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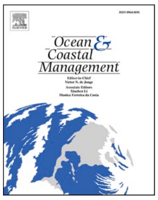

The impact of touristic whale-watching on *Delphinus Delphis* and *Tursiops truncatus* in the Algarve Coast: Combining acoustic analysis and land observations

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A R T I C L E I N F O

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A B S T R A C T

Touristic whale watching (WW) is an important socioeconomic activity worldwide. Recently, short and long-term impacts caused by WW have been reported for several cetacean species, including *Delphinus delphis* and *Tursiops truncatus*, the two most observed species in Portugal. Most of the operations in mainland Portugal are concentrated on the South Coast (Algarve). However, despite their importance for the region, studies focused on the impact of this activity on the animals are still scarce. We used acoustic behaviour analysis and land-based observations to determine the alterations in the vocalization patterns of these animals caused by WW vessels and the length of exposure to this stressor. We found WW presence significantly altered five out of six acoustic parameters of whistles, whistle rate, and whistle type distribution for *D. delphis*, whereas *T. truncatus* exhibited significant changes in three acoustic parameters. Conversely, *T. truncatus* significantly reduced echolocation click rates, while *D. delphis* did not show significant changes. We also found that the Central region of this coast is the most affected, with animals exposed to WW vessels for up to 38.9% of daylight hours. Furthermore, 66.7% of the observation time in this area had several vessels that exceeded the limit established by law. These results suggest that our study species are impacted by WW, while *D. delphis* is more affected during social behaviours, and *T. truncatus* is more affected during foraging activities. Both behaviours are biologically significant, and their disturbance might, in the long term, lead to adverse effects at the population level by decreasing reproductive success and fitness. A gap in knowledge, inadequate legislation and compliance issues threaten the development of a sustainable WW industry in the Algarve and might endanger local populations, therefore immediate attention is needed.

1. Introduction

Whale Watching (WW) refers to observing cetacean species (whales, dolphins and porpoises) in their natural environment (Hoyt, 2021). In contrast with whaling, WW is often promoted as a solution and sustainable alternative to the exploitation of cetaceans; it can provide socioeconomic advantages while also serving as a tool for conservation efforts and fostering a perception of cetaceans as a more valuable resource, alive rather than dead (Mustika et al., 2012; Parsons, 2012). Several studies have indicated short-term responses to WW disturbance, such as changes in behaviour (e.g. Arcangeli and Crosti, 2009; Cecchetti et al., 2018), group structure (e.g. Toro et al., 2021), vocalisations (e.g. Fouda et al., 2018; Van Ginkel et al., 2018), as well as habitat displacements (e.g. Bejder et al., 2006), and boat avoidance (e.g. Bejder et al., 2006; Constantine, 2001) which can negatively impact the target species. Short-term behaviour changes might lead to long-term impacts by detracting from biologically significant behaviour such as foraging, resting and reproduction (Lusseau and Bejder, 2007; Sitar and Parsons, 2015). Nonetheless, it is hard to ascertain how each short-term impact affects long-term population outcomes; contextual information is essential when evaluating the biological relevance of observed short-term changes (Lusseau and Bejder, 2007). Population ecology

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highly influences the disturbance level that can be tolerated in any given area; small and closed populations, unable to avoid the disturbance, are the most sensitive, while open populations can withstand a higher probability of interacting with WW vessels (New et al., 2020). In mainland Portugal, WW primarily focuses on offshore populations, except for the Sado Estuary (e.g., Luís et al., 2014). Despite the operation of many vessels targeting these diverse cetacean populations, there remains a significant gap in our understanding of the impacts of WW activities on them.

Between 1998 and 2008, WW started showing substantial growth, claiming Portugal approximately 23% of total WW revenues in Europe – the most significant portion of the continent (O'Connor et al., 2009). There are 90 tourism companies licensed for WW in mainland Portuguese waters, 52 of which operate off the south coast, known as the Algarve (ICNF, 2024). WW activities in Portugal are regulated by the Decreto Lei n. º 9/2006 (Decreto, 2006) which stipulates conduct rules such as the prohibition of more than three vessels to remain within a 100-m radius of the animals and observation limits of 30 min. Currently, no studies have focused on evaluating regulation compliance in the Algarve. However, observations made during behavioural research show that over a ten-year period, 36.5% of observations on the Algarve coast were made in the presence of three or more vessels and that the highest number of boats and recorded infractions are concentrated between Portimão and Albufeira (Grave, 2022). The lack of effective oversight and data scarcity contribute to many unlicensed companies operating, a problem further exacerbated by insufficiently trained staff unable to provide accurate information to the public (Castro, 2010). To further complicate management, a long-term monitoring program has never been established, and most of the existing knowledge for the region is published as grey literature, with peer-reviewed publications being scarce (Morais et al., 2021). The first broadscale and long-term assessment of cetacean diversity off the Algarve was done using records from WW companies' social media accounts and identified 15 species, of which *Delphinus delphis* and *Tursiops truncatus* were the most observed (Morais et al., 2021).

These two dolphin species are global and abundant and have a wide distribution in temperate, subtropical and tropical waters of the Atlantic, Pacific and Indian Oceans (Jefferson and Waerebeek, 2002). In *The IUCN Red List of Threatened Species,* they have been classified as "least concern" (Braulik et al., 2021; Wells et al., 2019), although both have at least one subpopulation that is locally vulnerable, endangered or critically endangered (Bearzi, 2003; Bearzi et al., 2012; Birkun, 2012; Currey et al., 2013). WW has been shown to cause a series of short-term impacts on *D. delphis* and *T. truncatus*; vessel collisions (e.g. Dwyer et al., 2014; Martinez and Stockin, 2013), behavioural changes such as a decrease in socializing and resting bouts (e.g. Sitar and Parsons, 2015), reduction of foraging time coupled with increased travelling time (e.g. Cecchetti et al., 2018), changes in group cohesion and dynamics (e.g. Nowacek et al., 2001) and changes in acoustic behaviour (e.g. Rako Gospić and Picciulin, 2016; Van Ginkel et al., 2018). The Algarve coast is an essential area for both species as it functions as a nursery and breeding ground (Castro, 2010; Castro et al., 2020; Grave, 2022; Vieira, 2017). Changes in acoustic parameters might be particularly significant in more sensitive groups such as those comprising mother-calf pairs; thus, further understanding of the changes in the overall acoustic repertoire of dolphins, the relationship between these changes, the behavioural budget and group composition in the presence of disturbance factors to assess potential implications at the population level is essential (Rako Gospić and Picciulin, 2016).

