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LIFE CONCEPTU MARIS

CONservation of CEtaceans and Pelagic sea TUrtles in Med: Managing Actions for their Recovery In Sustainability

DELIVERABLE C1

Identification of important offshore CEPTU areas and risk areas in Western Mediterranean (WMED) and Adriatic and Ionian (ADRION) marine regions

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Introduction

This document presents a comprehensive analysis of marine species distribution and habitat suitability in the Western Mediterranean and Adriatic Sea, with a focus on cetaceans and sea turtles. It outlines both observed distribution patterns and ecological potential ranges, and examines trends in species occurrence over time. Habitat preferences are investigated through the identification of key environmental variables influencing species presence, using Habitat Selection analysis, Principal Component Analysis (PCA), and Species Distribution Models (SDMs) validated with independent datasets. The report also incorporates environmental DNA (eDNA) as a complementary monitoring tool and applies stable isotope analysis (SIA) to assess baseline biogeochemical conditions and trophic structures. Finally, it addresses anthropogenic pressures such as marine litter and maritime traffic by developing a vulnerability index to pinpoint priority conservation areas, underscoring the need for integrated, cross-border protection strategies.

Cetaceans and Pelagic Sea Turtles (hereinafter referred as CEPTU species) are charismatic marine species of high conservation concern and constitute a vital component of Mediterranean marine biodiversity, playing essential roles in ecosystem functioning. All CEPTU species occurring in European Mediterranean waters are listed in Annex IV of the EU Habitats Directive (HD), which mandates their strict protection. Additionally, species such as the bottlenose dolphin and the loggerhead turtle are also included in Annex II.

Despite their ecological significance, CEPTU species remain relatively poorly understood due to their high mobility and wide-ranging behavior. Their distribution is shaped by the physical, chemical, and biological characteristics of water masses, which determine pronounced seasonal and cyclical movements. A key challenge in their conservation is the identification of critical developmental and foraging habitats, as well as migratory corridors. Data collection on these species is particularly difficult and resource-intensive in offshore areas and across all seasons, leading to limited knowledge regarding their distribution, population size, and habitat suitability. Consequently, many CEPTU species are frequently classified as data deficient in conservation assessments.

The LIFE CONCEPTU MARIS project directly addresses the obligations set forth by the HD, specifically Article 11 (i.e., monitoring of conservation status) and Article 17 (i.e., reporting). To enhance data collection and assessment, the project developed and implemented a multidisciplinary, integrated approach for systematic surveillance. This approach leverages passenger ferries as observation platforms, enabling cost-effective, repeated sampling along fixed transboundary transects that include high sea areas and are conducted throughout the year. This methodology facilitates the synoptic collection of data on CEPTU presence, major anthropogenic stressors (e.g., maritime traffic, marine litter, entanglement marks), and relevant environmental and ecological parameters. Furthermore, the project introduced environmental DNA (eDNA) analysis as a novel, large-scale complementary tool to improve data collection for the assessment of conservation status indicators.

This Deliverable is based on a comprehensive dataset collected within the project's core and replication areas, supplemented by historical data. It applies the methodology outlined in Deliverable C1.2, "*Report on Identified Indicators to Evaluate the Conservation Status of CEPTU Species"* (Arcangeli et al., 2025), which identified the most effective approaches for improving the predictive understanding of CEPTU ecological requirements and for mapping their key areas.

The primary objective of this document is to identify important offshore CEPTU areas and associated risk zones through a robust, knowledge-based understanding of the distribution of suitable habitats for target species, including the *Balaenoptera physalus*, *Stenella coeruleoalba*, *Delphinus delphis*, *Tursiops truncatus*, *Grampus griseus*, *Globicephala melas*, *Ziphius cavirostris*, *Physeter macrocephalus*, and *Caretta caretta* in the Western Mediterranean (WMed) and Adriatic (Adrion) marine regions.

The analyses were conducted using the HD assessment framework. First, the species parameters, specifically population size and trends, were examined for four of the most common species: *Balaenoptera physalus, Stenella coeruleoalba, Ziphius cavirostris,* and *Physeter macrocephalus*. Then, the spatial parameters, including species ranges and habitats, were assessed for all cetacean and sea turtle species, as outlined in Deliverable C1.2, which forms the analytical foundation of this report.

Once this comprehensive overview was established, a vulnerability index was applied to identify both overall and seasonal priority areas for conservation, in response to the policymakers' needs for a system that can support more efficient and informed management decisions.

The second step involved assessing anthropogenic pressures, with a particular focus on marine litter and maritime traffic. This deliverable presents the methodologies used to evaluate these stressors, including analyses of risk exposure assessment and near-miss events, and showcases the main findings.

The findings presented herein contribute to the scientific knowledge base necessary for the effective management of CEPTU species in the Mediterranean Sea and provide support to EU Member States in fulfilling their reporting obligations under the HD.

1. Parameters' assessment

1.1 Population and trend

Population trends have been analyzed following the methodology described in Deliverable C1.2 (Arcangeli et al., 2025). Population trends were calculated for *Balaenoptera physalus*, *Stenella coeruleoalba*, *Ziphius cavirostris*, and *Physeter macrocephalus*, as the dataset for these species provided enough temporal coverage and frequency of observations to allow a meaningful analysis.

Population and trend Balaenoptera physalus

TECHNICAL SUMMARY:
Balaenoptera physalus presence shows an overall stable presence in the western Mediterranean Sea, while it is considered rare in the Adriatic Sea. Over the whole period, no single or monotonic trend can be identified in the abundance of *Balaenoptera physalus* in the western Mediterranean region, but strong interannual variability is confirmed. The years 2009 and 2014 are identified as the most anomalous. Among the different Habitat Directive reporting periods (2008–2012, 2013–2018, and 2019–2024) no statistically significant differences in *Balaenoptera physalus* abundance are detected, although a more stable phase is observed during the second period and a statistically significant increasing trend is recorded during the third. The species presence in French EEZ (Exclusive Economic zone) waters is approximately twice as high as in Italian and Spanish waters. Spain and Italy's waters show the strongest interannual variability, with a notable decline observed in Spanish waters in recent years. Across the three reporting periods a stable trend is observed in both Italian and French waters, while Spanish waters exhibit less interannual variability but a clear decreasing trend. The Pelagos Sanctuary is confirmed as a very important area for the species, where its presence remains relatively stable over time, despite some anomalous years, and shows an overall increasing trend during the third reporting period. Conversely, in both the Life Conceptu maris Core Area (Tyrrhenian Sea and Sardinia-Sicilian channels) and the area from the Spanish Cetacean Migration Corridor to the Alboran Sea, the species shows a decreasing trend.

SUMMARY FOR POLICY MAKERS: *Balaenoptera physalus* in the Western Mediterranean

1. **Overall Status:** The fin whale (*Balaenoptera physalus*) shows a stable presence in the western Mediterranean, while its presence in the Adriatic Sea remains rare.
2. **Trends and Variability:**
    a. No consistent long-term trend is observed across the region, but significant year-to-year variability exists.
    b. 2009 and 2014 were particularly anomalous years.
    c. a positive trend is emerging within the years of the most recent period (2019–2024), while no significant changes were found across EU Habitats Directive reporting periods.
3. **Geographic Patterns:**
    a. The French EEZ hosts approximately twice the whale presence compared to Spain and Italy's waters.
    b. The abundance within Spanish waters shows a clear recent decline, while within Italian and French EEZs it exhibits stable trends.

c. In the area from Spanish Cetacean Migration Corridor to the Alboran Sea and the Life Conceptu maris Core Area (Tyrrhenian and Sardinia-Sicilian channels) the species shows declining trends.
d. The Pelagos Sanctuary remains a key conservation area, with a relatively stable and increasing presence during the last reporting period.

Policy Implications

- Conservation focus should remain strong in the Pelagos Sanctuary to maintain positive trends.
- Targeted monitoring and mitigation measures are recommended in Spanish and Core Areas where declines are observed.
- Cross-border collaboration between France, Italy, and Spain is essential to ensure regional population stability.
- Continued long-term monitoring is crucial for detecting trends and informing adaptive management strategies.

Method. Two density indices, D_sight (based on number of sightings) and D_animals (based on number of animals) were computed applying effective strip widths (ESWs) shown in Table 1.1.1.

Table 1.1.1. ESWs values for fin whale

Type of ferry	Height of command deck	ESW (m)
I	< 20 m	2023
II	20 - 25 m	3140
III	>= 25 m	2848

The final dataset used for the population assessment included 2,010 surveys, resulting in a total of 2,666 sightings. Of these, 1,450 surveys were conducted during the summer season (April to September), accounting for 2,277 sightings, while 560 surveys were carried out in the winter season (October to March), resulting in 389 sightings.

Summer - <u>Mediterranean Basin</u>

The Density Index based on *Balaenoptera physalus* sightings (D_sight) showed **strong interannual variability** (Table 1.1.2 and Figure 1.1.1). The Kruskal-Wallis test confirmed this variability (chi-squared = 78.683, df = 16, p-value = 2.872e-10) while the post-hoc Dunn test highlighted **2009 and 2014 as the most anomalous years**, indicating periods when the species appeared to be either less present in the western Mediterranean region or more dispersed throughout the Mediterranean basin. Similar results were observed using the Density Index based on the number of animals (D_animals) (Table 1.1.3, Figure 1.1.2), with the Kruskal-Wallis test confirming significant interannual variability (chi-squared = 79.889, df = 16, p-value = 1.743e-10). However, the Dunn post-hoc test identified only 2009 as an anomalous year. Due to the overall similarity, further analyses focused solely on the D_sight, which was used as an index of species abundance.

Fin whale population assessment		
density of sighitngs		
year	D_sight	95% CI
2008	0.05	0.01—0.08
2009	0.05	0.00—0.10
2010	0.25	0.16—0.34
2011	0.17	0.08—0.26
2012	0.25	0.16—0.35
2013	0.24	0.16—0.32
2014	0.05	0.03—0.06
2015	0.20	0.14—0.25
2016	0.15	0.05—0.24
2017	0.14	0.08—0.20
2018	0.14	0.08—0.20
2019	0.08	0.05—0.11
2020	0.04	0.00—0.08
2021	0.17	−0.03—0.37
2022	0.20	0.13—0.27
2023	0.25	0.17—0.33
2024	0.12	0.08—0.17

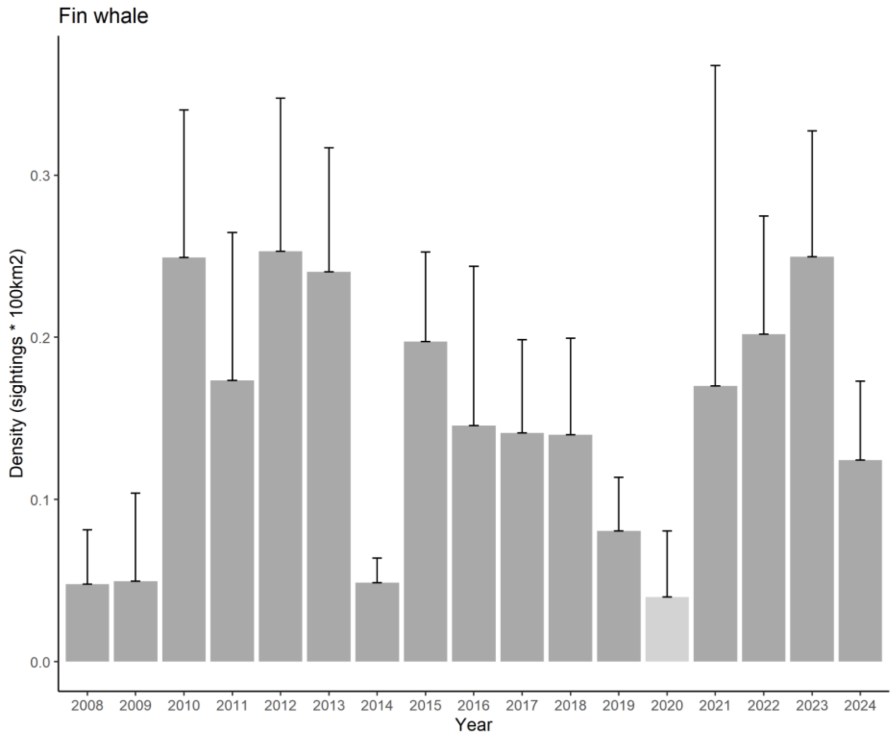


Table 1.1.2 and Figure 1.1.1. Table showing yearly averages of *Balaenoptera physalus* abundance (Density Index based on sightings, D_sight), with 95% confidence intervals. The graph displays yearly averages along with the upper 95% confidence limit. The year 2020 is shown in light gray, as the lower number of surveys conducted that year may limit the representativeness of the results.

Fin whale population assessment		
density of animals		
year	D_animals	95% CI
2008	0.05	0.01—0.08
2009	0.05	0.00—0.10
2010	0.25	0.16—0.34
2011	0.17	0.08—0.26
2012	0.25	0.16—0.35
2013	0.24	0.16—0.32
2014	0.05	0.03—0.06
2015	0.20	0.14—0.25
2016	0.15	0.05—0.24
2017	0.14	0.08—0.20
2018	0.14	0.08—0.20
2019	0.08	0.05—0.11
2020	0.04	0.00—0.08
2021	0.17	−0.03—0.37
2022	0.20	0.13—0.27
2023	0.25	0.17—0.33
2024	0.12	0.08—0.17

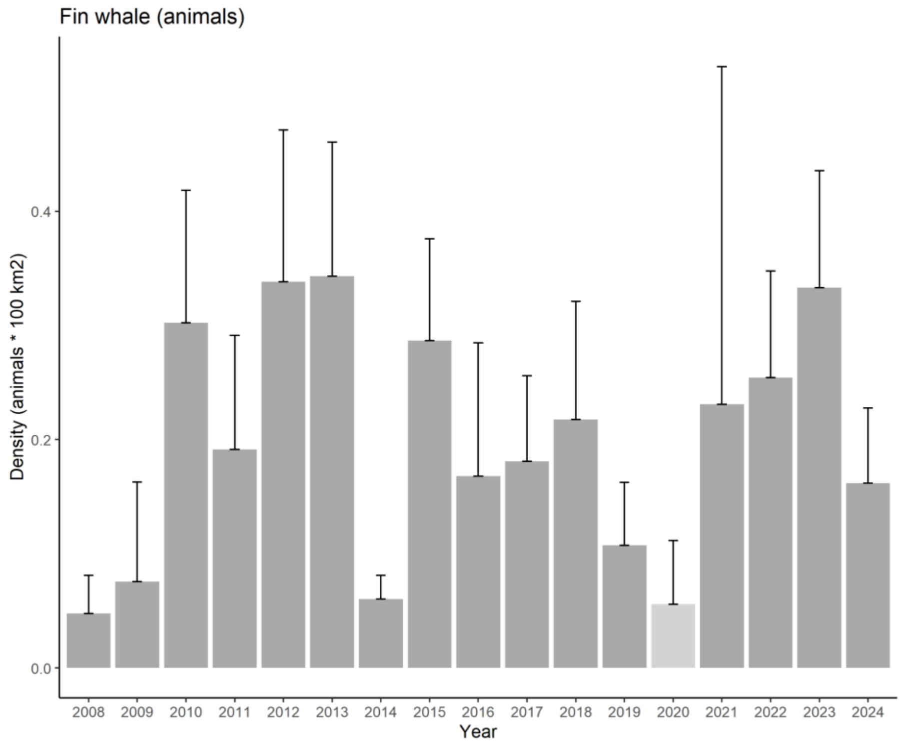


Table 1.1.3 and Figure 1.1.2. Table showing yearly averages of *Balaenoptera physalus* abundance (Density index based on the number of animals, D_animals) with 95% confidence intervals. The graph displays yearly averages along with the upper 95% confidence limit. The year 2020 is shown in light gray, as the lower number of surveys conducted that year may affect the representativeness of the results.

Marine regions

Balaenoptera physalus has never been regularly observed in the Adriatic basin, except for a single sighting in 2024. While its presence in the Adriatic is considered rare, its overall stable presence is confirmed in the western Mediterranean, thus all analyses presented for the Mediterranean basin are performed for this region only.

National EEZs

The abundance of *Balaenoptera physalus* (Density index, D_sight) within the French EEZ is generally higher compared to the other two countries considered (Spain and Italy). **The species presence in France is approximately twice as high as in the Italian and Spanish areas**. **Spain and Italy show the strongest interannual variability**, with a notable **decline in Spain in recent years** (Figure 1.1.3). It should be noted that only two surveys were conducted in 2021, so both 2020 and 2021 should not be considered representative.

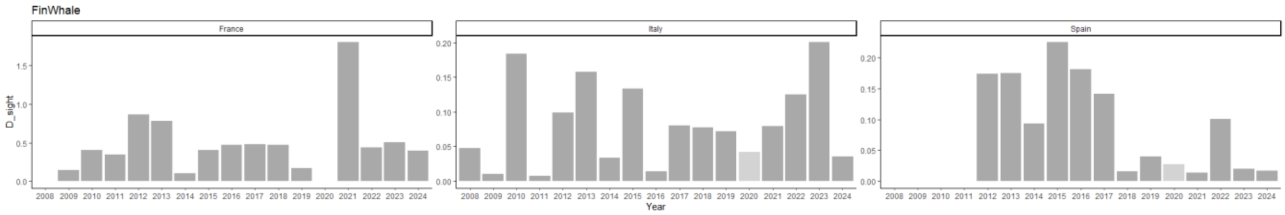


Figure 1.1.3. Yearly averages of *Balaenoptera physalus* Density index (based on sightings, D_sight) for the France, Italian and Spanish EEZs areas

Life CONCEPTU MARIS areas

Balaenoptera physalus has been absent from the Adriatic and Gibraltar Strait, except for a single sighting, but has been consistently present during summer in all other areas. **In both the Core Area (Tyrrhenian and Sardinia-Sicilian channels) and the area from the Spanish Cetacean Migration Corridor to Alboran Sea, the species shows a decreasing trend, while in the Pelagos Sanctuary, its presence remains relatively stable, though marked by some anomalous years** (Figure 1.1.4).

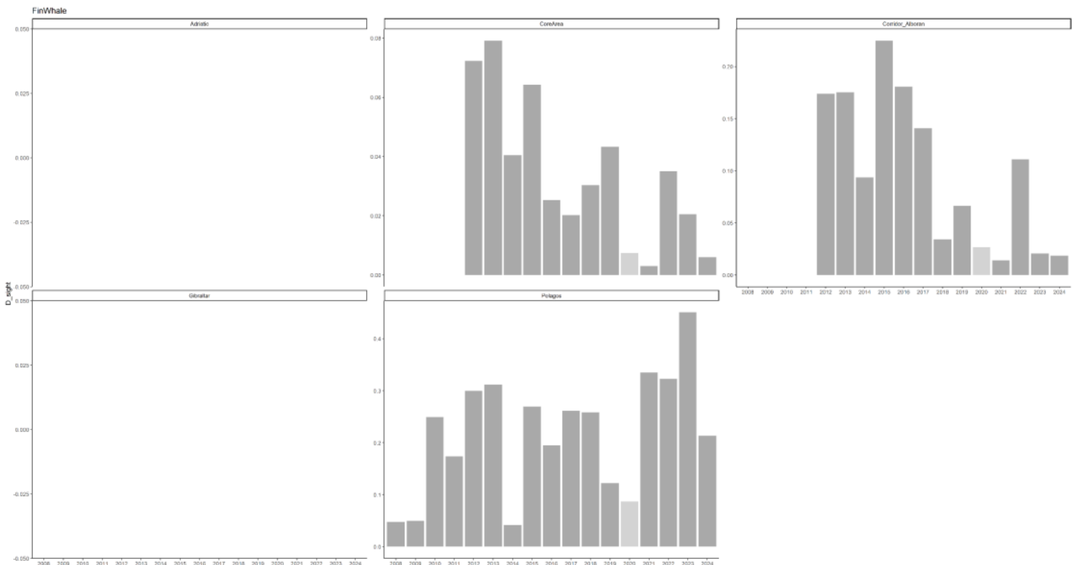


Figure 1.1.4. Yearly averages of *Balaenoptera physalus* Density index (based on sightings, D_sight) for the the different project areas

TREND IN ABUNDANCE - *Balaenoptera physalus*

Considering the similarities in the results of the two proposed indexes for calculating the abundance parameter, the trend analysis is presented considering the Density index based on sightings (D_sight) as the index for species abundance.

Mediterranean basin

Figure 1.1.5 represents the overall abundance trend (black line) overlapped with the 2 years rolling mean (red line). **No single or monotonic trend** can be identified in *Balaenoptera physalus* abundance and **strong interannual variability** is confirmed.

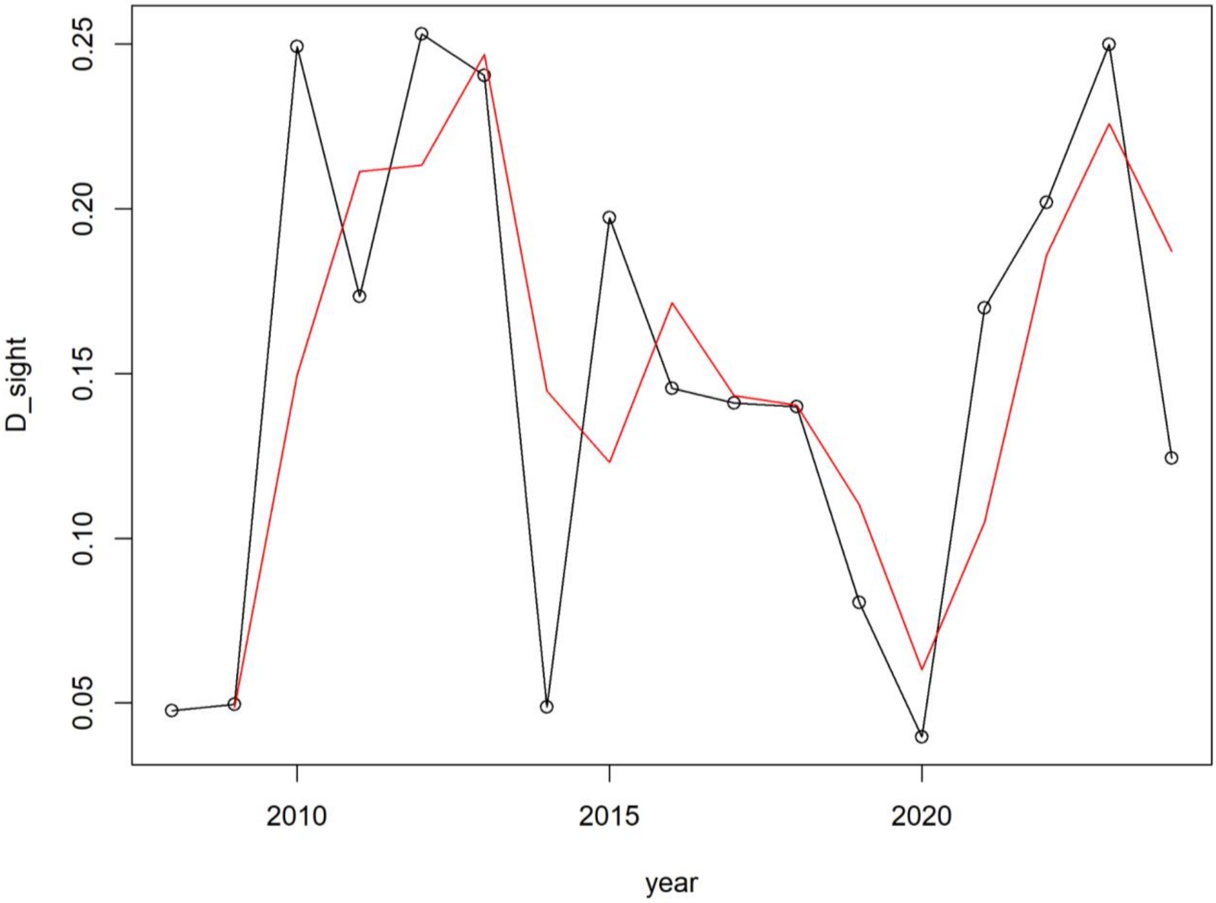


Figure 1.1.5. Trend in *Balaenoptera physalus* abundance, showing overall yearly averages (black line) and a 2-year rolling mean (red line).

No statistically significant differences are detected in *Balaenoptera physalus* abundance **among different Habitat Directive reporting periods (2008-2012, 2013-2018 and 2019-2024**) (Figure 1.1.6) even though the variability occurring on a yearly basis has to be taken into account as a masking factor for differences. Indeed a more stable phase is evidenced in the second reporting period, compared with the higher variance shown in the first and third periods.

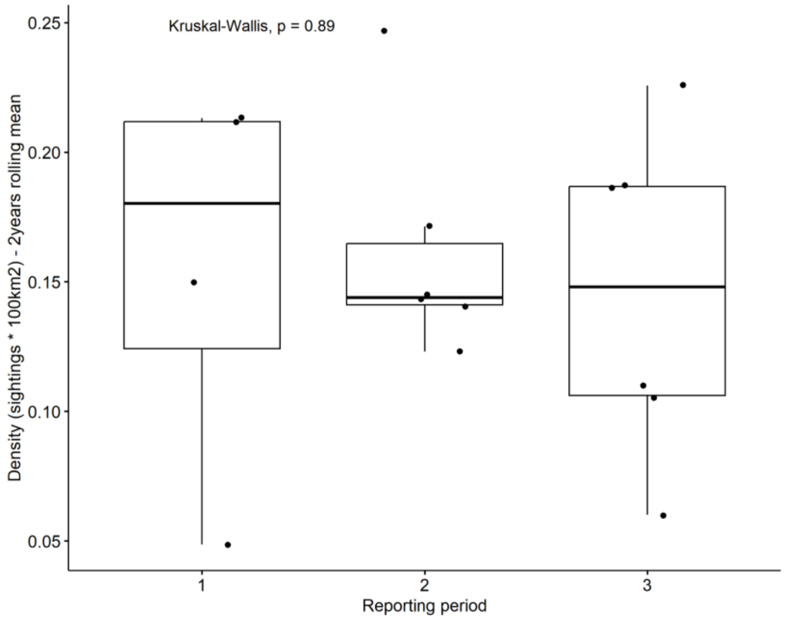


Figure 1.1.6.- Box plots of *Balaenoptera physalus* abundance (Density based on sightings, D_sight) for three Habitat Directive reporting periods (1st = 2008-2012; 2nd = 2013-2018; 3rd = 2019-2024).

A more stable phase in *Balaenoptera physalus* abundance during the second Habitat Directive reporting period (2013-2018) is confirmed when looking at trends within reporting periods. It has to be noted that **the increasing trend within the third period is statistically significant**, evidencing an overall higher presence of the species compared to the previous two periods (Figure 1.1.7)

Figure 1.1.7.- *Balaenoptera physalus* intra period abundance trends considering a 95% CI. P-values are referred to the linear model of each Habitat Directive reporting period (1st = 2008-2012; 2nd = 2013-2018; 3rd = 2019-2024).

National

Balaenoptera physalus abundance in national EEZs shows a **stable trend across the three reporting periods, in both Italian and French waters**, even if still characterized by strong interannual variability, especially in French waters. In contrast, its abundance in **Spanish waters shows less interannual variability, but a clear decreasing trend is evident** (Figure 1.1.8).

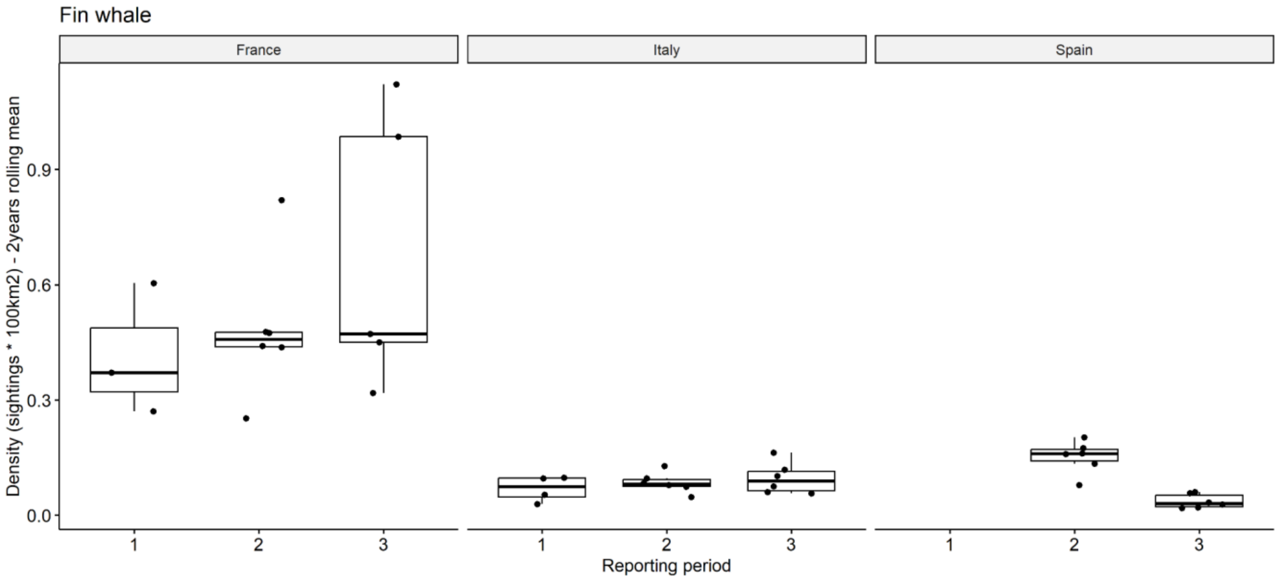


Figure 1.1.8. Box plot of *Balaenoptera physalus* abundance (Density based on sightings, D_sight) for the France, Italian and Spanish EEZs areas among Habitat Directive reporting periods (1st = 2008-2012; 2nd = 2013-2018; 3rd = 2019-2024)

Intraperiod trends confirm the stability of *Balaenoptera physalus* abundance indices for Italy, French and Spanish waters. Nevertheless, the difference in scales must be evidenced (Figure 1.1.9).

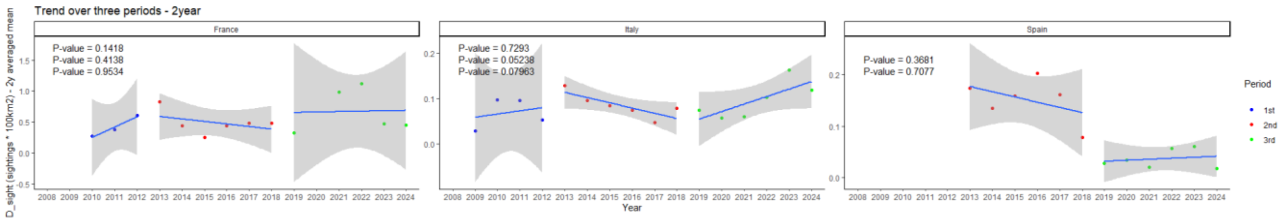


Figure 1.1.9. *Balaenoptera physalus* intraperiod abundance trend for the France, Italian and Spanish EEZs areas considering a 95% CI. P-values are referred to the linear model of each Habitat Directive reporting period (1st = 2008-2012; 2nd = 2013-2018; 3rd = 2019-2024).

Life CONCEPTU MARIS areas

Balaenoptera physalus shows very different overall presence in the different project areas among Habitat Directive reporting periods, with the **Pelagos Sanctuary confirmed as a very important area for the species**, where presence is apparently increasing in the last period (Figure 1.1.10)

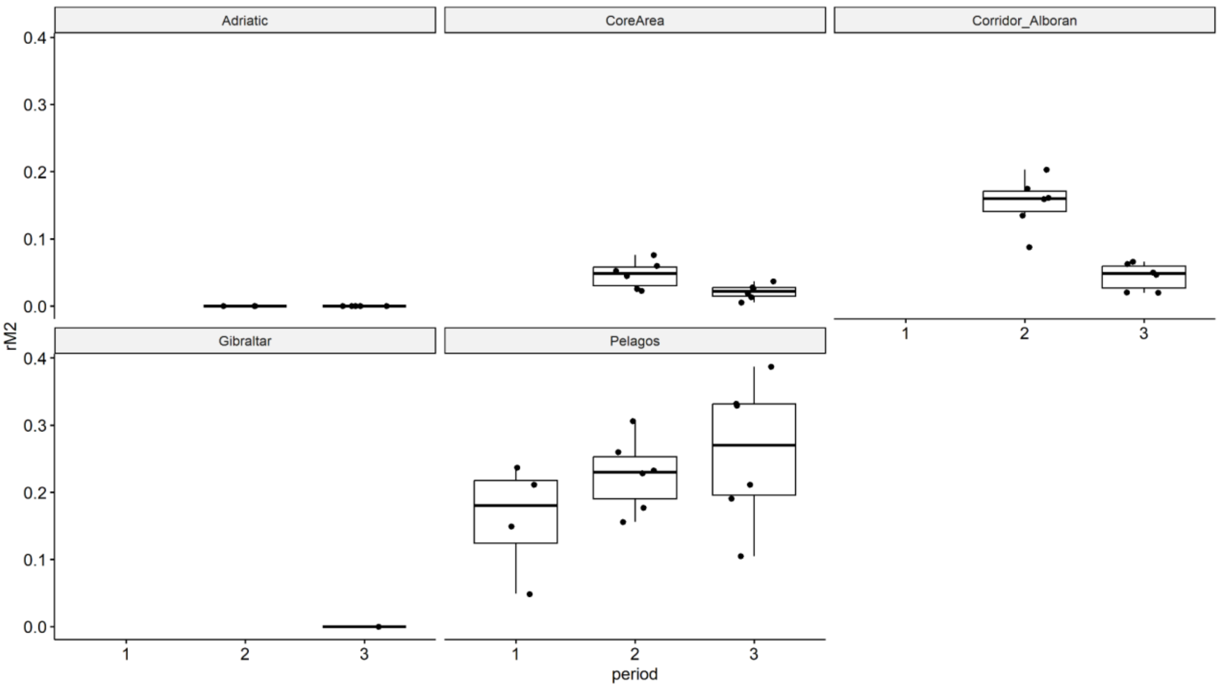


Figure 1.1.10. Box plot of *Balaenoptera physalus* abundance (Density based on sightings, D_sight) for the different project areas among Habitat Directive reporting periods (1st = 2008-2012; 2nd = 2013-2018; 3rd = 2019-2024).

A strong decreasing trend in the abundance of *Balaenoptera physalus* in the Life CONCEPTU MARIS Core Area (Tyrrhenian and Sardinia-Sicilian channels) is evidenced with the intraperiod analysis. The species presence shows an **increasing trend in the Pelagos Sanctuary area, especially when compared to the neighbouring areas such as the Core Area and the area from the Spanish Cetacean Migration Corridor to the Alboran Sea. In these two project areas decreasing intraperiod trends are evidenced** (Figure 1.1.11)

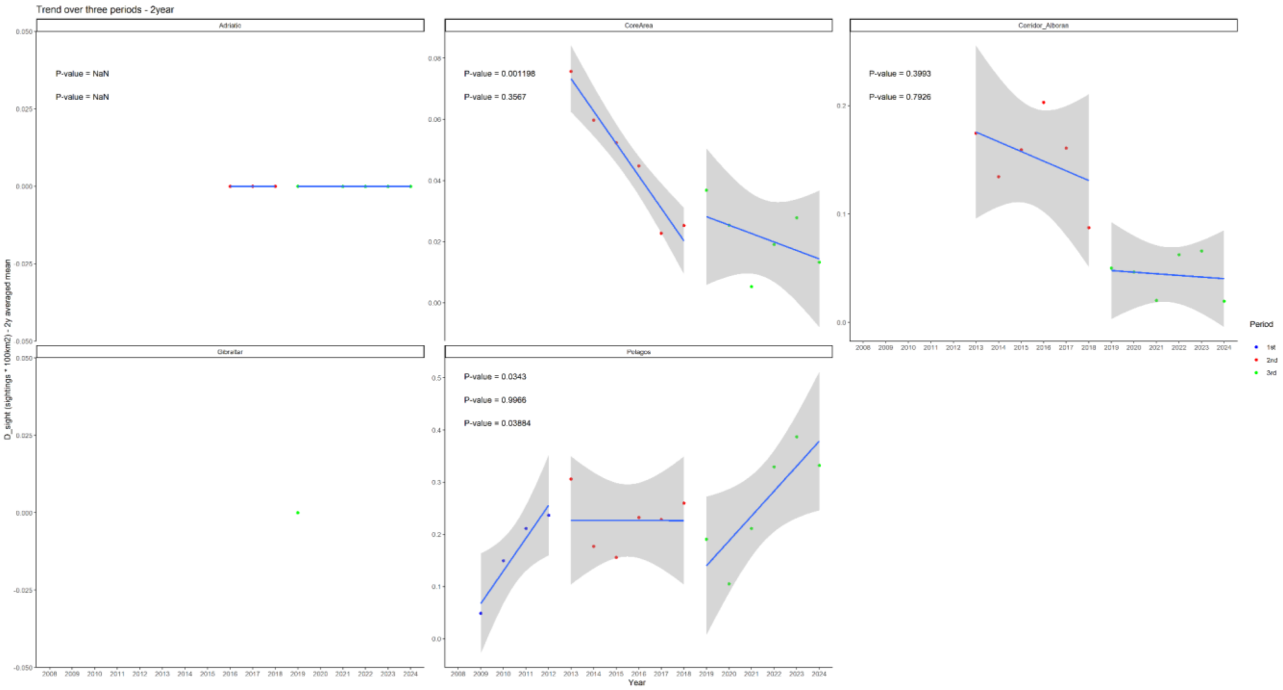


Figure 1.1.11. *Balaenoptera physalus* Intraperiod abundance trends for the different Life CONCEPTU MARIS project areas considering a 95% CI. P-values are referred to the linear model of each Habitat Directive reporting period (1st = 2008-2012; 2nd = 2013-2018; 3rd = 2019-2024).

Population and trend *Stenella coeruleoalba*

TECHNICAL SUMMARY:
Stenella coeruleoalba presence shows an overall stable presence in the western Mediterranean Sea during the last 8 years, while a decline has been observed from 2010 to 2016. The species is present constantly in the Adriatic Sea, with lower densities than in the western basin. Over the whole period, two different trends can be identified in the presence and abundance of *Stenella coeruleoalba* in the western Mediterranean region, with strong negative years confirmed for 2014 and 2016. Among the different Habitat Directive reporting periods (2008–2012, 2013–2018, and 2019–2024) a significant difference between the first and the two following periods is evidenced in *Stenella coeruleoalba* abundance, confirming the decline from the first period and a more stable phase during the second and third period. The species presence in French EEZ waters is approximately twice as high as in Italian and Spanish waters. For the three countries a strong interannual variability is detected when considering the animal density, while more stability is shown considering the number of sightings, with a decreasing trend across the three reporting periods observed in French waters, and a stable trend in Italian and Spanish waters. When looking at the number of individuals though, an increasing trend is observed for Italian waters, while stronger variability is observed for French and Spanish waters.
The Pelagos Sanctuary is confirmed as a very important area for the species, where its presence remains relatively stable over time and an increasing number of individuals is observed, leading to an increasing in size of observed groups. In the Life Conceptu maris Core Area (Tyrrhenian Sea and Sardinia-Sicilian channels) the species shows lower densities but more stability, while in the area from the Spanish Cetacean Migration Corridor to the Alboran Sea, the species shows a decreasing trend of the number of individuals.

SUMMARY FOR POLICYMAKERS: *Stenella coeruleoalba* in the Western Mediterranean

4. **Overall Status:** The striped dolphin (*Stenella coeruleoalba*) shows a stable presence in the western Mediterranean and in the Adriatic seas, with higher density in the western Mediterranean sea. Some anomalous years are evidenced.
5. **Trends and Variability:**
   a. No consistent long-term trend is observed across the region, but a decreasing trend from 2010 to 2016 is observed, followed by a more stable phase.
   b. The decrease is confirmed from the 1st Reporting period to the 2nd, while stability is observed for the last reporting period
   c. A recovery in group size indicated by an increasing trend in the number of animals is observed.
6. **Geographic Patterns:**
   a. The French EEZ hosts approximately twice the dolphin presence compared to Spanish and Italian waters.
   b. The abundance within French waters shows a clear decline, while within the Italian and Spanish EEZ it exhibits stable trends.
   c. An increase in group size is observed in Italian waters, while a strong variability is observed in French waters and more stability in Spanish waters
   d. In the Spanish Cetacean Migration Corridor and the Life Conceptu maris Core Area (Tyrrhenian and Sardinia-Sicilian channels) the species shows stable trends, with lower densities compared to the Pelagos Sanctuary

e. The Pelagos Sanctuary remains a key conservation area, with a relatively stable presence and increasing trend in the number of animals during the last reporting period.

Policy Implications

- Conservation focus should remain strong in the Pelagos Sanctuary to maintain positive trends in the number of animals, as well as in the Spanish and Core areas to maintain stable trends
- Stronger attention should be put in French waters, where a decline in the species abundance is evidenced
- Cross-border collaboration between France, Italy, and Spain is essential to ensure regional population stability.
- Continued long-term monitoring is crucial for detecting trends and informing adaptive management strategies.

Method. The two identified density Index D_sight and D_animals (considering number of sightings or number of animals, respectively) have been computed by applying the ESWs shown in Table 1.1.4.

Table 1.1.4. ESWs values for *Stenella coeruleoalba*

Type of ferry	Height of command deck	ESW (m)
I	< 20 m	751
II	20 - 25 m	1264
III	>= 25 m	1264

The final dataset used for the population assessment accounted for 3,194 surveys, for a total of 6,854 sightings. Among these, 2,237 surveys have been conducted during the summer season (i.e, from April to September) for a total of 5,583 sightings, while 957 surveys were conducted during the winter season (October-March) for a total of 1,271 sightings.

Summer - <u>Mediterranean basin</u>

Considering the overall Mediterranean basin, the species is constantly present, with less variability than the *Balaenoptera physalus* but still with some negative years emerging from the results (Table 1.1.4 and Figure 1.1.12).

Striped dolphin population assessment

density of sightings

year	D_sightings	95% CI
2008	0.61	0.31—0.91
2009	0.90	0.67—1.14
2010	0.96	0.77—1.14
2011	0.91	0.70—1.12
2012	0.85	0.69—1.02
2013	0.71	0.59—0.83
2014	0.57	0.46—0.69
2015	0.88	0.70—1.07
2016	0.48	0.39—0.57
2017	0.72	0.54—0.90
2018	0.57	0.44—0.71
2019	0.69	0.53—0.84
2020	0.54	0.30—0.78
2021	0.87	0.54—1.20
2022	0.58	0.42—0.73
2023	0.71	0.58—0.84
2024	0.60	0.49—0.72

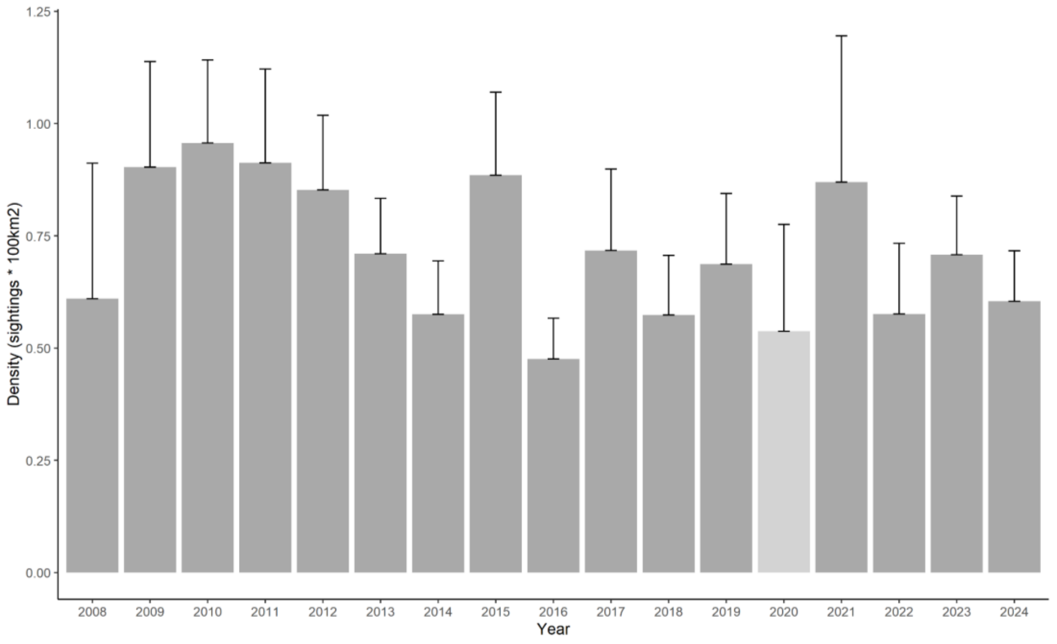


Table 1.1.4 and Figure 1.1.12. Table of yearly averages of *Stenella coeruleoalba* D_sight index with 95% confidence interval. The graph shows yearly averages of D_sight for *Stenella coeruleoalba* index with upper-95%value. The year 2020 is in light gray as, considering the lower number of surveys conducted that year, results might not be representative.

The KW test confirms a statistical difference in the overall dataset (Kruskal-Wallis chi-squared = 42.231, df = 16, p-value =0.0003645), and the Dunn post-hoc test confirms 2010 as an anomalous year compared to the others.

When considering the density index based on the number of animals, obtained by the best estimation of group sizes, the resulting graph is different and a variable animal density among years emerges. As density of sightings and density of animals differ, results can be interpreted as differences in average group sizes.

Striped dolphin population assessment		
density of animals		
year	D_animals	95% CI
2008	3.42	1.79—5.05
2009	7.15	4.14—10.15
2010	12.62	9.60—15.63
2011	6.54	4.64—8.45
2012	8.64	6.38—10.90
2013	8.45	6.55—10.35
2014	4.88	3.19—6.56
2015	7.59	5.59—9.59
2016	3.21	2.18—4.23
2017	6.89	4.70—9.08
2018	8.38	4.70—12.06
2019	9.72	6.74—12.69
2020	5.22	2.39—8.05
2021	12.30	6.02—18.58
2022	7.77	4.85—10.70
2023	9.49	7.10—11.88
2024	5.42	4.20—6.63

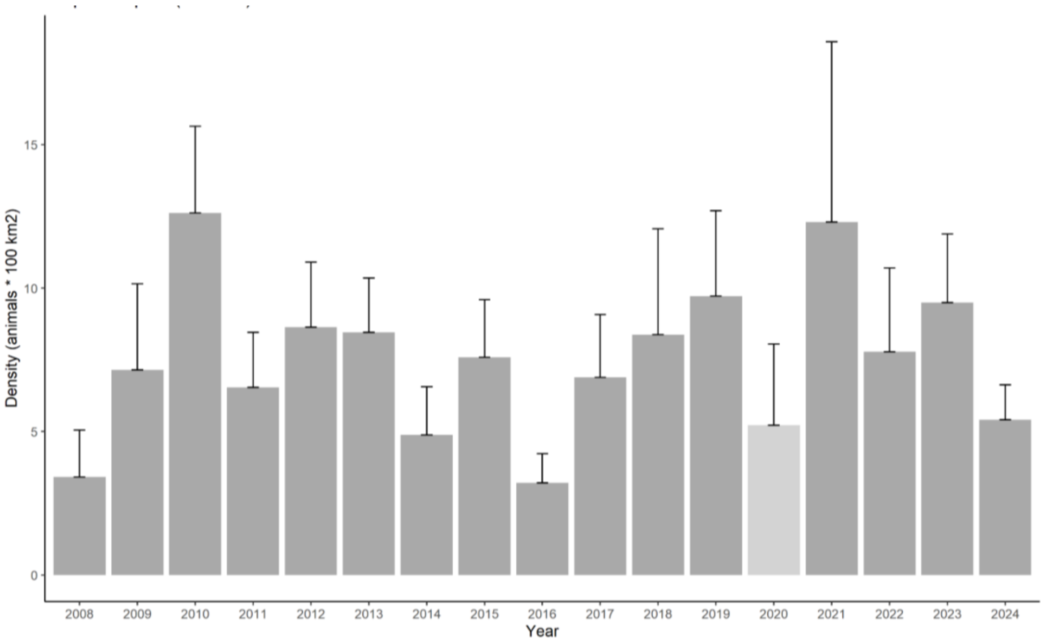


Table 1.1.5 and Figure 1.1.13. Table of yearly averages of the D_animals index for *Stenella coeruleoalba* with 95% confidence interval. The graph shows yearly averages of the D_animals index for *Stenella coeruleoalba* with upper-95%value. The year 2020 is in light gray as, considering the lower number of surveys conductedr that year, results might not be representative.

While 2010 still emerges as the anomalous year, differences in other years have also been evidenced by the Post Hoc Dunn test. In order to include consideration on group size in the report, analyses have been performed with the two indexes D_sight (Density based on sightings) and D_animals (Density based on the number of animals).

Marine Regions

Generally, the species is more present in the western Mediterranean region rather than in the Adriatic region, with maximum values of D_sight reaching 0.96 sightings every 100km2 in the western Mediterranean, three times higher than the highest average values recorded for the Adriatic sea (0.35) (Table 1.1.6).

Striped dolphin population assessment			
density of sightings			
Marine region	year	D_sight	95% CI
WMed	2008	0.61	0.31—0.91
WMed	2009	0.90	0.67—1.14
WMed	2010	0.96	0.77—1.14
WMed	2011	0.91	0.70—1.12
WMed	2012	0.85	0.69—1.02
WMed	2013	0.71	0.59—0.83
WMed	2014	0.57	0.46—0.69
Adriatic	2015	0.15	0.04—0.25
WMed	2015	0.96	0.76—1.16
Adriatic	2016	0.09	−0.03—0.22
WMed	2016	0.50	0.41—0.60
Adriatic	2017	0.11	0.04—0.18
WMed	2017	0.78	0.58—0.98
Adriatic	2018	0.35	0.12—0.58
WMed	2018	0.59	0.45—0.73
Adriatic	2019	0.10	0.03—0.17
WMed	2019	0.73	0.57—0.90
WMed	2020	0.54	0.30—0.78
Adriatic	2021	0.16	0.11—0.22
WMed	2021	0.92	0.57—1.26
Adriatic	2022	0.16	0.06—0.27
WMed	2022	0.64	0.46—0.81
Adriatic	2023	0.13	0.05—0.22
WMed	2023	0.79	0.64—0.93
Adriatic	2024	0.12	0.04—0.19
WMed	2024	0.66	0.53—0.78

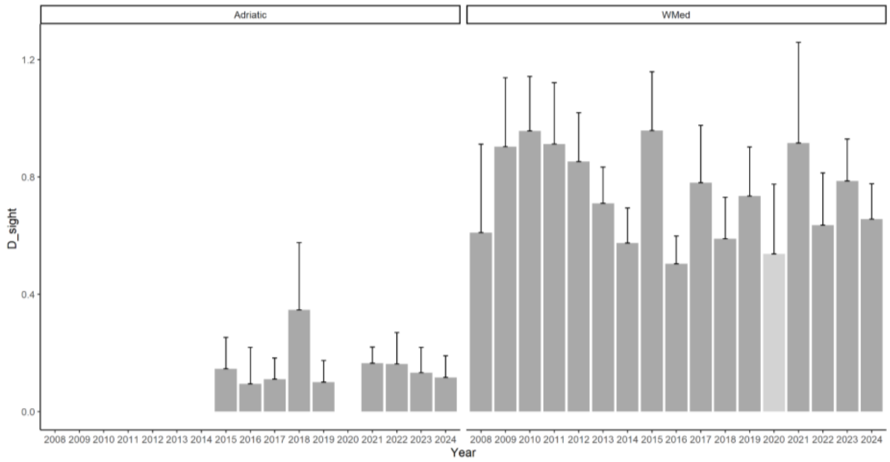


Table 1.1.6 and Figure 1.1.14. Table of yearly averages of the D_sight index for *Stenella coeruleoalba* with 95% confidence interval, for the two considered marine regions. The graph shows yearly averages of the D_sight index for *Stenella coeruleoalba* with upper-95%value for the two considered marine regions. The year 2020 is in light gray as, considering the lower number of surveys conducted that year, results might not be representative.

A similar pattern is evidenced when analyzing the density of animals, with yearly average density higher in the western Mediterranean than in the Adriatic region (Table 1.1.7 Figure 1.1.15), where the density of animals has reached higher values in 2018, but still lower than the average densities registered in the western Mediterranean region.

Striped dolphin population assessment			
density of animals			
Marine region	year	D_animals	95% CI
WMed	2008	3.42	1.79—5.05
WMed	2009	7.15	4.14—10.15
WMed	2010	12.62	9.60—15.63
WMed	2011	6.54	4.64—8.45
WMed	2012	8.64	6.38—10.90
WMed	2013	8.45	6.55—10.35
WMed	2014	4.88	3.19—6.56
Adriatic	2015	0.90	−0.01—1.80
WMed	2015	8.26	6.09—10.43
Adriatic	2016	0.43	−0.20—1.06
WMed	2016	3.41	2.32—4.50
Adriatic	2017	0.50	−0.07—1.07
WMed	2017	7.55	5.16—9.93
Adriatic	2018	3.89	1.06—6.72
WMed	2018	8.68	4.76—12.61
Adriatic	2019	0.29	−0.08—0.65
WMed	2019	10.48	7.30—13.67
WMed	2020	5.22	2.39—8.05
Adriatic	2021	1.15	−0.30—2.60
WMed	2021	13.03	6.38—19.67
Adriatic	2022	0.78	0.16—1.39
WMed	2022	8.79	5.49—12.10
Adriatic	2023	1.21	0.47—1.95
WMed	2023	10.62	7.95—13.28
Adriatic	2024	1.13	0.01—2.24
WMed	2024	5.87	4.55—7.19

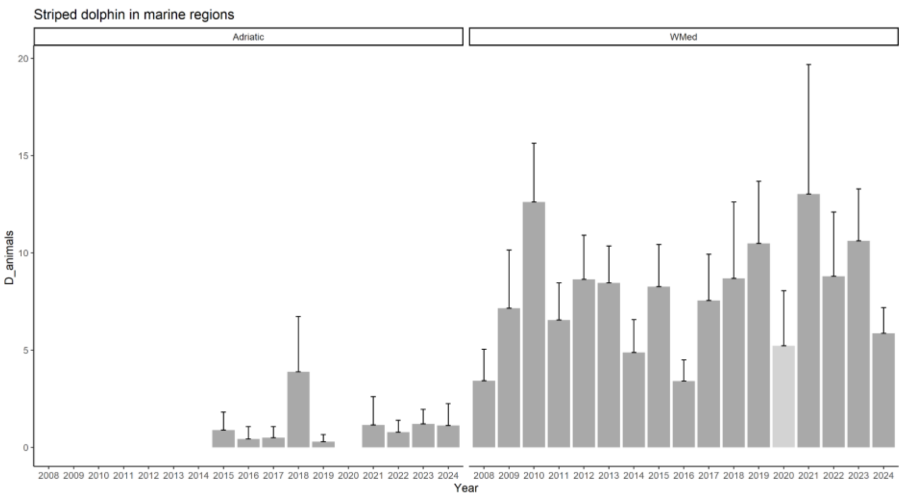


Table 1.1.7 and Figure 1.1.15. Table of yearly averages of the D_animals index for *Stenella coeruleoalba* with 95% confidence interval, for the two considered marine regions. The graph shows yearly averages of the D_animals index for *Stenella coeruleoalba* with upper-95%value for the two considered marine regions. The year 2020 is in light gray as, considering the lower number of surveys conducted that year, results might not be representative.

National EEZs

Looking at national EEZs, the presence of *Stenella coeruleoalba* is higher in French waters compared to Italian and Spanish ones. It is interesting to underline a strong interannual variability especially in animal densities (D_animals), as D_sight appears more stable in the three countries. 2018 and 2019 emerge as particularly rich years for the Spanish area while this pattern is not confirmed in the other two countries (Figure 1.1.16 and Figure 1.1.17)

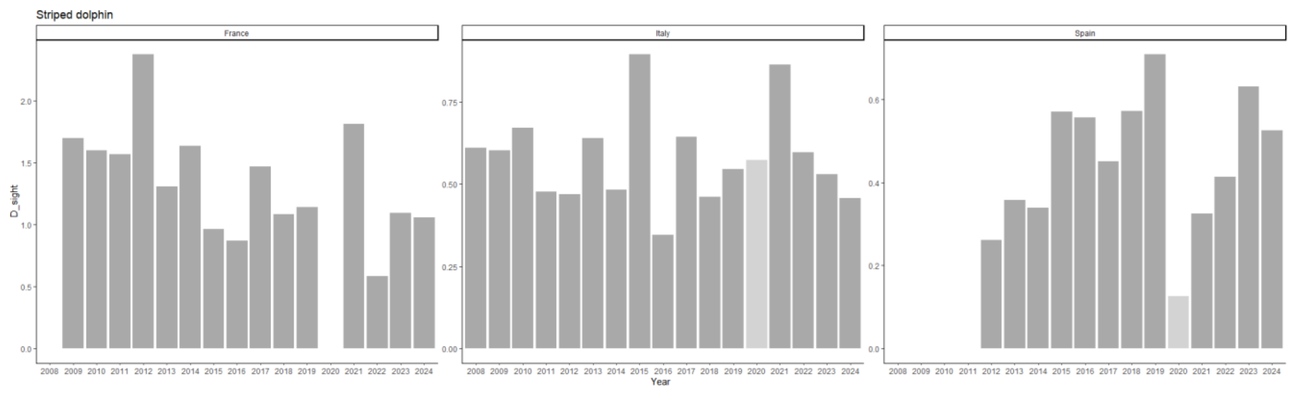


Figure 1.1.16. The graph shows yearly averages of the D_sight index for *Stenella coeruleoalba* with upper-95%value for the France, Italian and Spanish EEZs. The year 2020 is in light gray as, considering the lower number of surveys conducted that year, results might not be representative.

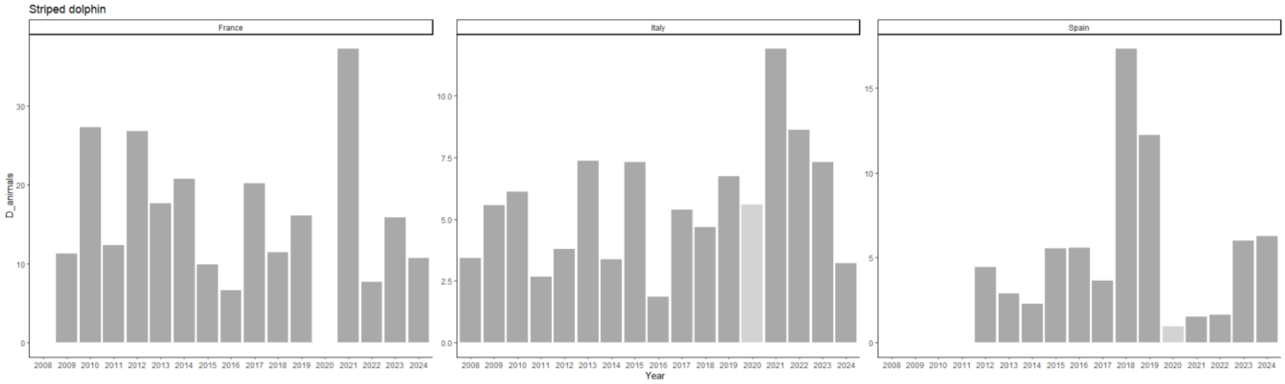


Figure 1.1.17. The graph shows yearly averages of the D_animals index for *Stenella coeruleoalba* with upper-95%value for the France, Italian and Spanish EEZs. The year 2020 is in light gray as, considering the lower number of surveys conducted that year, results might not be representative.

<u>Project areas</u>

When looking at the different areas covered by the project, the species presence has been recorded in all areas covered by the project (Figure 1.1.18), with the Pelagos Sanctuary emerging as the richest area. Its presence in the area from Spanish Cetacean Migration Corridor to Alboran Sea seems to be increasing.

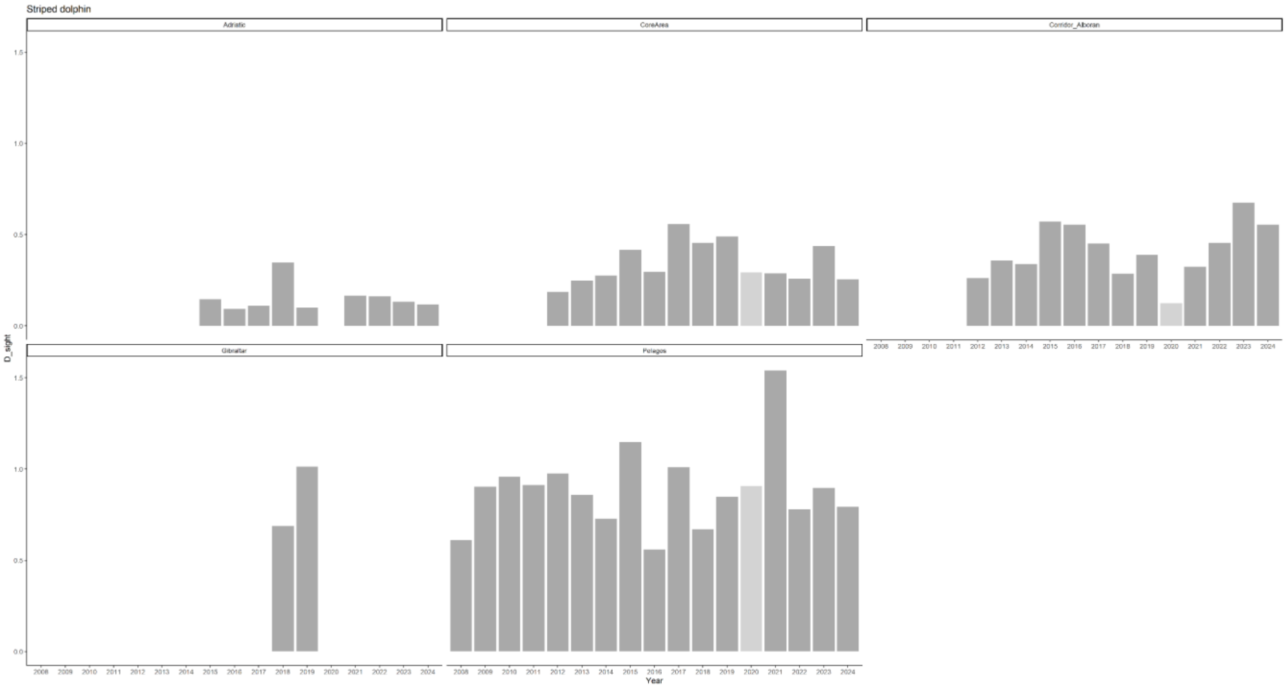


Figure 1.1.18. The graph shows yearly averages of the D_sight index for *Stenella coeruleoalba* with upper-95%value for the different project areas. The year 2020 is in light gray as, considering the lower number of surveys conducted that year, results might not be representative.

