Interreg
Italy - Croatia
SOUNDSCAPE

EUROPEAN UNION

# Creation of habitat suitability models (HSMs) that provide the expected distribution of target organisms.

---

Final Version of 22/06/2021

Deliverable Number D.4.4.1

INSTITUTE OF OCEANOGRAPHY AND FISHERIES SPLIT
CNR ISMAR ISTITUTO DI SCIENZE MARINE
BLUE WORLD INSTITUTE
CNR IRBIM ISTITUTO PER LE RISORSE BIOLOGICHE E LE BIOTECNOLOGIE MARINE
arpa FVG agenzia regionale per la protezione dell'ambiente del Friuli Venezia Giulia
FONDAZIONE CETACEA onlus
REGIONE MARCHE
REPUBLIC of CROATIA Ministry of Economy and Sustainable Development
NASTAVNI ZAVOD ZA JAVNO ZDRAVSTVO
INM ISTITUTO DI INGEGNERIA DEL MARE INSTITUTE OF MARINE ENGINEERING

| | |
|---|---|
| Project Acronym | SOUNDSCAPE |
| Project ID Number | 10043643 |
| Project Title | Soundscapes in the north Adriatic Sea and their impact on marine biological resources |
| Priority Axis | 3 |
| Specific Objective | 3.2 |
| Work Package Number | 4 |
| Work Package Title | Data collection about target species |
| Activity Number | 4.4 |
| Activity Title | Habitat suitability modelling for specific target species |
| Partner in Charge | CNR |
| Partners Involved | CNR, BWI |
| Authors | Daphnie Galvez (CNR-ISMAR), Giorgio Castellan (CNR-ISMAR), Marko Radulović (BWI), Marta Picciulin (CNR-ISMAR), Raffaela Falkner (BWI), TihanaVučurBlazinić (BWI), NikolinaRako-Gospić (BWI), MašaFrleta-Valić (BWI), Viliam Antoninić (BWI), Alexandra Constaratas, Fantina Madricardo (CNR-ISMAR), and Michol Ghezzo (CNR-ISMAR) |
| Status | Final |
| Distribution | Public |
| Citation | Galvez D., Castellan G., Radulović M., PicciulinM., Falkner R., VučurBlazinić T., Rako-Gospić N., Frleta-Valić M., Antoninić V., Constaratas A., Madricardo F., Ghezzo M. Creation of habitat suitability models (HSMs) that provide the expected distribution of target organisms. SOUNDSCAPE project, WP4, 28 pp, 2021 |

# Summary

1 Introduction ........ 4
2. Data Acquisition and Processing ........ 7
  2.1. Study Area ........ 7
  2.2. Environmental Data ........ 8
  2.3. Proxy Data for Anthropogenic Activities ........ 8
  2.4. Presence Data of the Target Species ........ 11
  2.5 Encounter rate data calculation/processing ........ 12
3. Methodology for Habitat Characterization ........ 15
  3.1. Modelling Approach ........ 16
  3.2. Input Data for the HSM ........ 17
    3.2.1. Presence-Absence Data of the Target Species ........ 17
    3.2.2. Predictor Variables ........ 18
  3.3. Feature Selection ........ 18
  3.4. Model Calibration and Validation ........ 19
4 Results ........ 20
5 Seasonal habitat characterization and speciesdistributionbased on presence-absence data and encounter rate models ........ 20

5.1.1 Bottlenose Dolphin, considering only natural factors in the model .......... 20
5.1.2 Summer 2019-2020 .......... 21
5.1.3 Winter 2019-2020 .......... 21
5.1.4 Summer to Winter .......... 22
6 Loggerhead Sea Turtle and natural factors .......... 23
6.1.1 Summer 2019-2020 .......... 23
6.1.2 Winter 2019-2020 .......... 24
6.1.3 Summer to Winter .......... 24
7 Anthropogenic influence in the HSM and species distribution .......... 26
7.1 Influence on bottlenosedolphins .......... 26
7.2 Influence on loggerhead sea turtles .......... 27
7.3 Influence of underwater noise .......... 28
8 Discussion .......... 30
8.1.1 Habitat suitability models .......... 31
8.1.2 Bottlenose Dolphin Habitats .......... 31
8.1.3 Loggerhead Sea Turtle Habitats .......... 32
8.1.4 Soundscape influence on habitats .......... 33
8.1.5 Limitations and Recommendations .......... 34
9 Conclusion .......... 35
10 References .......... 35
11 APPENDIX .......... 40

# Abstract

This report describes the development of habitat suitability models (HSM) for the two target species, namely *Tursiops truncatus* (bottlenose dolphin) and *Caretta caretta* (loggerhead sea turtle), which protection is relevant in the framework of the SOUNDSCAPE project. HSM would help in the

understanding of the potential relationships between species and habitat within the study area. For this purpose, two modelling approaches were tested: single-model and ensemble model. The models were developed using the environmental data (see Deliverable 4.3.1.), presence data, and encounter rate data of the target species from boat surveys (see deliverable 4.1.1).The same approach was used to include a suite of anthropogenic data (here considered as distance from the marinas, distance from fish farms, distance from gasoline stations, and underwater noise levels at the 1/3 octave bands centred at 250 and 4000 Hz) in addition to environmental variables.

Areas with high suitability for bottlenose dolphin presence were identified in waters with high nutrient concentration, shallow depths, and moderately saline. The inclusion of anthropogenic data led to high suitability areas for bottlenose dolphin predicted close to fish farms and gasoline stations, suggesting a relationship with dolphin presence.

The areas predicted as highly suitable for loggerhead sea turtles in Cres-Losinj were characterized by soft-bottom sediments, shallow depths, and high concentration of phytoplankton and dissolved oxygen. The models suggest a seasonal variation in habitat preference and species distribution of loggerhead turtles. They also showed an inverse correlation between anthropogenic data and turtle presence, which seems to prefer areas far from anthropogenic activities.

The incorporation of underwater noise data to the HSM of bottlenose dolphins highlight a direct relationship between noise and dolphin presence, which is in contrast with previous study in Cres-Lošinj documenting dolphin avoidance in noisy areas. The difference might be caused by the unusual setting in the area during data collection conducted during the Covid-19 lockdown period, thus lesser maritime traffic and underwater noise than usual was recorded. Dolphin presence was detected at 82-84 dB (for the 1/3 octave band centred at 4000 Hz) and at 86 dB (for the 1/3 octave band centred at 250 Hz).

The extension of areas with high suitability for turtle presence decreased when noise data at 1/3 octave band frequency centred at 250 Hz was included in the HSM. However, it changed when we used higher noise frequency (4000 Hz); larger areas with high suitability for loggerhead turtle occurrence were detected. The higher noise frequency might be associated to geophonic components like wind intensity, which may be used to orient towards their food choice.

# 1 Introduction

In the northern Adriatic Sea, the presence of bottlenose dolphins (*Tursiops truncatus*) and loggerhead sea turtles (*Caretta caretta*) have been documented by several studies (Bearzi et al., 1997; Casale et al., 2018; Marini et al., 2015; Muckenhirn et al., 2021; Rako et al., 2013a; Zbinden et al., 2008). The water column in the Adriatic Sea is under the influence of cool waters and low salinity (Pinardi et al., 1997) and it experiences favourable summer sea temperature. The area is rich in benthic communities and neritic habitats that are ideal as feeding grounds for both bottlenose dolphins (Bearzi et al., 2005; Castellote et al., 2015; Natoli et al., 2005) and loggerhead sea turtles (Castellote et al., 2015; Lazar et al., 2004; Zbinden et al., 2008).

Bottlenose dolphins in the Mediterranean Sea are protected under the EU Integrated Maritime Policy and are classified as vulnerable by the IUCN Red List due to their decline by at least 50% within the last 50 years (Muckenhirn et al., 2021). The habitats of the bottlenose dolphin in the Adriatic Sea include coastal areas, open waters, lagoons, and river estuaries where they feed on fish and cephalopods. Food availability is one of the main drivers of bottlenose dolphins' distribution (Hastie et al., 2004). They have been commonly reported to follow trawling boats to take advantage of discarded fish or seize fish from the net in different areas of the Mediterranean (Bearzi et al., 1999; Fortuna et al., 2010; Pace et al., 2012).In fact, areas with fish farms or nearby fish trawling activity yielded highest levels of dolphin presence due to an increase in the concentration of prey resources. Presence of fishing vessels in the nearby ports has also been attributed to the diel presence of bottlenose dolphins (Castellote et al., 2015).

Information about the distribution of loggerhead turtles outside the breeding habitat is scarce in most areas, but Northern Adriatic represents key areas for female adult Mediterranean loggerhead sea turtles and also serves as home to juveniles during winter season (Zbinden et al., 2008). Moreover, the highest by-catch rates of loggerhead turtles have been recorded in the Adriatic Sea and in the easternmost part of the Levantine Basin (Casale et al., 2018). Loggerhead sea turtles are diurnal predators in oceanic habitats, and they rely primarily on gelatinous plankton (i.e., jellyfish and tunicates), although fish and squid can also supplement their diet. They also forage on the seabed, especially the larger juvenile and adult, where they favour invertebrates such as crabs, hermit crabs, bivalves, gastropods, and cephalopods (Casale et al., 2018).In some areas, they may also consume large amounts of fish discarded by fishing vessels (Houghton et al., 2000; Tomas et al., 2006)

Anthropogenic activities such as fishing, tourism, maritime traffic, and underwater noise influence the distribution, population, and habitat of the two target species. Presence of boats, vessel traffic, and underwater noise has been found to cause behavioural changes and variation in whistle frequencies of the bottlenose dolphins (Marley et al., 2017; Rako Gospić and Picciulin, 2016; Rako et al., 2013a). On the other hand, fishing activity in the eastern basin of the Mediterranean impacts more heavily on sea turtle species because of intensive fishing activities and the likelihood of losing part of a fishing gear, which may cause incidental capture of turtles by abandoned fishing gear (i.e., ghost fishing; (Casale et al., 2018; Duncan et al., 2017).

Habitat suitability modelling (HSM) is an important tool to investigate the habitat preferences for species, to explore the processes influencing their biogeography and ultimately provide a probability of presence (Guisan et al., 2017; Marini et al., 2015). With the growing need to protect marine species from the impacts of climate change and human activities, predicting their habitat preference and spatial distribution can assist in the decision-making of how to protect them. One of the first steps in environmental management is to understand the location and pattern of distribution of the target species. For example, sea turtle populations that mainly consist of juveniles of small size, never come ashore, which makes empirical estimation of their abundance extremely challenging (Casale et al., 2018). In this case, HSM can be used to provide information on the possible location, abundance, and habitat of the target species to aid in identifying possible areas for protection.

Here, the recorded dolphin and turtle presence data will be combined with a suite of environmental variables to identify areas suitable for the presence of the target species in the Cres-Lošinj archipelago (northern Adriatic, Croatia). In Cres–Lošinj, a resident bottlenose dolphin population has been consistently monitored since 1990 (Bearzi et al., 1997; Fortuna, 2007) and the abundance of this population has shown a significant decline of over 30% between 1995 and 2003 (Fortuna, 2007)This led to the declaration of a part of the Kvarnerić as the Cres-Lošinj Special Marine Reserve (CLSMR) in 2006.

A subsequent study conducted between 2004 and 2011 in the CLSMR area documented an increase in the number of bottlenose dolphins with respect to the period 1995–2003 (Pleslić et al., 2015). Due to its importance as a habitat for common bottlenose dolphin, in 2014 the Cres-Lošinj area was further designated as a Site of Community Importance (SCI), part of the European Union NATURA 2000 ecological network (Cres and Lošinj SCI, HR3000161). A more recent study (Rako-Gospić et al., 2017) highlighted a seasonal influence of nautical tourism on resident dolphins through changes in their home range sizes, confirming that recreational boating has adverse effects on dolphin communication and habitat use in this Cres and Lošinj SCI (RakoGospić and Picciulin, 2016; Rako et al., 2013b)However, no nesting locations or reproductive sites of loggerhead sea turtles have been identified along the Croatian coast (Lazar et al., 2004)Recoveries Catches of turtles tagged in Greece suggest that the eastern Adriatic Sea might represent a major migration corridor for loggerhead sea turtles, with the shallow northern Adriatic representing an important feeding area; further observations revealed a prolonged permanence of loggerheads the Adriatic area, suggesting that a cluster of specimens might periodically re-occupy the area (Lazar et al., 2004). Collected data corroborate the hypothesis that part of the Greek population spends their entire life in different habitats of the north Ionian/Adriatic area (Casale et al., 2012). As a consequence, the Ionian-Adriatic loggerhead turtles play an important role in nesting, processes. The main identified threats for loggerhead sea turtles in the Adriatic basin include incidental capture in fishing gears, collision with boats and intentional killing (Casale et al., 2012). Recent records on loggerhead sea turtles in the Cres and Lošinj archipelago come from the citizen science application and boat surveys conducted by Blue World Institute.

Identifying the spatial distribution and habitat characteristics of the bottlenose dolphins and loggerhead sea turtles is crucial to develop effective ecosystem management strategies, under the framework of the SOUNDSCAPE project. For this purpose, this study aims to (1) understand the role of environmental variables (i.e., temperature, salinity etc.) in creating suitable habitats for bottlenose dolphins and loggerhead sea turtles; (2) explore the potential spatial distribution of the two species in the archipelago; and (3) assess how environmental variables (i.e., seasonal variation)and anthropogenic activities influence the presence of suitable habitats.

# 2. Data Acquisition and Processing

## 2.1. Study Area

The Cres-Lošinj archipelago (44.51133º, 14.4973°) has been designated as a Site of Community Importance (SCI) of the NATURA 2000 network due to its importance as habitat for the resident bottlenose dolphin population. The area is characterized by steep rocky shores, a seabed patched with muddy areas and sea grass flats, and water depth of < 200 m (avg. 70 m)(Arko-Pijevac et al., 2003; Rako et al., 2013b). The sea surface temperature ranges between 7-15 °C in the winter and 22-25 °C during the summer (Favro and Saganić, 2017). The island of Lošinjis a well-known tourist destination that attracts hundreds of thousands of tourists each year during the summer season (Rako et al., 2013b). The Blue World Institute of Marine Research and Conservation conducted boat-based surveys to collect data on target species in the periods from July to September 2019 and from January to April 2020. The surveyed area stretches from the west coast of Istrian peninsula in the north to the island of Dugiotok in the south (Fig. 1). Two Natura 2000 sites are located within the surveyed area: Western Istria (HR5000032) and Cres-Lošinj Archipelago (HR3000161). The study area is approximately 12,096 km$^2$ in size (Fig. 1). More details on the study area are reported in deliverable 4.3.1.

**Figure 1.** Location and coverage of the habitat suitability models developed for Cres- Lošinj

## 2.2. Environmental Data

Environmental data for the HSM was previously reported in deliverable 4.3.1, which includes COPERNICUS marine service, the seafloor sediment data come from EMODNET-Geology, and the bathymetry data collected from Geo-global dataset.

## 2.3. Proxy Data for Anthropogenic Activities

Anthropogenic activities that were incorporated in the HSM were distance from the marinas, distance from fish farms, distance from gasoline stations, and underwater noise calculated as SPLs for 1/3 octave bands centred at 250 and 4000 Hz by QUONOPS numerical model (Fig. 2-4, more detail in deliverable 5.2). Since data on human activities in the area were limited, some activities were also. Used as a proxy for other activity. For example, the distance from gasoline stations was used as proxy for the presence of recreational or small-scale fishing vessels. In addition, data on commercial shipping in the study area, provided by the AIS and VMS tracking systems, were used for the noise model. The AIS data were not used directly as a map but were incorporated in the noise map developed for the Lošinj area by Quiet Ocean using the Quonops Model. The 50º percentile was calculated (Figure 3 and 4) in the whole Losinj area for the ⅓ octave bands centred at 250 and 4000 Hz respectively considering the monthly average of the model results for October. This choice match with the available target data period and it was the only data available for the area at the time of the study.