Studying cetaceans presents many challenges. During vessel-based observations, the effects of the research vessel on the animals cannot be avoided entirely and must be considered when establishing the "control" group (Guerra et al., 2014). Land-based observations provide an expanded coverage area (Zahn et al., 2022) without directly impacting the animals (Hoyt and Parsons, 2014). On the other hand, acoustic behaviour studies can provide insights into impacts that are not as visible at the surface. One approach to understanding acoustic impacts is to assess parameters of vocalisations such as frequency (kHz), range (kHz), duration (s), whistle rate and types, inflection points, steps and click rates in the presence and the absence of vessels (Alves da Silva, 2022; Rako Gospić and Picciulin, 2016; Van Ginkel et al., 2018). In this study, we used land-based observations as a non-invasive method to assess the environmental pressure of WW vessels in the Algarve, and acoustic behaviour analysis to determine the impact of this activity on *D. delphis* and *T. truncatus*.

The impact of WW activities in the Algarve is still poorly studied, and this knowledge gap impedes the development of adequate mitigation measures and conservation programs. Tourism continues to be a vital part of the Algarve's economy, and WW activities are not likely to slow down as thousands of tourists visit every year. The availability of WW operators to contribute to studies in the region (e.g. Castro et al., 2020; Moura et al., 2012), the present one included, shows a willingness to collaborate for a common goal of sustainability. WW vessels spend a potentially large amount of targeted time near cetaceans; therefore, if adverse impacts are to be reduced and the industry is to be sustainable, regulators, stakeholders and operators must understand the levels of vessel noise and their effects (Arranz et al., 2021). Furthermore, tourists express concerns about the proximity to the whales, the high number of boats surrounding mother and calf groups, the speed of the boat when approaching the whales, and the fact that engine noise might disturb the animals (Finkler and Higham, 2004; García-Cegarra and Pacheco, 2017), which goes to show that improving WW guidelines and implementing proper management and mitigation measures benefits not only the species involved but also the industry itself (Bentz et al., 2016). In the Algarve coast, there is currently no estimate of how long the animals are exposed to WW and the extent of the impact this activity has on the animals in this region is not known.

The present work aims to provide a quantitative analysis of the impact of WW activities in the Algarve by combining acoustic analysis and land-based observations to determine short-term changes in acoustic behaviour and how long the animals are exposed to this stressor. Based on previous studies, we hypothesise that whistle parameters (lower frequency (kHz), higher frequency (kHz), range (kHz), duration (s), whistle rate and types, inflections, and steps) are different between recordings in the presence and absence of WW boats. We also hypothesise that clicks per minute are lowered in the presence of boats as the dolphins detract from foraging activity. Furthermore, we hypothesise that pressure by boats is higher around the Central region than the Eastern and Western regions and that boat number limits established by law are frequently exceeded. The results of this study might give some more background not only in the issues revolving around WW on the south coast of mainland Portugal but also on this activity worldwide, helping to identify specific management priorities and mitigation strategies that are appropriate for this region and elsewhere, thus aiding in creating a more sustainable industry.

2. Materials and methods

2.1. Land-based observation

Five viewpoints were chosen across the Algarve Coast: one in the Western side of the coast, Cabo de São Vicente Lighthouse, two in the Central region, Alfanzina Lighthouse and Albufeira, and two in the Eastern region, Vilamoura and Santa Maria Lighthouse (Fig. 1). In three cases the observations were made from a lighthouse, Santa Maria Lighthouse, Cabo de São Vicente Lighthouse and Alfanzina Lighthouse. For the viewpoints in Albufeira and Vilamoura observation was done from the cliffs (see Fig. 1).

With the exception of Cabo de São Vicente Lighthouse, which had the least observations due to logistics, the viewpoints were visited 2 to 5 times a week when weather conditions were favourable. Using Bresser 20x80 binoculars fixed to a tripod, up to three 90-min observations, each

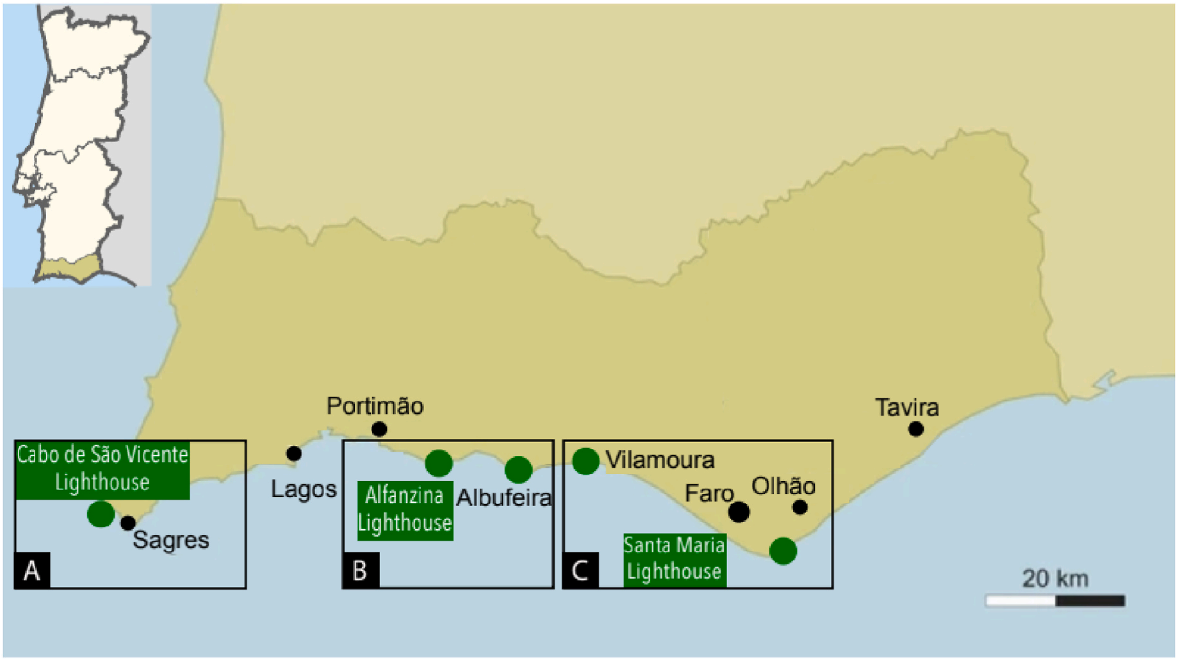

Fig. 1. Map of the Algarve coast showing the location of the five viewpoints. The boxes indicate the areas; A - Western Coast, B - Central region and C - Eastern region.

composed of three 180-degree scans of approximately 30 min, were carried out on the same day between 7:30 and 20:00, from September 2021 until November 2023.