A similar pattern is evidenced by the animal density: it is interesting to note that the species was present in high numbers in the Gibraltar area, even higher than the Pelagos Sanctuary area (Figure 1.1.19)

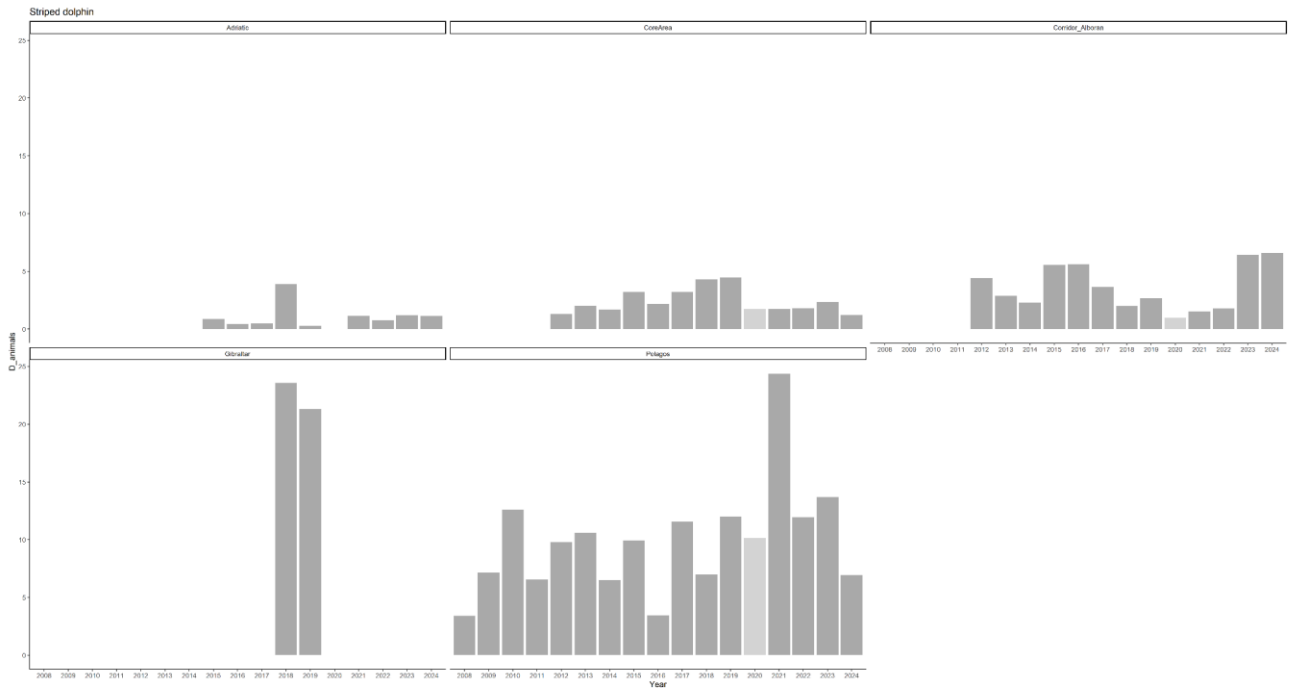


Figure 1.1.19. The graph shows yearly averages of the D_animals index for *Stenella coeruleoalba* with upper-95%value for the different project areas. The year 2020 is in light gray as, considering the lower number of surveys conducted that year, results might not be representative.

TREND IN ABUNDANCE - *Stenella coeruleoalba*

<u>Mediterranean basin</u>

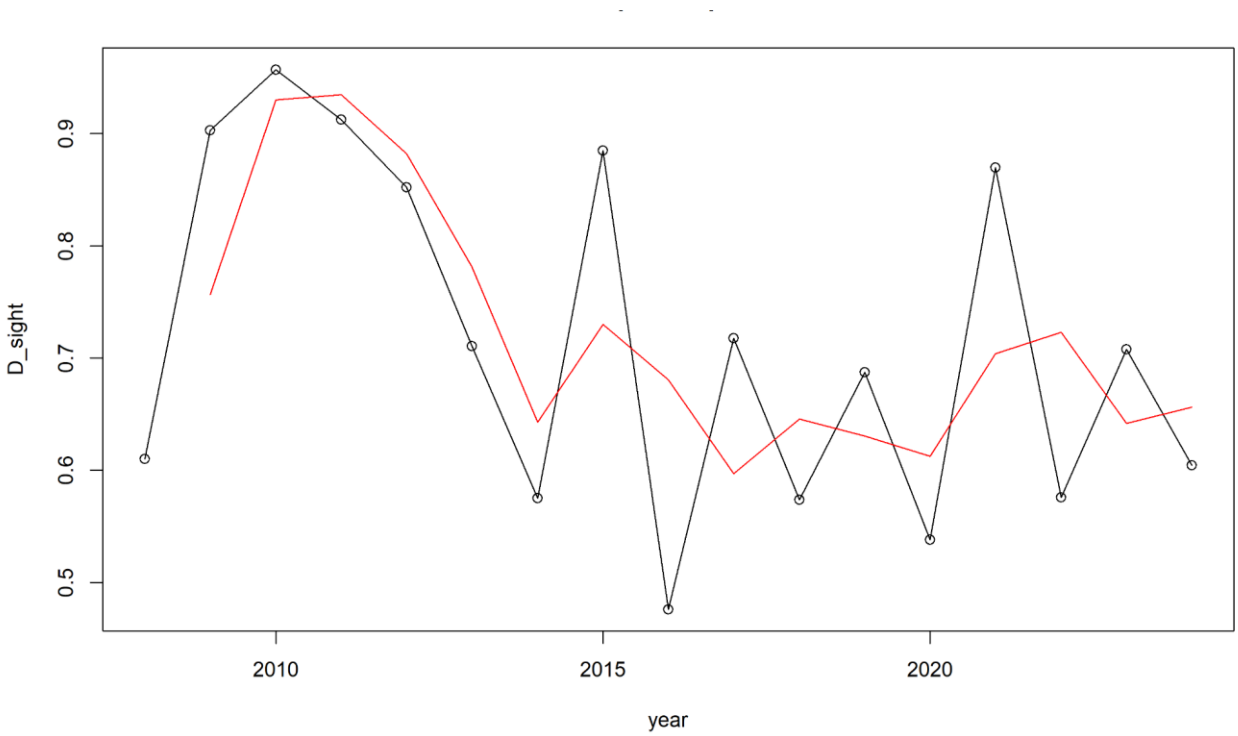


Figure 1.1.20. Trend in abundance for *Stenella coeruleoalba* considering overall yearly averages (black line) as well as applying a 2-years rolling mean (red-line)

The average yearly D_sight (black line) and the 2 years rolling mean (red line), shown in Figure 1.1.20, indicate a general negative trend of sightings up to 2015 and a more stable trend in the past 10 years. The constant decline from 2010 to 2014 is also reflected by the values of the three reporting periods separately (Figure 1.1.21). In fact, the first period, which encompasses just the first 2 years of decline, shows higher D_sight, while period 2 and 3 show lower values, but do not differ from each other.

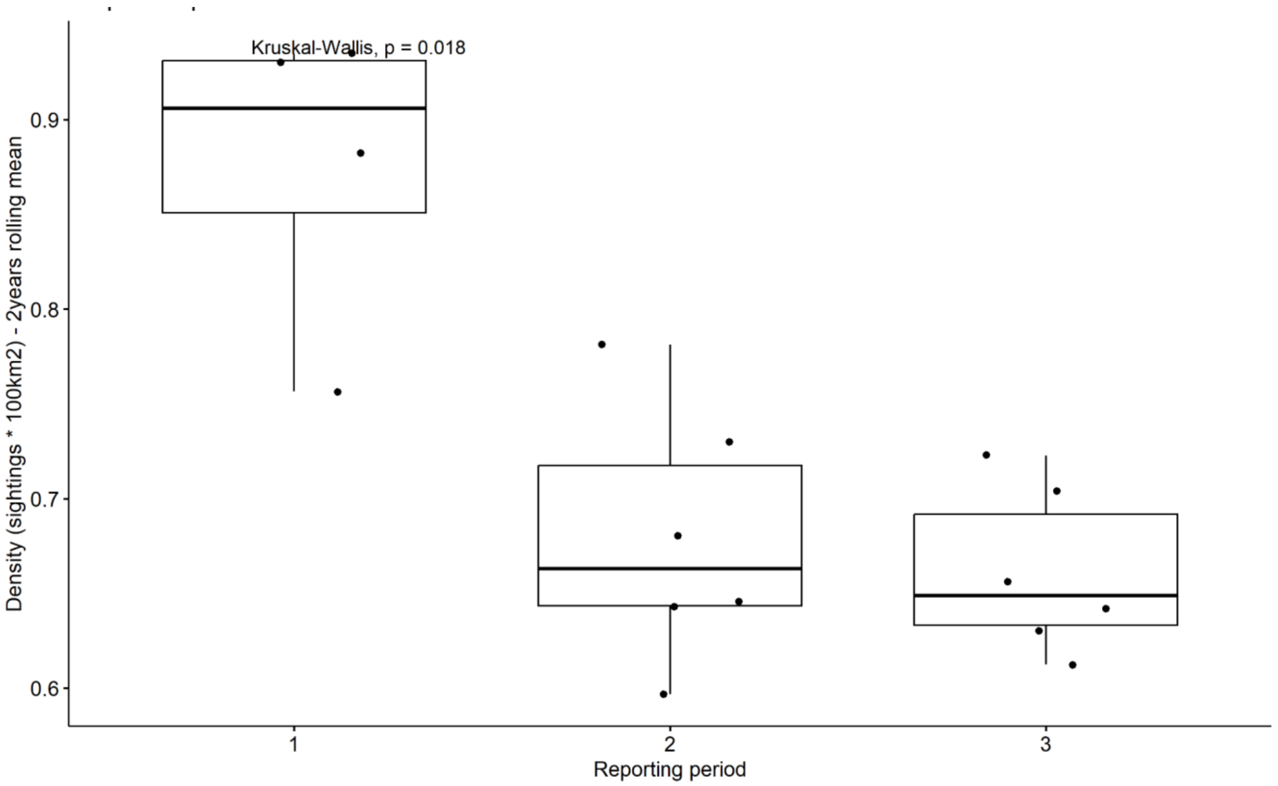


Figure 1.1.21. Box plots of D_sight for *Stenella coeruleoalba* for the considered reporting periods.

The intra period trend shows first an increasing trend for the first reporting period, while the negative years occurring during the second period caused the negative trend for the following years. For the third period the trend is stable.

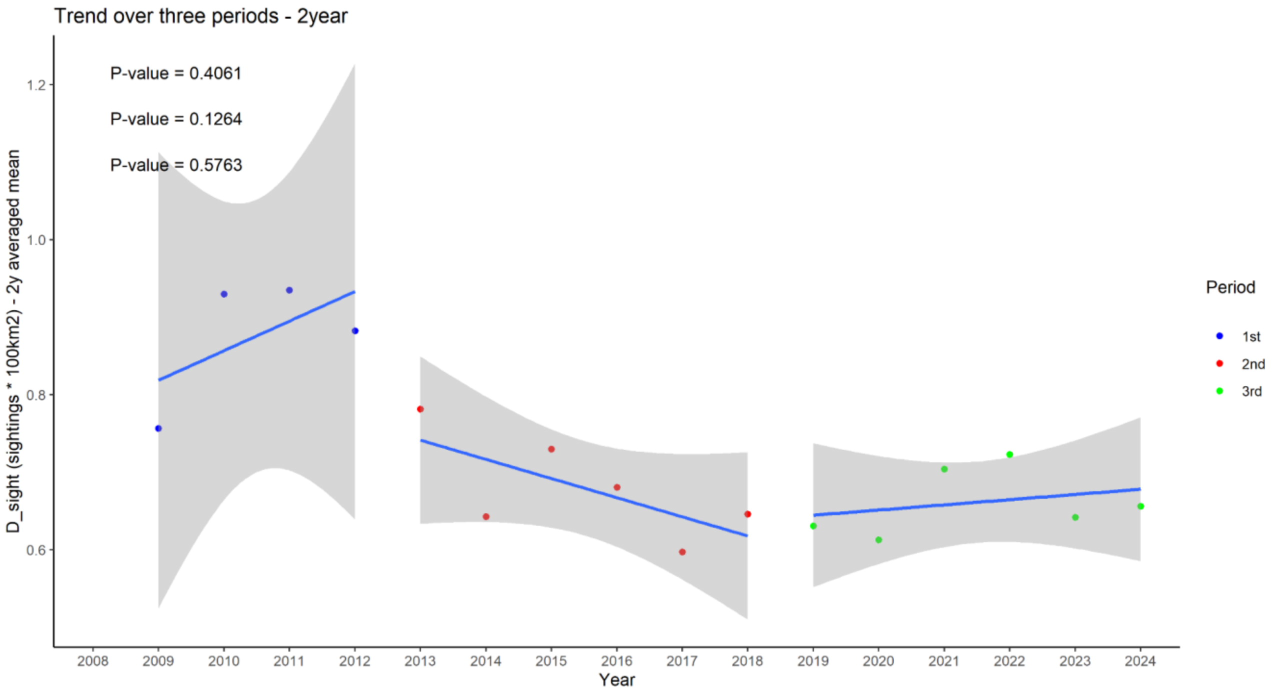


Figure 1.1.22. Intra period trends for *Stenella coeruleoalba* considering a 95% CI. P-values are referred to the linear model of each reporting period.

Looking at the number of animals, a different situation is highlighted. A decreasing trend in the number of sighted animals, to be considered as a proxy for group size, is present from 2010 to 2016, year that marks the lowest mean D_animals in the basin, while a positive trend is evidenced in the last 5 years, indicating the presence of larger groups than in the past.

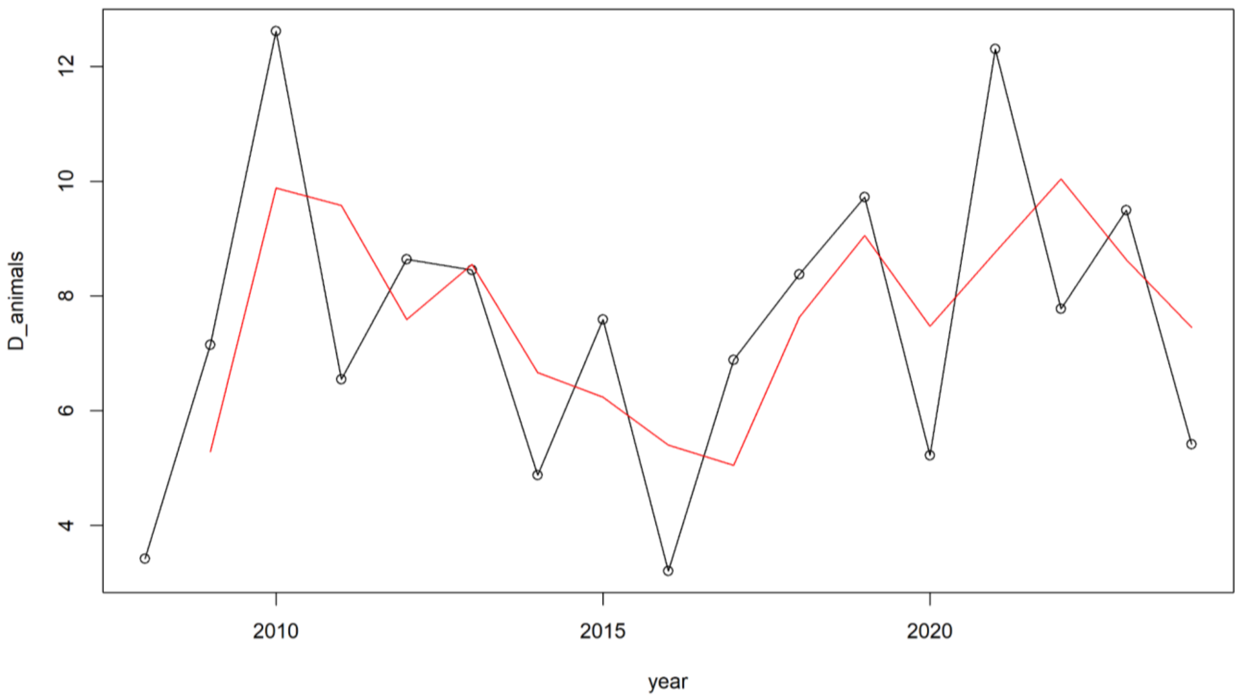


Figure 1.1.23. Trend in animals density for *Stenella coeruleoalba* considering overall yearly averages (black line) as well as applying a 2-years rolling mean (red-line)

This pattern is even more evident when looking at the three reporting periods, with the 3rd period showing a recovery in the D_animals, compared to the 2nd period (Figure 1.1.24)

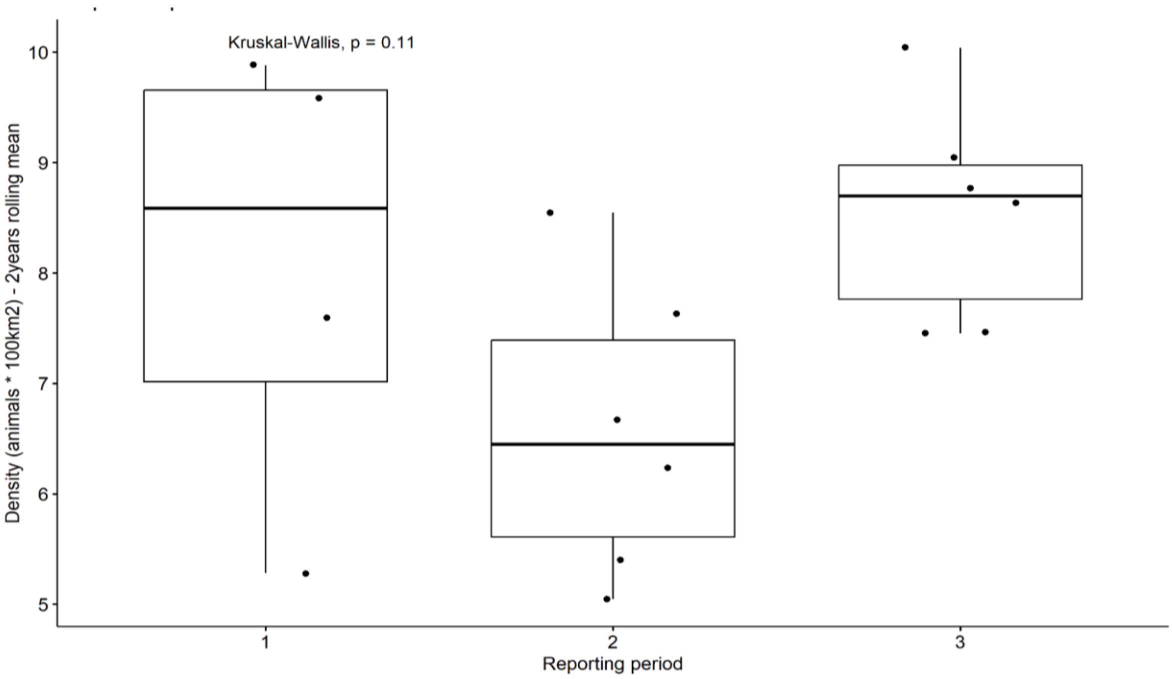


Figure 1.1.24. Box plots of D_animals for *Stenella coeruleoalba* for the considered reporting periods.

The intra period trend for the number of animals indicates more stability within every single period, with a slight decrease in the second one.

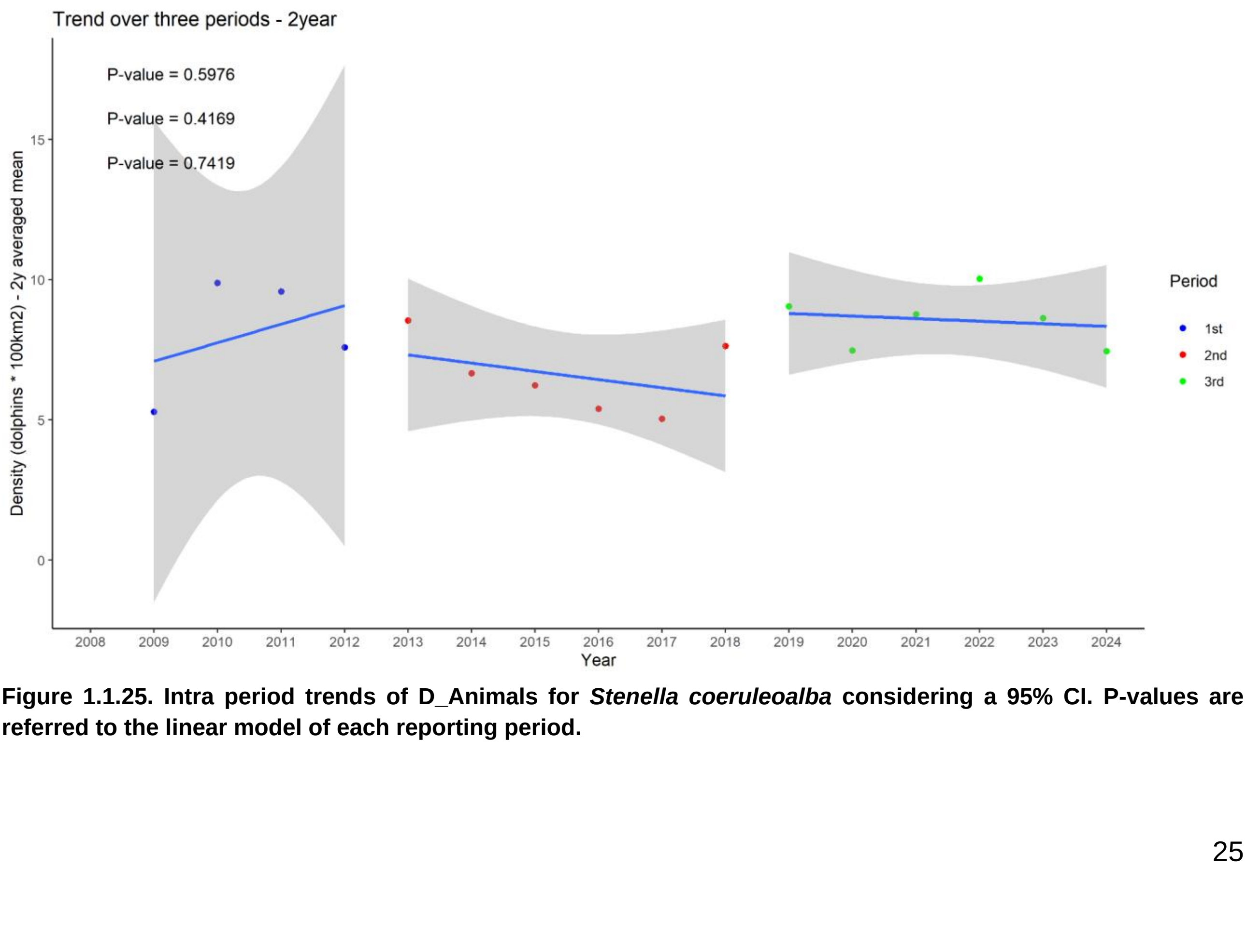


Figure 1.1.25. Intra period trends of D_Animals for *Stenella coeruleoalba* considering a 95% CI. P-values are referred to the linear model of each reporting period.

Marine Regions

The species presence is stable in the second and third reporting periods in the Adriatic region, while a statistically significant difference is evidence for the western Mediterranean region, with higher density values in the first reporting period followed by a decrease in the last two periods (Figure 1.1.26).

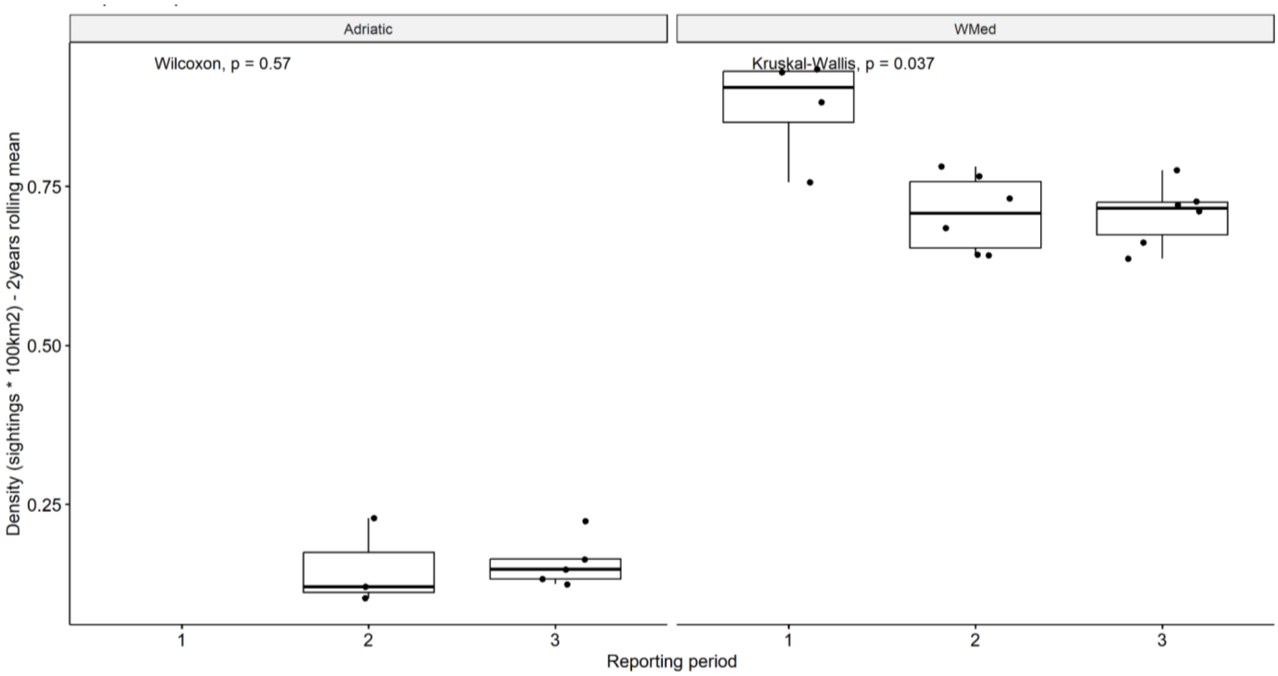


Figure 1.1.26. Box plots of D_sight for *Stenella coeruleoalba* for the considered reporting periods for the two marine regions

No significant trend is evidenced within any period, indicating relative stability for the species presence in both considered marine regions.

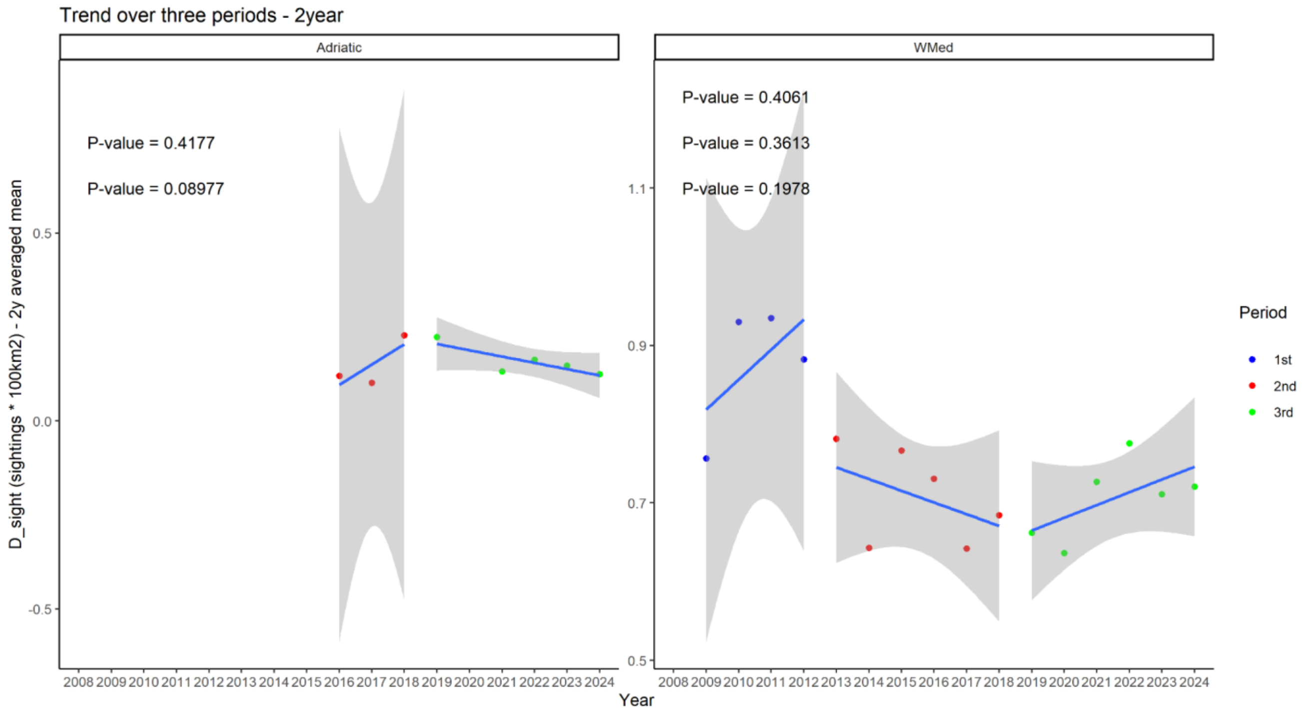


Figure 1.1.27. Intra period trends of D_sight for *Stenella coeruleoalba* considering a 95% CI for the two considered marine regions. P-values are referred to the linear model of each reporting period.

When looking at animal densities, the trend, especially in the western Mediterranean region is very different, probably indicating the presence of larger groups in that marine region (Figure 1.1.28).

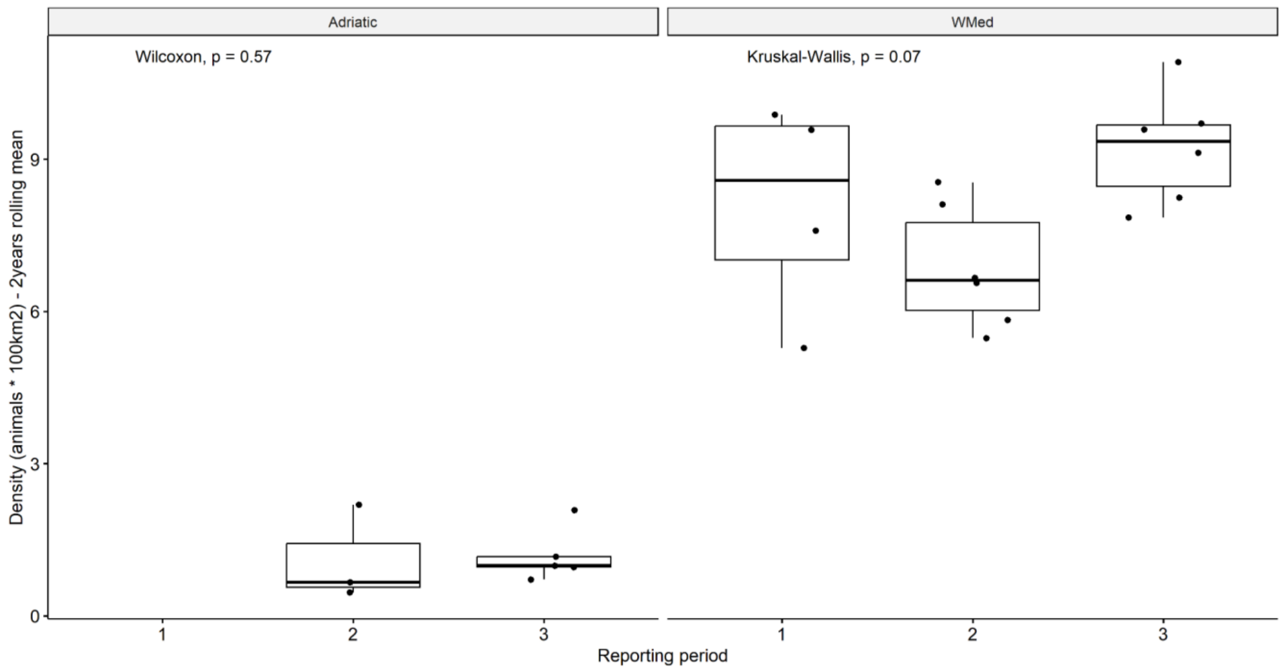


Figure 1.1.28. Box plots of D_animals for *Stenella coeruleoalba* for the considered reporting periods for the two marine regions

National EEZs

Zooming into National EEZs, it is evident how the decline evidenced for the western Mediterranean region is particularly due to a strong decline registered in the French EEZ, while for both Italian and Spanish waters the species is stable over the three periods (Figure 1.1.29).

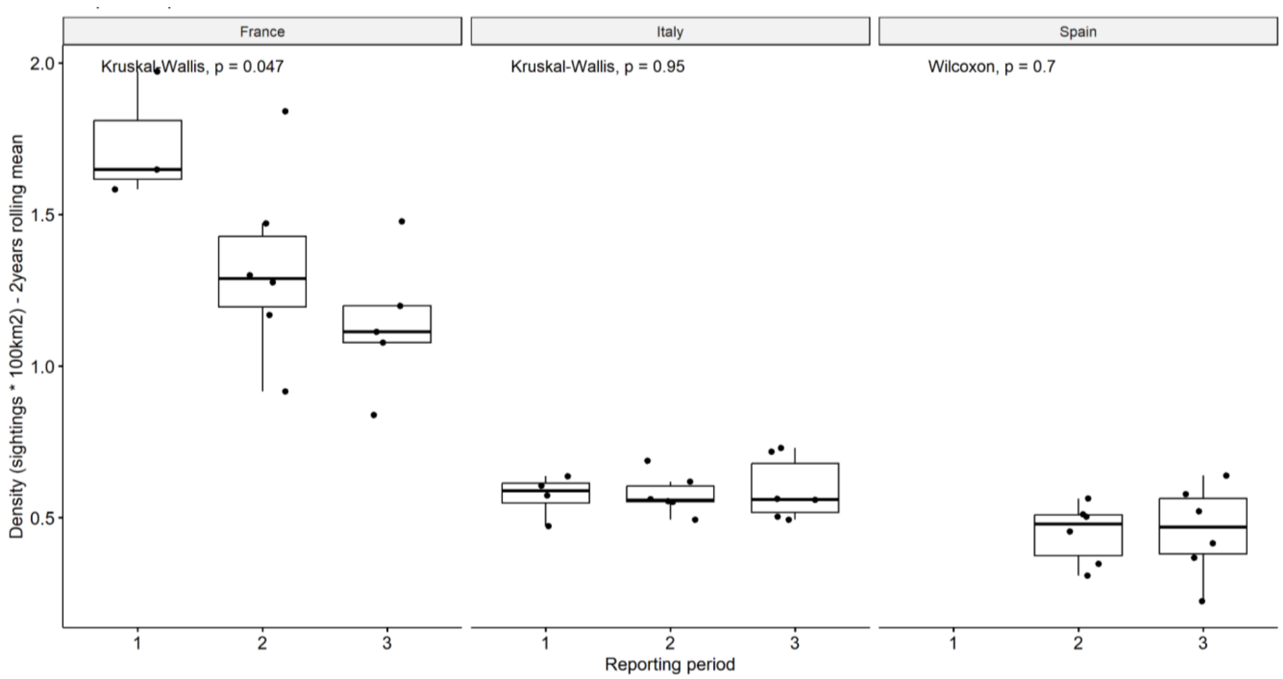


Figure 1.1.29. Box plots of D_sight for *Stenella coeruleoalba* for the considered reporting periods for French, Italian and Spanish EEzs

The strong interannual variability in the three national waters does not allow to highlight any intra-period trend, apart from Spain, where a statistically significant positive trend is evidenced for the second period, probably indicating an increase in species presence followed by a more stable 3rd period (Figure 1.1.30)

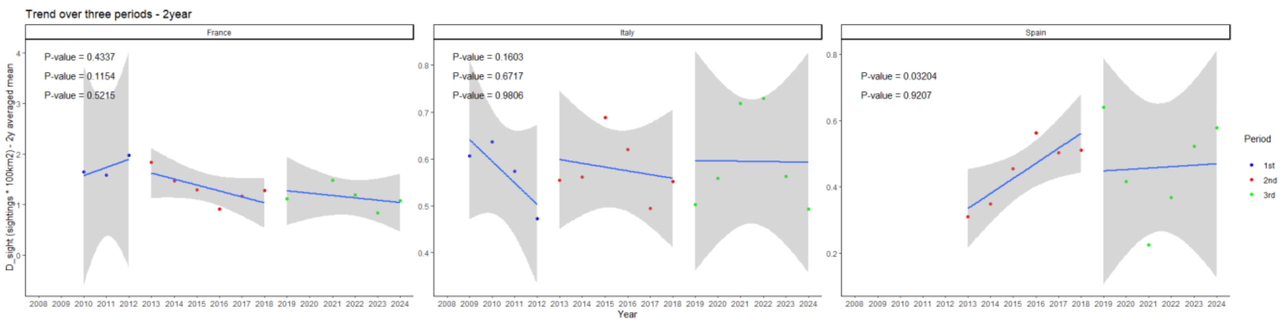


Figure 1.1.30. Intra period trends of D_sight for *Stenella coeruleoalba* considering a 95% CI for the French, Italian and Spanish EEZs. P-values are referred to the linear model of each reporting period.

In National EEZs animal density varies, especially in the French area, where, although the number of sightings is apparently declining, the number of animals does not show a similar trend, thus indicating a different group size, especially on a yearly basis. A statistically significant positive trend in the number of animals, on the other hand, is highlighted in the Italian waters and this result, coupled with a stability in density of sightings, could imply the presence of larger groups (Figure 1.1.31).

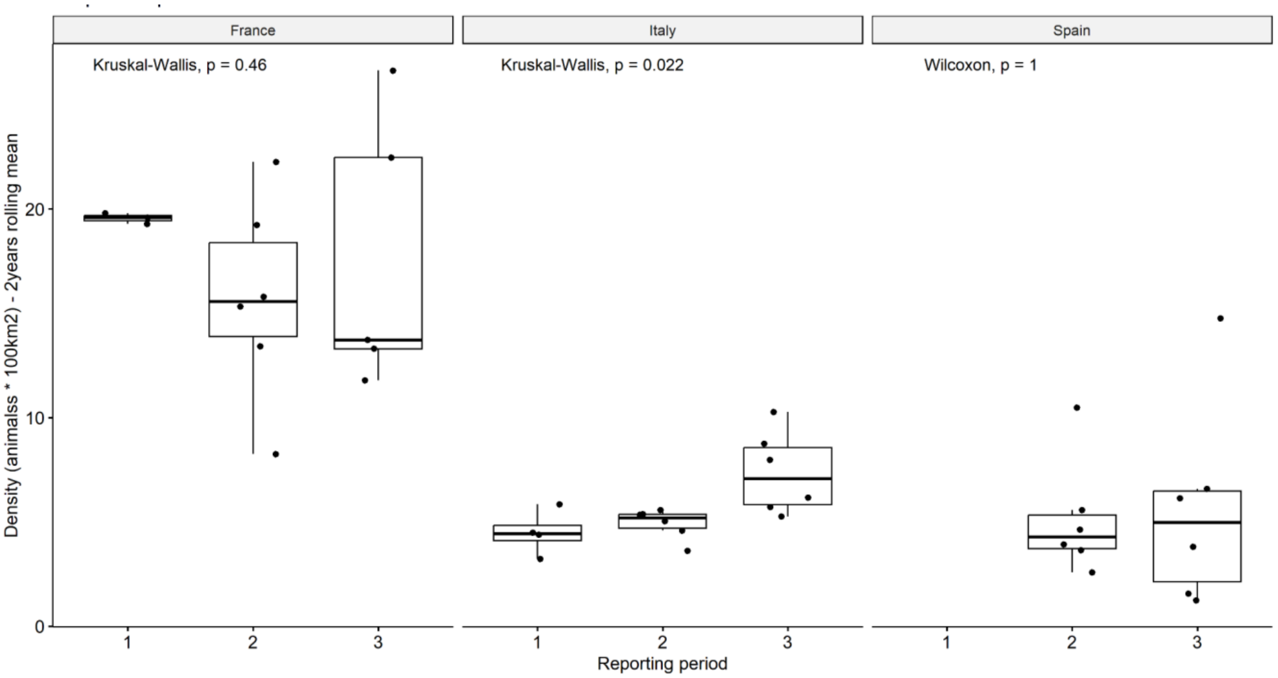


Figure 1.1.31. Box plots of D_animals for *Stenella coeruleoalba* for the considered reporting periods for French, Italian and Spanish EEZs.

<u>Project area</u>

When considering the project areas, no strong difference is evidenced in the presence of sightings over the three reporting periods. However, in the Pelagos Sanctuary area, a strong interannual variability is evidenced for the last period (Figure 1.1.32).

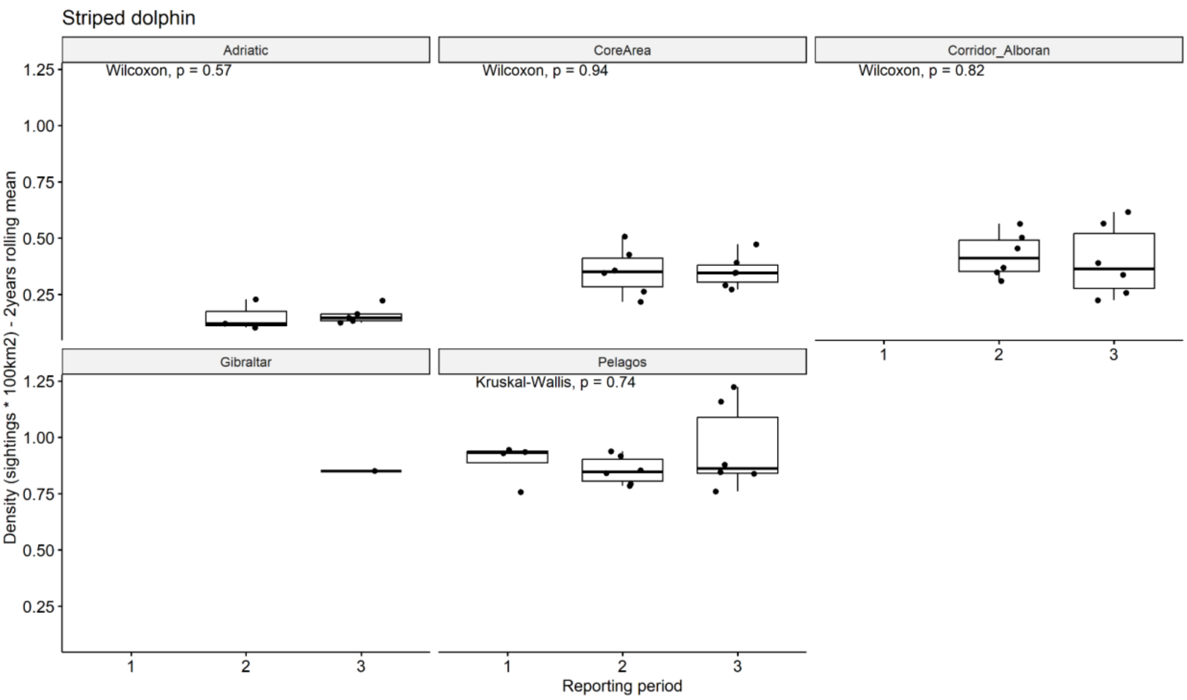


Figure 1.1.32. Box plots of D_sight for *Stenella coeruleoalba* for the considered reporting periods for the different project areas

Trends in the periods confirm the stability of the index for the Pelagos Sanctuary area, while showing an increase in the third period in the Spanish Cetacean Migration Corridor and in the first period for the Core Area. In this area, though, a decline seems to characterize the last period (Figure 1.1.33).

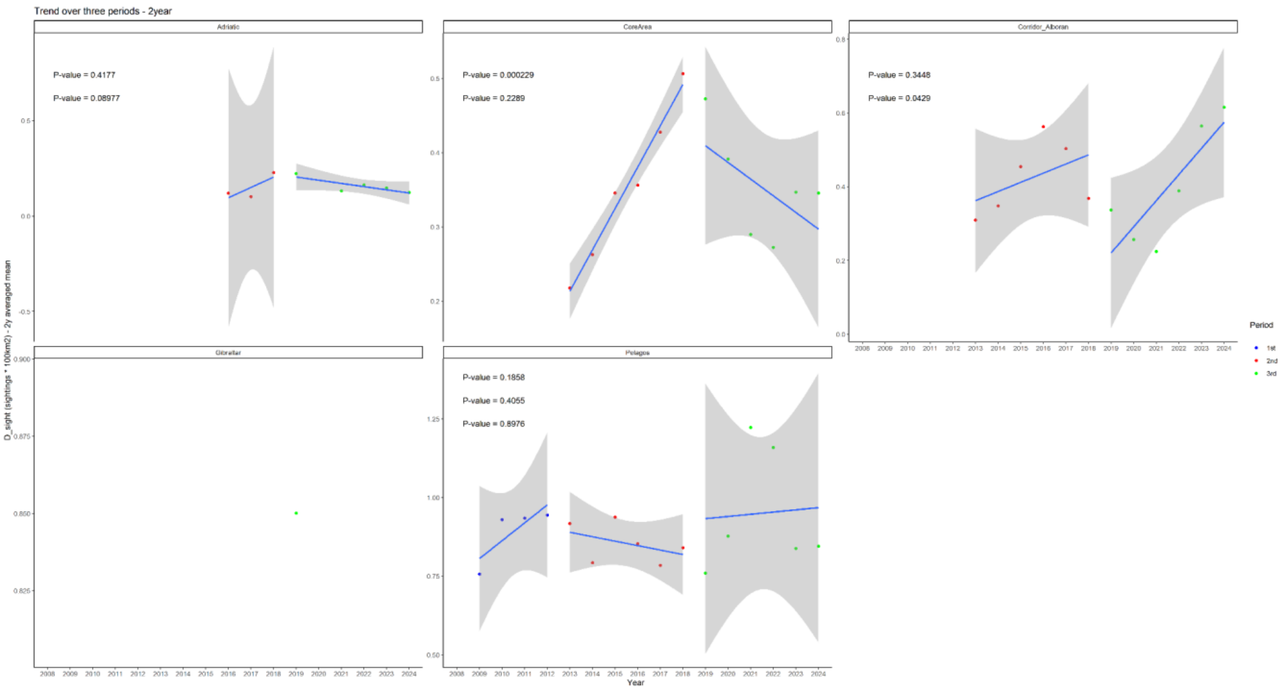


Figure 1.1.33. Intra period trends of D_sight for *Stenella coeruleoalba* considering a 95% CI for the different project areas. P-values are referred to the linear model of each reporting period.

This pattern is further confirmed when looking at the number of animals. For the Pelagos Sanctuary area, an increase in the number of animals is evidenced for the third period (Figure 1.1.34)

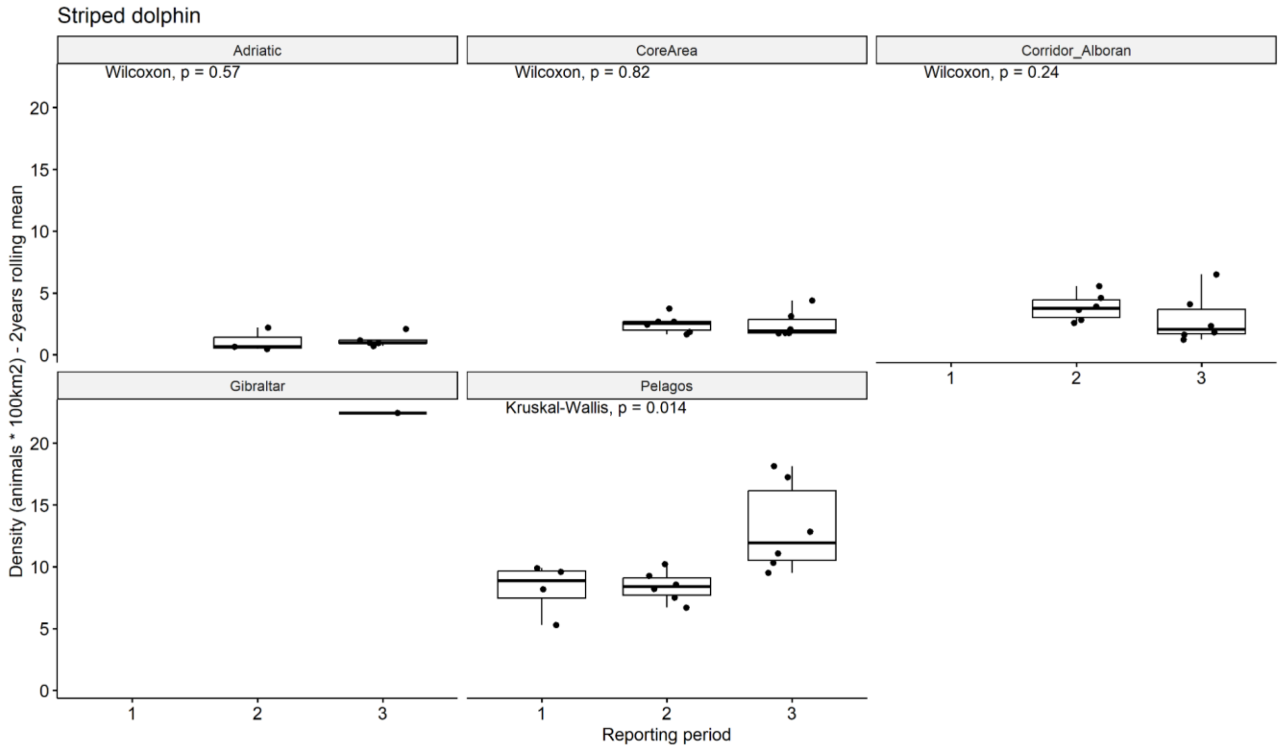


Figure 1.1.34. Box plots of D_animals for *Stenella coeruleoalba* for the considered reporting periods for the different project areas

The intra periods trend reflects the pattern evidenced for the number of sightings (Figure 1.1.35)

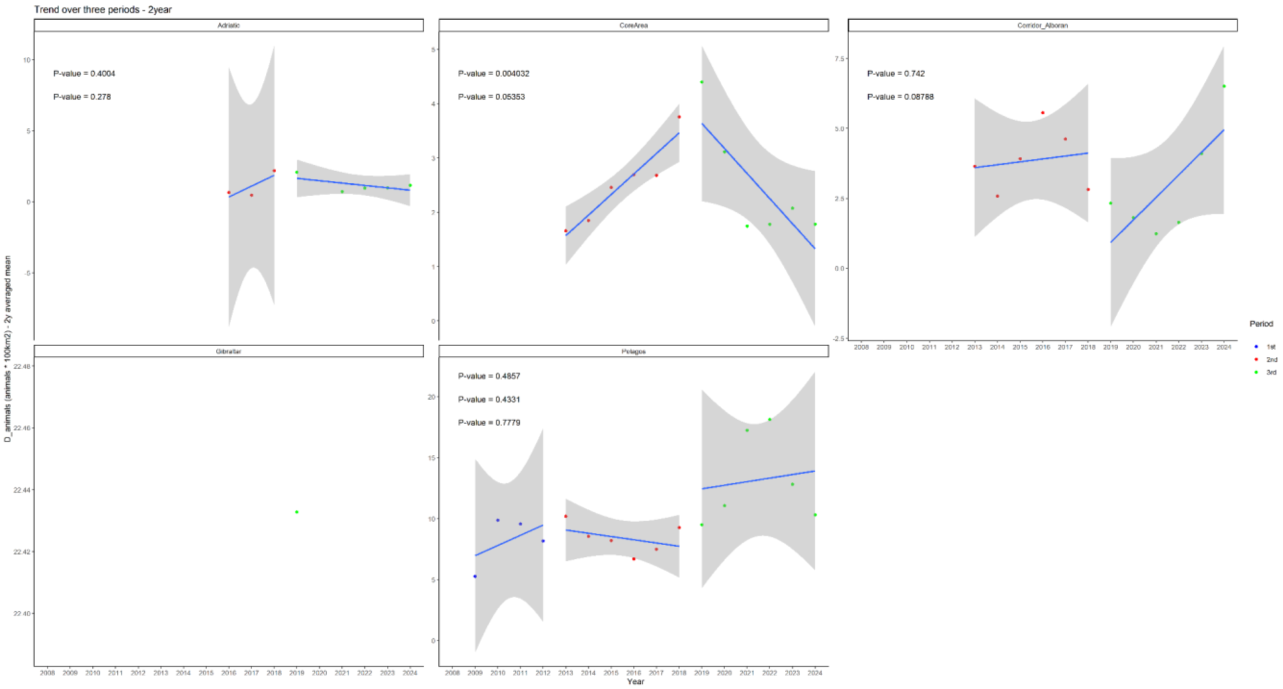


Figure 1.1.35. Intra period trends of D_animals for *Stenella coeruleoalba* considering a 95% CI for the different project areas. P-values are referred to the linear model of each reporting period.

Population and trend *Ziphius cavirostris*

TECHNICAL SUMMARY:
Ziphius cavirostris presence shows generally low values in the Mediterranean Sea, with a marked interannual variability. The species is present constantly in the Western Mediterranean sea, while it is occasional in the Adriatic Sea. Particularly anomalous years are evidenced for 2011 and 2021, identified as the poorest and richest years respectively, and a general increase trend is evidenced for the last 5 years. Among the different Habitat Directive reporting periods (2008–2012, 2013–2018, and 2019–2024) a significant difference among the first and the second, as well as among the second and the third periods is evidenced, confirming the increase in species abundance. The species presence in French EEZ and in Italian EEZ waters is higher than Spanish waters. For the three countries a strong interannual variability is detected. Across the three reporting periods the increasing trend is confirmed for Italian waters, while the species presence is more constant in French and Spanish waters.
The Pelagos Sanctuary is confirmed as a very important area for the species, where its presence is increasing over time. An increasing trend is observed also in the Core Area and in the area from the Spanish Cetacean Migration Corridor to the Alboran Sea, even if lower densities are detected here compared to the Pelagos Sanctuary Area.

SUMMARY FOR POLICYMAKERS: *Ziphius cavirostris* in the Western Mediterranean

7. **Overall Status:** The goose-beaked whale (*Ziphius cavirostris*) shows an increasing presence in the western Mediterranean, while its presence in the Adriatic sea is occasional. In the western Mediterranean sea some anomalous years are evidenced.
8. **Trends and Variability:**
    a. No consistent long-term trend is observed across the region, but a stable trend from 2008 to 2020 is observed, followed by an increasing phase.
    b. The increase is confirmed from the 1st Reporting period to the 2nd, and from the 2nd to the 3rd.
9. **Geographic Patterns:**
    a. French and Italian EEZs host higher densities of the species compared to Spanish waters.
    b. The abundance within French and Spanish waters shows more stability, while within Italy it exhibits a strong increasing trend.
    c. The Pelagos Sanctuary remains a key conservation area, with an increasing presence during the last reporting period.
    d. In the area from Spanish Cetacean Migration Corridor to the Alboran sea and the Life Conceptu maris Core Area (Tyrrhenian and Sardinia-Sicilian channels) the species shows lower densities but an increasing trend in both areas in the last reporting period.

Policy Implications

- Conservation focus should remain strong in the Pelagos Sanctuary to maintain positive trends, as well as in the Spanish and Core areas to confirm the positive trends.
- Cross-border collaboration between France, Italy, and Spain is essential to ensure regional population stability.

- Continued long-term monitoring is crucial for detecting trends and informing adaptive management strategies.

Method. For *Ziphius cavirostris*, as not enough sightings from all types of ferries were present to allow for a proper characterization of ESWs, it has been decided to apply to all ferries the ESW computed from Type I ferries, eliminating all sightings occurring outside the visibility range of those ferries (set at 3,347 m linear distance). So the final applied ESW is 947 m.

The final dataset used for the population assessment accounted for 3,194 surveys, for a total of 289 sightings. Among these, 2,237 surveys have been conducted during the summer season (i.e., from April to September) for a total of 263 sightings, while 957 surveys were conducted during the winter season (October-March) for a total of 26 sightings.

Summer - <u>Mediterranean Basin</u>

Generally, the species presence is low in the entire basin, with maximum values reaching 0.09 sightings/100 km2 in 2021 (Table 1.1.8). A strong interannual variability is present also for this species (Figure 1.1.36), confirmed as significative also by the KW test (Kruskal-Wallis chi-squared = 61.419, df = 16, p-value = 3.013e-07).

Goose-beaked whale population assessment

density of sightings

year	D_sightings	95% CI
2008	0.03	−0.01—0.06
2009	0.00	0.00—0.01
2010	0.02	0.00—0.03
2011	0.00	0.00—0.01
2012	0.02	0.01—0.04
2013	0.03	0.01—0.04
2014	0.03	0.01—0.04
2015	0.04	0.02—0.06
2016	0.02	0.01—0.04
2017	0.05	0.02—0.07
2018	0.02	0.00—0.03
2019	0.03	0.01—0.06
2020	0.04	0.00—0.08
2021	0.09	0.03—0.14
2022	0.07	0.03—0.11
2023	0.06	0.03—0.09
2024	0.05	0.03—0.08

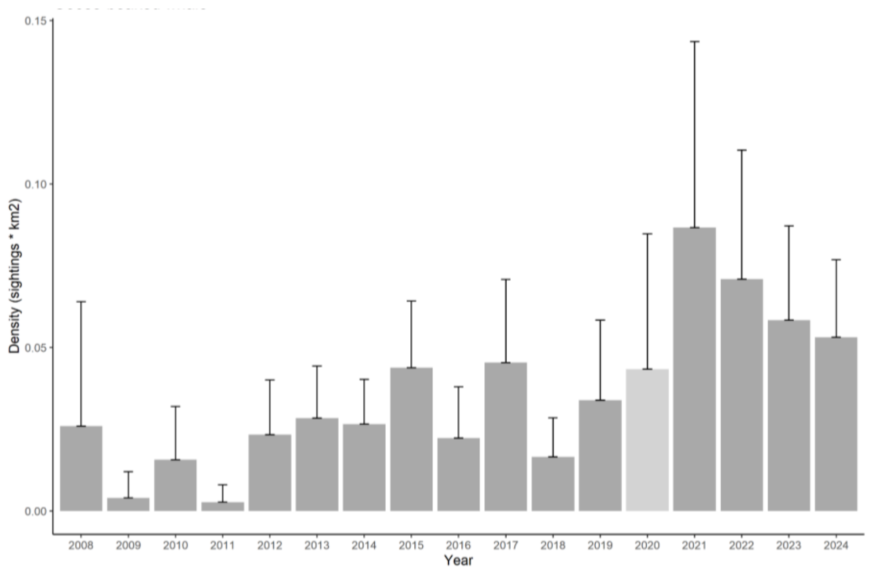


Table 1.1.8 and Figure 1.1.36. Table of yearly averages of the D_sight index *for Ziphius cavirostris* with 95% confidence interval. The graph shows yearly averages of the D_sight index *for Ziphius cavirostris* with upper-95%value. The year 2020 is in light gray as, considering the lower number of surveys conducted that year, results might not be representative.

The post-hoc Dunn test evidences 2011 and 2021 as anomalous years, as the richest and the poorest years, respectively. As similar results are obtained with the D_animals index, the subsequent analyses have been performed only considering the D_sight index.

Marine regions

The species is constantly present in the western Mediterranean region, while it has to be considered as rare/occasional in the Adriatic region (Figure 1.1.37). Considering the low number of sightings for the Adriatic region (5 in total), no analysis on trends was done in the region, and the pattern described for the entire Mediterranean Basin is that reflected by the western Mediterranean region.

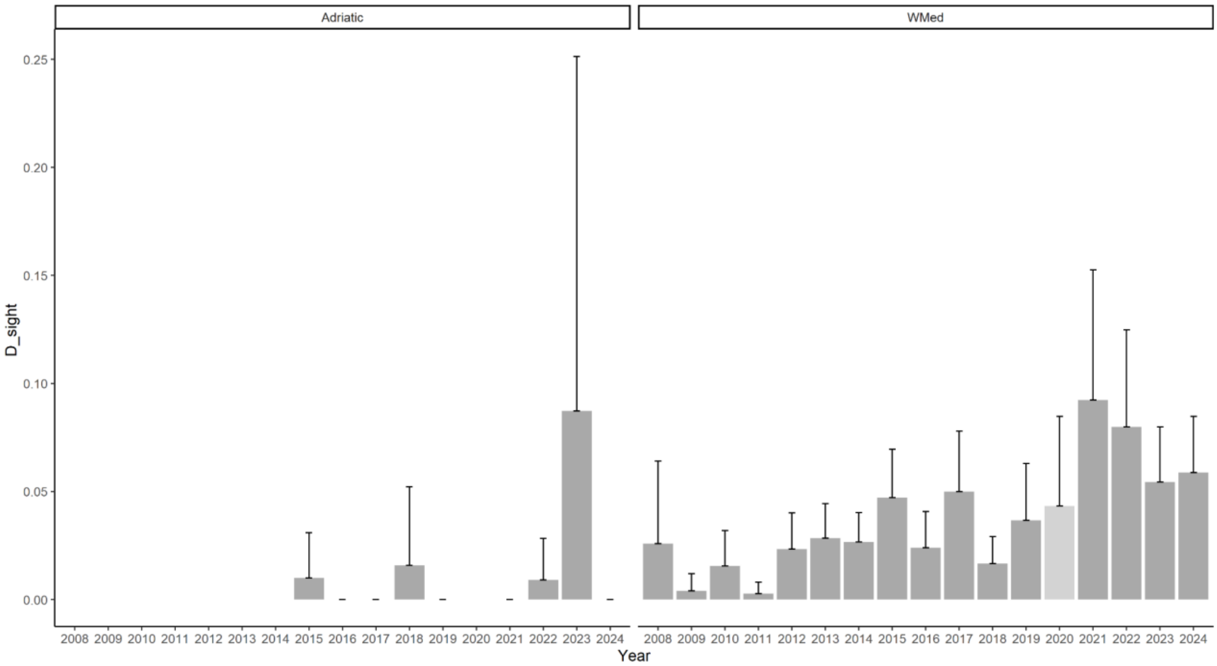


Figure 1.1.37. The graph shows yearly averages of the D_animals index *for Ziphius cavirostris* with upper-95%value for the two considered marine regions. The year 2020 is in light gray as, considering the lower number of surveys conducted that year, results might not be representative.

National EEZs

Looking at national waters, the range of values is generally similar across the three countries, with a comparable pattern of strong interannual variability (Figure 1.1.38).

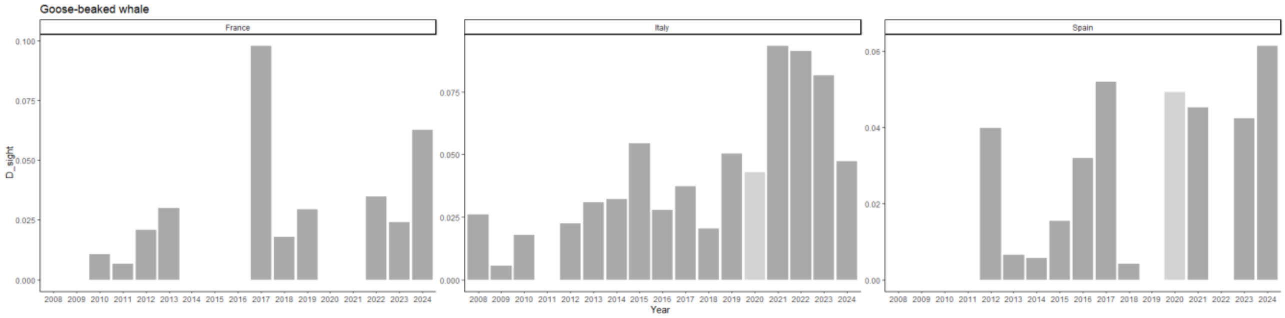


Figure 1.1.38. The graph shows yearly averages of the D_animals index *for Ziphius cavirostris* with upper-95%value for the France, Italian and Spanish EEZs. The year 2020 is in light gray as, considering the lower number of surveys conducted that year, results might not be representative.

Project areas

Zooming into project areas (Figure 1.1.39), the species presence is constant in the Core area, in the Pelagos Sanctuary and in the area from the Spanish Cetacean Migration Corridor to the Alboran Sea, while it was occasionally sighted in the Adriatic and never observed in the Gibraltar area, where, considering the elusive behaviour of this species, the lower effort could explain the absence of sightings.

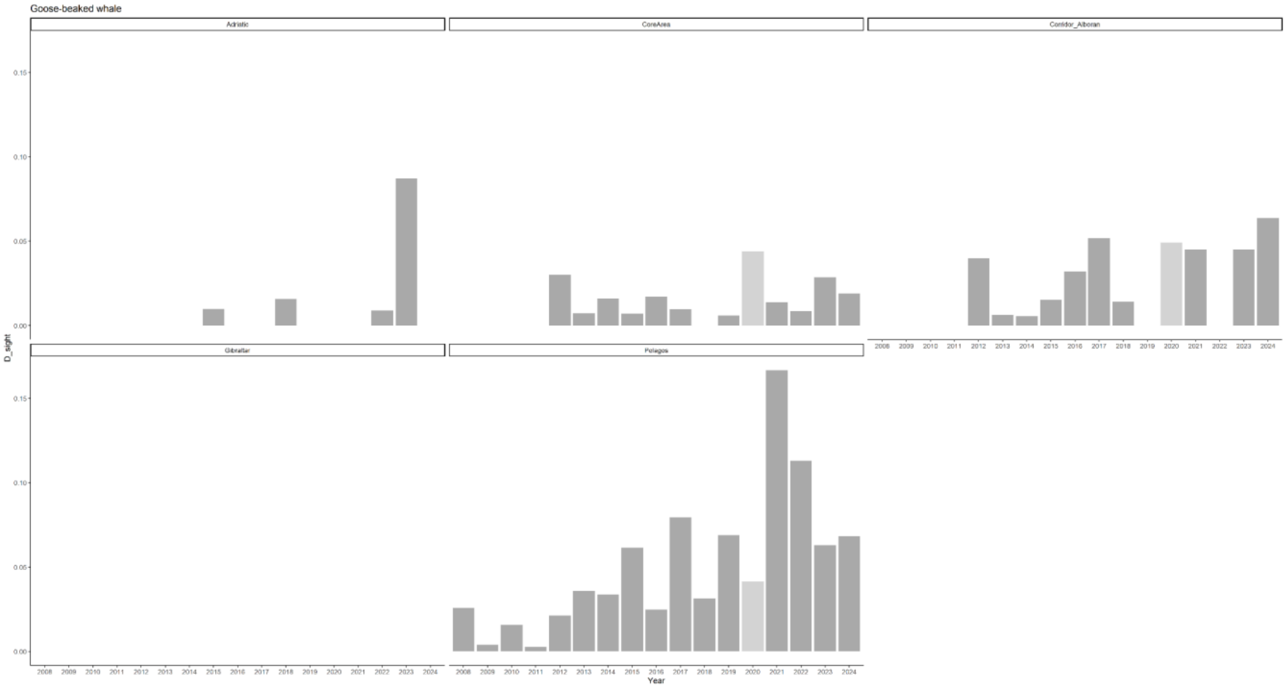


Figure 1.1.39. The graph shows yearly averages of the D_sight index *for Ziphius cavirostris* with upper-95%value for the different project areas. The year 2020 is in light gray as, considering the lower number of surveys conducted that year, results might not be representative.

