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Anthropogenic noise effects on Risso's dolphin vocalizations in the Gulf of Taranto (Northern Ionian sea, central Mediterranean sea)

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ABSTRACT

Anthropogenic noise may significantly affect marine mammals' vocalizations. The aim of this work is to describe for the first time the acoustic features of the click trains, buzzes, burst pulses and whistles produced by the Risso's dolphins in the Gulf of Taranto (Northern Ionian Sea, Central Mediterranean), the concurrent levels of noise to which dolphins are exposed, and the potential reactive changes in the acoustic structure of the species vocalizations. About 6 h of recordings were collected from April 2019 to September 2022 during daytime boat surveys. Elevated ambient noise levels were mainly present at the frequencies lower than 63 Hz, at about 1 kHz and 50 kHz likely attributable to anthropogenic activity, such as shipping and sonars. Even if the acoustic features of all the vocalizations can be disrupted, especially with increasing noise below 1 kHz and between 20 and 63 kHz, the click trains were the most affected vocalizations, showing changes in their Inter-Click-Interval and in the Peak Amplitude. Since these vocalizations are used for navigation and searching for prey, their alteration raises concerns on the potential negative effects on the well-being of the Risso's dolphin population in the Gulf of Taranto.

1. Introduction

Over the last two decades, anthropogenic underwater noise is increasingly recognized as a pervasive pollutant for marine ecosystems, and as a stressor on a broad variety of marine species including cetaceans (Simmonds et al., 2014; Williams et al., 2015; Todd, 2016). Multiple negative impacts on cetacean health may be caused by anthropogenic sounds. For example, their acoustic space for communication, which is essential to build and maintain social relationships, to echo-locate prey and for orientation in the natural and social environment might be reduced (e.g. Richardson et al., 1995; Hildebrand, 2005; Nowacek et al., 2007; Southall et al., 2007; Erbe et al., 2016; Thomsen et al., 2021). Furthermore, physical and physiological damage, including permanent or temporal hearing threshold shift (Finneran, 2015), and short-term or chronic neuroendocrine stress (Yang et al., 2021) can occur. Finally, anthropogenic noise can cause the alteration of behaviour, consisting of avoidance of the impacted area (Wensveen et al., 2019), changing their activity patterns (i.e., Blair et al., 2016; Isojunno et al., 2016; Wisniewska et al., 2018), and their acoustic behaviour (Parks et al., 2007), such as increasing the signal intensity, shifting frequencies, changing the time of emission, and the calling rate, as well as adjusting signals in relation to real-time noise by increasing or decreasing species-specific frequency parameters (Papale et al., 2015; van Ginkel et al., 2017), or simplifying their calls (Fouda et al., 2018). This alarming condition requires the implementation of international, regional, and national policies to address the issue of underwater noise, and their integration to implement mitigation and management measures of noise impacts on cetaceans. Within the European Union (EU),

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underwater noise and other forms of energy have been addressed by the Marine Strategy Framework Directive's (MSFD) Good Environmental Status descriptor 11, where threshold limits are currently being proposed considering impulsive and continuous sources of noise (EC, 2017; Merchant et al., 2022; Borsani et al., 2023).

Nevertheless, for several cetacean species there is insufficient information at present to understand their vulnerability to noise and thus assess the Level of Onset of Biological adverse Effect (LOBE).

Currently in the Mediterranean Sea, the Risso's dolphin, *Grampus griseus,* is among the species on which there is a lack of information in terms of its occurrence, spatial distribution and hearing sensitivity, despite its conservation status having been recently changed, passing from Data Deficient to Endangered by IUCN (ACCOBAMS, 2021a; Lanfredi et al., 2021). Some studies on its pattern of distribution, habitat suitability and abundance have been carried out in the Mediterranean (e.g., Cañadas et al., 2002, 2005; Azzellino et al., 2008, 2016; Bearzi et al., 2011;Hartman et al., 2008; Lanfredi et al., 2018; ACCOBAMS, 2021b; Maglietta et al., 2018, 2022;Carlucci et al., 2018a 2020a; Cipriano et al., 2022; Menniti and Vella, 2022; Luna et al., 2022; Chicote et al., 2023). However, none is known about the acoustic repertoire of Risso's dolphin in this basin strongly affected by different anthropogenic pressures (Coll et al., 2012; Micheli et al., 2013; Maglio et al., 2015; Viola et al., 2017; Picciulin et al., 2024).

The repertoire of Risso's dolphin populations outside the Mediterranean Sea includes broadband clicks, burst-pulse signals, low-frequency narrowband sounds, and complex vocalizations resulting from the simultaneous emission of tonal and burst-pulsed sounds (Corkeron et al., 2001; Neves, 2013). Click trains are defined as series of pulses with a constant or variable (increasing or decreasing) Inter-Click-Interval (ICI) higher than 4 ms, most commonly produced during foraging, but also in other behavioural contexts (Arranz et al., 2016). Buzzes corresponded to high-repetition-rate sequences of clicks starting after regular clicks, with an abrupt decrease in ICI (Arranz et al., 2016). They have an average duration of about 1 s and consist of 100–600 clicks. Buzzes are emitted while diving, probably when in pursuit of prey (Arranz et al., 2016). Finally, burst pulses can be considered as shorter sequences of high-repetition-rate clicks with an ICI usually shorter than 4 ms, mainly produced at the surface for communicative aims (Neves, 2013; Arranz et al., 2016). In addition, Risso's dolphins rarely emit narrowband frequency-modulated whistles for communication, with a frequency range from about 4 to 20 kHz (Rendell et al., 1999; Corkeron et al., 2001; Neves, 2013; Pelagatti, 2020). These narrowband frequency-modulated whistles were recorded particularly during socializing, and the highly stereotyped and repetitive nature of some whistle contours, also suggest the occurrence of signature whistles (Caldwell et al., 1969; Favaro et al., 2011; Neves, 2013; Pelagatti, 2020). More recently, some studies have identified geographic variations in the acoustic structure of its vocalizations (Azzolin, 2008; Neves, 2013; Soldevilla et al., 2017). In particular, Soldevilla et al. (2017) suggested that variation may result from morphological differences in the sound production pathway, functional variation related to prey type and size, behavioural and social context, or from the local environment related to ambient noise conditions.

