Seismic survey risk assessment on common dolphins in the south-western coast of Portugal

Giulia Spadoni, Ricardo Duarte, Cristiano Soares, Marc Fernandez and Sérgio M. Jesus

Abstract While ship traffic is the primary source of anthropogenic underwater noise worldwide, locally, other sources may have a higher impact on marine life, such as seismic surveys. Although the impacts of this practice conducted in deep waters are widely investigated, less is known about the risk to biodiversity when such surveys are undertaken in shallow waters using light seismic techniques, such as for offshore wind development. The objective of this study is to assess at-risk areas by combining habitat suitability maps for the common dolphin (*Delphinus delphis*), selected as the target species, and noise maps from a light seismic survey simulation in the region of Setúbal (Portugal), an area of high marine biodiversity. Noise maps indicate that sound levels may reach up to 190 dB re 1μPa, impacting the species' hearing perception in a range of approximately 40 km around the surveying zone. Habitat suitability maps showed high values in low-depth areas of the above-mentioned region. Risk maps, obtained by overlapping seismic survey noise and habitat suitability maps, showed the particular sensitivity of coastal areas, especially until the bathymetric line of 250 m and higher levels of risk in a broader area in summer than in winter. The relevance of risk maps as a powerful tool for supporting environmental and marine life management policies is emphasized.

Key words: light seismic surveys; sound pressure level; risk maps; habitat suitability; common dolphin; Portugal.

Giulia Spadoni, Ricardo Duarte and Sérgio M. Jesus
LARSys, Universidade do Algarve, Faro, Portugal
e-mail: gspadoni,rjduarte,sjesus@ualg.pt

Cristiano Soares
Marsensing Lda., Campus de Gambelas, Faro, Portugal, e-mail: csoares@marsensing.com

Marc Fernandez
MARE-Madeira/ARDITI, Funchal, Portugal, e-mail: marc.fern@gmail.com

1 Introduction

The ruthless search for sustainable energy led us to explore the ocean and the wind as potential energy sources [1,2]. Compared to conventional oil and gas, wave and wind energy is cleaner and greener, but it also has significant disadvantages. These consist of the impact of the necessary infrastructures during their installation and operation. Prior to installing infrastructure at sea, the bottom structure must be assessed for platform fixing or anchoring and cable lay down. This is routinely carried out using light seismic surveying, a low power/high resolution version of traditional oil and gas seismic survey [3, 4]. Light seismic surveying relies on the emission of high or very high energy impulsive sound waves that reflect in the bottom and are received on towed streamers of hydrophones. Its effects on marine species, at short term and for those areas where these activities take place, have already been studied [5, 6].

Portugal, as well as other countries with an important seafront, has made plans for building several offshore wind farms along the Portuguese coastline, as referred in the Portugal's National Strategy for the Sea 2013–2020 [2, 7–9].

Besides that, the Portuguese coast is of great relevance in terms of marine biodiversity, partly due to the highly dynamic and complex topographic-oceanographic features of the coast and to the natural upwelling, which favours a great biodiversity richness and a countless number of cetacean occurrences every year [10]. In particular, the region between Sines and Setúbal, in the SW coast of Portugal, is known to host many different species of cetaceans [10, 11].

The lack of knowledge on light seismic survey noise emissions, and the potential threat it represents for cetaceans and biodiversity, led us to design a simulated typical test case scenario for a seismic survey event taking place in the SW coast of Portugal, near the region of Setúbal. The common dolphin (*Delphinus delphis*) was selected as representative species, commonly present in the test area.

A prediction tool was developed to estimate: a) the sound pressure level (SPL) field on the target area due to a typical light seismic survey, b) the common dolphin habitat suitability (HS) through Ecological Niche Modeling (ENM) and c) the potential at-risk areas for this particular species due to a seismic event in two periods of the year (January and June). Habitat can be defined as "an area with a combination of resources and environmental conditions that promotes occupancy by a given species (or population) and allows those individuals to survive and reproduce" [12]. Suitability indicates the quality of these conditions and resources.