Each time a group of cetaceans was located a new sighting was registered, if no cetaceans were present during the whole 90 min, the observation was marked as “no sightings”. For each sighting, weather conditions (sea state, cloud cover and visibility), species, behaviour, group size and number of boats per type (maritime touristic (MT) boats, fishing vessels and other vessels) were collected. From land-based observations it was almost always possible to identify the cetacean species with 100% certainty. The only situation where species may be confused is between *D. delphis* and *Stenella coeruleoalba*, which are very similar when spotted several miles away and therefore individuals were assigned to the family Delphinidae.

2.2. Acoustic behaviour analysis

WW trips were used as a platform of opportunity for data collection for this study. Trips were two and a half hours long, and the biologist on board was responsible for acoustic sampling collected from random transects under the permit AOC/08/2022. Data was collected between April 2022 and October 2023. The audio files were recorded by deploying an Aquarian AS-1 Hydrophone; Linear range: 1Hz to 100 kHz ±2 dB; Receiving Sensitivity: −208dBV re 1 μPa (40 μV/Pascal), off the side of the boat at 5 m depth. All recordings were made with animals within approximately 100 m range from the boat to minimize the attenuation effect of distance. The control group “no boats” refers to recordings when the vessel making the recordings was the only one present and had the engine off. The species present, date and notable observations were registered during the recording. Any recordings with other species, more than one species, less than a minute or no vocalisations were discarded. The files were divided into 1-min samples, each assigned a unique number. The boat-based observations were conducted on 100% certainty of species identification.

Samples were analysed using the advanced audio spectrum editor SpectraLayers Pro 10 by Steinberg Media Technologies. Spectral modelling synthesis (Fierro and Välimäki, 2022; Verma and Meng, 2000) (“unmix” function set to “components”) was used to separate transient sounds (targeting the pulsed sounds, i.e. echolocation clicks), tonal sounds (targeting the narrow-band tonal sounds, i.e. whistles) and noise. Since this analysis did not intend to look at volume, the three components were individually edited to enhance the clarity of the spectrogram by increasing the intensity (i.e. volume) and resolution of transient and tonal components and decreasing the noise intensity. The enhanced spectrograms were visually analysed; clicks were marked using time markers, and whistles were marked using spectral markers. Additionally, whistle type, inflections (i.e. changes in slope from negative to positive and vice versa) and steps (i.e. unmodulated or “flat” patches within a modulated whistle) were recorded in the note section of each marker. Time markers provide timestamps corresponding to each click. Spectral markers provide starting time, duration (sec), lower frequency (kHz), range (kHz) and notes (which were used for whistle types, inflections, and steps). All data was summarised in two Excel files (one for clicks and one for whistles), which also contained sample numbers, audio file references and the presence/absence of boats.

Whistle types were classified into A (unmodulated/constant), B (upsweep), C (downsweep), D (convex), E (concave), and F (sine) (Ansmann, 2005; Bazúa-Durán and Au, 2002; Taubitz, 2007). Small modulations at the start or the end of a whistle were considered “further modulation” if they had less than half the central part’s frequency span and were not considered for the “type” classification. However, they affected the number of inflections and steps. For example, a B whistle with one inflection would have a further modulation at the start or end but not long enough to classify it as a D or E.

2.3. Data analysis

Data analysis was performed in R using RStudio 2023.12.1 (Posit, 2024), packages dplyr, tidyr, readxl, tidyverse, stats and nortest were employed, ggplot2 and patchwork were used for data visualization. Statistical analysis of acoustic parameters, whistle and click rates was done through a non-parametric Wilcoxon test, as the data was not normally distributed. Whistles were individually used to analyse lower frequency (kHz), higher frequency (kHz), range (kHz), duration (sec), inflections, and steps. Higher frequency was obtained for each whistle by summing lower frequency and range. The data was summarised by sample number and boat presence to analyse click and whistle rates. For the whistle "types" distribution, a weighted chi-squared test was used as our sample sizes were significantly different for the presence and absence of boats. The three boat-type data were combined into a total boat column used to create a violin plot for land observations. To analyse the hours of impact, the total number of observations (with or without sightings) was multiplied by 90 min, and the number of observations with MT boats was multiplied by 30 min, assuming the maximum legal time of observation was respected. Observations with only non-MT boats were not considered as no duration estimate was available.

3. Results

3.1. Changes in acoustic behaviour

We analysed a total of 267 samples, corresponding to 80 min for *D. delphis* and 187 min for *T. truncatus*. There were 2442 and 1418 whistles for *D. delphis* and *T. truncatus*, respectively. There were recordings from each month with the exception of January, February, and August, with April and May being represented the most. Both species present statistically significant differences in range (W = 724169, p-value $<2.2e^{-16}$ and W = 269160, p-value = $4.7e^{-07}$), which resulted from a downshift in the higher frequencies (14.6 kHz–12.8 kHz for *D. delphis* and 14.2 kHz–12.8 kHz for *T. truncatus*) which was also statistically significant (W = 708318, p-value $<2.2e^{-16}$ and W = 311316, p-value = $1.5e^{-10}$). Both species also showed statistically significant differences in the number of inflections (W = 629050, p-value = $1.3e^{-12}$ and W = 250363, p-value = 0.007) (see Fig. 2).

In both cases, the number of inflections decreased with the presence of boats from 0.8100 to 0.4930 for *D. delphis* and 1.043 to 0.8638 for *T. truncatus*. Regarding duration and number of steps, only *D. delphis* presented statistically significant differences (W = 645554, p-value = $1.3e^{-13}$ and W = 494126, p-value = 0.001 respectively). Whistles in the presence of boats were shorter, 0.6053 s compared to 0.7395 s, and the increased number of steps was 0.5749 compared to 0.4756. *T. truncatus* did not show statistically significant differences for these parameters (W = 238612, p-value = 0.3966 and W = 234149, p-value = 0.7232) (see Fig. 2).

The whistle "types" distribution only showed statistically significant differences for *D. delphis*, with simpler whistle types (A - unmodulated, B - upsweep, and C - downsweep) being much more prevalent in the presence of boats than in their absence (Fig. 3).