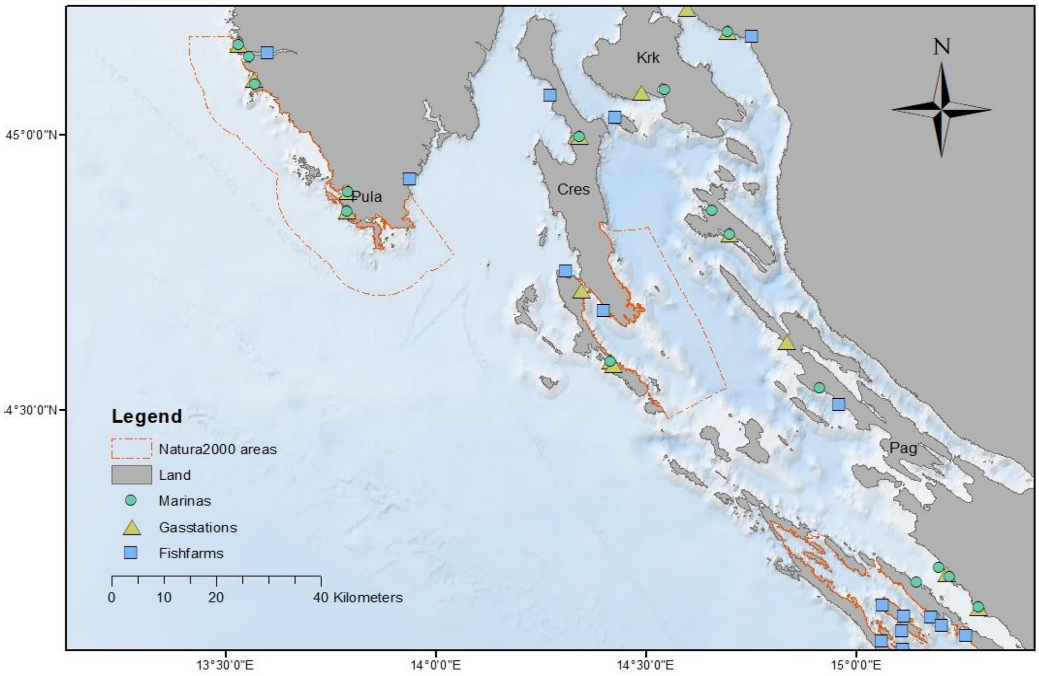

**Figure 2.** Locations of marinas, gasoline stations, and fish farms that were used as input data in the models.

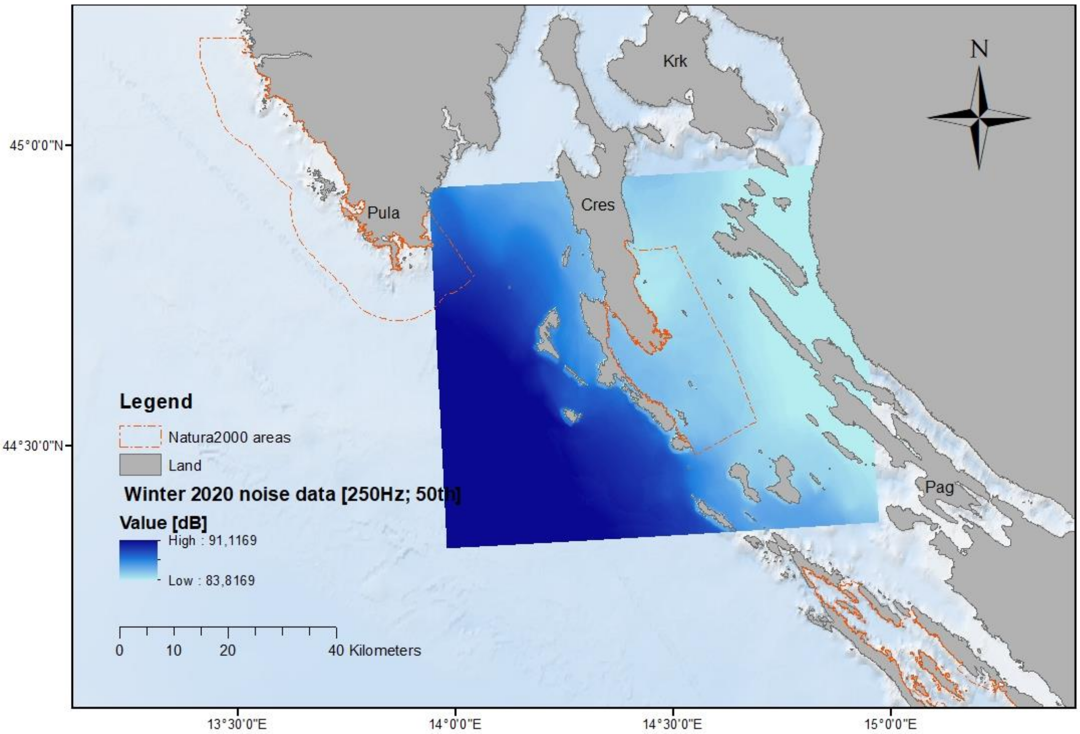

**Figure 3.** Underwater noise SPL [dB] simulated by QUONOPS model during winter season for the frequency of 250 Hz

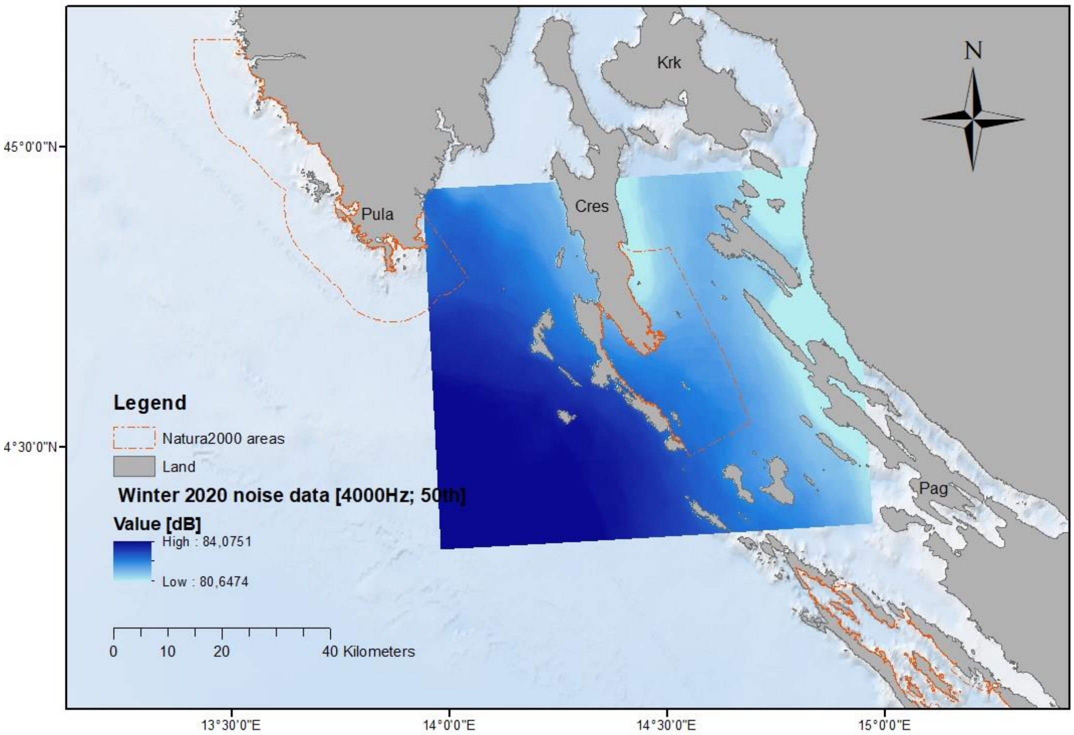

**Figure 4.** Underwater noise SPL [dB] simulated by QUONOPS model during winter season for the frequency of 4000 Hz.

## 2.4. Presence Data of the Target Species

Presence data were collected through dedicated boat surveys by BWI and using citizen science application software. Surveys were conducted using a 6 m inflatable boat with four-stroke engine (100 hp) at sea conditions of less than four Beaufort scale and with good visibility. Research effort was determined ad libitum according to current weather conditions. The speed of the boat was maintained at around 14 knots during surveys. At least two experienced researchers were always on board, continually inspecting the horizon in a standing position, covering the 180° range in the direction of the movement of the vessel. Information on the presence of fishing vessels within the study area and the locations of other interesting marine species had been recorded as well. NaviLog application was used to collect the navigation data on a Samsung SM-T550 tablet, developed specifically for the needs of the Blue World Institute. The location of observed dolphin and loggerhead turtles' presence are presented in Figures 5 and 6.

For the survey, an array of data was recorded: date, time, coordinates of navigation, sea state changes, the weather conditions, the current research activity, the locations of the sightings of target species, group size, age categories within the group, and behaviour within the groups. All the navigation data was transferred to the navigation database and total amount (in km) and spatial distribution of research effort were obtained using the ESRI ArcMap 10.2 software (ESRI, 2011). The dates of the surveys and amount of data collected are presented in Table 1.

## 2.5 Encounter rate data calculation/processing

To obtain encounter rates for the target species, the study area was overlaid with a 2x2 km square grid. For each grid cell total number of kilometres travelled on effort and total number of encountered bottlenose dolphin groups or loggerhead turtle individuals were calculated. The encounter rate for each grid cell was then calculated as ER = n/L, where ER is encounter rate, n it the number of encountered bottlenose dolphin groups or loggerhead turtle individuals, and L is the distance travelled on effort. The encounter rates were then shown on grid as heat map. This procedure was done for the whole duration of the study (Figure 7 and Figure 8), and for the summer and winter seasons. Detailed overview of encounter rates is given in Deliverable D4.1.1).

**Table 1.** Dates of boat survey conducted by the BWI, and the number of presence data collected for bottlenose dolphins and loggerhead sea turtles

| Season | Year | Starting date | Ending date | Bottlenose Dolphin | Loggerhead Sea Turtle |
|---|---|---|---|---|---|
| Summer 1 | 2019 | 07.2019 | 09.2019 | 51 | 36 |
| Winter 1 | 2019 | 10.2019 | 05.2020 | 32 | 11 |
| Summer 2 | 2020 | 06.2020 | 09.2020 | 56 | 20 |
| Winter 2 | 2020 | 10.2020 | 03.2021 | 48 | 20 |

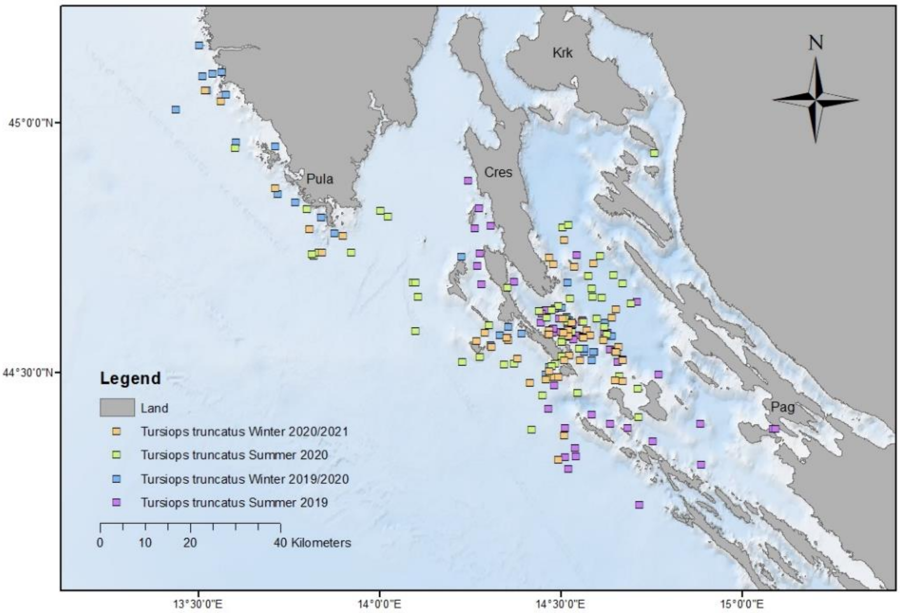

**Figure 5.** Location of collected presence data of *Tursiops truncatus* (bottlenose dolphins) from 2019 to 2021

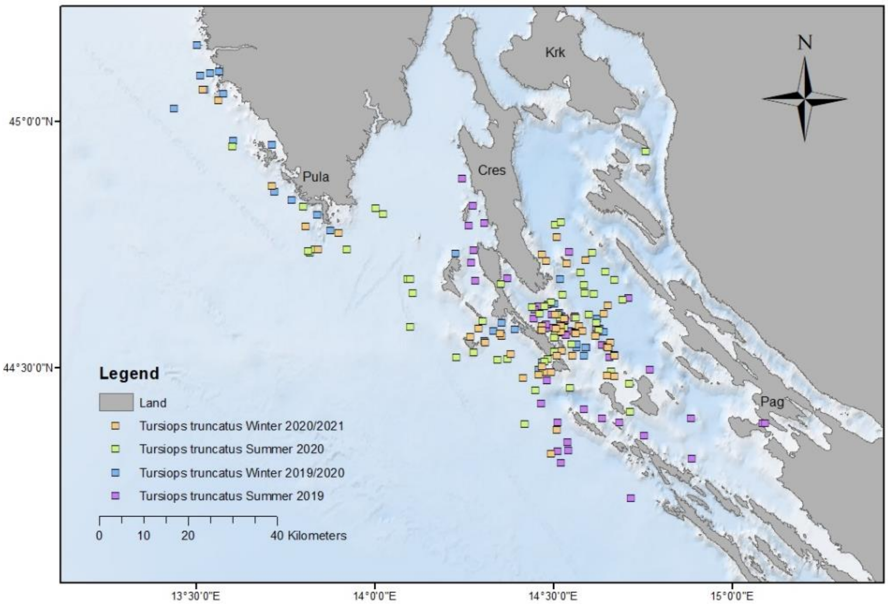

**Figure 6.** Presence data of *Caretta caretta* (loggerhead sea turtle) obtained from boat-based surveys from 2019 to 2021

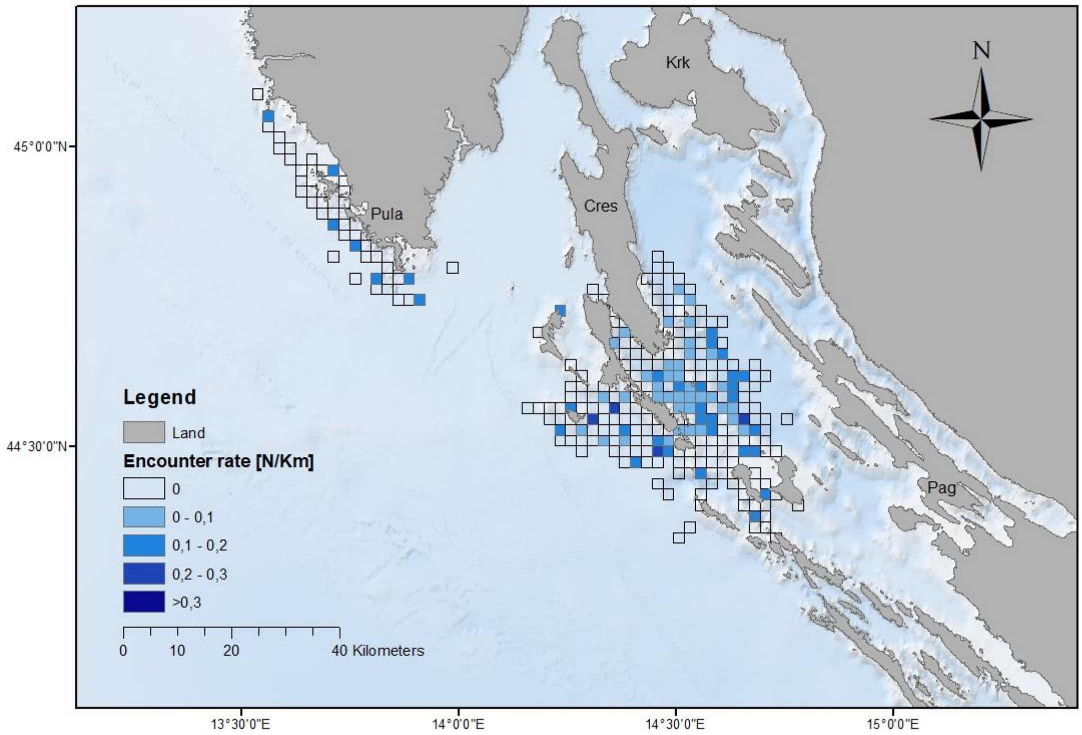

Figure 7. Encounter rates for bottlenose dolphins for the period from 2019 to 2021.

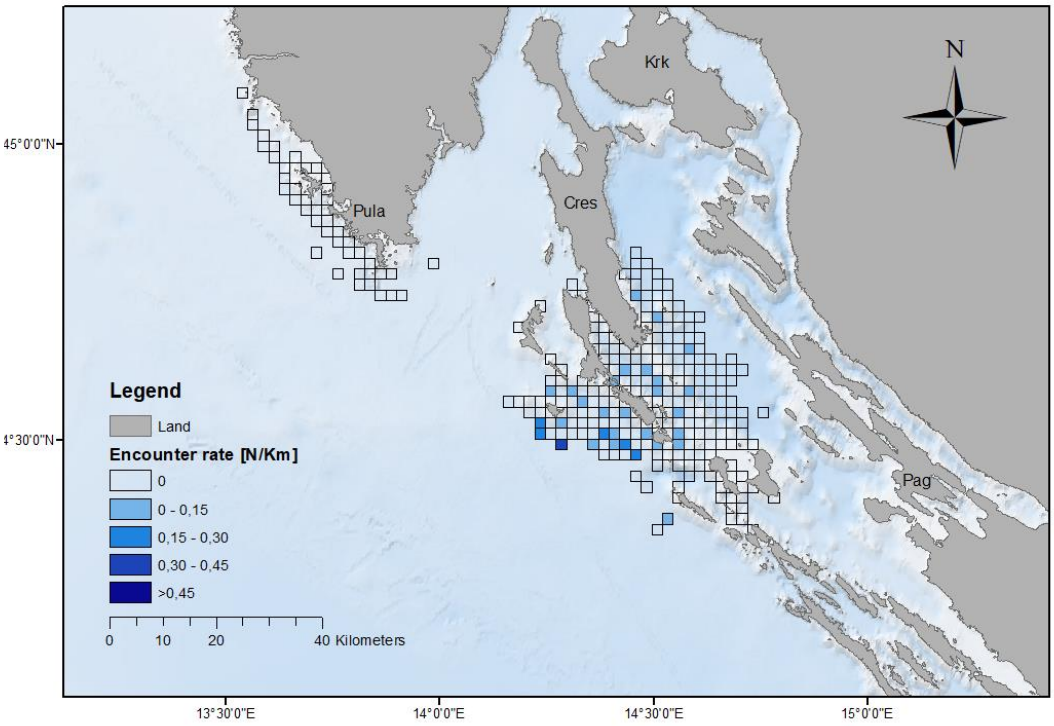

Figure 8. Encounter rates for loggerhead turtles for the period from 2019 to 2021.