TREND IN ABUNDANCE - *Ziphius cavirostris*

Mediterranean Basin

Figure 1.1.40 shows the overall trend for the species presence in the Mediterranean basin (mainly driven by the assessment for the western Mediterranean region as previously explained). An overall increasing trend is evident for both the annual (black line) and 2-year rolling mean average values (red-line).

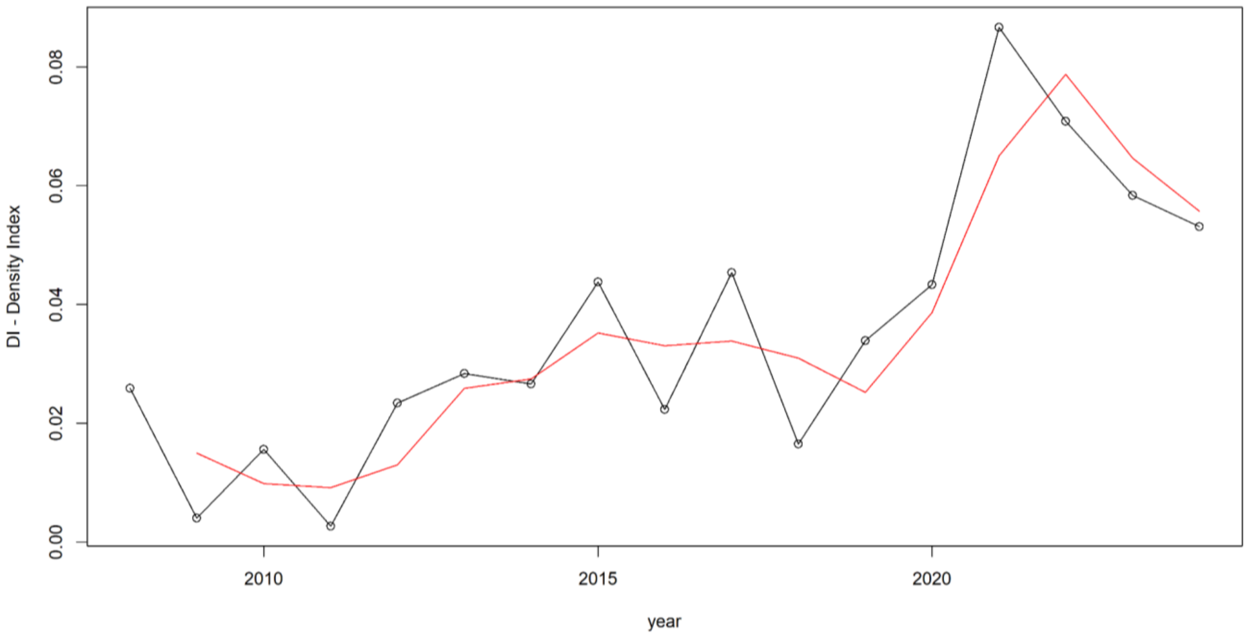


Figure 1.1.40. Trend in abundance *for Ziphius cavirostris* considering overall yearly averages (black line) as well as applying a 2-years rolling mean (red-line).

This tendency is further confirmed by looking at the three considered reporting periods, all being statistically different from each other and with higher values in the 2nd and 3rd period compared to the 1st (Figure 1.1.41)

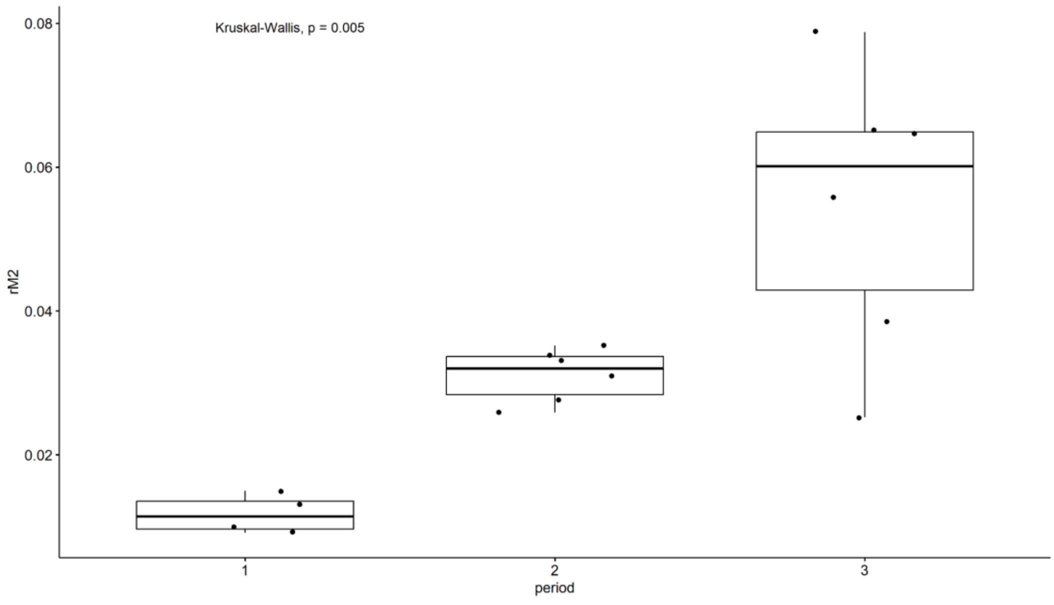


Figure 1.1.41. Box plots of D_sight *for Ziphius cavirostris* for the considered reporting periods.

The intra-period trends are all increasing, with a steeper increase in the 3rd considered reporting period (Figure 1.1.42)

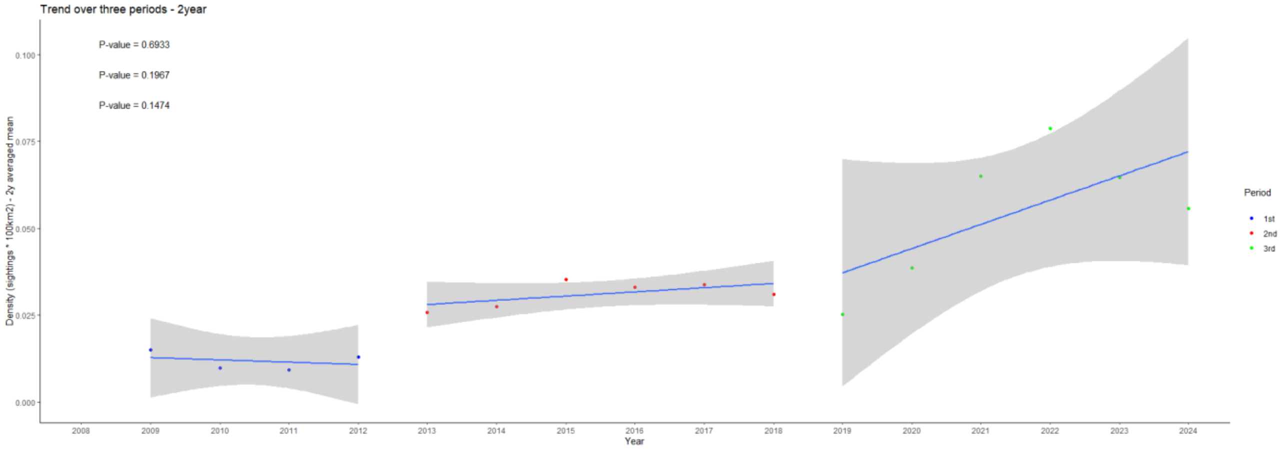


Figure 1.1.42. Intra period trends of D_sight *for Ziphius cavirostris* considering a 95% CI. P-values are referred to the linear model of each reporting period.

National EEZs

When considering national EEZs, the increasing trend is confirmed only for Italy, while in France and Spain the species seems to be more stable.

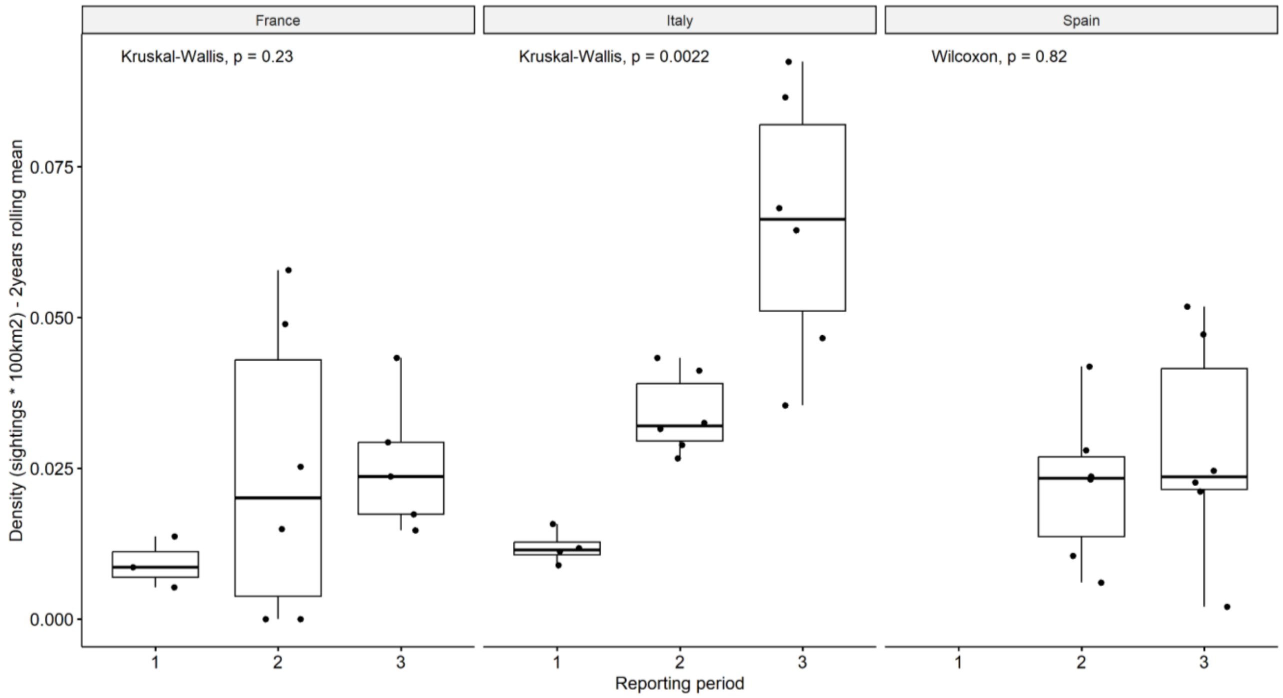


Figure 1.1.43. Box plots of D_sight *for Ziphius cavirostris* for the considered reporting periods for French, Italian and Spanish EEzs

The intra-period trends show an increasing tendency especially for the third period for the three countries, confirming the general increasing presence of the species (Figure 1.1.44)

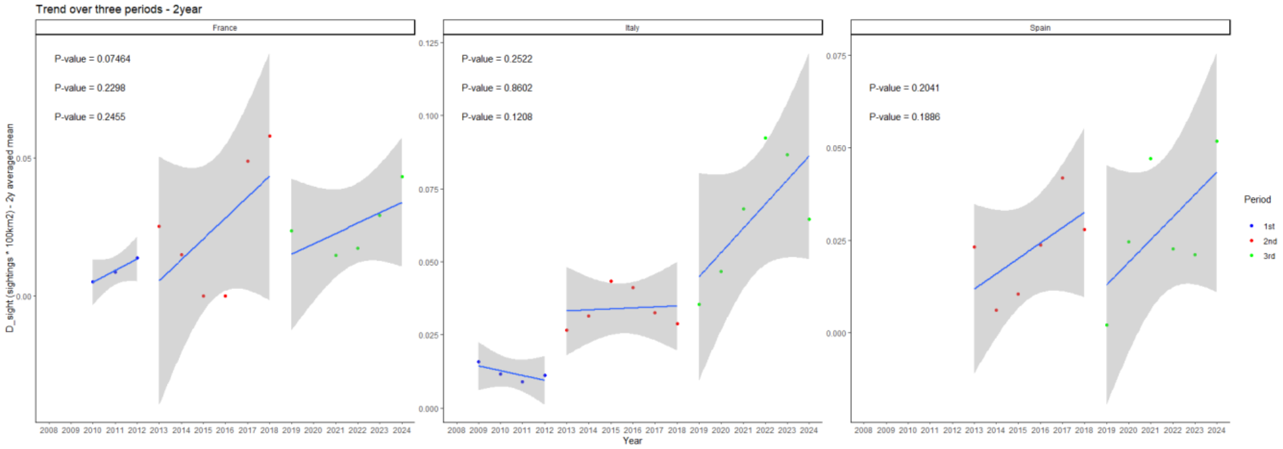


Figure 1.1.44. Intra period trends of D_sight *for Ziphius cavirostris* considering a 95% CI for the French, Italian and Spanish EEZs. P-values are referred to the linear model of each reporting period.

<u>Project areas</u>

When considering the different project areas, the increasing trend is confirmed for the Pelagos Sanctuary area, while more stable values are shown for the Core Area, the area from Spanish Cetacean Migration Corridor to the Alboran Sea and the Adriatic sea.

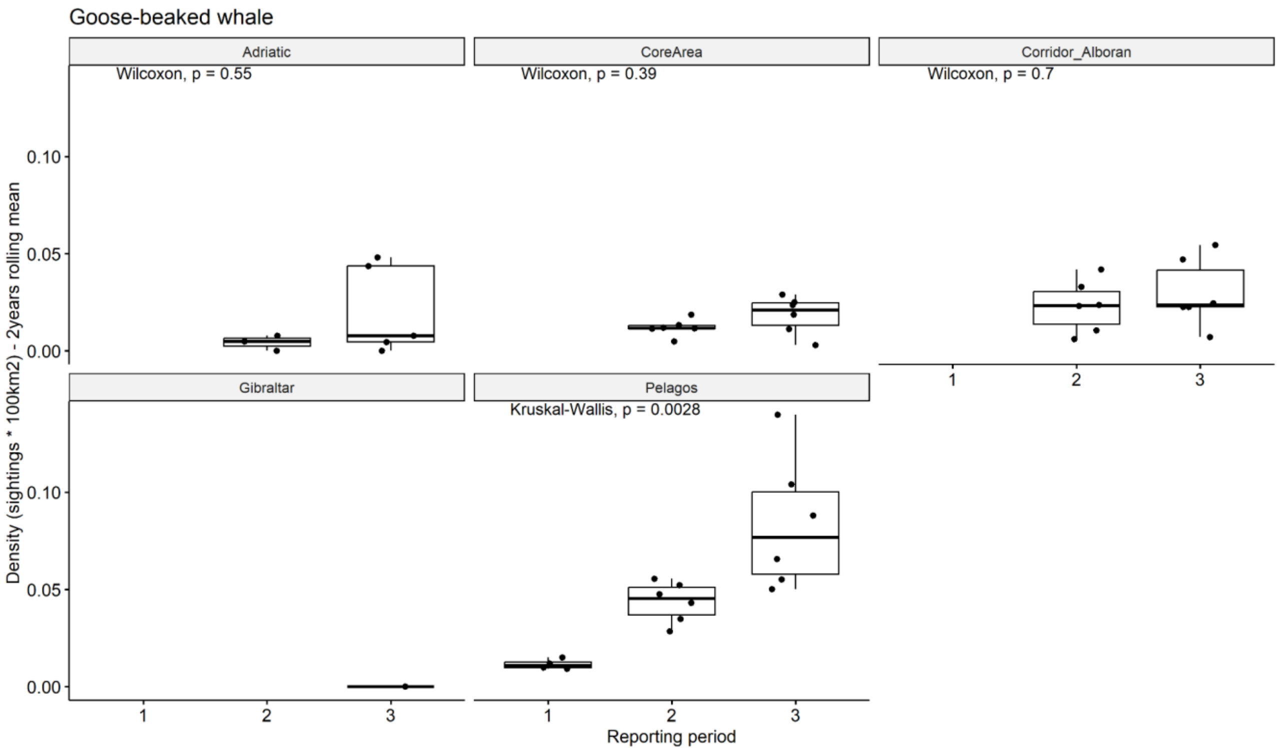


Figure 1.1.45 - box plots of D_sight *for Ziphius cavirostris* for the considered reporting periods for the different project areas.

The intraperiod trends, on the other hand, show a positive trend for the second and third period, with a negative trend in the second period only in the Core Area (Figure 1.1.46).

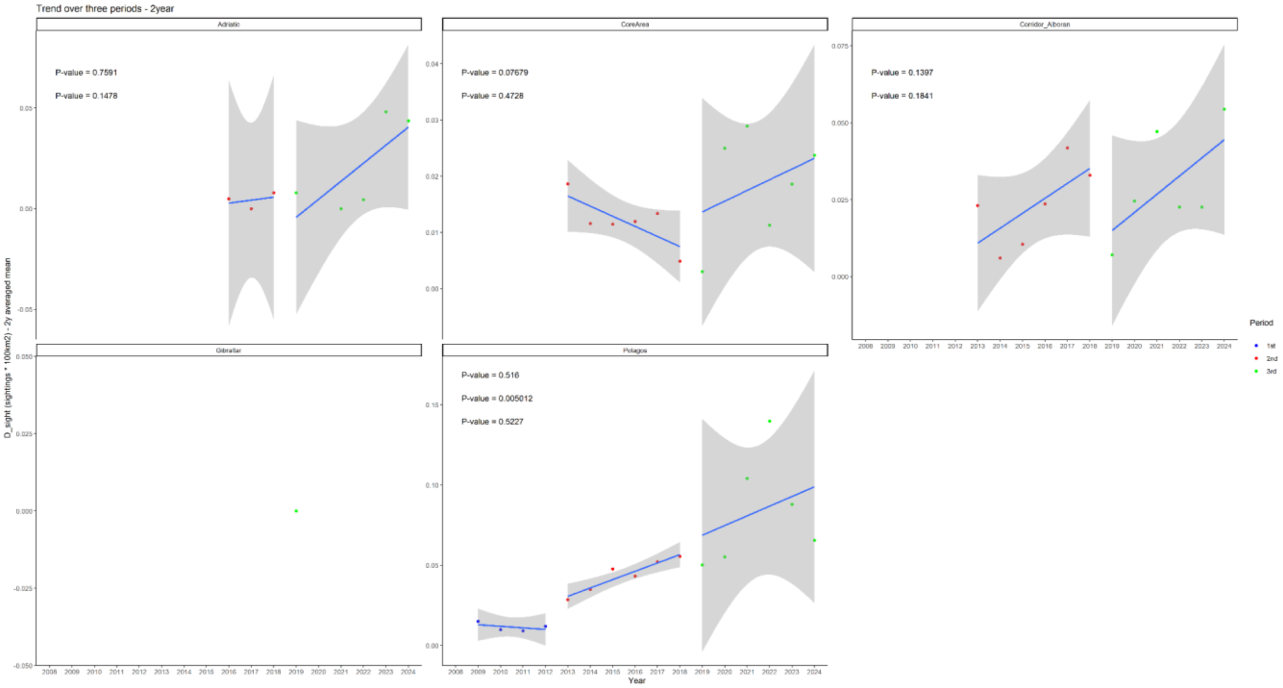


Figure 1.1.46. Intra period trends of D_sight *for Ziphius cavirostris* considering a 95% CI for the different project areas. P-values are referred to the linear model of each reporting period.

Population and trend *Physeter macrocephalus*

TECHNICAL SUMMARY:

Physeter macrocephalus presence shows generally low values in the Mediterranean Sea, with a marked interannual variability. The species is present constantly in the Western Mediterranean sea, while it is occasional in the Adriatic Sea. No anomalous years are evidenced and, while peak years have occurred in 2012 and 2017, generally no trend can be evidenced. Stability is confirmed also among the different Habitats Directive reporting periods (2008–2012, 2013–2018, and 2019–2024), even if the strong interannual variability needs to be underlined. Species presence in the French EEZ waters is twice higher than in the Italian and Spanish waters. The strong interannual variability is detected for France and Spain, while more stability is evidenced for Italian waters. Across the three reporting periods, no differences are evidenced in trends in the Italian waters, while in the French waters an increase from 1st to 2nd periods, followed by a decrease from 2nd to 3rd period is evidenced. A decrease within the 3rd period is detected for Spanish waters. The Pelagos Sanctuary is confirmed as a very important area for the species, where its presence is stable over time; a decreasing trend from 2nd to 3rd period is observed in the project Core Area (Tyrrhenian and Sardinia-Sicilian channels) and in the area from the Spanish Cetacean Migration Corridor to the Alboran sea

SUMMARY FOR POLICY MAKERS: *Physeter macrocephalus* in the Western Mediterranean

10. **Overall Status:** The sperm whale (*Physeter macrocephalus*) shows a variable presence in the western Mediterranean, while its presence in the Adriatic sea is occasional. In the western Mediterranean sea some peak years are evidenced, with a generally stable trend.
11. **Trends and Variability:**
    a. No consistent long-term trend is observed across the region.
    b. No differences are evidenced for the three reporting periods
12. **Geographic Patterns:**
    a. The French EEZ hosts higher densities of the species compared to Italian and Spanish waters.
    b. The abundance within Italian and Spanish waters shows more stability, while within France an increase from 1st to 2nd period and a decrease from 2nd to 3rd are evidenced.
    c. The Pelagos Sanctuary remains a key conservation area, where the species presence is more stable.
    d. In the area from Spanish Cetacean Migration Corridor to Alboran Sea and the Life Conceptu maris Core Area (Tyrrhenian and Sardinia-Sicilian channels) the species shows an apparent decline from 2nd to 3rd period, but an increasing trend within the 3rd period.

Policy Implications

- Conservation focus should remain strong in the Pelagos Sanctuary to maintain constant trends, while attention should be increased in the Spanish and Tyrrhenian and Sardinia-Sicilian channels to assess the trends for the next reporting periods

- Cross-border collaboration between France, Italy, and Spain is essential to ensure regional population stability.
- Stronger attention is needed in French waters where species abundance decline is evidenced.
- Continued long-term monitoring is crucial for detecting trends and informing adaptive management strategies.

For *Physeter macrocephalus*, as not enough sightings from all types of ferries were present to allow for a proper characterization of ESWs, it has been decided to apply to all ferries the ESW computed from Type I ferries (i.e., 2,532 m), eliminating all sightings occurring outside the visibility range of those ferries (set at 4,449 m linear distance).

The final dataset used for the population assessment accounted for 3,194 surveys, for a total of 395 sightings. Among these, 2,237 surveys have been conducted during the summer season (i.e., from April to September) for a total of 336 sightings, while 957 surveys were conducted during the winter season (October-March) for a total of 59 sightings.

Species presence is generally constant over the years, with values ranging from 0.01 to 0.03 sightings/100 km2 (Table 1.1.9 and Figure 1.1.47)

Sperm whale population assessment

year	D_sightings (density of sightings)	95% CI
2008	0.00	0.00—0.00
2009	0.01	0.00—0.03
2010	0.01	0.01—0.02
2011	0.02	0.01—0.03
2012	0.03	0.01—0.05
2013	0.01	0.01—0.02
2014	0.01	0.01—0.02
2015	0.02	0.01—0.03
2016	0.02	0.01—0.03
2017	0.02	0.01—0.04
2018	0.02	0.00—0.03
2019	0.02	0.00—0.03
2020	0.01	0.00—0.02
2021	0.02	0.00—0.04
2022	0.01	0.00—0.02
2023	0.02	0.01—0.03
2024	0.02	0.01—0.03

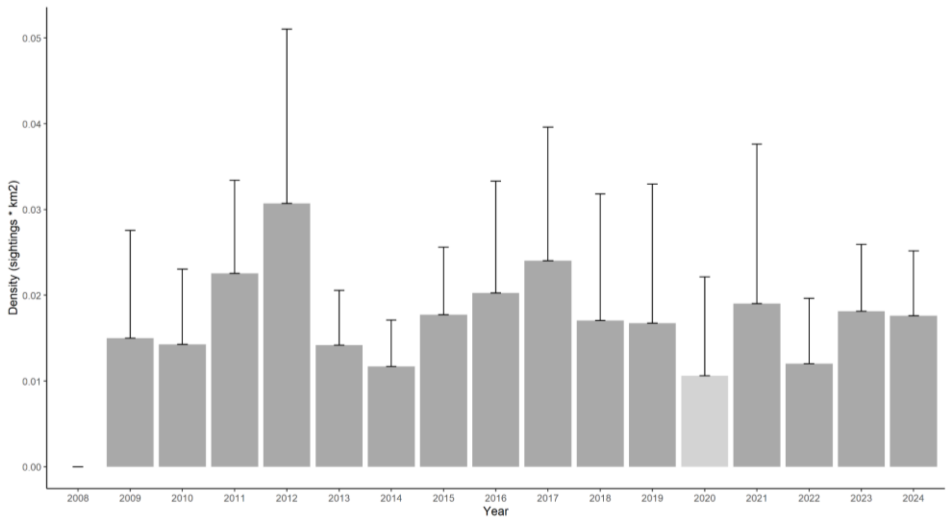


Table 1.1.9 and Figure 1.1.47. Table of yearly averages of the D_sight index for *Physeter macrocephalus* with 95% confidence interval, for the Mediterranean basin. The graph shows yearly averages of the D_sight index for *Physeter macrocephalus* with upper-95%value for the Mediterranean basin. The year 2020 is in light gray as, considering the lower number of surveys conducted that year, results might not be representative.

The KW test confirms no differences among years (Kruskal-Wallis chi-squared = 21.362, df = 16, p-value = 0.165). Since no differences are evidenced considering D_sight or D_animals, all the following analyses have been performed considering D_sight.

Marine Regions

Since the species was observed only once in the Adriatic Region, the Mediterranean basin analysis reflected the species presence in the Western basin only.

National EEZs

The species presence is generally higher in the French waters followed by the Spanish and Italian waters (Figure 1.1.48). The difference in scales must be evidenced, due to the different magnitude of species presence in the different considered EEZ (up to 0.1 in French waters, 0.02 in Italian and 0.05 in Spanish waters).

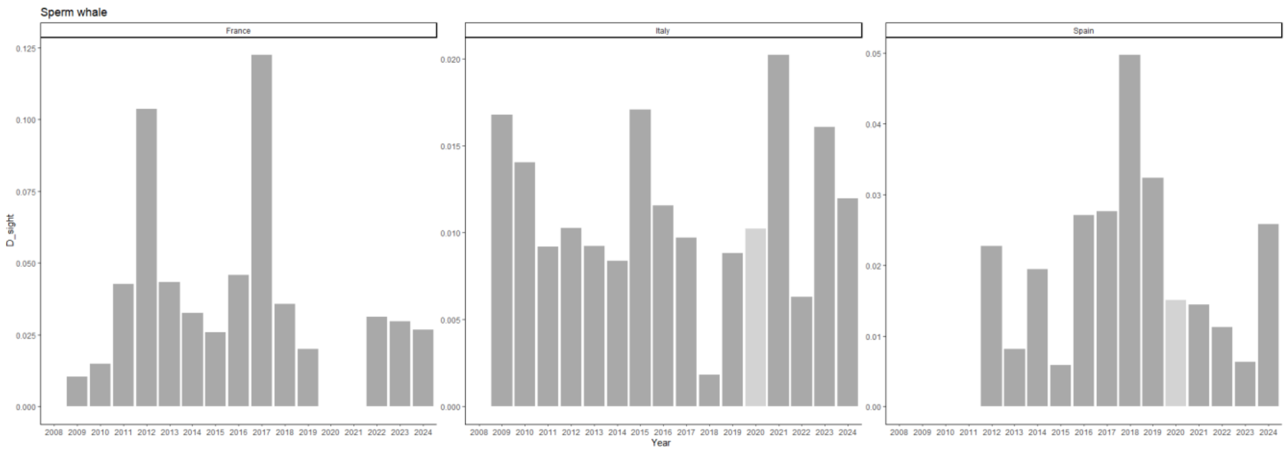


Figure 1.1.48. The graph shows yearly averages of the D_sight index for *Physeter macrocephalus*with upper-95%value for the different national EEZs. The year 2020 is in light gray as, considering the lower number of surveys conducted that year, results might not be representative.

Project area

When analyzing species presence in the different project areas, it can be noted that the species has never been sighted in the Adriatic Sea, while its presence has been almost constant over the study period in the Core Area, the Pelagos Sanctuary and the area from the Spanish Cetacean Migration Corridor to the Alboran Sea (Figure 1.1.49). In the Gibraltar area, it was always present during the sampled years (2018-2019)

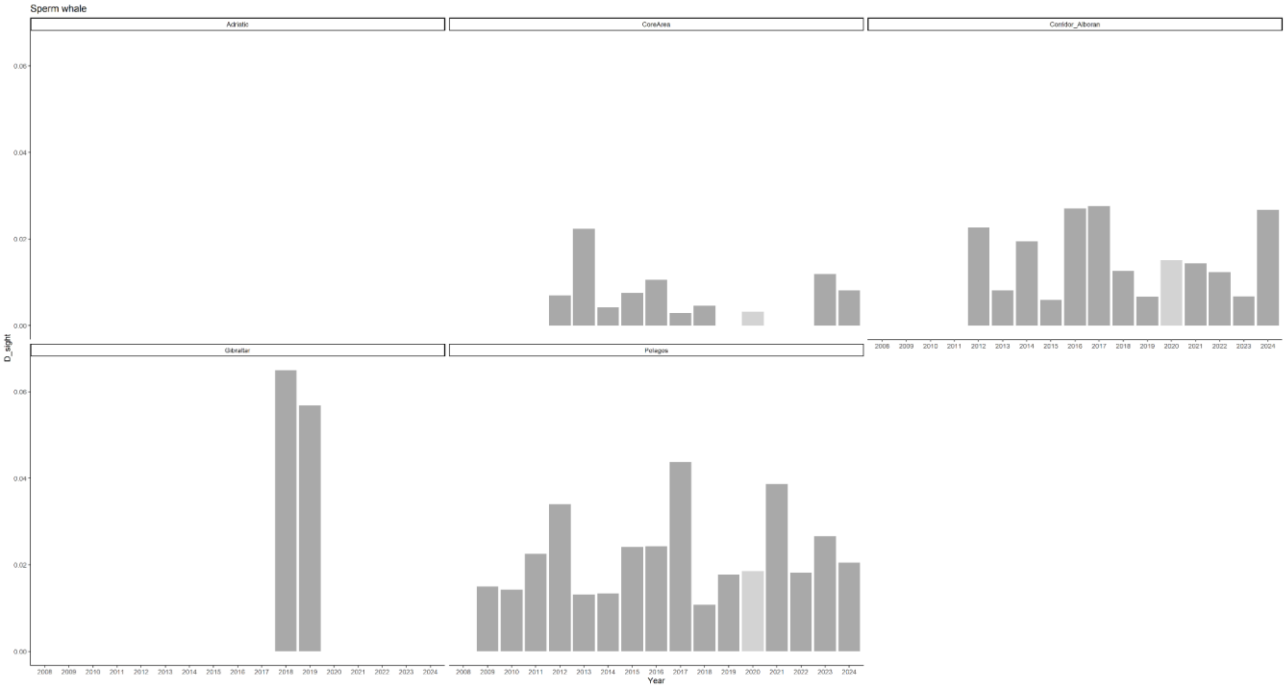


Figure 1.1.49. The graph shows yearly averages of the D_sight index for *Physeter macrocephalus* with upper-95%value for the different Project areas. The year 2020 is in light gray as, considering the lower number of surveys conducted that year, results might not be representative.

<u>TREND IN ABUNDANCE - *Physeter macrocephalus*</u>

Figure 1.1.50 shows the overall presence of the species in the Mediterranean basin, indicated with yearly average (black line) or two-years rolling mean(red line) of D_sight. After a first increase, which could be driven also by the enlargement of surveyed areas, and a drop in 2014, already observed for other species, the species presence has been fairly constant over the last ten years.

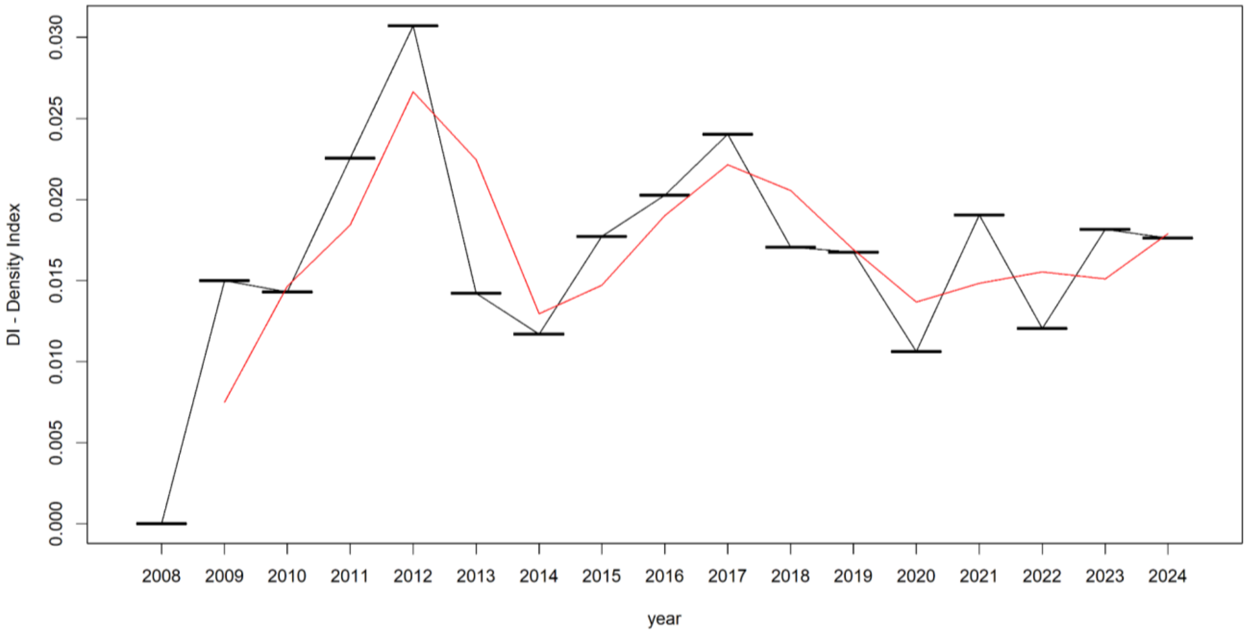


Figure 1.1.50. Trend in abundance *for Physeter macrocephalus* considering overall yearly averages (black line) as well as applying a 2-years rolling mean (red-line).

This pattern is also confirmed when looking at the three reporting periods, as no statistical difference is evidenced (Figure 1.1.51)

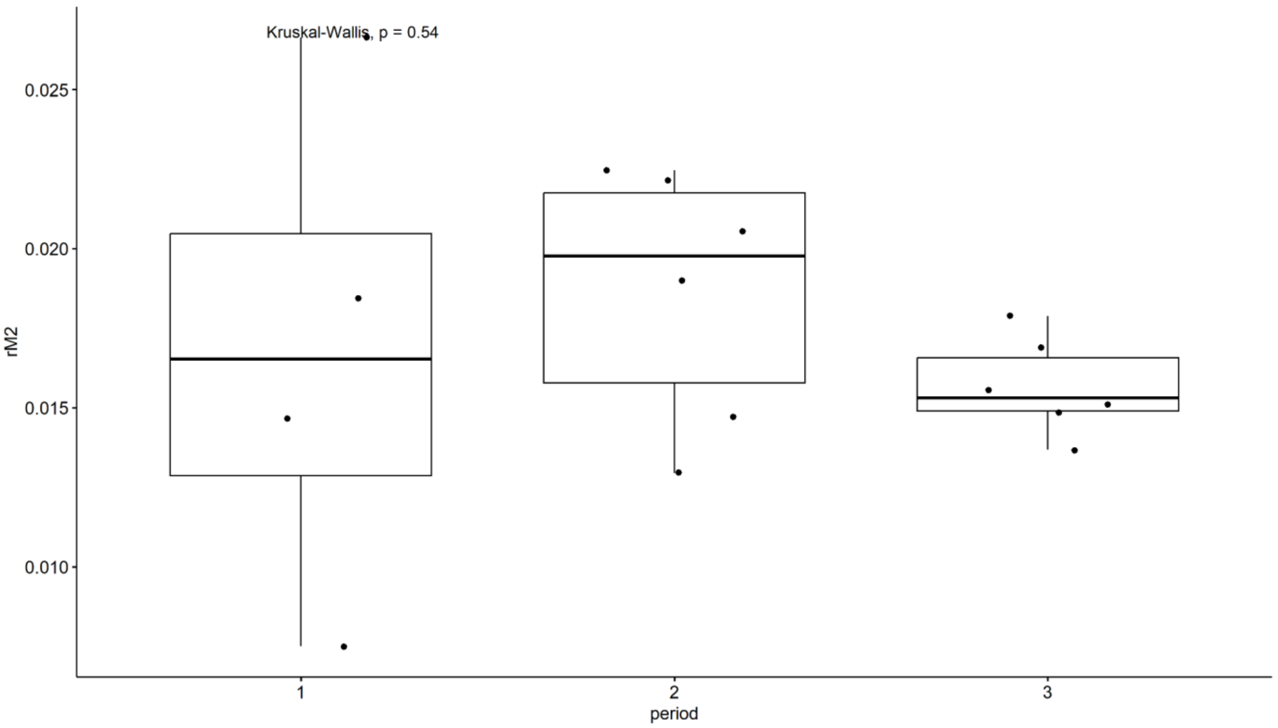


Figure 1.1.51. Box plots of D_sight *for Physeter macrocephalus* for the considered reporting periods.

Intra period trends for the second and third period do confirm the stability of the species presence in the Mediterranean basin. Yet, for the first period a strong increase is confirmed.

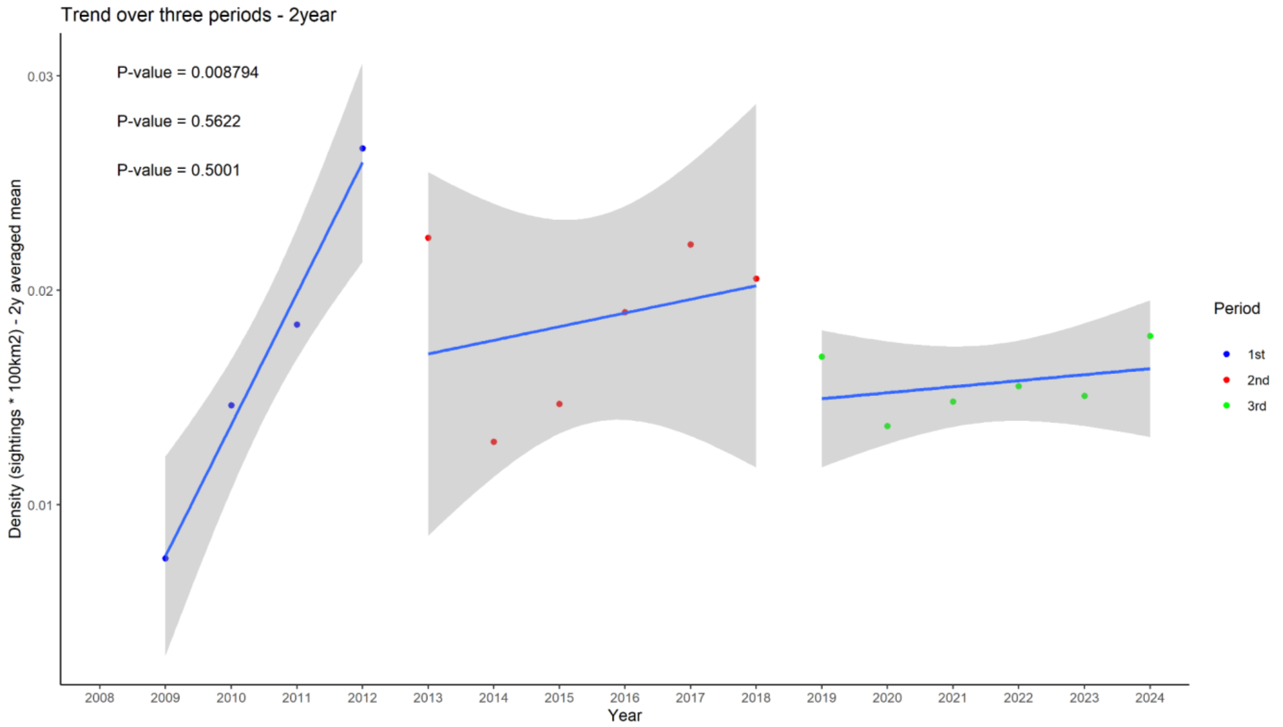


Figure 1.1.52. Intra period trends of D_sight *for Physeter macrocephalus* considering a 95% CI. P-values are referred to the linear model of each reporting period.

<u>National EEZs</u>

When looking at the National EEZs, a statistical significant difference among the three reporting periods is highlighted for France, especially due to an increase of the species presence in the second reporting period. For Italy and Spain, on the other hand, the species presence is constant all over the reporting periods (Figure 1.1.53). It has to be underlined that the species is generally more frequent in French waters rather than in the other national waters.

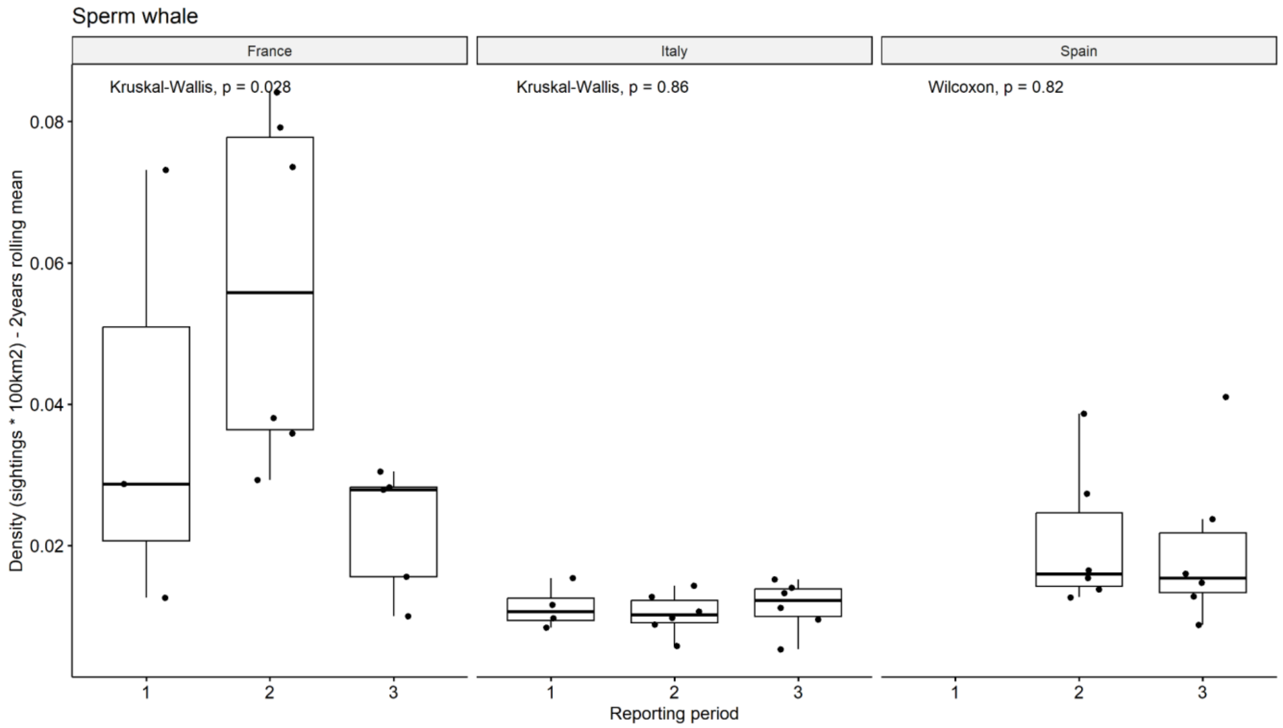


Figure 1.1.53. Boxplots of D_sight *for Physeter macrocephalus* for the considered reporting periods for the different nationals EEZs

When examining intra-period trends (Figure 1.1.54), a positive trend is observed in France during the first period and in Spain during the second period. In Italy, a positive trend appears to be emerging in the third period, although it is not statistically significant, likely due to strong interannual variability. A marked decrease is evident in Spanish waters during the third period. It is important to note the difference in scales among the three countries, which confirms a stronger species presence in France, followed by Spain and Italy.

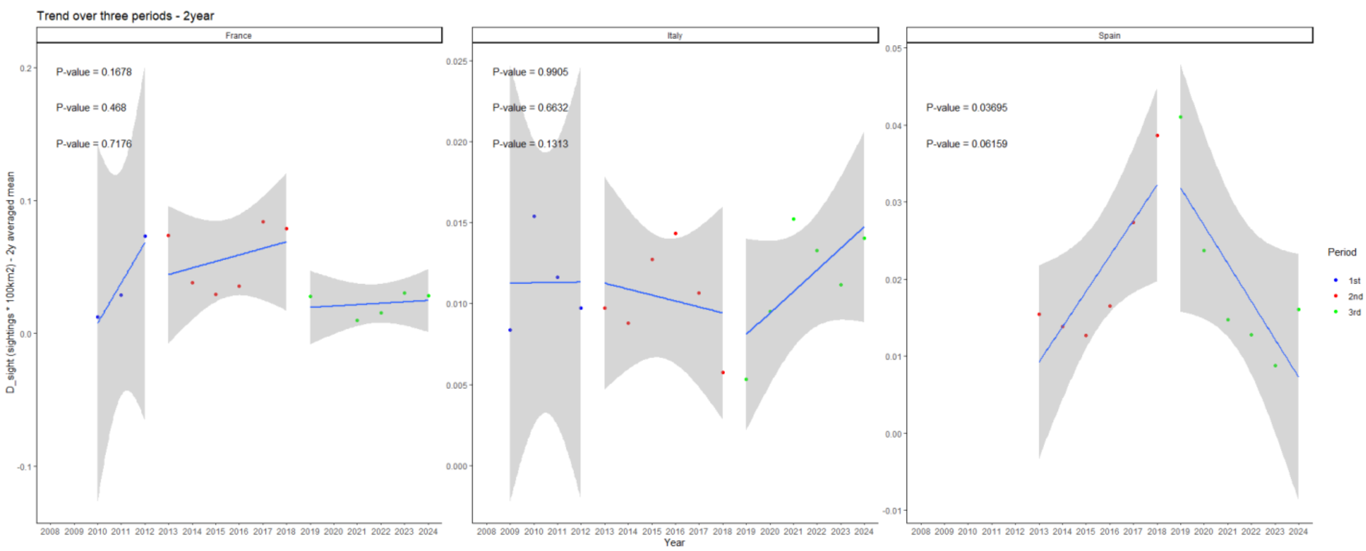


Figure 1.1.54. Intra period trends of D_sight *for Physeter macrocephalus* considering a 95% CI for the French, Italian and Spanish EEZs. P-values are referred to the linear model of each reporting period.

<u>Project areas</u>

The species presence in different project areas shows a decrease highlighted for the core area and for the area from the Spanish Cetacean Migration Corridor to the Alboran Sea, even if not statistically significant (Figure 1.1.55).

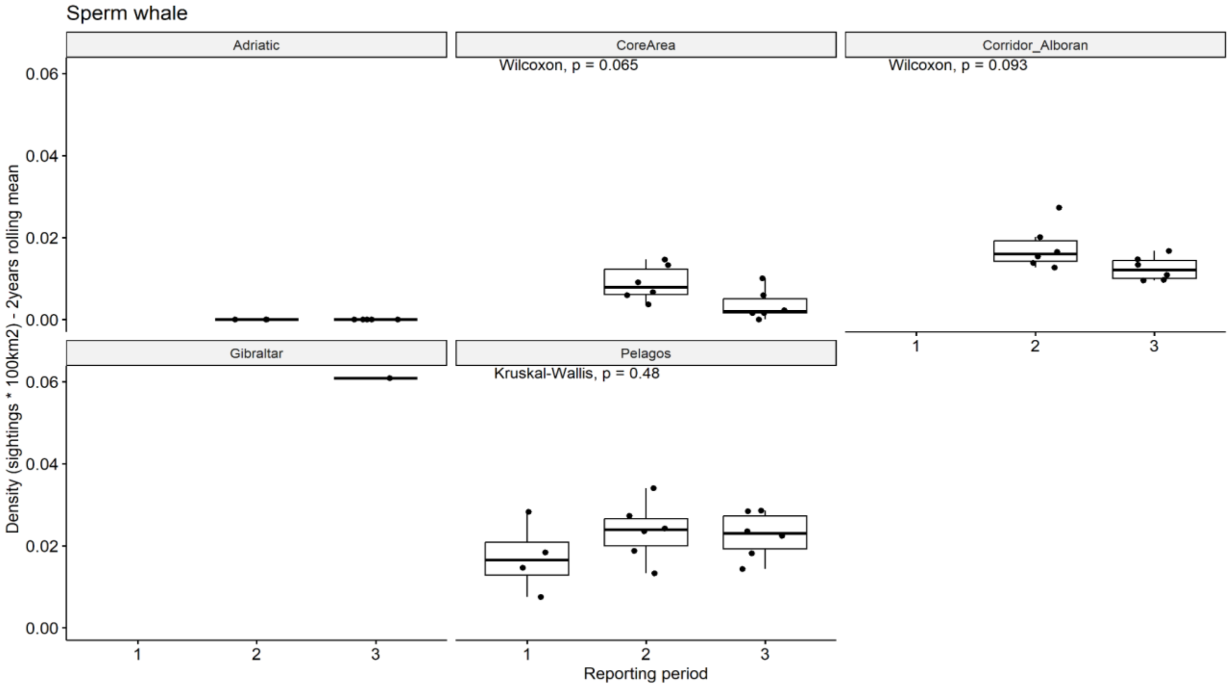


Figure 1.1.55. Boxplots of D_sight *for Physeter macrocephalus* for the considered reporting periods for the different project areas

The intra-period trends highlight a negative trend for the Core Area for the second period, while slightly positive trends are present in the other project areas (Figure 1.1.56)

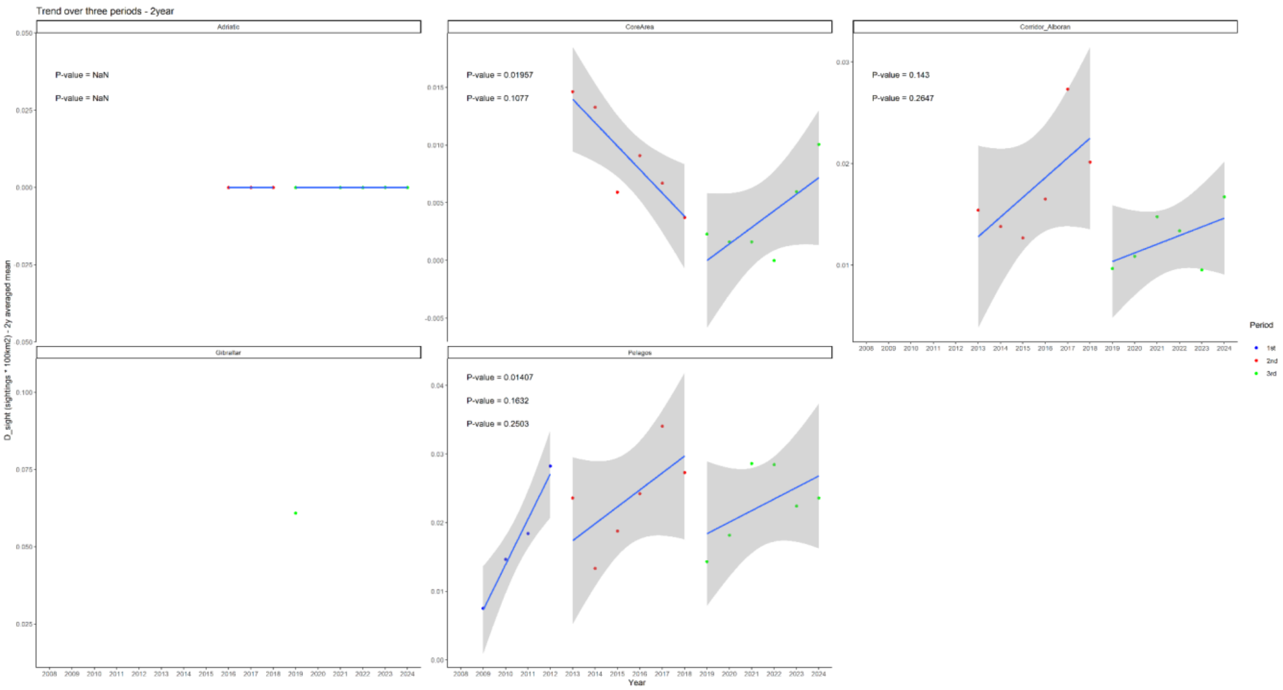


Figure 1.1.56. Intra period trends of D_sight *for Physeter macrocephalus* considering a 95% CI for the different project areas. P-values are referred to the linear model of each reporting period.

1.2 Range and trend

TECHNICAL SUMMARY - Species Observed Distribution Range and Ecological Potential Range (EPR) in the Western Mediterranean and Adriatic Sea:

- ***Stenella coeruleoalba***. Widespread in both regions, mainly in deeper offshore areas. Core areas include the Pelagos Sanctuary and Tyrrhenian sea, waters around Sardinia and Balearic Islands the Alboran Sea and northern Africa.
- ***Balaenoptera physalus***. Concentrated in northwestern areas and the Spanish Cetacean Migration Corridor. EPR mostly in the western Mediterranean, with core areas in the Central Tyrrhenian, Pelagos Sanctuary, and between Sardinia and the Balearics.
- ***Tursiops truncatus.*** Broadly distributed, favoring coastal and continental shelf areas. EPR core areas nearshore, especially in the Adriatic, with limited presence in offshore waters.
- ***Delphinus delphis***. Scattered distribution in the western Mediterranean, rare at higher latitudes. EPR core area in the Alboran–Gibraltar region, with potential range extending from Gibraltar to the Sardinian Channel and scattered areas in southern Tyrrhenian and Sicily Channel.
- ***Grampus griseus***. Broadly present in the western Mediterranean with scattered sightings in the Tyrrhenian and Adriatic. Core areas in the Ligurian Sea and around the Balearic islands, extending to the Alboran Sea.
- ***Globicephala melas***. Mostly in the westernmost Mediterranean. Core areas in the northwest and south from the Alboran Sea to northern Africa; also seen near to Corsica, Sardinia, and west of Sicily.
- ***Ziphius cavirostris.*** Scattered throughout the northwestern Mediterranean and the Ionian Sea. Core areas are primarily located in the central Ligurian and central Tyrrhenian Seas, as well as offshore Barcelona and in the Alboran Sea, reflecting a relatively confined ecological range.
- ***Physeter macrocephalus***. Primarily distributed in the northern areas of the western Mediterranean. Core potential areas are located in the central-northern western Mediterranean, with additional spots around southeastern Sardinia, the Pontine Archipelago, and the southern Adriatic.
- ***Caretta caretta***. Widespread across all monitored areas. Core areas in the south-western Mediterranean and northern Adriatic, with potential range extending to the southern Tyrrhenian, Balearics, Ligurian Sea, and northern Adriatic.

Summary of Species Observed Distribution Range Trends (Normalized by Effort Area)

Western Mediterranean Region

Several species in the Western Mediterranean exhibited an initial increase in the percentage of the Area of Occupancy (AOO) related to the effort area, followed by a more or less marked decline among three Habitats Directive reporting periods (2008-2012, 2013-2018, 2019-2024). *Stenella coeruleoalba* AOO increased from 39% to 45% of the effort area, then slightly decreased by 4 percentage points. *Balaenoptera physalus* slightly increased from 23% to 29%, before contracting by 11 percentage points. Similarly, *Tursiops truncatus* showed a slight increase from 9% to 16%, followed by a minimal 2 percentage point decrease.

Other species demonstrated relatively stable or only minimal fluctuations. *Delphinus delphis* AOO remained stable between 4% and 6% of the effort area, experiencing a minor dip followed by a 2 percentage point increase. *Grampus griseus* consistently hovered around 3%. *Globicephala melas* maintained a stable AOO (near 2%), with a modest rise in the most recent period (+2%). *Ziphius cavirostris* occurrence ranged within 5% to 6%, with a small contraction (-1%). *Physeter macrocephalus* AOO remained steady at 10% to 11%, but showed a notable decline in the last period (-5%). A distinct pattern was observed for *Caretta caretta*, which experienced a significant expansion marked by a strong increase of AOO (+29%).

Adriatic Region

The Adriatic region remained a marginal area for most cetacean species. *Grampus griseus*, *Ziphius cavirostris*, *Physeter macrocephalus*, and *Delphinus delphis* were rare or only occasionally present. *Stenella coeruleoalba* Area of Occupancy (AOO) range remained stable at approximately 15% to 16% of the effort area, while *Tursiops truncatus* showed a slightly positive expansion from 11% to 16%. In contrast to cetaceans, *Caretta caretta* maintained a consistently high and stable range between 30% and 34% of the effort area over all periods (2015-2024).

Overall Patterns

The Western Mediterranean exhibits more dynamic species range trends, with most species undergoing initial expansion phases followed by mild to moderate contractions. Meanwhile, the Adriatic region remains marginal for most cetaceans, with generally low or occasional presence. Exceptions include *Tursiops truncatus*, whose percentage of Area of Occupancy (AOO) related to the effort area slightly increased, and *Caretta caretta*, which consistently maintains high range levels.

SUMMARY FOR POLICYMAKERS: Key Marine Species and Priority Conservation Areas in the Western Mediterranean and Adriatic Sea based on Observed Distribution and Ecological Potential Range

The distribution patterns of cetaceans and sea turtles across the western Mediterranean and Adriatic Sea highlight critical areas essential for marine biodiversity conservation and spatial planning. The observed and ecological potential ranges of key species, such as *Stenella coeruleoalba*, *Balaenoptera physalus*, *Tursiops truncatus*, *Delphinus delphis*, *Grampus griseus*, *Globicephala melas*, *Ziphius cavirostris*, *Physeter macrocephalus*, and *Caretta caretta,* indicate a combination of widespread, coastal, offshore, and regionally confined distributions.

Several areas emerge as common ecological hotspots supporting multiple species, making them strategic priorities for marine conservation policies and spatial management:

2. **Pelagos Sanctuary (Ligurian Sea):** A key habitat for at least six species, including *Tursiops truncatus, Balaenoptera physalus*, *Stenella coeruleoalba*, *Grampus griseus*, *Ziphius cavirostris, Physeter macrocephalus* and also of importance for *Caretta caretta*.
3. **Tyrrhenian Sea:** A shared core area for *Balaenoptera physalus*, *Ziphius cavirostris, Stenella coeruleoalba* and *Physeter macrocephalus* primarily in the central, and *Caretta caretta* and *Delphinus delphis* in the south, supporting both deep-diving and migratory species.
4. **Balearic Islands Region:** Important for species with both pelagic and coastal preferences, including *Stenella coeruleoalba*, *Grampus griseus*, *Physeter macrocephalus, Tursiops truncatus,* and *Caretta caretta*.
5. **Alboran Sea and Gibraltar Region:** A high-priority biodiversity corridor supporting especially *Delphinus delphis*, *Globicephala melas*, *Grampus griseus*, *Ziphius cavirostris, Stenella coeruleoalba*, and others.
6. **Sardinian basin:** Essential for both resident and migratory species including *Balaenoptera physalus*, *Stenella coeruleoalba*, *Grampus griseus*, and *Physeter macrocephalus*.
7. **Adriatic Sea:** A vital coastal zone for *Tursiops truncatus* and *Caretta caretta*, with *Stenella coeruleoalba* also present, and occasional sightings of *Physeter macrocephalus* in the southern Adriatic.

These overlapping core habitats emphasize the need for integrated cross-border marine protection strategies, enhanced monitoring, and targeted conservation actions in these shared ecological zones. Focusing efforts in these key areas can maximize conservation outcomes across multiple species and support regional biodiversity objectives.

Method. Following the approach described in the Deliverable C1.2 (Arcangeli et al., 2025) and Arcangeli et al. (2023), the range of the species was calculated as: 1) **Area of Occupancy (AOO)** as distribution maps of 10x10km grid cells within the area of performed effort, 2) **Observed Distribution Range (ODR)** using the Kernel Density Estimator (KDE) to spatially generalize the distribution of the species occurrence, and 3) **Ecological Potential Range (EPR)** based on projected sites of species occurrence using spatially predicted sites based on the habitat map models. Some refinement on the methodological approach has been applied as follows.

13. **Distribution map of Area of Occupancy (AOO)**: the species distribution is mapped on a 10x10 km UTM grid, where occupied cells indicate confirmed presence based on available occurrence data. The standard 10x10 km UTM grid used for harmonized reporting at the European level is used (European 10 km Grid, ETRS89-LAEA projection).
14. **The Observed Distribution Range (ODR)** calculated through the KDE provides a smoothed representation of the species' occurrence patterns, offering a more detailed spatial resolution than the Minimum Convex Polygon (MCP), while reducing the influence of outlier records and gaps in data coverage. It was calculated following the approach of Arcangeli et al. (2023) for the entire study period, using the KDE with a 50 km search radius and a spatial resolution of 500 m. KDEs were generated using Sighting per Unit Effort (SPUE) values for the more common species, and presence points for the less common ones (*Grampus griseus, Globicephala melas, Ziphius cavirostris, Physeter macrocephalus*). When SPUE was used, cells with zero values were masked, as SPUE equal to zero can introduce errors and falsely inflate the distribution range. This correction was not necessary for the less common species, since their KDEs were based on presence points, which do not generate artificially large areas of zero values. The resulting KDE raster was classified into four categories using the Natural Breaks (Jenks) method. All four classes represent the overall distribution range, while upper classes 2, 3, and 4 identify the species' core distribution areas. After reclassification, the raster was converted into a polygon layer to delineate distribution contours.
15. **The Ecological Potential Range (EPR)** was derived from species distribution models developed using the MaxEnt algorithm (see Methods in Deliverable C1.2 and Arcangeli et al., 2024a). The continuous prediction outputs were classified into 12 classes. From these, the Jenks natural breaks method was applied to identify the threshold separating the second and third classes, which was used to delineate the EPR. The core area was identified using the Maximum Sensitivity plus Specificity Logistic Threshold, which is computed automatically by the MaxEnt software. This threshold defines the core zone with the highest predicted suitability for the species.