The whistle and click rates presented opposite results for the two species (Fig. 4). *D. delphis* presented statistically significant differences in whistle rates (W = 119.5, p-value = 0.048) with an increase from 37.46 to 63.78 whistles per minute. No statistically significant differences were shown for click rate (W = 435, p-value = 0.219). *T. truncatus*, on the other hand, did not show statistically significant differences in whistle rate (W = 1267, p-value = 0.600) but did show statistically

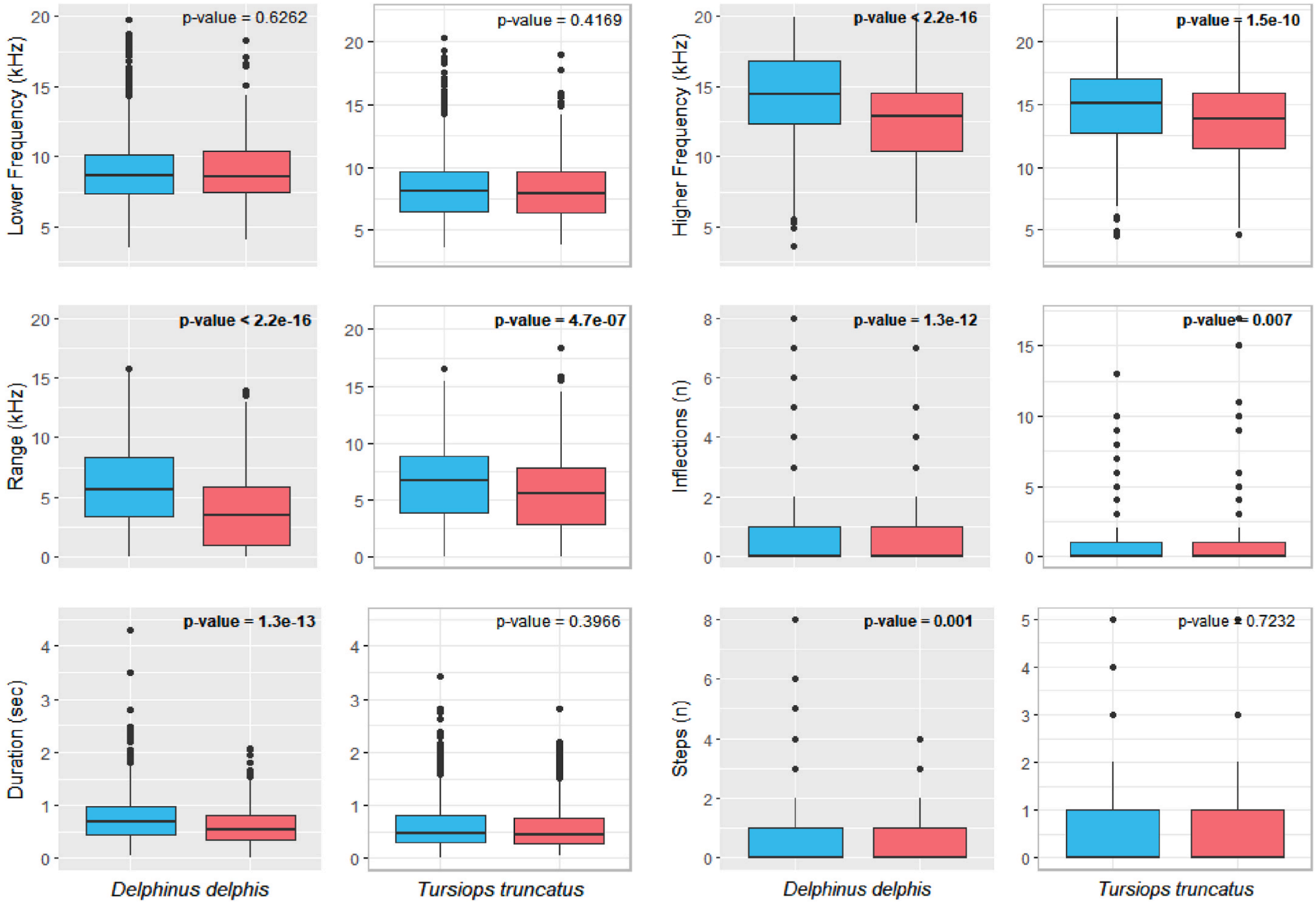

Fig. 2. Within each box, horizontal black lines denote median values; boxes extend from the 25th to the 75th percentile of each group's distribution of values; vertical extending lines denote adjacent values (i.e., the most extreme values within 1.5 interquartile range of the 25th and 75th percentile of each group); dots denote observations outside the range of adjacent values. Red boxes represent the presence of boats, and blue boxes represent the absence of vessels. The background colour indicates the species: grey for *D. delphis* and white for *T. truncatus*. P-values for the non-parametric Wilcoxon test are at the top right corner; statistically significant results are bolded.

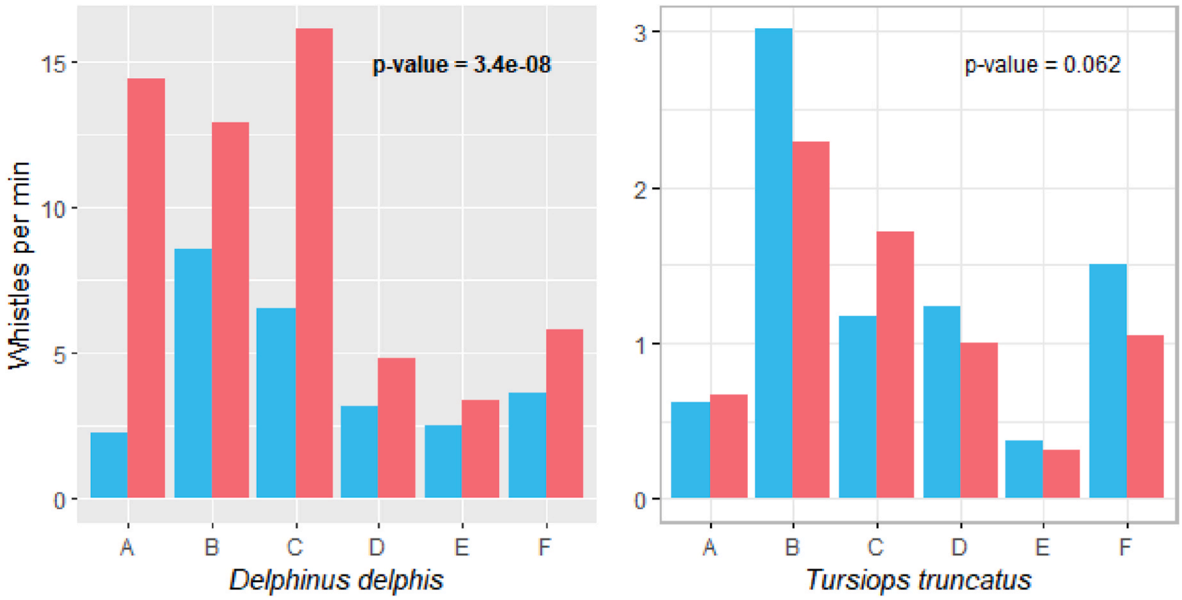

Fig. 3. Relative frequency of whistle types. Red bars represent the presence of boats, and blue bars represent the absence of boats. Background colour indicates species; grey for *D. delphis* and white for *T. truncatus*. P-values for non-parametric Wilcoxon test at the top right-corner, statistically significant results are bolded.