# 3. Methodology for Habitat Characterization

The methodology for habitat characterization is illustrated in Fig. 7. Initially, data were processed to homogenize the extents and resolutions of the variables. Then, the values of the predictor variables were extracted at the location of the presence data (i.e., encounter rate and presence/absence data). The data preparation was followed by variable selection (see Sec. 3.3) and by the modelling process (see Sec. 3.4). The outputs from the modelling process were the product of two modelling approaches: single-modelling and ensemble modelling.

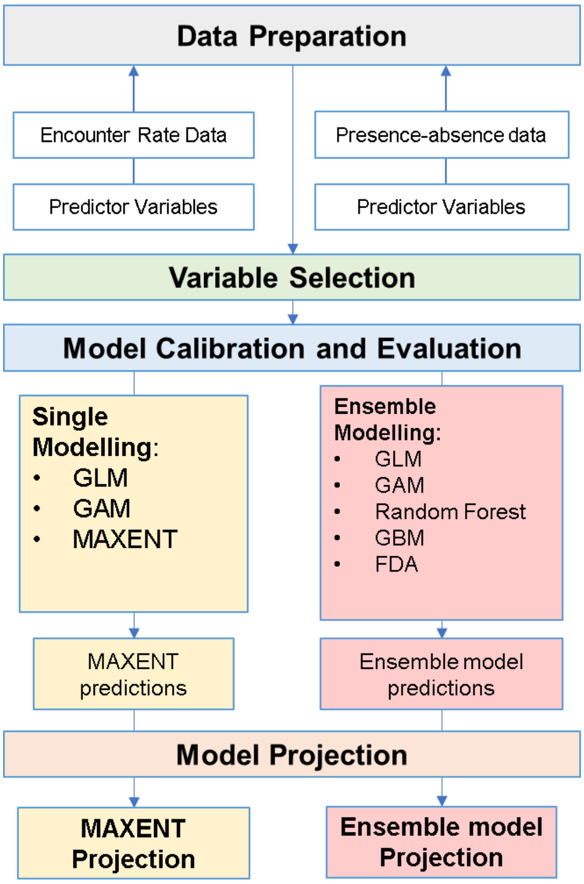

**Figure 7.** Habitat suitability modelling workflow

## 3.1. Modelling Approach

Two different approaches were conducted to assess which model algorithm performs better for our small datasets: single-model approach and ensemble modelling. Moreover, two different datasets were tested to explore the difference in the predictions when using different type of presence data: presence with pseudo-absences and presence using encounter rates (ER).

The single-model approach (i.e., using one algorithm to derive a prediction) tested woregression models and maximum entropy (Maxent). Regression-based approaches are the most used in habitat suitability modelling and rely on robust statistical theories. Regression relates a response variable (e.g., presence-absence) to a set of pre-selected environmental predictors (e.g., climate, resource) (Guisan et al., 2017). The Generalized Linear Model (GLM) and Generalized Additive Model (GAM) were applied to model species distribution of bottlenose dolphins(Marini et al., 2015; van derRoest, 2019) and habitats of green turtles (Papale et al., 2020). GLM are useful for fitting linear relationships with non-Gaussian data distributions (i.e., presence-absence data), and relates the dependent variable to a linear combination of explanatory variables (Hirzel et al., 2001; Jongman et al., 1987; McCullagh and Nelder, 1989; Nicholls, 1989). GAM is based on non-parametric smoothing functions of the predictors and was commonly used to implement no-parametric smoothers in regression models (Guisan et al., 2017; Wood, 2006). The principle of Maxent states that the probability distribution that best represents the data is the one with the greatest entropy i.e., the one which best reproduces the data (Guisan et al., 2017; Shipley et al., 2011). For the single-model approach, presence data were modelled using GLM, GAM and Maxent where the data was divided into 70-30 split—70% for testing and 30% for validation. Only one run per model was performed.

The rationale for using ensemble models (i.e., using multiple algorithms to derive a prediction) is that two or more models may have very similar predictive performance, which makes it difficult to know which of the equivalent candidate models to use. Ensemble modelling was performed using the BIOMOD2 package in R, which has been found to remove or lessen model selection bias and was able to accurately predict spatial distribution using small datasets (Araujo and New, 2007; Breiner et al., 2015; Galvez et al., 2021; Guisan et al., 2017). We selected five modelling algorithms within the BIOMOD2 package to model the distribution of turtles and dolphins: GLM, GAM, Random Forest, GBM, and Flexible Discriminant Analysis (FDA). Initially, each of the five algorithms was run 30 times to model the species distribution, with a 70-30 data split and 10 permutations to calculate variable importance. Subsequently, the five single models were ensembled to generate one prediction. The models with TSS (true skill statistic) value of >0.7, which indicate good performance, were selected to be included in the ensemble. The ensemble models were then used to project the species distribution model using the mean and committee average of the single models.

## 3.2. Input Data for the HSM

### *3.2.1. Presence-Absence Data of the Target Species*

Presence data from BWI were converted into points and binary format for the model. The value 1 was assigned to locations of species occurrence (presences or points with ER>0) whilst the value 0 was assigned to points where the species was supposed to (pseudo-absence) or was absent (ER=0). For single models, pseudo-absences were generated once using random sampling. In the ensemble modelling, pseudo-absences were generated three times using random sampling to prevent sampling bias.

### 3.2.2. Predictor Variables

#### Environmental Predictors

Each environmental data (see section 2.2.) were processed to obtain the yearly mean value and were vertically averaged from 0 to 100 m water depth. The environmental data considered in the model were: Sea surface temperature, salinity, dissolved molecular oxygen, chlorophyll-a (Chl-a), phytoplankton distribution, bathymetry, and sediment grain size distribution.

Temperature and salinity can provide an estimation of density gradients and anomalies. Oxygen saturation, chlorophyll-a, and phytoplankton distribution can be used as a proxy for the distribution of zooplankton, and potentially, of nektonic fauna that represents food source for both target species. We included bathymetry to test if the target species prefer shallow or deeper waters. The sediment type distribution was considered to explore whatever benthic habitats concur to create suitable situations for the preference of target species.

#### Anthropogenic Activities

As explained in section 2.3, available data on human activities were included in the HSMs such as distance from the marinas, fish farms, and gasoline stations, and underwater noise. The available data of underwater noise were derived from data recorded by the hydrophone, and the underwater noise simulated by the QUONOPS model (see deliverable 5.2). The data represents a direct impact of vessel traffic (AIS mandatory ships), and the maps of Sound Level Pressure (dB) at 50 percentiles around the most sensitive frequency for the target species. The 1/3 octave band frequency centred at 250 Hz was used to examine the sound levels for loggerhead seaturtles in winter (Fig. 3), while the 1/3 octave band frequency centred at 4000 Hz was used for the bottlenose dolphins (Fig. 4,), in accordance with deliverable 4.2.1. The instantaneous SPLs data were averaged and the values corresponding to 50th percentile were considered.

## 3.3. Feature Selection

The selection of predictor variables is an important step to avoid model overfitting, especially when working with small datasets (Breiner et al., 2015). For single-model predictions, variables reporting a Pearson correlation index greater than ± 0.8 were excluded.

In the ensemble modelling, the selection of variables to be included in the model was conducted in an iterative process, following the procedure in (Galvez et al., 2021). Initially, the predictors were assessed for multi-collinearity by plotting in a correlation matrix and through the variance inflation factor (VIF) analysis. The VIF analysis evaluates the variables from multi-collinearity based on the square of multiple correlation coefficient (R2) resulting from regressing the predictor variable against all other predictor variables (Naimi et al., 2011; Naimi and Araújo, 2016). A VIF value greater than 10 indicates a collinearity problem (Chatterjee and Hadi, 2006). Here, all predictor variables were analysed in a stepwise procedure using the ‘vifstep’ function in the R package ‘usdm’, whereas variables with VIF of >5 were removed from the model. Further feature selection was conducted during model calibration based on the variable importance score. The higher the value, the more important the predictor variable is in the model. Here, the variable importance was calculated through 20 permutations and predictor variables with a low mean variable importance score (≤0.1) were excluded from the modelling. Moreover, the response curves of the predictor variables in the models were evaluated to assess influence of the predictors to the HSMs of the target species.

## 3.4. Model Calibration and Validation

Single and ensemble models were calibrated using 70% of the presence-absence data and validated with the remaining 30%.

For the single models, several model runs were performed to calibrate the model using one cross-validation run. Model calibration was repeated until the optimal area under the curve (AUC) value of (>0.7) was attained. The AUC represents how well the predictions were ranked and measures the ability of a classifier to distinguish between classes.

In ensemble modelling, the settings and complexity of the five model algorithms (GLM, GAM, GBM, FDA, RF) were repeatedly modified until the optimal TSS value (>0.7) was achieved. Model performance was assessed by the receiver operator characteristics (ROC), TSS and Cohen’s Kappa. ROC shows the trade-off between sensitivity and specificity of the classifiers, TSS score of 0.7 or higher indicates good or exceptionally good model performance, and Kappa indicates the best possible agreement. After the single model calibration, only single models with TSS value of >0.7 were included in the ensemble model by committee averaging. In committee averaging, each model decides for the species being either present or absent, and then the sum was divided by the number of models (Thuiller et al., 2010, 2009). Moreover, model bias was removed across the selected models by applying the same weight to all predictions to derive a consensus prediction. The weights are calculated based on models’ predictive accuracy on test data. The committee-average gives both the prediction and measure of uncertainty. Mean probability and coefficient of variation of the ensemble models were also calculated.

# 4 Results

After multiple calibration tests, two models performed the best in predicting the spatial distribution of the target species and in identifying the critical habitat: Maxent and ensemble models. The two modelling approaches predicted the target species distribute with an accuracy of 80-95%. Therefore, the results presented here are derived from the Maxent and Ensemble model predictions (Table 2).

**Table 2.** Summary of the model outputs presented in this report.

| **PREDICTOR VARIABLE IN THE MODEL** | **DOLPHIN** | | **TURTLE** | |
|---|---|---|---|---|
| **Environmental factors** | Summer 2019/2020 | ER; P/A | Summer2019/2020 | ER; P/A |
| | Winter 2019/2020 | ER; P/A | Winter 2019/2020 | ER; P/A |
| **Environmental and anthropogenic factors** | Summer 2019/2020 | ER; P/A | Summer2019/2020 | ER; P/A |
| | Winter 2019/2020 | ER; P/A | Winter 2019/2020 | ER; P/A |
| **Environmental, anthropogenic, and noise factors** | n.d. | n.d. | n.d. | n.d. |
| | Winter 2020 | ER; P/A | Winter 2020 | ER; P/A |

# 5 Seasonal habitat characterization and species distribution based on presence-absence data and encounter rate models

### *5.1.1 Bottlenose Dolphin, considering only natural factors in the model*

### 5.1.2 *Summer 2019-2020*

#### Presence-Absence Model

During summer, ensemble and single-model predictions presented similar results, detecting areas suitable for bottlenose dolphin occurrence in the central part of the study area, around the southern area of Cres, Losinj, Pula and Medulin (Fig. 8A and 8C). The highest suitable areas (>80%) presented high concentration of Chl-a (0.08-0.10 mg/m$^3$) and phytoplankton (0.35-0.45 mmol/m$^3$), and moderate-high saline water (38.6-38.8 ppt). Areas with lower (suitability values around 60%) were identified offshore Losinj, in correspondence of sea floor characterized by very fine sands, depth ranging from 20 to 70 m, and warm waters (21-25°C). An increase in the extent of areas suitable for dolphin presence was observed in the summer of 2020, where larger portions predicted as highly suitable (>80%) than the summer 2019 prediction. The sea areas had medium to very fine sand seafloor, high Chl-a concentration, and moderate saline water.

#### Encounter Rate Model

Using encounter rate as target distributions, the ensemble approach identified highly suitable areas (> 60%) for bottlenose dolphin in summer 2019atthe northern offshore of the study area, along Pula coast and is lands behind Losinj (close to Krk and Rabisland, see Fig. 8B and 8D). On the contrary, single-model technique predicted areas with high suitability in the central sector of the study area, showing a decrease with distance from the coast. The suitable areas for summer 2020 showed areas presenting moderate-to-high suitability close to the coast and offshore of Pula and Losinj (Fig. 8B and 8D).

### 5.1.3 *Winter 2019-2020*

#### Presence-Absence Model

The distribution extent of highly suitable areas for bottlenose dolphins predicted with ensemble models in winter 2019 was lower than the summer period (Fig. 8A and 8C). High suitability areas (>80%) were observed in the northwest (Rovinj and Porec), and in the southern-central part of the study area (Losinj and Novalja). These areas were characterized by medium to fine sand seafloor, water depths ranging between 20-40 m, lower salinity (38.4psu), and high phytoplankton concentration (0.4-0.5mmol/m$^3$). Single-model approach predicted the presence of high suitable areas in the north-central sector of the study area, mainly offshore. In 2020, the extent of high suitable area was larger than that of 2019, with a medium-high suitability area (40-60%) detected in the southern part of the modelled area.

#### Encounter Rate Model

In winter 2019, the ensemble approach prediction showed suitability values decreasing from the coast to offshore areas. The lowest suitability was identified in the northern and in the southern sectors of the study area (Fig. 8B and 8D). Highest suitability values predicted around Istrian coast, southern cape of Losinj and other small inner coastal areas. Medium-high suitability areas were identified also offshore.

The single-model approach failed in predicting the suitability for bottlenose dolphin in the study area in winter 2019 because the number of data is too low (11 data with ER>0). In winter 2020, high suitability areas were identified mainly in the north-central sector.

### *5.1.4 Summer to Winter*

#### Presence-Absence Model

Based on the models, the distribution of areas suitable for bottlenose dolphins changed during summer and winter (Fig. 8A and 8C). In general, suitable areas were concentrated in the centre of the Cres-Losinj archipelago during summer, whilst the northern and southern sectors resulted more suitable during winter. Our results suggest that bottlenose dolphins might occur mainly northwest (Porec and Rovinj), with the sector between Pula and Cres seems less suitable for their presence during winter. The area south of Losinj was highly suitable in both summer and winter periods.

#### Encounter Rate Model

Inter annual differences were observed between the winter2019 and 2020 whilst the two summer predictions were more similar (Fig. 8B and 8D). During winter seasons areas with higher suitability values were predicted in the northern part of the study area. In contrast, highly suitable areas were projected in the central part and along the coast of the modelled.

The two approaches differ in predicting the suitable areas for bottlenose dolphin, with presence/absence method identifying less areas with medium-high suitability values in summer season and more in winter (2020).

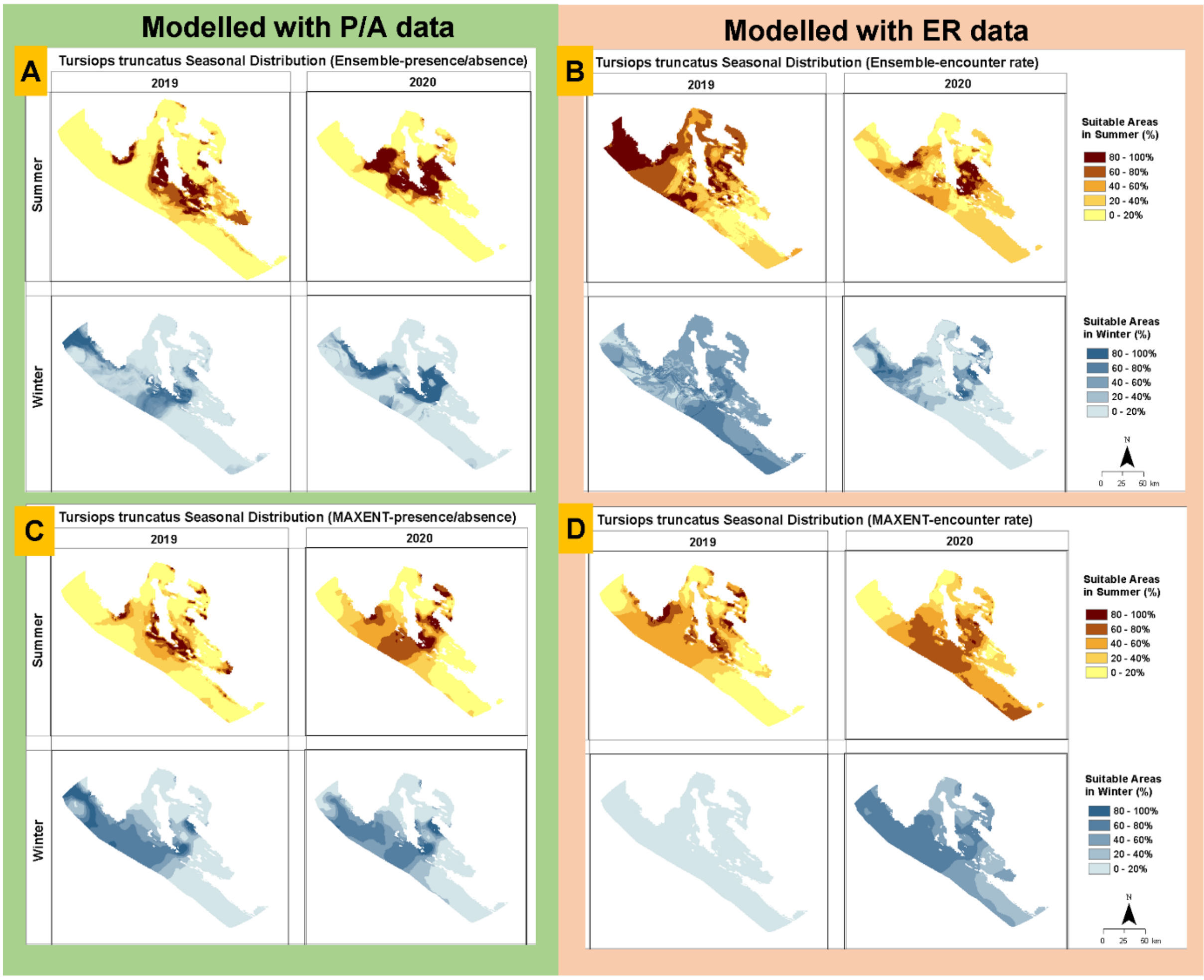

**Figure 8.** **(A)** Ensemble model prediction of seasonal distribution of bottlenose dolphins from 2019-2020 using presence-absence data; **(B)** Ensemble model prediction using encounter rate data; **(C)** Maxent model prediction using presence-absence data; **(D)** Maxent model prediction of bottlenose dolphins using encounter rate data. High-resolution versions of the figures are available in the appendices.