However, the characteristics and the functionality of vocalizations produced by this species, as well as temporal variations during the day and night, are still little explored (Neves, 2013; Arranz et al., 2016). Therefore, the aim of this work was to describe Risso's dolphin vocalizations recorded in the Gulf of Taranto (Northern Ionian Sea, Central Mediterranean Sea) where its local population could be exposed to several anthropogenic pressures insisting in the area (Carlucci et al., 2021). Moreover, the ambient noise levels that Risso's dolphins are exposed to, and the potential real-time changes in the acoustic structure of the vocalizations to noise level variation were evaluate to study the possible responses of the species and estimate potential negative effects on the groups living in the area.

2. Materials and methods

2.1. Study area

The Gulf of Taranto is located in the Northern Ionian Sea (Central Mediterranean Sea) and covers an area of approximately 14,000 km^2, extending from Santa Maria di Leuca to Punta Alice (Fig. 1). The basin is characterized by a complex geomorphology, with a wide continental shelf and terraces in the eastern sector, and a narrow continental shelf with a steep slope cut by several channels in the western one, both descending toward the submarine canyon system of "Taranto Valley" reaching depths of over 2200 m (Harris and Whiteway, 2011; Pescatore and Senatore, 1986; Rossi and Gabbianelli, 1978). Consequently, the water circulation is complex, with significant upwelling currents increasing primary production (De Lazzari et al., 1999; Dimatteo et al., 2011; Civitarese et al., 2010). These conditions make the entire Gulf a hot spot of biodiversity due to the presence of different cetacean species (Carlucci et al., 2017), as well as sensitive habitats and vulnerable marine ecosystems (VMEs), such as the Santa Maria di Leuca cold-water coral province and the Amendolara shoal (Bo et al., 2011; Capezzuto et al., 2010; Carlucci et al., 2018b; Chimienti et al., 2019; Castellan et al., 2019; D'Onghia et al., 2016; Maiorano et al., 2022). The Gulf is suggested as a Cetacean Critical Habitat (CCH *sensu* ACCOBAMS definition, ACCOBAMS-ECS-WK Threats, 2017) for different species such as the striped dolphin (*Stenella coeruleoalba*), the common bottlenose dolphin (*Tursiops truncatus*) and the Risso's dolphin (Carlucci et al., 2016, 2018c, 2018d, 2020a, 2021, 2022; Papale et al., 2020; Santacesaria et al., 2019; Cipriano et al., 2022). It also represents a potential key habitat for other species such as the common dolphin (*Delphinus delphis*), the sperm whale (*Physeter macrocephalus*), the fin whale (*Balaenoptera physalus*), and the Cuvier's backed whale (*Ziphius cavirostris*) (Dimatteo et al., 2011; Fanizza et al., 2019; Bellomo et al., 2019; Carlucci et al.,

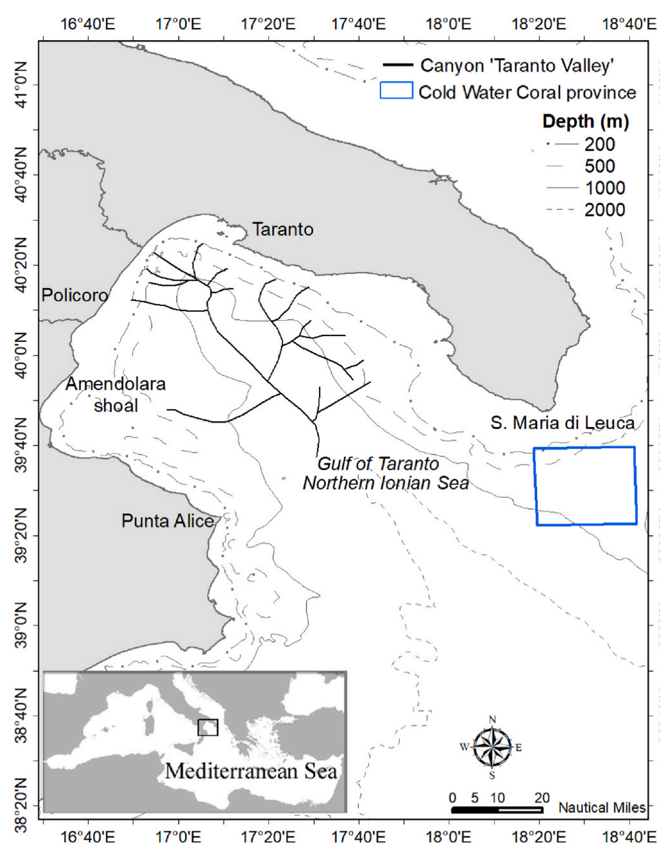

Fig. 1. Map of the study area with indication of main physiographic characters and sensitive habitats in the area.

