS (except for more chirps being produced at MS5 Susak) as well as NTS and TS. (Table 11)

Table 11: Summary of whistle parameters that differed significantly between NTS/TS and day/night.

	NTS	TS
NTS vs TS	higher end freq	more inflection points
	Day	Night
Day vs Night (only NTS)	higher start, end, min, max, preak freq; longer duration, wider freq range; more inf. points	
Day vs Night (only TS)	higher start, end, min, max, preak freq; wider freq range; more inf. points	
Day vs Night (NTS + TS)	higher start, end, min, max, preak freq; wider freq range; more inf. points	

As part of the Soundscape project, data on boat traffic was collected with a theodolite to cover the west and east side of the Cres-Lošinj archipelago (Figure 9 & 10). Vessels without AIS include research boat, recreational boats, dolphin watching boat, local boat, sailing boat, tour boat, gillnetter and bottom trawler (east side). Vessels with AIS include purse seiner, bottom trawler (west side), ferry and cargo. Vessels with AIS are more present on the west side of the Cres-Lošinj archipelago whereas vessels without AIS are especially high during the TS on the east side of the Cres-Lošinj archipelago. To conclude, whistle parameters did not differ much between seasons. However, it was evident that bottlenose dolphins in the Cres-Lošinj archipelago changed their whistle parameters to adapt to the underwater noise and boat traffic during the day.

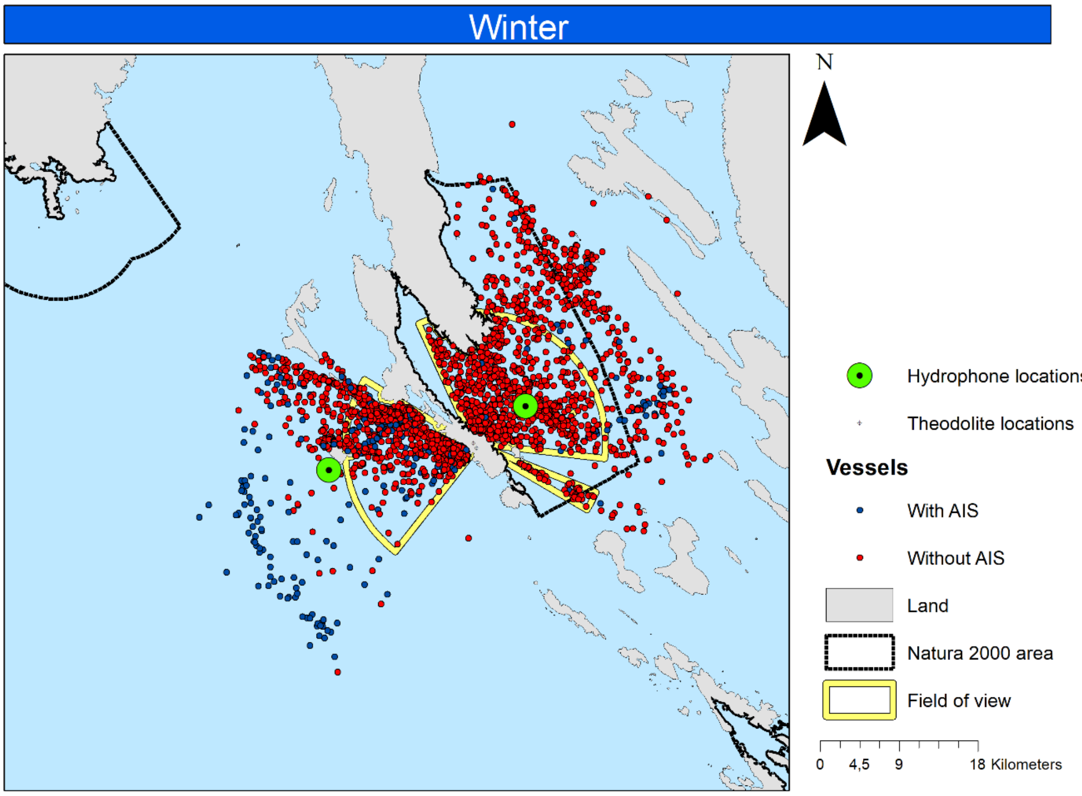

Figure 9: Locations of vessels with and without AIS collected with a theodolite during the NTS (October 2020 to May 2021).