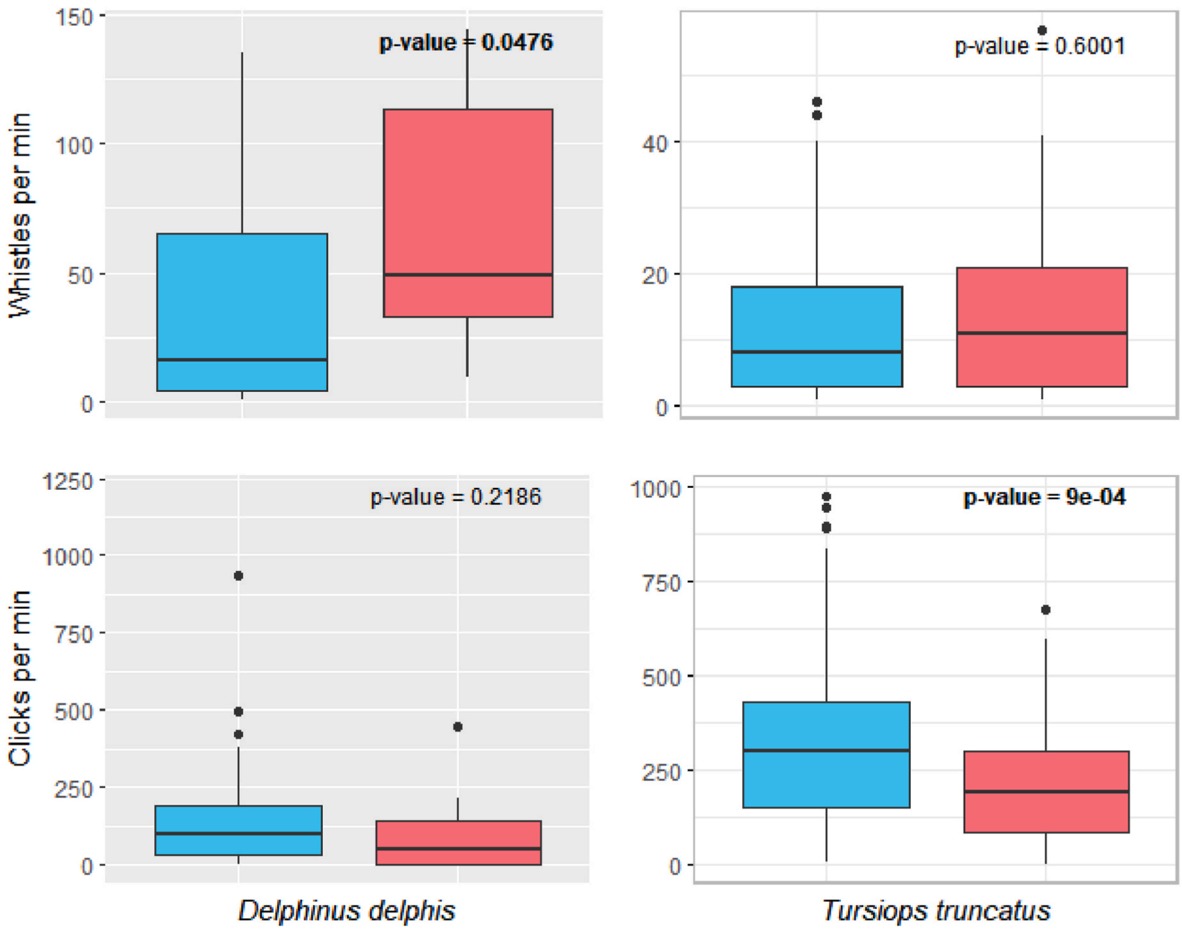

Fig. 4. Within each box, horizontal black lines denote median values; boxes extend from the 25th to the 75th percentile of each group's distribution of values; vertical extending lines denote adjacent values (i.e., the most extreme values within 1.5 interquartile range of the 25th and 75th percentile of each group); dots denote observations outside the range of adjacent values. Red boxes represent the presence of boats, and blue boxes represent the absence of boats. Background colour indicates species; grey for *D. delphis* and white for *T. truncatus*. P-values for non-parametric Wilcoxon test at the top right-corner, statistically significant results are bolded.

significant differences in click rate (W = 5361, p-value = 0.001) with a decrease from 327.81 to 218.63 clicks per minute.

Neither species had statistically significant differences concerning lower frequency (W = 528919, p = 0.626 and W = 238346, p-value = 0.417).

3.2. Land-based observation

We conducted a total of 177 observations, corresponding to 265.5 h of effort, among the five viewpoints; 4.5 h from Cabo de São Vicente Lighthouse, 42 h from Alfanzina Lighthouse, 9 h from Albufeira, 69 h from Vilamoura and 141 h from Santa Maria Lighthouse. Cabo de São Vicente Lighthouse had no observations with more than one boat. The two viewpoints on the Central region (Albufeira and Alfanzina Lighthouse) had a more homogeneous distribution, from 0 to 15 boats and Alfanzina Lighthouse had the most significant number of boats recorded by far, reaching a total of 15 vessels observed around the animals at one time (Fig. 5). The two viewpoints in the Eastern side of the coast (Vilamoura and Santa Maria Lighthouse) had far more observations with no boats and under two vessels.

From the observations, we estimated the percentage of daylight time that the animals are exposed to WW and the percentage of time when current regulations regarding the number of vessels are not followed (Table 1). Albufeira, Alfanzina Lighthouse, and Santa Maria Lighthouse had, respectively, the highest percentages regarding time spent in the presence of boats (38.89%, 32.14% and 30.14%). However, there is a big contrast between Santa Maria Lighthouse and the two Central region viewpoints in the percentage of time with more than three boats, which for Santa Maria was only 2.35% of the time boats were present, corresponding to 0.71% of the total time the animals were exposed to this stressor. More than three vessels were present in the Central region viewpoints 42.86% and 66.67% of the time during which boats were present. These results mean that cetaceans in this area could spend 16.67% and 21.43% of their daylight time in the presence of over three vessels.