2020b), in which to enforce specific conservation measures aimed at mitigating the anthropogenic pressure according to ACCOBAMS and the MMPATF (Marine Mammal Protected Areas Task Force) indications (Carlucci et al., 2021). In the study area, several studies on Risso's dolphin were carried out and focused on different topics from occurrence (Carlucci et al., 2020a), ecological modelling (Maglietta et al., 2023a), photo-identification (Maglietta et al., 2018, 2020, 2022, 2023b), behavioural pattern and social structure (Bellomo et al., 2021; Cipriano et al., 2022; Santacesaria et al., 2019).

However, several anthropogenic activities that voluntarily or involuntarily introduce underwater noise affect the area (Ricci et al., 2021; Carlucci et al., 2021). The coastal system is characterized by high-density urbanization, fishing, commercial and tourist traffic, strong industrialization in the steel and aquaculture sector and, more recently, by the building of offshore wind farms (https://va.mite.gov.it/en-GB/Oggetti/Info/299). Furthermore, a Navy harbour, an active military practice zone, and a submarine exercise area are all present within the Gulf (Carlucci et al., 2016; Rizzo et al., 2022).

2.2. Data collection

Data were collected from April 2019 to July 2021 during vessel-based surveys conducted onboard two 12 m catamarans and covering a survey area of approximately 960 km^2 in the Gulf of Taranto using a line transect sampling approach (Buckland et al., 2001). Daily surveys were carried out only in favourable weather conditions (Beaufort scale $\leq$4), setting the sampling effort at 5 h (from 10:00 a.m. to 15:00 p.m. approximately) per day along 35 nautical miles. Observations were carried out with the naked eye or with 7x50 binoculars by three observers. Once a group of Risso's dolphins was sighted, it was observed at a minimum distance of 50 m. GPS position, date, time, species, group size of focal group, depth (m) and behavioural data were collected on a virtual sighting board created with the support of the Zoho Creator app (Zoho Creator- Business Process Automation).

The collection of behavioural data of groups of Risso's dolphins encountered was carried out by applying the focal-group protocol with instantaneous scan sampling (Mann, 1999; Neumann, 2001). A focal group is defined as all the dolphins within a radius of 100 m of each other, observed in apparent association, moving in the same direction, and engaged in similar activity (Irvine et al., 1981; Möller et al., 2002; Shane, 1990). In detail, the focal group was scanned every 3 min for a total session of at least 15 min. For each instantaneous scan, the predominant group activity, among those identified by Shane (1990) was recorded, namely feeding, resting, socializing, or traveling. Predominant activity means the behavioural category in which more than 50% of the dolphins within the focal group were involved. Acoustic data were collected simultaneously with behavioural data, with the engine turned off, using a pre-amplified omnidirectional hydrophone (ColmarGP190) with a sensitivity of -175 ± 5 dB re 1V/μPa between 5 and 170 kHz, and a flat response of -171 dB re 1V/μPa under 12 kHz, connected through an onboard junction box within a gain preamplification of 32 dB to an onboard laptop. Data were collected at a sampling frequency of between 192 and 300 kHz, with a resolution of 16 bits. Acoustic recordings up to 12 min of data were collected per sightings. Only sightings including the single species alone were considered for the analysis.

2.3. Data selection

All the recordings with acquisition failures were discarded. The recordings were first scrolled out to select Risso's dolphin vocalizations. Signals were selected for analyses when no overlap occurred with other vocalizations of the same species. Clipped impulsive signals, and tonal signals were discarded when the time-frequency contour was not completely visible following Papale et al. (2013, 2021). Furthermore, whistles with the same contour were measured only once.

Before each vocalization, a fragment of about 10 s (mean = 7.33, SD = 2.21), without Risso's dolphin emissions, was selected for noise analyses.

2.4. Data analysis

Whistles were manually analysed through spectrogram visualization (Hamming window, FFT size 4096) in iZotope RX3 Advanced (iZotope, Inc., Cambridge, MA, USA). Twelve parameters were measured following Papale et al. (2013):

1. Duration (in seconds)
2. Start frequency (Hz)
3. End frequency (Hz)
4. Minimum frequency (Hz)
5. Maximum frequency (Hz)
6. Frequency range (Maximum frequency - Minimum frequency) (Hz)
7. Number of inflection points (point at which the curve changes its concavity)
8. Number of steps (rapid frequency jump)
9. Number of maxima (number of relative maxima within the curve)
10. Number of minima (number of relative minima within the curve)
11. Number of interruptions
12. Harmonics (multiple frequencies of the fundamental frequency) (presence/absence).