Results on noise modeling showed the importance of bathymetry on the attenuation of the noise field along the continental shelf, while attaining significant sound pressure levels in large swaths of the study area, that also have a high HS for the common dolphin. The deduced potential risk is consistent, in space and time, with the HS distribution and the propagation of noise from the simulated seismic survey. These results give hints for producing indicators and to support management, conservation and biodiversity monitoring.

This chapter is structured as follows: section 2 gives a description of the physical and biological characteristics of the area, as well as the methodology used for seismic survey noise and habitat suitability modeling, and a description of the risk estimation technique. Section 3 shows and discusses the obtained results. Finally, section 4 points out some conclusions regarding the risk assessment for this study area.

2 Materials and Methods

This section describes the environmental and biological properties of the Setúbal test case area used as an hypothetical scenario to estimate risk resulting from seismic survey for the common dolphin population.

2.1 Definition of the target area

The study area was limited to -9.3° to -8.5° longitude west and 38.2° to 38.6° latitude north, as shown in Figure 1. The area reveals a relatively flat continental platform extending up to approximately 45 km from the coastline where the water depth reaches 250 m and then rapidly deepens to the west. In addition, the presence of an east-west oriented steep-sided valley (known as the Setúbal submarine canyon) at approximately 38.2° latitude north, which reaches approximately 1000 m depth, is considered an interesting feature of the area. The seismic surveying area, represented by the black rectangle in Figure 1, is characterized by a relatively small bathymetric slope and water depths varying between 30 and 100 m, which are suitable for the installation of offshore wind farm structures (pylons, anchors, cables, etc).

2.2 Definition of the target species

The entire coast of Portugal is known to be a rich ecosystem in terms of marine biodiversity, covering a variety of groups from fish to marine invertebrates and sea turtles [14]. The cetacean occurrence is one of the most studied aspect as well as one of the highlights of the coast [10, 11]. The common dolphin (*Delphinus delphis*) is one of the most abundant species of cetacean in the North-east (NE) Atlantic in general and in this region of the Portuguese coast in particular [15] . This species has, in fact, the highest number of records in dedicated databases [16]. Additionally, common dolphins belong to both the small cetacean group and to the mid-/high-frequency cetacean group [17, 18]. Therefore, due to their hearing sensitivity, they may be impacted by seismic surveying.

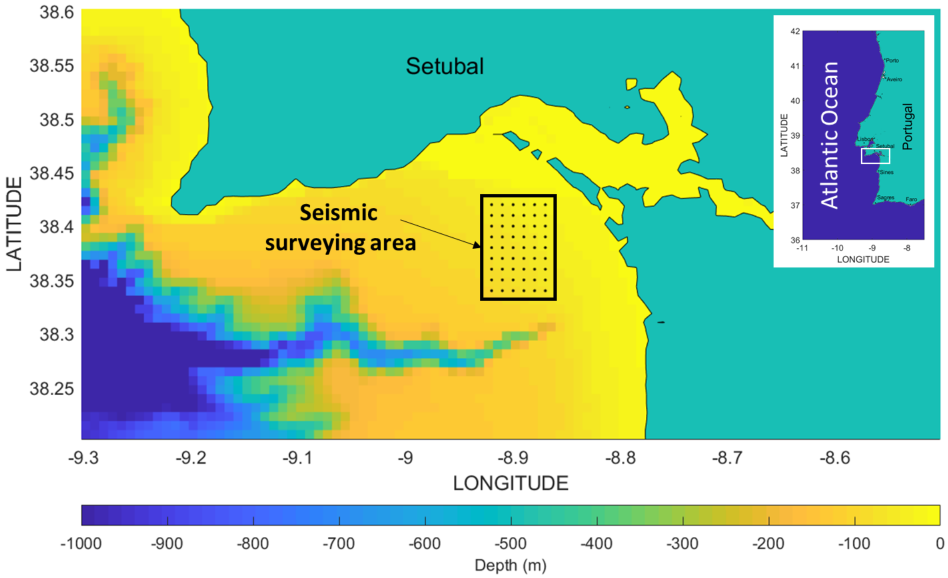

Fig. 1: Bathymetry of the Setúbal region obtained from GEBCO database [13]. The rectangular box of 50 km^2 was defined for seismic surveying simulation (longitude -8.92° and -8.87° and latitude 38.34° and 38.42°).