It is also worth pointing out that, although we did not record specific data for legislation breaches other than several vessels, during our observations, we often saw poorly performed approaches and vessels positioned in a circular form around the animals instead of parallel to each other, even more so when there were many boats.

4. Discussion

The present study demonstrates that whale-watching (WW) activities influence biologically significant behaviours in two species along the Algarve coast, especially in the Central region. Notably, there is an uneven distribution of WW activities across the Algarve coast, with a predominant concentration of vessels in one region. Consequently, cetaceans in this area are exposed to intensive WW activities during many daylight hours.

As the data collection for this study was done using WW operators as a platform of opportunity, there are some limitations. We could not measure the noise levels and acoustic parameters of the boat engines, or the noise level received by the animals. This data would have been important for a more robust acoustic analysis and recording comparison. We also did not have access to the number of boats present during the recordings and therefore could only analyse differences between “presence” and “absence”, but it is known that with an increasing number of boats, effects also increase (Constantine et al., 2004; Marley et al., 2017). Furthermore, we did not have access to data on group composition and behaviour, which could have been further correlated with changes in vocalizations. Nonetheless, as this is an initial analysis in an area that lacks previous research on the subject, the information acquired is relevant to highlight a serious conservation concern that urgently needs further, more detailed studies.

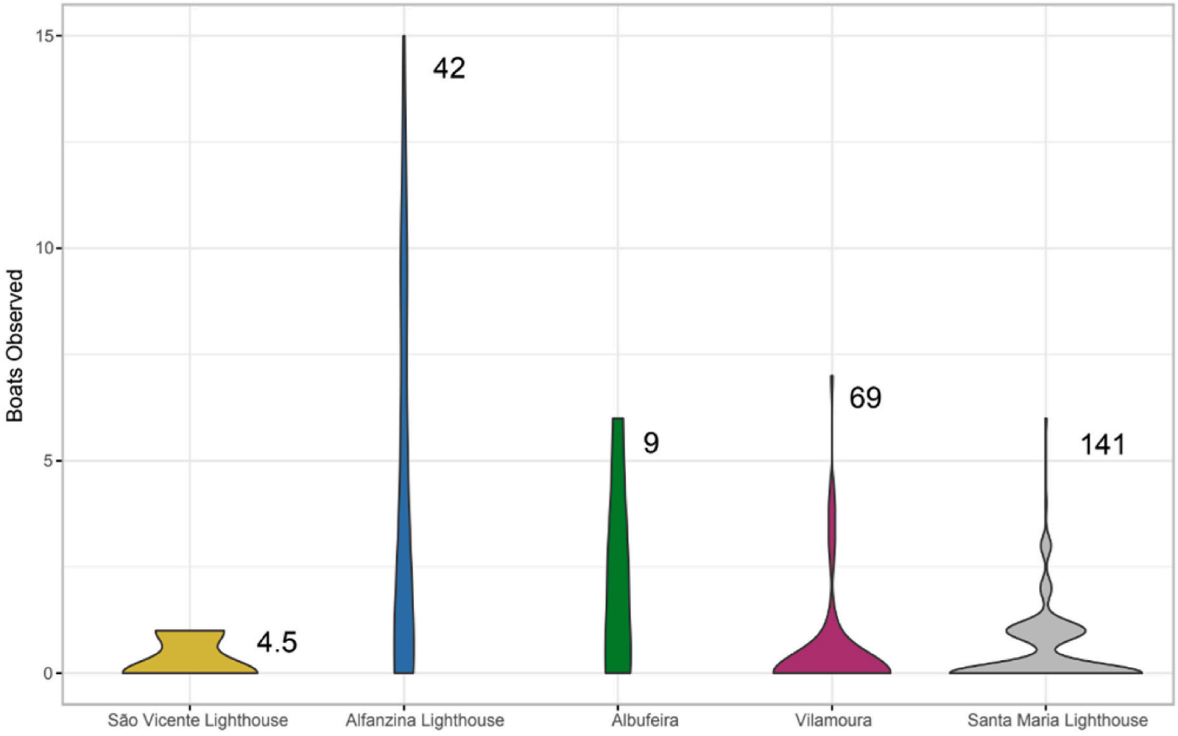

Fig. 5. Relative frequency of total number of boats observed for each viewpoint. The width of the shaded areas represents the proportion of observations in which that number of boats was present. The numbers in the figure represent total observation time, in hours, for each viewpoint. Viewpoints are ordered geographically from West (left) to East (right).

Table 1
Estimated time that the animals were in the presence of MT boats and that the number of MT boats exceeded the legal limit (three boats) for each viewpoint. Viewpoints are ordered geographically from West (left) to East (right).

	Western coast	Central region		Eastern region	
	Cabo de São Vicente Lighthouse	Alfanzina Lighthouse	Albufeira	Vilamoura	Santa Maria Lighthouse
Daylight time in the presence of boats (%)	22.22	32.14	38.89	8.69	30.14
Observation time with more than three boats (%)	0.00	66.67	42.86	33.33	2.35
Daylight time with more than three boats (%)	0.00	21.43	16.67	2.90	0.71

4.1. Short-term changes in acoustic behaviour

The acoustic data reveals distinct impacts of WW boats on the two dolphin species studied, with *D. delphis* exhibiting more pronounced changes in vocalization patterns compared to *T. truncatus*. *D. delphis* showed alterations in five of the six whistles' acoustic parameters tested. Overall, *D. delphis* whistled more frequently in the presence of boats, and their whistles were shorter, simpler, and less modulated (increased number of A type, less inflections, and increased steps). Additionally, they reduced frequency range by downshifting the higher frequencies while the lower frequencies remained stable. These results are in agreement with prior observations of decreased frequency range and whistle simplification (Fouda et al., 2018). *T. truncatus*, on the other hand, only showed modifications in three parameters, with the same trend of decreasing frequency range by lowering higher frequencies and some simplification through decreased number of inflections. Most prior studies for these two species indicate that they tend to increase the frequency of their vocalizations in the presence of vessel noise, supposedly as a coping mechanism to counteract acoustic masking (Alves da Silva, 2022; Ansmann, 2005; Fouda et al., 2018; Heiler et al., 2016; May-Collado and Wartzok, 2008; Papale et al., 2015; Van Ginkel et al., 2018). Nonetheless, dolphins decreasing the frequency of their vocalizations in the presence of noise is not unheard of (e.g. Morisaka et al., 2005; Rako Gospić and Picciulin, 2016). Decreased frequency and modulation for *Tursiops aduncus* in the presence of increased ambient noise has been observed (Morisaka et al., 2005). Rako Gospić and Picciulin (2016) showed that while dolphins significantly increase frequency when background noises are between 63 Hz and 2 kHz, they significantly reduce their whistle maximum frequencies, range, and the number of inflections when background noises are in higher frequency ranges (2–20 kHz). To successfully compensate for acoustic masking, dolphins may choose frequency bands which minimize background noise (Papale et al., 2015), shifting their whistle frequencies to the range with lower noise interference to increase transmission efficiency and detectability of their signals (Rako Gospić and Picciulin, 2016).