The temporal and spectral acoustic characteristics of impulsive sounds were analysed using a modified Matlab code (version 2022a) already applied to describe the properties of impulsive sound of crustaceans, fish and dolphins (Buscaino et al., 2015, 2020, 2021). The code first applies a band-pass filter (cut-off frequency 25–95 kHz, order 200) and then the Teager Kaiser operator (Kaiser, 1990). A detector of peaks and a fixed threshold were used to identify pulses that exceeded this threshold. Then, the beginning and end of each train was calculated using the regularity of the inter-click of detected pulses (Matlab "ischange" function). Considering only the peaks of detected pulses within the train, a window was extracted from the 1 kHz high-pass filtered waveform. Within this window, the sound duration in seconds (s) was calculated, measured by applying the "envelope" function and defining the points at which 25% of the peak value were reached. Moreover, the Power Spectral Density (PSD) was calculated (Matlab "pwelch" function) in the window ranging between the onset and end of the pulse. On PSD, the 1st and 2nd peak frequencies were calculated (defined as the frequencies corresponding to the highest and second-highest amplitude values, respectively) as well as the amplitude of the 1st and 2nd peak frequencies and the 3 dB bandwidth (the frequency band between the lower and upper half-powers, or 3 dB down from the maximum PSD).

To test differences between the impulsive vocalization types (click trains, buzzes and burst pulses), the Kruskall-Wallis and the post-hoc Tamhane statistical tests were conducted on signal parameters (Jaykaran, 2011; McDonald, 2014). Furthermore, a Discriminant Function Analysis (DFA) was performed to evaluate classification accuracy, based on the acoustic parameters of the impulses, using the freely available statistics package R (R development core Team, 2020).

The one-third octave levels (dB re 1 μPa) were calculated starting from the 16 Hz central frequency and using the "poctave" Matlab function. The maximum sound pressure level (Lp - dB re 1 μPa peak) was assessed for each recording fragments.

Spearman's correlation test was used to detect possible relations between the acoustic parameters of each sound and the noise levels, at the 38 different frequency bands considered. Based on the results of this test, Generalized Linear Mixed Models were performed in R (lmer Test-package). Signal parameters were tested as a function of the noise bands selected from the results of the previous correlation matrix. The general behaviour recorded for each sighting was considered as a random effect, to minimize the influence of the activity in which dolphins were engaged on the variations of the sounds.

3. Results

3.1. Characterization of Risso's dolphin vocalizations

From April 2019 to September 2022, 41 sightings of Risso's dolphins were collected corresponding to 5.20 h of recordings. In 56% of sightings (23/41 sightings) Risso's dolphins were engaged in traveling, in 22% (9/41) they were engaged in resting, and in 15 (6/41) and 7% (3/41) they were engaged in socializing and feeding activities, respectively.

In total, 195 click trains, 13 buzzes, and 126 burst pulses were selected for analysis over 28 recording encounters (see Fig. 2). The median, 10 and 90 percentiles of the acoustic parameters of the impulsive vocalizations are reported in Table 1.

Click trains were characterized by a median duration of 1.45 s (10 and 90 percentiles: 0.43–5.31) and made up of a median of 14 clicks (10 and 90 percentiles: 5–47). Buzzes were shorter compared to click trains (median = 0.91 s, 10 and 90 percentiles: 0.52–1.28), with a higher number of clicks (median = 49, 10 and 90 percentiles: 26–92), and therefore a shorter Inter-Click-interval (ICI) (20.19 ms median). Burst pulses were divided into two categories based on their duration: barks and short burst pulses. The former lasted from 0.21 to 0.41 s, the latter instead had a duration from 0.03 to 0.17 s. A total of 59 barks and 67 short burst pulses were considered for analysis. The median, 10 and 90 percentiles of the acoustic parameters of the impulsive vocalizations are reported in Table 1.

The Kruskall Wallis tests highlighted significant differences between the impulsive vocalization types for all the parameters ($p < 0.05$), except for the second peak of frequency ($\chi^2 = 1.82$, $p = 0.61$) and the intensity of both the first and second peak of frequency (respectively, $\chi^2 = 6.81$, $p = 0.08$; $\chi^2 = 1.19$, $p = 0.76$). The Box plots representing the values of the parameters of the impulsive vocalization types and the results of the Tamhane tests are presented in Fig. S1. Discriminant Function Analysis performed on the 334 impulsive signals showed that almost 80% of the cross-validated cases were correctly assigned, with click trains 89% attributed to their class. Whereas buzzes were only 46% correctly discriminated and mainly misclassified with short burst pulses (38%), probably due to the very low number of buzzes collected (Fig. 3). The number of clicks, the duration of vocalizations and the Inter-Click-interval and the duration of the vocalizations were the parameters that contributed most to the variation (Standardized Coefficient of the Discriminant Function: 0.80, −0.60, −0.48, respectively).

Over 150 whistles were recorded but only 36 could be used for analysis, because of the low quality of the sound, the overlapping of other sounds, or the repetition of a single contour type. Table 2 details the whistle parameters. Whistles had a mean duration of 0.70 s (SD = 0.31), and a mean frequency range of less than 6000 Hz. Almost all the signals analysed had harmonics.

3.2. Environmental background noise

The mean levels of noise (Lp dB re 1 μPa) in 1/3 octave bands, experienced by the species in the area are shown in Fig. 4 and Table 3. The highest noise levels were reached at frequency lower than 50 Hz. Furthermore, two peaks at about 100 dB are clearly visible: one around 1000 Hz, and the other at about 50000Hz.