2.3 Noise source definition

For modeling purposes, a Geo-Source 200 sparker (developed and commercialized by GEO Marine Survey Systems, The Netherlands geomarinesurveysystems.com) with two arrays of 100 electrode tips each, was used as reference for seismic source. This type of seismic source is suitable for water depths from 2 to 500 m with a penetration in the order of dozens of meters below the seabed (depending on seabed type), which is commonly used in wind farms seabed prospecting and is characterized by a peak source level of 223 dB re 1μPa.

2.4 Seismic surveying modeling

The bathymetric data of the target area was obtained from the General Bathymetric Chart of Oceans (GEBCO, www.gebco.net) database [13], with a 1 km x 1 km spatial resolution (see Figure 1).

In accordance with the description given by [19, 20] and outlined in Table 1, the bottom and sub-bottom acoustic properties were configured as a two-layer bottom model made up of a fluid sandy sediment layer over a rocky semi-infinite sub-bottom.

Table 1: Assumed seabed parameters (adapted from [19, 20]).

Model Parameter (units)	**Value**
Sediment speed (m/s)	1650
Sediment density (g/cm^3)	1.9
Sediment attenuation (dB/λ)	0.8
Sediment thickness (m)	10
Sub-bottom speed (m/s)	1800
Sub-bottom density (g/cm^3)	2.8
Sub-bottom attenuation (dB/λ)	0.2

Water columns' physical properties (temperature and salinity) of the target area were obtained for the months of January and June 2019 from the Copernicus - CMEMS database (https://marine.copernicus.eu/). Fig. 2 shows the superposition of profiles for the total area and for the months of January (upper row) and June 2019 (lower row), for temperature ((a) and (d)), salinity ((b) and (e)) and estimated sound speed ((c) and (f)). For each dataset, the black line represents the mean profile. As expected, the temperatures in January are typically lower than in June. A 50 m thick mixed layer develops for the month of January, followed by a deep gradient until 500 m depth both in January and in June. Salinity shows a similar behavior between January and June (see plots (b) and (d)), with however higher variations in the mid water column in January than in June, with typical values between 35 and 37 parts per thousand (ppt). The sound speed profile was estimated using the nine-term Mackenzie approximate equation, resulting in plots (c) and (f) for January and June, respectively. As expected, the sound speed profiles of January and June follow, approximately, the same shape as the temperature plots of the respective months. It is also noted that the sound speed profiles in the deeper area have a double minima, which is a common feature in this region.

For simulation purpose, the seismic survey was centered on a relatively small rectangular area of 50 km^2 (see box in Figure 1) with a spatial resolution of 1 km x 1 km. The previously described sparker seismic source was set to a source level of 223 dB re 1μPa at 1 m, placed at 1 m depth with a 5 s firing interval considering a tow ship moving at 5 knot in a traditional lawn-mower pattern resulting in a regular set of emission positions along the area of Figure 1. A total duration of one month was considered with a time resolution of 10 min.

Although the range of audible frequencies of cetaceans may extend well beyond 1000 Hz, in this study, in order to maintain the noise calculation computationally manageable, only the frequency range 300-1000 Hz in 1/3-octave (10 base) bands was considered, which corresponds to the seismic source maximum level frequency band.

The acoustic receivers were placed at 5, 15, 30, 50, 75 and 100 m depth and the final noise map sound pressure level was evaluated as the mean field over depth. The statistical indicator percentile 50 (p50), which describes the percentage of time