# 6 Loggerhead Sea Turtle and natural factors

### *6.1.1 Summer 2019-2020*

Presence-Absence Model

Areas predicted as highly suitable for the presence of loggerhead sea turtle during summer presented medium-high phytoplankton concentration (0.35-0.38 mmol/m$^3$) and medium-fine sand seafloor substrate. A lower suitability (<40%) was observed in areas with low Chl-a concentration and depth of 40-60 m. The predictions for 2019 and 2020 differed, with more highly suitable areas observed in the latter. Our results suggest that the central-northern sector of the study area might present conditions more suitable for turtles (Fig. 9A and 9C). Seafloor sediment resulted as the most significant factor in summer models (Papale et al., 2020; Rako et al., 2013).

#### Encounter Rate Model

The models based on ER predicted highly suitable areas mainly offshore with ensemble approach whilst presence/absence model suggested that the suitable areas are nearby the coast of Losinj and some part in the south (Fig. 9B and 9D). The predictions of for summer 2020 with encounter rate data were also similar to those of 2019; highly suitable areas for the loggerhead sea turtles were located offshore.

### *6.1.2 Winter 2019-2020*

#### Presence-Absence Model

In winter, areas with high concentration of dissolved oxygen (240-245 mmol/m$^3$) and medium-fine sand seafloor surface. Were predicted as highly suitable for loggerhead sea turtles in the Cres-Losinj archipelago (Fig. 9A and 9C). High suitability areas were observed in the north-western part of the study area (Rovinj, Pula and Susak) in winter 2019 whilst the southwestern part of Losinj resulted as more suitable in winter 2020,

#### Encounter Rate Model

The suitable areas for loggerhead sea turtles in winter 2019 predicted with ER data and ensemble model were mainly located offshore and along the north-eastern coast of the study area (Fig. 9B and 9D). In winter 2020 models, both modelling techniques predicted the southern areas of the archipelago as the most suitable.

### *6.1.3 Summer to Winter*

#### Presence-Absence Model

In general, highly suitable areas for loggerhead sea turtles were predicted far from the coast, where the water depths range from 40-60 m in summer, and 20-40 m during winter (Fig. 9A and 9C). The models showed differences in the spatial distribution between summer and winter. The suitable conditions for turtles are mainly located in the northern sector of the modelled area in winter, whilst the southern, offshore area resulted as more suitable in summer. Seafloor sediment, bathymetry, and sea water properties (i.e., dissolved oxygen and phytoplankton concentration) were the major contributing factors to the predictions.

## Encounter Rate Model

The predictions for summer and winter showed similar results with both ensemble and single-model approach. The highly suitable areas for the loggerhead sea turtles were mainly located offshore, far from the coastal areas (Fig. 9B and 9D).

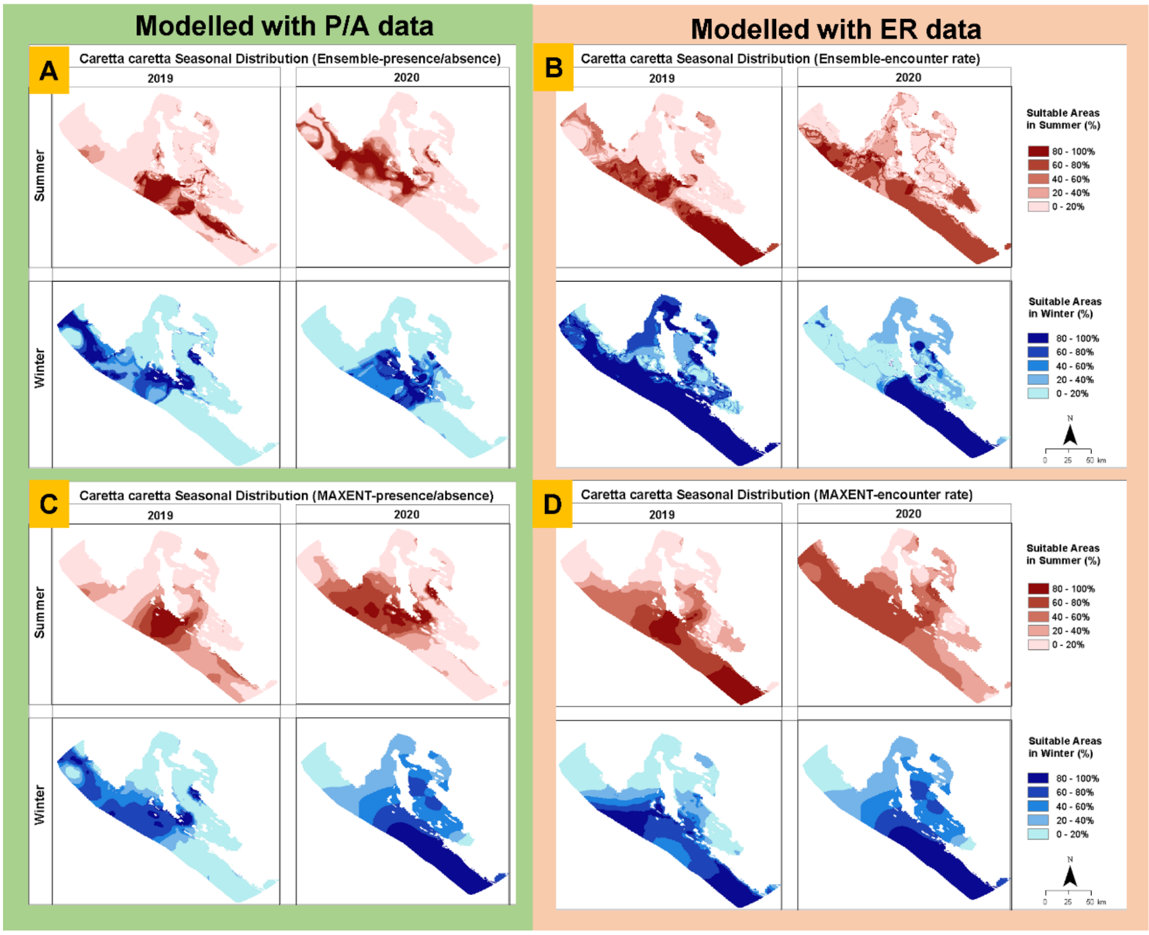

**Figure 9. (A)** Ensemble model prediction of seasonal distribution of loggerhead sea turtles from 2019-2020 using presence-absence data; **(B)** Ensemble model prediction using encounter rate data; **(C)** Maxent model prediction using presence-absence data; **(D)** Maxent model prediction of loggerhead sea turtles using encounter rate data. High-resolution versions of the figures are available in the appendices.

# 7 Anthropogenic influence in the HSM and species distribution

## 7.1 Influence on bottlenosedolphins

### Presence-Absence Model

The predicted distribution of areas suitable for the presence of bottlenose dolphins was not significantly different to those obtained by using only environmental variables. The south of Pula and Medulin area, and southwest of Cres and Losinj resulted as highly suitable for bottlenose dolphins (Fig. 10A).

During summer season, the high suitability of occurrence was observed in areas close to fish farms, characterized by high concentration of Chl-a and medium-fine sand substrates. Model predictions in winter season reported a high suitability for bottlenose dolphin around Losinj and south of Pula. These areas presented medium-fine sand seafloor, medium-high phytoplankton concentration, and were located nearby gasoline stations (only in Losinj) (Fig.10A). Since gasoline stations were also used as proxy for the possible presence of fishing or recreational boats, the results suggest that dolphins might be potentially influenced by the presence of boats during winter.

In summary, the presence of fish farms during summer and gasoline stations during winter were contributing factors to the observed suitability, potentially influencing the presence of bottlenose dolphins.

### Encounter Rate Mode

The single-model predictions for summer 2020 suggest that areas nearby the coast might be more suitable for bottlenose dolphins (Fig. 10B). Highly suitable areas were located at the periphery of the gasoline stations, suggesting a role of boat presence. in the final prediction. On the contrary, the results from ensemble model showed only small portions of the study area as suitable for bottlenose dolphins during summer 2020.

The predictions of the two models for winter 2020 were strongly different. The single-model approach predicted high suitable areas (60-80%) around the coastal areas, but the ensemble model predicted the sea areas low suitable. The ensemble model projected highly suitable areas offshore of the north-western part of the study area.

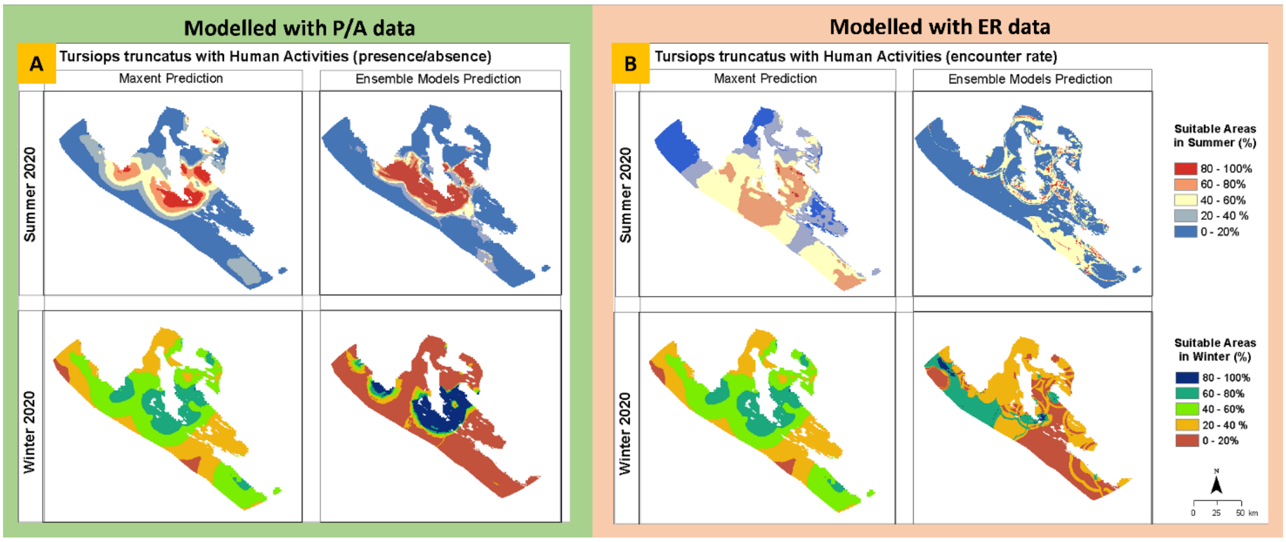

**Figure 10. (A)** Maxent and Ensemble models' prediction of the distribution of bottlenose dolphins with consideration of human activities without noise data and using presence-absence data.; **(B)** Prediction using encounter rate data. Higher-resolution version of the figures are available in the Appendix.

## 7.2 Influence on loggerhead sea turtles

### Presence-Absence Model

The inclusion of anthropic activities to models changed the distribution of highly suitable areas obtained considering only environmental variables (Fig. 11A). High suitability values were predicted in areas nearby the coast characterized by medium-sand seafloor, medium-high Chl-a concentration, and by the presence of fish farms and marinas. The models suggest that loggerhead sea turtles might be found near the marinas and fish farms (0.2-0.3 Euclidean distance).

Highly suitable areas were observed in the Losinj area for the winter period, while low suitability values were obtained around Pula (Fig. 11A). The highest suitable areas occurred nearby the gasoline stations, and in environments characterized by medium-fine sand seafloor, waters (water depth of 40-60 m, and medium-high concentration of dissolved oxygen.

### Encounter Rate Model

Contrarily to the presence/absence predictions, the models based on ER showed suitable areas for the loggerhead sea turtles occurring far from human activities (Fig. 11B). Low suitability was observed nearby the coastal areas, while high suitability was predicted in the offshore areas.

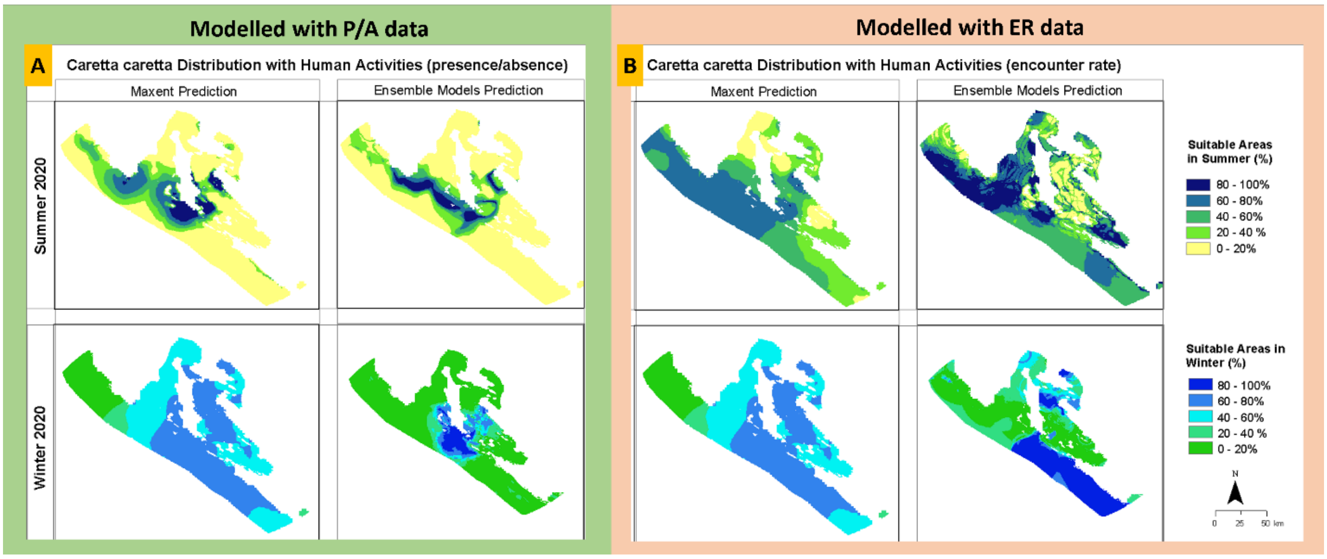

**Figure 11. (A)** Maxent and Ensemble models' prediction of the distribution of loggerhead sea turtles with consideration of human activities without noise data and using presence-absence data; **(B)** Prediction using encounter rate data. Higher-resolution version of the figures are available in the Appendix.

## 7.3 Influence of underwater noise

Figures3 and 4 show the noise distribution for each frequency at 50 percentile calculated by QUONOPS model during the month of October 2020, the only available at the time of the study and the only matching with the time of target data. This model is based only on AIS data so it does not take into account the noise produced by recreational boats. In the deliverable 4.4.2, the relationship between records and recreational boats suggested that at the 50 percentile the offshore hydrophone (Susak) recorded levels of noise higher than the Losinj hydrophone and that it is not possible to correlate directly recreational boat passages with recorded noise. This means that the noise map in figure X are the most objective representation of the monthly underwater noise in the area.

### Presence-Absence Model

Noise data that were simulated using the 1/3 octave band frequencies centred at 250 and 4000 Hz, which were included in the HSM to test for variations in species distribution.

The inclusion of underwater noise data in the HSM revealed a positive relationship between underwater noise and the predicted suitable areas for the two target species (Fig. 12). Suitable areas for bottlenose dolphins were highly predicted in areas with sound level of 82-83 dB at cantered frequency of 4000 Hz around Losinj, Susak and Ilovik. Using lower frequency (250 Hz 1/3 octave band), the model predicted similar pattern including additional areas away from the coast with low suitability (<40%). Higher probability of dolphin occurrence can be predicted at 83 dB using 4000 Hz 1/3 octave band, and at 86 dB with 250 Hz 1/3 octave band.

The predictions for loggerhead sea turtles, using different frequency, were very different from each other. Larger areas of possible loggerhead presence were predicted using 4000 Hz than with noise data simulated at 250 Hz, resulting to wider spatial distribution of turtle presence away from the coast. These results cannot be related to the direct effect of noise on turtles because they cannot hear this frequency but can be considered as indirect effect. In contrast, HSM simulated with 250 Hz only identified possible areas of turtle presence nearby the coasts of Losinj, Susak, and Ilovik (Fig. 12). Underwater noise of 84 dB (4000 Hz 1/3 octave band) and 85 dB (250 Hz 1/3 octave band) suggests a 40% probability of turtle presence in the area.

## Encounter rate Model

The predictions simulated using ER data show an indirect relationship of underwater noise to both target species, which contrasted with the presence-absence HSM prediction (Fig. 13). Suitable areas for bottlenose dolphins were predicted in areas away from the shore and characterized by higher level of noise (4000 Hz), except at coast of Lopar and Ilovik, where the calculated noise is slightly lower.

The prediction for loggerhead sea turtles was also very different from the presence-absence HSM projection. The most suitable areas include offshore waters characterized by higher underwater noise (250 Hz).