3.3. Influence of noise levels on vocalizations

The correlation matrix between the acoustic parameters and the noise levels at 1/3 octave bands for the different vocalization types was showed in Fig. 5. Based on these results, GLMM were performed. Only

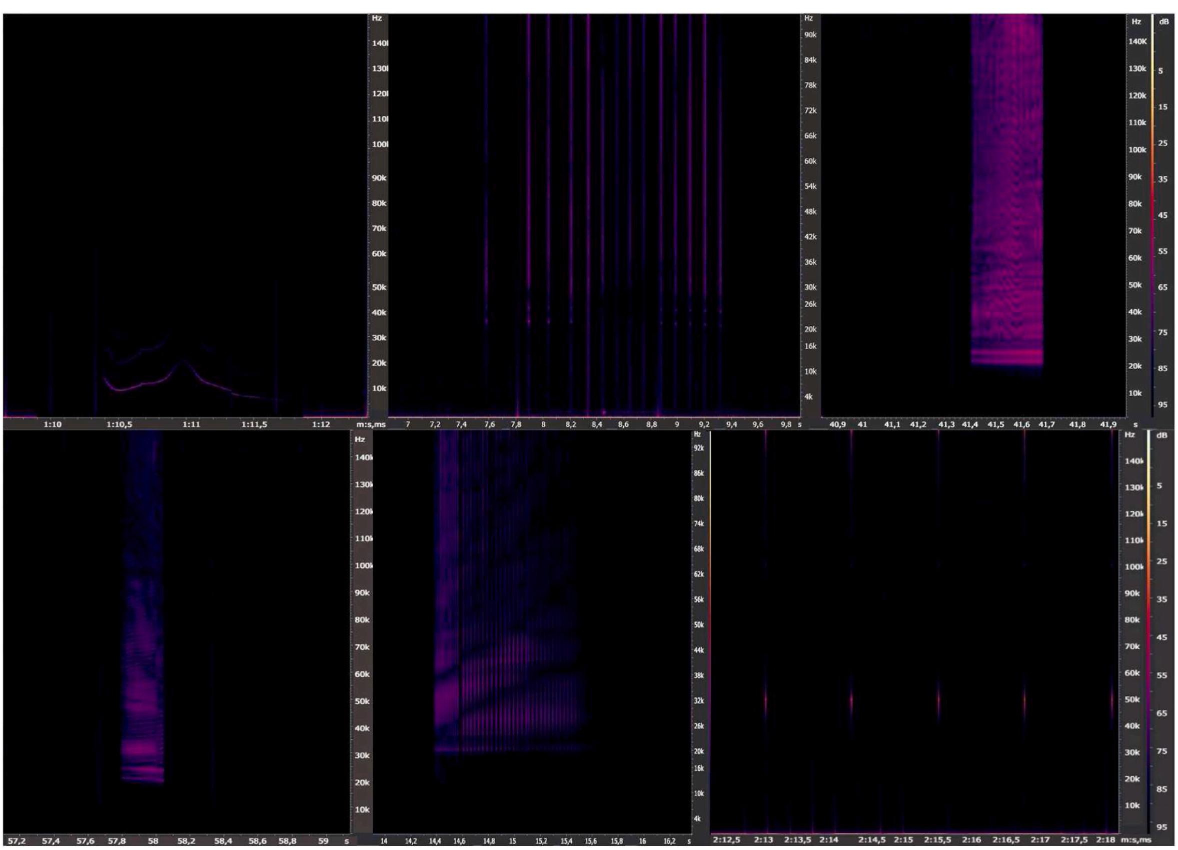

Fig. 2. Spectrogram of a whistle (a), click train (b), bark (c), short burst pulse (d), and buzz (e) produced by *Grampus griseus* in the Gulf of Taranto and of a high frequency sonar (f).

Table 1
Median values (and the 10 and 90 percentiles) of the parameters measured for each impulsive vocalization types.

		Duration (s)	# Clicks	ICI (ms)	Click duration (ms)	Frequency Peak 1 (Hz)	Frequency Peak 2 (Hz)	Peak1 amplitude (dB)	Peak2 amplitude (dB)	Median Band Pw (Hz)
Click Train N = 195	median	1.45	14.00	110.49	0.05	41,476	76,666	76.95	60.88	11,077
	10 percentile	0.43	5.00	33.89	0.04	31,415	56,683	57.40	47.51	504
	90 percentile	5.31	47.60	174.12	0.11	54,138	84,010	89.80	81.41	24,642
Buzz N = 13	median	0.91	49.00	20.19	0.11	26,593	75,546	73.51	56.38	8236
	10 percentile	0.52	26.60	9.22	0.09	16,290	68,222	65.39	52.52	3521
	90 percentile	1.28	92.40	25.88	0.16	35,913	82,789	89.89	7707	16,690
Barks N = 59	median	0.25	83.00	3.24	0.07	35,994	78,231	74.60	59.20	9236
	10 percentile	0.21	60.60	2.77	0.04	27,838	66,875	62.45	50.48	530
	90 percentile	0.41	106.80	3.86	0.18	43,655	87,591	86.10	78.60	20,931
Short Burst Pulse N = 67	median	0.09	30.00	2.93	0.07	38,877	77,718	70.37	60.47	1667
	10 percentile	0.03	10.00	2.42	0.04	26,741	57,679	58.20	50.17	606
	90 percentile	0.17	60.80	3.84	0.19	55,159	85,610	83.09	70.31	12,910