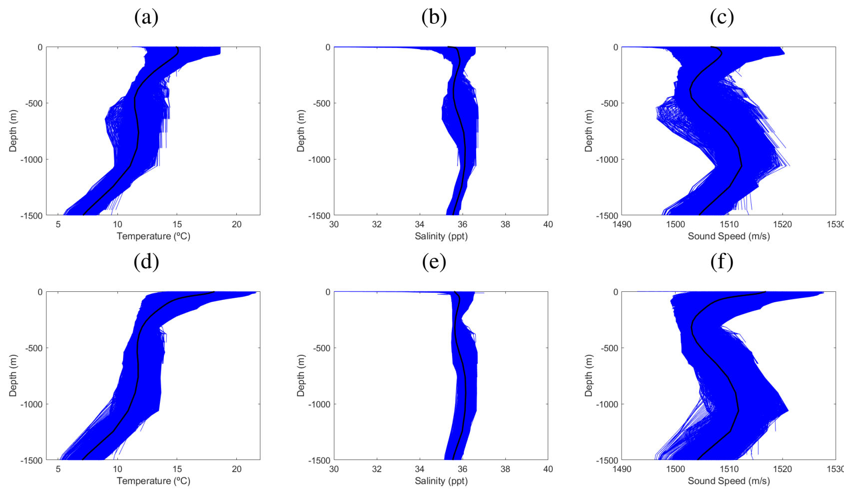

Fig. 2: Temperature ((a) and (d)), salinity ((b) and (e)) and sound speed profiles ((d) and (f)) variation for January (top row) and June 2019 (bottom row). Black lines represent the mean profile. (Source: CMEMS-Copernicus Marine Service).

that a specific value sound pressure level is exceeded, was adopted for sound map estimates and for the production of risk maps.

The normal mode propagation model Kraken [21] was used in combination with bathymetry, seafloor parameters and sound speed profile (SSP) to estimate the transmission loss (TL) and thus the sound pressure level (SPL) calculated according to Soares et.al. [19].

Since the assumptions for 1/3-octave bands may not be valid when dealing with impulsive noise that is emitted only at given time intervals, the estimation of a correction factor was deemed necessary. Considering that seismic exploration deals with a succession of periodic pulses at a given time rate, the concept of sound pressure level (SPL), that allows to include transmission time, was used. In a T_0=5 s cycle only $T = 1$ s is active, therefore using the usual definition of SPL as:

$$\mathrm{SPL}_{\mathrm{cycle}} = \mathrm{SPL}_{\mathrm{emitted}} - 10\log_{10}(T/T_0) \tag{1}$$

gives a correction factor of approximately -7 dB relative to $\mathrm{SPL}_{\mathrm{emitted}}$. $\mathrm{SPL}_{\mathrm{emitted}}$ corresponds to the SPL in 1 s of emission. However, this does not take into account the time spreading nature of the acoustic channel, which may make the short emitted pulse look much longer at the receiver. In fact, the quantity of interest will be the emitted and specially the received energy, rather than the frequency band power based on 1/3-octave bands only, as normally used for SPL definition. In order to better grasp the difference, a test was performed according to the following steps:

- two points A and B, representing source and receiver, spaced 2 km apart were selected in the study area. KRAKEN was used to calculate modes for all frequencies between 300 and 1000 Hz in order to estimate the channel impulse response (CIR);
- the input signal was convolved with the CIR to obtain the received signal;
- the SPL was calculated for a duration of 10 min with a duty cycle of one pulse every 5 s;
- the obtained SPL was then compared with the SPL obtained considering 1/3-octave band levels, and a 4 dB correction factor was determined, that was subsequently used in the simulations.

2.5 Habitat suitability modeling

The common dolphin's HS was modelled through an ENM taking into account observation records of the common dolphin and environmental characteristics of the study area using a maximum entropy algorithm. The output of this model are, on one side, habitat suitability maps of the species and on the other side, the percentage of contribution of each environmental predictor to the model (see Figure 3).

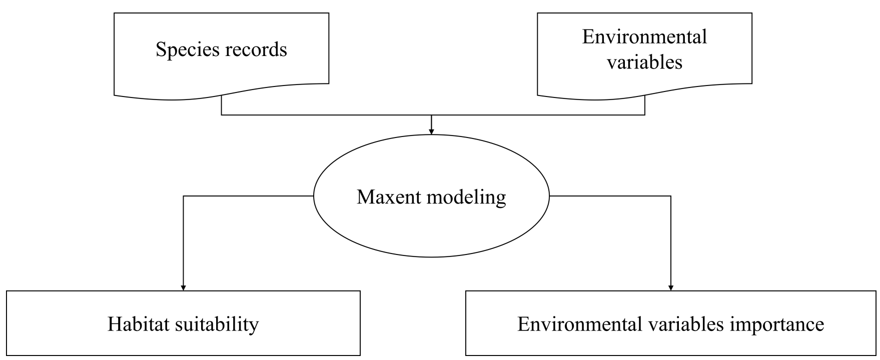

Fig. 3: Methodological framework of Maxent modeling (adapted from [22]).