In summary, the presence-absence HSM predictions and encounter rate HSM predictors suggests almost opposite distribution. The only common area for both target species predicted by every model is the southern extreme part of Losinj island, which has relatively low noise for 1/3 octave band 250 Hz and medium for 1/3 octave band at 4000 Hz.

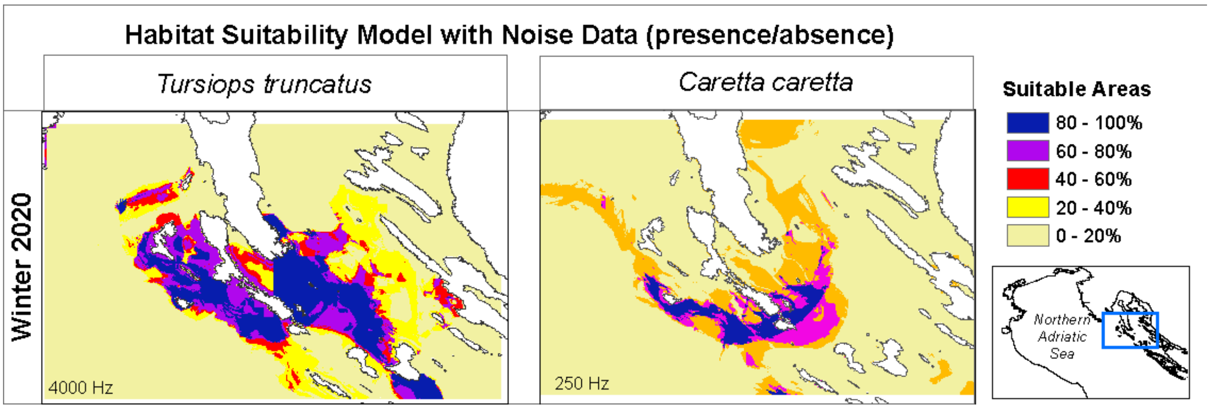

**Figure 12.** Probable distribution of the target species when simulated using both 4000Hz and 250Hz noise data and presence-absence data.

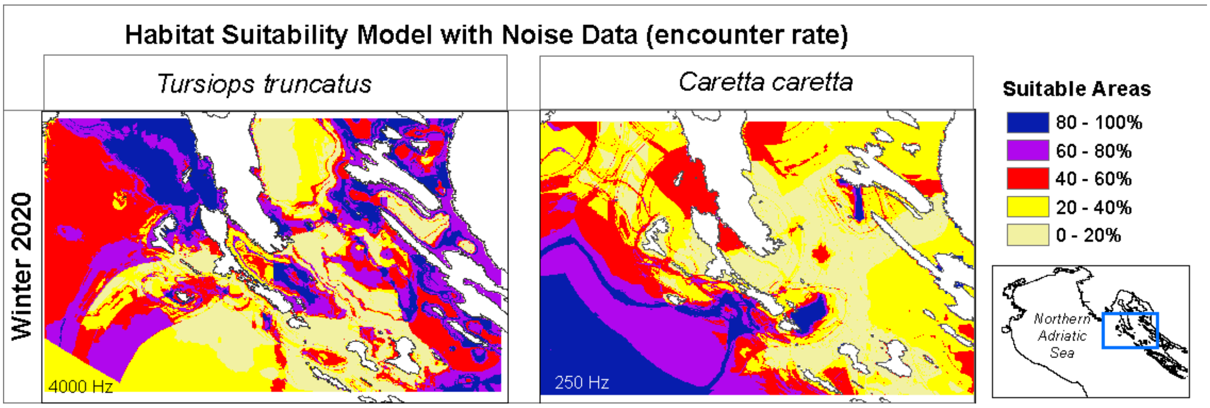

**Figure 13.** Probable distribution of the target species when simulated using both 4000Hz and 250Hz noise data and encounter rate data.

# 8 Discussion

This study describes the prediction of suitable areas for the presence of bottlenose dolphins and loggerhead seaturtles for the Cres-Losinj archipelago. Both environmental and anthropogenic variables were utilized to model suitable areas for the winter and summer seasons.

### 8.1.1 Habitat suitability models

It must be noted that models using presence-absence data differed significantly from the models using ER, in some cases giving opposite results. However, the presence/absence models reported consistently better performance than models based on ER. This can be attributed to differences in the amount of available data. Presence-absence data used in this study were collected during boat-based surveys (detailed in Deliverable D4.1.1) and citizen science application, resulting in a larger data set, potentially increasing modelling performances. However, this data does not consider the amount of research effort and is therefore biased towards over representing areas where researchers during boat surveys or leisure boaters reported sightings via citizen science application spend most of the time. These areas presented a higher density of marine traffic and were characterized by larger values of underwater noise.

Despite ER data are a better descriptor of the species' preference by considering the amount of research effort, models using ER showed generally poor performance. This can be attributed to insufficient amount of encounter rate data. However, the predictions from the models using ER were more in line with results from previous studies on bottlenose dolphins and loggerhead turtles in the study area (see details for each target species below). Despite deficiencies in both approaches, our efforts aim at orienting future research activities: habitat suitability models developed here provide a good baseline about the presence of suitable area for bottlenose dolphin and loggerhead turtle in the Cres-Losinj archipelago. However, more modelling efforts based on larger datasets reporting ER information are needed.

### 8.1.2 Bottlenose Dolphin Habitats

In general, our results suggest that bottlenose dolphins in the area might prefer shallow waters (20-70 m), with high nutrients concentration (Chl-a and phytoplankton), moderate-saline water, and in seafloor areas with soft substrate. Previous studies have shown that environmental variables such as Chl-a levels, SST, and salinity play a major role in defining bottlenose dolphin suitable habitats. High nutrients in seawater may indicate an increase in primary production and may represent a proxy of prey distribution.

Moreover, bottlenose dolphins are commonly spotted in shallow waters (<100m) that might represent preferred feeding grounds. The neritic domain has been identified as hosting food sources, potentially influencing the dolphin presence (Bearzi et al., 2009; Carlucci et al., 2018, 2016; Gómez de Segura et al., 2008; La Manna et al., 2016; Marini et al., 2015; Muckenhirn et al., 2021). In addition, neritic area includes habitats (such as seagrass meadows) which host a variety of demersal prey including European hake (*Merlucciusmerluccius*) and European conger (*Congerconger*), commonly consumed by bottlenose dolphins (Muckenhirn et al., 2021). Moreover, bottlenose dolphins in the northern Adriatic are have been documented to prefer neritic zones than oceanic zone areas (Fortuna et al., 2010).

Studies on bottlenose dolphins have reported an inverse relationship between dolphin presence and recreational activities and maritime traffic (Marley et al., 2017; Rako et al., 2013a), but direct relationship to fish farming and fishing vessels (Bearzi et al., 1997; Castellote et al., 2015; Fortuna, 2007). In this study, the models support the latter statement, since suitable areas for dolphin were observed close to fish farms and areas likely presenting fishing vessels, suggesting that these situations might provide foraging benefits. Bottlenose dolphins have commonly been reported to feed close to floating cages, and to follow fishing boats to feed on discarded fish or seize fish from the nets (Bearzi et al., 2009; Castellote et al., 2015; Fortuna et al., 2010). Dolphins observed following bottom trawlers to feed has been documented in various areas of the Adriatic Sea (Holcer, 2012; Pleslić et al., 2021).

Our models using presence/absence data suggested that areas close to popular destinations, i.e., most heavily frequented by boaters, might be suitable for bottlenose dolphins. However, models with ER suggest more that areas offshore and far from those destinations might be more suitable for dolphins, in accordance with the results of previous studies. On the scale of the whole Adriatic, aerial surveys conducted in 2010 and 2013 found highest predicted densities of bottlenose dolphins in offshore waters of the northern Adriatic(Fortuna et al., 2018). Furthermore, when considering only part of the Cres-Lošinj archipelago, bottlenose dolphins tend to prefer the areas far from the eastern coast of island of Lošinj (see Figure 3.3 in Fortuna 2007).

### 8.1.3 Loggerhead Sea Turtle Habitats

The northern Adriatic Sea represents key area for adult loggerhead sea turtles because hosts a rich population of benthic invertebrates (main prey of adult loggerhead), which serves as foraging area for loggerhead during winter season (Bjorndal, 2017; Casale et al., 2018; Hochscheid et al., 2007; Zbinden et al., 2008). Our models suggest that the suitable areas for loggerhead sea turtles in the Cres-Losinj archipelago might be characterized by medium-fine sand seafloor, shallow water depths (40-60 m), with medium-high concentration of phytoplankton and dissolved oxygen.

Preference to sandy seafloor could be related with the foraging habits of the loggerhead turtles on the seabed. Larger juvenile and adult loggerhead turtles favour invertebrates such as crabs, hermit crabs, bivalves, gastropods, and cephalopods, which inhabit in soft-bottom sediments (Casale et al., 2018). The highly suitable areas for loggerhead turtles were observed in areas with nutrient-rich water (i.e., high phytoplankton concentration), which is likely attributed to prey distribution in those areas. In oceanic areas, loggerhead sea turtles rely primarily on gelatinous plankton (jellyfish and tunicates), with fishes and squid representing a supplement to their diet (Casale et al., 2018). Loggerhead turtles may also consume large amounts of fish discarded by fishing vessels (Houghton et al., 2000; Tomas et al., 2006), which may explain the predicted high suitability of areas near the fish farms and boat hubs, resulting from the models.

Seasonal changes in sea water temperature do not usually elicit seasonal migrations of loggerhead, except in the Northern Adriatic Sea (Zbinden et al., 2008). The model results show similar findings reporting differences in the spatial distribution of suitable areas between summer and winter seasons. The turtle stend to move from the coast to further offshore, and from north to south within the study area. Recent studies have shown that in some cases, loggerhead sea turtles prefer the shallow waters in summer and then migrate to deeper offshore areas during the winter(Broderick et al., 2007; Casale and Simone, 2017).

When compared to bottlenose dolphins, results of all models for loggerhead turtles are in accordance with previous knowledge on their distribution within the Adriatic Sea, showing the highest densities of loggerhead turtles in offshore areas of the northern Adriatic Sea (Fortuna et al. 2018). Here, all models predicted suitable habitats on the western side of Cres-Lošinj archipelago and offshore, in accordance with ER data (see Figure 29 to Figure 33 in Deliverable D4.1.1). However, the results of presence/absence models were probably reflecting the research effort rather than the presence of turtles. Despite presenting low performances, in fact, ER models predicted suitable area west of the outer stretch of islands and further far from the coast.

### 8.1.4 Soundscape influence on habitats

The influence of underwater noise to the habitats of the target species varies depending on the type of dataset that was used for the HSM. The HSM with the presence-absence data shows a positive relationship with noise data, but the model with encounter rate data an inverse relationship. This suggests that the selection of input data to model the relationship of underwater noise to the habitats is an essential step and requires guidance from the species expert. Moreover, this study is based on citizen science data provided by BWI in a short temporal period and restricted area, which surely represent a limit for modelling. Furthermore, it must be noted that here only AIS data were used and therefore further studies are needed to investigate the influence of leisure boat traffic and related noise on the habitat suitability for the target species.

Studies on the impact of underwater noise to marine mammals and turtles have been conducted in recent years (Accomando et al., 2020; Bailey et al., 2010; Bartol and Bartol, 2014; Finneran and Schlundt, 2007; Houser and Finneran, 2006; Marley et al., 2017; Rako Gospić and Picciulin, 2016; Rako et al., 2013b). Focus have been given on how sound can affect the species behaviour and population, but only few have studied how the soundscape can influence the habitat preference and distribution of the species (Papale et al., 2020; Rako et al., 2013b).

The incorporation of underwater noise data to the HSM of bottlenose dolphins exhibit a direct relationship between noise and dolphin presence. This is contrary to previous study in Cres-Losinj, where dolphin avoidance in noisy areas was documented (Rako et al., 2013). The difference might be caused by the unusual ambient setting in the area during data collection. Most of the presence data were collected during the Covid-19 lockdown period, thus lesser maritime traffic and under water noise were recorded. It must be noted, at the time of the study, only under water noise simulated by QUONOPS model in Autumn 2020 in the Losinj restricted area was available. In this case the variability in the noise map is very limited.

Dolphin presence was detected at 82-84 dB (4000 Hz 1/3 octave band) and at 86 dB (250 Hz 1/3 octave band). Experiments with bottlenose dolphins have shown that high levels of noise exposure are needed to induce temporary threshold shifts, and above 40 kHz is needed to cause hearing loss to dolphins (Finneran et al., 2005; Finneran and Schlundt, 2007; Houser and Finneran, 2006; Schlundt et al., 2000). Moreover, research suggest that bottlenose dolphin thresholds were more than 20 dB above the ambient noise spectral density at all frequencies (1-100 kHz) (Finneran and Schlundt, 2007).

In contrary, loggerhead sea turtles and underwater noise have an inverse relationship despite the unusual ambient setting during data collection. Low probability of turtle presence was obtained when noise data at 250 Hz 1/3 octave band was simulated in the HSM. However, it changed when we used higher noise frequency; wider areas were predicted with very good probability of loggerhead turtle occurrence. A study on the hearing capabilities of loggerhead sea turtles found that they only respond to low frequencies (<1200 Hz) and at levels of 85-117 dB re. 1µPa. Both post-hatchlings and juveniles respond to founds between 50 and 1200 Hz (Bartol and Bartol, 2014). Another study suggests that loggerhead sea turtles have low frequency hearing with best sensitivity between 100 and 400 Hz, and threshold of 110 dB re.1µPa(Martin et al., 2012). As a result, although he 4000 Hz 1/3 octave band cannot be not directly detectable by the species, it might be associated to geophonic components like wind intensity, being therefore a possible proxy about the presence of macro- and mega-zooplankton brought to the coast by higher wind intensity (Papale et al., 2020).

### 8.1.5 Limitations and Recommendations

This study suggests that using encounter rate data can provide HSMs that are more representative to real-life observations but have low accuracy. On the other hand, presence-absence derived HSMs are more statistically accurate, but the model may reflect the research effort rather than the distribution of turtles. The inconsistencies between models with different set of data may be attributed to the inappropriate scale of data that were used for the HSMs. The environmental data used for the models are rescaled data for the Northern Adriatic, and thus have too coarse grids to model a smaller study area. As a result, the data used may not capture the actual conditions in the study area and may consequently affect the accuracy of the HSM predictions. This limitation may be addressed by using higher-resolution data that are scaled specifically to the study site or increase the size of the study area to be modelled to match the resolution of the data. However, larger study areas require additional presence data to improve model performance.

Another limitation that was encountered in this study is the challenge to choose the most appropriate model. If modellers have little biological knowledge, the decision to select the best models will be based on the statistical performance of the model because they are unaware of the real-life scenarios. Therefore, it is recommended that an expert is necessary to evaluate which HSMs would represent a more realistic scenario.

# 9 Conclusion

This report provides information on the suitable habitat conditions for the bottlenose dolphins and caretta during different seasons (summer and winter). The results presented highlights the different conditions for the two species with and without the presence of anthropogenic activities and underwater noise. This will aid in the understanding of the potential relationships between the species and their habitat within the study area, and how they will respond to underwater noise. Moreover, the habitat suitability models from this report can assist in the development of effective ecosystem management strategies for the two target species, under the framework of the SOUNDSCAPE project.

# 10 References

Accomando, A.W., Mulsow, J., Branstetter, B.K., Schlundt, C.E., Finneran, J.J., 2020. Directional hearing *sensitivity* for 2–30 kHz sounds in the bottlenose dolphin ( *Tursiops truncatus* ). The Journal of the Acoustical Society of America 147, 388–398. https://doi.org/10.1121/10.0000557

Araujo, M., New, M., 2007. Ensemble forecasting of species distributions. Trends in Ecology & Evolution 22, 42–47. https://doi.org/10.1016/j.tree.2006.09.010

Arko-Pijevac, M., Benac, Č., Kovačić, M., Kirinčić, M., Gržančić, Ž., Besendorfer, V., 2003. Ecological and geological valorisation of the coastal line and submarine area of the islands Ćutin mail and Ćutin veli aiming to establish a protected area. U: Zbornik sažetaka priopćenja Osmog hrvatskog biološkog kongresa. Hrvatsko biološko društvo, Zagreb 407–408.

Bailey, H., Senior, B., Simmons, D., Rusin, J., Picken, G., Thompson, P.M., 2010. Assessing underwater noise levels during pile-driving at an offshore windfarm and its potential effects on marine mammals. Marine Pollution Bulletin 60, 888–897. https://doi.org/10.1016/j.marpolbul.2010.01.003

Bartol, S.M., Bartol, I.K., 2014. Hearing Capabilities of Loggerhead Sea Turtles (Caretta caretta) throughout Ontogeny: An Integrative Approach involving Behavioral and Electrophysiological Techniques (No. JIP Grant No.22 07-14). Norfolk, VA.

Bearzi, G., Fortuna, C.M., Reeves, R.R., 2009. Ecology and conservation of common bottlenose dolphins *Tursiops truncatus* in the Mediterranean Sea. Mammal Review 39, 92–123. https://doi.org/10.1111/j.1365-2907.2008.00133.x

Bearzi, G., Notarbartolo-DI-Sciara, G., Politi, E., 1997. Social ecology of bottlenose dolphins in the Kvarberic (Northern Adriatic Sea). Marine Mammal Sci 13, 650–668. https://doi.org/10.1111/j.1748-7692.1997.tb00089.x

Bearzi, G., Politi, E., Agazzi, S., Bruno, S., Costa, M., Bonizzoni, S., 2005. Occurrence and present status of coastal dolphins (Delphinus delphis andTursiops truncatus) in the eastern Ionian Sea. Aquatic Conserv: Mar. Freshw. Ecosyst. 15, 243–257. https://doi.org/10.1002/aqc.667

Bearzi, G., Politi, E., Sciara, G.N., 1999. DIURNAL BEHAVIOR OF FREE-RANGING BOTTLENOSE DOLPHINS IN THE KVARNERIĆ (NORTHERN ADRIATIC SEA)1. Marine Mammal Sci 15, 1065–1097. https://doi.org/10.1111/j.1748-7692.1999.tb00878.x

Bjorndal, K.A., 2017. Foraging ecology and nutrition of sea turtles., in: The Biology of Sea Turtles. CRC press, p. pp.199-231.