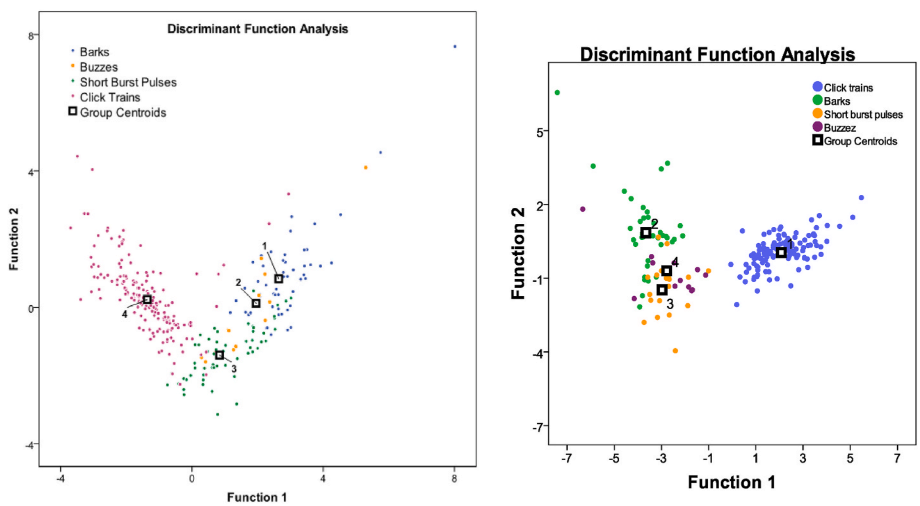

Fig. 3. Plot of the first and second discriminant function analysis performed on the impulsive signals (click trains, buzzes, short burst pulses and barks).

Table 2
Mean value and standard deviation of the parameters measured for Risso's dolphin's whistles (N = 36).

Parameters	Mean	SD
Duration (s)	0.70	0.31
Starting Frequency Hz)	9468	4282
Ending Frequency (Hz)	9978	3499
Minimum Frequency (Hz)	7171	2239
Maximum Frequency (Hz)	13,045	3900
Frequency Range (Hz)	5874	2845
# Inflection points	1.08	1.34
# Steps	1.06	1.55
# Contour maxima	0.42	0.69
# Contour Minima	1.22	1.29
# Interruptions	0.28	0.57

the correlations showing the highest significant level ($p < 0.001$) and the highest correlation coefficient for each parameter were considered for GLMM analysis. The results of this latter analysis revealed that, excluding the effect of behaviour, whistles and buzzes did not show variation in relation to noise levels, while the acoustic structure of barks, short burst pulses, and click trains changed when noise levels increased. In detail, for barks the amplitude of the first and second peaks of frequency increased when noise increased in the band centered at 25 kHz (GLMM $p = 0.001$; $p = 0.005$), while the short burst pulses show an increase in the click duration when noise increase at the bands centered at 50 Hz and 63 kHz (GLMM $p < 0.001$). For click trains, when noise increased, the Inter-Click-Interval increased in the bands centered at 50 Hz, and from 7 to 19 kHz (GLMM $p < 0.001$); while the amplitude of the first peak increased when noise levels increased at the bands centered from 7 to 31 kHz (GLMM $p < 0.001$) (Table 4).

4. Discussion

This work provides the first characterization of Risso's dolphin vocalizations at Mediterranean scale and investigates levels of noise experienced by the species in the Northern Ionian Sea, Central Mediterranean Sea, highlighting the reactive changes in the acoustic structure of different type of vocalizations recorded during the study period.

Most of the impulsive signals recorded were click trains. They represented 58% of the signals analysed. In this work, the ICI ranged from 0.03 s for the 10-percentile to 0.17 s for the 90-percentile, in agreement

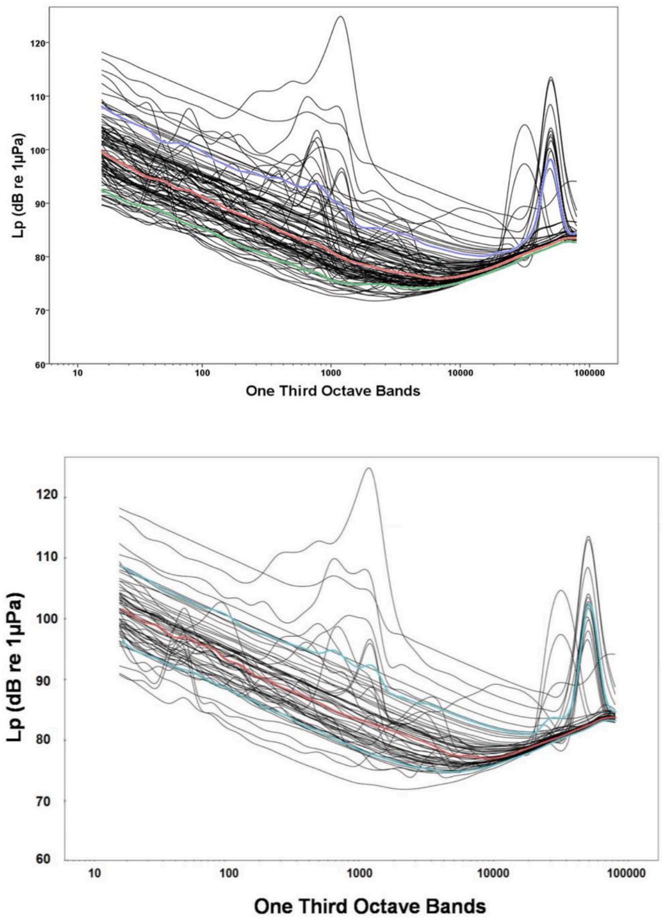

Fig. 4. Ambient noise (Lp dB re 1 μPa) in 1/3 Octave bands measured from the recording segments extracted for analysis (black lines). The red line represents the median value, while the green line shows the 10 percentile and the blue line the 90 percentiles.