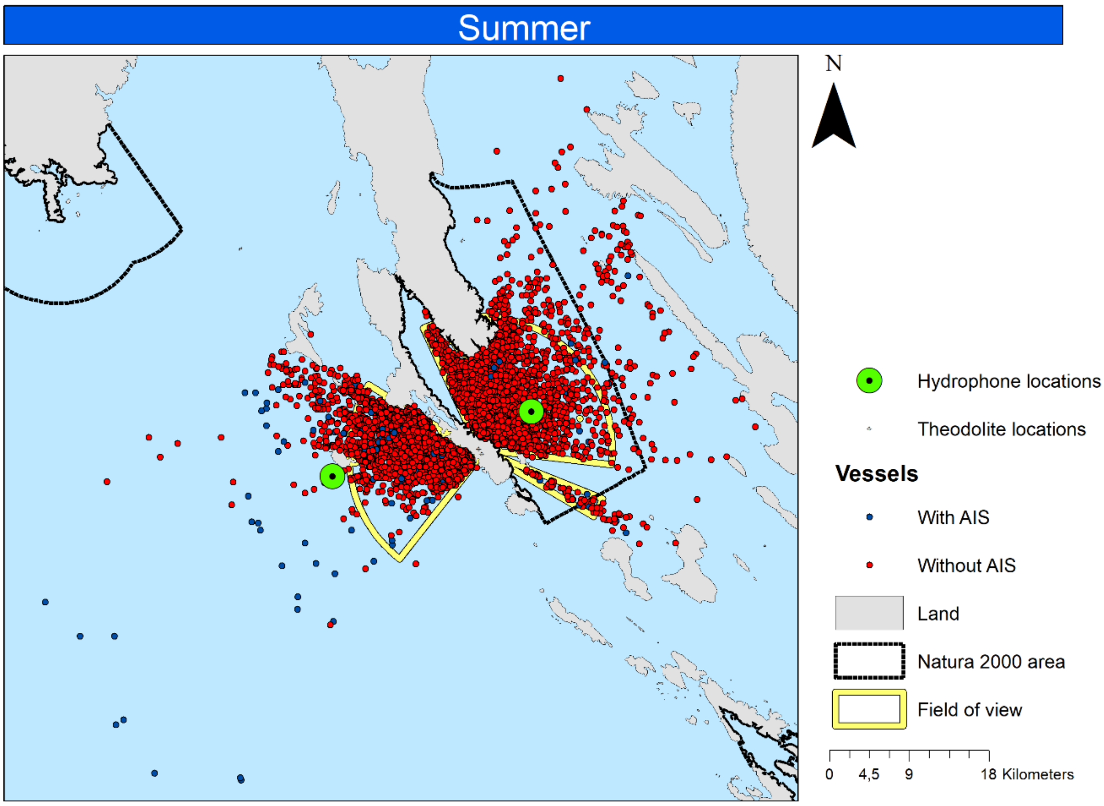

Figure 10: Locations of vessels with and without AIS collected with a theodolite during the TS (June 2020 to September 2020).

6.2 MS5 Susak

In summary, whistle parameters differed significantly between NTS and TS. The start frequency was higher and whistles had more inflection points in the TS. The end, minimum, maximum and peak frequency were lower and the frequency range was smaller in the TS. In general, whistle parameters did not differ significantly between day and night. In the NTS: only the start and end frequency were lower during the day. In the TS: only the end frequency was lower during the day. When looking at the NTS and TS combined: only the start and min frequency were lower during the day. Regarding other dolphin vocalisations, more chirps were produced during the NTS, however there was no difference in the number of LFN sounds produced between NTS and TS. (Table 12)

Table 12: Summary of whistle parameters that differed significantly between NTS/TS and day/night.

	NTS	TS
NTS vs TS	higher end, min, max peak freq; wider freq range	higher start freq; more inf points
	Day	Night
Day vs Night (only NTS)		higher start, min freq
Day vs Night (only TS)	higher end freq	
Day vs Night (NTS + TS)		higher start, min freq

To put our findings into perspective, it is important to be aware of the noise environment around the MS5 Susak monitoring station (Figure 9 & 10). Compared to the east side of the Cres-Lošinj archipelago, the west side was exposed to less but still substantial recreational boating. Additionally, the west side was exposed to higher commercial shipping by bigger vessels. From the data on boat traffic collected with a theodolite, the presence of boats with AIS was evident in the NTS and TS. Boats without AIS were present in NTS and TS, however the presence of boats without AIS was much higher in the TS. To conclude, whistle parameters differed between seasons, however, is it important to note that the sample size during the TS was very low. Also, whistle parameters did not differ much between day and night which could be because the bottlenose dolphins around the MS5 Susak monitoring station are exposed to the continuous noise from commercial shipping.

6.3 MS6 Lošinj

In summary, whistle parameters differed significantly between NTS and TS. The maximum and peak frequency was higher and the minimum frequency was lower in the TS. Additionally, the frequency range was wider, the duration was longer and whistles had more inflection points in the TS. In general, whistle parameters differed significantly between day and night. In the NTS: the start frequency was higher, the frequency range wider, the duration longer and whistles had more inflection points during the day. In the TS: the start, end, minimum, maximum and peak frequency were higher, the frequency range wider and whistles had more inflection points during the day. When looking at the NTS and TS combined: the start, minimum, maximum and peak frequency were higher, the frequency range wider, the duration longer and whistles had more inflection points during the day. Regarding other dolphin vocalisations, there was no difference in the number of chirps and LFN sounds produced between NTS and TS. (Table 13)

Table 13: Summary of whistle parameters that differed significantly between NTS/TS and day/night.

	NTS	TS
NTS vs TS	higher min freq	higher max, peak freq; wider freq range; longer duration; more inf points
	Day	Night
Day vs Night (only NTS)	higher start freq; longer duration, wider freq range; more inf. points	
Day vs Night (only TS)	higher start, end, min, max, preak freq; wider freq range; more inf. points	
Day vs Night (NTS + TS)	higher start, min, max, preak freq; longer duration, wider freq range; more inf. points	

To put our findings into perspective, it is important to be aware of the noise environment around the MS6 Lošinj monitoring station (Figure 9 & 10). Compared to the west side of the Cres-Lošinj archipelago, the east side is subject to intense recreational boating. Additionally, the east side was exposed to some commercial fishing activities. From the data on boat traffic collected with a theodolite, the presence of boats with AIS was evident in the NTS and TS. Boats without AIS were present in NTS and TS, however the presence of boats without AIS was extremely high in the TS. To conclude, it is evident that bottlenose dolphins changed their whistle parameters around the MS6 Lošinj monitoring to adapt to the underwater noise and boat traffic during the TS and during the day. Rako and Picciulin (2016) also showed that there were changes in whistle structure of bottlenose dolphins in relation to underwater noise and boat traffic on the east side of the Cres-Lošinj archipelago. Moreover, previous studies have shown that leisure boating noise on the east side of the Cres-Lošinj archipelago was a trigger for the displacement of the bottlenose dolphins in the TS (Rako et al., 2013).

7. References

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