Breiner, F.T., Guisan, A., Bergamini, A., Nobis, M.P., 2015. Overcoming limitations of modelling rare species by using ensembles of small models. Methods Ecol Evol 6, 1210–1218. https://doi.org/10.1111/2041-210X.12403

Broderick, A.C., Coyne, M.S., Fuller, W.J., Glen, F., Godley, B.J., 2007. Fidelity and over-wintering of sea turtles. Proc. R. Soc. B. 274, 1533–1539. https://doi.org/10.1098/rspb.2007.0211

Carlucci, R., Cipriano, G., Paoli, C., Ricci, P., Fanizza, C., Capezzuto, F., Vassallo, P., 2018. Random Forest population modelling of striped and common-bottlenose dolphins in the Gulf of Taranto (Northern Ionian Sea, Central-eastern Mediterranean Sea). Estuarine, Coastal and Shelf Science 204, 177–192. https://doi.org/10.1016/j.ecss.2018.02.034

Carlucci, R., Fanizza, C., Cipriano, G., Paoli, C., Russo, T., Vassallo, P., 2016. Modeling the spatial distribution of the striped dolphin ( Stenella coeruleoalba ) and common bottlenose dolphin ( Tursiops truncatus ) in the Gulf of Taranto (Northern Ionian Sea, Central-eastern Mediterranean Sea). Ecological Indicators 69, 707–721. https://doi.org/10.1016/j.ecolind.2016.05.035

Casale, P., Affronte, M., Scaravelli, D., Lazar, B., Vallini, C., Luschi, P., 2012. Foraging grounds, movement patterns and habitat connectivity of juvenile loggerhead turtles (Caretta caretta) tracked from the Adriatic Sea. Mar Biol 159, 1527–1535. https://doi.org/10.1007/s00227-012-1937-2

Casale, P., Broderick, A., Camiñas, J., Cardona, L., Carreras, C., Demetropoulos, A., Fuller, W., Godley, B., Hochscheid, S., Kaska, Y., Lazar, B., Margaritoulis, D., Panagopoulou, A., Rees, A., Tomás, J., Türkozan, O., 2018. Mediterranean sea turtles: current knowledge and priorities for conservation and research. Endang. Species. Res. 36, 229–267. https://doi.org/10.3354/esr00901

Casale, P., Simone, G., 2017. Seasonal residency of loggerhead turtles Caretta caretta tracked from the Gulf of Manfredonia, south Adriatic. Medit. Mar. Sci. 18, 4. https://doi.org/10.12681/mms.1663

Castellote, M., Brotons, J.M., Chicote, C., Gazo, M., Cerdà, M., 2015. Long-term acoustic monitoring of bottlenose dolphins, Tursiops truncatus, in marine protected areas in the Spanish Mediterranean Sea. Ocean & Coastal Management 113, 54–66. https://doi.org/10.1016/j.ocecoaman.2015.05.017

Chatterjee, S., Hadi, A.S., 2006. Regression Analysis by Example, Fourth. ed. John Wiley & Sons, Inc., Hoboken, New Jersey.

Duncan, E., Botterell, Z., Broderick, A., Galloway, T., Lindeque, P., Nuno, A., Godley, B., 2017. A global review of marine turtle entanglement in anthropogenic debris: a baseline for further action. Endang. Species. Res. 34, 431–448. https://doi.org/10.3354/esr00865

ESRI, 2011. ArcGIS Desktop: Release 10. Environmental Systems Research Institute., Redlands, CA.

Favro, S., Saganić, I., 2017. Prirodna obilježja hrvatskog litoralnog prostora kao komparativna prednost za razvoj nautičkog turizma. Geoadria 12, 59–81. https://doi.org/10.15291/geoadria.116

Finneran, J.J., Carder, D.A., Schlundt, C.E., Ridgway, S.H., 2005. Temporary threshold shift in bottlenose dolphins (Tursiops truncatus) exposed to mid-frequency tones. J.Acoust.Soc.Am. 118, 2696–2705. https://doi.org/10.1121/1.2032087

Finneran, J.J., Schlundt, C.E., 2007. Underwater sound pressure variation and bottlenose dolphin (Tursiops truncatus) hearing thresholds in a small poola). J.Acoust.Soc.Am. 122, 606–614.

Fortuna, C.M., 2007. Ecology and conservation of bottlenose dolphins (Tursiops truncatus) in the north-eastern Adriatic Sea (Doctoral dissertation). University of St Andrews.

Fortuna, C.M., Cañadas, A., Holcer, D., Brecciaroli, B., Donovan, G.P., Lazar, B., Mo, G., Tunesi, L., Mackelworth, P.C., 2018. The Coherence of the European Union Marine Natura 2000 Network for Wide-Ranging Charismatic Species: A Mediterranean Case Study. Front. Mar. Sci. 5, 356. https://doi.org/10.3389/fmars.2018.00356

Fortuna, C.M., Vallini, C., Filidei, E., Ruffino, M., Consalvo, I., Di Muccio, S., Gion, C., Scacco, U., Tarulli, E., Giovanardi, O., Mazzola, A., 2010. By-catch of cetaceans and other species of conservation concern during pair trawl fishing operations in the Adriatic Sea (Italy). Chemistry and Ecology 26, 65–76. https://doi.org/10.1080/02757541003627662

Galvez, D., Papenmeier, S., Sander, L., Hass, H., Fofonova, V., Bartholomä, A., Wiltshire, K., 2021. Ensemble Mapping and Change Analysis of the Seafloor Sediment Distribution in the Sylt Outer Reef, German North Sea from 2016 to 2018. Water 13, 2254. https://doi.org/10.3390/w13162254

Gómez de Segura, A., Hammond, P.S., Raga, J.A., 2008. Influence of environmental factors on small cetacean distribution in the Spanish Mediterranean. J. Mar. Biol. Ass. 88, 1185–1192. https://doi.org/10.1017/S0025315408000386

Guisan, A., Thuiller, W., Zimmermann, N.E., 2017. Habitat Suitability and Distribution Models: With Applications in R. Cambridge University Press, Cambridge. https://doi.org/10.1017/9781139028271

Hastie, G.D., Wilson, B., Wilson, L.J., Parsons, K.M., Thompson, P.M., 2004. Functional mechanisms underlying cetacean distribution patterns: hotspots for bottlenose dolphins are linked to foraging. Marine Biology 144, 397–403. https://doi.org/10.1007/s00227-003-1195-4

Hirzel, A.H., Helfer, V., Metral, F., 2001. Assessing habitat-suitability models with a virtual species. Ecological Modelling 145, 111–121. https://doi.org/10.1016/S0304-3800(01)00396-9

Hochscheid, S., Bentivegna, F., Bradai, M., Hays, G., 2007. Over-wintering in sea turtles: dormancy is optional. Mar Ecol Prog Ser 340, 287–298.

Holcer, D., 2012. Ecology of the common bottlenose dolphin, Tursiops truncatus (Montagu, 1821) in the Central Adriatic sea. (PhD Thesis). University of Zagreb.

Houghton, J.D.R., Woolmer, A., Hays, G.C., 2000. Sea turtle diving and foraging behaviour around the Greek Island of Kefalonia. J. Mar. Biol. Ass. 80, 761–762. https://doi.org/10.1017/S002531540000271X

Houser, D.S., Finneran, J.J., 2006. A comparison of underwater hearing sensitivity in bottlenose dolphins (Tursiops truncatus) determined by electrophysiological and behavioral methods. The Journal of the Acoustical Society of America 120, 1713–1722. https://doi.org/10.1121/1.2229286

Jongman, R.H.G., Ter Braak, C.J.F., Van Tongeren, O.F.R., 1987. Data Analysis in Community and Landscape Ecology. Cambridge University Press, Cambridge.

La Manna, G., Ronchetti, F., Sarà, G., 2016. Predicting common bottlenose dolphin habitat preference to dynamically adapt management measures from a Marine Spatial Planning perspective. Ocean & Coastal Management 130, 317–327. https://doi.org/10.1016/j.ocecoaman.2016.07.004

Lazar, B., Margaritoulis, D., Tvrtković, N., 2004. Tag recoveries of the loggerhead sea turtle *Caretta caretta* in the eastern Adriatic Sea: implications for conservation. J. Mar. Biol. Ass. 84, 475–480. https://doi.org/10.1017/S0025315404009488h

Marini, C., Fossa, F., Paoli, C., Bellingeri, M., Gnone, G., Vassallo, P., 2015. Predicting bottlenose dolphin distribution along Liguria coast (northwestern Mediterranean Sea) through different modeling techniques and indirect predictors. Journal of Environmental Management 150, 9–20. https://doi.org/10.1016/j.jenvman.2014.11.008

Marley, S.A., Salgado Kent, C.P., Erbe, C., Parnum, I.M., 2017. Effects of vessel traffic and underwater noise on the movement, behaviour and vocalisations of bottlenose dolphins in an urbanised estuary. Sci Rep 7, 13437. https://doi.org/10.1038/s41598-017-13252-z

Martin, K.J., Alessi, S.C., Gaspard, J.C., Tucker, A.D., Bauer, G.B., Mann, D.A., 2012. Underwater hearing in the loggerhead turtle ( Caretta caretta): a comparison of behavioral and auditory evoked potential audiograms. Journal of Experimental Biology 215, 3001–3009. https://doi.org/10.1242/jeb.066324

McCullagh, P., Nelder, J., 1989. Generalized Linear Models, second ed. ed. Chapman and Hall, CRC, Boca Raton.

Muckenhirn, A., Akkaya Bas, A., Richard, F.-J., 2021. Assessing the Influence of Environmental and Physiographic Parameters on Common Bottlenose Dolphin (Tusiops truncatus) Distribution in the Southern Adriatic Sea &lt;sup&gt;†&lt;/sup&gt;, in: Proceedings of 1st International Electronic Conference on Biological Diversity, Ecology and Evolution. Presented at the 1st International Electronic Conference on Biological Diversity, Ecology and Evolution, MDPI, Sciforum.net, p. 9434. https://doi.org/10.3390/BDEE2021-09434

Naimi, B., Araújo, M.B., 2016. sdm: a reproducible and extensible R platform for species distribution modelling. Ecography 39, 368–375. https://doi.org/10.1111/ecog.01881

Naimi, B., Skidmore, A.K., Groen, T.A., Hamm, N.A.S., 2011. Spatial autocorrelation in predictors reduces the impact of positional uncertainty in occurrence data on species distribution modelling: Spatial autocorrelation and positional uncertainty. Journal of Biogeography 38, 1497–1509. https://doi.org/10.1111/j.1365-2699.2011.02523.x

Natoli, A., Birkun, A., Aguilar, A., Lopez, A., Hoelzel, A.R., 2005. Habitat structure and the dispersal of male and female bottlenose dolphins ( *Tursiops truncatus* ). Proc. R. Soc. B. 272, 1217–1226. https://doi.org/10.1098/rspb.2005.3076

Nicholls, A.O., 1989. How to make biological surveys go further with generalised linear models. Biological Conservation 50, 51–75. https://doi.org/10.1016/0006-3207(89)90005-0

Pace, D.S., Pulcini, M., Triossi, F., 2012. Anthropogenic food patches and association patterns of Tursiops truncatus at Lampedusa island, Italy. Behavioral Ecology 23, 254–264. https://doi.org/10.1093/beheco/arr180

Papale, E., Prakash, S., Singh, S., Batibasaga, A., Buscaino, G., Piovano, S., 2020. Soundscape of green turtle foraging habitats in Fiji, South Pacific. PLoS ONE 15, e0236628. https://doi.org/10.1371/journal.pone.0236628

Pinardi, N., Korres, G., Lascaratos, A., Roussenov, V., Stanev, E., 1997. Numerical simulation of the interannual variability of the Mediterranean Sea upper ocean circulation. Geophys. Res. Lett. 24, 425–428. https://doi.org/10.1029/96GL03952

Pleslić, G., Rako Gospić, N., Mackelworth, P., Wiemann, A., Holcer, D., Fortuna, C., 2015. The abundance of common bottlenose dolphins *(Tursiops truncatus)* in the former special marine reserve of the Cres-Lošinj Archipelago, Croatia: THE ABUNDANCE OF THE COMMON BOTTLENOSE DOLPHINS IN KVARNERIĆ, CROATIA. Aquatic Conserv: Mar. Freshw. Ecosyst. 25, 125–137. https://doi.org/10.1002/aqc.2416

Pleslić, G., Rako-Gospić, N., Holcer, D., 2021. Bottlenose dolphins ( *Tursiops truncatus* ) in North Dalmatia, Croatia: Occurrence and demographic parameters. Mar Mam Sci 37, 142–161. https://doi.org/10.1111/mms.12735

Rako Gospić, N., Picciulin, M., 2016. Changes in whistle structure of resident bottlenose dolphins in relation to underwater noise and boat traffic. Marine Pollution Bulletin 105, 193–198. https://doi.org/10.1016/j.marpolbul.2016.02.030

Rako, N., Fortuna, C.M., Holcer, D., Mackelworth, P., Nimak-Wood, M., Pleslić, G., Sebastianutto, L., Vilibić, I., Wiemann, A., Picciulin, M., 2013a. Leisure boating noise as a trigger for the displacement of the bottlenose dolphins of the Cres–Lošinj archipelago (northern Adriatic Sea, Croatia). Marine Pollution Bulletin 68, 77–84. https://doi.org/10.1016/j.marpolbul.2012.12.019

Rako, N., Picciulin, M., Vilibić, I., Fortuna, C.M., 2013b. Spatial and temporal variability of sea ambient noise as an anthropogenic pressure index: the case of the Cres-Lošinj archipelago, Croatia. J. Mar. Biol. Ass. 93, 27–36. https://doi.org/10.1017/S0025315412001233

Rako-Gospić, N., Radulović, M., Vučur, T., Pleslić, G., Holcer, D., Mackelworth, P., 2017. Factor associated variations in the home range of a resident Adriatic common bottlenose dolphin population. Marine Pollution Bulletin 124, 234–244. https://doi.org/10.1016/j.marpolbul.2017.07.040

Schlundt, C.E., Finneran, J.J., Carder, D.A., Ridgway, S.H., 2000. Temporary shift in masked hearing thresholds of bottlenose dolphins, Tursiops truncatus, and white whales, Delphinapterus leucas , after exposure to intense tones. J.Acoust.Soc.Am. 107, 3496–3508. https://doi.org/10.1121/1.429420

Shipley, B., Laughlin, D.C., Sonnier, G., Otfinowski, R., 2011. A strong test of a maximum entropy model of trait-based community assembly. Ecology 92, 507–517. https://doi.org/10.1890/10-0394.1

Thuiller, W., Lafourcade, B., Araujo, M., 2010. Presentation Manual for BIOMOD.

Thuiller, W., Lafourcade, B., Engler, R., Araújo, M.B., 2009. BIOMOD - a platform for ensemble forecasting of species distributions. Ecography 32, 369–373. https://doi.org/10.1111/j.1600-0587.2008.05742.x

Tomas, J., Aznar, F.J., Raga, J.A., 2006. Feeding ecology of the loggerhead turtle Caretta caretta in the western Mediterranean: Feeding ecology of Caretta caretta in the western Mediterranean. Journal of Zoology 255, 525–532. https://doi.org/10.1017/S0952836901001613

van der Roest, R.A., 2019. Habitat suitability mapping for Tursiops truncatus in the Aegean Sea (MSc Thesis). University of Ultrecht, The Netherlands.

Wood, S.N., 2006. Generalized Additive Models: an Introduction with R,. CRC Press.