Table 3
Mean levels of noise (Lp dB re 1 μPa) and standard error (SE) in each 1/3 octave band measured on the recorded fragments selected for analysis.

Central frequency 1/3 Octave Bands	Mean (dB)	SE
16 Hz	105.46	0.26
20 Hz	104.23	0.27
25 Hz	102.87	0.27
32 Hz	101.66	0.28
40 Hz	100.64	0.28
50 Hz	99.45	0.28
63 Hz	98.54	0.28
79 Hz	97.97	0.27
100 Hz	96.63	0.27
126 Hz	95.55	0.28
158 Hz	94.84	0.27
200 Hz	94.31	0.31
251 Hz	94.34	0.43
316 Hz	94.12	0.48
398 Hz	94.23	0.52
501 Hz	95.08	0.58
631 Hz	95.94	0.49
794 Hz	97.43	0.60
1000 Hz	101.77	0.84
1259 Hz	104.33	0.88
1585 Hz	91.08	0.75
1995 Hz	84.48	0.33
2512 Hz	83.13	0.27
3162 Hz	82.09	0.25
3981 Hz	81.19	0.24
5012 Hz	80.39	0.23
6310 Hz	79.81	0.21
7943 Hz	79.32	0.20
10,000 Hz	79.14	0.18
12,589 Hz	79.09	0.15
15,849 Hz	79.24	0.12
19,953 Hz	79.63	0.08
25,119 Hz	82.52	0.32
31,623 Hz	82.19	0.14
39,811 Hz	86.06	0.24
50,119 Hz	98.14	0.46
63,096 Hz	86.51	0.22
79,433 Hz	84.27	0.09

with the mean value of ICI (0.15 s) reported by Arranz et al. (2016) that collected acoustic data on this species in California with tags. Buzzes, instead were collected in small number in our dataset. This was an expected result since they were considered catching-associated vocalizations and likely occur more frequently during the night when dolphin engage in foraging (Arranz et al., 2016). The mean values of the buzz duration measured by Arranz et al. (2016) was 1.1 s, fitting in the 10–90 percentile range found in this work (0.52 and 1.28 s). However, a lower number of clicks were counted and, therefore, a longer ICI was measured (26.60–92.40 clicks, and 0.009–0.025 s, respectively). Regarding burst pulses, they are usually defined as isolated fast click series with an ICI lower than 0.004 s (Neves, 2013; Arranz et al., 2016). The burst pulses recorded in the Gulf of Taranto with this feature were correctly classified through DFA into two different classes: barks, with a duration from 0.21 to 0.41 s, and a median of 83 clicks, and short burst pulses ranging from 0.03 to 0.17 s, and a median of 30 clicks. As for other areas, whistles were not the most emitted vocalization as expected from a delphinid species. In this work, the low number of whistles analysed is prevalently due to the high number of repetitions of the same contour. This suggests the occurrence of possible signature whistles as already proposed by Favaro et al. (2011), Neves (2013), Pelagatti (2020). However, descriptive results showed longer mean duration compared to the whistles collected in the Azores, Scotland (Rendell et al., 1999), California, Egypt and the Canary Islands (Neves, 2013), but shorter compared to Australia (Corkeron et al., 2001). Minimum and maximum frequencies were comparable to the ones recorded in the Azores, Gran Canaria, and California, while higher compared to the ones recorded in Egypt (Neves, 2013). Geographic variation of the species repertoire may be generated by adaptations to different acoustic conditions aimed to improve transmission through the environment. Therefore, noise levels that characterize an area play a crucial role in shaping and modifying the acoustic emissions of a species. Our recordings show that the Gulf of Taranto was characterized by environmental background noise made up of biotic and abiotic signals, with peaks at 100 dB on average at the lowest frequencies (until 60 Hz), the mid-frequencies (∼1000Hz), and the highest frequencies (∼50000Hz). Noise at the lowest frequency generally comes from vessel traffic (≤1 kHz) (Viola et al., 2017; Picciulin et al., 2024), while biotic impulses of fish and invertebrates might influence the mid frequency bands (500 Hz–8 kHz) (Buscaino et al., 2015; Ceraulo et., 2018). The peak at 50000Hz instead, was very likely generated by intense impulses of anthropogenic origin, attributable to sonars (Parsons, 2017; McQueen et al., 2018).

Generally, the outcomes revealed that click train and buzzes are particularly affected by the noise at the lowest frequency (<200 Hz), suggesting the vessel traffic, and especially commercial shipping, as the anthropogenic stressor most impacting the Risso's dolphin acoustic behaviour. High frequency noise from 7 to 31 kHz also influences parameters of short burst pulses and barks. In detail, according to GLMM results the click trains were the most affected vocalizations from both the lowest and the highest frequencies. These sounds are especially used for navigation and for searching for prey. With high level of noise, dolphins change the ICI duration of click trains. This implies that noise might alter the perception of the surrounding environment and of prey detection. Furthermore, the amplitude of the first frequency peak increased, suggesting that dolphins need to overcome noise to