Range of *Stenella coeruleoalba*

- **Distribution map of Area of Occupancy (AOO) and trend**

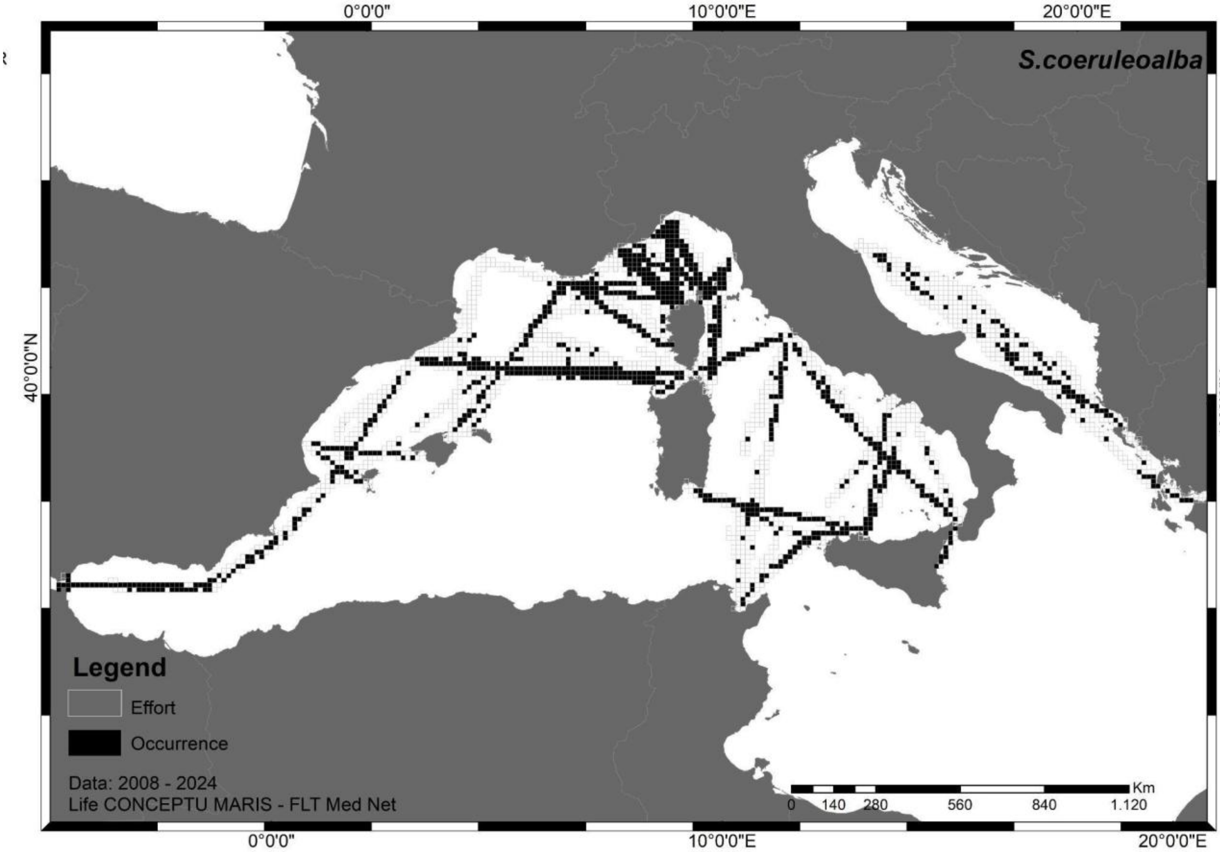


Figure 1.2.1. Occupancy of *Stenella coeruleoalba* over the entire period (2008-2024) on the European 10x10 km Grid, ETRS89-LAEA projection.

Table 1.2.1. AOO of *Stenella coeruleoalba* on number of occurrence 10x10 Km cells and percentage point change of occurrence vs number of effort cells over three Habitats Directive reporting periods (Trend, pp).

SubRegion	Temporal resolution		*S.coeruleoalba* N.occurrence cells	N.effort cells	Occurrence/Effort	Trend (Percentage point change, pp)
MWE	Entire period	2008-2024	898	2003	45%	
MAD		2008-2024	95	416	23%	
MWE	1 HP period	2008-2012	253	655	39%	
	2 HP period	2013-2018	495	1096	45%	7%
	3 HP period	2019-2024	628	1515	41%	-4%
MAD	1 HP period	2008-2012	*NA*	*NA*	*NA*	
	2 HP period	2013-2018	53	329	16%	
	3 HP period	2019-2024	55	361	15%	-1%

- **Observed Distribution Range (ODR) and Ecological Potential Range (EPR)**

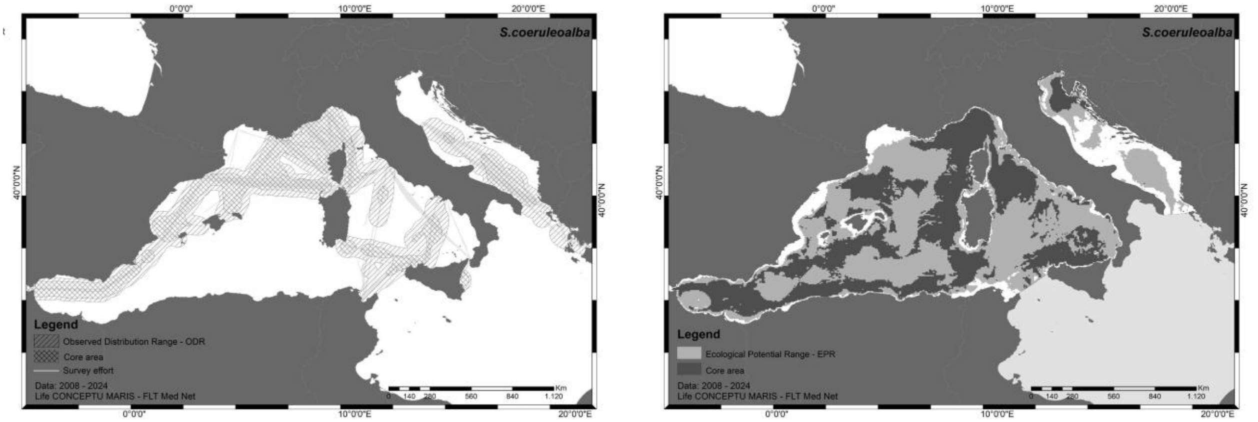


Figure 1.2.2. Observed Distribution Range (ODR, left) and Ecological Potential Range (EPR, right) of Stenella coeruleoalba in the western Mediterranean and Adriatic Regions.

The ODR of *Stenella coeruleoalba* is widespread across most monitored areas in both the western Mediterranean and the Adriatic Sea, with a preference for deeper offshore regions. This pattern is reflected in its EPR, which extends throughout pelagic waters. Core areas are primarily concentrated in the Pelagos Sanctuary, the waters off western and southern Sardinia, around the Balearic Islands, the Alboran Sea, the northern coast of Africa, and northern Sicily.

In the western Mediterranean, the percentage of the AOO range of *Stenella coeruleoalba* within the effort area was assessed at 39–45% between the first and second periods, followed by a slight contraction of 4 percentage points in the most recent period. In contrast, the species remained almost stable at 16% - 15% in the Adriatic region.

Range of *Balaenoptera physalus*

- **Distribution map of Area of Occupancy (AOO) and trend**

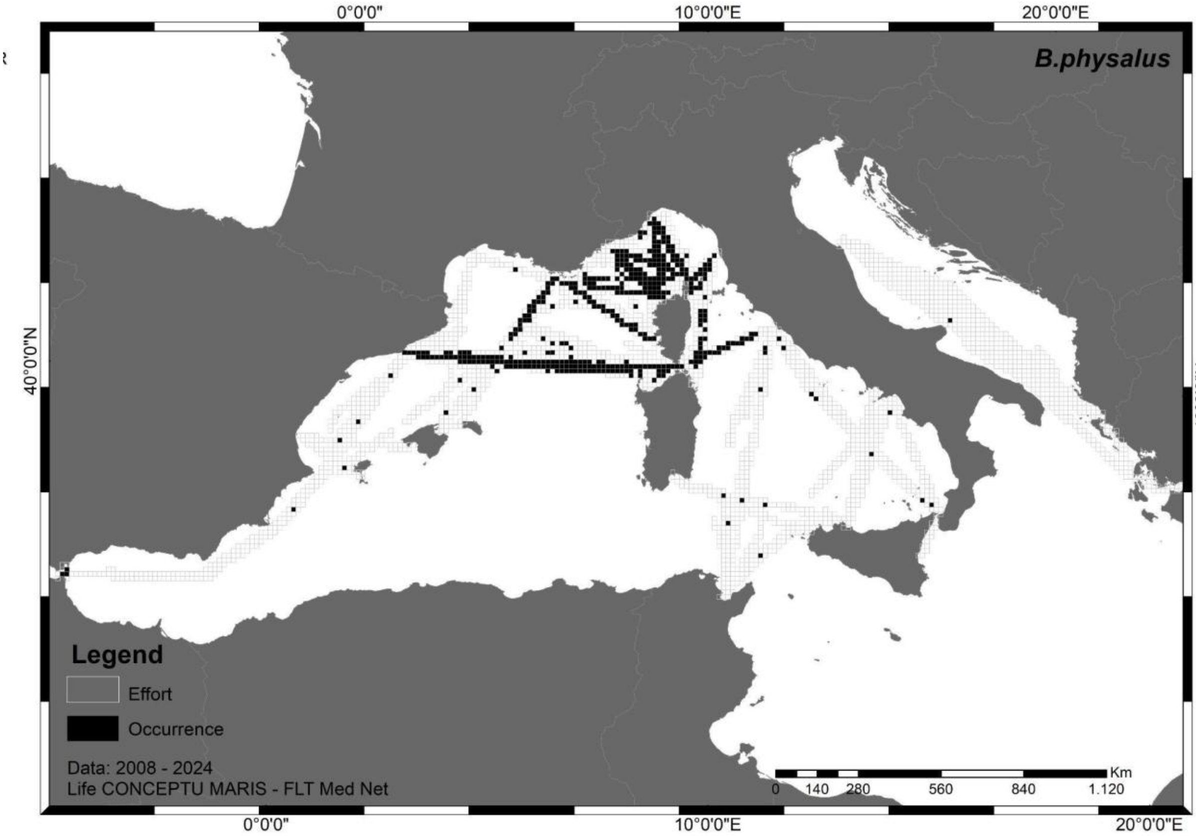


Figure 1.2.3. Occupancy of *Balaenoptera physalus* over the entire period (2008-2024) on the European 10x10 km Grid, ETRS89-LAEA projection.

Table 1.2.2. AOO of *Balaenoptera physalus* on number of occurrence 10x10 Km cells and percentage point change of occurrence vs number of effort cells over three Habitats Directive reporting periods (Trend, pp).

SubRegion	Temporal resolution		*B.physalus* N.occurrence cells	N.effort cells	Occurrence/Effort	Trend (Percentage point change, pp)
MWE	Entire period	2008-2024	439	2003	22%	
MAD		2008-2024	1	416	0%	
MWE	1 HP period	2008-2012	149	655	23%	
	2 HP period	2013-2018	320	1096	29%	6%
	3 HP period	2019-2024	280	1515	18%	-11%
MAD	1 HP period	2008-2012	*NA*	*NA*	*NA*	
	2 HP period	2013-2018	1	329	0%	
	3 HP period	2019-2024	0	361	0%	0%

- **Observed Distribution Range (ODR) and Ecological Potential Range (EPR)**

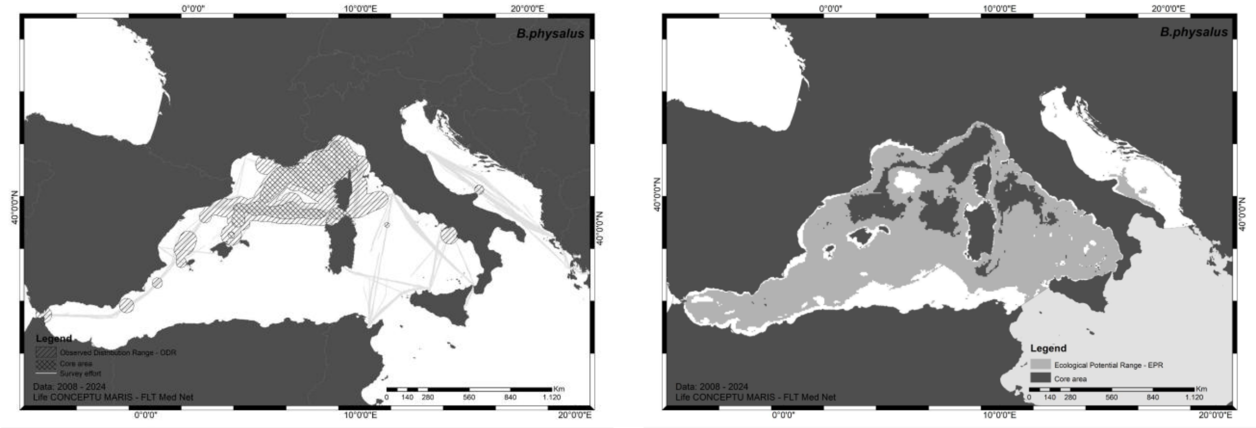


Figure 1.2.4. Observed Distribution Range (ODR, left) and Ecological Potential Range (EPR, right) of *Balaenoptera physalus* in the western Mediterranean and Adriatic Regions.

The ODR of *Balaenoptera physalus* is primarily concentrated in the northwestern region of the monitored areas and along the Spanish Cetacean Migration Corridor. The EPR indicates a potential distribution that mostly covers the western Mediterranean, with limited extension into the Adriatic Sea. Core areas clearly align with the observed range, particularly in the central Tyrrhenian Sea, the Pelagos Sanctuary, and the waters of the Sardinia-Balearic basin.

In the western Mediterranean, the percentage of the AOO of *Balaenoptera physalus* within the effort area was assessed at 23–29% between the first and second periods, followed by a contraction of 11 percentage points in the most recent period. In contrast, the species remained almost absent in the Adriatic region.

Range of *Tursiops truncatus*

- **Distribution map of Area of Occupancy (AOO) and trend**

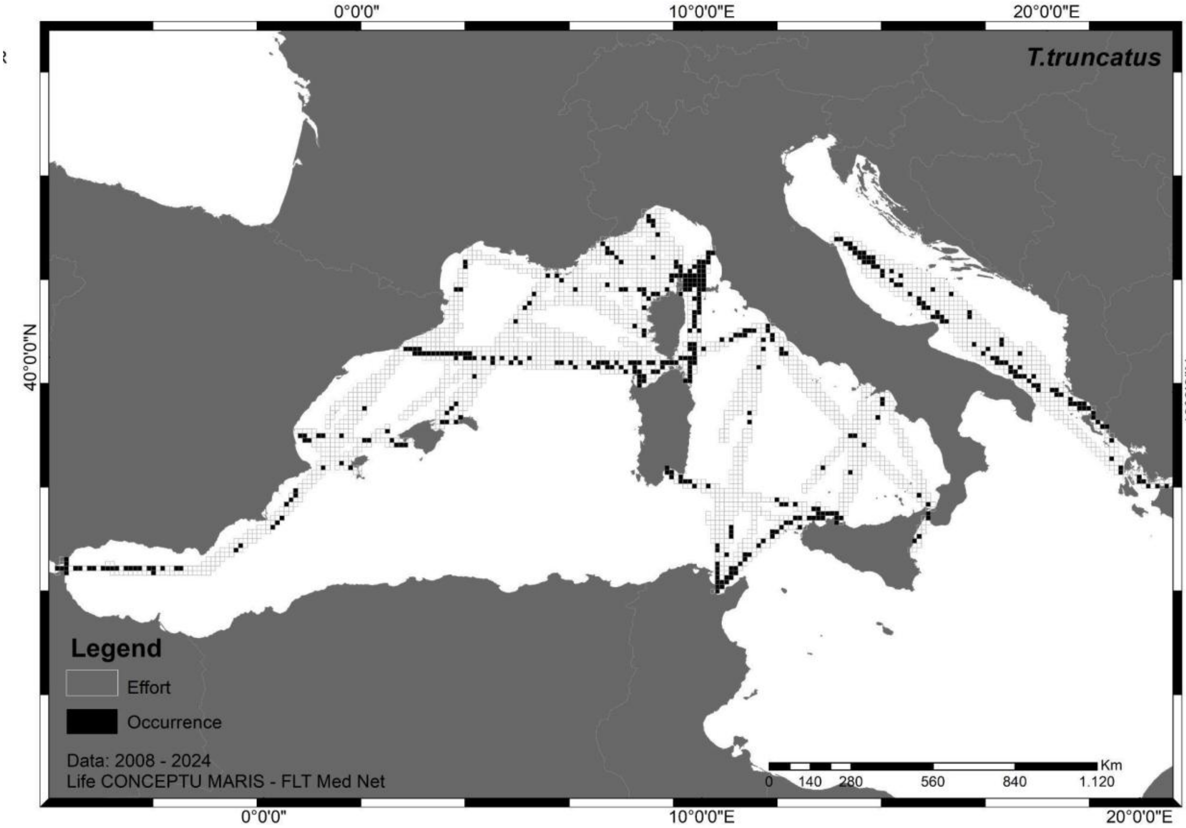


Figure 1.2.5. Occupancy of *Tursiops truncatus* over the entire period (2008-2024) on the European 10x10 km Grid, ETRS89-LAEA projection.

Table 1.2.3. AOO of *Tursiops truncatus* on number of occurrence 10x10 Km cells and percentage point change of occurrence vs number of effort cells over three Habitats Directive reporting periods (Trend, pp).

SubRegion	Temporal resolution		T.truncatus N.occurrence cells	N.effort cells	Occurrence/Effort	Trend (Percentage point change, pp)
MWE	Entire period	2008-2024	325	2003	16%	
MAD		2008-2024	78	416	19%	
MWE	1 HP period	2008-2012	61	655	9%	
	2 HP period	2013-2018	170	1096	16%	6%
	3 HP period	2019-2024	199	1515	13%	-2%
MAD	1 HP period	2008-2012	NA	NA	NA	
	2 HP period	2013-2018	36	329	11%	
	3 HP period	2019-2024	58	361	16%	5%

- **Observed Distribution Range (ODR) and Ecological Potential Range (EPR)**

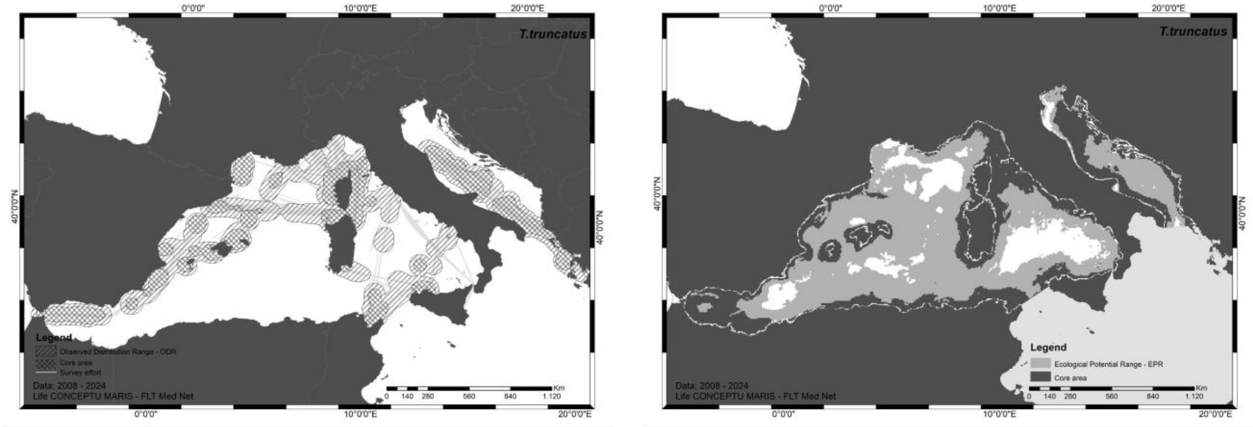


Figure 1.2.6. Observed Distribution Range (ODR, left) and Ecological Potential Range (EPR, right) of *Tursiops truncatus* in the western Mediterranean and Adriatic Regions

The ODR of *Tursiops truncatus* is widespread across almost all monitored areas, with core areas located closer to the coast. This pattern reflects the species' EPR, showing a preference for coastal areas and the upper continental shelf of the Adriatic region. However, the distribution also extends into pelagic waters, excluding the most remote offshore areas.

The percentage of the AOO of the predominantly coastal *Tursiops truncatus* within the largely pelagic effort area remains relatively small (9–16%) and mostly stable in the western Mediterranean. There was a slight fluctuation, with an increase of 6 percentage points between the first and second periods (from 9% to 16%), followed by a 2-point decrease in the most recent period. In the Adriatic Sea, the ODR covers a similar proportion, showing a slight increase in recent years (from 11% to 16%).

Range of *Delphinus delphis*

- **Distribution map of Area of Occupancy (AOO) and trend**

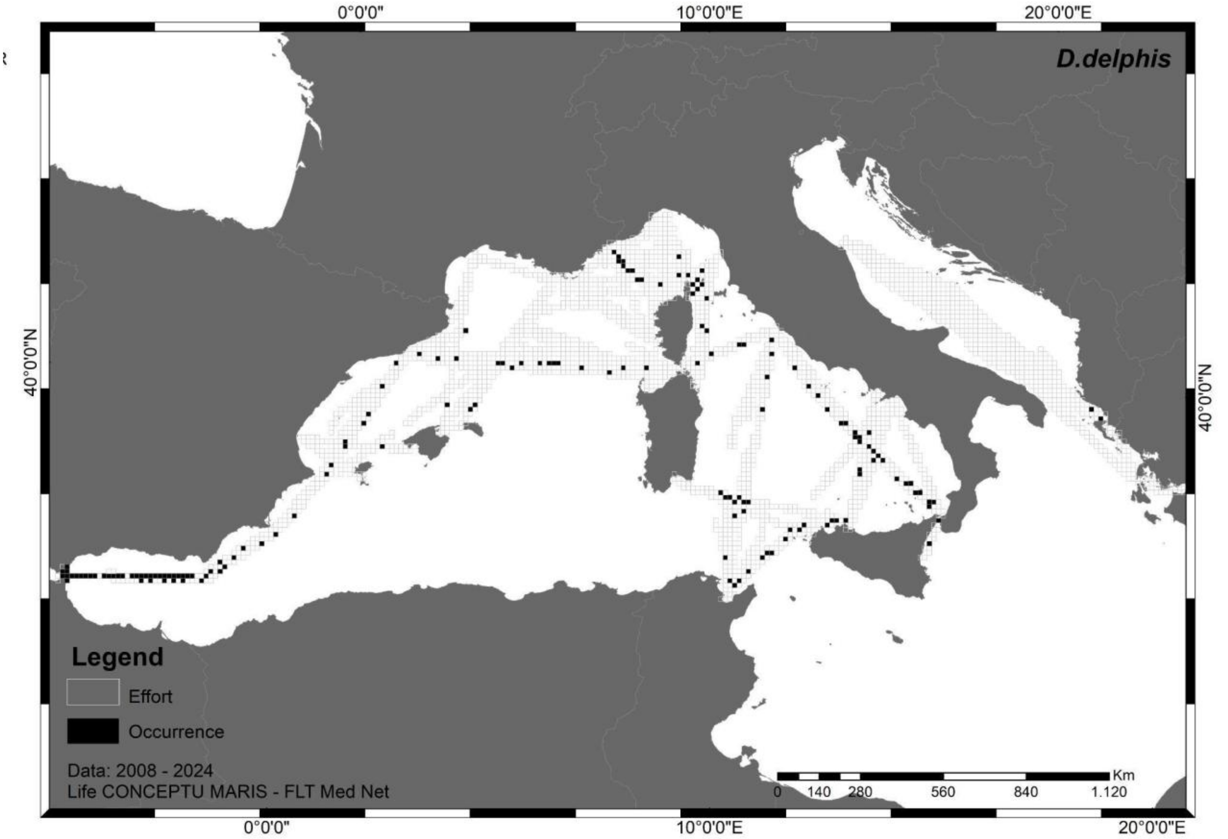


Figure 1.2.7. Occupancy of *Delphinus delphis* over the entire period (2008-2024) on the European 10x10 km Grid, ETRS89-LAEA projection.

Table 1.2.4. AOO of *Delphinus delphis* on number of occurrence 10x10 Km cells and percentage point change of occurrence vs number of effort cells over three Habitats Directive reporting periods (Trend, pp).

SubRegion	Temporal resolution		*D.delphis* N.occurrence cells	N.effort cells	Occurrence/Effort	Trend (Percentage point change, pp)
MWE	Entire period	2008-2024	156	2003	8%	
MAD		2008-2024	2	416	0%	
MWE	1 HP period	2008-2012	32	655	5%	
	2 HP period	2013-2018	45	1096	4%	-1%
	3 HP period	2019-2024	89	1515	6%	2%
MAD	1 HP period	2008-2012	*NA*	*NA*	*NA*	
	2 HP period	2013-2018	0	329	0%	
	3 HP period	2019-2024	2	361	1%	1%

- **Observed Distribution Range (ODR) and Ecological Potential Range (EPR)**

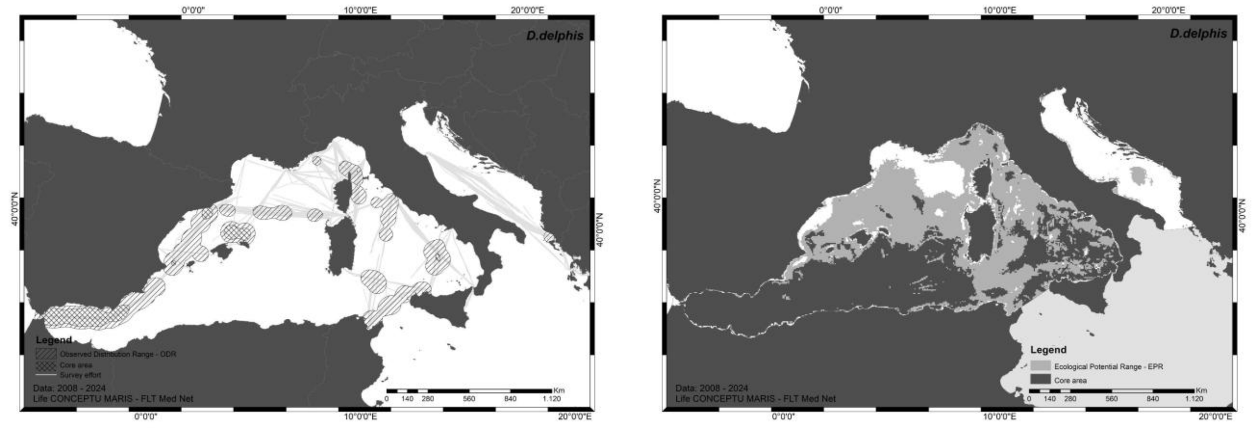


Figure 1.2.8. Observed Distribution Range (ODR, left) and Ecological Potential Range (EPR, right) of *Delphinus delphis* in the western Mediterranean and Adriatic Regions

The ODR of *Delphinus delphis* is scattered across the monitored areas of the western Mediterranean, with occurrences becoming rarer at higher latitudes. A more continuous core area is evident in the Alboran–Gibraltar region. The EPR confirms a predominantly southern distribution within the western Mediterranean, with an extended core area stretching from Gibraltar to the Sardinian Channel, and more scattered suitable areas in the southern Tyrrhenian Sea and the Sicily Channel.

The percentage of *Delphinus delphis* AOO, normalized by the effort area, remained almost stable in the Western Mediterranean region (4-6%), with minimal fluctuation between periods (-1pp between the first and second periods and +2pp in recent years), while it remained merely occasional in the Adriatic region.

Range of *Grampus griseus*

- **Distribution map of Area of Occupancy (AOO) and trend**

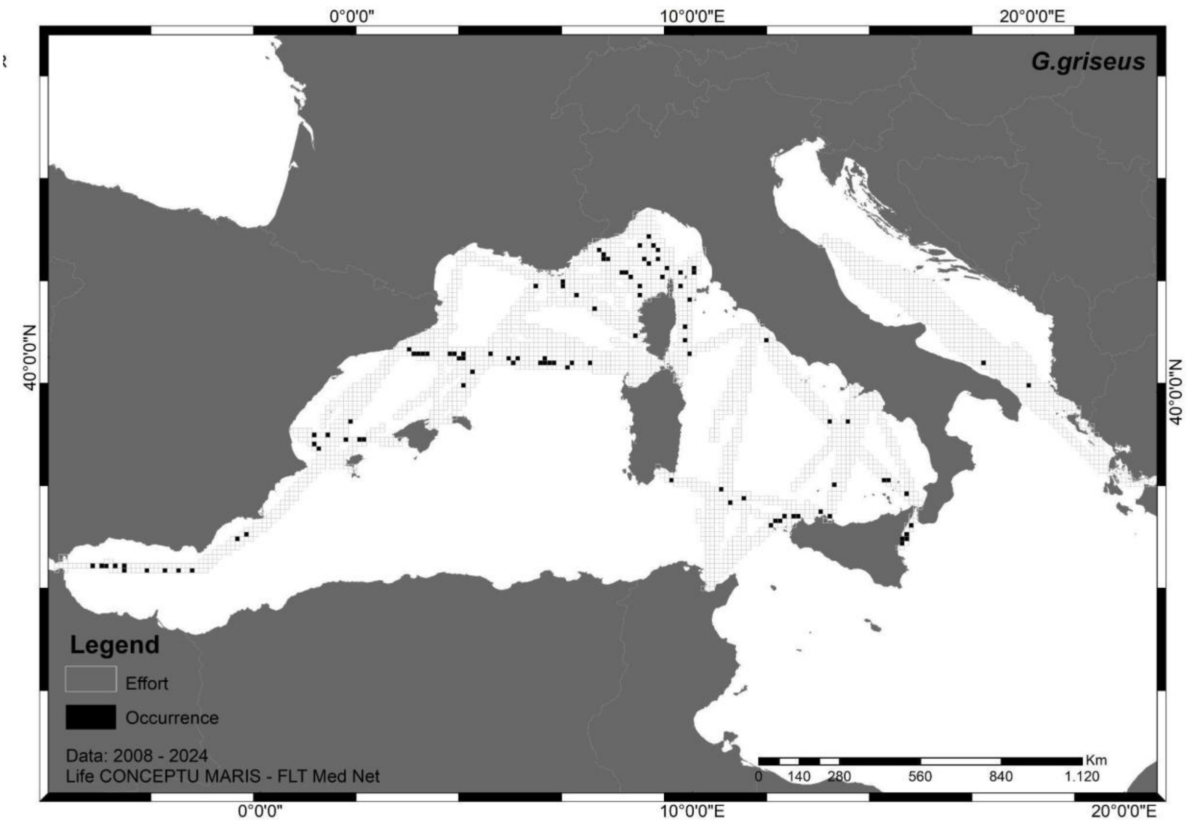


Figure 1.2.9. Occupancy of *Grampus griseus* over the entire period (2008-2024) on the European 10x10 km Grid, ETRS89-LAEA projection.

Table 1.2.5. AOO of *Grampus griseus* on number of occurrence 10x10 Km cells and percentage point change of occurrence vs number of effort cells over three Habitats Directive reporting periods (Trend, pp).

SubRegion	Temporal resolution		*G.griseus* N.occurrence cells	N.effort cells	Occurrence/Effort	Trend (Percentage point change, pp)
MAD	Entire period	2008-2024	2	416	0%	
MWE		2008-2024	95	2003	5%	
MWE	1 HP period	2008-2012	18	655	3%	
	2 HP period	2013-2018	37	1096	3%	1%
	3 HP period	2019-2024	52	1515	3%	0%
MAD	1 HP period	2008-2012	*NA*	*NA*	*NA*	
	2 HP period	2013-2018	0	329	0%	
	3 HP period	2019-2024	2	361	1%	1%

- **Observed Distribution Range (ODR) and Ecological Potential Range (EPR)**

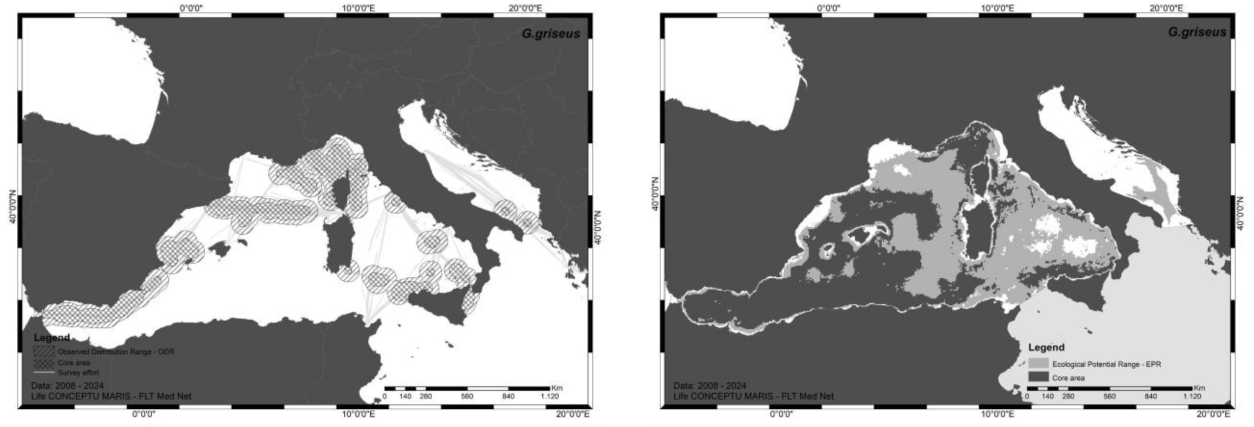


Figure 1.2.10. Observed Distribution Range (ODR, left) and Ecological Potential Range (EPR, right) of *Grampus griseus* in the western Mediterranean and Adriatic Regions

The ODR of *Grampus griseus* extends broadly across the monitored areas of the western Mediterranean, with a more scattered presence in the southern Tyrrhenian Sea and occasional sightings in the southern Adriatic region. This pattern is supported by the EPR, which also spans the western Mediterranean but excludes parts of the southern Tyrrhenian. Core areas are primarily located in the Ligurian Sea and around the Balearic Islands, extending southward to the Alboran Sea.

The percentage of *Grampus griseus* AOO, normalized by the effort area, remained almost stable at 3% in the Western Mediterranean region, while it remained merely occasional in the Adriatic region.

Range of *Globicephala melas*

- **Distribution map of Area of Occupancy (AOO) and trend**

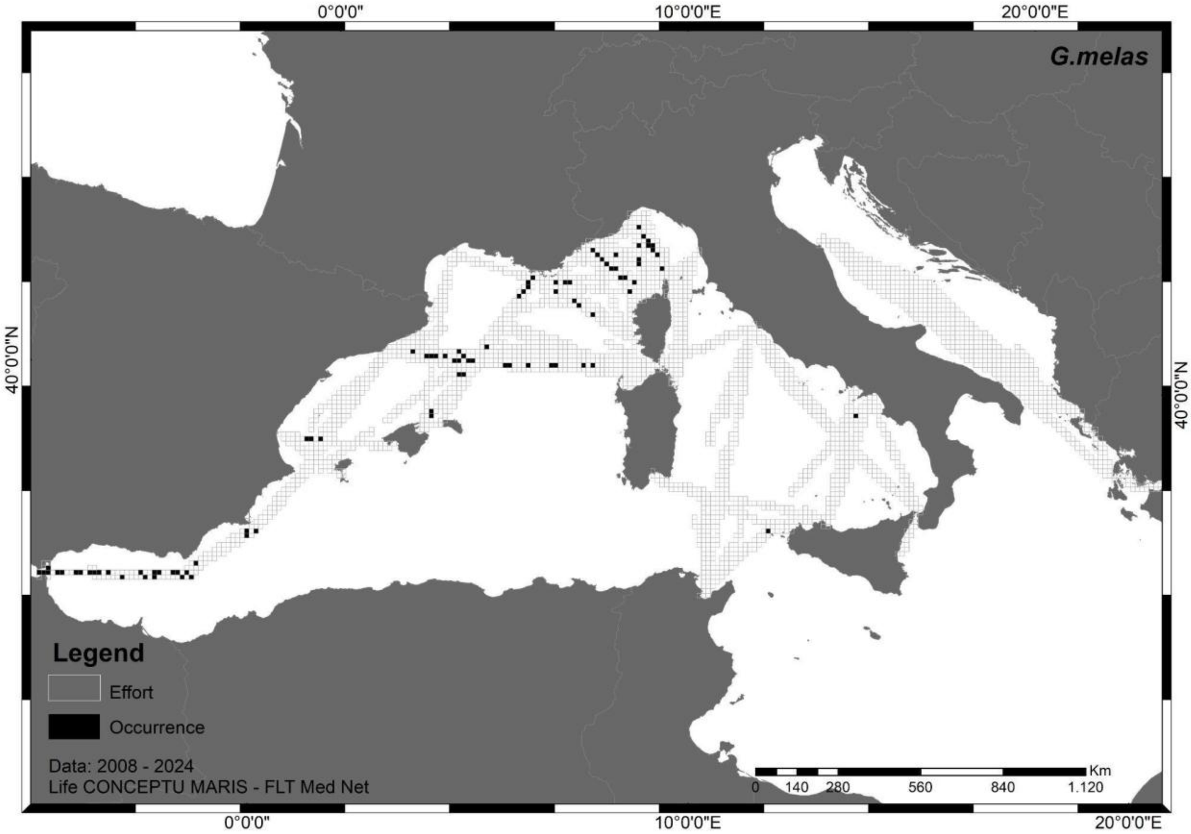


Figure 1.2.11. Occupancy of *Globicephala melas* over the entire period (2008-2024) on the European 10x10 km Grid, ETRS89-LAEA projection.

Table 1.2.6. AOO of *Globicephala melas* on number of occurrence 10x10 Km cells and percentage point change of occurrence vs number of effort cells over three Habitats Directive reporting periods (Trend, pp).

SubRegion	Temporal resolution		*G.melas* N.occurrence cells	N.effort cells	Occurrence/Effort	Trend (Percentage point change, pp)
MAD	Entire period	2008-2024	0	416	0%	
MWE		2008-2024	89	2003	4%	
MWE	1 HP period	2008-2012	13	655	2%	
	2 HP period	2013-2018	22	1096	2%	0%
	3 HP period	2019-2024	60	1515	4%	2%
MAD	1 HP period	2008-2012	*NA*	*NA*	*NA*	
	2 HP period	2013-2018	0	329	0%	
	3 HP period	2019-2024	0	361	0%	0%

- **Observed Distribution Range (ODR) and Ecological Potential Range (EPR)**

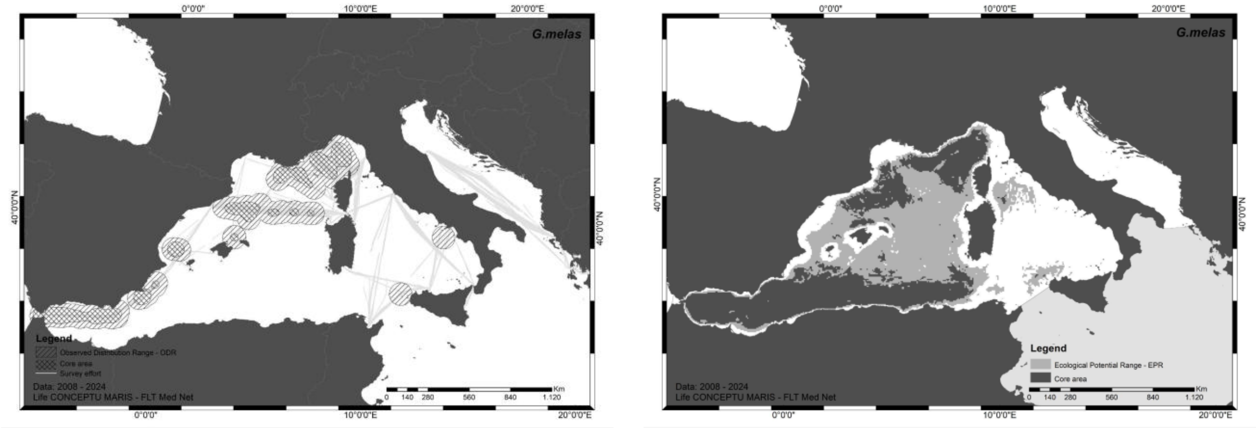


Figure 1.2.12. Observed Distribution Range (ODR, left) and Ecological Potential Range (EPR, right) of *Globicephala melas* in the western Mediterranean and Adriatic Regions

The ODR of *Globicephala melas* is mostly confined to the westernmost part of the western Mediterranean, with a few exceptions near the Campanian and Pontine Archipelagos and the Egadi Islands west of Sicily. The EPR confirms this westernmost distribution, extending west of Corsica and Sardinia, with core areas located in the northwestern region and primarily in the southern sector, stretching from the Alboran Sea to the northern African coast.

The percentage of *Globicephala melas* AOO, normalized by the effort area, remained almost stable at around 2% in the western Mediterranean region between the first and second periods, with a minimal increase of 2 percentage points in the most recent period, while it remained absent in the Adriatic region.

Range of *Ziphius cavirostris*

- **Distribution map of Area of Occupancy (AOO) and trend**

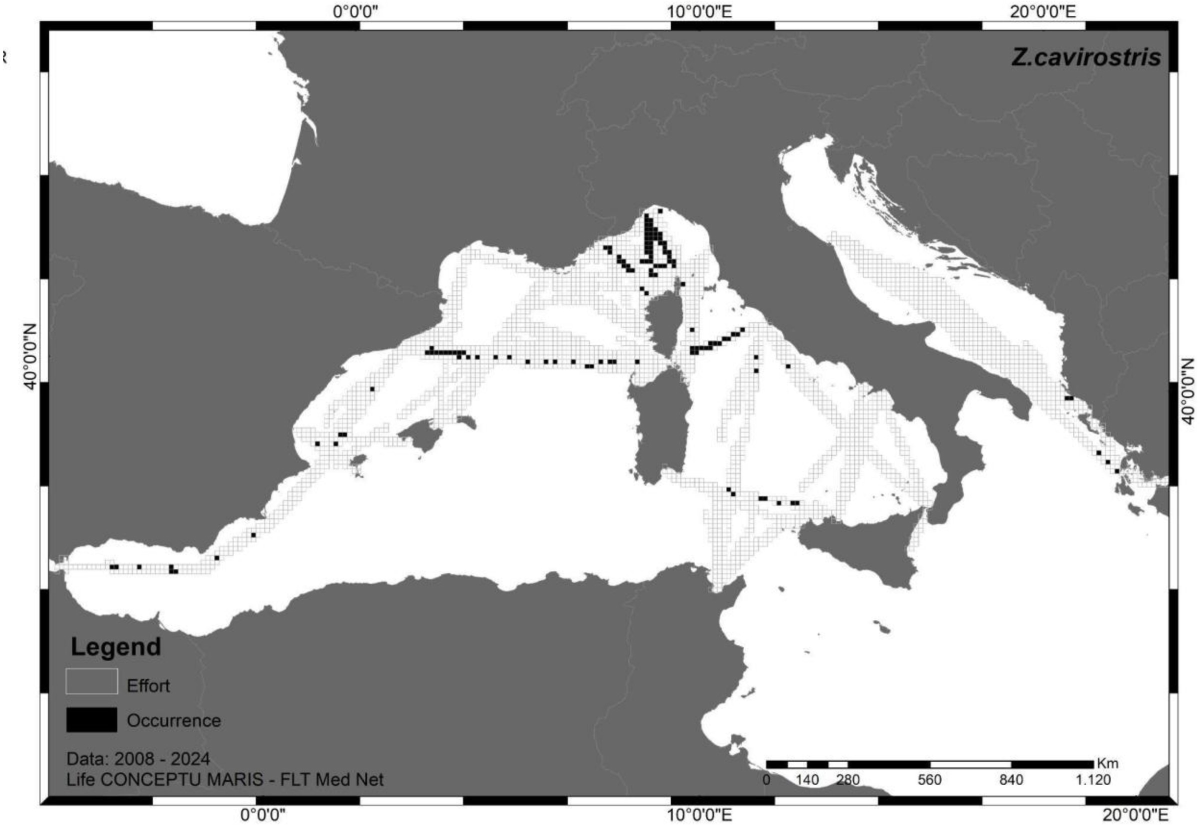


Figure 1.2.13. Occupancy of *Ziphius cavirostris* over the entire period (2008-2024) on the European 10x10 km Grid, ETRS89-LAEA projection.

Table 1.2.7 AOO of *Ziphius cavirostris* on number of occurrence 10x10 Km cells and percentage point change of occurrence vs number of effort cells over three Habitats Directive reporting periods (Trend, pp).

SubRegion	Temporal resolution		*Z.cavirostris*			Trend
			N.occurrence cells	N.effort cells	Occurrence/Effort	(Percentage point change, pp)
MAD	Entire period	2008-2024	2	416	0%	
MWE		2008-2024	119	2003	6%	
MWE	1 HP period	2008-2012	26	655	4%	
	2 HP period	2013-2018	67	1096	6%	2%
	3 HP period	2019-2024	75	1515	5%	-1%
MAD	1 HP period	2008-2012	*NA*	*NA*	*NA*	
	2 HP period	2013-2018	1	329	0%	
	3 HP period	2019-2024	2	361	1%	0%

- **Observed Distribution Range (ODR) and Ecological Potential Range (EPR)**

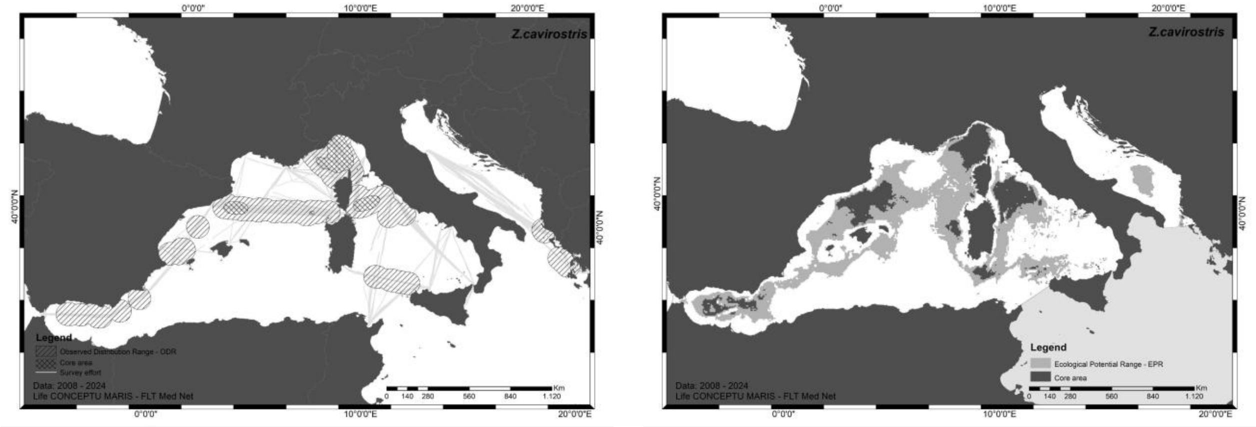


Figure 1.2.14. Observed Distribution Range (ODR, left) and Ecological Potential Range (EPR, right) of *Ziphius cavirostris* in the western Mediterranean and Adriatic Regions

The ODR of *Ziphius cavirostris* is scattered primarily across the northwestern Mediterranean, with a few occurrences in the Ionian Sea. Core areas are concentrated in the central Ligurian Sea, the central Tyrrhenian Sea, and northern Balearic islands. The EPR reflects this highly confined distribution, aligning with the observed pattern and concentrating in the central Ligurian Sea, central Tyrrhenian Sea, the northern sector of the Spanish Cetacean Migration Corridor (northern Balearic Islands), and a few scattered areas in the Alboran Sea and southern and western Sardinia.

In the western Mediterranean, the percentage of the AOO of *Ziphius cavirostris* within the effort area remained stable and confined at 5–6%, with a minimal decrease of just 1 percentage point in the most recent period. In the Adriatic region (i.e., southern areas), the species remained confined to a maximum of 1%.

Range of *Physeter macrocephalus*

- **Distribution map of Area of Occupancy (AOO) and trend**

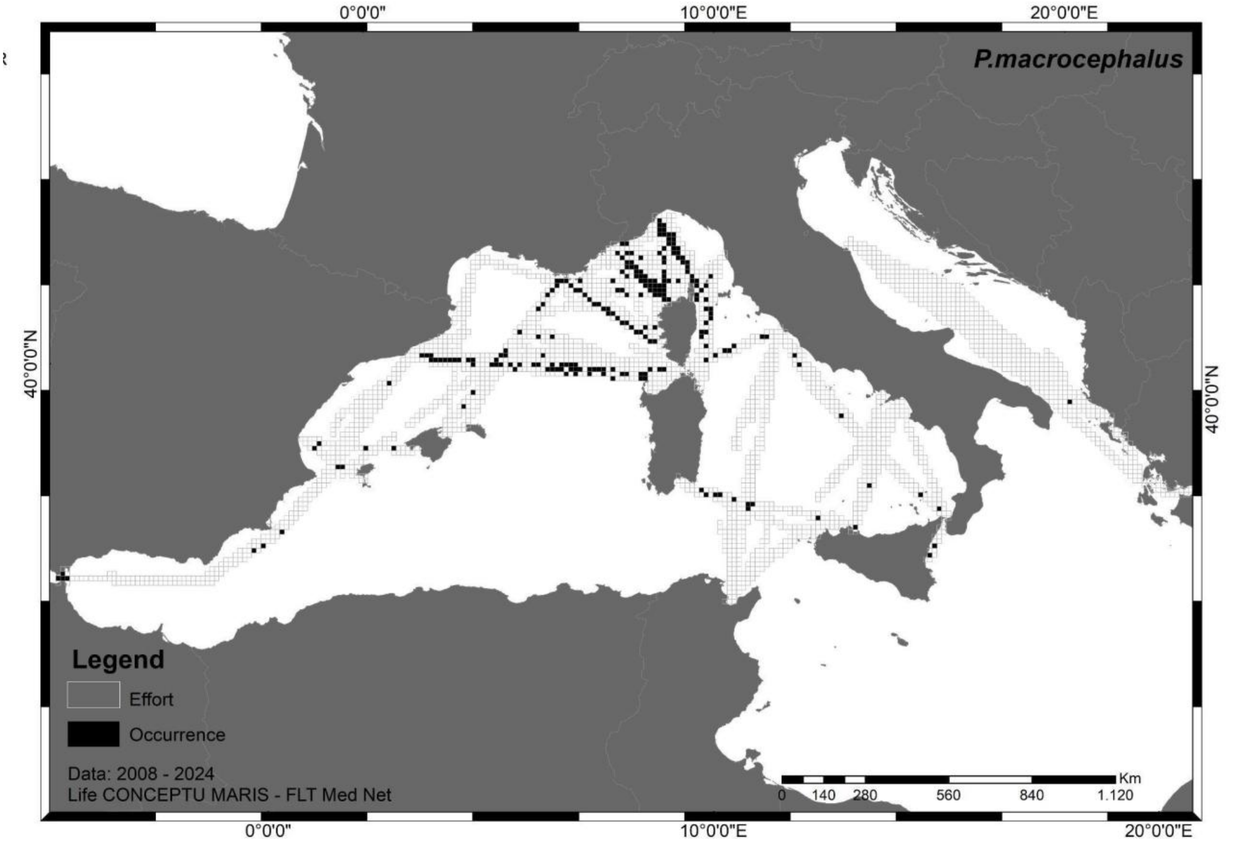


Figure 1.2.15. Occupancy of *Physeter macrocephalus* over the entire period (2008-2024) on the European 10x10 km Grid, ETRS89-LAEA projection.

Table 1.2.8. AOO of *Physeter macrocephalus* on number of occurrence 10x10 Km cells and percentage point change of occurrence vs number of effort cells over three Habitats Directive reporting periods (Trend, pp).

SubRegion	Temporal resolution		*P.macrocephalus*			Trend
			N.occurrence cells	N.effort cells	Occurrence/Effort	(Percentage point change, pp)
MAD	Entire period	2008-2024	1	416	0%	
MWE		2008-2024	223	2003	11%	
MWE	1 HP period	2008-2012	65	655	10%	
	2 HP period	2013-2018	121	1096	11%	1%
	3 HP period	2019-2024	95	1515	6%	-5%
MAD	1 HP period	2008-2012	*NA*	*NA*	*NA*	
	2 HP period	2013-2018	0	329	0%	
	3 HP period	2019-2024	1	361	0%	0%

- **Observed Distribution Range (ODR) and Ecological Potential Range (EPR)**

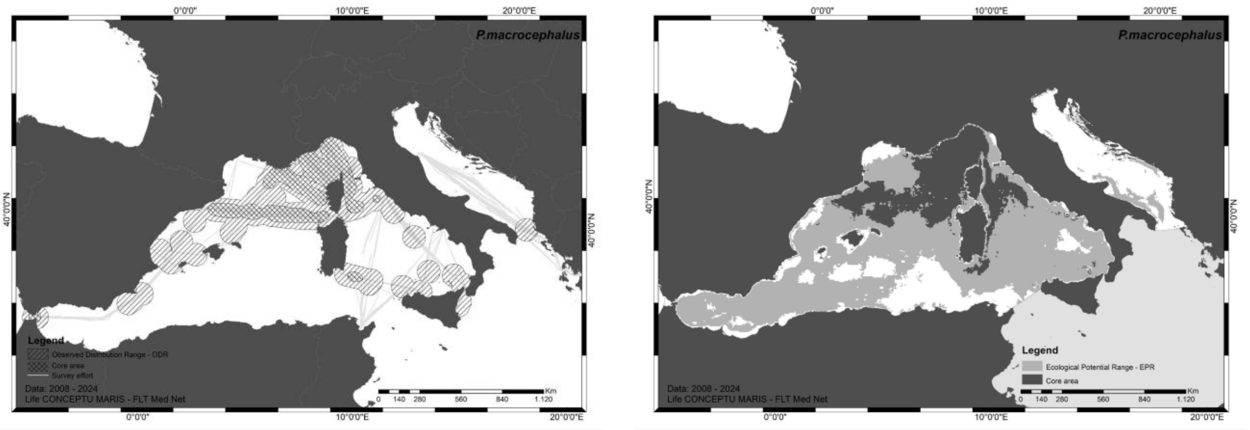


Figure 1.2.16. Observed Distribution Range (ODR, left) and Ecological Potential Range (EPR, right) of *Physeter macrocephalus* in the western Mediterranean and Adriatic Regions

The ODR of *Physeter macrocephalus* is mostly confined to the northern portion of the monitored areas in the western Mediterranean, with a few exceptions in the southeastern coast of Sardinia and in the southern Adriatic region. The EPR similarly reflects a predominantly western Mediterranean distribution, with an extended core area in the northern part of the region within the Pelagos Sanctuary, northern Balearic Islands and central Tyrrhenian Sea.

In the western Mediterranean, the percentage of the AOO of *Physeter macrocephalus* within the effort area remained stable at 10–11% between the first and second periods, followed by a slight contraction of 5 percentage points in the most recent period. In the Adriatic region (i.e., southern areas), the species remained merely occasional.

Range of *Caretta caretta*

- **Distribution map of Area of Occupancy (AOO) and trend**

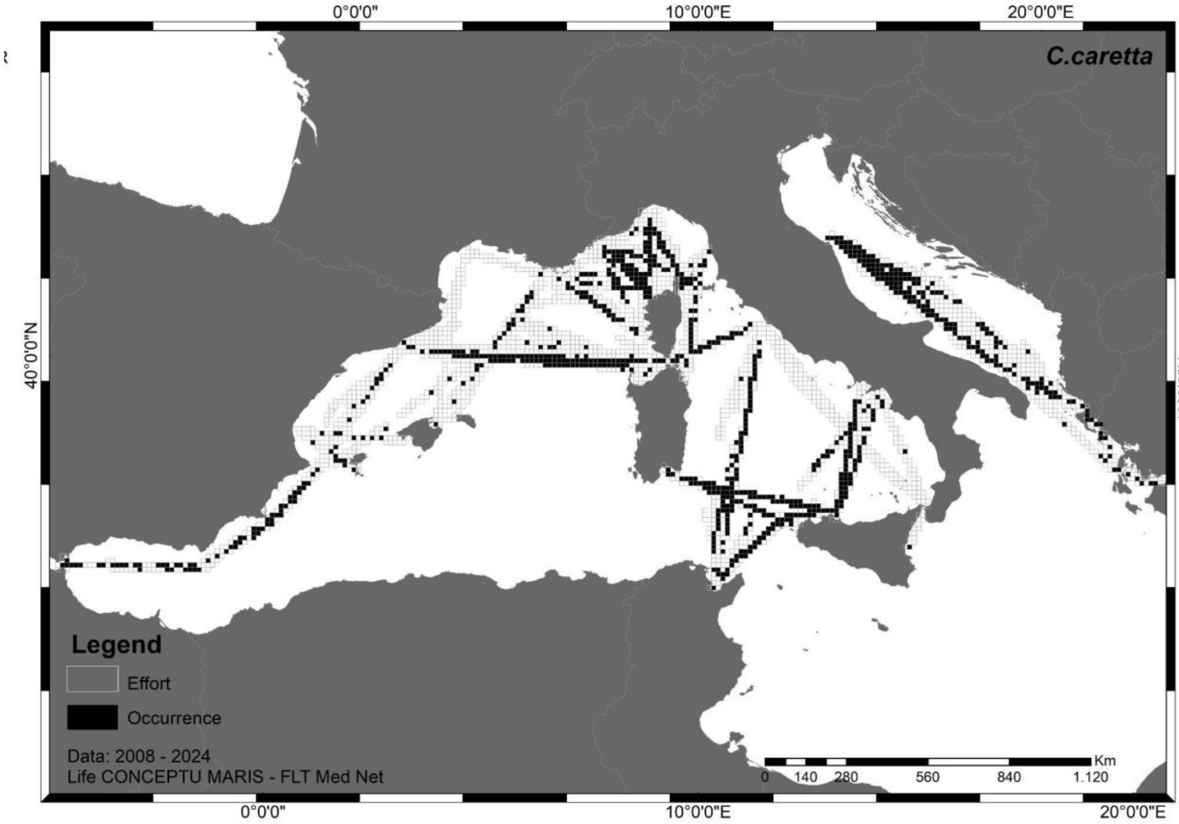


Figure 1.2.17. Occupancy of *Caretta caretta* over the entire period (2008-2024) on the European 10x10 km Grid, ETRS89-LAEA projection.

Table 1.2.9. AOO of *Caretta caretta* on number of occurrence 10x10 Km cells and percentage point change of occurrence vs number of effort cells over three Habitats Directive reporting periods (Trend, pp).

SubRegion	Temporal resolution		*C.caretta* N.occurrence cells	N.effort cells	Occurrence/Effort	Trend (Percentage point change, pp)
MWE	Entire period	2008-2024	678	2003	34%	
MAD		2008-2024	171	416	41%	
MWE	1 HP period	2008-2012	39	655	6%	
	2 HP period	2013-2018	326	1096	30%	24%
	3 HP period	2019-2024	514	1515	34%	4%
MAD	1 HP period	2008-2012	*NA*	*NA*	*NA*	
	2 HP period	2013-2018	53	329	16%	
	3 HP period	2019-2024	162	361	45%	29%

- **Observed Distribution Range (ODR) and Ecological Potential Range (EPR)**

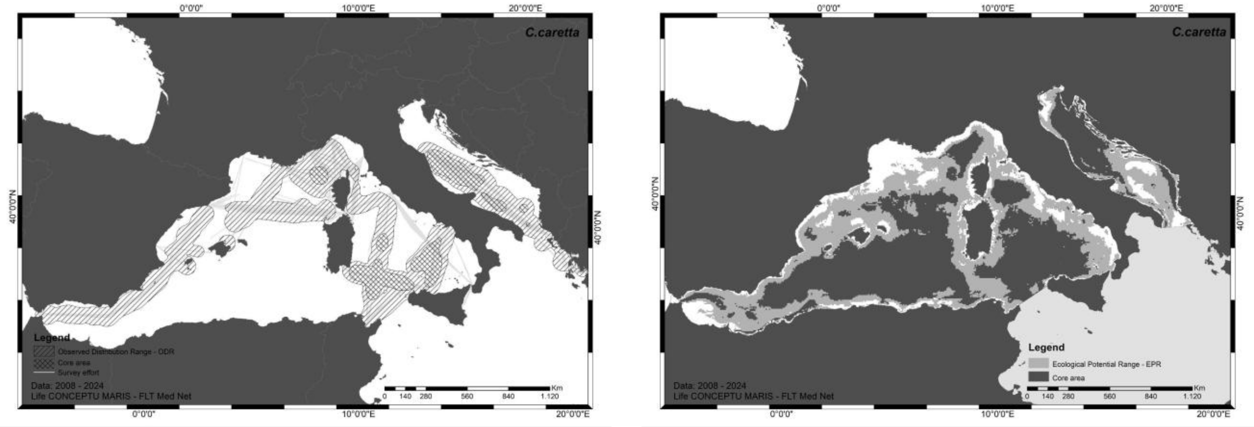


Figure 1.2.18. Observed Distribution Range (ODR, left) and Ecological Potential Range (EPR, right) of *Caretta caretta* in the western Mediterranean and Adriatic Regions

The ODR of *Caretta caretta* spans all monitored areas in both the western Mediterranean and the Adriatic regions, with core areas primarily located in the southern part of the western Mediterranean and the northern Adriatic. The EPR reflects this pattern, showing extended core areas in the Tyrrhenian Sea especially in the southern part including Sardini-Sicilian channels, in the Algerian basin up to Balearic Islands, the central Ligurian Sea, and the northern Adriatic region.

In the Adriatic region, the percentage of *Caretta caretta* AOO within the effort area remained relatively stable at around 30–34%. In contrast, in the western Mediterranean it increased significantly, by over 29 percentage points, confirming a general expansion of the area used by *Caretta caretta* in this region in recent years.

1.3 Habitat for the species

The Habitats Directive requires the assessment of the "habitat for the species" parameter usually in terms of the quality of species habitats. Since the ecological niche or habitat of most cetaceans and sea turtles in pelagic waters remains largely unknown, this parameter is explored here through the identification of species' ecological niches, both generally and seasonally, and potential temporal shifts that may be linked to environmental or climate-related changes.

Method. **Environmental Niche Analysis and SDM.** Building upon a systematic review of scientific literature on SDMs (Pasanisi et al., 2024) and the methodology reported in Deliverable C1.2 (Arcangeli et al., 2023), a streamlined but consistent framework was applied to assess habitat selection and support the construction of Species Distribution Models (SDMs). This multi-step approach served a dual purpose: to identify the best set of ecologically meaningful and non-redundant variables for SDMs, and to independently verify the environmental niche of each species through separate analyses. The procedure included: 1) **Preliminary analysis on environmental variable correlation**; 2) **Habitat Selection Analysis:** comparison between environmental variable distributions at presence and effort locations; 3) **Principal Component Analysis (PCA**) on species presence; 4) **SDMs**; 5) **Models outputs validation using a fully independent dataset** (over 24,000 records), to significantly strengthen the reliability of the results. This comprehensive validation confirms the robustness of the models and their applicability to real-world ecological scenarios. This framework ensured that variables were either retained or consciously justified for modeling in each species case, enhancing both model robustness and ecological interpretation. Details on the methodology applied is given below:

1. ***Preliminary analysis on Environmental variable correlation.*** Correlation among 17 candidate environmental variables was assessed using Pearson correlation analysis. A threshold of 0.8 was applied to identify strong correlations, and the correlation structure was visualized using a heatmap (Figure 1.3.1). The results revealed several highly correlated variable pairs, such as *chl_mean* with *chl_sd*, *temperature_mean* with *temperature_sd*, *EKE* with *current_magnitude*, and *dist_shelf* with *dist_coast*, suggesting that in each case, one variable may sufficiently represent the underlying information. Among these pairs, variables were selected based on ecological relevance and expert judgment for each species (Table 1.3.1).
2. **Habitat Selection Analysis: comparison between Environmental Variable Distributions at Presence and Effort Locations.** For each species, environmental values were extracted from raster layers at both presence locations and standardized effort points. These datasets were merged and labeled as "selected" (presence) and "effort" (available), enabling statistical comparisons. Differences in the distributions of environmental variables were tested using the Mann–Whitney U test (for medians) and the Kolmogorov–Smirnov test (for overall distribution shapes). The Mann-Whitney U test compares the distribution of two independent samples, in this case, the values of environmental variables between the available and selected habitats. A significant p-value indicates that the two distributions differ, suggesting habitat selection by the species.The Kolmogorov–Smirnov test highlights even subtle differences in the shape of the distributions. The agreement between the two tests strengthens the evidence of ecological selection regarding the variables considered. Results were visualized using violin plots to illustrate potential habitat selection patterns.
3. **Principal Component Analysis (PCA) on Species Presence**. To explore underlying environmental gradients and reduce dimensionality, PCA was performed on the standardized (z-score transformed) environmental dataset at presence locations. Loadings on the first

principal component (PC1) were extracted to identify the most influential variables, and spatial projections of PC1 and PC2 were mapped to visualize dominant environmental patterns across the study area.