Zbinden, J.A., Aebischer, A., Margaritoulis, D., Arlettaz, R., 2008. Important areas at sea for adult loggerhead sea turtles in the Mediterranean Sea: satellite tracking corroborates findings from potentially biased sources. Mar Biol 153, 899–906. https://doi.org/10.1007/s00227-007-0862-2

# 11 APPENDIX

High-resolution versions of the figures presented in the report

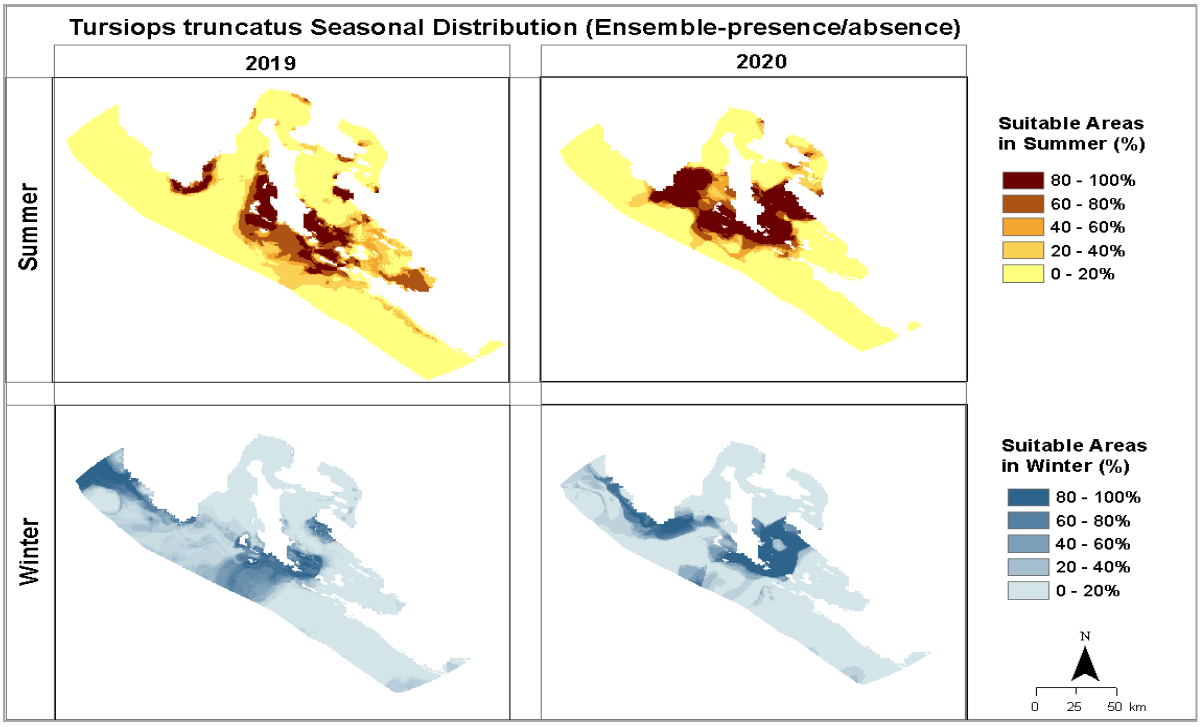

**Figure A.1.** Ensemble model prediction of seasonal distribution of bottlenose dolphins from 2019-2020 using presence-absence data

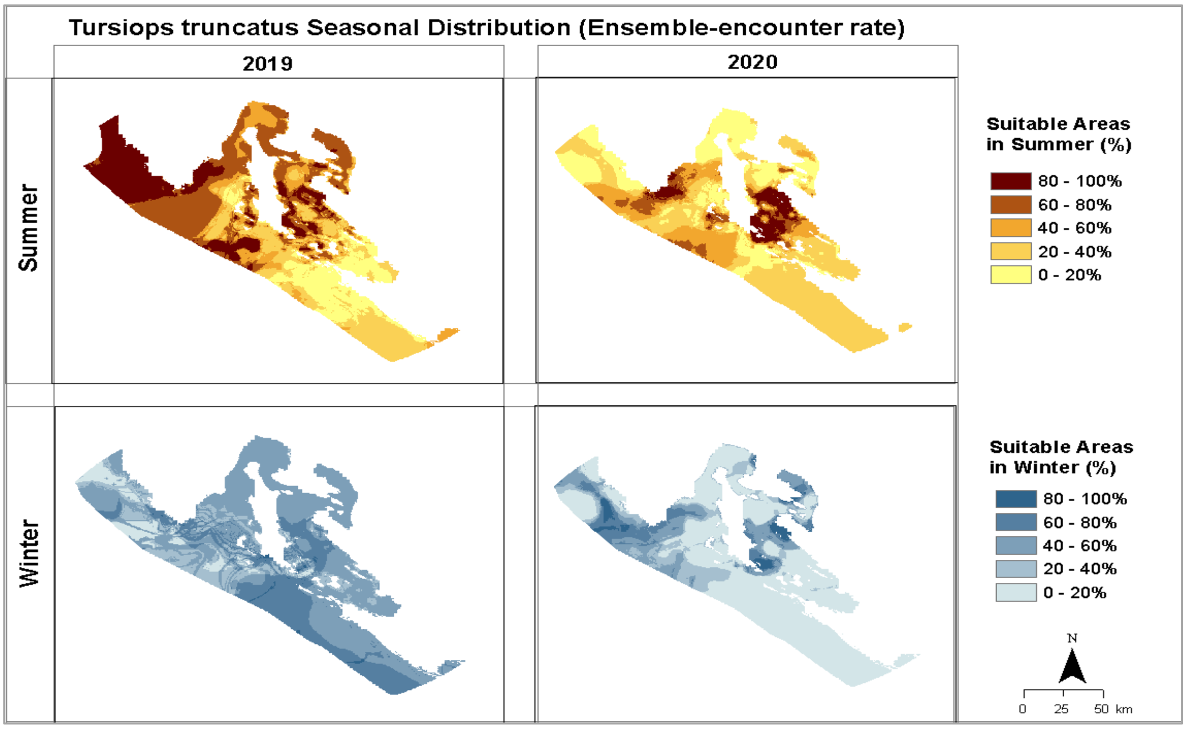

**Figure A.2.** Ensemble model prediction of seasonal distribution of bottlenose dolphins from 2019-2020 using encounter rate data

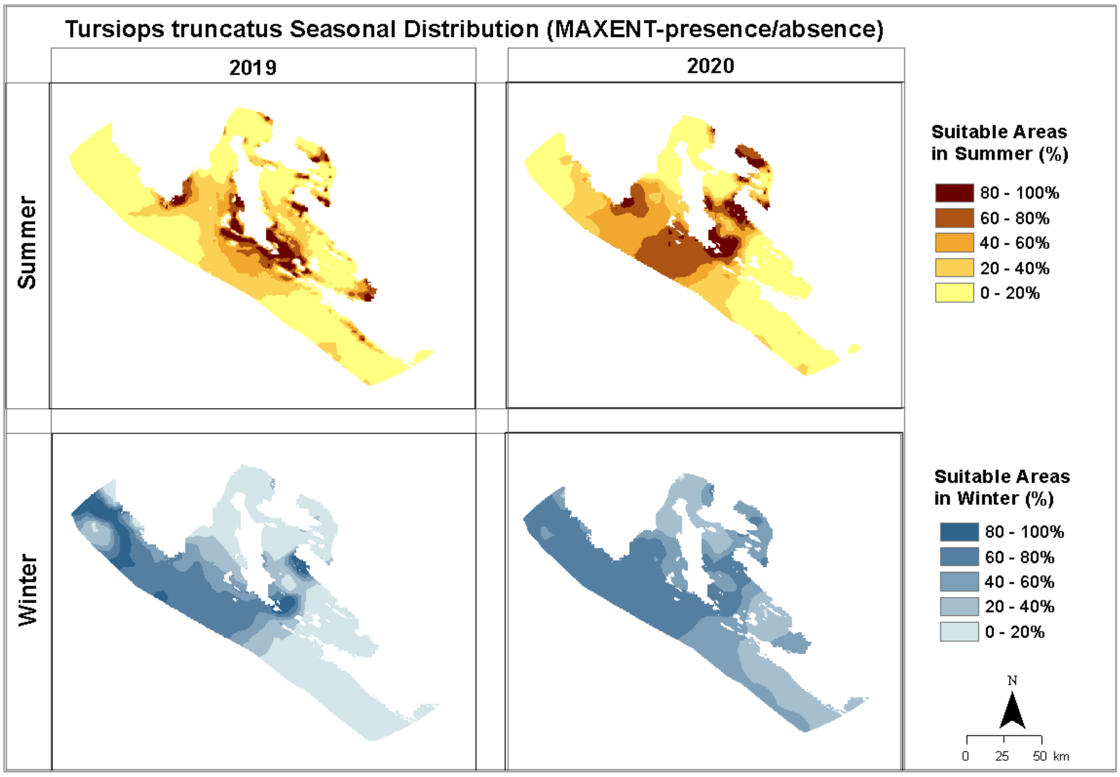

**Figure A.3.** Maxent single model prediction of seasonal distribution of bottlenose dolphins from 2019-2020 using presence-absence data

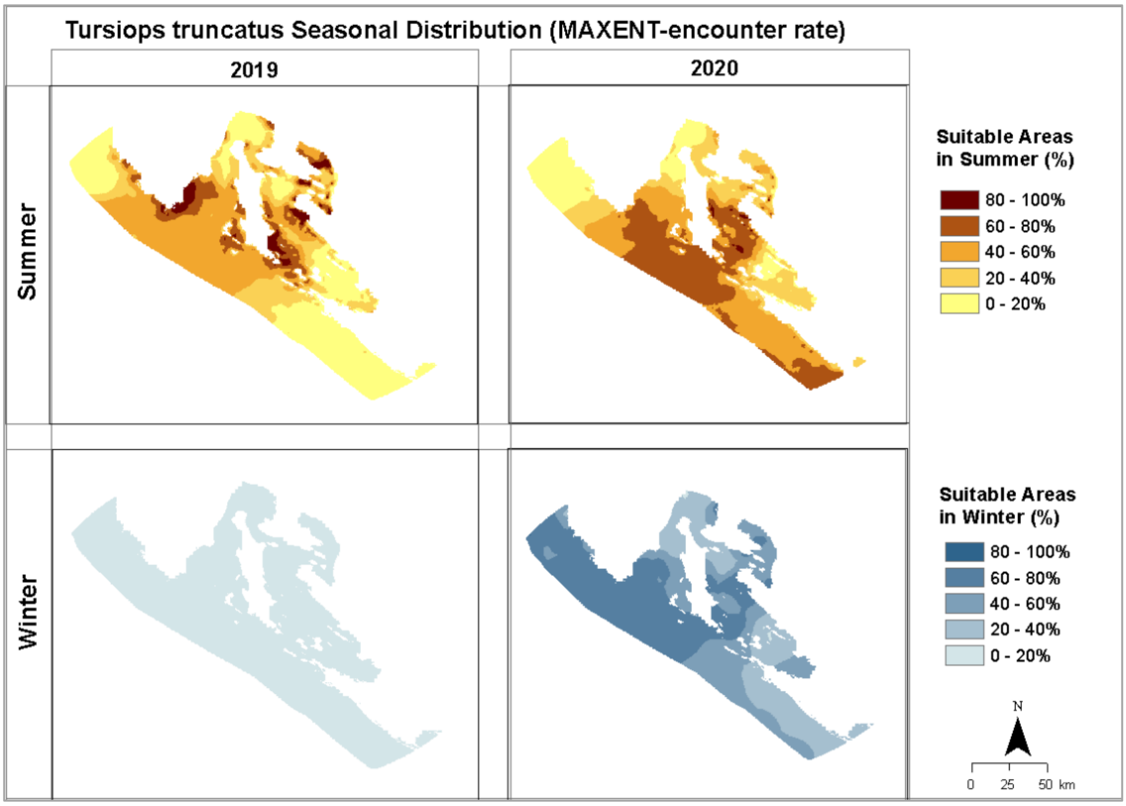

**Figure A.4.** Maxent single model prediction of seasonal distribution of bottlenose dolphins from 2019-2020 using encounter rate data as explanatory variable

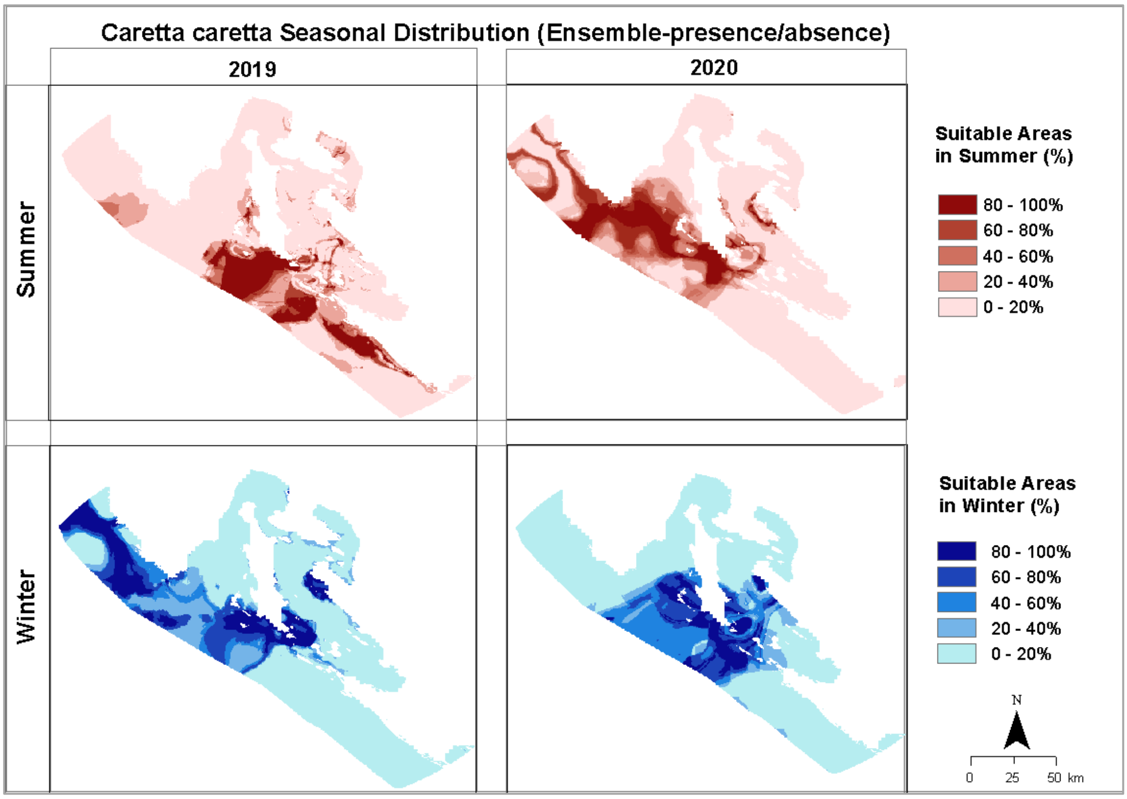

**Figure A.5.**Ensemble model prediction of the seasonal distribution of Caretta from 2019-2020 using presence-absence data

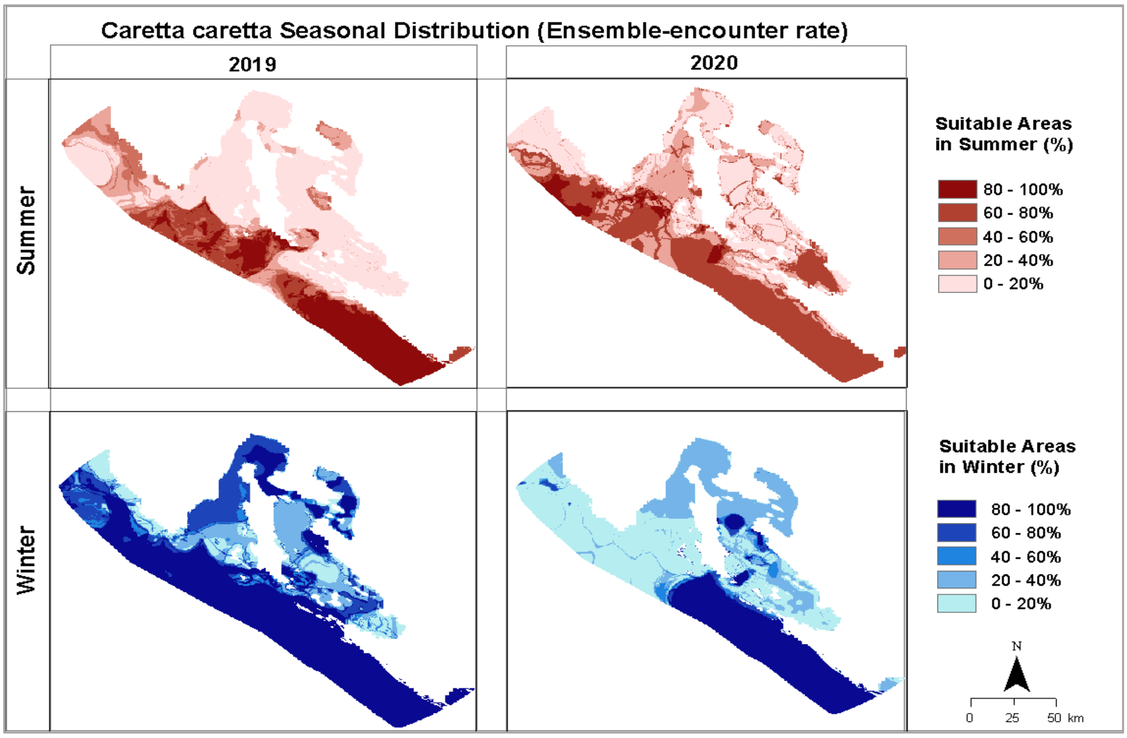

**Figure A.6.** Ensemble model prediction of the seasonal distribution of Caretta from 2019-2020using encounter rate data