Maxent modeling [23] was chosen among other methods essentially because of the few input data required, the availability of these data for the present case study and for being proven to give better predictions than other methods for small data amounts, such as those employed in this study [24]. Additionally, it was assumed that for one specific species, habitat suitability can be interpreted as an estimate of the probability of species presence, conditioned on environmental variables, indicating the habitat quality for that particular species [25].

Cetacean occurrences (top left box of Figure 3) were obtained from two different types of opportunity platforms over a period of fifteen years (from 2005 to 2020): a) through the Portuguese Society for the Study of Birds (SPEA) and b) through two whale-watching companies, SeaEO Tours and MarIlimitado as described in Table 2.

Table 2: Cetacean occurrences' datasets characteristics.

Observations' source	Code	Region	Coordinates Lon x Lat	Period of time	Background points creation method
SPEA	SPEA	Portuguese coast	[-10.5 -7.5]x[36 42.5]	2005-2020	Using the transects of boat trips for all the species
SeaEO tours	SeaEO	Setúbal	[-9.6 -8.7]x[38.3 38.8]	2019-2020	Minimum Sampled Area (MSA)
MarIlimitado	MI	Sagres	[-9.3 -8.5]x[36.7 37.2]	2005-2020	Minimum Sampled Area (MSA)

The SPEA dataset spans the period from 2005 to 2020, with records equally distributed along the year. SeaEO tours observations cover a two year period, 2019-2020, and were collected whole year round. Instead, Mar Ilimitado dataset covers a much wider period, from 2005 to 2020, but with records mostly concentrated between the months of April and October.

Five environmental variables (see Table 3), already proven to affect the habitat suitability of small cetaceans and already adopted for the same purpose and same species in the literature (see for example Moura et.al [26]), were selected as potential explanatory variables to calibrate HS models for the common dolphin (top right box of Figure 3). The collinearity among the environmental variables, a challenging issue in ENM [27], was evaluated taking into account the variance inflation factor (VIF) approach, revealing no dependency among them.

This data were then pulled together into a temporal resolution of 8 days, and 2x2 km spatial resolution in the World Geodetic System 1984 zone UTM 29N projection.

Table 3: Selected environmental variables.

Environmental Variable	ACR	UNIT	Source	Modifications
Depth	DEPTH	m	NOAA, ETOPO 1 Global Relief Model	Resampled to the selected resolution and extent
Slope	SLOPE	°	Calculated on QGIS3.18	Resampled to the selected resolution and extent
Sea Surface Temperature	SST	K	Copernicus Marine System	Scaled to the selected temporal and spatial resolution
Chlorophyll-a	CHL	mg.m-3	Copernicus Marine System	Scaled to the selected temporal and spatial resolution
Chlorophyll-a Standard Deviation	SD_CHL	mg.m-3	Calculated from the CHL layer	Scaled to the selected temporal and spatial resolution

The biggest issue facing presence-only and presence-background ENMs is accounting for sampling bias. The possibility of mapping sampling effort rather than the underlying HS exists when no sampling correction is implemented in the model [28].

Therefore, in order to avoid this issue, a filtering approach was applied to remove potentially related sightings [29–32]. Moreover, two different target-background methods were applied according to the different nature of the selected dataset:

- **SPEA dataset:** to generate the background data and to have a measure of the potential sampled area, transects between all the points with records for all species of cetaceans (not only the target one) over a period of 8 days were considered;
- **Whale Watching (WW) datasets:** because of the opportunistic character of the sampling effort, a Minimum Sampled Area (MSA) technique was adopted, as used in Fernandez et al. (2017) [33]. All the sightings for each distinct temporal scale and for all species (again including the non-target one) were pulled together using a Minimum Convex Polygon, adding a 1 km buffer. Grids crossing the polygon were considered as potentially sampled areas, therefore classified as background.