Different types of vessels have different effects on dolphin vocalization parameters (Luís et al., 2014). WW and small research vessels with outboard engines have been found to produce noise received by the animals in the frequency band between 2 and 12.5 kHz and depend primarily on speed; at speeds lower than 2.5 knots, measured noise levels are comparable to background noise (Jensen et al., 2009). For the present study, we could not evaluate the noise produced by the WW boats. Assuming the WW vessels used in the Algarve produce noise in a similar frequency range, our results agree with Rako Gospić and Picciulin (2016), and the animals could be shifting their vocalizations down to compensate for increased mid-high frequency noise.

Another factor that might influence how dolphins cope with increased ambient noise is the group composition (Kragh et al., 2019). In the presence of tour and research vessels, *T. truncatus* groups without calves have been found to lower the frequency and duration of their whistles, while groups with calves would increase both frequency and duration when exposed to the same stressor (Guerra et al., 2014). The only previous study in the Algarve found that both species increased whistle frequencies in the presence of WW vessels (Alves da Silva, 2022). It is interesting to note that data collection for that study happened between June and August 2022 (Alves da Silva, 2022), which coincides with peak calving season for both species (Murphy et al., 2009; Wells and Scott, 2009). In the present study, we collected data over a period of 19 months, with most recordings coming from April and May, before calving season. That being said, we are more likely to have recordings of groups without calves than Alves da Silva (2022) which may explain the differences between the results.

When it comes to the whistle "types" distribution, only *D. delphis* had significant differences between presence and absence of boats. The distributions we obtained were very similar to that of previous studies with upsweeps and downsweeps being the most prevalent types (Ansmann, 2005; Griffiths, 2009; Pagliani et al., 2022; Petrella et al., 2012), which helps sustain the hypothesis that whistle repertoire is at least somewhat stable within species even across long geographical distances. We found an increase in the three less modulated whistle types in the presence of boats, particularly so on constant unmodulated whistles. Similarly, this type of whistle increased in areas with more significant vessel traffic and noise (Griffiths, 2009). These modifications may help reduce potential loss of information due to masking by simplifying the calls (Fouda et al., 2018) and were also reflected in reduced number of inflections.

D. delphis also whistled more frequently in the presence of boats. This has been observed before (Buckstaff, 2004; Heiler et al., 2016; Scarpaci et al., 2000) and could reflect an effort to keep communication despite increased noise. This change might also suggest that group cohesion is affected by the approach of WW vessels causing the animals to increase whistling to better ascertain the whereabouts of other group members (Hawkins and Gartside, 2009; Scarpaci et al., 2000). Behavioural studies have also pointed to changes related to maintaining group cohesion, such as decreasing interanimal distance and changing in heading altering course away from approaching boats (Nowacek et al., 2001). Alternatively, it may reflect the heightened levels of excitement experienced during interactive behaviours (Hawkins and Gartside, 2009). Dolphins are known to be interested in and interact with vessels (Samuels and Bejder, 2004) and increases in whistle rate have been related to interactive behaviours (Hawkins and Gartside, 2009).

T. truncatus did not show any significant differences in whistle types or whistle rates. *T. truncatus* in the Algarve coast are concentrated close to shore living near human activities (Vieira, 2017), for this reason they might show a greater level of habituation to anthropogenic impact (Bejder et al., 2009). Furthermore, *T. truncatus* groups are usually small and made up of closely associated individuals, while *D. delphis* groups tend to be larger (Jefferson et al., 2015). This might explain the *D. delphis* overall whistling rate being naturally higher, and the need to keep such a large group together could also account for the statistically significant increase in whistling rate in the presence of boats observed in the present study. In contrast, *T. truncatus* smaller groups might not need to increase the whistling rate as much to maintain group cohesion, hence why no statistically significant difference between whistle rates in the presence and absence of boats was observed. On the other hand, *T. truncatus* did show a decrease in click rate, which was not shown for *D. delphis*, indicating that the impact for this species might be more related to foraging rather than social behaviour. *T. truncatus* has been shown to decrease foraging activity by 49% in short-term while in the presence of boats (Pirotta et al., 2015). *D. delphis* feeds mostly on small pelagic schooling fish (Silva, 1999) while *T. truncatus* feeds primarily on demersal fish (Giménez et al., 2017). Given the ecological niche of the two species these results might indicate that *T. truncatus* is more impacted when it comes to foraging behaviour as they might be more dependent on echolocation for prey detection and acquisition, but less impacted in the communication aspect as they form smaller groups which are easier to coordinate.

When it comes to click and whistle rates, ideally, we would have divided the number of clicks and whistles in a sample by the number of animals present to eliminate group size effects; however, we did not have access to this data. Nonetheless, the fact that for both species, whistle rate increased (although for *T. truncatus* it was not statistically significant) and click rates decreased (although for *D. delphis* it was not statistically significant) shows that these trends cannot be attributed simply to changes in group size. Previous studies have also found that the whistle rate does not relate to the number of dolphins (Santos et al., 2005; Hawkins and Gartside, 2009); therefore, the changes observed seem to be related to the presence of boats.

4.2. Implications and further research

Although it is hard to ascertain the extent to which these changes are harmful, short-term changes in behaviour might lead to long-term impacts by detracting from biologically significant behaviour such as foraging (Cecchetti et al., 2018; Quintana Martín-Montalvo et al., 2021); for example, if reduced foraging results in reduced prey capture, it can lead to decreased energy acquisition (Lusseau et al., 2009). Long-term decline in abundance has been shown for the Indo-Pacific bottlenose dolphins of Shark Bay, Australia (Bejder et al., 2006). If the click rate decrease observed for *T. truncatus* in this study translates into a decrease in prey capture, it might lead to a decline in population. Low genetic diversity and connectivity in *T. truncatus* small coastal populations mean such perturbations could have drastic effects (Nykänen et al., 2019). Resting and social behaviour can also be biologically significant, affecting fitness and reproduction success (Fumagalli et al., 2019; Gerber et al., 2022; Holmes et al., 2024). Reduction in reproduction success and long-term area avoidance resulting in habitat displacement has been linked to unsustainable dolphin-watching tourism in Fiordland, New Zealand (Lusseau et al., 2006). As the function of the whistle is communication (Dudzinski et al., 2009), the impact observed here for *D. delphis* could impair their communication capability, affecting population dynamics by disrupting social behaviour. This becomes even more problematic when it comes to groups with infants and juveniles (Guerra et al., 2014) who are learning these communication patterns under stressful conditions. Therefore, future studies in this area should further investigate the tendencies observed here. If possible, recording vessel noise under controlled conditions and having a volume reference across recordings would allow for the evaluation of volume changes which might also be relevant. Adding further data to the acoustic parameters, such as group sizes, behaviour, number of boats and time of the day will also bring new insights onto how this activity is affecting the animals.