4. **Species Distribution Models**. According with the results of the test performed on the historical dataset (Deliverable C1.2, Arcangeli et al. 2025) SDMs were implemented using Maxent on the harmonized historical and Life CONCEPTU MARIS dataset (Table 1.3.1) and the selected set of variables (Table 1.3.2), adopting species-specific settings (Table 1.3.3). In general, Maxent models were run using logistic output with autofeatures enabled and a regularization multiplier of 1. A total of 1,000 background points were used, with 30% of the data randomly set aside for internal validation. Models were replicated 100 times using bootstrap resampling. Each run was allowed up to 5,000 iterations with a convergence threshold of 0.00001 to ensure accurate model fitting. Models were applied across different temporal resolutions: entire period, seasonal subsets, and EU reporting periods. For each model, the percentage contribution and permutation importance of the variables were extracted and analyzed. Model outputs were spatially projected first with a focus at the scale of the sampling area, the western Mediterranean Sea and Adriatic Sea, then also at the entire Mediterranean Sea scale, to identify suitable habitats and species-environment relationships. Based on the thresholds selected for model validation (see point 5), two contours were used to delineate key habitats for the species: the Maximum Test Sensitivity plus Specificity logistic threshold and the Natural Jenks threshold.
5. ***Models' output validation with independent dataset.*** Models were validated using independent datasets (27.183 records, Table 1.3.4) to assess their robustness and generalizability. This step is of extreme importance, as **validating model outputs with independent data ensures reliability, and confirms that species distribution models (SDMs) accurately reflect real-world ecological patterns** (Arcangeli et al., 2024a). To validate the models, the continuous colour scheme of suitable-unsuitable prediction of the output maps were reclassified in binary suitable-unsuitable predictions under appropriate thresholds scenarios (e.g., Maximum test sensitivity plus specificity logistic threshold, Arcangeli et al. 2023). **In the context of ecological modeling for habitat suitability prediction of cetaceans and sea turtles, selecting an appropriate threshold is critical, especially when the primary objective is to prioritize presence detection. Failing to identify suitable habitats may lead to inadequate protection measures or missed opportunities for effective species conservation.** In such cases, the most suitable threshold is generally the one that maximizes the F1-score and precision, as these metrics balance the ability to identify true presences (recall) with the reliability of predicted presences (precision). Among the evaluated options, the threshold derived from the maximum performance on the independent test set were *Maximum test sensitivity plus specificity logistic threshold* to identify the core areas and *Natural Jenks threshold* for the extended suitable areas. The latter was calculated dividing the suitable values in eleven classes after the exclusion of zero values, with the threshold set at the value separating the second and third classes. These thresholds maximize true positive predictions and yield the highest F1-score, reflecting strong performance in presence prediction. Although this approach may slightly reduce specificity, the trade-off is acceptable when the overarching goal is to minimize omission errors and ensure that potential habitats are not overlooked in conservation planning. The validation of the models was carried out using several performance indices. The **Area Under the Curve (AUC)** was applied to continuous models to evaluate their ability to distinguish between presence and absence, with values above 0.7 considered good and above 0.9 considered excellent. **Accuracy** measured the proportion of correct predictions

across all cases, while **Sensitivity (or Recall)** assessed the model's ability to correctly identify actual presences. **Specificity** quantified the ability to correctly identify absences. To account for the possibility of correct predictions occurring by chance, especially in imbalanced datasets, **Cohen's Kappa** was used to adjust the accuracy accordingly. Finally, the **True Skill Statistic (TSS)** combined sensitivity and specificity (TSS = Sensitivity + Specificity – 1) to provide a balanced measure of model performance, where values closer to 1 indicated high predictive skill. All SDM maps were validated for the LIFE CONCEPTU MARIS project regions (western Mediterranean and Adriatic Sea) and tested for their ability to predict suitable habitats across the entire Mediterranean basin.

Table 1.3.1. Number of presence records used as input for Maxent models, sorted by species and temporal resolution (Harmonized FLT Med Net historical dataset and Life CONCEPTU MARIS dataset). *Stenella coeruleoalba, Sc; Balaenoptera physalus, Bp; Tursiops truncatus, Tt; Delphinus delphis, Dd; Grampus griseus, Gg; Globicephala melas, Gm; Ziphius cavirostris, Zc; Physeter macrocephalus, Pm; Caretta caretta, Cc* 1st period HD: 2008-2012; 2nd period HD: 2013-2018; 3rd period HD: 2019-2024).

Time period	*Sc*	*Bp**	*Tt*	*Dd*	*Gg*	*Gm*	*Zc*	*Pm*	*Cc*
Entire period	**6854**	**3684**	**1025**	**325**	**140**	**137**	**305**	**419**	**4636**
Winter	*569*	*190*	*165*	*55*	*11*	*22*	*10*	*13*	*366*
Spring	*1977*	*1168*	*324*	*107*	*38*	*25*	*71*	*81*	*1299*
Summer	*3606*	*2027*	*345*	*95*	*70*	*64*	*208*	*275*	*2562*
Autumn	*702*	*299*	*191*	*68*	*21*	*26*	*16*	*50*	*409*
1 Period HD	1349	711	149	42	23	15	29	100	105
2 Period HD	2814	1541	406	76	41	29	121	180	1538
3 Period HD	2691	1432	470	207	76	93	155	139	2993**

**Bp available occurrences were reduced to 1/3 for modeling*
*** Adults of Cc counted in the period 2021-2024: tot 557, 36 in winter, 186 in spring, 276 in summer, 59 in autumn.*

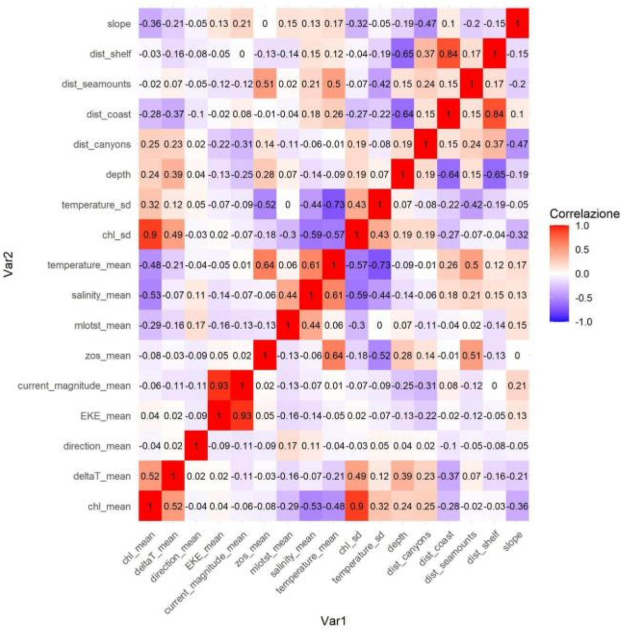


Figure 1.3.1. Heatmap showing Pearson correlation coefficients among the 17 environmental predictor variables.

Table. 1.3.2. Specie-specific set of environmental variables used for MaxEnt. (*Stenella coeruleoalba, Sc; Balaenoptera physalus, Bp; Tursiops truncatus, Tt; Delphinus delphis, Dd; Grampus griseus, Gg; Globicephala melas, Gm; Ziphius cavirostris, Zc; Physeter macrocephalus, Pm; Caretta caretta, Cc*)

VARIABLES	SPECIES								
	Sc	***Bp***	***Tt***	***Dd***	***Gg***	***Gm***	***Zc***	***Pm***	***Cc***
Bathymetry	x	x	x	x	x	x	x	x	x
Chl_mean	x	x	x	x	x	x	x	x	x
Chl_sd	x	x	x	x	x	x	x	x	x
Current_dir									x
Current_mag									x
deltaT			x						x
Dist.canyons	x	x	x	x	x	x	x	x	x
Dist.coast		x	x	x	x	x	x	x	x
Dist.seamount	x	x	x	x	x	x	x	x	x
Dist.shelf	x								
EKE	x	x	x	x	x	x	x	x	
mlotst		x	x						x
Salinity	x	x	x	x	x	x	x	x	x
Slope	x	x	x	x	x	x	x	x	x
Temp_mean	x	x	x	x	x	x	x	x	x
Temp_sd		x	x	x					x
zos		x	x					x	x

Table.1.3.3. Specie-specific setting of MaxEnt.(*Stenella coeruleoalba, Sc; Balaenoptera physalus, Bp; Tursiops truncatus, Tt; Delphinus delphis, Dd; Grampus griseus, Gg; Globicephala melas, Gm; Ziphius cavirostris, Zc; Physeter macrocephalus, Pm; Caretta caretta, Cc*)

SETTING	SPECIES								
	Sc	***Bp***	***Tt***	***Dd***	***Gg***	***Gm***	***Zc***	***Pm***	***Cc***
Autofeatures	x	x	x	x	x	x	x	x	x
Output format	Log	Log	Log	Log	Log	Log	Log	Log	Log
Random test %	30	30	30	20	20	20	20	20	30
RM	1	1	1	1	1	1	1	1	1
max n of background points	1000	10000	1000	10000	10000	10000	10000	10000	1000
Replicates	100	100	100	100	100	100	100	100	100
Replicated run type	bootstrap	bootstrap	bootstrap	bootstrap	bootstrap	bootstrap	bootstrap	bootstrap	bootstrap
Max iter	5000	5000	5000	5000	5000	5000	5000	5000	5000
Conv. threshold	0.00001	0.00001	0.00001	0.00001	0.00001	0.00001	0.00001	0.00001	0.00001

Table 1.3.4. Number of presence records used for external model validation (Independent datasets on sea turtle and cetaceans)

Data owners (Independent dataset)	*Cc*
ASI	3727
ORCA	29
Totale complessivo	**3756**

Data owner (Indipendent dataset)	*Sc*	*Bp*	*Tt*	*Dd*	*Gg*	*Gm*	*Pm*	*Zc*	*Tot*
Acquario di Genova	34	3	113	5	4			1	160
Alnilam	1524	61	448	1256	118	568	41	37	4053
Archipelagos Institute via Happywhale.com							7		7
ASI	285	47	171		63	14	14	16	610
Ass. Cetacea	5	1	3						9
Bottlenose Dolphin Research Institute	4	4	174	1					183
Caroline Lagier via Happywhale.com		1							1
Cecile Constantin via Happywhale.com							1		1
Cetacean Research Centre (CE.TU.S.)	39	13	327	4	5		3	2	393
Christian Wegener via Happywhale.com			2						2
Claudio Fossati, University of Pavia	153	16	2		7		36		214
Cyril VATHELET via Happywhale.com					11		1		12
De WuGlobicephala melas Maurina (maluga) via Happywhale.com		1							1
Edy Mercuriali via Happywhale.com		1							1
Enrico Pirotta, Sea Mammal Research Unit (SMRU)							1124		1124
Fra. Vest, National Natural History Museum Paris Service du Patrimoine naturel (MNHN-Physeter macrocephalusN)	264	69	108		36	7	11	2	497
International Fund for Animal WeGlobicephala melasare, Song of the Whale Team	314	75	88	71	17	1	67		633
Israel Marine Mammal Research and Assistance Center (IMMRAC)	15	7		45	11		11		89
Italo-Tunisian Cetacean Research Project	73	12	39	9			2	2	137
Jonian Dolphin Conservation	134	1	19		1				155
KYMA sea conservation & research	114	1	25	6			8	5	159
Luca Giovagnoli, CetaceanSound.org	48		65	14	7		4		138
Madelon RosenplÃƒÂ¤nter via Happywhale.com		1							1
OBIS Secretariat, Intergovernmental Oceanographic Commission of UNESCO	2			2					4
Observatoire PELAGIS - Reseau National Echouage (French stranding network) - UAR 3462 University La Rochelle - CNRS	1971	107	365	36	94	62	46	34	2715
Observatoire PELAGIS UAR 3462 University La Rochelle - CNRS	503	119	286	1	64	21	15	7	1016
Observatoire PELAGIS UMS 3462 University La Rochelle - CNRS	12	6	31	1					50
OceanCare	521	26	25	11	10	11	65	5	674
ORCA	379	61	83	277	38	20	23	23	904
Patricia Gozalbes Aparicio, Marine Zoology Unit, University of Valencia	237	8	36	5	23	4		3	316
Paula Hoppe via Happywhale.com	1						1		2
Raimondeau via Happywhale.com		1							1
SAD-DEMAG (Underwater Research Society - Marine Mammals Research Group)			12				1		13
Sara Fullone via Happywhale.com							2		2
Simone Panigada via Happywhale.com							1		1
Siri Hartvedt, Institute of Marine Research (IMR)				2					2
Tanja via Happywhale.com							1		1
Tethys Research Institute	4691	1119	2058	521	201	61	335	76	9062
UK Royal Navy	16	1	19	35		7	2		80
University of Rhode Island				1					1
Wildlife Conservation Society							3		3
Tot	**11339**	**1762**	**4499**	**2303**	**710**	**776**	**1825**	**213**	**23427**

Suitable habitat for *Stenella coeruleoalba*

Stenella coeruleoalba habitat is characterized by clear seasonal and regional patterns. The species prefers dynamic, deep, and productive offshore areas, often near seamounts and canyons. While suitable areas are spread across most of the Mediterranean Sea, there are signs of a slight habitat shift in recent years, possibly due to changing ocean conditions.

Summary of *Stenella coeruleoalba* Habitat Preferences and Distribution

The SDM, validated with independent datasets, confirms a broad distribution of suitable habitats for *Stenella coeruleoalba*, particularly in the western Mediterranean and Adriatic regions. Core areas include the Pelagos Sanctuary, the Tyrrhenian sea, the Sardinia-Balearic and Algerian basins, and the Alboran Sea.

Stenella coeruleoalba demonstrates strong habitat flexibility, selecting specific environmental conditions across a wide ecological gradient. Violin plot analyses reveal a preference for dynamic and productive waters, characterized by stronger currents, elevated Eddy Kinetic Energy (EKE), high chlorophyll concentration, phytoplankton abundance, and primary productivity, typically near canyons and seamounts. PCA results support this finding, showing high environmental heterogeneity in the species' distribution, reflected by low cumulative explained variance and widespread presence across environmental gradients.

Among SDM predictors, depth was the most influential (45.6%), followed by mean sea surface temperature (SST, 13%). Static variables collectively accounted for 56.6% of model contribution, emphasizing preferences for deep habitats in proximity to seamounts, canyons, and steep slopes. Chlorophyll (8.8%) and salinity (6.1%) were also significant. Habitat suitability increased with chlorophyll levels up to a certain threshold, after which it declined, suggesting a non-linear response to productivity. Preferred SST values clustered around 18°C.

Across the three HD periods (2008–2024), *Stenella coeruleoalba* habitat suitability was consistently shaped by hydrographic, bathymetric, and productivity-related variables, though their relative importance varied over time. In 2008–2012, thermocline depth was the strongest predictor, followed by depth and EKE, highlighting the influence of vertical and dynamic ocean features. Between 2013–2018, depth became dominant, with chlorophyll and thermocline depth also contributing, indicating a shift toward productivity-related drivers. In 2019–2024, depth remained the top predictor, with salinity gaining importance and a reduced role for productivity and temperature. Throughout all periods, suitable habitats were broadly distributed across all Mediterranean sub-basins.

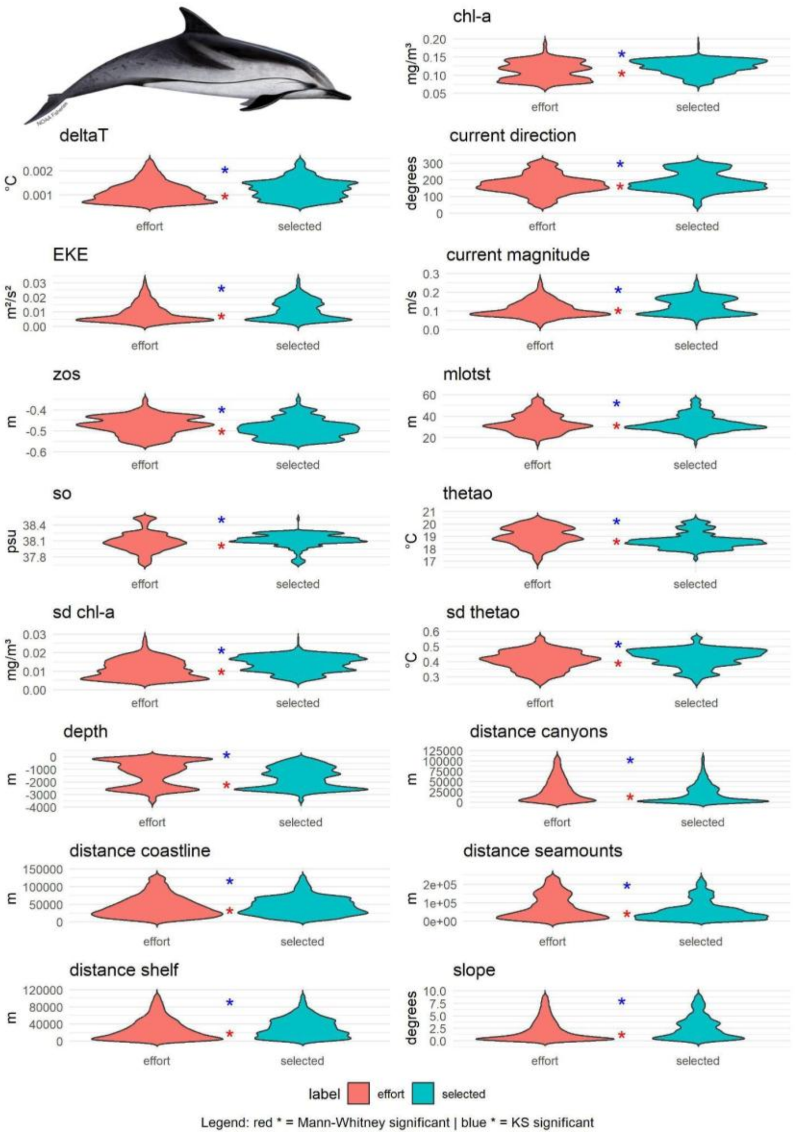
Policy Implications for *Stenella coeruleoalba* Conservation:

1. **Maintain Broad-Scale Protections Across the Mediterranean**: Given the widespread and ecologically flexible distribution of *Stenella coeruleoalba*, conservation measures should extend across multiple sub-basins, especially core areas like the Pelagos Sanctuary, Tyrrhenian Sea, Alboran Sea, and Sardinia-Balearic and Algerian basins.
2. **Protect Offshore Dynamic Features**: Key habitat preferences include deep, productive waters near seamounts, canyons, and steep slopes. These static and semi-permanent features should be incorporated into Marine Protected Area (MPA) planning and management.
3. **Implement Adaptive, Seasonally Informed Management**: Seasonal shifts in habitat use

and environmental drivers (e.g., thermocline depth, EKE, SST) require dynamic conservation strategies that account for seasonal oceanographic variability.

4. **Monitor Shifting Habitat Drivers**: The recent decrease in productivity's importance and the rise of salinity and static features as key predictors suggest potential responses to ocean changes. Continued environmental monitoring is critical to update species distribution models and inform future conservation priorities.
5. **Support Regional Coordination and Data Sharing**: The broad distribution of suitable habitat across national jurisdictions calls for enhanced cross-border collaboration and standardized habitat modeling

1) Habitat Selection of *Stenella coeruleoalba*. Comparison between selected environmental variable range at present locations and available range of values across the effort area.

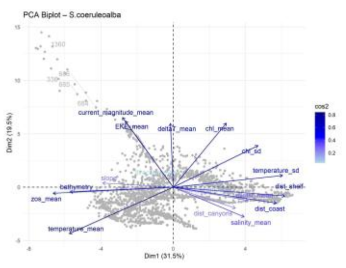
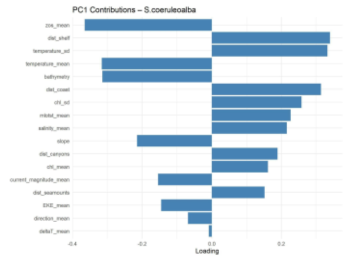
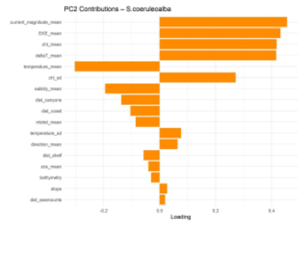
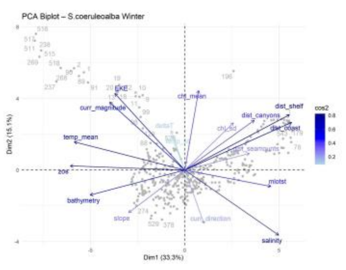
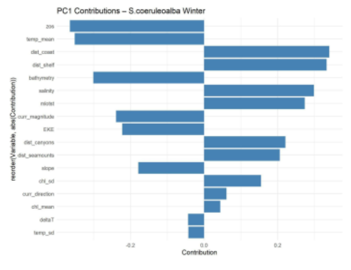
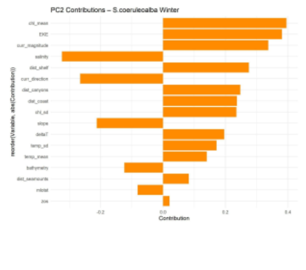
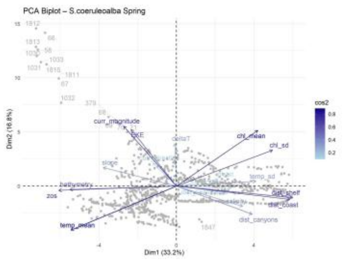
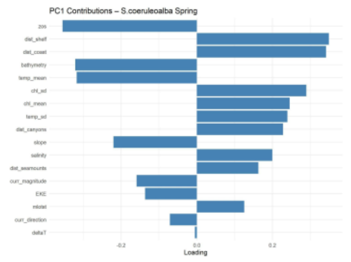
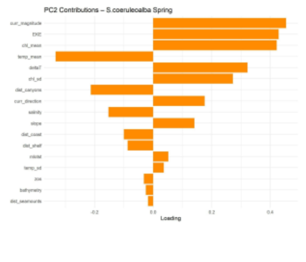
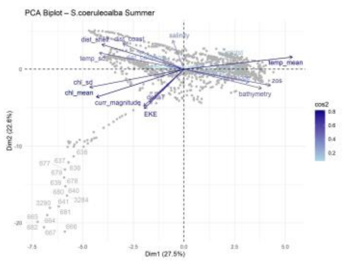
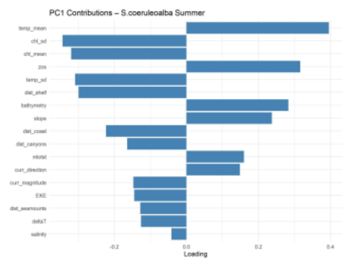
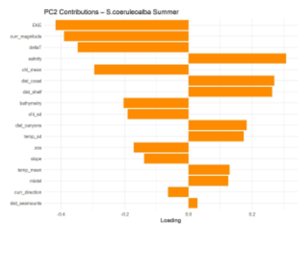
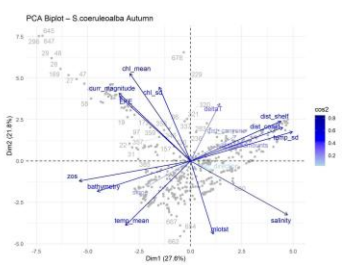
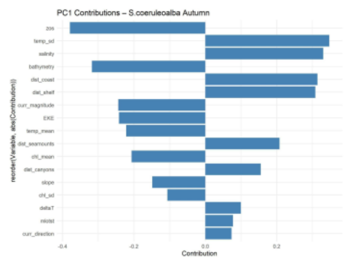
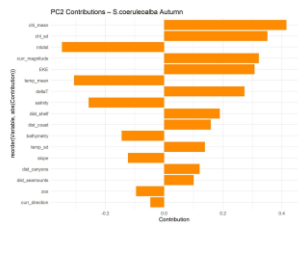


Summary: Stenella coeruleoalba selects specific ranges of several environmental variables, showing a preference for more dynamic areas (e.g., higher current and EKE) and productive waters (e.g., elevated chlorophyll, phytoplankton concentration, and primary productivity), often located near canyons and seamounts (Figure 1.3.2).

Figure 1.3.2. Habitat selection of *Stenella coeruleoalba*. Distribution of environmental variable values at presence locations (left, red violin plots) and available range of values across the effort area (right, blue violin plots).

2) Principal Component Analysis (PCA) of *Stenella coeruleoalba*

Table 1.3.5 *Stenella coeruleoalba* PCA Biplot and Barplot of PC1 (blue) and PC2 (orange) loadings for different temporal resolutions.

Temporal res.	Biplot	Loadings PC1	Loadings PC2
Entire period 51% explained variance			
Winter 48.4% explained variance			
Spring 50% explained variance			
Summer 50.1% explained variance			
Autumn 49.4% explained variance			

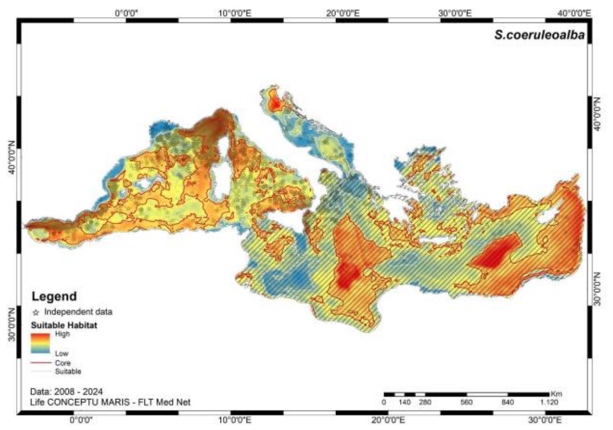
Stenella coeruleoalba distribution reflects **high environmental heterogeneity**, as shown by the widespread of observations and medium cumulative PCA variance (Table 1.3.4). Over the entire period, in fact, *Stenella coeruleoalba* distribution ranges from **deep, dynamic and productive offshore waters to shallower, more stable shelf-associated environments, with higher salinity, warmer surface waters and deeper mixed layers**. Still in **winter**, *Stenella coeruleoalba* uses both productive offshore environments and shelf-slope regions, shaped by surface mixing. Its

spring distribution also shows flexible habitats, with a strong gradient between dynamic, productive pelagic zones and more stable, coastal areas. In **summer**, the species distribution is influenced by a gradient between warm, mixed, coastal/shelf waters to highly energetic, productive deep-ocean zones. During **autumn**, *Stenella coeruleoalba* spans from stable, saline shelf-influenced waters and highly energetic, productive and dynamic oceanic/deep-water ones. Across all seasons, *Stenella coeruleoalba* respond to a broad ecological gradient, ranging from stable, saline, shelf-associated waters to dynamic, deep, and productive offshore environments, reflecting **high habitat flexibility** and likely adaptation to shifting prey conditions.

3) Stenella coeruleoalba Species Distribution Model

Entire period SDM *Stenella coeruleoalba*
(AUC train=0.70, AUC test=0.68)

Maxent - avg predictions



Maxent - std

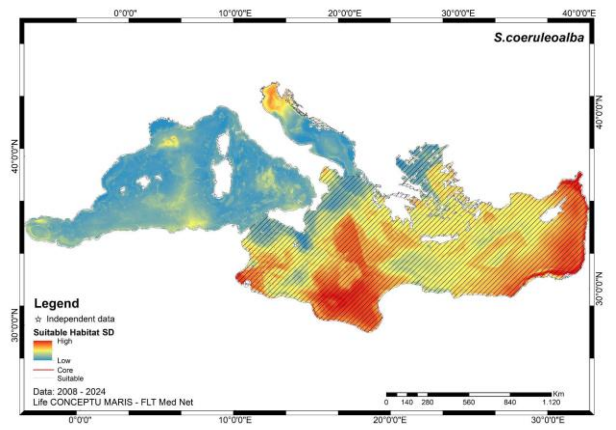


Figure 1.3.3. Species Distribution Model for *Stenella coeruleoalba* covering the entire period from 2008 to 2024.

Table 1.3.6. Validation results of the Species Distribution Model for *Stenella coeruleoalba* using an independent dataset, both within the LIFE CONCEPTU MARIS project area (Western Mediterranean and Adriatic regions) and across the entire Mediterranean basin.

External validation with independent dataset	W Med + Adriatic		Mediterranean Sea	
	Maximum test sensitivity plus specificity Logistic threshold	Natural jenks threshold	Maximum test sensitivity plus specificity Logistic threshold	Natural jenks threshold
AUC	0.78	0.78	0.74	0.74
Precision	0.67	0.53	0.67	0.52
F1	0.72	0.69	0.71	0.68

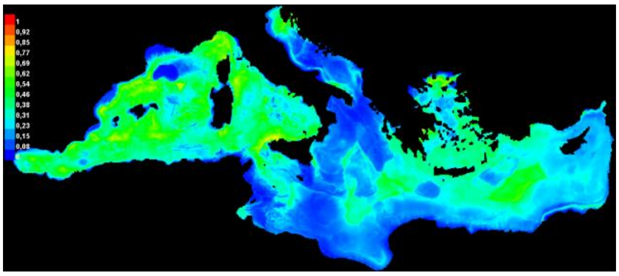
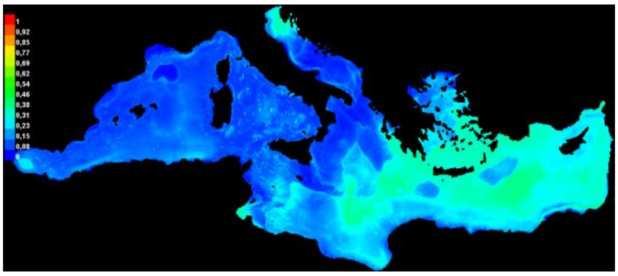
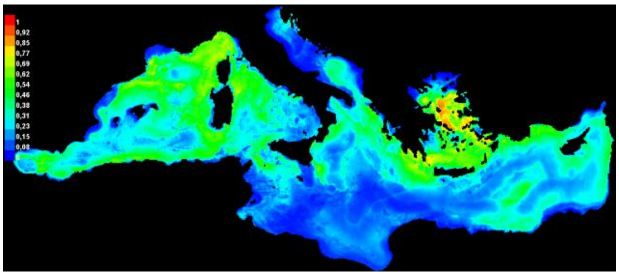
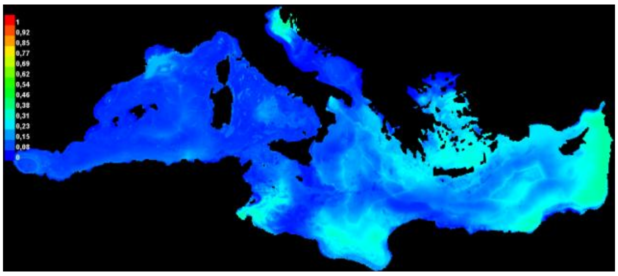
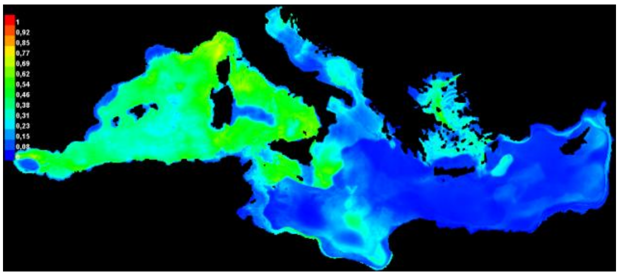
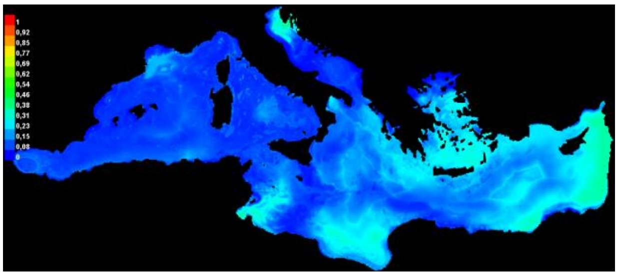
Table 1.3.7 - *Stenella coeruleoalba* environmental variable contribution: summary of PCA loadings and Maxent output for each environmental variable over the entire period, expressed as percentage contribution and permutation importance.

Entire period				
Variable	PCA		SDM output	
	PC1	PC2	% contrib	per. imp
Bathymetry	-0.314	-0.031	45.6	31
Chl_mean	0.162	0.418	8.8	7.6
Chl_sd	0.258	0.272	NA	NA
Curr.direction	-0.154	0.064	NA	NA
Curr.magnitude	-0.008	0.455	NA	NA
deltaT	-0.068	0.416	1.8	1.4
Dist. canyons	0.189	-0.137	2.1	2.3
Dist.coast	0.314	-0.105	NA	NA
Dist.seamounts	0.152	0.020	6.1	7.7
Dist.shelf	0.339	-0.057	4.9	6
EKE	-0.145	0.432	3.9	1.8
mlotst	0.227	-0.086	2.3	3.5
Salinity	0.216	-0.195	6.1	4.4
Slope	-0.214	0.027	2.5	3.8
Temp_mean	-0.316	-0.304	13	21.4
Temp_sd	0.332	0.077	NA	NA
zos	-0.365	-0.040	2.8	9.2

Entire period: the spatial projection indicates that habitat suitability is evenly distributed across all Mediterranean sub-basins.

The SDM for *Stenella coeruleoalba* was **well validated** by the independent dataset, both within the LIFE CONCEPTU MARIS project areas (Western Mediterranean and Adriatic regions) and at the broader Mediterranean basin level (Table 1.3.5).

The model indicates that ***Stenella coeruleoalba's suitable* habitat extends across a large portion of the western Mediterranean and the Adriatic Sea** (Figure 1.3.3). Core areas are primarily concentrated in the Pelagos Sanctuary, the Sardinia-Balearic basin, the Algerian basin and the Alboran Sea. Interestingly, a suitable area has emerged in the northeastern Adriatic Sea around the Istria Peninsula, where occasional sightings and stranded individuals have been reported in the literature particularly in Croatian waters, possibly indicating a suitable habitat not yet fully exploited by the species. Throughout the entire study period, **depth** emerged as the most significant environmental predictor, contributing to 45.6% of the model's overall effectiveness. Mean SST followed, with a contribution of 13%. Together, all static variables accounted for 56.6% of the model's total contribution. Notably, the contributions of depth (45.6%), distance from the shelf (4.9%), distance from seamounts (6.1%), distance from canyons (2.1%), and slope (2.5%), along with their corresponding response curves, indicate that the species have a **preference for deeper waters located near seamounts and canyons**, which tend to be more productive. Chlorophyll also plays a crucial role, contributing 8.8% to the model, as indicated by its response curve. Interestingly, while habitat suitability increases with higher levels of chlorophyll initially, it begins to decline after reaching a certain threshold. Furthermore, SST (13%) and salinity (6.1%) data suggest a preference for water temperatures around 18°C.

Seasonal SDM *Stenella coeruleoalba*	
Maxent - avg predictions	Maxent - std
WINTER (AUC train=0.79, AUC test=0.74)	
	
SPRING (AUC train=0.76, AUC test=0.73)	
	
SUMMER (AUC train=0.72, AUC test=0.69)	
	
AUTUMN (AUC train=0.80, AUC test=0.75)	

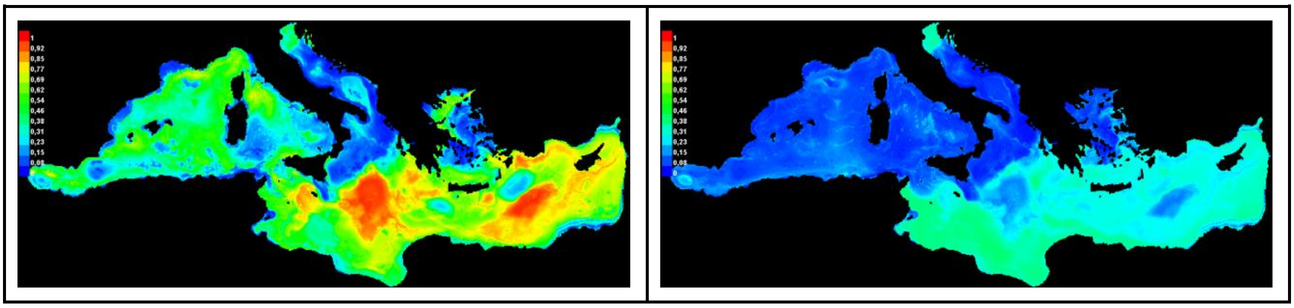


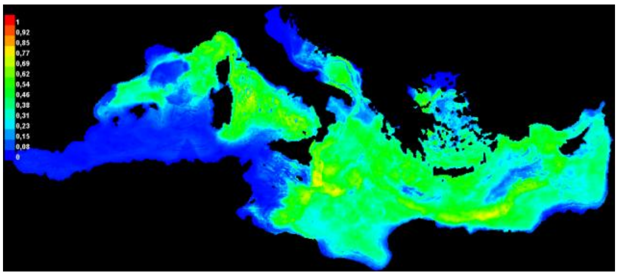
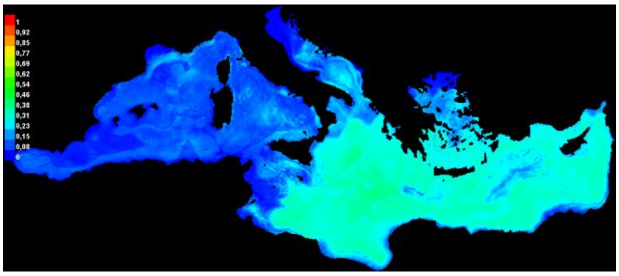
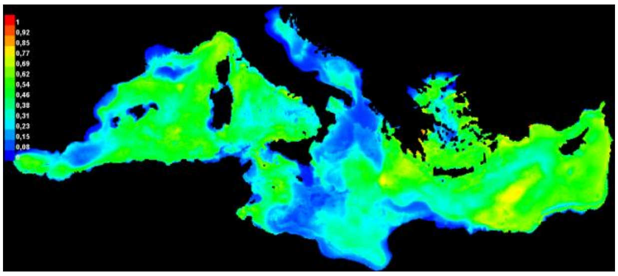
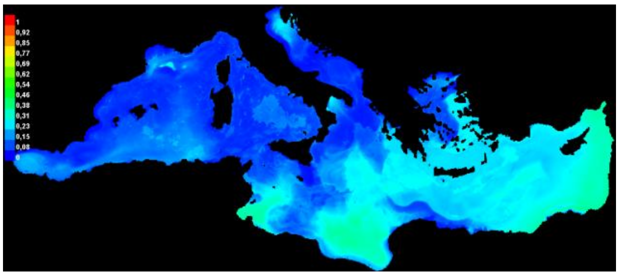
Figure 1.3.4. Species Distribution Model for *Stenella coeruleoalba* during the four seasons (WIN from January to March, SPR from April to June, SUM from July to September, AUT from October to December).

Table 1.3.8 - *Stenella coeruleoalba* environmental variable contribution: summary of PCA loadings and Maxent output for each environmental variable over the seasons, expressed as percentage contribution and permutation importance.

Variable	Winter				Spring				Summer				Autumn			
	PCA		SDM output		PCA		SDM output		PCA		SDM output		PCA		SDM output	
	PC1	PC2	% contrib	perm. imp	PC1	PC2	% contrib	perm. imp	PC1	PC2	% contrib	perm. imp	PC1	PC2	% contrib	per. imp
Bathy metry	-0.301	-0.124	26.1	23.4	-0.321	-0.025	37.3	24.1	0.283	-0.204	45.1	30.1	-0.318	-0.144	32.4	21.5
Chl_mean	0.044	0.395	24.3	19.3	0.245	0.422	7	2.6	-0.320	-0.296	5.8	9.4	-0.207	0.416	14.7	12.3
Chl_sd	0.155	0.235	/	/	0.289	0.272	/	/	-0.344	-0.191	/	/	-0.106	0.351	/	/
Curr.Dir	0.061	-0.265	/	/	-0.071	0.176	/	/	0.149	-0.065	/	/	0.073	-0.047	/	/
Curr.magn	-0.24	0.337	/	/	-0.159	0.454	/	/	-0.147	-0.391	/	/	-0.244	0.322	/	/
deltaT	-0.04	0.196	4.4	9	-0.005	0.32	2.1	2.8	-0.126	-0.348	1.9	2.6	0.100	0.273	5.4	3.7
Dist. canyons	0.22	0.25	7.7	6.2	0.23	-0.21	6.3	5.5	-0.17	0.182	2.1	2.2	0.155	0.121	2.7	3.4
Dist.coast	0.34	0.24	/	/	0.34	-0.100	/	/	-0.22	0.269	/	/	0.314	0.158	/	/
Dist.seamounts	0.206	0.083	7.8	16.1	0.16	-0.02	3.5	6.2	-0.13	0.03	5.2	9.2	0.21	0.10	5	4.1
Dist.shelf	0.333	0.275	6.3	8.5	0.349	-0.087	2.8	3.7	-0.300	0.263	3.3	8.6	0.31	0.19	4.6	6.2
EKE	-0.222	0.381	3.6	6.6	-0.137	0.429	2.8	2.6	-0.145	-0.42	3.1	3.7	-0.24	0.31	4.4	4.1
mlotst	0.274	-0.081	3.9	5.8	0.13	0.052	1.8	1.2	0.160	0.125	3.9	5.3	0.077	-0.35	3.3	6.5
Salinity	0.298	-0.32	3.2	4.1	0.199	-0.15	4.6	11.2	-0.041	0.31	17.2	10.1	0.330	-0.26	12.5	7.8
Slope	-0.179	-0.21	5.7	4.5	-0.220	0.14	3.9	3.7	0.237	-0.14	2.8	3.5	-0.148	-0.12	4.2	5.6
Temp_mean	-0.351	0.14	2.8	1.8	-0.32	-0.33	23.7	25.5	0.396	0.129	6.2	11.5	-0.222	-0.31	5.1	12
Temp_sd	-0.04	0.17	/	/	0.24	0.04	/	/	-0.309	0.173	/	/	0.347	0.14	/	/
zos	-0.36	0.02	4.2	4.8	-0.35	-0.03	4.1	10.8	0.32	-0.17	3.3	2.9	-0.38	-0.09	5.7	12.9

Seasonal patterns: **the spatial projection indicates that spatial distribution of suitable habitats slightly changes across seasons.** The wide distribution of **suitable habitat for *Stenella coeruleoalba* in pelagic waters is consistent across seasons**, with suitable areas spread throughout most of the Mediterranean (Figure 1.3.4).

MaxEnt models indicate that depth is the most significant environmental predictor, followed by chlorophyll, salinity, and temperature, with their impact varying across seasons (Table 1.3.7). Additionally, proximity to seamounts and canyons, as well as distance from the shelf and slope, contribute consistently across seasons, suggesting a **preference for topographically complex areas likely linked to prey availability**. **Chlorophyll** concentration has a notable contribution in **winter** (24.3%) and a moderate impact in other seasons. **Salinity** plays a crucial role during **summer** and **autumn**, indicating a preference for intermediate values typically found in frontal zones and water mass mixing. In **spring**, **temperature** becomes the most important dynamic predictor. During **winter**, static variables collectively account for 53.6% of the variability, while chlorophyll accounts for 24.3%. Over the entire observation period, habitat suitability increases with higher chlorophyll levels initially, but starts to decline after reaching a certain threshold. In **spring**, static variables account for 53.8% of the variability, with temperature being the most significant dynamic predictor (23.7%). There is a preference for temperatures up to 18°C, after which suitability decreases, and the contribution of chlorophyll is less significant in this season (7%). In **summer**, static variables account for 58.5% of the variability, with salinity being the most important dynamic variable (17.2%), followed by temperature (6.2%). Salinity response curves show an increased preference up to approximately 38.5, followed by a decrease. The temperature response curves are less linear and more complex. Similarly, in **autumn**, static variables account for 48.9% of the variability, with salinity (12.5%) and temperature (5.1%) identified as the most critical dynamic predictors for the season.

Habitats Directive Reporting periods *Stenella coeruleoalba*	
2008-2012 (AUC train=0.76, AUC test=0.70)	
Maxent - avg predictions	Maxent - std
	
2013-2018 (AUC train=0.75, AUC test=0.72)	
	

2019-2024
(AUC train=0.73, AUC test=0.70)

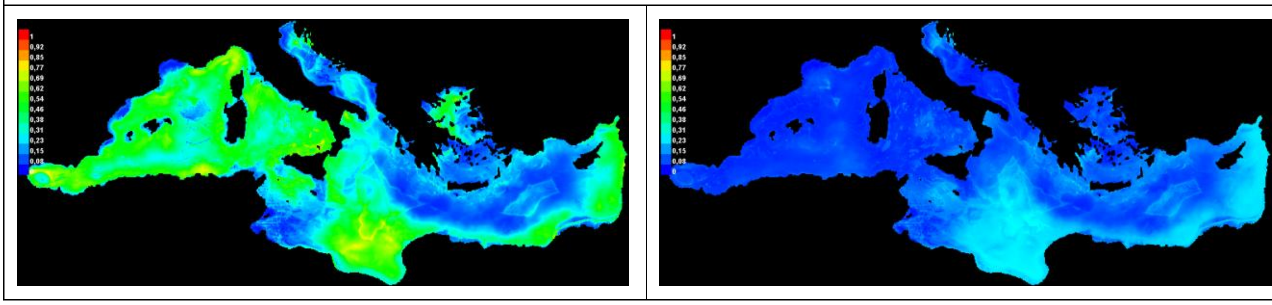


Figure 1.3.5. Species Distribution Model for *Stenella coeruleoalba* covering the three Habitat Directive reporting periods (2008-2012, 2013-2018, 2019-2024).

Table 1.3.9. *Stenella coeruleoalba* environmental variable contribution: summary of PCA loadings and Maxent output for each environmental variable over the reporting periods, expressed as percentage contribution and permutation importance.

Variable	2008-2012		2013-2018		2019-2024	
	SDM output		SDM output		SDM output	
	% contrib	perm. imp	% contrib	perm. imp	% contrib	perm. imp
Bathy metry	16.2	11.4	40.8	33	41.5	26.5
Chl_mean	3.2	3.7	14.5	10.1	3.5	7.7
Chl_sd	/	/	/	/	/	/
Curr.Dir	/	/	/	/	/	/
Curr.magn	/	/	/	/	/	/
deltaT	5.3	7.9	1.4	1.6	1.4	1.9
Dist. canyons	5.4	6.3	5.3	3.3	6.8	10.7
Dist.coast	/	/	/	/	/	/
Dist.seamoun ts	6.7	6.2	5.5	9.1	4.1	7.5
Dist.shelf	7.2	12.4	4.2	8.5	2.1	6.1
EKE	11.5	6.3	3.2	4.2	6.4	3.7
mlotst	20.2	5.5	9.5	7.3	1.4	4.1
Salinity	6.9	17.3	4.1	5.3	20	2.7
Slope	9.2	9.3	2.1	2.5	4.5	10.1
Temp_mean	/	/	/	/	/	/
Temp_sd	/	/	/	/	/	/
zos	5.4	9.6	4.1	6.9	2.8	6.1

Habitats Directive Reporting Periods: the range of suitable habitats became slightly more extended, suggesting a widespread of favorable conditions and possibly a larger ecological niche, potentially driven by changing oceanographic conditions. Throughout the three periods examined, the habitat suitability for *Stenella coeruleoalba* was consistently influenced by a combination of hydrographic, bathymetric, and productivity-related factors, although their relative importance changed over time. During the **first period (2008-2012)** the leading predictor of habitat suitability was thermocline depth (20.2%), followed by water depth (16.2%) and EKE (11.5%). This indicates the significant role of bathymetric and hydrographic gradients in determining habitat suitability. The model shows that suitable habitats are evenly distributed across all Mediterranean sub-basins, particularly in the Tyrrhenian Sea and Central Mediterranean. During the **second period (2013–2018)**, water depth became the top predictor (40.8%), followed by chlorophyll concentration (14.5%) and thermocline depth (9.5%). Suitable habitats remain evenly distributed throughout the entire Mediterranean Sea extending towards west. During the **third period (2019–2024)**, water depth was confirmed as the most important predictor (41.5%), while salinity (20%) also influenced habitat suitability, along with EKE (6.4%). The impact of productivity and thermal variables decreased.

Suitable habitat for *Balaenoptera physalus*

Balaenoptera physalus consistently prefers deep, cold, productive, and dynamic offshore areas, especially in regions with complex topography like the northwestern Mediterranean and central Tyrrhenian Sea, where major upwelling phenomena take place. While habitat suitability shifts slightly with the seasons, most key areas remain stable over time.

Summary of Habitat Suitability for *Balaenoptera physalus* *Balaenoptera physalus* consistently selects cold, productive pelagic habitats across the Mediterranean Sea, especially in the northwestern basin, with strong habitat suitability in the Corso-Ligurian-Provencal Basin and the central Tyrrhenian Sea. These areas, marked by high productivity, dynamic oceanographic processes, and complex bathymetry, offer favorable foraging conditions year-round.

The SDM results highlight bathymetry as the most influential variable, with preference for intermediate to deep waters, often near seamounts and far from the continental slope. Additional key predictors include moderate sea surface temperature, chlorophyll concentration, salinity, and EKE, indicating a reliance on upwelling zones and frontal systems associated with krill aggregations. PCA results confirm that *Balaenoptera physalus* distribution spans a broad environmental gradient, ranging from deep, cold, productive offshore waters to more thermally stable shelf environments. This variability underscores the species' high ecological plasticity and ability to track prey in diverse oceanographic contexts.

Seasonal Patterns: While the core suitable areas remain stable across seasons, habitat suitability varies slightly in spatial extent and environmental drivers.

- **Winter:** High importance of chlorophyll and thermal variability highlights a reliance on productive, dynamic areas.
- **Spring:** Suitable habitat including the large portion of the medium latitudes of the western Mediterranean. Bathymetry and chlorophyll drive suitability, especially near seamounts and frontal zones.
- **Summer:** Suitable habitat confined to the northern portion of the western Mediterranean and Corso-Ligurian-Provencal basin, especially the Pelagos Sanctuary. Bathymetry dominates, with sea surface height and sea surface temperature variability indicating a preference for stratified, dynamic waters.
- **Autumn:** Broader habitat suitability expanding towards more southern latitudes across the western Mediterranean, with increased importance of bathymetry, EKE, and sSST.

Habitat Directive Reporting Periods (2008–2024): The northwestern Mediterranean consistently emerged as a key habitat across all three reporting periods, although the spatial extent of suitable areas progressively contracted.

- **2008–2012:** Broad distribution across the western Mediterranean, with salinity, distance to canyons, and sea temperature variability as primary predictors.

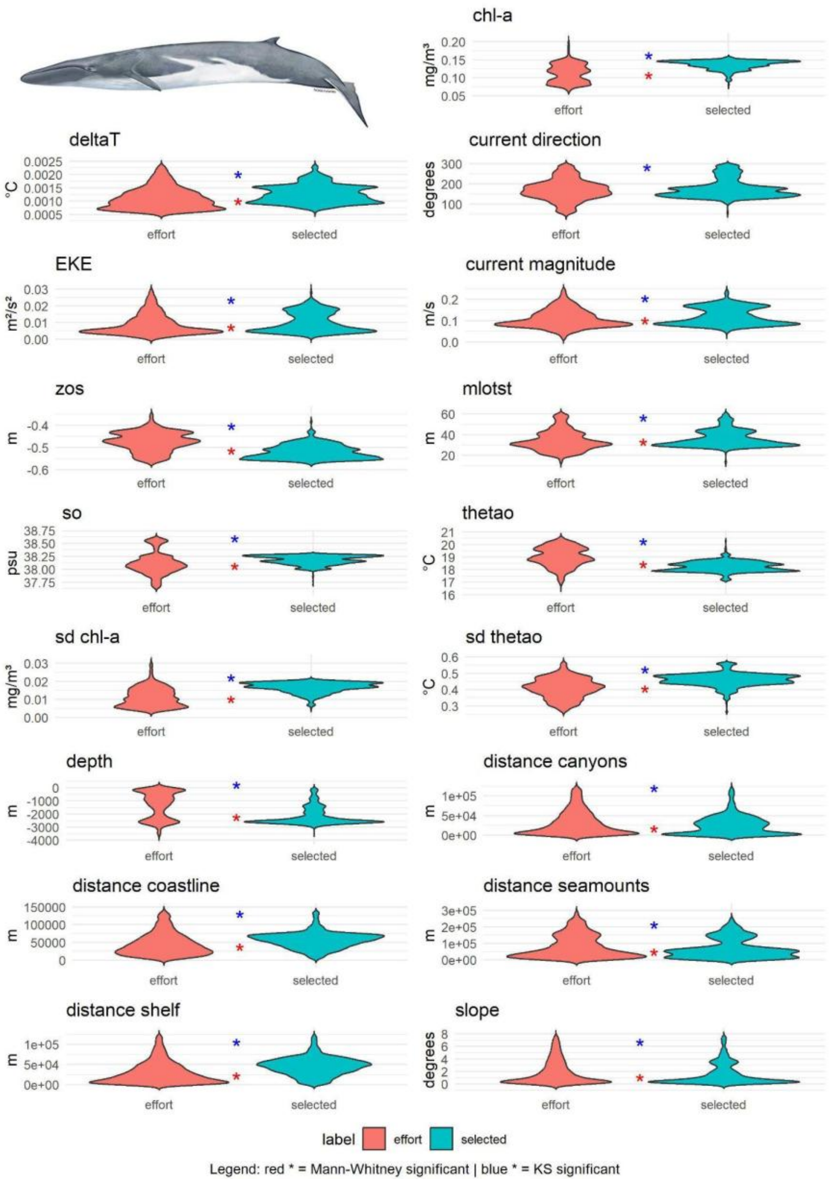
- **2013–2018:** Suitability became more restricted to the northwestern Mediterranean and central Tyrrhenian Sea. Sea surface height (zos) became the most influential variable, highlighting mesoscale processes.

- **2019–2024:** Habitat further contracted, with sea temperature variability becoming the dominant predictor. Salinity, depth, and chlorophyll also gained relevance, indicating a possible shift toward greater dependence on biologically productive areas

Policy Implications for *Balaenoptera physalus* Conservation:

1. **Reinforce Protection in Core Offshore Habitats**: The northwestern Mediterranean, especially the Corso-Ligurian-Provencal Basin and central Tyrrhenian Sea, remains consistently critical year-round. These areas should be prioritized for strict protection.
2. **Safeguard Key Oceanographic Features**: Conservation efforts should focus on preserving upwelling zones, seamounts, and frontal systems that support krill aggregations and fin whale foraging.
3. **Enhance Monitoring in the Face of Habitat Contraction**: The observed reduction in suitable habitat from 2008 to 2024 suggests potential vulnerability to climate-driven oceanographic shifts. Strengthening long-term monitoring of sea surface variability, chlorophyll, and EKE is essential to anticipate changes in whale distribution.
4. **Prioritize Dynamic and Seasonal Management**: While core areas are stable, seasonal shifts in habitat extent and drivers call for flexible, adaptive management strategies that adjust protection efforts according to seasonal oceanographic conditions.
5. **Promote Transboundary Collaboration**: Given the pelagic, wide-ranging nature of *Balaenoptera physalus*, coordinated conservation strategies across Mediterranean nations are vital to ensure connectivity and effective protection throughout its migratory range.

1) **Habitat Selection of *Balaenoptera physalus*.** Comparison between selected environmental variable range at present locations and available range of values across the effort area.

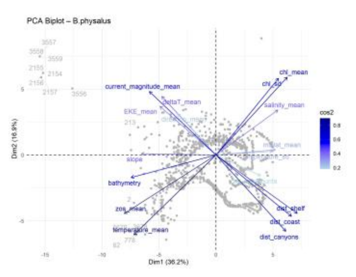
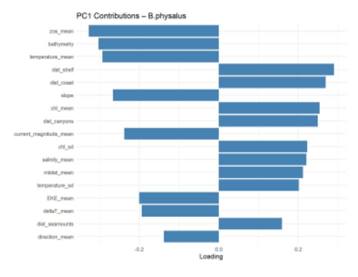
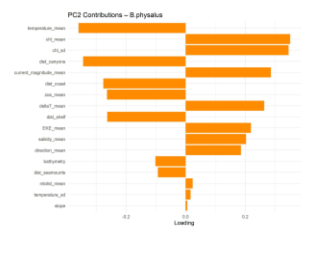
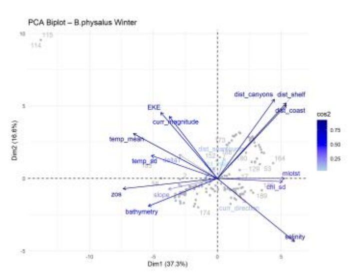
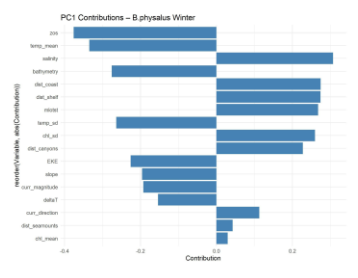
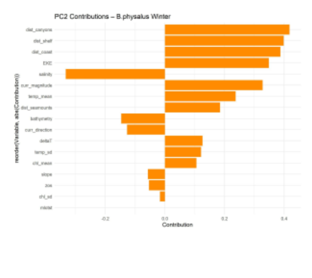
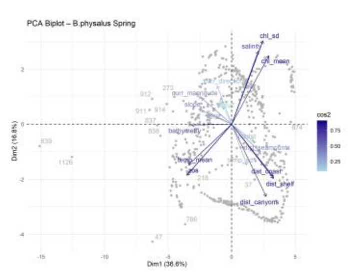
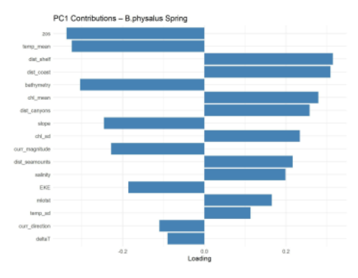
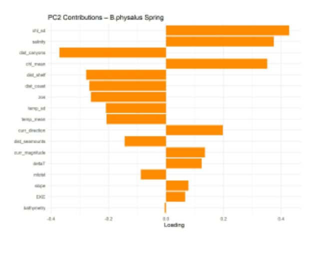
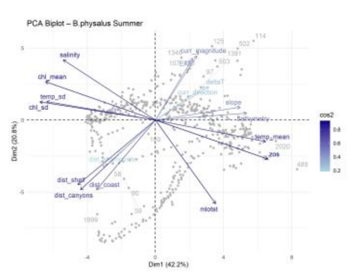
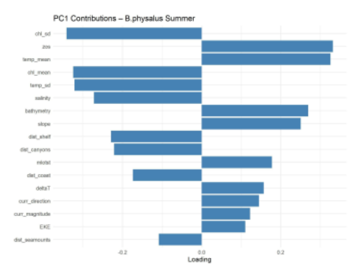
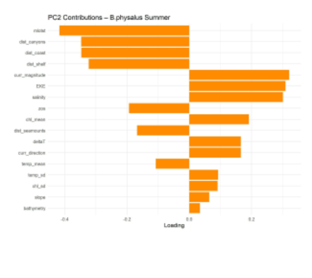
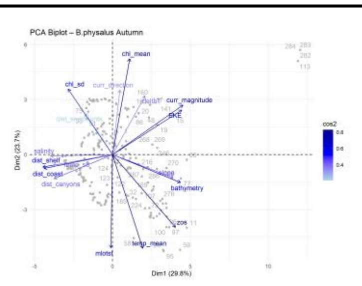
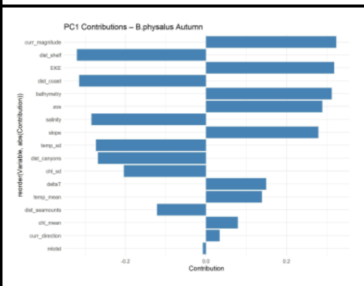
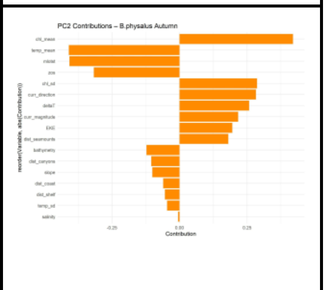


Summary:
Balaenoptera physalus tends to occupy deeper, offshore waters farther from the coastline and the continental shelf, favouring areas with medium values of temperature and chl-a concentration and avoiding highly turbulent waters.

Figure 1.3.6. Habitat selection of *Balaenoptera physalus*. Distribution of environmental variable values at presence locations (left, red violin plots) and available range of values across the effort area (right, blue violin plots).

2) **Principal Component Analysis (PCA) of *Balaenoptera physalus***

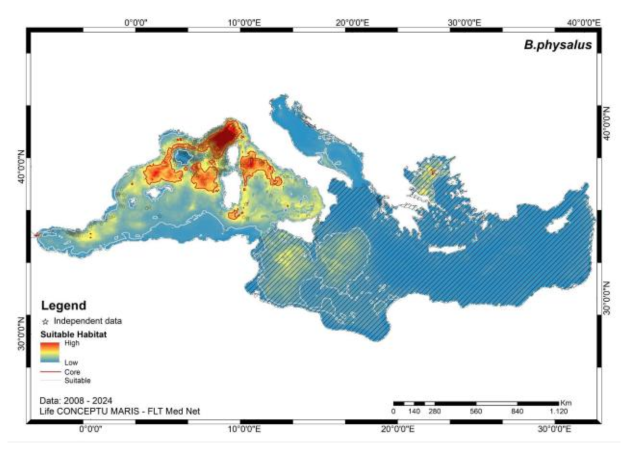
Table 1.3.10. *Balaenoptera physalus* PCA Biplot and Barplot of PC1 (blue) and PC2 (orange) loadings for different temporal resolutions.

Temporal res	Biplot	Loadings PC1	Loadings PC2
Entire period 53.1% explained variance			
Winter 53.9% explained variance			
Spring 53.4% explained variance			
Summer 63% explained variance			
Autumn 53.5% explained variance			

Overall, *Balaenoptera physalus* selects for **cold, productive pelagic habitats, often over deep seafloors, characterized by high chlorophyll concentrations and thermally stable water, indicative of upwelling foraging areas**. Across all seasons, *Balaenoptera physalus* distribution reflects a strong gradient between deep, cold, productive offshore habitats and warmer, more stable shelf regions, with seasonal shifts suggesting a strategy aligned with krill availability in areas influenced by vertical mixing and dynamic ocean features. In **winter**, *Balaenoptera physalus* is associated with deep, dynamic environments with strong physical gradients, like supporting prey aggregation in colder months. In **spring** it seems to use coastal-shelf transition zones, where increased productivity and variable salinity may indicate seasonal peaks in prey availability. During **summer** *Balaenoptera physalus* shows a clear preference for offshore habitats, influenced by ocean dynamics and subsurface productivity. In **autumn**, *Balaenoptera physalus* likely exploits energetic shelf-edge systems, where currents and vertical mixing prevail; the role of mixed layer depth suggests shifts in prey depth distribution to seasonal turnover.

3) ***Balaenoptera physalus* Species Distribution Model**

Entire period SDM *Balaenoptera physalus* (AUC train=0.88, AUC test=0.80)	
Maxent - avg predictions	Maxent - std



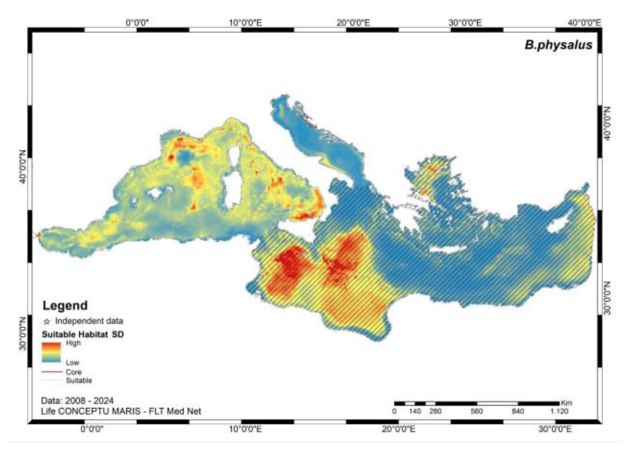


Figure 1.3.7. Species Distribution Model for *Balaenoptera physalus* covering the entire period from 2008 to 2024.

Table 1.3.11. Validation results of the Species Distribution Model for *Balaenoptera physalus* using an independent dataset, both within the LIFE CONCEPTU MARIS project area (Western Mediterranean and Adriatic regions) and across the entire Mediterranean basin.