The total amount of effort per temporal unit (8-days) was considered using the number of sea trips performed during a specific period. Occurrences and the selected background grids from both datasets were put together to proceed with the MaxEnt analysis. For each analysis, random background datasets (n = 10,000) were generated.

The common dolphin's habitat suitability maps along the Portuguese coast were obtained using Maximum Entropy modeling, as described in [23]. The HS maps resulting from this modeling, for the selected months of January and June, were then cropped for the detailed study area of Setúbal.

2.6 Risk maps

The risk maps presented in this chapter were produced taking into account the overlapping between sound pressure level and the biological distribution. In this particular case, this overlapping was performed between the SPL 50-th percentile (or median) and the HS maps, for each point in space and time. According to the methodology proposed by Erbe et al. [34], noise maps and habitat maps were normalized between 0 and 1 and then point wise multiplied. The result of this multiplication was then normalized again. As a result of these successive normalization, the resulting risk maps cannot be used for comparison between species, but gives a relatively good assessment of areas at high noise risk for the considered species. The risk maps were produced with a 2 km x 2 km spatial resolution.

3 Results and Discussion

This section presents the results obtained for the Setúbal area test case as: a) the noise resulting from a simulated seismic survey, b) the habitat suitability for the common dolphin and c) the estimated risk level for the common dolphin population as a result of a seismic surveying event.

3.1 Seismic survey simulation results

The SPL resulting from seismic surveying noise prediction modeling during the months of January and June 2019, is presented in Fig. 4 (a) and (b), respectively.

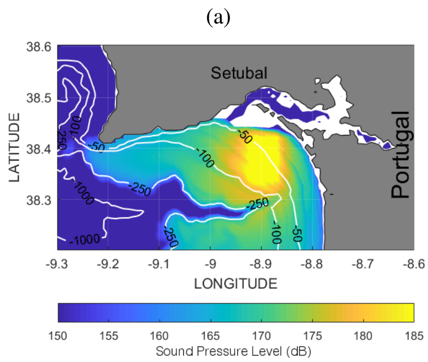

Fig. 4: Percentile 50 of the Sound Pressure Level due to a seismic survey simulation for the months of January (a) and June (b).

For a matter of comparison between the two cases, the color coded noise level scale is presented between 150 and 185 dB which means that values lower than 150 are considered in blue and higher levels than 185 dB in yellow. It is observed that noise propagation is largely influenced by the bathymetry of the area which is significantly attenuated over the entire platform till it reaches its edge. At that point, the signal is dispersed over a much larger water column, so the sound level abruptly falls off. Additionally, it was observed that the pressure levels calculated in January are higher and have a wider spatial spread than those obtained in June, which may be explained by the sound speed profiles of both months, described in section 2.4. In both cases, the generated noise largely exceeds the typical mean ambient noise, resulting exclusively from wind (65-75 dB) and from the noise produced by continuous sources such as ships (120 dB according to Soares et.al. *et.al.* [19]). Consequently, noise may represent a potential harmful impact on species sensitive in this frequency band.

3.2 Habitat suitability results

HS resulting from the ENM for the common dolphin in the area of Setúbal was obtained for the months of January and June as shown in Figure 5 (a) and (b), respectively.

(a) (b)

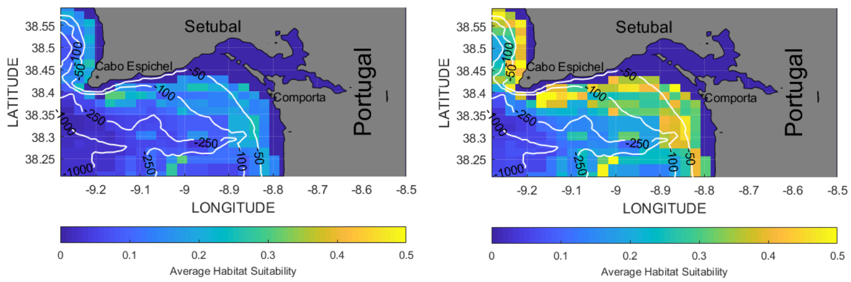

Fig. 5: Common dolphin habitat suitability for the months of January (a) and June (b).