As several studies have shown changes in behaviour in the presence of WW boats (Arcangeli and Crosti, 2009; Parsons, 2012; Cecchetti et al., 2018) and whistle characteristics are significantly correlated to behaviour (Janik and Slater, 1998; Ansmann, 2005; Heiler et al., 2016; La Manna et al., 2019), it cannot be discarded that the changes observed might simply reflect the changes in behaviour. For example, decreased mean maximum frequency and range, coupled with increased steps have been correlated to travelling (Ansmann, 2005) and increasing in travelling has been correlated with WW vessel approach (e.g. Sitar and Parsons, 2015). However, the question of “do vocalizations change because behaviour changed, or do they change their behaviour because acoustic masking limits the behaviours they can still perform?” is not easy to answer. This is particularly relevant when discussing management approaches; if acoustic masking is the source of these changes, then minimizing noise might be a good enough solution, however if the simple presence of the boats is enough to cause changes, then different approaches such as “no go” zones might be necessary. It is likely that both factors interact with each other and that the answer to this question isn’t a clear-cut one but instead a complex dynamic. Pirotta et al. (2015) found that while noise level alone cannot explain changes in echolocation activity for *T. truncatus*, the mere presence of boats is also insufficient to elicit an activity change. Further studies focusing on behaviour as well as acoustic behaviour can help clarify some of these issues, however the big challenge of acquiring data for a true “control” in the absence of boats while also collecting behavioural data remains. Nonetheless, acoustic studies can provide a great insight into disturbances that are not so easily observed at the surface and, even if these changes are purely behavioural, can be used as a proxy which, with increasingly powerful software available, has the potential to be less subjective than behaviour observations.

4.3. Impact distribution in the Algarve coast and management recommendations

It is clear from this and from previous studies (e.g. Alves da Silva, 2022; Grave, 2022) that the Central region is the most affected area in the Algarve coast, not only by the largest number of boats but also by the highest number of law infringements. Our results indicate that *T. truncatus* and *D. delphis* have, respectively, their foraging and social behaviours potentially disturbed for up to 39% of daylight hours in the Central area. Although we have not examined the correlation of the observed changes with the number of boats, previous studies have shown that larger number of boats increases acoustic behaviour changes (e.g. Pirotta et al., 2015; Marley et al., 2017). Not only are dolphins exposed to WW boats for longer in the Central region but also, they are in the presence of over three boats for up to 66% of the time during which they experience this stress. In the area observed from Santa Maria Lighthouse the animals were exposed to WW vessels for 30% of daylight time, but only 2.35% of this time, the supposedly safe number of boats established by law was exceeded. Further studies are needed to better establish the correlation between the number of boats and the effects on acoustic behaviour. Furthermore, it is important to estimate the effect of this disturbance on behavioural budgets and infer the meaning of these changes for the animals. If they simply shift their activities to accommodate this 39% of time interacting with WW vessels and can compensate for this time when boats are not present, then the disturbance would not be as harmful as losing this foraging and socializing time completely.

While we can make management recommendations based on the different manners in which each species is affected, the compliance issue must be at the front of any conversation aiming to create a sustainable industry. Even when licenced WW operations present high levels of compliance, they do not consider recreational, opportunistic and unlicenced vessels which approach the animals unaware or simply choose to ignore legislation (Allen et al., 2023). Proper enforcement and monitoring of conduct, as well as public education, is of utmost importance, even before any new measures can be implemented. This is particularly true for high-demand areas such as the Central region of the Algarve coast.

Staggered departure times and continued interactions involving multiple boats mean dolphins are exposed for several hours even if all operators obey the 30-min rule (Allen et al., 2023). So aside from improvements in monitoring and enforcement, improved rules of conduct must also be developed. Our results illustrate how different species react differently to the same stressor; therefore, effective rules should consider biologically relevant information about each target species. Establishing “no go” zones and speed restriction zones can also help reduce impact by giving the animals a safe area where to retreat to avoid disturbance and noise. Although noise reduction equipment can be used on the boats, further research needs to be conducted on the effectiveness of this strategy as it has been pointed out that changes in acoustic behaviour are not due to boat noise alone (Pirotta et al., 2015).

In conclusion, both species are affected by WW activity on the Algarve coast, especially in the Central region, where the animals are frequently exposed to more vessels than the legal limit. While the correlation and causation between acoustic behaviour and behaviour changes are not fully understood, changes in vocalization patterns are an appropriate tool to assess disturbances that are not readily observable and give insight into what is happening underneath the surface when the animals are exposed to various stressors. Effective regulations should consider biologically relevant characteristics of each target species, as the results presented illustrate that the effects of WW are not the same across species and, therefore, neither can be the mitigation measures. This study provides one of the first assessments of WW impact on the Algarve coast, highlighting an issue that needs immediate attention if this industry is to be sustainable and successful.

CRediT authorship contribution statement

M.Júlia Forli: Writing – original draft, Software, Methodology, Investigation, Formal analysis, Conceptualization. **Rui Peres dos Santos:** Writing – review & editing, Writing – original draft, Software, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Alfredo Rodrigues:** Writing – review & editing, Methodology, Funding acquisition, Data curation. **Rita Castilho:** Writing – review & editing, Supervision, Resources, Project administration, Investigation.

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.

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Data availability

Data will be made available on request.

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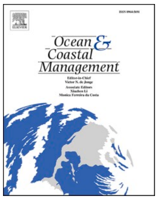

Corrigendum to “The impact of touristic whale-watching on Delphinus Delphis and Tursiops truncatus in the Algarve Coast: Combining acoustic analysis and land observations” [Ocean Coast Manag. 259 (2024) 107431]

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The authors regret a typographical error in the title of the article. The scientific name *Delphinus delphis* incorrectly had the specific epithet capitalized, which constitutes a violation of the rules of binomial nomenclature. We consider this typographical error to be significant as the correct use of species names is essential for maintaining consistency and accuracy in scientific communication.

The authors would like to apologise for any inconvenience caused.

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