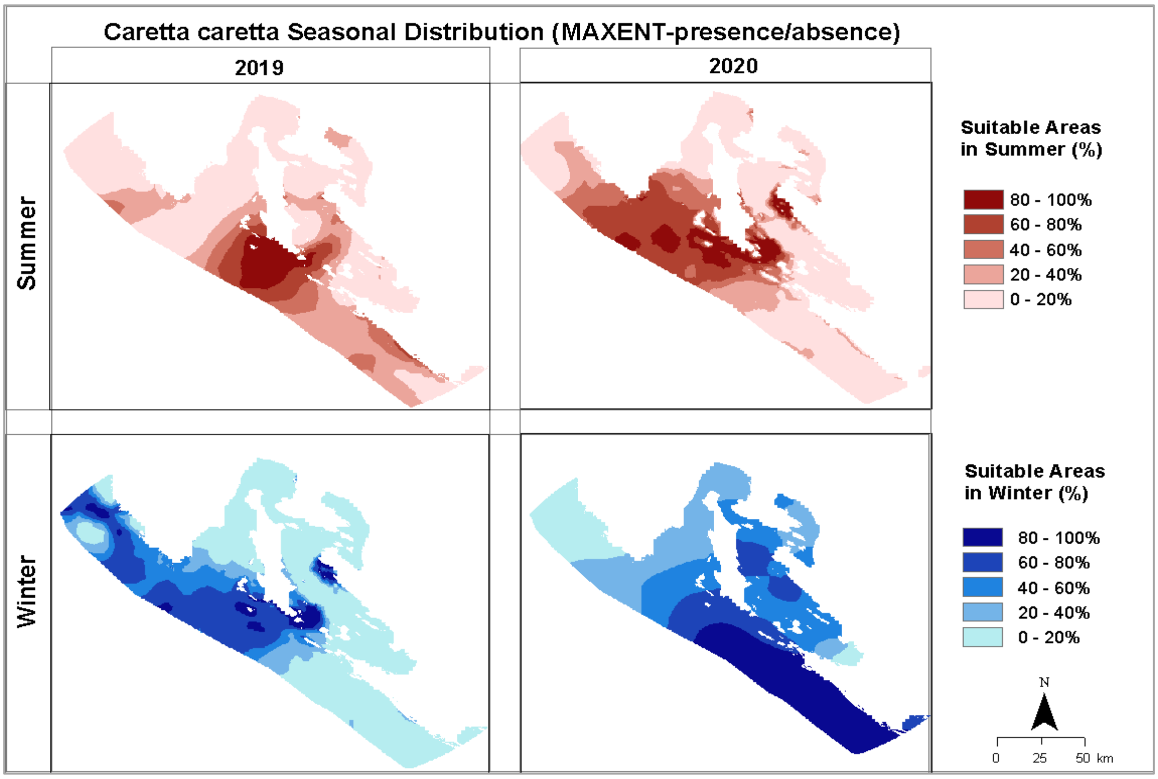

**Figure A.7.** Maxent prediction of the seasonal distribution of Caretta from 2019-2020 using presence-absence data

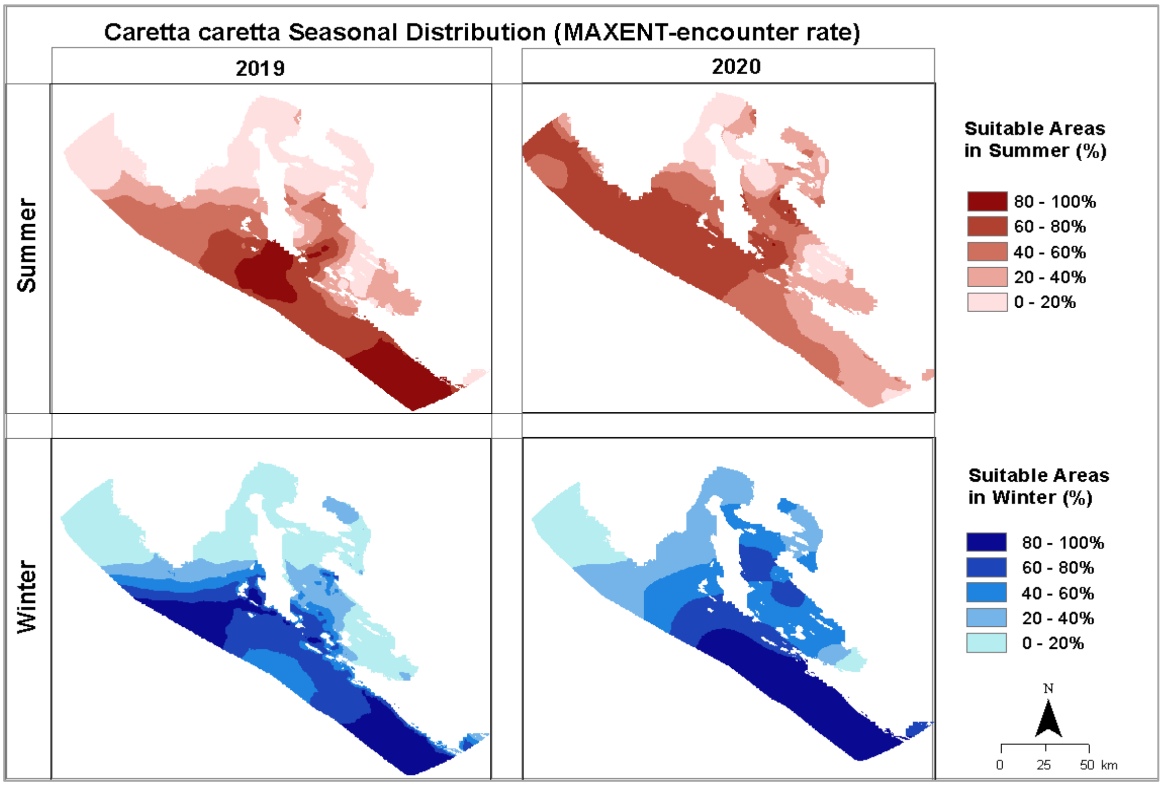

**Figure A.8.** Maxent prediction of the seasonal distribution of Caretta from 2019-2020 using encounter rate data

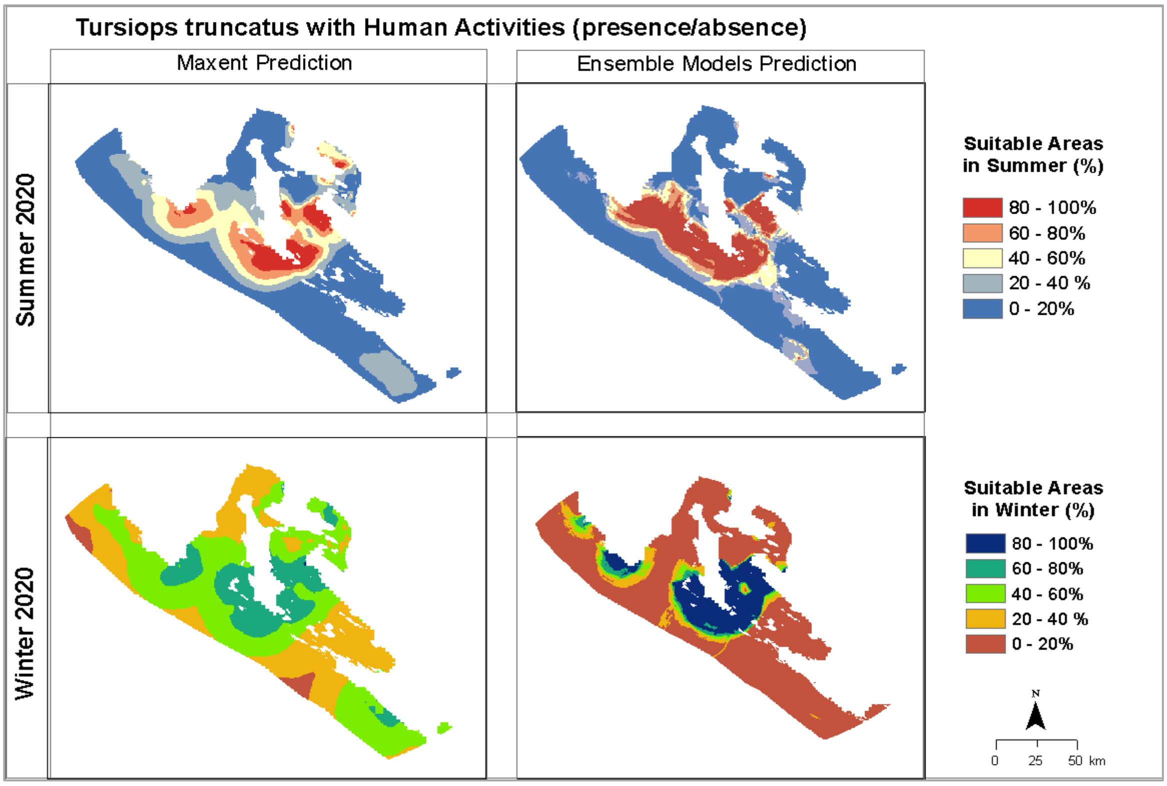

**Figure A.9.** Maxent and Ensemble models prediction of the distribution of bottlenose dolphins with consideration of human activities without noise data, using presence-absence data

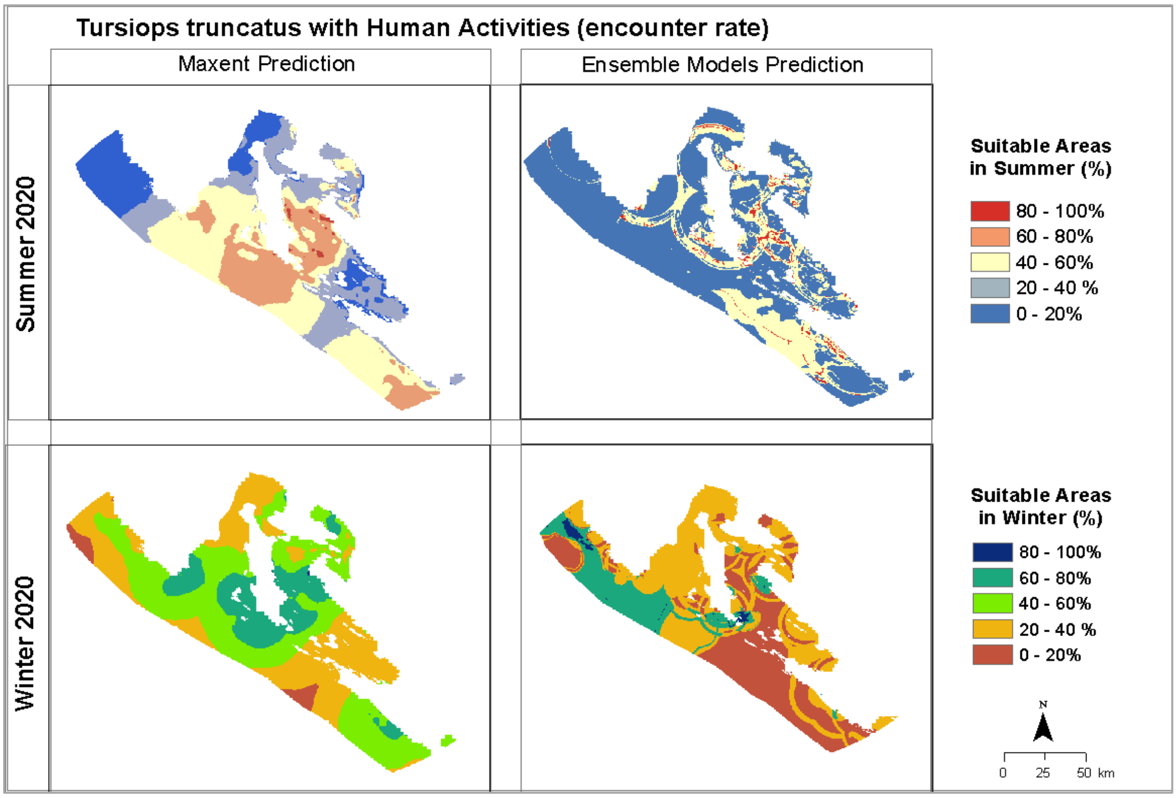

**Figure A.10.** Maxent and Ensemble models prediction of the distribution of bottlenose dolphins with consideration of human activities without noise data.

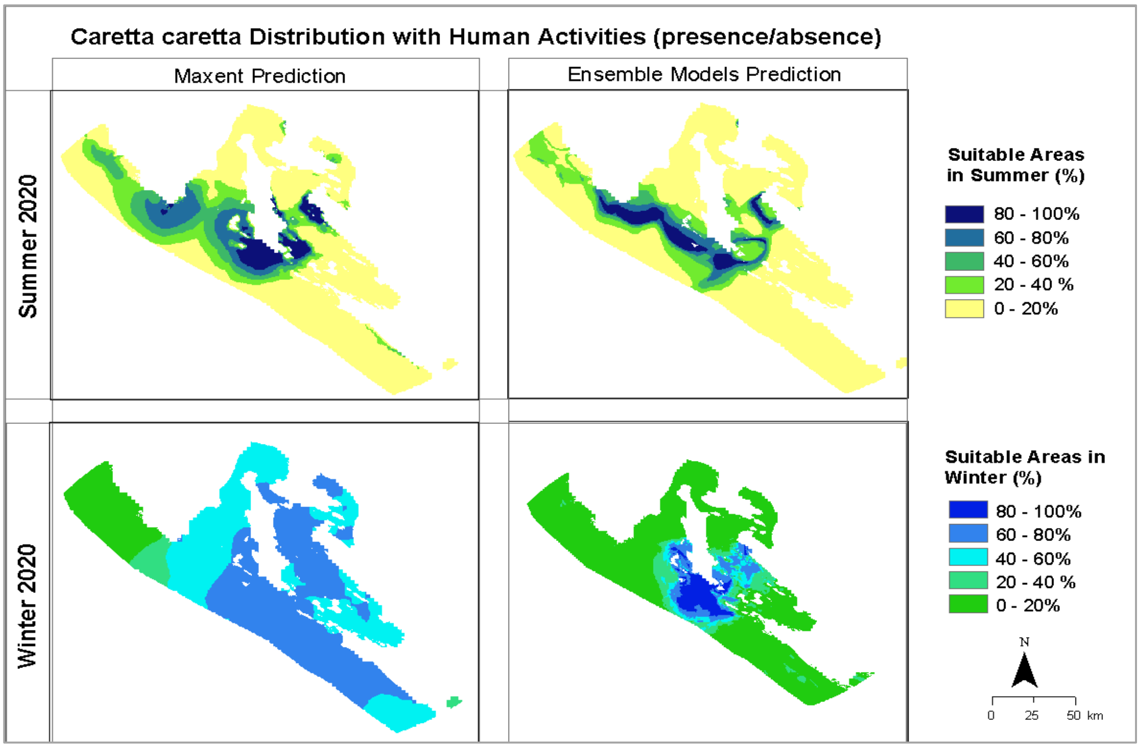
Caretta caretta Distribution with Human Activities (presence/absence)
Maxent Prediction
Ensemble Models Prediction
Summer 2020
Winter 2020
Suitable Areas in Summer (%)
80 - 100%
60 - 80%
40 - 60%
20 - 40 %
0 - 20%
Suitable Areas in Winter (%)
80 - 100%
60 - 80%
40 - 60%
20 - 40 %
0 - 20%
N
0
25
50 km

**Figure A.11.** Predictions of the distribution of loggerhead sea turtles with consideration of human activities using presence-absence data

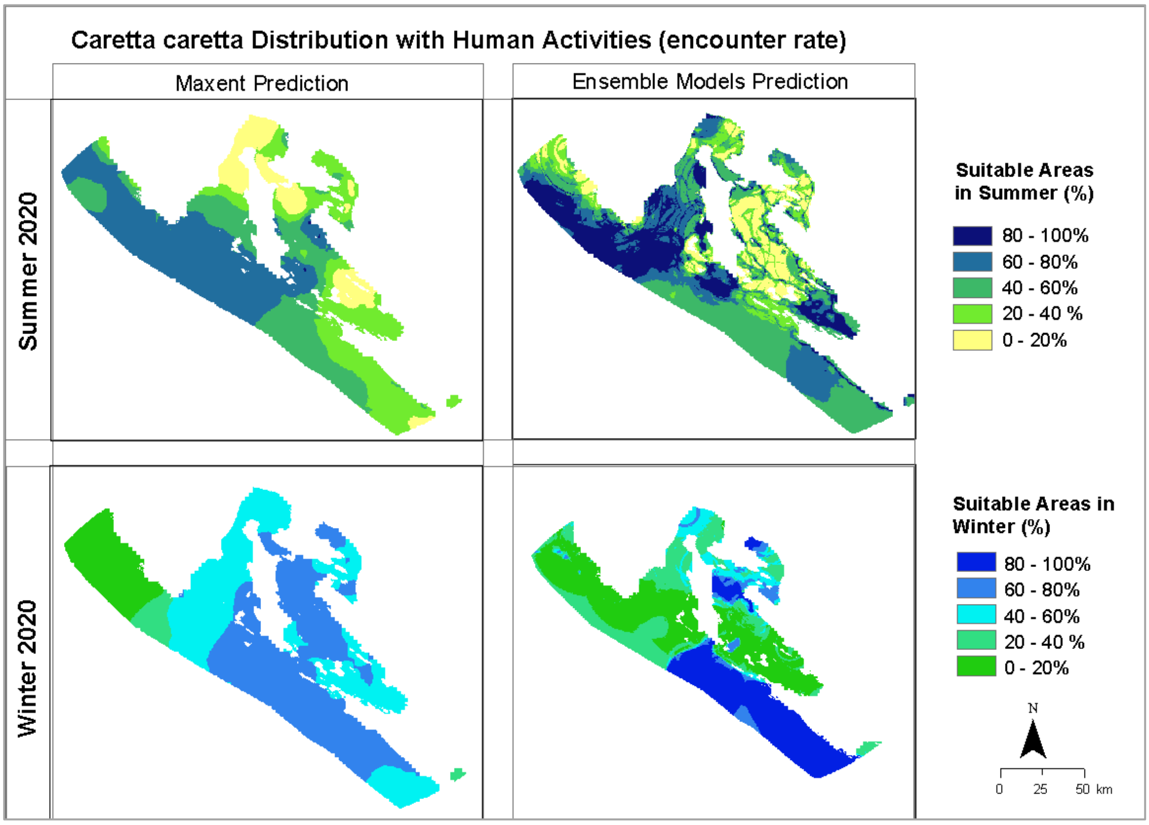

**Figure A.12.** Predictions of the distribution of loggerhead sea turtles with consideration of human activities using encounter rate data