The results show that the quality of the habitat for the common dolphin is higher in the summer season than in winter. However, in both months, the most favorable conditions are in the region delimited by the bathymetric line of 50 m and in the region delimited by the bathymetric lines between 100-200 m near Cabo Espichel, where the platform shortens. The areas where habitat suitability presents the greatest values are those near Cabo Espichel and Comporta.

3.3 Risk assessment results

Fig. 6 shows the regions of predicted risk, estimated in the region of Setúbal, for the population of common dolphins, for the months of January (a) and June 2019 (b), using the methodology outlined in the previous section.

(a) (b)

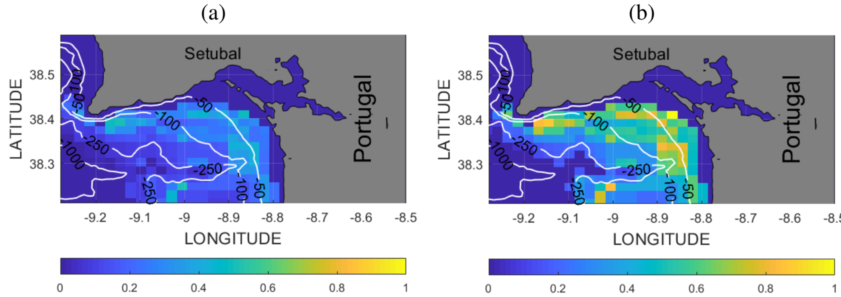

Fig. 6: Risk maps for: January (a) and June (b) 2019.

It can be observed that January shows lower risk levels than June although the "affected area" has a much larger extension in the month of January than in June. In both cases, it is observed that the highest risk areas are located near the shore, especially till the bathymetric line of 100 m. As previously observed, the region near Comporta presents the highest risk levels, due to the highest HS of the common dolphin in this area as described in the previous section 3.2.

In general, both the risk spatial distribution and its seasonality, reflect the combination of the HS distribution and the noise propagation. The areas with higher risk are those where: 1) HS values were higher (near shore) and 2) noise from the simulated seismic survey reached higher SPL values (near the area where the seismic survey took place). Summer presents higher risk levels because: 1) HS was higher in this season and 2) the highest values of SPL are more concentrated in this season. Additionally, risk maps reveal how regions that showed very high levels of HS, such as the northern coast of Cabo Espichel (between latitude 38.45 and 38.6, and longitude -9.3 and -9.2), but that were protected from the noise dispersion, present levels of risk very close or equal to zero. These findings confirm that risk is consistent with both the habitat suitability of the common dolphin and the propagation of the simulated noise from a seismic survey.

4 Conclusions

This chapter presents a risk simulation for the common dolphin population in the region of Setúbal when exposed to a light seismic survey to assess the viability of offshore wind farm structures.

The results of habitat suitability show that in both cases, the higher habitat quality area follows the coast line configuration, especially considering the bathymetric line of 100 m, which in the literature is known to correspond to an area with high productivity [35]. Additionally, the lower HS in January may be due to a winter decrease in upwelling and consequently to the decrease of the common dolphins' most important preys as the sardines [16, 36], showing that the seasonality in the habitat suitability is mostly related to prey biomass and water productivity [37].

Seismic surveys inject important quantities of energy into the ocean and consequently put at risk marine species in the surrounding area. Installing offshore wind farms occurs usually in shallow water, between 30 and 50 m depth, even though, as shown in the results, noise levels spread out for many kilometers. However, the coastal bathymetry induces an attenuation of the signal over the entire platform. Since light seismic surveys occur at such low depths which, as previously stated, are known for their high productivity, it is clear that it may potentially impact a higher number of individuals than typical seismic survey that occur in deep water.

The results confirm the important impact that seismic surveys may have on marine species, suggesting that, if they can not be avoided, then periods and areas at lower risk should be chosen, whenever possible, in order to diminish the impact of these practices on marine species.

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