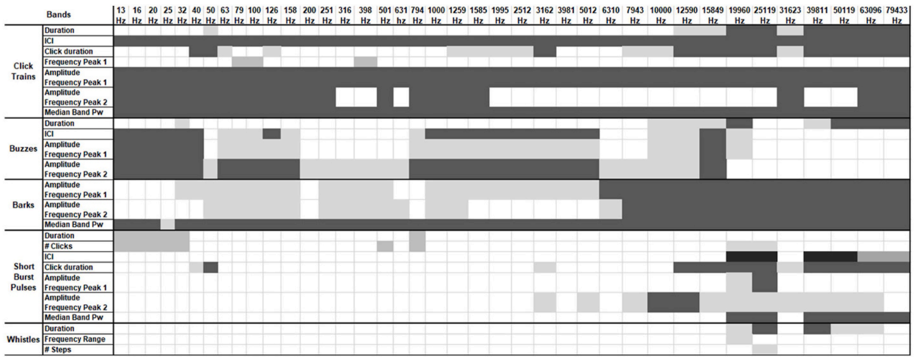

Fig. 5. Table representing the levels of p value and the sign of the correlation between noise levels at the different 1/3 Octave Bands and the acoustic parameters: positive $p < 0.05$ (light grey); positive <0.001 (dark grey); Negative <0.05 (medium grey); Negative <0.001 (black).

Table 4
Results and details of the GLMMs obtained for click trains, short burst pulses, barks and buzzes.

	Central frequency 1/3 Octave Bands	Random effect	Estimates	Standard error	T value	P
Click Trains						
ICI	50 Hz	Behaviour	0,003	0,001	4650	<0,001
	7943 Hz		0,005	0,001	4402	<0,001
	10,000 Hz		0,006	0,001	4295	<0,001
	12,589 Hz		0,007	0,001	4246	<0,001
	15,848 Hz		0,009	0,002	4188	<0,001
	19,952 Hz		0,010	0,002	4017	<0,001
Peak 1 amplitude (dB)	7943 Hz	Behaviour	1454	0,335	4339	<0,001
	10,000 Hz		1693	382,000	4433	<0,001
	12,589 Hz		2062	0,449	4587	<0,001
	15,848 Hz		2521	0,536	4702	<0,001
	19,952 Hz		3336	0,621	5368	<0,001
	25,118 Hz		0,880	0,258	3409	<0,001
	31,622 Hz		1333	0,289	4607	<0,001
Short burst pulses						
Click duration	50 Hz	Behaviour	0,001	0,001	4734	<0,001
	63,095 Hz		0,001	0,001	5155	<0,001
Barks						
Peak 1 amplitude (dB)	25,118 Hz	Behaviour	2429	0,707	3434	0,001
Peak 2 amplitude (dB)	25,118 Hz	Behaviour	6412	2156	2975	0,005

investigate the environment, probably to avoid masking at the same frequencies. This compensatory mechanism has been noted in other species such as killer whale in San Juan Islands (Washington, USA) (Holt et al., 2009, 2011) and common bottlenose dolphin in Sarasota Bay (Florida, USA) (Kragh et al., 2019).

For the short burst pulses, the click duration is both affected by low frequency noise from vessels and by high frequency noise attributable to sonars. These types of signals have been demonstrated to elicit an acoustic behavioral response in different cetacean species such as the long-finned pilot whales (Rendell and Gordon, 1999; ICES, 2005), the humpback whales (Miller et al., 2000; Fristrup et al., 2003) and the blue whales (Melcón et al., 2012).

Finally, barks show an increase in the intensity of both the first and the second peak of frequency. These signals are prevalently used during social context, and the changes in their acoustic structures suggest a possible interference of noise with communication purpose.

In conclusion, the results of this study represent the baseline of information relating to the acoustic characterization of the vocalizations emitted by the Risso's dolphin in the Mediterranean Sea, as well as the noise levels they experienced in an area particularly impacted by several anthropic activities (Carlucci et al., 2021). The variation in the acoustic structure of vocalizations in response to high levels of noise raises concerns about the potential effects of noise on behavioral budget of the species, highlighting the need to carefully monitor continuously the species, covering nocturnal hours as well, and the study area. Indeed, future studies should be aimed at deeply investigate how characteristics of the vocalizations change during behavioral activities engaged by the species.

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CRediT authorship contribution statement

R. Carlucci: Writing – review & editing, Writing – original draft, Conceptualization. **G. Cipriano:** Writing – review & editing, Writing – original draft. **M. Bonato:** Writing – review & editing, Methodology, Data curation. **G. Buscaino:** Writing – review & editing, Writing – original draft, Methodology, Formal analysis, Data curation. **R. Crugliano:** Writing – review & editing, Methodology, Investigation, Data curation. **C. Fanizza:** Writing – review & editing, Methodology, Data curation. **S. Gatto:** Writing – review & editing, Methodology, Formal analysis, Data curation. **R. Maglietta:** Writing – review & editing, Methodology, Data curation. **C. Papetti:** Writing – review & editing, Methodology, Data curation. **M. Pelagatti:** Writing – review & editing, Methodology, Investigation, Formal analysis, Data curation. **P. Ricci:** Writing – review & editing, Writing – original draft, Methodology, Data curation. **F.C. Santacesaria:** Writing – review & editing, Methodology, Investigation, Data curation. **E. Papale:** Writing – review & editing, Writing – original draft, Methodology, Formal analysis, Data curation, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

No data was used for the research described in the article.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ocecoaman.2024.107177.

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