External validation with independent dataset	**W Med + Adriatic**		**Mediterranean Sea**	
	Maximum test sensitivity plus specificity Logistic threshold	Natural jenks threshold	Maximum test sensitivity plus specificity Logistic threshold	Natural jenks threshold
AUC	0.86	0.86	0.93	0.92
Precision	0.85	0.57	0.94	0.68
F1	0.74	0.72	0.76	0.80

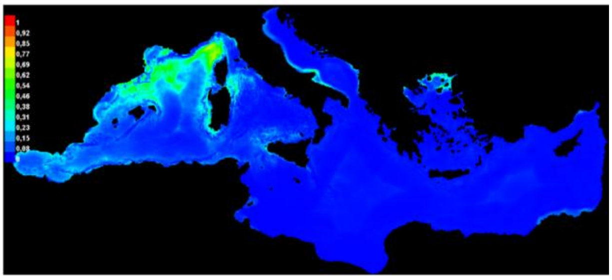
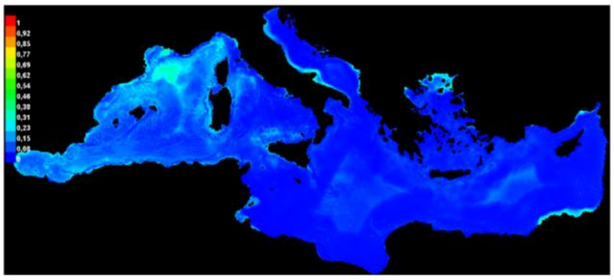
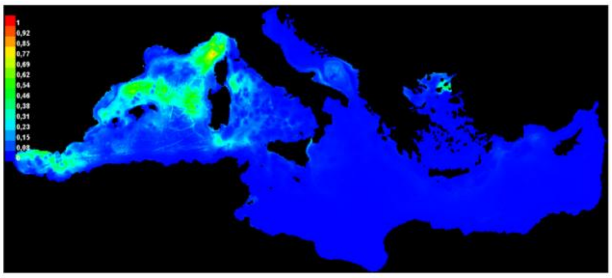
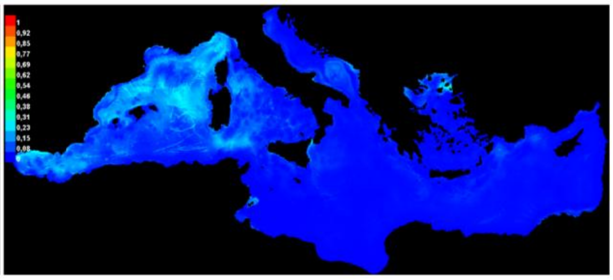
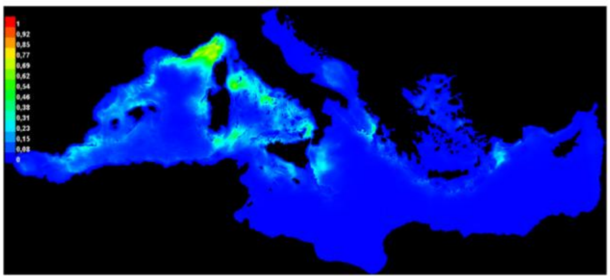
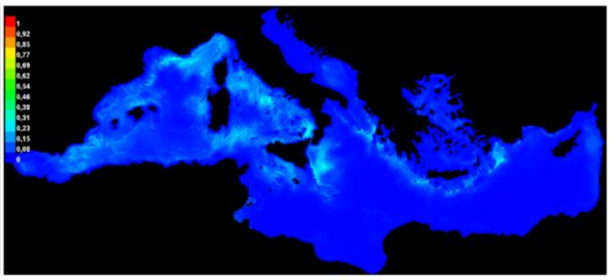
Table 1.3.12. Summary of PCA loadings and Maxent output for each environmental variable over the entire period, expressed as percentage contribution and permutation importance.

Entire period				
Variable	PCA		SDM output	
	PC1	PC2	% contrib	per. imp
Bathymetry	-0.303	-0.101	19.2	8.2
Chl_mean	0.254	0.351	7.2	2.7
Chl_sd	0.223	0.346	5.3	8.2
Curr.direction	-0.138	0.186	NA	NA
Curr.magnitude	-0.238	0.286	NA	NA
deltaT	-0.194	0.264	NA	NA
Dist. canyons	0.249	-0.344	3.3	5.6
Dist.coast	0.269	-0.276	4.9	9
Dist.seamounts	0.159	-0.093	12	14.7
Dist.shelf	0.290	-0.263	NA	NA
EKE	-0.200	0.219	7	9.6
mlotst	0.212	0.024	6.5	7.9
Salinity	0.220	0.203	11.6	11.1
Slope	-0.266	0.006	3.1	6.5
Temp_mean	-0.293	-0.359	12.4	11.9
Temp_sd	0.201	0.017	2	2.3
zos	-0.327	-0.264	5.6	2.3

Entire period: spatial predictions highlight high suitability in the northwestern Mediterranean, particularly around the Corso Ligurian Provencal basin and the central Tyrrhenian Sea.

The SDM for *Balaenoptera physalus* was **well validated** by the independent dataset, both within the LIFE CONCEPTU MARIS project areas (western Mediterranean and Adriatic regions) and at the broader Mediterranean basin level (Table 1.3.7).

Over the entire period, *Balaenoptera physalus* tends to occupy **deep pelagic waters, particularly in areas influenced by upwelling systems, far from the continental slope**. The model reveals that bathymetric and physical oceanographic features are the most influential predictors of habitat suitability for the species. Specifically, **bathymetry** was the top contributing variable (19.2%) with a preference for intermediate depths. Temperature also played an important role, with a preference for moderate values. Proximity to seamounts was another important factor, reinforcing the role of topographic complexity in shaping fin whale distribution. Salinity also contributes meaningfully, with a peak of suitability at intermediate values. Other notable variables include chlorophyll concentration and EKE, both pointing to the **importance of productivity and dynamic oceanographic features in defining the habitat for the species**.

<table>
<tr><th colspan="2">Seasonal SMD Balaenoptera physalus</th></tr>
<tr><td>Maxent - avg predictions</td><td>Maxent - std</td></tr>
<tr><td colspan="2">WINTER
(AUC train=0.96, AUC test=0.83)</td></tr>
<tr><td></td><td></td></tr>
<tr><td colspan="2">SPRING
(AUC train=0.94, AUC test=0.85)</td></tr>
<tr><td></td><td></td></tr>
<tr><td colspan="2">SUMMER
(AUC train=0.93, AUC test=0.86)</td></tr>
<tr><td></td><td></td></tr>
</table>

AUTUMN
(AUC train=0.93, AUC test=0.83)

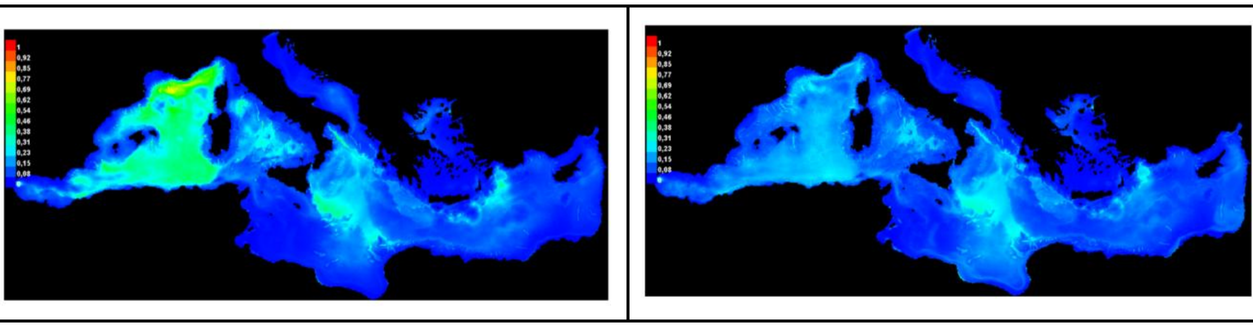
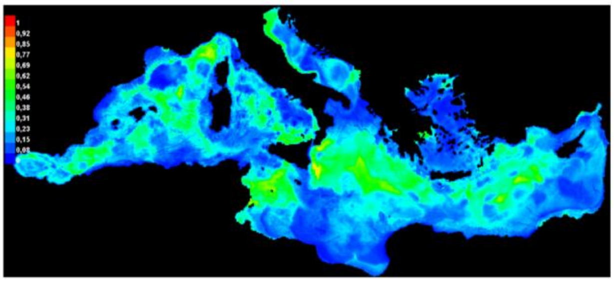
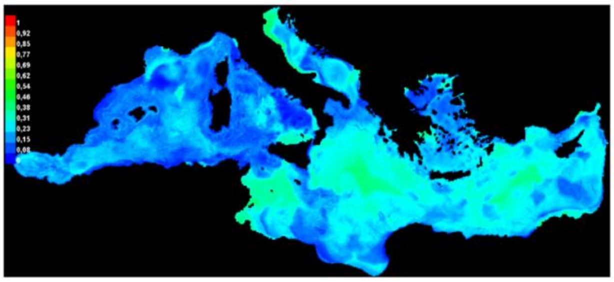
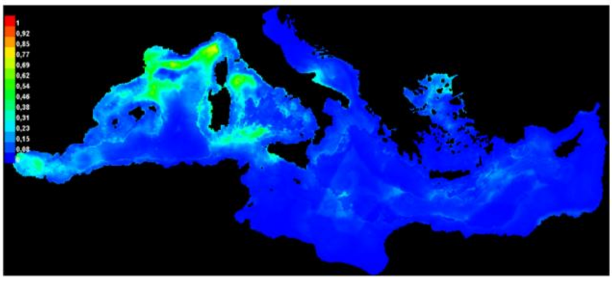
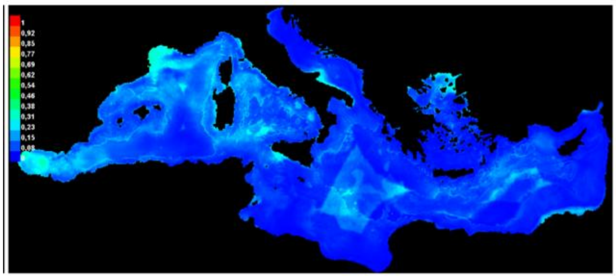


Figure 1.3.8. Species Distribution Model for *Balaenoptera physalus* during the four seasons (WIN from January to March, SPR from April to June, SUM from July to September, AUT from October to December).

Table 1.3.13. *Balaenoptera physalus* environmental variable contribution: summary of PCA loadings and Maxent output for each environmental variable over the seasons, expressed as percentage contribution and permutation importance.

	Winter				Spring				Summer				Autumn			
Variable	PCA		SDM output		PCA		SDM output		PCA		SDM output		PCA		SDM output	
	PC1	PC2	% contrib	perm. imp	PC1	PC2	% contrib	perm. imp	PC1	PC2	% contrib	perm. imp	PC1	PC2	% contrib	per. imp
Bathy metry	-0.276	-0.146	5.2	3.9	-0.304	-0.005	16	10.3	0.270	0.034	23	15.2	0.312	-0.122	32.6	39.3
Chl_mean	0.030	0.106	24.1	31.4	0.279	0.352	15.8	10.7	-0.325	0.191	2.3	6.8	0.079	0.419	1.4	1.5
Chl_sd	0.260	-0.017	8.2	5.3	0.234	0.428	10.7	2.5	-0.342	0.091	0.9	2.5	-0.204	0.287	6.6	12.2
Curr.Dir	0.113	-0.127	NA	NA	-0.110	0.197	NA	NA	0.145	0.166	NA	NA	0.034	0.282	NA	NA
Curr.magn	-0.192	0.328	NA	NA	-0.228	0.135	NA	NA	0.122	0.321	NA	NA	0.323	0.217	NA	NA
deltaT	-0.154	0.126	NA	NA	-0.090	0.124	NA	NA	0.157	0.166	NA	NA	0.150	0.257	NA	NA
Dist. canyons	0.228	0.418	8.5	4.9	0.258	-0.371	5.1	2.5	-0.222	-0.347	4.8	8	-0.268	-0.105	5.2	4.7
Dist.coast	0.274	0.388	5.2	8	0.309	-0.267	6	6.5	-0.174	-0.347	3.3	3.4	-0.315	-0.061	2.1	3.5
Dist.seamounts	0.043	0.185	4.1	5.1	0.216	-0.144	12.4	19	-0.108	-0.168	11.3	10.9	-0.122	0.180	3.5	5.3
Dist.shelf	0.274	0.399	NA	NA	0.315	-0.278	NA	NA	-0.229	-0.323	NA	NA	-0.320	-0.054	NA	NA
EKE	-0.226	0.349	8.5	9.1	-0.186	0.066	10.5	7.1	0.110	0.309	7.4	5.8	0.318	0.195	13.8	8.4
mlotst	0.268	0.000	1.5	2.4	0.165	-0.088	4	8.7	0.178	-0.417	9.3	8.5	-0.008	-0.407	2.6	2.2
Salinity	0.307	-0.333	0.4	2.4	0.199	0.375	0.4	0.6	-0.272	0.301	2.1	0.8	-0.284	-0.006	1	4.6
Slope	-0.196	-0.057	6	14.5	-0.246	0.078	4.9	9.3	0.251	0.064	4.2	4.7	0.279	-0.101	2.4	2.7
Temp_mean	-0.335	0.237	8	5.1	-0.325	-0.207	3.7	10.4	0.326	-0.108	1.5	4	0.139	-0.409	8.4	1.7
Temp_sd	-0.264	0.121	11	5.3	0.113	-0.209	6.3	8.6	-0.322	0.092	12.6	23.9	-0.273	-0.046	3.8	5.1
zos	-0.376	-0.054	9.4	2.5	-0.338	-0.261	4.1	3.9	0.332	-0.194	17.4	5.6	23.90.289	-0.317	16.5	8.8

Seasonal patterns: *Balaenoptera physalus* habitat suitability is consistently shaped by a combination of productivity, dynamic oceanographic processes, and topographic complexity across all seasons. Core suitable areas are repeatedly identified in the Corso-Ligurian-Provencal Basin and the central Tyrrhenian Sea, regions characterized by high productivity, strong oceanographic dynamics, and complex bathymetry. In **winter**, chlorophyll concentration and thermal variability are key predictors, highlighting the species' association with productive, dynamic environments. During **spring**, bathymetry and chlorophyll remain the primary drivers, indicating a preference for moderately deep waters near seamounts and frontal zones. The suitable range includes a large portion of the intermediate latitudes of the western Mediterranean. In **summer**, bathymetry continues to dominate, with sea surface height (zos) and sea surface temperature variability reflecting a selection for stratified and dynamic areas. The suitable habitat is extremely confined to the northern portions within the Corso-Ligurian-Provecal basin. In **autumn**, bathymetry gains even more influence, alongside zos, EKE, and temperature, suggesting a preference for intermediate-depth habitats influenced by both topographic and hydrographic features. Suitable habitats expand to include the Balearic and Sardinian Seas, suggesting a seasonal shift with a range extension.

Habitat Directive Reporting periods *Balaenoptera physalus*	
Maxent - avg predictions	Maxent - std
2008-2012 (AUC train=0.92, AUC test=0.80)	
	
2013-2018 (AUC train=0.92, AUC test=0.81)	
	

2019-2024
(AUC train=0.91, AUC test=0.83)

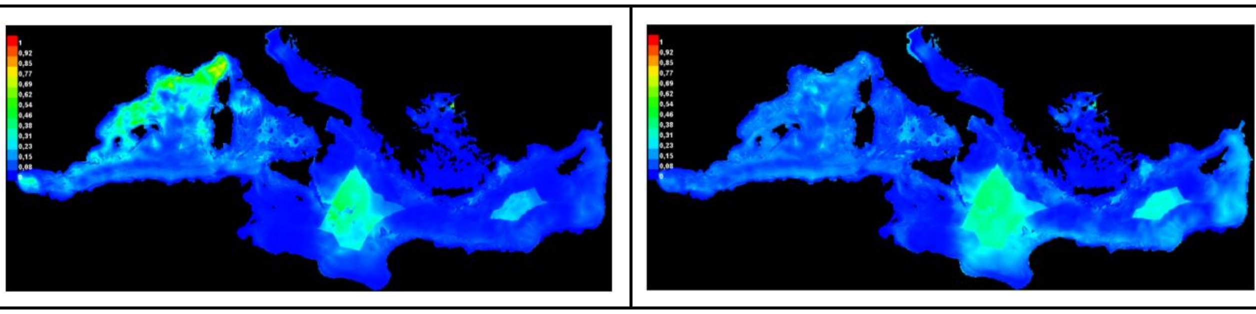


Figure 1.3.9. Species Distribution Model for *Balaenoptera physalus* covering the three Habitat Directive reporting periods (2008-2012, 2013-2018, 2019-2024).

Table 1.3.14. *Balaenoptera physalus* environmental variable contribution: summary of PCA loadings and Maxent output for each environmental variable over the reporting periods, expressed as percentage contribution and permutation importance.

	2008-2012		2013-2018		2019-2024	
Variable	SDM output		SDM output		SDM output	
	% contrib	perm. imp	% contrib	perm. imp	% contrib	perm. imp
Bathy metry	8.5	13.4	14.3	12.3	14.4	4.4
Chl_mean	3.4	4	3.4	2.5	9.1	6.9
Chl_sd	6.4	6.8	9.5	2.3	1.5	2.9
Curr.Dir	NA	NA	NA	NA	NA	NA
Curr.magn	NA	NA	NA	NA	NA	NA
deltaT	NA	NA	NA	NA	NA	NA
Dist. canyons	15.9	8.8	11.1	13.2	6.1	8.4
Dist.coast	4.6	6.5	6.8	6.9	4.7	6.5
Dist.seam ounts	8	5.5	9.9	8.7	5.9	5
Dist.shelf	NA	NA	NA	NA	NA	NA
EKE	6.3	4.6	6.1	5.5	7.1	7.5
mlotst	3.9	18.5	3.5	7.1	2.6	8.8
Salinity	17	2.1	0.7	2.7	14.8	3.2
Slope	6	11.4	3.2	5.6	4	6.4
Temp_me an	5	6.3	8.6	24.6	2.4	10.4
Temp_sd	13.6	9.9	5	3.8	19	24
zos	1.6	2.1	18	4.8	8.5	5.6

Habitats Directive Reporting Periods: the consistent importance of the northwestern Mediterranean Sea as a key habitat for *Balaenoptera physalus* was confirmed across all three reporting periods, although a progressive spatial contraction of suitable areas was observed over time. Habitat suitability was shaped by a combination of oceanographic and bathymetric variables, though the relative influence of these factors shifted between periods. In the **first period**, suitable habitats were broadly distributed across the western Mediterranean Sea. The primary predictors were salinity, distance to canyons, and sea temperature variability. Higher salinity and moderate thermal variability were associated with increased probability of fin whale presence, with the Ligurian Sea identified as the most suitable area. During the **second period**, habitat suitability became more spatially restricted, with high-probability areas concentrated in the northwestern Mediterranean Sea, although the central Tyrrhenian Sea remained relevant. Mean sea surface height (zos) emerged as the most influential predictor, highlighting the growing role of mesoscale oceanographic processes. Bathymetric complexity remained important, while mean temperature and chlorophyll variability also increased in influence. In the **third period**, suitable habitats became more confined to the northwestern sector of the western Mediterranean Sea. Sea temperature variability became the dominant predictor, indicating a preference for areas with moderate to high thermal dynamics. Salinity and depth continued to play key roles, while the contribution of mean chlorophyll concentration increased, suggesting a possible shift toward greater reliance on biologically productive regions.

Suitable Habitat for *Tursiops truncatus*

Tursiops truncatus exhibits seasonal plasticity in habitat use, combined with spatial consistency in its ecological preferences. The species favours dynamic environments, primarily coastal and shelf areas with specific depth ranges, temperature variability, and productivity levels. The convergence of results from statistical comparisons, PCA, and SDMs enhances the reliability of the findings and provides a robust basis for spatial conservation planning.

Summary of Habitat Suitability for *Tursiops truncatus.* The integrated niche analysis and SDM results revealed consistent ecological patterns for *Tursiops truncatus* across the study area. The comparison between environmental conditions at presence locations and those available in the study area showed statistically significant differences for several variables suggesting active habitat selection. Violin plots and non-parametric tests indicated that occurrences are concentrated in areas with intermediate depth, proximity to the coast and moderate levels of temperature and chlorophyll.

Maxent models, applied across multiple temporal resolutions, confirmed a stable preference for coastal waters. The contribution of environmental variables to the models aligned with PCA outputs: bathymetry, distance to coast, temperature_sd, and chl_mean emerged as the most influential predictors, both in terms of percent contribution and permutation importance. Salinity also emerged as a contributing factor, particularly in spring and summer, suggesting that this variable may play a secondary but meaningful role in shaping habitat suitability, possibly in relation to freshwater inputs or oceanographic fronts.

Key stable areas have been evidenced such as the Alboran Sea, the Balearic Islands, the Tunisian shelf and the Adriatic Sea

Seasonal Patterns:

Habitat suitability showed clear seasonal dynamics, expanding in spring and summer and contracting in autumn and winter. Spring and summer distributions highlighted key coastal hotspots such as the Alboran Sea, Balearic Islands, Tuscan Archipelago, and Northern Tyrrhenian Sea. Winter suitability was highest in more sheltered areas, including coastal Tunisia, the Northern Adriatic, and the western Alboran Sea. Core environmental predictors remained stable across seasons, with bathymetry and distance to coast consistently important, although the role of chlorophyll-a declined in winter.

Habitat Directive Reporting Periods (2008–2024):

Predicted habitat suitability varied across reporting periods, reflecting potential temporal trends in spatial use by *Tursiops truncatus*. The second period (2013–2018) was characterized by a more coastal and restricted distribution, while the third period (2019–2024) showed a broader use of offshore areas. Key environmental drivers such as bathymetry, coastal proximity, sea surface variability, and moderate productivity remained consistent across all periods.

Policy Brief: Habitat Suitability of the Bottlenose Dolphin (*Tursiops truncatus*) in the Mediterranean Sea

Key Findings:

- **Consistent Coastal Preference**: *Tursiops truncatus* shows a strong and stable preference for coastal and continental shelf areas across seasons and years, especially regions with moderate depth, sea surface temperature variability, and productivity.
- **Seasonal Habitat Dynamics**: Dolphin distribution expands in **spring and summer**, concentrating around the **Alboran Sea, Balearic Islands, Tuscan Archipelago**, and **Northern Tyrrhenian Sea**, while in **autumn and winter**, it contracts to **more sheltered**

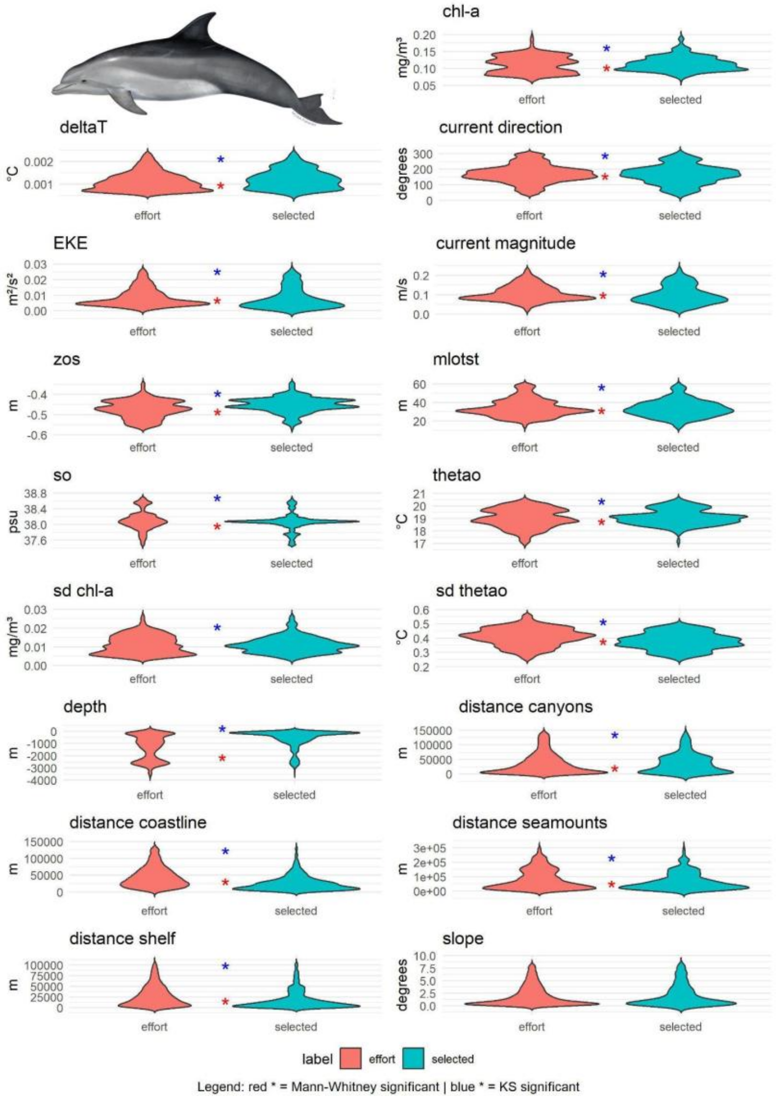
coastal areas, such as **Tunisia and the Northern Adriatic**.

- **Ecological Predictors**: The most influential environmental variables determining suitable habitat are:
    - **Bathymetry** (depth),
    - **Distance to coast**,
    - **Temperature variability**,
    - **Chlorophyll-a levels** (productivity),
    - **Salinity**, particularly relevant in spring/summer.
- **Temporal Trends (2008–2024)**:
    - During 2013–2018, dolphins used **more restricted coastal areas**.
    - From 2019–2024, models suggest **broader offshore use**, possibly indicating ecological shifts or increased mobility.

Implications for Policy and Conservation:

- **Protect Coastal Hotspots**: Consistently used areas like the **Alboran Sea, Balearic Islands, Tunisian shelf, and Adriatic Sea** should be prioritized for conservation and included in marine spatial planning and protected area design.
- **Incorporate Seasonal Variability**: Management strategies must account for **seasonal shifts** in habitat use to ensure year-round protection.
- **Monitor Environmental Change**: Long-term monitoring of key environmental drivers is critical to anticipate future changes in dolphin distribution linked to climate change and human activity.
- **Support EU Habitat Directive Goals**: These insights directly support reporting and planning obligations under the **EU Habitats Directive**, contributing to improved management of Annex II species.

1) Habitat Selection of *Tursiops truncatus*. Comparison between selected environmental variable range at present locations and available range of values across the effort area.



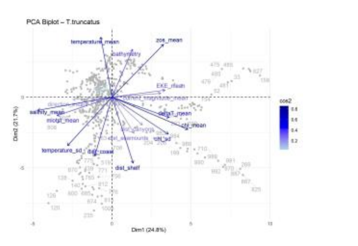
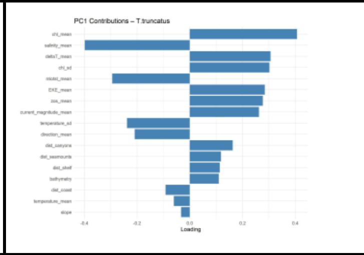
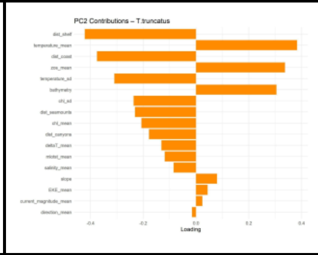
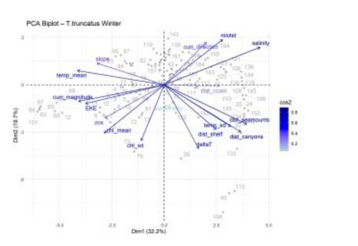
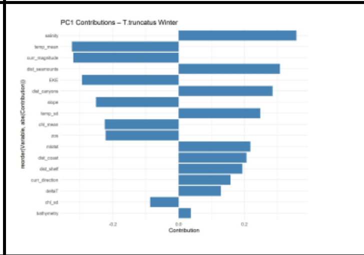
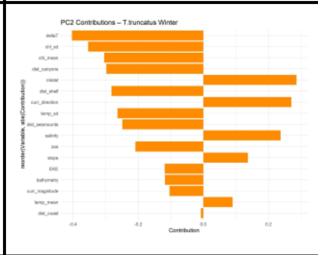
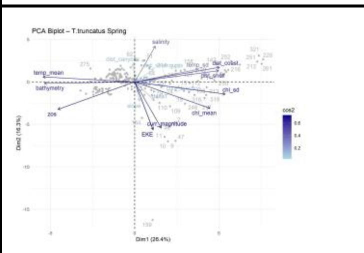
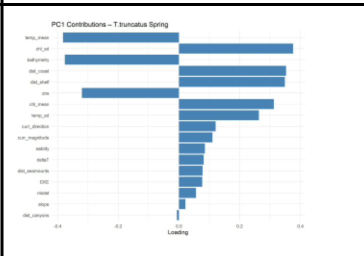
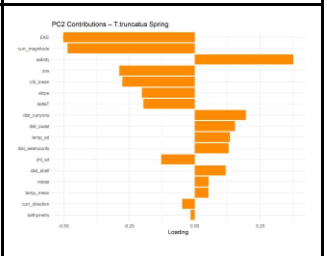
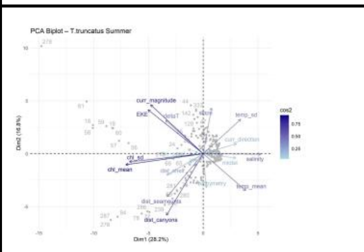
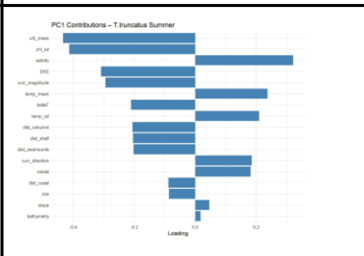
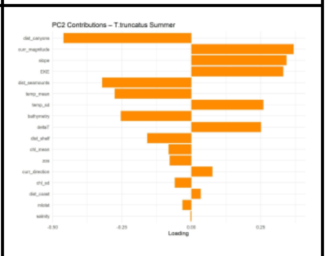
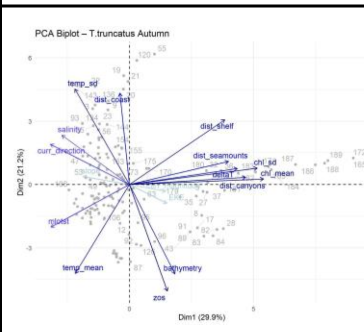
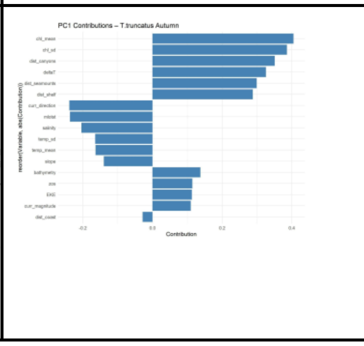
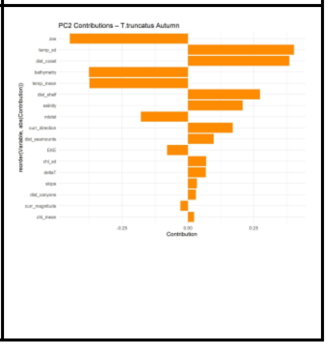
Summary:

Several environmental variables differ significantly at the locations of *Tursiops truncatus* sightings compared to the background environmental conditions within the surveyed area, indicating active habitat selection. Violin plots and non-parametric tests (Mann-Whitney and Kolmogorov-Smirnov) confirmed statistically significant differences between presence locations and available habitat, with occurrences concentrated in areas of intermediate depth, coastal proximity, and moderate levels of temperature and chlorophyll.

Figure 1.3.10. Habitat selection of *Tursiops truncatus*. Distribution of environmental variable values at presence locations (left, red violin plots) and available range of values across the effort area (right, blue violin plots). Include Mann-Whitney U and Kolmogorov–Smirnov tests.

2) Principal Component Analysis (PCA) of *Tursiops truncatus*

Table 1.3.15. *Tursiops truncatus* PCA Biplot and Barplot of PC1 (blue) and PC2 (orange) loadings for different temporal resolutions.

Temporal res	Biplot	Loadings PC1	Loadings PC2
Entire period 46.5% explained variance			
Winter 51.9% explained variance			
Spring 42.7% explained variance			
Summer 45% explained variance			
Autumn 51.1% explained variance			

Over the entire period, *Tursiops truncatus* distribution is driven by salinity, surface productivity, thermal structure and mixed layer depth. Dynamic features such as sea surface height, EKE and current strength also play an important role, particularly in shaping prey accessibility. **Across all seasons, bottlenose dolphins respond to an ecological gradient between structured coastal and shelf-associated zones and more dynamic, productive waters, shaped by salinity, thermal variability, and current activity, likely tracking prey in frontal and mixed environments.** In **winter**, the species is linked to salinity, temperature and current-related variables, as well as to complex bathymetric features like slopes, canyons and seamounts. These conditions suggest use of shelf-edge and upper slope habitats, where physical structure and water mass properties help retain prey during less productive months. In **spring**, *Tursiops truncatus* frequents transitional coastal habitats influenced by seasonal stratification and mixing. Key drivers include temperature, bathymetry, chlorophyll concentration and dynamic features such as current strength and salinity, which support prey availability near the surface. **Summer** habitat use reflects an association with energetic and productive coastal zones, particularly near canyons and shelf edges. Salinity, productivity, and temperature gradients indicate foraging along areas where prey may be aggregated by currents and small-scale instabilities. In **autumn**, distribution shifts toward shelf-slope systems characterized by post-stratification dynamics. Productivity gradients, topographic complexity, and vertical thermal structure likely facilitate nutrient fluxes and prey redistribution in coastal and frontal zones.

3) Tursiops truncatus Species Distribution Model.

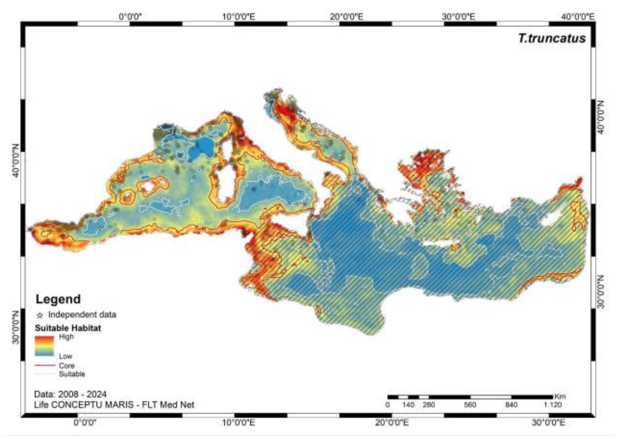
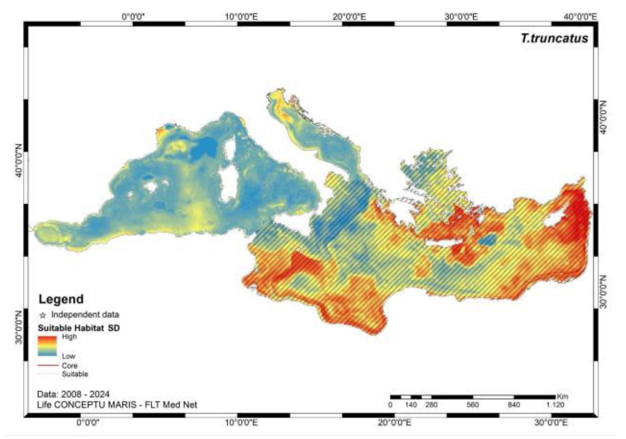
Entire period SDM *Tursiops truncatus* (AUC train=0.80, AUC test=0.76)	
Maxent - avg predictions	Maxent - std
	

Figure 1.3.11. Species Distribution Model for *Tursiops truncatus* covering the entire period from 2008 to 2024.

Table 1.3.16. Validation results of the Species Distribution Model for *Tursiops truncatus* using an independent dataset, both within the LIFE CONCEPTU MARIS project area (Western Mediterranean and Adriatic regions) and across the entire Mediterranean basin.

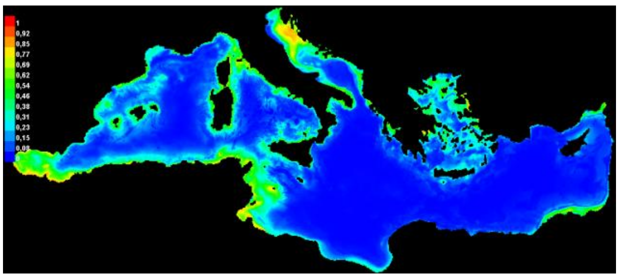
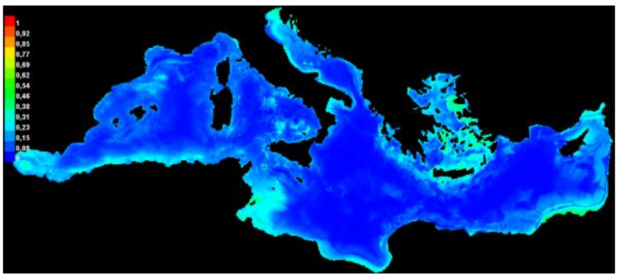
External validation with independent threshold	**W Med + Adriatic**		**Mediterranean Sea**	
	Maximum test sensitivity plus specificity Logistic threshold	Natural jenks threshold	Maximum test sensitivity plus specificity Logistic threshold	Natural jenks threshold
AUC	0.76	0.75	0.81	0.81
Precision	0.72	0.53	0.79	0.57
F1	0.70	0.68	0.73	0.71

Table 1.3.17. *Tursiops truncatus* environmental variable contribution: summary of PCA loadings and Maxent output for each environmental variable over the entire period, expressed as percentage contribution and permutation importance. Top 3 values in each column are in bold.

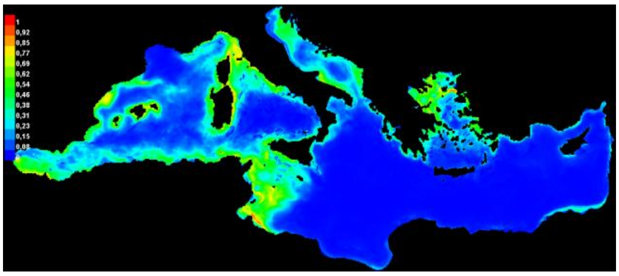
Entire period				
Variable	PCA		SDM output	
	PC1	PC2	% contrib	per. imp
Bathymetry	0.110	0.305	28.9	8.9
Chl_mean	0.406	-0.207	9.4	6.8
Chl_sd	0.302	-0.237	6.4	7.9
Curr.direction	-0.209	-0.015	NA	NA
Curr.magnitude	0.262	0.024	NA	NA
deltaT	0.306	-0.131	3	6
Dist. canyons	0.163	-0.178	2.3	5.3
Dist.coast	-0.092	-0.376	12.4	15.7
Dist.seamounts	0.118	-0.231	3.5	4.4
Dist.shelf	0.114	-0.422	NA	NA
EKE	0.284	0.044	3.7	5.4
mlotst	-0.294	-0.119	1.7	4
Salinity	-0.398	-0.085	3.2	3.3
Slope	-0.033	0.080	2.4	4.7
Temp_mean	-0.060	0.383	6.3	10
Temp_sd	-0.238	-0.310	9.9	11.4
zos	0.277	0.337	6.9	6.1

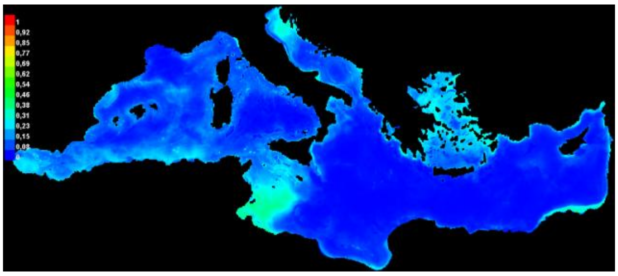
Entire period: The model covering the entire period highlights areas of high suitability primarily along coastal and continental shelf zones, particularly in the Ligurian Sea, northern Tyrrhenian Sea, northern Adriatic, the Alboran Sea, and the Tunisian platform. Deep-sea areas are mostly predicted as unsuitable, consistent with the species' known preference for more coastal, productive environments. Among the environmental predictors, bathymetry, distance to coast, chlorophyll-a concentration, and SST variability emerged as the most influential, underscoring the ecological importance of shallow depths, proximity to land, and dynamic oceanographic conditions. Independent validation points fall largely within suitable zones, with high AUC, precision, and F1 scores observed both within the study area and across the entire basin, confirming the model's strong predictive performance.

Seasonal SDM *Tursiops truncatus*

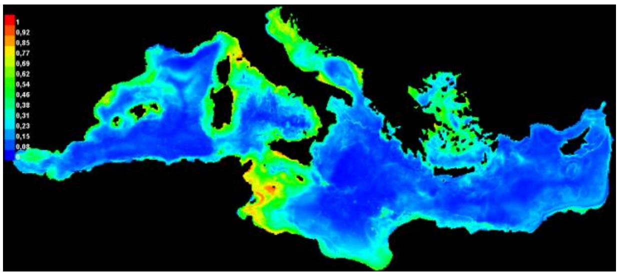
Maxent - avg predictions	Maxent - std
WINTER (AUC train= 0.89, AUC test= 0.81)	
	

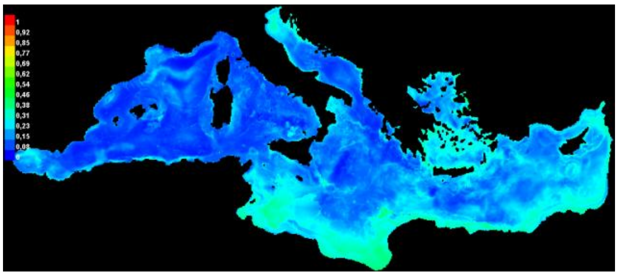
SPRING
(AUC train=0.85, AUC test=0.78)



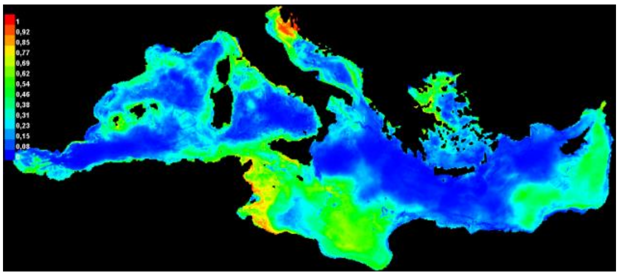


SUMMER
(AUC train=0.83, AUC test=0.75)





AUTUMN
(AUC train=0.88, AUC test=0.79)



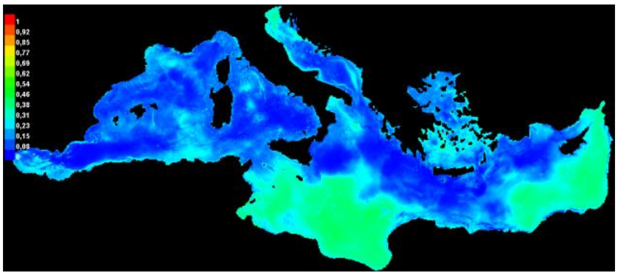


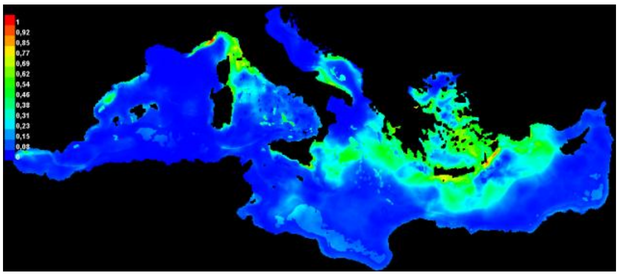
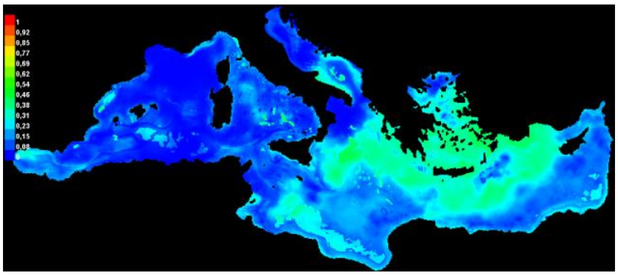
Figure 1.3.12. Species Distribution Model for *Tursiops truncatus* during the four seasons (WIN from January to March, SPR from April to June, SUM from July to September, AUT from October to December).

Table 1.3.18. *Tursiops truncatus* environmental variable contribution: summary of PCA loadings and Maxent output for each environmental variable over the seasons, expressed as percentage contribution and permutation importance. The top 3 values in each column are in bold.

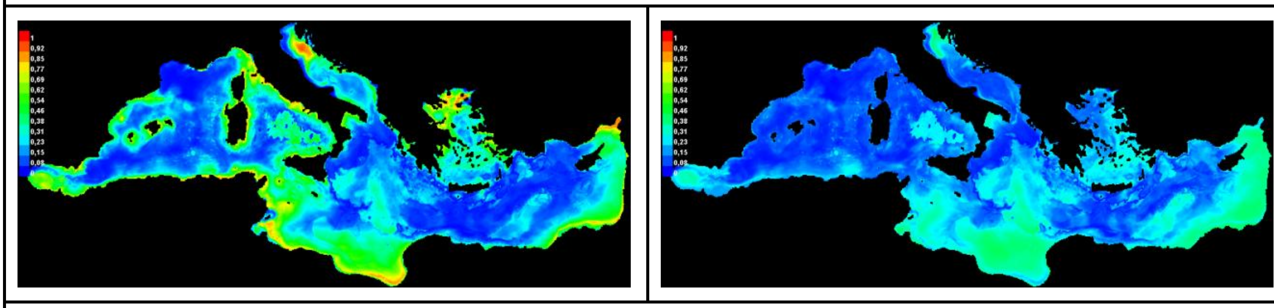
	Winter				Spring				Summer				Autumn			
Variable	PCA		SDM output		PCA		SDM output		PCA		SDM output		PCA		SDM output	
	PC1	PC2	% contrib	perm. imp	PC1	PC2	% contrib	perm. imp	PC1	PC2	% contrib	perm. imp	PC1	PC2	% contrib	per. imp
Bathy metry	0.037	-0.118	**24.6**	**18.1**	-0.376	-0.016	**17.6**	**15.5**	0.017	-0.254	**29.2**	**18.**	0.137	-0.376	**17.8**	**19.1**
Chl_mean	-0.224	-0.305	9.5	**12.9**	0.313	-0.276	4.4	6.6	-0.434	-0.082	3.3	3.7	0.405	0.023	4.5	3.9
Chl_sd	-0.086	-0.353	5.4	7.3	0.376	-0.128	**10.3**	**11.5**	-0.414	-0.060	2.2	5.6	0.386	0.069	7	**9.9**
Curr.Dir	0.158	0.270	NA	NA	0.121	-0.048	NA	NA	0.185	0.076	NA	NA	-0.239	0.170	NA	NA
Curr.magn	-0.320	-0.104	NA	NA	0.110	-0.485	NA	NA	-0.295	0.369	NA	NA	0.110	-0.029	NA	NA
deltaT	0.128	-0.403	2.1	1.9	0.082	-0.196	5.7	7.6	-0.211	0.251	6.3	7.4	0.326	0.067	3.3	3.4
Dist.	0.286	-0.298	6.1	9.1	-0.007	0.195	2.8	6.6	-0.206	-0.461	3.7	9.6	0.351	0.030	**9.6**	**14.1**

canyons																
Dist.coast	0.206	-0.008	**13.5**	**20.5**	0.353	0.153	**24.4**	**11.7**	-0.088	0.034	**12.3**	**12.3**	-0.028	0.385	8.8	6.8
Dist.seamounts	0.308	-0.249	4.1	6.1	0.078	0.129	7.5	10	-0.202	-0.322	6.4	**11.6**	0.299	0.098	5.4	7.8
Dist.shelf	0.194	-0.282	NA	NA	0.349	0.118	NA	NA	-0.205	-0.159	NA	NA	0.288	0.273	NA	NA
EKE	-0.294	-0.118	7.8	3.3	0.077	-0.501	4	3.6	-0.309	0.331	4.4	4.4	0.113	-0.079	6	3
mlotst	0.218	0.286	1.9	4	0.056	0.052	4.8	4.4	0.182	-0.032	6.7	3.1	-0.237	-0.179	3.6	2.4
Salinity	0.358	0.237	3.6	0.5	0.085	0.376	3.7	2.4	0.322	-0.003	**8.1**	2.4	-0.204	0.208	6.5	4
Slope	-0.251	0.137	3.6	6	0.021	-0.201	3.3	5.5	0.046	0.343	4	10.1	-0.140	0.034	8.3	8.6
Temp_mean	-0.324	0.090	6.6	3.7	-0.382	0.052	3.1	6.1	0.237	-0.276	3.1	3.4	-0.163	-0.374	4.4	2.7
Temp_sd	0.248	-0.264	1.8	1.6	0.263	0.134	4.5	4.7	0.210	0.260	4.8	4.3	-0.164	0.402	2	4.7
zos	-0.222	-0.208	**9.2**	5.1	-0.320	-0.288	3.8	3.7	-0.086	-0.078	5.6	4	0.115	-0.449	**12.8**	9.5

Seasonal patterns: Seasonal SDMs confirmed that suitable habitats for *Tursiops truncatus* are not static but vary both spatially and temporally. During **spring** and **summer**, suitable areas expand considerably over the continental shelf and into more productive coastal waters. Key spring hotspots areas of increased suitability include the Alboran Sea, and the Balearic Islands, while during summer, increased suitability is observed in the Tuscan Archipelago, where a Natura 2000 Site (IT5160021) has been designed for the species. The northern Tyrrhenian Sea and parts of the Gulf of Lion shelf, also show high suitability, likely driven by seasonal peaks in biological productivity and prey availability. During **autumn** and **winter**, the predicted distribution becomes more fragmented and gradually contracts towards more sheltered, nearshore zones. In particular, suitable zones concentrate along the coastal waters of Tunisia, the northern Adriatic Sea, and the western sector of the Alboran sea, where it reaches its peaks in suitability. Despite these seasonal shifts, core environmental drivers such as bathymetry, distance to coast and chlorophyll-a variation remain consistently important across seasons, though their relative contributions fluctuates; for example, chlorophyll-a is less influential during winter.

<table>
<tr><th colspan="2">Habitats Directive Reporting periods Tursiops truncatus</th></tr>
<tr><td colspan="2">2008-2012
(AUC train=0.92, AUC test=0.87)</td></tr>
<tr><td>Maxent - avg predictions</td><td>Maxent - std</td></tr>
<tr><td></td><td></td></tr>
</table>

2013-2018
(AUC train=0.85, AUC test=0.79)



2019-2024
(AUC train=0.81, AUC test=0.74)

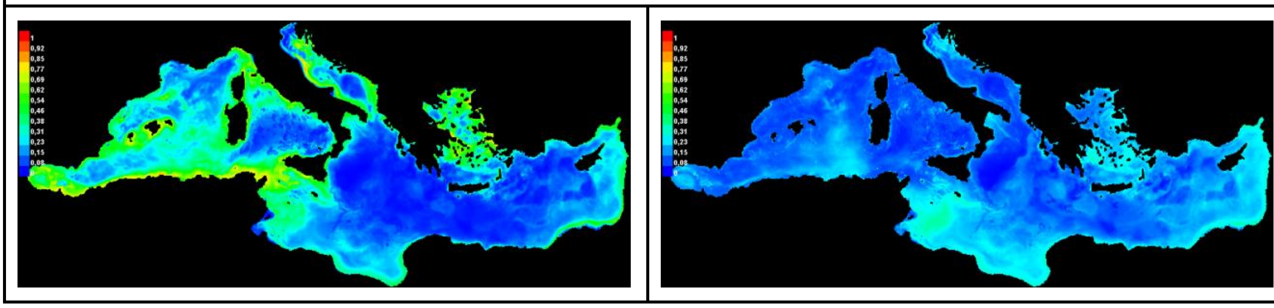


Figure 1.3.13. Species Distribution Model for *Tursiops truncatus* covering the three Habitat Directive reporting periods (2008-2012, 2013-2018, 2019-2024).

Table 1.3.19. *Tursiops truncatus* environmental variable contribution: summary of PCA loadings and Maxent output for each environmental variable over the reporting periods, expressed as percentage contribution and permutation importance.

	2008-2012		2013-2018		2019-2024	
Variable	SDM output		SDM output		SDM output	
	% contrib	perm. imp	% contrib	perm. imp	% contrib	perm. imp
Bathy metry	39.8	9.2	20	14.8	25.8	14.9
Chl_mean	1.1	0.7	1.4	2.4	7.3	5.5
Chl_sd	1.7	2.2	7.3	8.3	2.1	4.6
Curr.Dir	NA	NA	NA	NA	NA	NA
Curr.magn	NA	NA	NA	NA	NA	NA
deltaT	1.9	2	2.4	4.6	3.9	9.4
Dist. canyons	3.2	2.8	2.9	6.8	6.8	7.3
Dist.coast	7	11.4	22.6	21.3	7	8.7
Dist.seamounts	9.5	14.9	6.5	7.6	3.8	6.1
Dist.shelf	NA	NA	NA	NA	NA	NA
EKE	4.7	6.1	7.4	2.5	2.9	5.4
mlotst	0.5	2.9	5.4	4.6	1.8	3.6
Salinity	1.7	10.8	5.4	2.4	9.3	2.7
Slope	2.4	3	2.4	3.7	3.3	5.4
Temp_mean	2.5	3.3	5.2	13.1	4.7	3.2
Temp_sd	11.8	8.2	5.2	3.8	5.9	8.5
zos	12.2	22.5	5.8	4.2	15.4	15

Habitats Directive Reporting Periods: Predicted habitat suitability varied across the three Habitats Directive reporting periods (2008–2012, 2013–2018, 2019–2024), suggesting possible temporal trends in habitat use, potentially driven by environmental change or variations in survey coverage and monitoring effort. The second period (2013–2018) shows a more coastal and spatially restricted distribution, while the third period (2019–2024) reveals a wider distribution, including offshore areas, indicating a broader spatial use of the basin. Although the first period (2008–2012) achieved high AUC values, the predicted suitable areas were limited and highly localized, likely reflecting a lower coverage of survey routes, which may have failed to capture the full range of the species' spatial ecology, including both coastal and offshore preferences. In contrast, the models for the second and third periods appear to fully represent the species' distributional patterns. Despite these variations, the key drivers of habitat suitability remained consistent, reinforcing the role of bathymetry, coastal proximity, thermal variability, sea surface height and moderate productivity as stable ecological determinants.

Suitable Habitat for *Delphinus delphis*

Delphinus delphis consistently prefers salinity-driven habitat, mainly concentrated in the Alboran Sea and adjacent productive areas. A restriction of the suitable habitat was identified.

Summary of Habitat Suitability for *Delphinus delphis*~~~~*Delphinus delphis* prefer dynamic, productive waters near the continental shelf, canyons, and seamounts, especially in the Alboran Sea and the southern latitudes of the western Mediterranean Sea. Habitat use varies by season, with shifts linked to prey and hydrographic conditions. Over time, their suitable habitat appears to have narrowed, suggesting growing sensitivity to changing ocean environments.

Seasonal Patterns: Across all seasons, salinity was the most consistent driver, EKE supported prey aggregation dynamics, and preference for complex seafloor features persisted; chlorophyll played an indirect but seasonally significant role, especially in spring and summer.

- **Winter:** distribution was mainly driven by salinity and EKE, with a preference for topographically complex areas; suitable areas mostly confined to the **Alboran Sea**.
- **Spring**: Salinity still had the highest influence, with strong avoidance of high values. Suitable areas expands **eastward along African coast**
- **Summer:** Distribution shifted toward warmer, neritic zones (e.g., Tyrrhenian Sea, North African shelves), with temperature and depth becoming more relevant.
- **Autumn:** As in spring, salinity was the top predictor with strong selection against high levels. Suitable habitats expand between the Alboran sea and the complex bathymetric structures of the central and southern Tyrrhenian sea.

Habitat Directive Reporting Periods (2008–2024): Habitat was consistently shaped by hydrographic, bathymetric, and productivity-related variables, though the balance among them shifted over time, with a clear trend toward salinity-driven habitat selection and increasing spatial restriction in recent years.

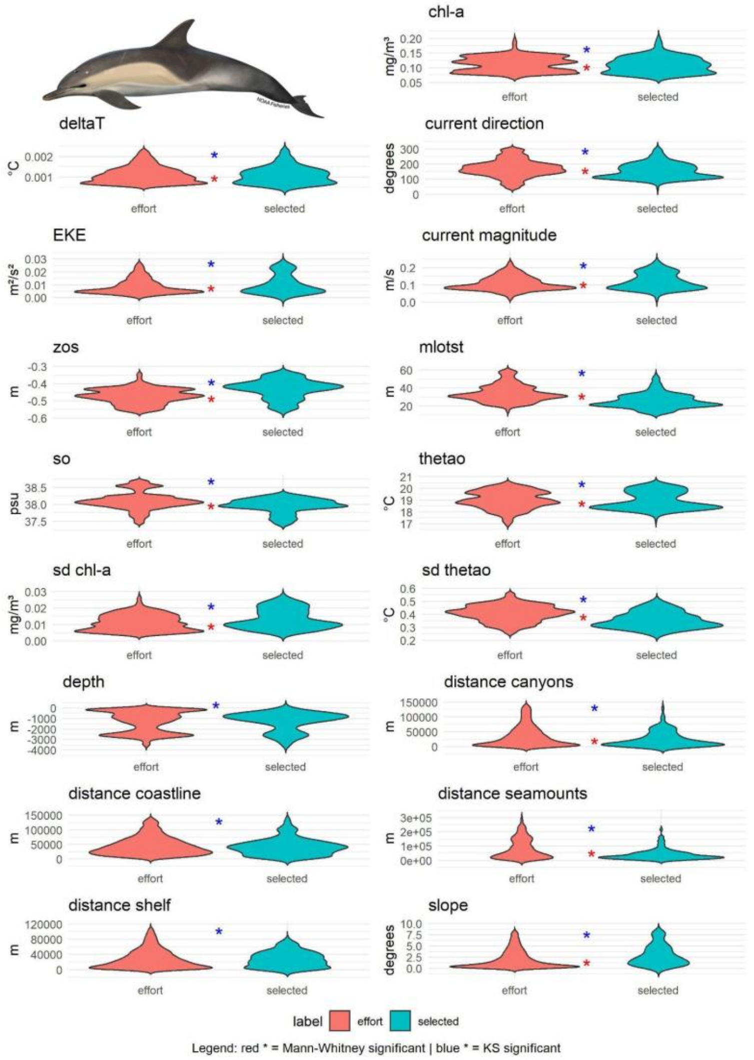
- **2008-2012:** Habitat suitability was primarily driven by chlorophyll concentration. Depth, temperature variability, and proximity to seamounts and canyons also played key roles. Several suitable areas, especially the Alboran Sea, northern Algeria, and the Balearic and Tyrrhenian regions.
- **2013–2018:** Salinity became the most important predictor, with preference for intermediate values; depth, slope, and chlorophyll variability remained relevant. Suitable habitats remained concentrated in the Alboran Sea, North African shelf, and parts of the Tyrrhenian Sea.
- **2019–2024:** Salinity's influence increased sharply. Suitable habitat became highly restricted, concentrated almost entirely in the Alboran Sea, suggesting a contraction in the ecological niche. Habitat suitability contracted in the last period, becoming largely restricted to the Alboran Sea suggesting a narrower ecological niche likely driven by shifting oceanographic conditions.

Policy Implications for common dolphin (*Delphinus delphis)* conservation:

The increasing reliance of Delphinus delphis on salinity-driven habitats, particularly in the Alboran Sea, and the observed contraction of suitable areas over time signal growing vulnerability to environmental change. To address this:

1. **Prioritize Protection in the Alboran Sea**: This region remains the species' core habitat, especially during winter and in recent years. It should be designated as a high-priority conservation zone under the EU Habitats Directive.
2. **Implement Seasonal and Adaptive Management**: Since habitat use shifts seasonally, dynamic conservation strategies should align with peak seasonal habitat preferences extending protections eastward in spring and toward neritic zones in summer.
3. **Enhance Cross-Border Collaboration**: Habitat suitability spans national waters (e.g., Alboran, North African shelf), requiring coordinated management among Mediterranean states to ensure effective species protection.
4. **Monitor Oceanographic Drivers**: Continued monitoring of salinity, EKE, and productivity indicators is critical to detect early signs of further habitat loss and to inform adaptive policy responses.
5. **Mitigate Broader Environmental Stressors**: The narrowing niche highlights sensitivity to climate and ocean changes. Conservation efforts should include measures to reduce cumulative stressors such as pollution, overfishing, and maritime traffic, especially in key foraging and breeding habitats.

1) Habitat Selection of *Delphinus delphis*. Comparison between selected environmental variable range at present locations and available range of values across the effort area.



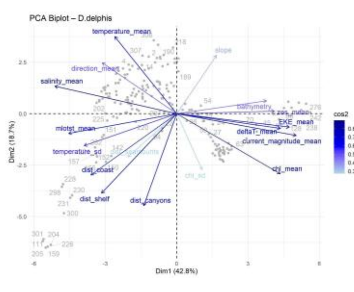
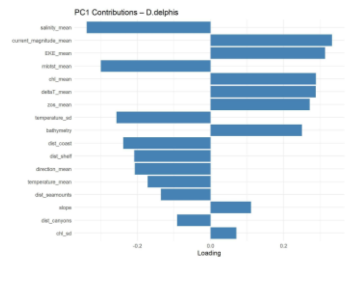
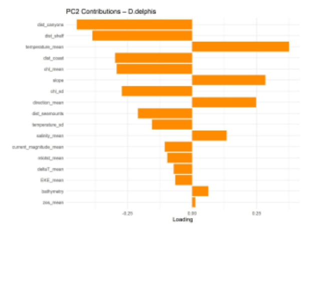
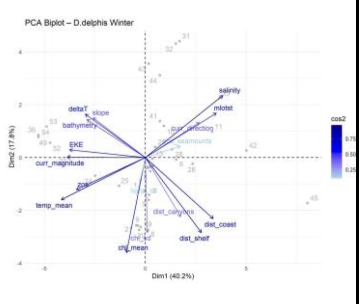
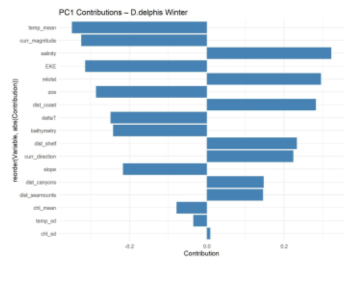
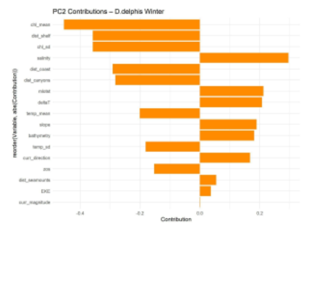
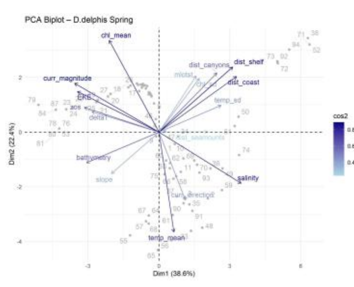
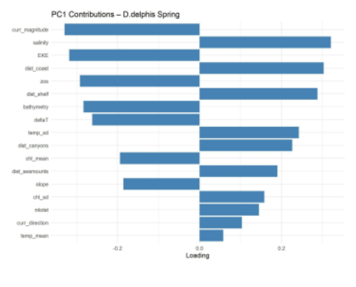
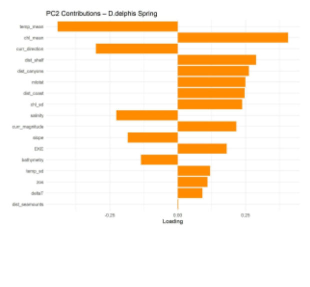
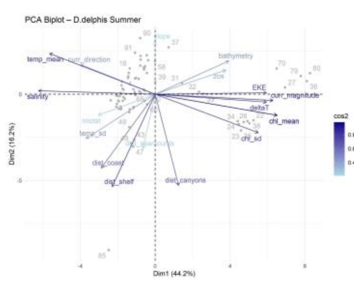
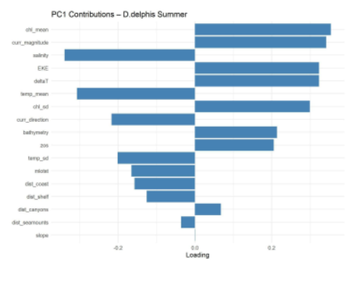
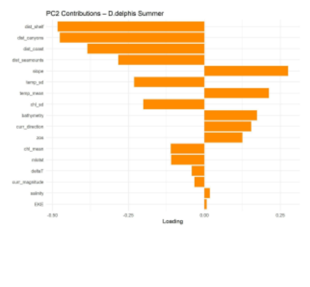
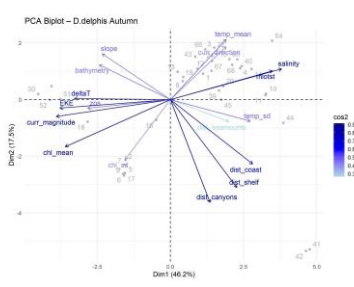
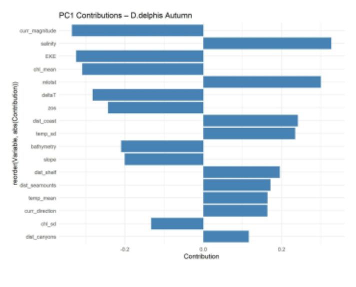
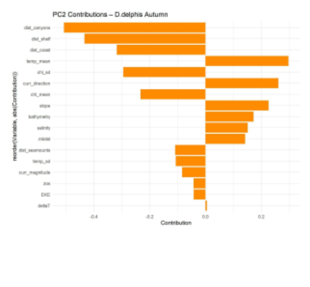
Summary:

Variables related to productivity show slightly higher values in the selected sites, suggesting a preference for medium to high productivity areas. Net Primary Production (nppv) and Total Phytoplankton Concentration (phyc) plots reveal two distinct clusters, indicating variable preferences across low to high ranges. A similar bimodal pattern is observed for SST. Oceanographic features like EKE are also elevated in selected areas, indicating a preference for dynamic regions (often associated with prey aggregations). Salinity is slightly lower at selected sites, possibly indicating use of frontal zones.

Figure 1.3.14 Habitat selection of *Delphinus delphis*. Distribution of environmental variable values at presence locations (left, red violin plots) and available range of values across the effort area (right, blue violin plots). Include Mann-Whitney U and Kolmogorov–Smirnov tests.

2) Principal Component Analysis (PCA) of *Delphinus delphis*

Table 1.3.20. *Delphinus delphis* PCA Biplot and Barplot of PC1 (blue) and PC2 (orange) loadings for different temporal resolutions.

<table>
<tr><th>Temporal res</th><th>Biplot</th><th>Loadings PC1</th><th>Loadings PC2</th></tr>
<tr><td>Entire period
61.5% explained variance</td><td></td><td></td><td></td></tr>
<tr><td>Winter
58% explained variance</td><td></td><td></td><td></td></tr>
<tr><td>Spring
61% explained variance</td><td></td><td></td><td></td></tr>
<tr><td>Summer
60.4% explained variance</td><td></td><td></td><td></td></tr>
<tr><td>Autumn
63.7% explained variance</td><td></td><td></td><td></td></tr>
</table>

Over the entire period, *Delphinus delphis* shows a **consistent preference for dynamic (high values of current magnitude and EKE), moderately productive, low-salinity water, often near**

canyons and shelf, likely associated with upwelling zones. *Delphinus delphis* **also favor shallower depths, suggesting use of continental shelf or slope edges.** Such regions typically support richer and more accessible prey communities due to upwelling and nutrient mixing. Lastly, proximity to canyons, shelf, and coast appears important, reflecting preference for complex, resource-rich habitats. **Across all seasons, the principal components consistently highlight a major environmental gradient. This gradient typically contrasts highly dynamic, energetic, productive deep water environments with more stable, warmer, saline and shallower coastal/shelf areas, probably following its prey preferences.** During **winter**, it seems that there's a preference for cold, more saline, less dynamic and productive waters, probably upwelling areas. In **spring**, *Delphinus delphis* once again confirms his preference for less dynamic, cold saline waters. **Summer** PC1 reaches higher values (44.2%), with a 61.4% of the explained variance. High productive, dynamic (positive loadings of magnitude and EKE), less saline waters, in proximity of the shelf and canyons still underline upwelling areas preferences. In **autumn** *Delphinus delphis* shows a strong gradient of preference from warmer, saline, less dynamic water, closer to canyons and to the shelf to waters with high dynamism (currents, EKE), more productive (chl_mean).

3) Delphinus delphis Species Distribution Model.

Entire period SDM *Delphinus delphis*
(AUC train=0.87, AUC test=0.82)

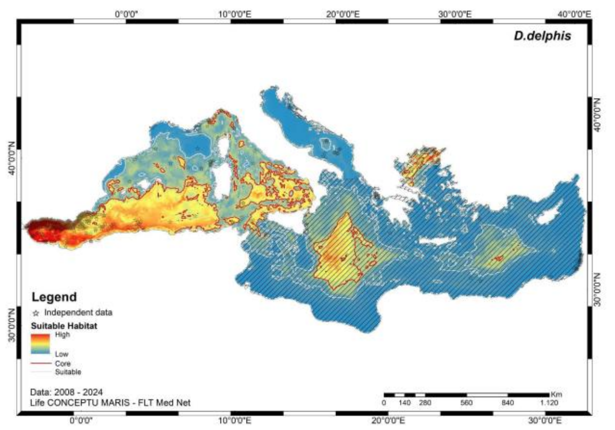
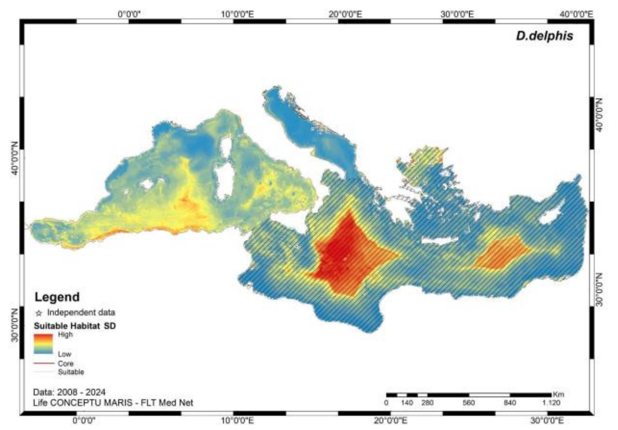
Maxent - avg predictions	Maxent - std
	

Figure 1.3.15. Species Distribution Model for *Delphinus delphis* covering the entire period from 2008 to 2024.

Table 1.3.21. Validation results of the Species Distribution Model for *Delphinus delphis* using an independent dataset, both within the LIFE CONCEPTU MARIS project area (western Mediterranean and Adriatic regions) and across the entire Mediterranean basin.

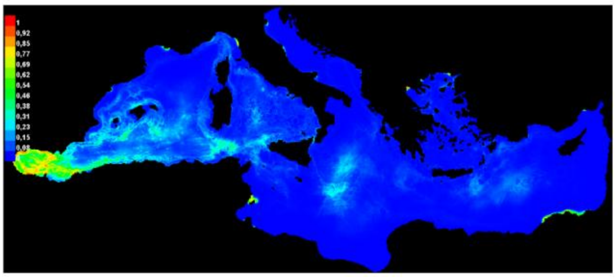
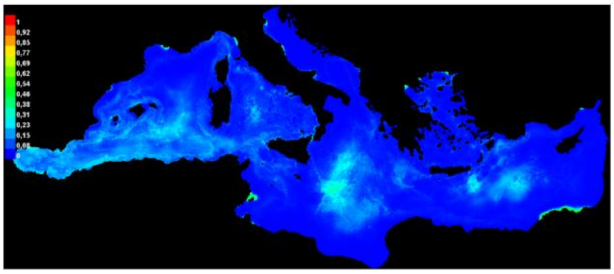
External validation with independent dataset	**W Med + Adriatic**		**Mediterranean Sea**	
	Maximum test sensitivity plus specificity Logistic threshold	Natural jenks threshold	Maximum test sensitivity plus specificity Logistic threshold	Natural jenks threshold
AUC	0.87	0.86	0.86	0.87
Precision	0.68	0.55	0.79	0.63

F1	0.77	0.70	0.79	0.75

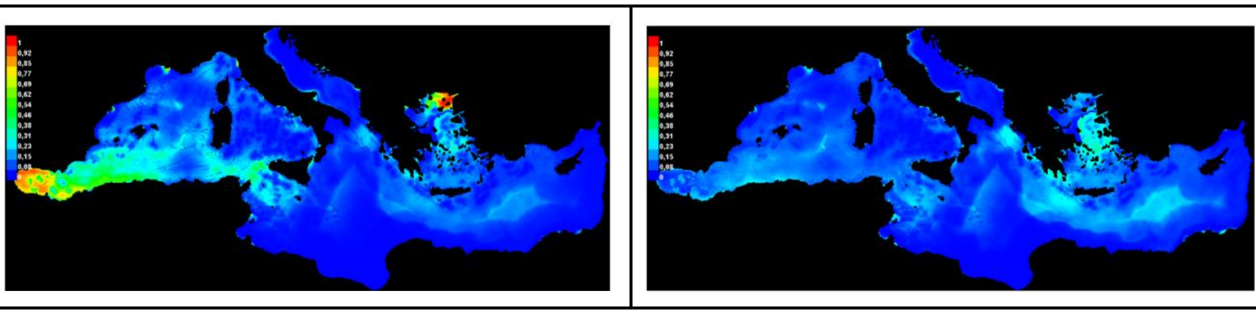
Table 1.3.22. *Delphinus delphis* environmental variable contribution: summary of PCA loadings and Maxent output for each environmental variable over the entire period, expressed as percentage contribution and permutation importance. Top 3 values in each column are in bold.

Entire period				
Variable	PCA		SDM output	
	PC1	PC2	% contrib	per. imp
[illegible]	0.250	0.063	8.8	19.9
[illegible]	0.288	-0.292	0.8	4.7
[illegible]	0.071	-0.272	1.1	5
[illegible]	0.332	-0.106	NA	NA
[illegible]	0.288	-0.071	NA	NA
[illegible]	-0.207	0.248	NA	NA
[illegible]	-0.092	-0.447	2.4	12
[illegible]	-0.239	-0.298	3.4	8.3
[illegible]	-0.136	-0.210	7.9	8.7
[illegible]	-0.209	-0.386	NA	NA
[illegible]	0.313	-0.065	3.8	4.9
[illegible]	-0.301	-0.096	NA	NA
[illegible]	-0.339	0.134	56.4	13.2
[illegible]	0.111	0.284	5.8	8.6
[illegible]	-0.172	0.375	1.8	3.3
[illegible]	-0.257	-0.156	7.8	11.4
zos	0.271	0.012	NA	NA

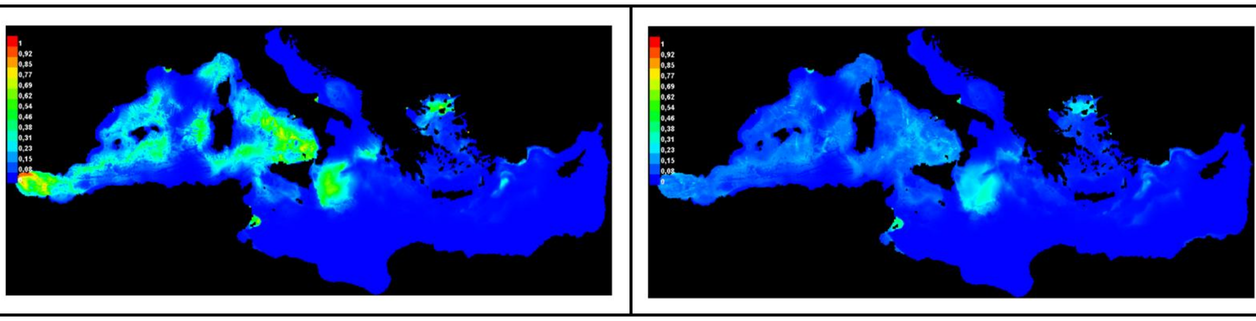
Entire period: spatial projections show the highest habitat suitability of *Delphinus delphis* in correspondence with the Strait of Gibraltar and the Alboran Sea. Results also highlight the importance of the Pelagos Sanctuary and of the central and southern Tyrrhenian Sea. Salinity was the most influential environmental predictor (56.4% contribution), while depth showed the highest permutation importance. Contribution from temperature variability and EKE suggest a preference for dynamic oceanographic environments. Additional contributions from slope and proximity to seamounts point to a marked selection for topographically complex areas, often linked to enhanced foraging opportunities.

Seasonal SDM *Delphinus delphis*	
Maxent - avg predictions	Maxent - std
WINTER (AUC train=0.96, AUC test=0.93)	
	

SPRING
(AUC train=0.92, AUC test=0.87)



SUMMER
(AUC train=0.90, AUC test=0.85)



AUTUMN
(AUC train=0.92, AUC test=0.82)

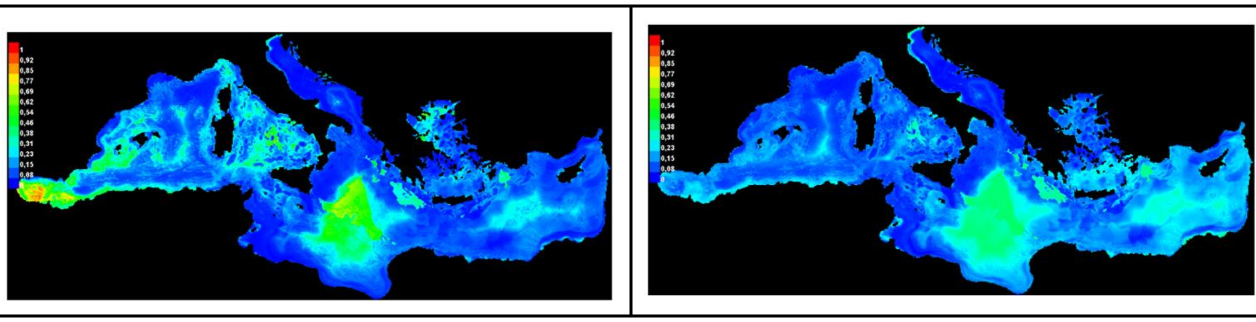


Figure 1.3.16. Species Distribution Model for *Delphinus delphis* during the four seasons (WIN from January to March, SPR from April to June, SUM from July to September, AUT from October to December).

Table 1.3.23. *Delphinus delphis* environmental variable contribution: summary of PCA loadings and Maxent output for each environmental variable over the seasons, expressed as percentage contribution and permutation importance. Top 3 values in each column are in bold.

	Winter				Spring				Summer				Autumn			
Variable	PCA		SDM output		PCA		SDM output		PCA		SDM output		PCA		SDM output	
	PC1	PC2	% contrib	perm. imp	PC1	PC2	% contrib	perm. imp	PC1	PC2	% contrib	perm. imp	PC1	PC2	% contrib	per. imp
Bathy metry	-0.242	0.181	1.2	2.6	-0.284	-0.135	3	6.7	0.214	0.173	**12.7**	**11.9**	-0.210	0.172	**7.5**	**8.6**
Chl_mean	-0.078	-0.454	7.3	**36.9**	-0.194	0.407	4.2	4.3	0.354	-0.111	6.1	19.8	-0.309	-0.233	1.9	4.1
Chl_sd	0.009	-0.358	0.5	4.2	0.158	0.238	1.6	3	0.299	-0.201	1.7	3.9	-0.133	-0.294	1.9	8.4
Curr.Dir	0.224	0.167	NA	NA	0.103	-0.301	NA	NA	-0.217	0.154	NA	NA	0.164	0.261	NA	NA
Curr.Magn	-0.325	0.001	NA	NA	-0.330	0.216	NA	NA	0.342	-0.033	NA	NA	-0.336	-0.084	NA	NA
deltaT	-0.249	0.207	NA	NA	-0.262	0.091	NA	NA	0.323	-0.041	NA	NA	-0.283	0.005	NA	NA

Dist. canyons	0.147	-0.282	3.4	10	0.226	0.262	2.5	4	0.068	-0.476	4.5	8.2	0.116	-0.507	3.8	6.5
Dist.coast	0.282	-0.291	3.2	7.2	0.303	0.246	2	3.7	-0.157	-0.385	1.5	3.2	0.242	-0.318	5.8	12
Dist.seamounts	0.145	0.054	5.9	**14.8**	0.190	0.002	9.1	17.2	-0.036	-0.283	15.3	25.1	0.171	-0.109	7.2	7.3
Dist.shelf	0.233	-0.358	NA	NA	0.288	0.289	NA	NA	-0.126	-0.483	NA	NA	0.195	-0.433	NA	NA
EKE	-0.315	0.037	18.2	3.9	-0.318	0.180	**18.5**	3.6	0.323	0.007	1.2	3	-0.325	-0.042	5.4	4.9
mlotst	0.295	0.212	NA	NA	0.145	0.249	NA	NA	-0.165	-0.110	NA	NA	0.300	0.142	NA	NA
Salinity	0.322	0.296	**46.5**	4.3	0.321	-0.226	**53.6**	**34.8**	-0.339	0.018	**29**	1.8	0.327	0.151	**52.1**	**30.5**
Slope	-0.217	0.190	9.7	6.2	-0.186	-0.184	3	4.9	-0.001	0.276	8	9	-0.201	0.226	**10.9**	**8.2**
Temp_mean	-0.349	-0.201	2	5.5	0.058	-0.442	1.3	**12.4**	-0.307	0.212	**17.6**	9.7	0.164	0.297	1.8	7.3
Temp_sd	-0.035	-0.181	1.9	4.3	0.242	0.119	1.2	5.3	-0.201	-0.231	2.3	4.5	0.234	-0.106	1.6	2.3
zos	-0.286	-0.153	NA	NA	-0.292	0.110	NA	NA	0.205	0.125	NA	NA	-0.243	-0.043	NA	NA

Seasonal patterns: ***Delphinus delphis* habitat suitability remained highest in the Alboran Sea throughout all seasons, with suitable habitat confined there during winter and progressively expanding eastward in spring and summer along the African coast and into the southern Tyrrhenian Sea, suggesting a dynamic, prey-driven redistribution aligned with shifting hydrographic and productivity regimes. In autumn, suitable areas extended between the Alboran Sea and scattered zones associated with the complex bathymetric structures of the southern Tyrrhenian Sea.**

MaxEnt models across seasons consistently identify **salinity as the most influential driver** of *Delphinus delphis* distribution, with a clear preference for intermediate values typically associated with frontal zones and water mass mixing. This pattern was most pronounced in **spring** (53.6% contribution), where a stronger avoidance of high-salinity areas suggests a more selective habitat use compared to **winter** (46.5%). In both seasons, EKE ranked second, reinforcing the species' association with mesoscale oceanographic processes that enhance prey aggregation. Proximity to seamounts, bathymetry and slope also contributed across seasons, indicating a consistent preference for topographically complex areas likely linked to prey availability. Chl concentration showed moderate to low direct contribution, but high permutation importance especially in winter and summer, pointing to a key indirect trophic role. In **summer**, the distribution expanded toward warmer, neritic regions such as the Tyrrhenian Sea. Mean temperature and bathymetry gain importance, while EKE becomes much less relevant. In **autumn**, salinity remained the dominant predictor with strong selection against high values followed by slope and batymetry.

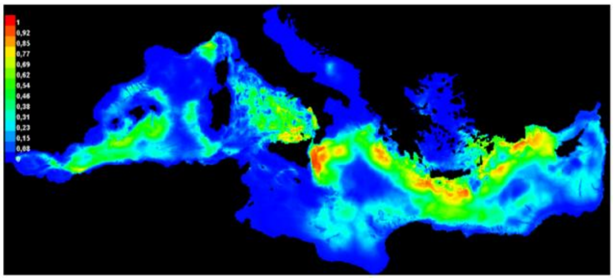
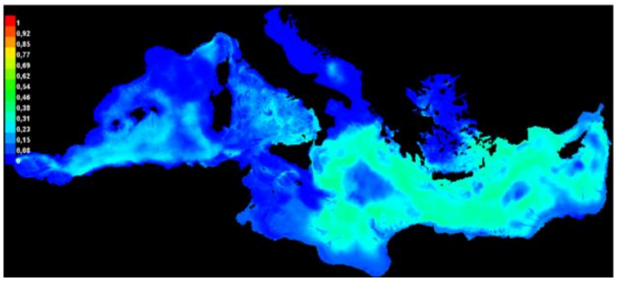
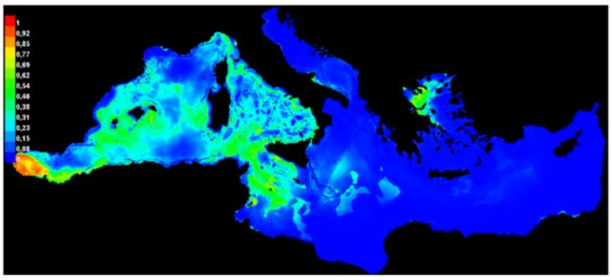
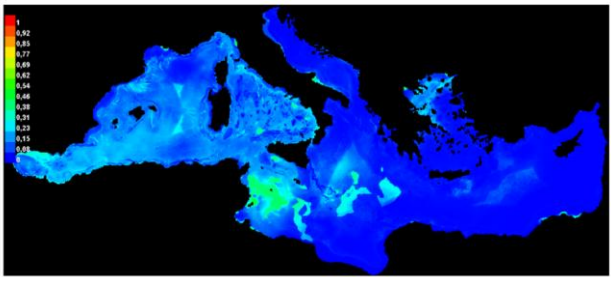
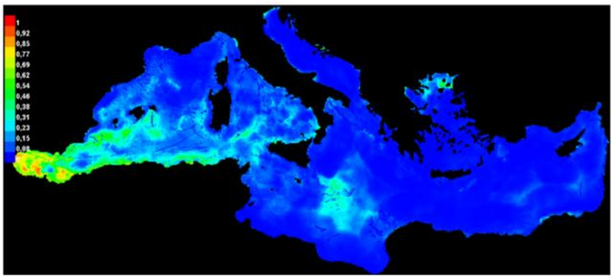
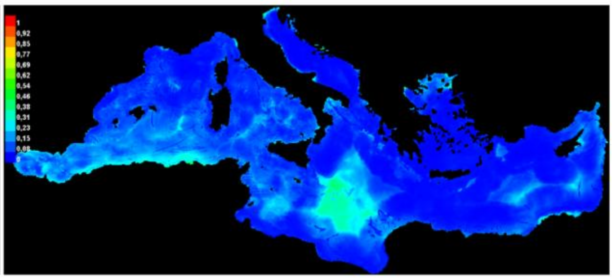
Habitats Directive Reporting periods *Delphinus delphis*	
Maxent - avg predictions	Maxent - std
2008-2012 (AUC train=0.94, AUC test=0.87)	
	
2013-2018 (AUC train=0.91, AUC test=0.83)	
	
2019-2024 (AUC train=0.93, AUC test=0.88)	
	

Figure 1.3.17. Species Distribution Model for *Delphinus delphis* covering the three Habitat Directive reporting periods (2008-2012, 2013-2018, 2019-2024).

Table 1.3.24. *Delphinus delphis* environmental variable contribution: summary of PCA loadings and Maxent output for each environmental variable over the reporting periods, expressed as percentage contribution and permutation importance.

	2008-2012		2013-2018		2019-2024	
Variable	SDM output		SDM output		SDM output	
	% contrib	perm. imp	% contrib	perm. imp	% contrib	perm. imp
Bathy metry	16.3	29.1	11.8	15.5	4	9.9
Chl_mean	28.4	1.9	1.2	3.9	0.8	2.9

Chl_sd	1.2	1.1	9.7	10.9	1.4	2
Curr.Dir	NA	NA	NA	NA	NA	NA
Curr.magn	NA	NA	NA	NA	NA	NA
deltaT	NA	NA	NA	NA	NA	NA
Dist. canyons	5.2	10.1	4.7	5.1	3.4	10.2
Dist.coast	1.6	2.6	4.9	5.8	2.2	7
Dist.seamounts	8.9	12.6	9.4	14.2	3.2	6.2
Dist.shelf	NA	NA	NA	NA	NA	NA
EKE	4.5	4	9.3	2.4	3.7	4.3
mlotst	NA	NA	NA	NA	NA	NA
Salinity	3.9	3.2	28.2	24.1	72.4	44.8
Slope	4.2	6	10.9	10.1	5.6	5.5
Temp_mean	12.8	7.8	0.8	1.8	0.9	1.4
Temp_sd	13.1	21.7	9	6.2	2.3	5.9
zos	NA	NA	NA	NA	NA	NA

Habitats Directive Reporting Periods: Across the three temporal periods, *Delphinus delphis* habitat suitability in the western Mediterranean was consistently shaped by a combination of hydrographic, bathymetric, and productivity-related variables, though their relative importance varied over time. In the **first period (2008-2012)**, chlorophyll concentration was the leading predictor, reflecting a strong dependence on primary productivity, while depth, temperature variability, and proximity to seamounts and canyons underscored the role of bathymetric and thermal structure in shaping habitat use. The model highlighted several suitable areas, especially the Alboran Sea, northern Algeria, and the Balearic and Tyrrhenian regions. During the **second period (2013–2018)**, salinity emerged as the top predictor, with preference for intermediate values, suggesting increased sensitivity to hydrographic gradients. Depth, slope, and chlorophyll variability also contributed, reinforcing the importance of structured, productive environments. Suitable habitats remained concentrated in the Alboran Sea, North African shelf, and parts of the Tyrrhenian Sea. In the **third period (2019–2024)**, salinity dominance intensified (72.4% contribution), while the influence of productivity and thermal variables diminished. **Habitat suitability became more restricted during the last period, with high suitability almost exclusively in the Alboran Sea, indicating a contraction of favorable conditions and possibly a narrower ecological niche, potentially driven by changing oceanographic conditions.**

Suitable habitat for *Grampus griseus*

Technical Summary: Habitat Use of *Grampus griseus* in the Western Mediterranean (2008–2024)

Grampus griseus is a flexible marine species that uses a wide range of habitats across the western Mediterranean, but shows consistent preferences for specific environmental conditions. It is especially associated with **mid-depth offshore areas**, **productive waters**, and **complex seafloor features** such as **seamounts** and **canyons**.

Summary of Habitat Suitability for *Grampus griseus*
Grampus griseus shows relatively low habitat selectivity compared to other species, yet displays consistent preferences for dynamic, productive areas, particularly those with high currents, EKE, and chlorophyll concentrations. The species favors regions close to seafloor features such as canyons and seamounts, reflecting a reliance on structurally complex and oceanographically active habitats. PCA reveals a broad distributional gradient across seasons and years, with the species occupying a range from deep, warm, high-current coastal waters to shallower, less variable shelf environments. Across all periods, bathymetry was the most influential predictor, followed by salinity, chlorophyll concentration, and proximity to underwater features, emphasizing the role of mid-depth, productive, and topographically complex environments.

Seasonal Patterns: Seasonal patterns indicate flexibility in habitat use, with **winter** distributions in deep, saline, productive offshore areas near seamounts; **spring** associations with temperature gradients and deep pelagic zones; **summer** preference for low-salinity, productive, and dynamic deep waters; and **autumn** use of both deep, warm waters and shallower, variable offshore habitats with a combination of bathymetry, canyon proximity, and productivity. SDMs identify the Alboran Sea, Strait of Gibraltar, and parts of the Balearic and Ligurian Seas as critical areas.

Habitat Directive Reporting Periods (2008–2024): Over time, *Grampus griseus* showed a broader and less defined use of suitable habitats in the western Mediterranean, consistently linked to intermediate depths and complex topography.

- **2008–2012**: Suitability was mostly limited to continental slopes from the Alboran to Ligurian Seas, driven by EKE and salinity, indicating preference for dynamic, saline offshore waters.
- **2013–2018**: Suitable areas expanded into more pelagic zones, especially in the Balearic and Tyrrhenian Seas, with bathymetry and chlorophyll variability as key drivers.
- **2019–2024:** Habitat suitability shifted and consolidated in the southwestern basin; salinity became the dominant driver, followed by bathymetry, slope, and proximity to seamounts and canyons.

Key Findings:

- **Core Areas**: The Alboran Sea, Strait of Gibraltar, Balearic Islands, and Ligurian Sea are critical habitats consistently used throughout the year.
- **Environmental Drivers**: Habitat use is shaped by water depth, salinity, ocean productivity, and underwater topography.
- **Seasonal Use**:
  - *Winter*: Prefers deep, saline, and productive offshore waters.
  - *Spring*: Shifts to areas with strong temperature and productivity gradients.
  - *Summer*: Favors highly dynamic and productive slope regions.
  - *Autumn*: Occupies both deep dynamic waters and variable offshore zones.

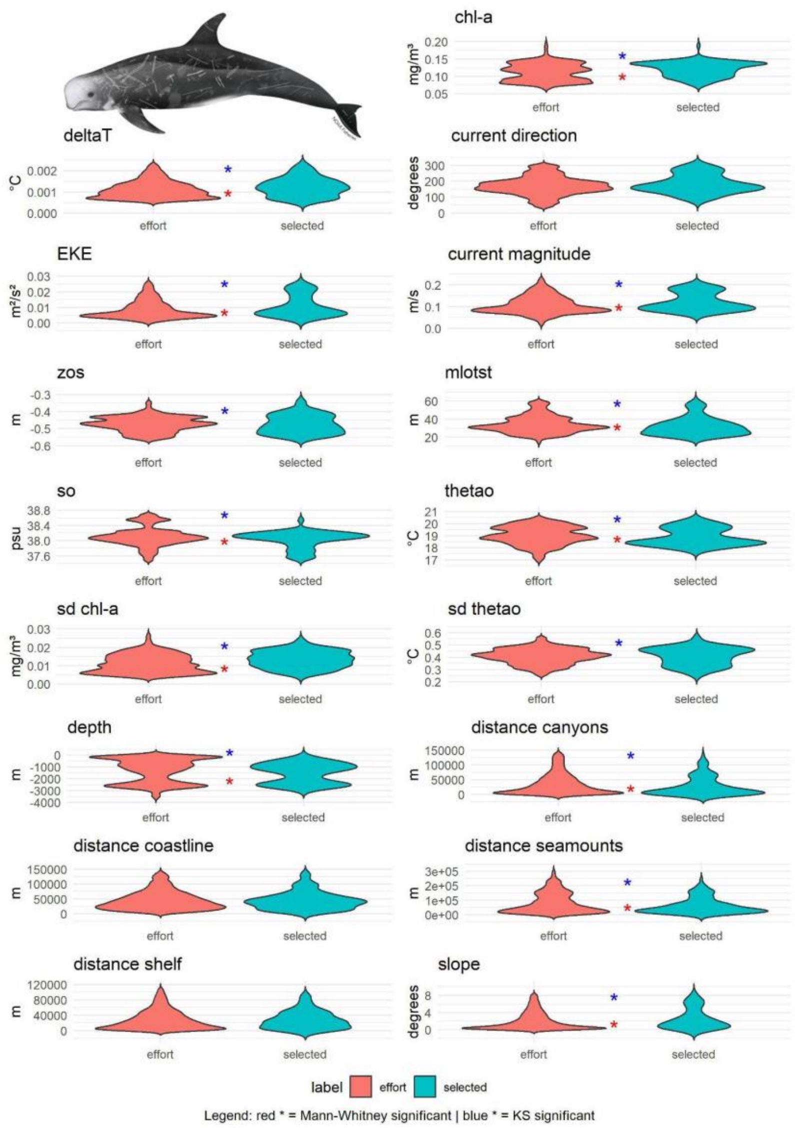
Long-Term Trends (2008–2024):

- Habitat used has become **more extensive** over time shifting towards more offshore and southwestern areas.
- The species consistently uses **structured, productive offshore environments**, especially those with **moderate salinity and dynamic ocean conditions**.

Implications for Policy and Management:

- **Priority Areas**: Protecting the Alboran Sea, Balearic and Ligurian regions as well as Tyrrhenian should be a conservation priority.
- **Monitoring**: The shift in habitat use by the species should be carefully monitored to identify the underlying drivers and to adapt conservation measures according to the detected changes.
- **Marine Spatial Planning**: Efforts should focus on preserving **dynamic oceanographic zones and underwater features**, as these are crucial for foraging and species presence.
- **Climate Sensitivity**: Changes in temperature, salinity, and productivity affect habitat use highlighting the species' **vulnerability to climate-driven ocean changes**.
- **Seasonal Protection**: Management strategies should be **seasonally adaptive** to reflect changing habitat use across the year.

1) Habitat Selection of *Grampus griseus*. Comparison between selected environmental variable range at present locations and available range of values across the effort area.



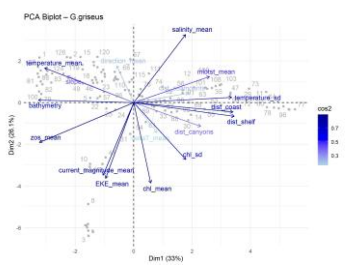
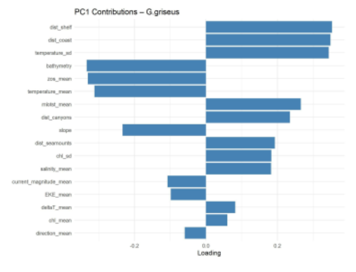
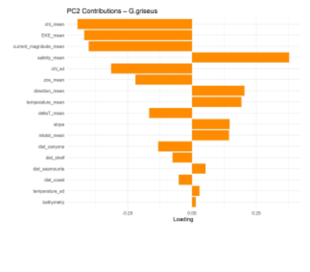
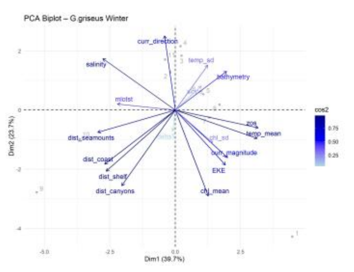
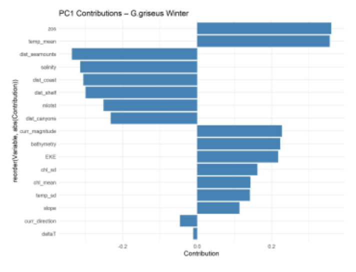
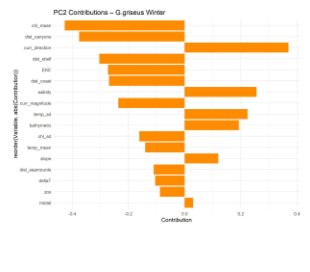
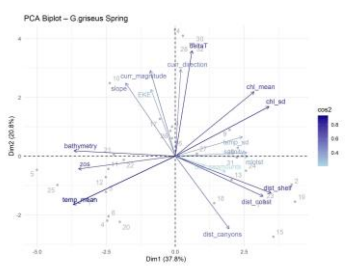
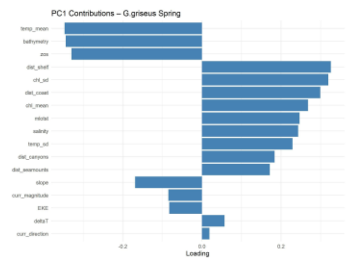
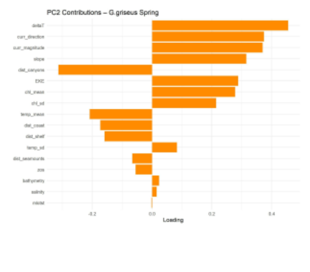
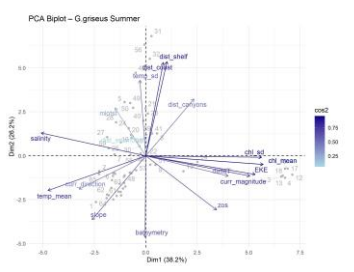
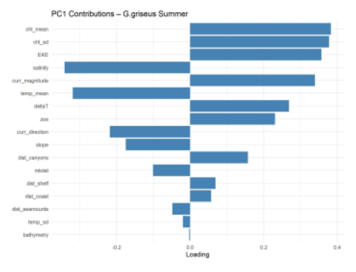
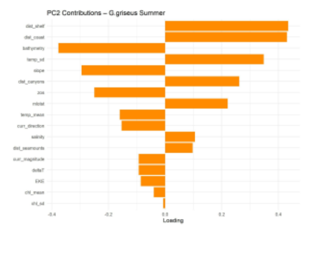
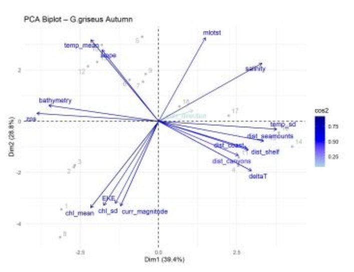
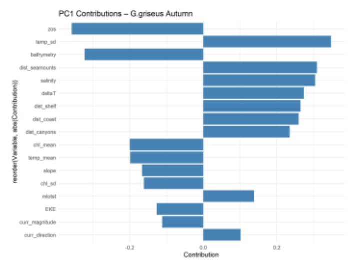
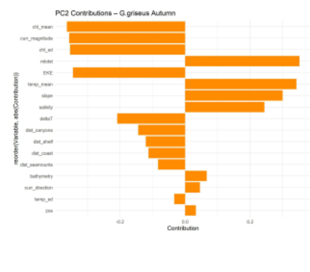
Summary:

Grampus griseus is among the less selective species, showing no strong or consistent spatial patterns. It appears to exhibit a more generalist habitat selection, with p-values > 0.05 for most environmental variables. However, preferences for specific ranges of certain variables are still evident, particularly for more dynamic areas (e.g., regions with higher current speeds and EKE) and productive waters (e.g., higher chlorophyll concentrations). The species also tends to occur closer to seafloor features such as canyons and seamounts, suggesting an affinity for dynamic and structurally complex habitats.

Figure 1.3.18. Habitat selection of *Grampus griseus*. Distribution of environmental variable values at presence locations (left, red violin plots) and available range of values across the effort area (right, blue violin plots). Include Mann-Whitney U and Kolmogorov–Smirnov tests.

2) Principal Component Analysis (PCA) of *Grampus griseus*

Table 1.3.25. *Grampus griseus* PCA Biplot and Barplot of PC1 (blue) and PC2 (orange) loadings for different temporal resolutions.

Temporal res	Biplot	Loadings PC1	Loadings PC2
Entire period 59.1% explained variance			
Winter 63.4% explained variance			
Spring 58.6% explained variance			
Summer 64.4% explained variance			
Autumn 68.2% explained variance			

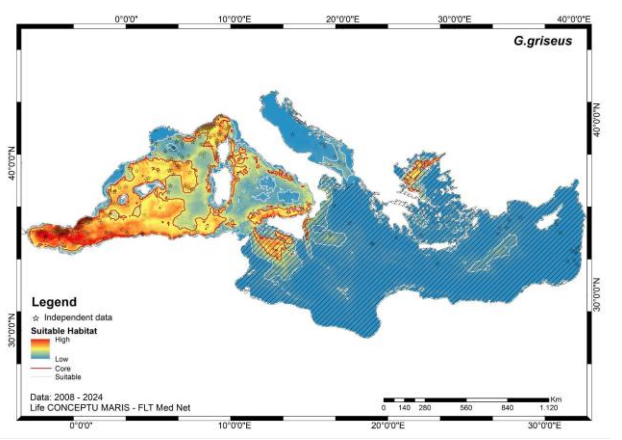
Over the entire period, *Grampus griseus* shows a **distributional gradient from deeper, warmer coastal areas with stronger currents and mean temperatures to shallower, less variable temperatures, further to the shelf and coast waters.** The species **also shifts across environments with higher chlorophyll concentrations and current activity, in contrast with areas that are saltier and less dynamic, reflecting variability in oceanographic productivity**.

Across all seasons, *Grampus griseus* shows flexible habitat use across deep, productive, and dynamic offshore waters and structured coastal zones, influenced by temperature, salinity, bathymetry, and oceanographic activity. During **winter**, *Grampus griseus* tends to occupy deep, saline, and productive waters, often near seamounts and shelf edges, and in areas with elevated sea surface height, suggesting foraging in complex offshore systems. In **spring**, habitat use is shaped by a strong temperature gradient, and the species is found in deep pelagic zones with high zos values and farther from shelf and coast, again pointing toward offshore preference under variable thermal conditions. During **summer**, they are associated with highly productive, low-salinity waters characterized by strong dynamism (currents and EKE), in deeper areas far from the coast. The role of bathymetric slope and distance from topographic features also supports the use of structured offshore habitats. During **autumn**, habitat selection spans a gradient from deep, warm, productive and dynamic waters to shallower offshore zones with greater temperature variability. Areas with high chlorophyll variability and strong currents seem particularly relevant, suggesting use of oceanographically active regions.

3) *Grampus griseus* Species Distribution Model.

Entire period SDM Grampus griseus
(AUC train = 0.86, AUC test = 0.79)

Maxent - avg predictions	Maxent - std



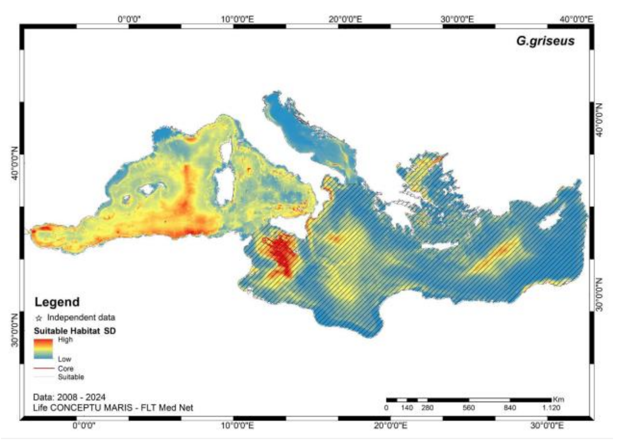


Figure 1.3.19. Species Distribution Model for *Grampus griseus* covering the entire period from 2008 to 2024.

Table 1.3.26. Validation results of the Species Distribution Model for *Grampus griseus* using an independent dataset, both within the LIFE CONCEPTU MARIS project area (western Mediterranean and Adriatic regions) and across the entire Mediterranean basin.

External validation with independent dataset	**W Med + Adriatic**		**Mediterranean Sea**	
	Maximum test sensitivity plus specificity Logistic threshold	Natural jenks threshold	Maximum test sensitivity plus specificity Logistic threshold	Natural jenks threshold
AUC	0.71	0.70	0.82	0.82
Precision	0.65	0.53	0.8	0.70

F1	0.68	0.67	0.72	0.78

Table 1.3.27. ***Grampus griseus*** **environmental variable contribution: summary of PCA loadings and Maxent output for each environmental variable over the entire period, expressed as percentage contribution and permutation importance. Top 3 values in each column are in bold.**

Entire period				
Variable	PCA		SDM output	
	PC1	PC2	% contrib	per. imp
Bathymetry	-0.334	0.015	29.2	22.8
Chl_mean	0.060	-0.445	13.4	17.8
Chl_sd	0.183	-0.314	4.3	4.7
Curr.direction	-0.059	0.204	NA	NA
Curr.magnitude	-0.107	-0.401	NA	NA
deltaT	0.082	-0.166	NA	NA
Dist. canyons	0.235	-0.131	6.5	10
Dist.coast	0.348	-0.051	6.6	9.5
Dist.seamounts	0.193	0.053	5.7	11.7
Dist.shelf	0.352	-0.075	NA	NA
EKE	-0.099	-0.418	8.3	6.2
mlotst	0.265	0.144	NA	NA
Salinity	0.182	0.377	15.9	3.6
Slope	-0.233	0.146	5.6	6.3
Temp_mean	-0.312	0.192	4.5	7.5
Temp_sd	0.343	0.029	NA	NA
zos	-0.330	-0.220	NA	NA

Entire period: critical areas for *Grampus griseus* resulted in the Alboran Sea up to the Algerian and Balearic basin, the Ligurian sea and the Tyrrhenian, particularly the central and the southern sector down to the Sicily strait.

Modeling results across the entire period highlight the species' preference for areas with specific oceanographic and topographic features. The most influential variable was bathymetry (29.2% of contribution, 22.8% permutation importance), indicating a strong association with mid-depth regions. Salinity and chlorophyll concentration also played a key role, suggesting that the species favors moderately saline and productive areas, likely due to prey availability. Proximity to seamounts, coastline, and canyons further influenced habitat suitability, emphasizing the importance of complex seafloor structures. Additionally, variables such EKE contributed to defining the habitat, reflecting the species' affinity for dynamic waters.

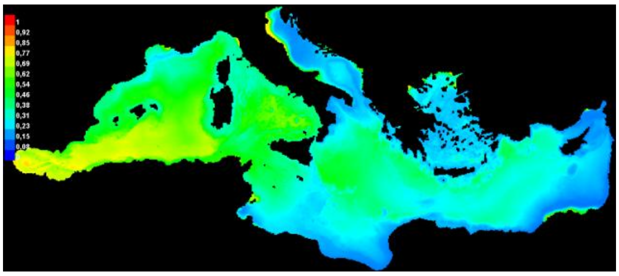
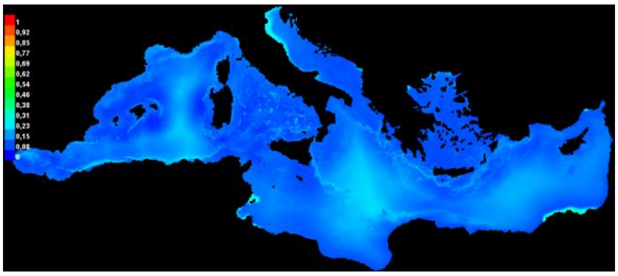
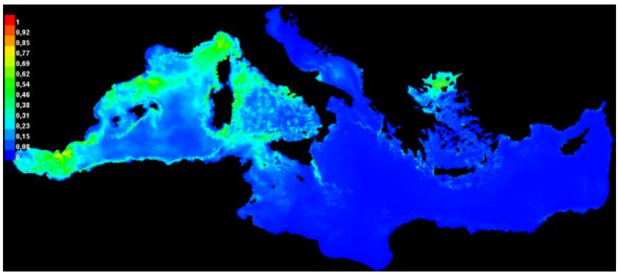
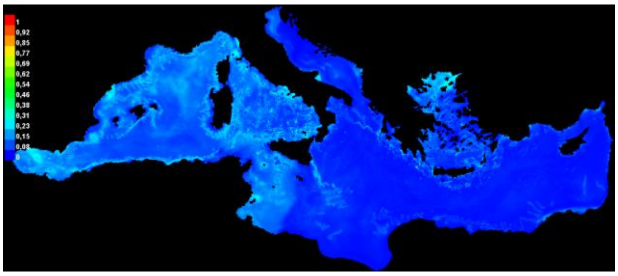
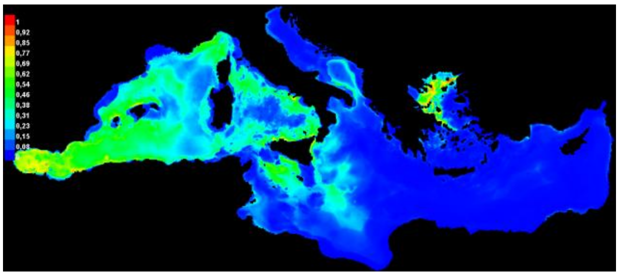
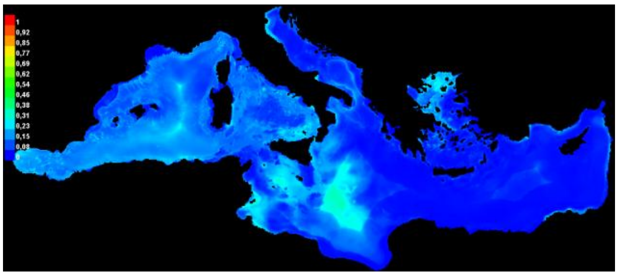
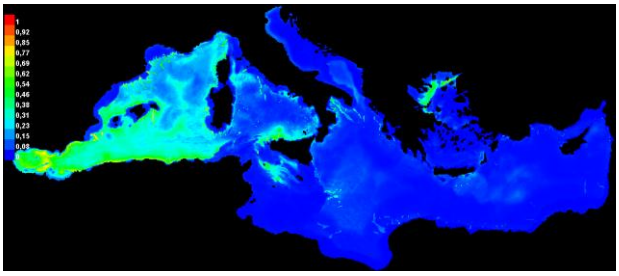
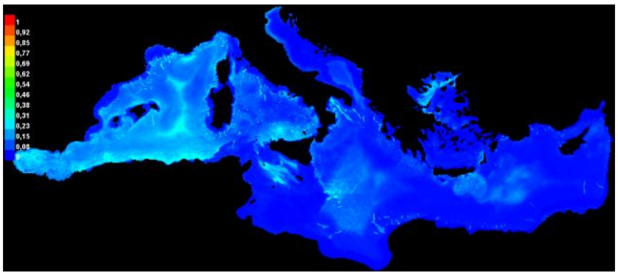
Seasonal SDM *Grampus griseus*	
Maxent - avg predictions	Maxent - std
WINTER (AUC train = 0.81, AUC test = 0.75)	
	
SPRING (AUC train = 0.89, AUC test =0.78)	
	
SUMMER (AUC train = 0.86, AUC test =0.76)	
	
AUTUMN (AUC train = 0.94, AUC test = 0.85)	
	

Figure 1.3.20. Species Distribution Model for *Grampus griseus* during the four seasons (WIN from January to March, SPR from April to June, SUM from July to September, AUT from October to December).

Table 1.3.28. *Grampus griseus* environmental variable contribution: summary of PCA loadings and Maxent output for each environmental variable over the seasons, expressed as percentage contribution and permutation importance. Top 3 values in each column are in bold.

	Winter				Spring				Summer				Autumn			
Variable	PCA		SDM output		PCA		SDM output		PCA		SDM output		PCA		SDM output	
	PC1	PC2	% contrib	perm. imp	PC1	PC2	% contrib	perm. imp	PC1	PC2	% contrib	perm. imp	PC1	PC2	% contrib	per. imp
Bathy metry	0.223	0.193	**23.2**	12.7	-0.345	0.023	7.9	8.5	-0.002	-0.377	**30.3**	**34.3**	-0.323	0.067	**26.8**	**43.3**
Chl_mean	0.143	-0.427	6.3	**27.6**	0.268	0.277	2.8	7.1	0.383	-0.040	3.5	11.1	-0.200	-0.363	1.4	2.1
Chl_sd	0.162	-0.161	2.2	3.1	0.319	0.214	**32**	**28.6**	0.378	-0.007	1.9	2.7	-0.162	-0.353	12.1	10.9
Curr.Dir	-0.046	0.370	NA	NA	0.019	0.374	NA	NA	-0.218	-0.154			0.101	0.045	NA	NA
Curr.magn	0.228	-0.236	NA	NA	-0.085	0.369	NA	NA	0.339	-0.093			-0.112	-0.356	NA	NA
deltaT	-0.011	-0.105	NA	NA	0.057	0.455	NA	NA	0.269	-0.093			0.274	-0.208	NA	NA
Dist. canyons	-0.232	-0.376	4.3	3.5	0.184	-0.313	16.6	10.7	0.157	0.262	4.5	5.2	0.235	-0.144	**23.1**	**6.3**
Dist.coast	-0.306	-0.269	2.6	2.7	0.299	-0.173	3.7	8.6	0.057	0.430	**10.2**	**14.4**	0.259	-0.112	6.1	13.1
Dist.seamounts	-0.336	-0.110	7.1	3.7	0.171	-0.066	**19.1**	**13.7**	-0.049	0.097	7.5	3.4	0.309	-0.083	2.4	2.9
Dist.shelf	-0.300	-0.304	NA	NA	0.326	-0.159	NA	NA	0.069	0.434			0.264	-0.121	NA	NA
EKE	0.218	-0.273	2.7	2.9	-0.083	0.288	5	7.8	0.357	-0.086	14	6.3	-0.127	-0.345	5.3	4.9
mlotst	-0.252	0.030	NA	NA	0.247	-0.002	NA	NA	-0.101	0.221			0.138	0.352	NA	NA
Salinity	-0.314	0.256	**47.1**	**39.7**	0.243	0.015	2	2.8	-0.341	0.105	**16.9**	**12.7**	0.304	0.244	**18.1**	**11.8**
Slope	0.113	0.120	4.3	1.4	-0.169	0.315	8.4	6.5	-0.175	-0.295	6.5	4	-0.167	0.300	3.8	3.9
Temp_mean	0.356	-0.141	0.2	2.9	-0.347	-0.208	2.6	5.7	-0.319	-0.160	4.9	6.1	-0.199	0.342	0.9	0.9
Temp_sd	0.142	0.224	NA	NA	0.229	0.083	NA	NA	-0.020	0.348			0.347	-0.033	NA	NA
zos	0.360	-0.088	NA	NA	-0.330	-0.055	NA	NA	0.231	-0.250			-0.358	0.033	NA	NA

Seasonal patterns: **throughout the seasons, *Grampus griseus* consistently selects habitats characterized by intermediate depths, dynamic oceanographic conditions, and complex underwater topography. These preferences are mirrored in the habitat suitability maps, which consistently highlight the western Mediterranean Sea, and particularly the Alboran, Balearic, and Ligurian seas as key for the species.** In **winter**, salinity emerges as the dominant driver (47.1% of contribution, 39.7% importance) with preferences for moderately saline water masses. Bathymetry was also highly significant, showing a preference for intermediate waters. In **spring**, the species strongly favors areas with high variability in primary productivity (chl_sd, 32% of contribution, 28.6% of importance) such as oceanographic fronts, alongside seamounts and canyon proximity, and moderate to steep slopes. During **summer**, bathymetry becomes the primary factor (30.3% of contribution, 34.3% of importance) followed by salinity and EKE, pointing to a preference for productive, energetic slope habitats. In **autumn** bathymetry still dominates (26.8% contribution, 43.3% of importance), with canyon proximity and productivity variability reinforcing the importance of structurally rich and trophically dynamic environments.

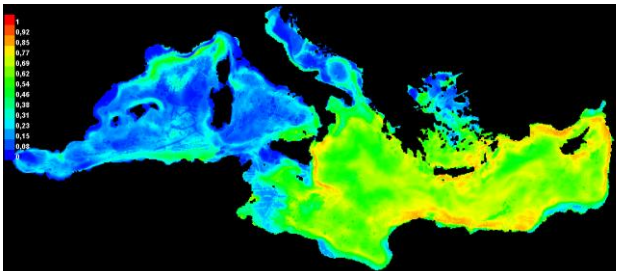
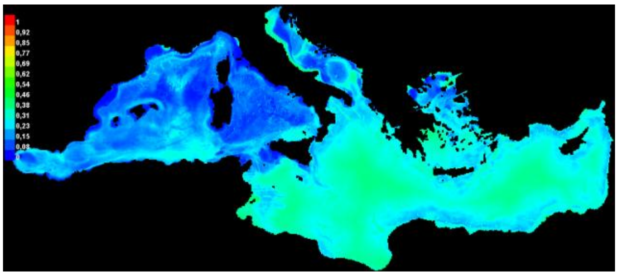
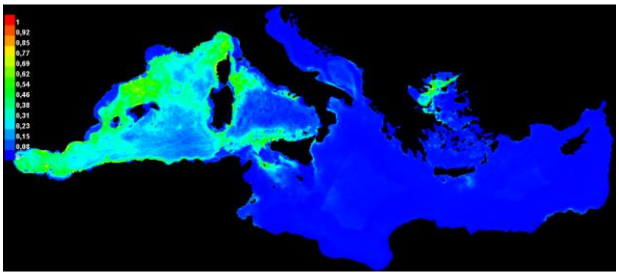
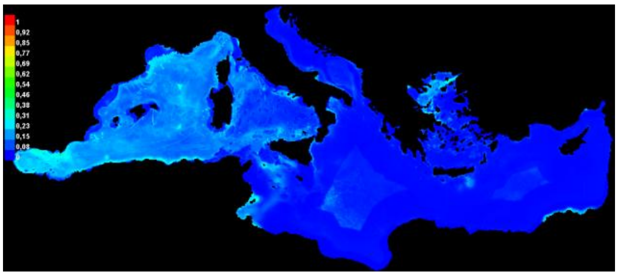
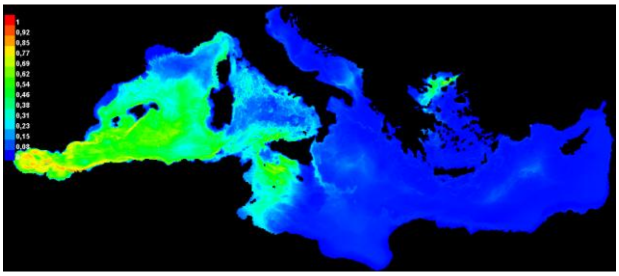
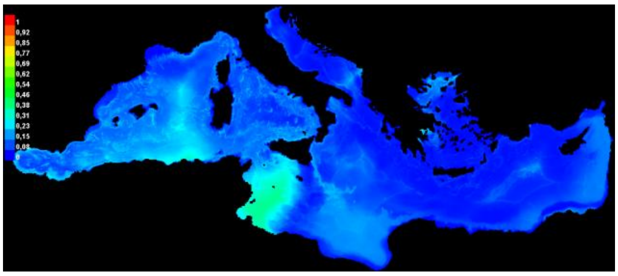
<table>
<tr><th colspan="2">Habitats Directive Reporting periods Grampus griseus</th></tr>
<tr><td colspan="2">2008-2012
(AUC train = 0.92, AUC test = 0.78)</td></tr>
<tr><td>Maxent - avg predictions</td><td>Maxent - std</td></tr>
<tr><td></td><td></td></tr>
<tr><td colspan="2">2013-2018
(AUC train = 0.90, AUC test = 0.81)</td></tr>
<tr><td></td><td></td></tr>
<tr><td colspan="2">2019-2024
(AUC train = 0.87, AUC test = 0.81)</td></tr>
<tr><td></td><td></td></tr>
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Figure 1.3.21. Species Distribution Model for *Grampus griseus* covering the three Habitat Directive reporting periods (2008-2012, 2013-2018, 2019-2024).

Table 1.3.29. *Grampus griseus* environmental variable contribution: summary of PCA loadings and Maxent output for each environmental variable over the reporting periods, expressed as percentage contribution and permutation importance.

2008-2012			2013-2018		2019-2024	
Variable	SDM output		SDM output		SDM output	
	% contrib	perm. imp	% contrib	perm. imp	% contrib	perm. imp
Bathy metry	5.6	6.1	**28.7**	**29**	**20.2**	**21.6**
Chl_mean	1.3	1.5	**10.4**	**15.8**	4.9	**11.1**
Chl_sd	4.4	6.3	20.8	18.4	2.7	3.8
Curr.Dir	NA	NA	NA	NA	NA	NA
Curr.magn	NA	NA	NA	NA	NA	NA
deltaT	NA	NA	NA	NA	NA	NA
Dist. canyons	**11.3**	**10.1**	9.2	3.9	5.1	6.5
Dist.coast	4.6	4.1	8.5	9.6	2.9	3.8
Dist.seamounts	9	4.6	6.7	10.3	5.3	**11.4**
Dist.shelf	NA	NA	NA	NA	NA	NA
EKE	23.4	12.1	8.5	5.9	2.2	2.3
mlotst	NA	NA	NA	NA	NA	NA
Salinity	**16.9**	**20.6**	1.1	2	**48.2**	**26.8**
Slope	**10.2**	**16.5**	4.5	4.1	6.7	8.6
Temp_mean	**13.3**	**18.2**	1.6	1.1	1.9	4
Temp_sd	NA	NA	NA	NA	NA	NA
zos	NA	NA	NA	NA	NA	NA

Habitats Directive Reporting Periods: over time, the species showed a progressively broader and less defined use of suitable habitats in the western Mediterranean Sea, strongly associated with intermediate depths and complex underwater topography. In the **first period (2008-2012)**, suitability was more mostly limited to continental slopes areas from the Alboran Sea up to the Ligurian sea, driven primarily by EKE (23.4% of contribution, 12.1 of importance) and salinity indicating a preference for moderately dynamic and saline offshore waters. During the **second period (2013-2018)** suitable areas expanded towards more pelagic regions especially in the Balearic basin and the Tyrrhenian Sea. Bathymetry (28.7% contribution, 29% importance) and chlorophyll variability became key drivers, pointing to an increasing reliance on productive environments. In the **third period (2019-2024)**, habitat suitability increased and consolidated towards the southwestern Mediterranean basin with lower suitability in the Ligurian and Tyrrhenian sea, with salinity (48% contribution, 26.8% importance) emerging as the dominant factor, followed by bathymetry, slope and proximity to seamounts and canyons.

Suitable habitat for *Globicephala melas*

Technical summary

Globicephala melas primarily inhabits the westernmost Mediterranean, with core areas around the Alboran Sea and in the northwestern Mediterranean up to the western Ligurian sea. Suitable habitats remain largely confined to this region throughout the year, though their distribution shifts seasonally. The Alboran Sea stands out as a critical and consistent habitat, especially during autumn when it serves as the species' almost exclusive refuge. In summer, the species' range extends to include both the Alboran Sea and the northwestern Mediterranean Sea, while in winter and spring, it adapts to more widespread environmental conditions. These patterns highlight the importance of protecting dynamic, productive, and structurally complex marine areas in the western Mediterranean to support the conservation of *Globicephala melas*.

Summary of Habitat Suitability: across methods and timeframes, *Globicephala melas* consistently shows a selective use of habitat, with strong preferences for dynamic, productive, and topographically complex environments. Selection analysis, PCA, and SDMs all highlight the importance of chlorophyll concentrations, current dynamics, and seafloor features in defining suitable habitat. While SDMs quantify spatial suitability and shifts over time, PCA provides insight into seasonal transitions and environmental gradients. Habitat selection analysis offers a detailed view of specific environmental thresholds used by the species. Over time, the species' reliance on productivity and dynamic processes has remained strong, although the role of salinity has become increasingly important, particularly in recent years. These patterns suggest that *Globicephala melas* is sensitive to broader oceanographic processes, including those related to climate-driven changes in water mass properties and circulation in the Mediterranean Sea.

Seasonal Patterns: both PCA and SDMs indicate strong seasonal dynamics in *Globicephala melas* habitat use. In **winter** and **spring**, EKE emerges as the dominant factor in SDMs, accounting for over 40% of habitat suitability, reflecting the species' strong reliance on mesoscale activity. These seasons are also marked by consistent associations with bathymetric complexity and proximity to seamounts and canyons. During **spring** and **summer**, the influence of chlorophyll concentration increases, suggesting a seasonal shift toward moderately deep, productive offshore waters. By **autumn**, the species' suitable habitat contracts primarily to the Alboran Sea, with salinity becoming the principal environmental driver. PCA supports this seasonal narrative, capturing transitions in habitat characteristics and environmental gradients that mirror the spatial patterns seen in SDMs. In particular, both methods highlight an expansion of habitat use during summer and a narrowing during autumn, with consistent reliance on productive and dynamic waters throughout the year.

Habitat Directive Reporting Periods (2008–2024):
From **2008 to 2012**, *Globicephala melas* favored dynamic, productive waters with high chlorophyll variability, moderate to high salinity and association with bathymetric features within the Alboran, Balearic, and Ligurian Seas. Between **2013 and 2018**, ocean dynamics (EKE) played a stronger role. From **2019 to 2024**, the southward range seems to enlarge toward the Algerian basin, with salinity emerging as the main driver while productivity and ocean dynamics declined in importance. Overall, these shifts suggest changes in habitat preferences likely driven by broader oceanographic changes.

Key Findings:

- *Globicephala melas* primarily occupies the westernmost Mediterranean, with core habitats in the Alboran Sea and in the northwestern Mediterranean.

- Suitable habitat remains largely in this region year-round but shifts seasonally, with the Alboran Sea serving as a critical refuge especially during autumn.

- The species shows strong preference for dynamic, productive, and structurally complex environments, including areas with high chlorophyll, strong currents, and proximity to seafloor features like canyons and seamounts.

- Seasonal habitat use varies: winter and spring suitability is driven by ocean dynamics (EKE), summer habitats are linked to productivity (chlorophyll), and autumn habitats contract mainly to the Alboran Sea where salinity dominates.

- Over time (2008–2024), habitat suitability shifted from productivity and chlorophyll-driven areas toward stronger influence of salinity and broader Atlantic water inflows, indicating sensitivity to changing oceanographic conditions.

Key important areas for *Globicephala melas*:

- **Alboran Sea:** the most critical and consistent habitat, especially important during autumn when it serves as the species' primary refuge.

- **Northwestern Mediterranean:** notably active as suitable habitat in summer, including coastal regions off Spain and France.

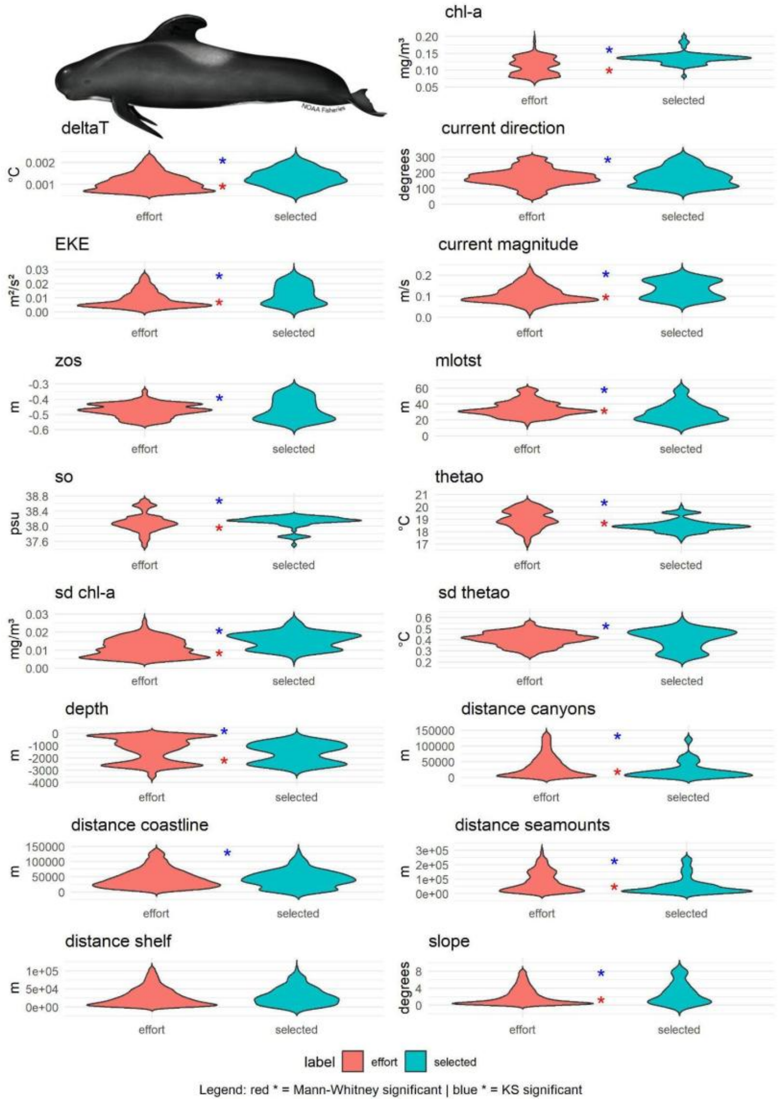
- **Balearic Sea:** part of the concentrated suitable habitat in mid-periods.

- **Ligurian Sea:** another core area with strong habitat suitability in several periods.

- **Algerian basin:** saw an expansion of suitable habitat southward in recent years (2019–2024).

Areas near seafloor structures such as canyons and seamounts throughout the western Mediterranean Sea, which provide important topographic complexity favored by the species.

1) Habitat Selection of *Globicephala melas*. Comparison between selected environmental variable range at present locations and available range of values across the effort area.

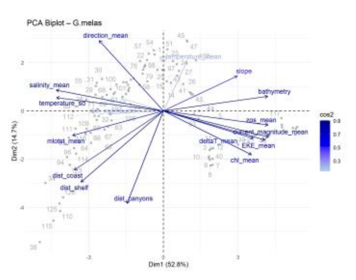
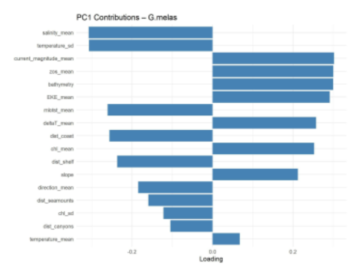
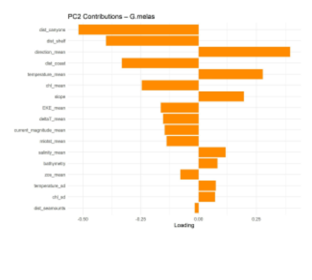
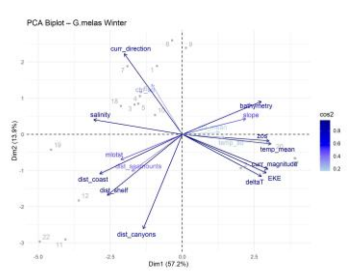
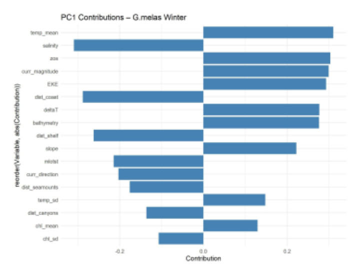
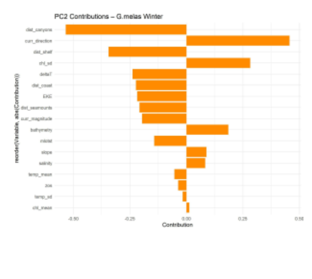
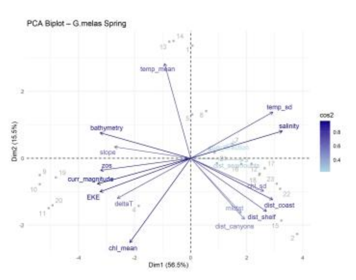
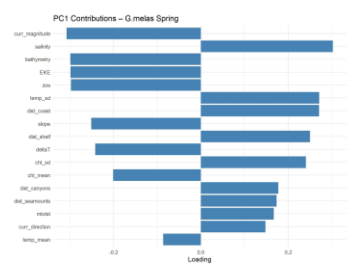
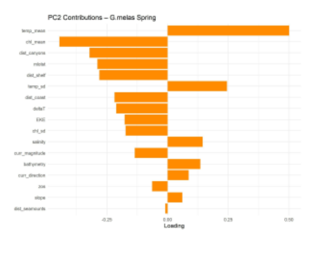
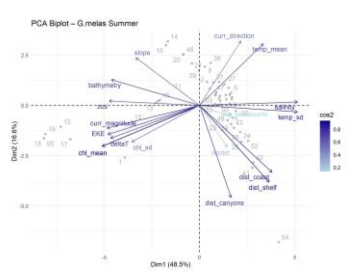
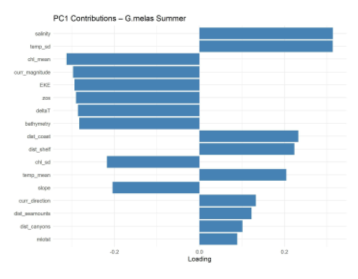
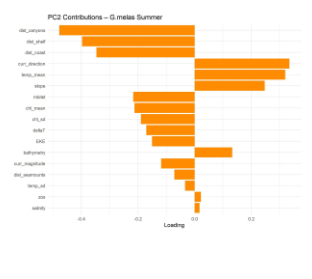
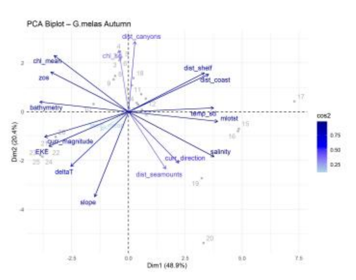
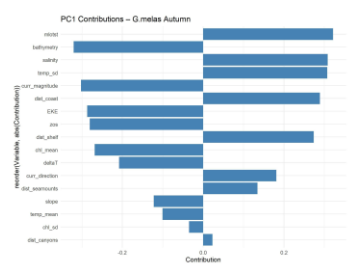
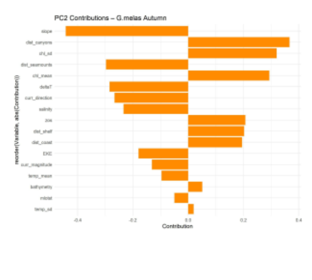


Summary.
Globicephala melas appears to select a well-defined set of environmental conditions, showing a preference for highly productive areas (e.g., higher values of chlorophyll, phytoplankton concentration, and net primary production), dynamic waters (e.g., higher current speeds and EKE), and specific salinity ranges. The species also prefer areas near seafloor features such as canyons and seamounts, indicating a strong association with structured marine habitats.

Figure 1.3.22. Habitat selection of *Globicephala melas*. Distribution of environmental variable values at presence locations (left, red violin plots) and available range of values across the effort area (right, blue violin plots). Include Mann-Whitney U and Kolmogorov–Smirnov tests.

2) Principal Component Analysis (PCA) of *Globicephala melas*

Table 1.3.30. *Globicephala melas* PCA Biplot and Barplot of PC1 (blue) and PC2 (orange) loadings for different temporal resolutions.

Temporal res	Biplot	Loadings PC1	Loadings PC2
Entire period 67.5% explained variance			
Winter 71.1% explained variance			
Spring 72% explained variance			
Summer 65.1% explained variance			
Autumn 69.3% explained variance			

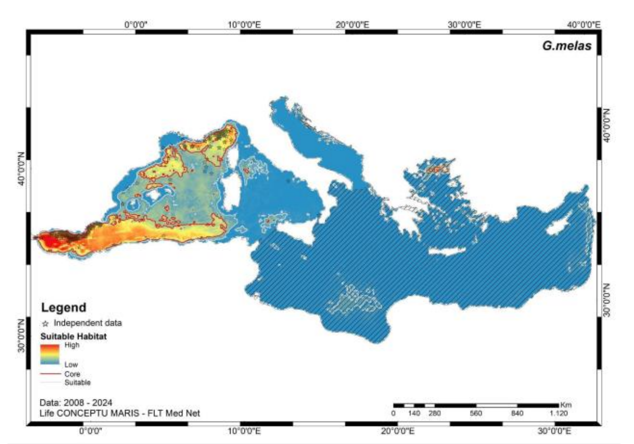
The PCAs show relatively high explained deviance percentages, indicating a more defined selection by the species for specific environmental features. Over the entire period, *Globicephala melas* are associated with pelagic low-salinity waters, thermally stable and

dynamic, with strong currents, high zos values, deep and high in chlorophyll and its variability. However, salinity may reflect a regional signal, particularly due to the low-salinity waters in the Alboran Sea, and may not represent a true ecological preference. During **winter**, there's a clear gradient from warm, high salinity and with strong zos values, closer to coastal, shelf and canyons water to deeper, steeper, dynamic (strong currents and high EKE) thermally unstable waters. In **spring**, *Globicephala melas* shows a gradient of preference from highly dynamic, deep, warmer waters to thermally unstable, productive one, further from structural features (coast, shelf and canyons). During **summer** the habitat preference gradient moves from thermally and dynamically unstable, productive deep waters, to low salinity waters, further from structural features (shelf, coast and canyons), indicating probably more mixed, open-ocean conditions. In **autumn**, the gradient goes from deep, high dynamic (EKE and magnitude) productive waters, with steeply sloped conditions, to offshore, saline, thermally variable, deeply mixed waters.

3) Globicephala melas Species Distribution Model.

Entire period SDM Globicephala melas
(AUC train = 0.92, AUC test = 0.89)

Maxent - avg predictions



Maxent - std

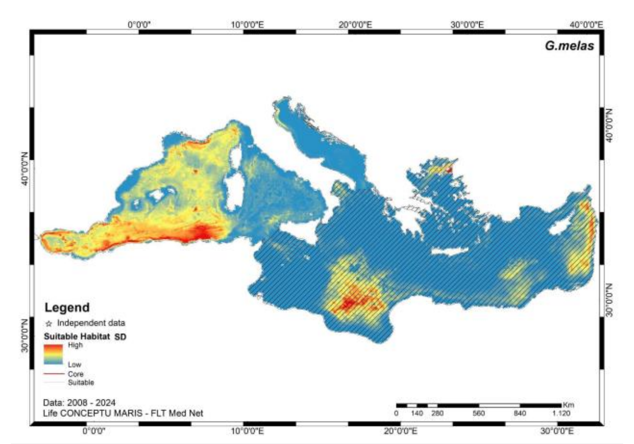


Figure 1.3.23. Species Distribution Model for *Globicephala melas* covering the entire period from 2008 to 2024.

Table 1.3.31. Validation results of the Species Distribution Model for *Globicephala melas* using an independent dataset, both within the LIFE CONCEPTU MARIS project area (western Mediterranean and Adriatic regions) and across the entire Mediterranean basin.

External validation with independent dataset	W Med + Adriatic		Mediterranean Sea	
	Maximum test sensitivity plus specificity Logistic threshold	Natural jenks threshold	Maximum test sensitivity plus specificity Logistic threshold	Natural jenks threshold
AUC	0.89	0.88	0.94	0.95
Precision	0.81	0.65	0.89	0.80
F1	0.86	0.78	0.91	0.88

Table 1.3.31. ***Globicephala melas*** **summary of PCA loadings and Maxent output for each environmental variable over the entire period, expressed as percentage contribution and permutation importance.**

Entire period				
Variable	PCA		SDM output	
	PC1	PC2	% contrib	per. imp
Bathymetry	0.300	0.082	19.6	30.6
Chl_mean	0.253	-0.246	33	8.4
Chl_sd	-0.122	0.071	4.6	7.6
Curr.direction	-0.185	0.396	NA	NA
Curr.magnitude	0.302	-0.146	NA	NA
deltaT	0.258	-0.154	NA	NA
Dist. canyons	-0.105	-0.519	2.6	6.7
Dist.coast	-0.256	-0.332	1.9	5.9
Dist.seamounts	-0.159	-0.017	3.4	5.3
Dist.shelf	-0.237	-0.400	NA	NA
EKE	0.291	-0.164	11.1	7.3
mlotst	-0.261	-0.138	NA	NA
Salinity	-0.308	0.117	20.5	12.3
Slope	0.212	0.196	2.4	10.9
Temp_mean	0.068	0.277	0.9	4.9
Temp_sd	-0.307	0.074	NA	NA
zos	0.300	-0.079	NA	NA

Entire period: overall, suitable areas are primarily located in the Alboran Sea stretching along the northern African coast and in the north-western Mediterranean up to the Ligurian sea. The most influential environmental variable in determining habitat suitability of *Globicephala melas* was Chlorophyll mean (33% of contribution), highlighting the importance of moderately productive waters likely linked to prey availability. Salinity, bathymetry and EKE also played a major role, indicating a strong preference for dynamic, less saline areas with intermediate depths.

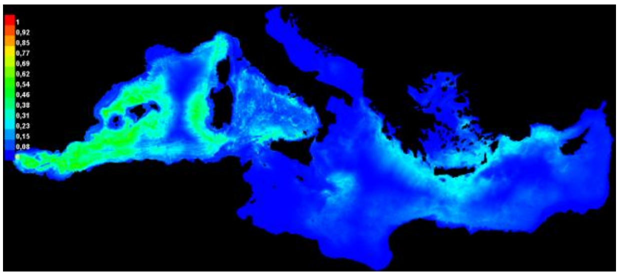
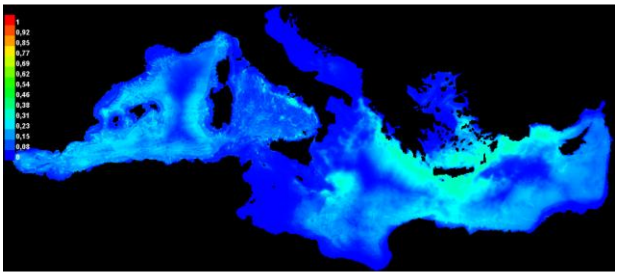
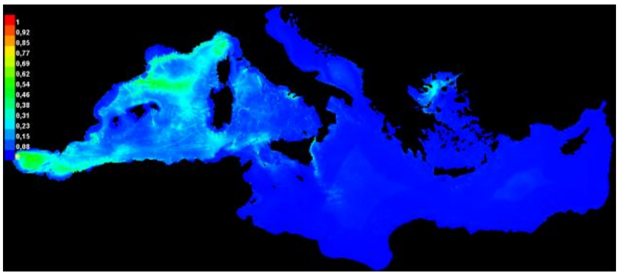
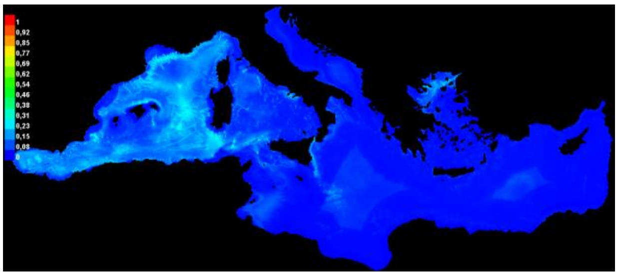
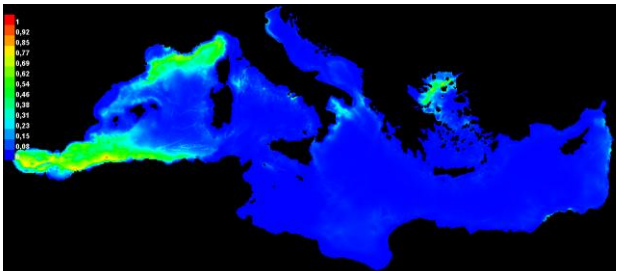
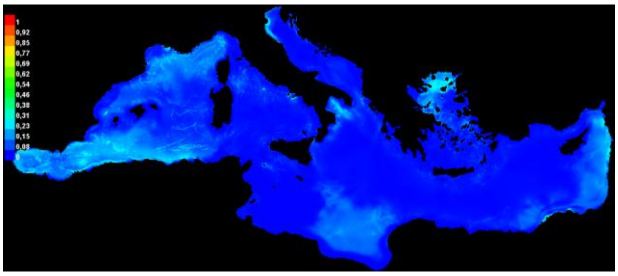
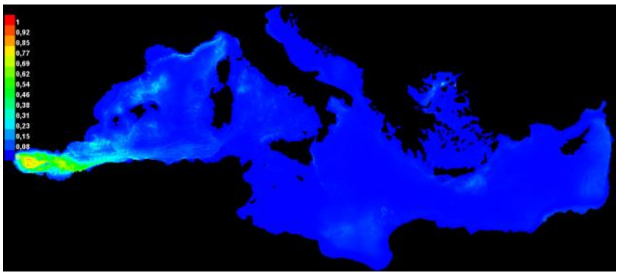
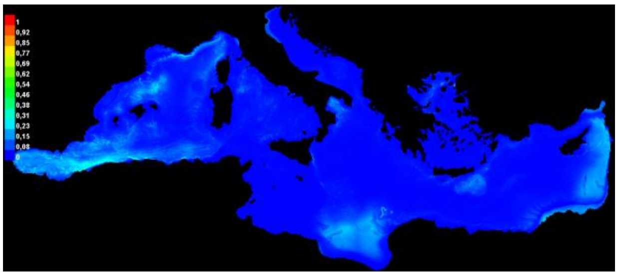
Seasonal SDM *Globicephala melas*	
Maxent - avg predictions	Maxent - std
WINTER (AUC train = 0.96; AUC test = 0.88)	
	
SPRING (AUC train = 0.93; AUC test = 0.84)	
	
SUMMER (AUC train = 0.93; AUC test = 0.89)	
	
AUTUMN (AUC train = 0.98; AUC test = 0.93)	
	

Figure 1.3.24. Species Distribution Model for *Globicephala melas* during the four seasons (WIN from January to March, SPR from April to June, SUM from July to September, AUT from October to December).

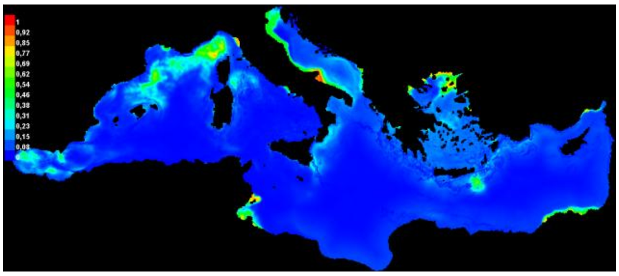
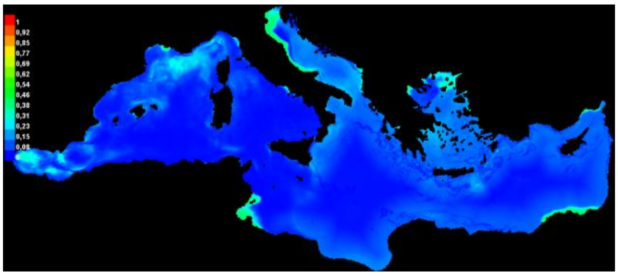
Table 1.3.32. *Globicephala melas* environmental variable contribution: summary of PCA loadings and Maxent output for each environmental variable over the seasons, expressed as percentage contribution and permutation importance. Top 3 values in each column are in bold.

	Winter				Spring				Summer				Autumn			
Variable	PCA		SDM output		PCA		SDM output		PCA		SDM output		PCA		SDM output	
	PC1	PC2	% contrib	perm. imp	PC1	PC2	% contrib	perm. imp	PC1	PC2	% contrib	perm. imp	PC1	PC2	% contrib	per. imp
Bathy metry	0.276	0.185	16	26.4	-0.299	0.135	12.5	15.4	-0.283	0.133	22.8	39.2	-0.321	0.051	9.1	29.1
Chl_mean	0.129	0.013	8.3	13.5	-0.201	-0.445	19.3	23.4	-0.312	-0.212	15.9	13.2	-0.268	0.293	6	14.1
Chl_sd	-0.107	0.282	3.1	11.4	0.241	-0.173	4.9	9.3	-0.217	-0.189	9.9	6.9	-0.035	0.320	0.8	2.8
Curr.Dir	-0.203	0.456			0.148	0.087			0.133	0.335			0.181	-0.267		
Curr.magn	0.299	-0.196			-0.307	-0.135			-0.297	-0.118			-0.302	-0.132		
deltaT	0.277	-0.238			-0.242	-0.211			-0.285	-0.171			-0.208	-0.284		
Dist. canyons	-0.136	-0.534	10.5	9.1	0.177	-0.322	8.8	7	0.101	-0.478	6.1	7.6	0.023	0.366	3.1	19.9
Dist.coast	-0.288	-0.223	1.2	2.8	0.270	-0.218	6.2	6.5	0.233	-0.347	2.6	8.5	0.289	0.195	0.3	1.3
Dist.seamounts	-0.176	-0.208	5.7	15.7	0.173	-0.010	5	15.1	0.122	-0.072	2.6	3	0.135	-0.297	3.8	14.2
Dist.shelf	-0.262	-0.344			0.250	-0.281			0.223	-0.397			0.274	0.202		
EKE	0.293	-0.218	41.9	3.6	-0.299	-0.176	37.3	5.2	-0.294	-0.150	16.4	7.5	-0.287	-0.180	5.5	4.9
mlotst	-0.215	-0.143			0.167	-0.289			0.089	-0.217			0.322	-0.050		
Salinity	-0.309	0.083	5.9	7	0.302	0.144	1.3	2.1	0.314	0.017	11.6	4.1	0.308	-0.234	67.8	6.7
Slope	0.222	0.088	3.4	9.6	-0.251	0.061	1.8	3	-0.204	0.248	2.9	4.9	-0.122	-0.443	2.7	4.9
Temp_mean	0.310	-0.053	4	0.9	-0.086	0.501	2.9	13.1	0.205	0.320	9.1	5.1	-0.101	-0.097	0.9	2
Temp_sd	0.148	-0.017			0.271	0.245			0.314	-0.034			0.307	0.020		
zos	0.303	-0.036			-0.298	-0.064			-0.290	0.022			-0.281	0.207		

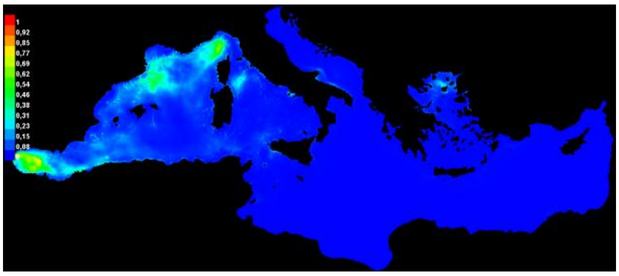
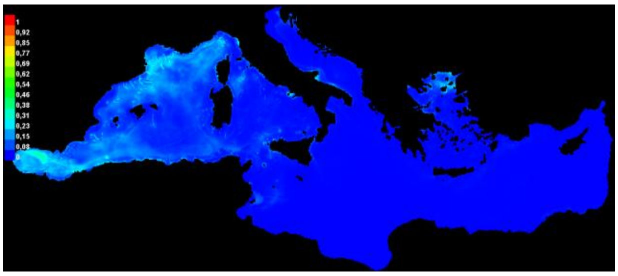
Seasonal patterns: overall, suitable areas are primarily located around the Alboran Sea and along the continental regions off the coasts of Spain and France. Throughout the seasons, suitable habitat for the species remains largely confined to the westernmost Mediterranean, although its spatial distribution varies seasonally. Core areas consistently include the Alboran Sea, which becomes almost the exclusive habitat during autumn. In summer, suitable habitat is more polarized between the Alboran Sea and the northwestern Mediterranean, while in winter and spring, the species appears to adapt to more widespread environmental conditions. The distribution of *Globicephala melas* is shaped by a combination of oceanographic and topographic factors, with regional and seasonal variations. In **winter and spring**, the species shows a strong preference for dynamic, productive waters where EKE is the dominant variable (41.9% of contribution in winter, 37.5% in spring), indicating reliance on mesoscale activity. Bathymetry, proximity to submarine canyons and seamounts consistently enhances habitat suitability across these seasons. During **spring and summer**, chlorophyll concentration becomes more influential, suggesting a shift towards moderately deep, productive offshore waters. By **autumn**, the species' habitat narrows significantly with suitability concentrated in the Alboran Sea. Salinity becomes the primary driver of habitat selection, with a preference for low-salinity waters, while bathymetric complexity continues to play an important role.

Habitats Directive Reporting periods *Globicephala melas*

2008-2012
(AUC train = 0.93, AUC test = 0.91)

Maxent - avg predictions	Maxent - std
	

2013-2018
(AUC train = 0.95, AUC test = 0.89)

2019-2024
(AUC train = 0.93, AUC test = 0.89)

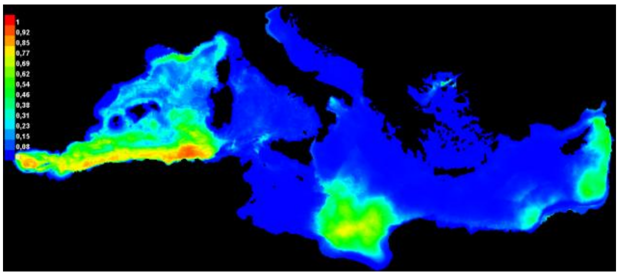
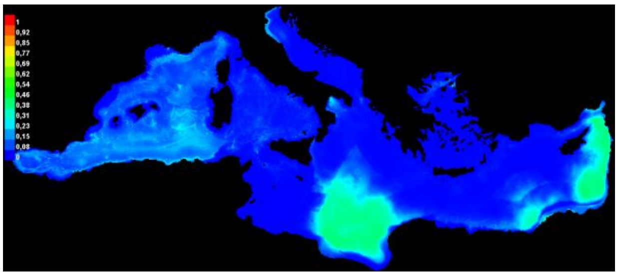
	

Figure 1.3.25. Species Distribution Model for *Globicephala melas* covering the three Habitat Directive reporting periods (2008-2012, 2013-2018, 2019-2024).

Table 1.3.33. *Globicephala melas* environmental variable contribution: summary of PCA loadings and Maxent output for each environmental variable over the reporting periods, expressed as percentage contribution and permutation importance.

	2008-2012		2013-2018		2019-2024	
Variable	SDM output		SDM output		SDM output	
	% contrib	perm. imp	% contrib	perm. imp	% contrib	perm. imp
Bathy metry	0.1	0.1	10.3	5	**22.2**	**24.6**
Chl_mean	0.7	1	**17.9**	**28.7**	**15.1**	**10.1**
Chl_sd	**55.8**	**38.7**	1	5.2	0.7	1.2

Dist. canyons	1	0.3	8	8.5	4.2	12.3
Dist.coast	6.3	**23.3**	1.5	2.5	1.2	6.4
Dist.seamounts	5.4	**13.8**	13.2	**21.2**	1.8	4.9
EKE	3.5	3.9	**30.1**	3.5	6.6	5.6
Salinity	**16.6**	**17.8**	1.5	0.1	**46.2**	**30.6**
Slope	3.2	1	1.1	2.6	1.5	3.1
Temp_mean	7.5	0	15.3	22.7	0.4	1.2
Temp_sd	NA	NA	NA	NA	NA	NA
zos	NA	NA	NA	NA	NA	NA

Habitats Directive Reporting Periods: over time, the habitat suitability of *Globicephala melas* has undergone notable spatial and environmental shifts. During the **first period (2008-2012)** the species favored areas with high chlorophyll variability (55.8% contribution), reflecting a strong association with dynamic productivity also associated with oceanographic features (e.g., distance from coast and seamounts). Salinity also played a significant role, with preference for moderate to high levels. In the **second period (2013-2018)** the suitability became more geographically concentrated (primarily in the Alboran Sea, Balearic region and Ligurian Sea) with EKE emerging as the dominant factor (30.1% of contribution) indicating a growing reliance on mesoscale oceanographic features. Productivity and topographic complexity also remained important, while salinity declined in relevance and SST began to gain influence. During the **third period (2019-2024)** the distribution expanded southward, particularly into the Algerian basin, with salinity becoming the most influential variable (46.3%), showing a strong preference for lower-salinity waters potentially tied to Atlantic flow. Meanwhile, EKE and chl-a influence diminished.

Suitable habitat for Ziphius cavirostris

Technical summary

Ziphius cavirostris demonstrates a strong and consistent preference for deep, offshore habitats characterized by both structural complexity and dynamic oceanographic conditions.

Summary of Habitat Suitability: *Ziphius cavirostris* favors areas with higher productivity, as indicated by elevated chlorophyll concentrations and variable net primary production. The species is typically found in regions with lower temperatures and a very narrow range of salinity, suggesting sensitivity to specific water mass characteristics. The species is closely associated with deep-sea features such as submarine canyons and seamounts, which are likely important for foraging. These habitats provide both structural complexity and enhanced prey availability due to local oceanographic processes. Preferred habitats are generally at intermediate to far distances from the coast, well beyond the continental shelf, in waters commonly exceeding 1000 meters in depth. Across all seasons, *Ziphius cavirostris* selects deep, warm, and thermally stable waters with low variability in chlorophyll and weaker currents, indicating a preference for less variable, structurally consistent pelagic zones.

Seasonal Patterns: the species shows a marked preference for deep, productive, and dynamic offshore environments, especially near seamounts and canyons, reflecting active foraging in oceanographically active waters. In **winter**, distance to seamounts and canyons, along with chlorophyll variability, drive a broad distribution favoring dynamic areas like the Balearic and Ligurian seas. In **spring**, bathymetry dominates, with productivity indicators pointing to deep offshore habitats in the central Tyrrhenian, Ligurian, northern Balearic, and partly Alboran seas. **Summer** sees a contraction to four core areas plus some spots south and west of Sardinia island, with seamount proximity and temperature as key factors. In **autumn**, the range expands coastward, still driven by canyons, seamounts, and bathymetry, underlining the species' consistent reliance on underwater features.

Habitat Directive Reporting Periods (2008–2024): between 2008 to 2024, *Ziphius cavirostris* showed spatial distribution shifts while consistently favoring deep, topographically complex habitats, especially in the **central Tyrrhenian**, **Ligurian**, **northern Balearic** and **Alboran** regions. Over time, the species showed an increasing reliance on the Tyrrhenian and Ligurian areas. While the importance of productivity fluctuated, bathymetry and proximity to underwater structures (seamounts and canyons) consistently dominated habitat suitability models.

- **2008–2012**: Distribution was broad; **distance to seamounts** was the top driver. The species favored **dynamic, prey-rich offshore habitats** from the Alboran Sea to Ligurian, Tyrrhenian and waters around Sardinia.

- **2013–2018**: Range became more **concentrated**. **Bathymetry** emerged as the main predictor, though seamount and canyon proximity remained important. **Temperature** began to play a stronger role.

- **2019–2024**: **Bathymetry** and **seamount distance** stayed dominant, with **slope** and **mean temperature** gaining importance. Core habitats remained centered in the **Tyrrhenian** and **Ligurian Seas**.

Key Findings:

Ziphius cavirostris is a deep-diving cetacean with a strong, year-round affinity for deep, thermally stable, and topographically complex offshore habitats, especially submarine canyons and seamounts. These findings underscore the importance of protecting deep-sea canyon systems and maintaining the ecological integrity of these productive offshore environments

Ziphius cavirostris occupies well confined core habitats in deep, offshore areas characterized by structural complexity and dynamic oceanographic conditions.

Key important areas for *Ziphius cavirostris:* The central Tyrrhenian Sea, central Ligurian Sea (notably the Genoa Canyon within the Pelagos Sanctuary), northern Balearic Islands, and the Alboran Sea are repeatedly identified as core habitats, particularly near steep slopes and canyon systems

Conservation priorities for *Ziphius cavirostris*:

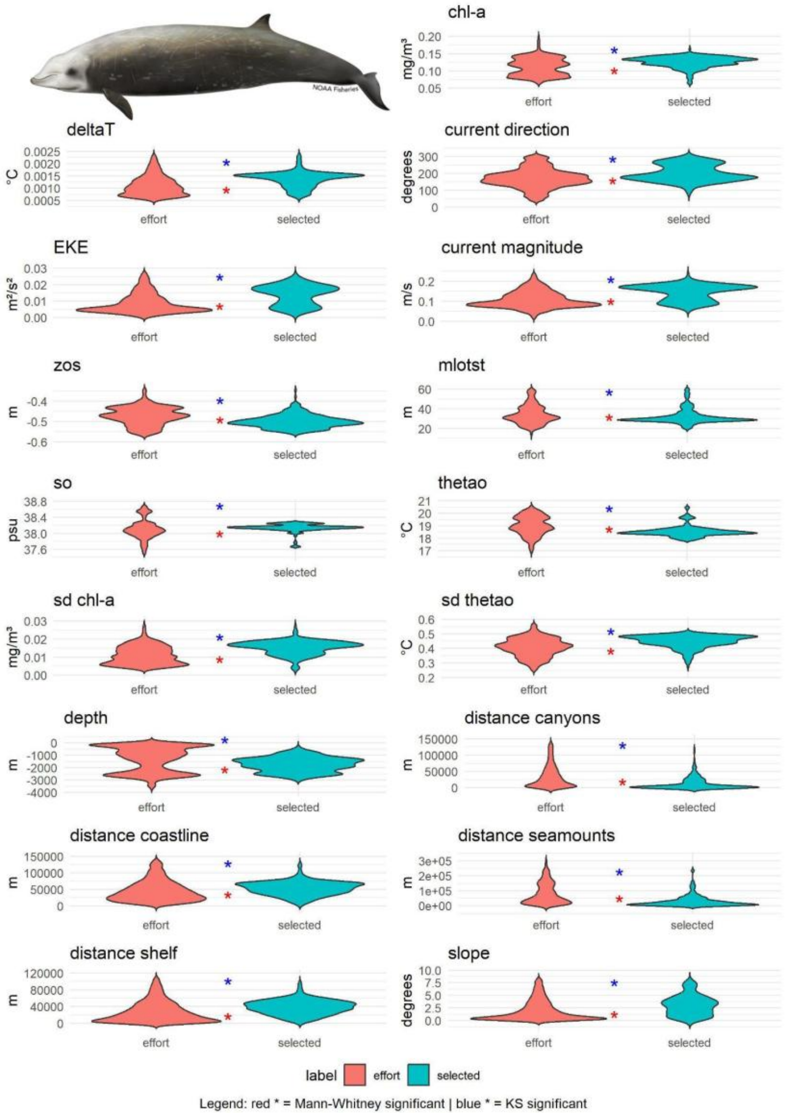
Prioritize Core Regions:

- **The Ligurian and Central Tyrrhenian Sea** are persistent core areas and should be **central to conservation efforts**.
- Secondary priorities include the **northern Balearic and Alboran Seas**, where observed changes require further investigation to understand and address the drivers of potential shifts.
- **Preserve deep offshore Oceanographic Features Supporting Productivity.** Prioritize regions with **structural complexity,** notably **seamounts**, **submarine canyons**, and **steep slopes,** which are critical for supporting the core ecological needs of *Ziphius cavirostris* in the Mediterranean sea.

Integrate Spatial Protection Tool. Design or update Marine Protected Areas (MPAs) to:

- Recognize the **increasing reliance** on the **Tyrrhenian** and **Ligurian** Seas over time.
- Include deep offshore zones near **seamounts and canyons.**
- **Seasonally dynamic habitats based on observed shifts.**

1) Habitat Selection of *Ziphius cavirostris*. Comparison between selected environmental variable range at present locations and available range of values across the effort area.

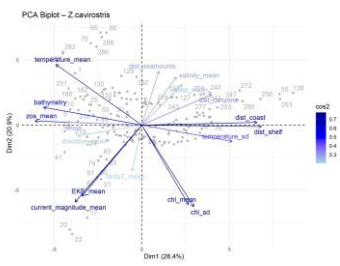
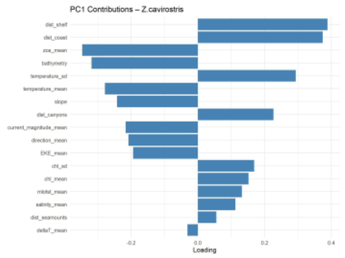
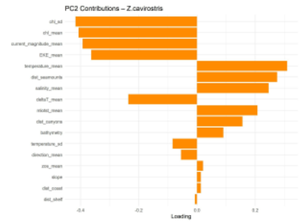
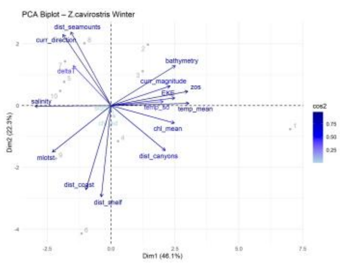
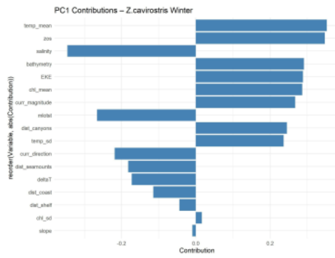
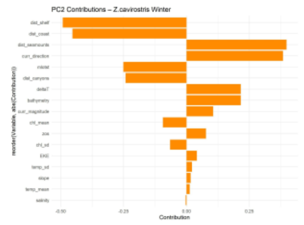
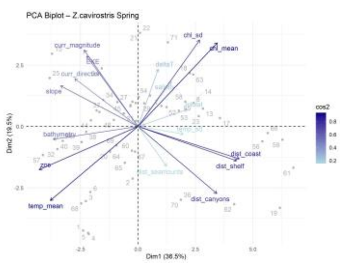
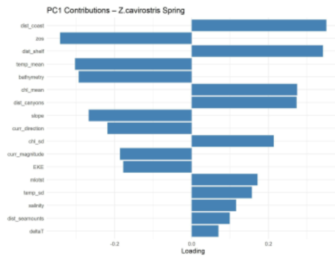
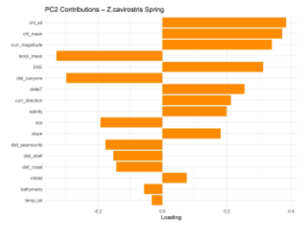
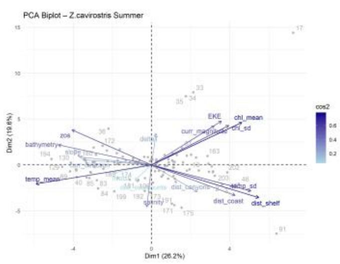
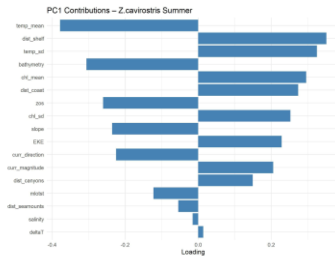
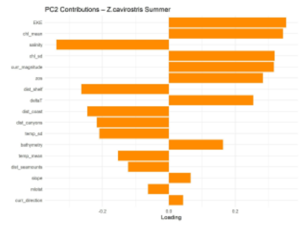
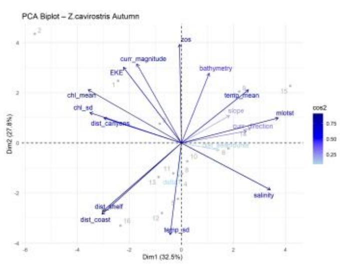
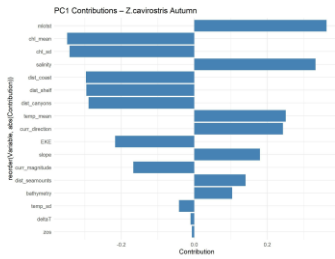
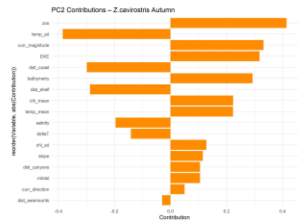


Summary.
Ziphius cavirostris appears to select specific habitat features, favoring more productive areas (higher chlorophyll, net primary production variability, and lower temperatures) and dynamic environments (close to canyons and seamounts), typically at intermediate distances from the coast, while occupying a very narrow range of salinity.

Figure 1.3.26. Habitat selection of *Ziphius cavirostris*. Distribution of environmental variable values at presence locations (left, red violin plots) and available range of values across the effort area (right, blue violin plots). Include Mann-Whitney U and Kolmogorov–Smirnov tests.

2) Principal Component Analysis (PCA) of *Ziphius cavirostris*

Table 1.3.34. *Ziphius cavirostris* PCA Biplot and Barplot of PC1 (blue) and PC2 (orange) loadings for different temporal resolutions.

Temporal res	Biplot	Loadings PC1	Loadings PC2
Entire period 49.3% explained variance			
Winter 68.4% explained variance			
Spring 56% explained variance			
Summer 45.8% explained variance			
Autumn 60.3% explained variance			

Over the entire period, *Ziphius cavirostris* is associated with deep offshore habitats, far from the coast and continental shelf, and characterized by thermally stable conditions, low chlorophyll variability, and weaker currents. This suggests a preference for less variable, structurally consistent pelagic zones. **Across all seasons, *Ziphius cavirostris* consistently selects deep, productive offshore waters, with stable thermal profiles and structural complexity, likely reflecting key foraging grounds over slope systems.** In **winter**, the species shows a marked preference for deep, warm, productive and dynamic environments, indicating foraging activity in oceanographically active offshore waters. During **spring**, the species still shows preference for pelagic, deep, dynamic and productive areas. The preference for deep, dynamic and productive, waters is also confirmed in **summer**. During **autumn**, higher depths are still preferred, together with steeper slopes, higher productivity and salinity, structured and well-mixed waters.

3) Ziphius cavirostris Species Distribution Model.

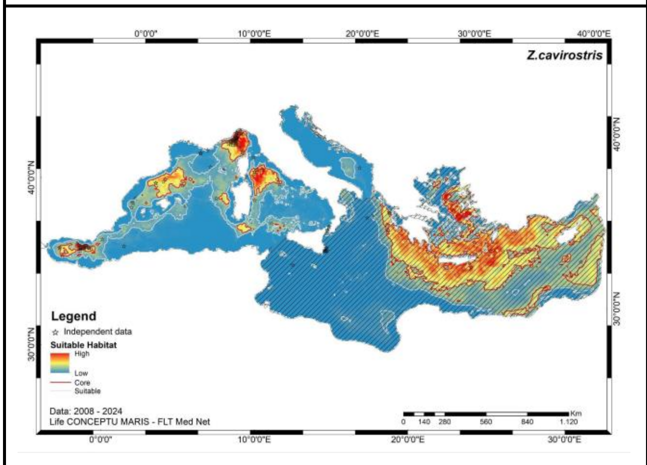
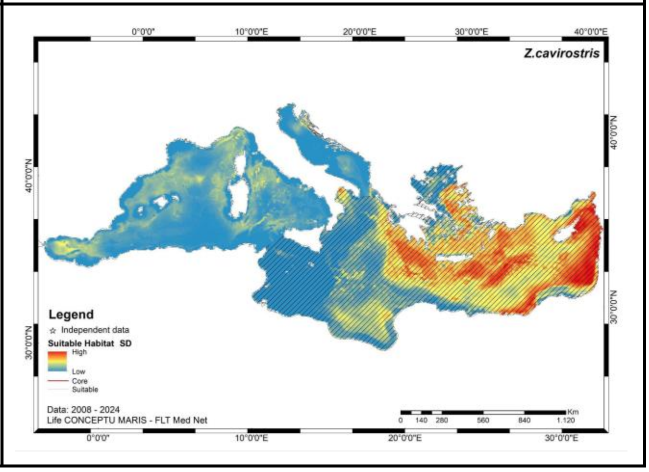
Entire period SDM Ziphius cavirostris (AUC train = 0.92; AUC test = 0.89)	
Maxent - avg predictions	Maxent - std
	

Figure 1.3.27. Species Distribution Model for *Ziphius cavirostris* covering the entire period from 2008 to 2024.

Table 1.3.35. Validation results of the Species Distribution Model for *Ziphius cavirostris* using an independent dataset, both within the LIFE CONCEPTU MARIS project area (western Mediterranean and Adriatic regions) and across the entire Mediterranean basin.

External validation with independent dataset	**W Med + Adriatic**		**Mediterranean Sea**	
	Maximum test sensitivity plus specificity Logistic threshold	Natural jenks threshold	Maximum test sensitivity plus specificity Logistic threshold	Natural jenks threshold
AUC	0.91	0.91	0.79	0.78
Precision	0.93	0.75	0.77	0.64
F1	0.83	0.83	0.73	0.73

Table 1.3.36. *Ziphius cavirostris* environmental variable contribution: summary of PCA loadings and Maxent output for each environmental variable over the entire period, expressed as percentage contribution and permutation importance. Top 3 values in each column are in bold.

Entire period				
Variable	PCA		SDM output	
	PC1	PC2	% contrib	per. imp
Bathymetry	-0.319	0.091	**28.8**	**32.3**
Chl_mean	0.152	-0.407	2.9	4.4
Chl_sd	0.169	-0.417	4.9	3.2
Curr.direction	-0.208	-0.055	NA	NA
Curr.magnitude	-0.217	-0.393	NA	NA
deltaT	-0.031	-0.236	NA	NA
Dist. canyons	0.226	0.156	7.9	3.1
Dist.coast	0.374	0.013	2.4	5.6
Dist.seamounts	0.055	0.275	**17.9**	**15.7**
Dist.shelf	0.388	-0.007	NA	NA
EKE	-0.194	-0.363	2.9	2.8
mlotst	0.132	0.208	NA	NA
Salinity	0.112	0.246	6.3	5.6
Slope	-0.243	0.013	3.6	5.3
Temp_mean	-0.279	0.309	**22.5**	**22**
Temp_sd	0.293	-0.084	NA	NA
zos	-0.347	0.021	NA	NA

Entire period: Overall, the species shows a strong dependence on complex, dynamic deep-sea habitats primarily located in the central Tyrrhenian Sea, central Ligurian Sea, northern Balearic Islands, and the Alboran Sea particularly near the steep slopes of the western Mediterranean. The most influential variable for the entire period was bathymetry (28.8% contribution, 32.3% importance) followed by mean temperature, pointing out the species' strong preference for deep and temperate waters. Distance to seamounts and canyons further contribute to its habitat suitability, suggesting that oceanographic features and proximity to underwater structures enhance prey availability.

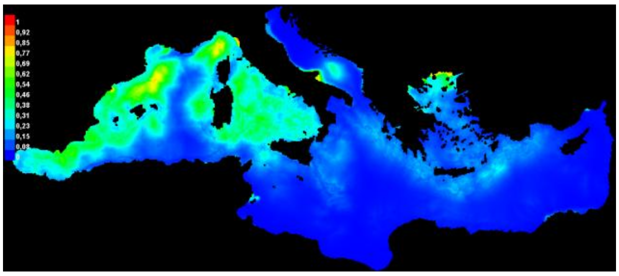
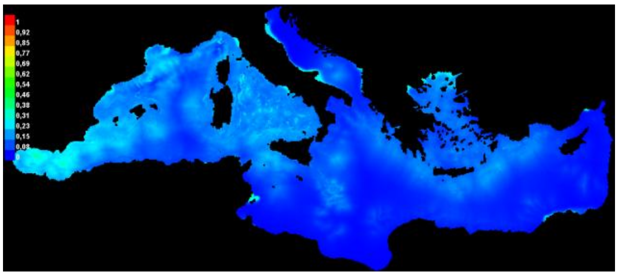
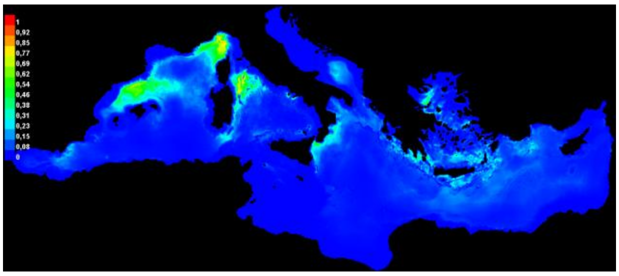
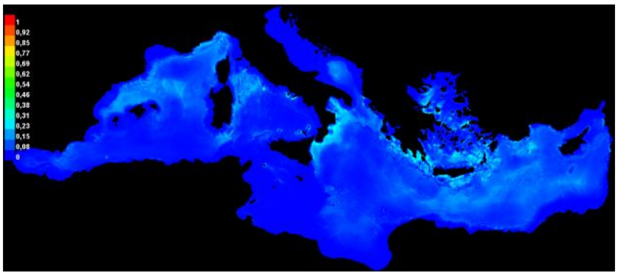
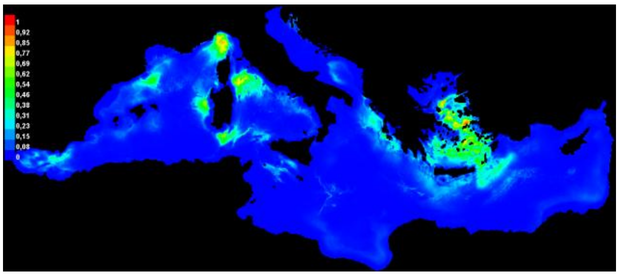
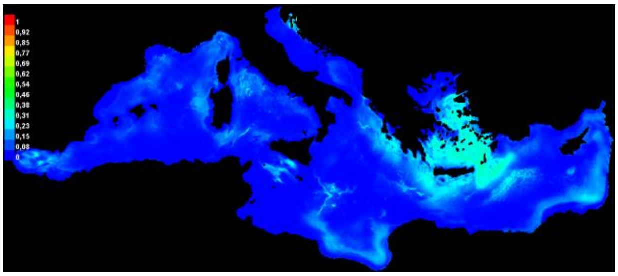
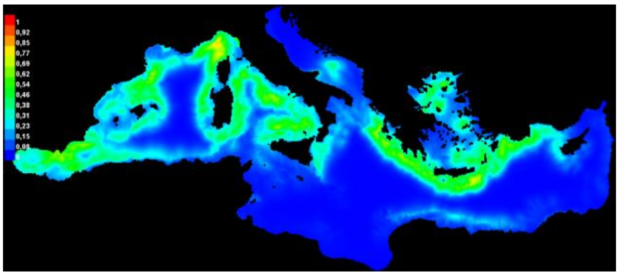
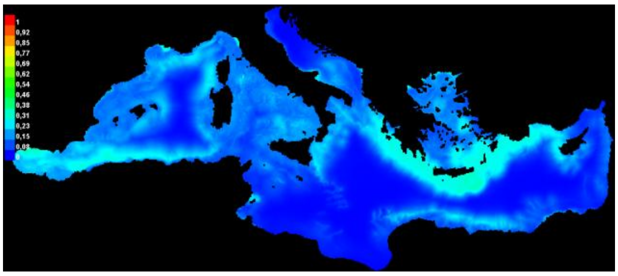
Seasonal SDM *Ziphius cavirostris*	
Maxent - avg predictions	Maxent - std
WINTER (AUC train = 0.91; AUC test = 0.80)	
	
SPRING (AUC train =0.93; AUC test = 0.89)	
	
SUMMER (AUC train =0.93; AUC test = 0.90)	
	
AUTUMN (AUC train = 0.90; AUC test = 0.79)	
	

Figure 1.3.28. Species Distribution Model for *Ziphius cavirostris* during the four seasons (WIN from January to March, SPR from April to June, SUM from July to September, AUT from October to December).

Table 1.3.37. *Ziphius cavirostris* environmental variable contribution: summary of PCA loadings and Maxent output for each environmental variable over the seasons, expressed as percentage contribution and permutation importance. Top 3 values in each column are in bold.

Variable	Winter				Spring				Summer				Autumn			
	PCA		SDM output		PCA		SDM output		PCA		SDM output		PCA		SDM output	
	PC1	PC2	% contrib	perm. imp	PC1	PC2	% contrib	perm. imp	PC1	PC2	% contrib	perm. imp	PC1	PC2	% contrib	per. imp
Bathy metry	0.291	0.216	4.9	0.1	-0.294	-0.057	**29.2**	**40.8**	-0.306	0.163	**21.5**	**16.6**	0.104	0.293	**14.4**	**16.8**
Chl_mean	0.287	-0.094	1.4	4.2	0.275	0.372	8.1	5.6	0.296	0.344	1.5	14.3	-0.348	0.224	0.3	0.9
Chl_sd	0.016	-0.065	**21.2**	**14.7**	0.214	0.384	**17.7**	9.3	0.253	0.318	1	3.6	-0.342	0.128	9.4	7.4
Curr.Dir	-0.219	0.383			-0.219	0.212			-0.225	0.043			0.243	0.050		
Curr.magn	0.268	0.106			-0.187	0.340			0.205	0.316			-0.167	0.332		
deltaT	-0.173	0.216			0.070	0.255			0.014	0.255			-0.010	-0.141		
Dist. canyons	0.245	-0.242	**21.4**	**33.9**	0.273	-0.298	8	2.9	0.149	-0.217	6.3	3.3	-0.289	0.105	**28.6**	**20.1**
Dist.coast	-0.115	-0.453	2.4	2.5	0.351	-0.143	2	5.9	0.274	-0.245	2.8	8.2	-0.297	-0.298	10.9	3
Dist.seamounts	-0.182	0.398	**30.7**	**17.4**	0.099	-0.177	**14.5**	**15.6**	-0.055	-0.123	**26**	**18.6**	0.141	-0.030	**20.5**	**35.6**
Dist.shelf	-0.044	-0.492			0.342	-0.152			0.351	-0.264			-0.296	-0.287		
EKE	0.289	0.041	0.8	1.7	-0.178	0.313	5.2	5	0.229	0.353	5	2.2	-0.217	0.318	1.6	1
mlotst	-0.266	-0.251			0.171	0.076			-0.123	-0.063			0.362	0.105		
Salinity	-0.346	-0.003	0.6	0.2	0.116	0.199	10.5	11.8	-0.015	-0.339	6.7	2.7	0.332	-0.196	3.1	3.7
Slope	-0.009	0.016	4.3	11	-0.268	0.181	3.7	2	-0.235	0.066	4.2	3.9	0.180	0.115	3.5	3.5
Temp_mean	0.353	0.012	12.4	14.3	-0.304	-0.329	1.2	1.2	-0.378	-0.153	**25**	**26.5**	0.251	0.223	7.9	8
Temp_sd	0.237	0.022			0.157	-0.033			0.325	-0.209			-0.042	-0.384		
zos	0.348	0.077			-0.342	-0.192							-0.007	0.414		

Seasonal patterns: **throughout the seasons, the distribution of *Ziphius cavirostris* is shaped primarily by topographic features and productivity-related variables, reflecting its deep-diving ecology and prey specialization.** In **winter**, the species is mostly influenced by distance to seamounts (30.7% of contribution, 17.4% of importance) and canyons, as well as chlorophyll variability, favoring dynamic environments such as the Balearic area and Ligurian sea but with a more spread favoured habitat. During **spring**, bathymetry becomes the dominant factor (29.2% contribution, 40.1% importance), indicating a preference for deep offshore habitats with chlorophyll levels and variability further supporting the role of productivity in shaping suitable areas. Suitable habitats are mostly confined to specific areas in the central Tyrrhenian and Ligurian, northern

Balearic islands and partially Alboran sea. In **summer**, the distribution further contracts towards the four main core areas, including also some spots south and west of Sardinia islands, with distance to seamounts and temperature emerging as key drivers. In **autumn**, the species' range broadens including more coastal zones, but continues to be defined by distance to canyons (28.6% contribution, 20.1% importance), seamounts and bathymetry, highlighting a persistent reliance on underwater geological features.

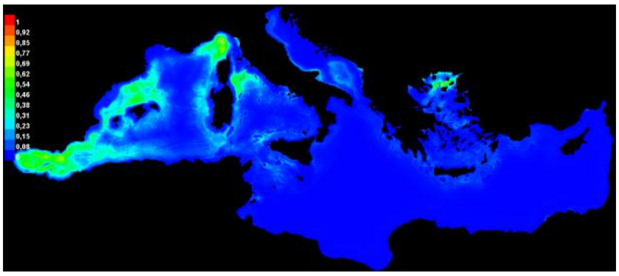
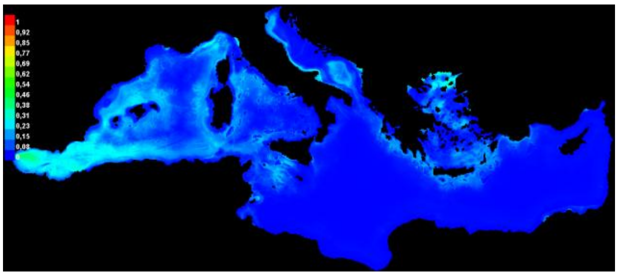
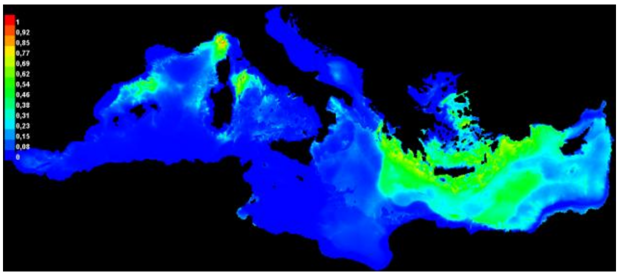
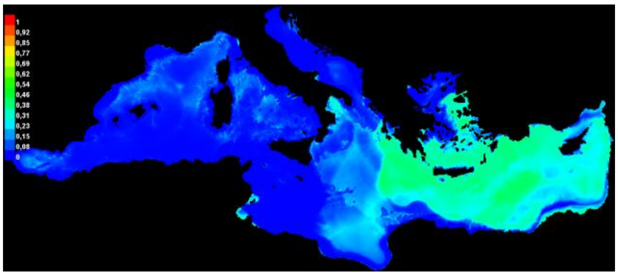
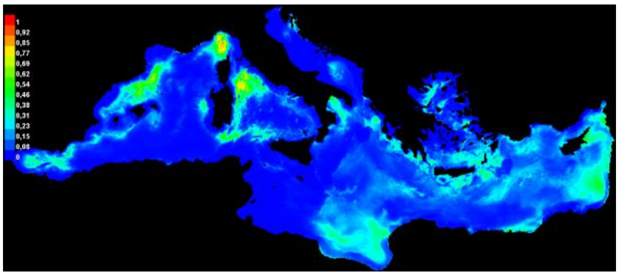
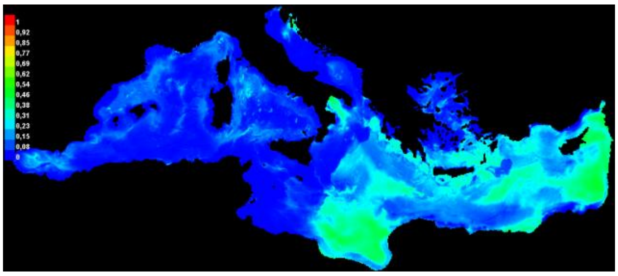
Habitats Directive Reporting periods *Ziphius cavirostris*	
2008-2012 (AUC train = 0.93, AUC test = 0.85)	
Maxent - avg predictions	Maxent - std
	
2013-2018 (AUC train = 0.94, AUC test = 0.91)	
	
2019-2024 (AUC train = 0.94, AUC test = 0.90)	
	

Figure 1.3.29. Species Distribution Model for *Ziphius cavirostris* covering the three Habitat Directive reporting periods (2008-2012, 2013-2018, 2019-2024).

Table 1.3.38. ***Ziphius cavirostris*** **environmental variable contribution: summary of PCA loadings and Maxent output for each environmental variable over the reporting periods, expressed as percentage contribution and permutation importance.**

	2008-2012		2013-2018		2019-2024	
Variable	SDM output		SDM output		SDM output	
	% contrib	perm. imp	% contrib	perm. imp	% contrib	perm. imp
Bathy metry	8.4	15.2	28	34.6	27.8	27.1
Chl_mean	12.4	14.7	2.7	17.4	3.2	3.7
Chl_sd	17.3	6.9	0.5	1.7	2.5	4.2
Curr.Dir	NA	NA	NA	NA	NA	NA
Curr.magn	NA	NA	NA	NA	NA	NA
deltaT	NA	NA	NA	NA	NA	NA
Dist. canyons	6.1	3.9	19.5	8.5	9.3	9.1
Dist.coast	7.6	7.7	1.5	3.3	3.2	3.9
Dist.seamounts	21	25.3	22.2	14.4	26.3	24.9
Dist.shelf	NA	NA	NA	NA	NA	NA
EKE	14	2.6	1.4	1	2.8	4
mlotst	NA	NA	NA	NA	NA	NA
Salinity	1	3.6	3.3	10.9	3.7	1.6
Slope	7	8	2.2	2.3	7.1	7.4
Temp_mean	5.1	12.2	18.8	5.9	14.2	14
Temp_sd	NA	NA	NA	NA	NA	NA
zos	NA	NA	NA	NA	NA	NA

Habitats Directive Reporting Periods: from 2008 to 2024, the distribution of *Ziphius cavirostris* exhibited spatial shifts while maintaining key areas such as the central Tyrrhenian sea, the Ligurian Sea and the northern Balearic region. Throughout the entire study period, *Ziphius cavirostris* consistently relied on deep, topographically complex habitats, while also showing an increasing sensitivity to temperature and variability in productivity. During the **first period (2008–2012),** the species showed a strong affinity for deep offshore waters near seamounts, with distance to seamounts emerging as the most important variable (21% importance, 25.3% contribution). Areas with moderate and variable productivity and complex seafloor features also played key roles, indicating a reliance on dynamic, prey-rich habitats. Suitable areas stretched from the Alboran sea towards the northern Balearic islands, the Liguran and central Tyrrhenian sea and steep waters around Sardinia island. **In the second period (2013–2018)**, the distribution became more concentrated, with bathymetry becoming the dominant driver (34.6% importance, 28% contribution). Distance to seamounts and canyons remained highly influential, reinforcing the significance of underwater structures. Although the importance of productivity variables declined, mean temperature emerged as a significant factor. In the **third period (2019–2024),** bathymetry and distance to seamounts continued to be the top predictors, while slope and mean temperature gained importance. Main core areas seem to rely on the Tyrrhenian and Ligurian seas.

Suitable habitat for *Physeter macrocephalus*

Technical summary

Summary of Habitat Suitability: *Physeter macrocephalus* selects deep, productive, and dynamic marine habitats characterized by higher chlorophyll, phytoplankton concentration, and net primary production, alongside strong currents and EKE, within specific salinity ranges. PCA analysis links the species to deep, steep-slope, thermally stable areas shaped by topographic complexity and moderate to high oceanic dynamism. SDMs identify **key high-suitability areas in the northwestern Mediterranean, including the Ligurian Sea and parts of the Tyrrhenian Sea extending down along the continental slope to the southeastern corner of Sardinia.** Bathymetry and mean temperature are the most influential environmental factors, indicating a preference for deep, moderately warm offshore waters. Salinity and chlorophyll variability also play significant roles, emphasizing the species' affinity for dynamic environments that promote prey aggregation.

Seasonal Patterns: *Physeter macrocephalus* shows seasonal shifts reflecting the use of slope systems and frontal zones where vertical mixing enhances prey availability. In **winter**, The species favors structurally complex canyons and seamounts with stable temperatures and moderate productivity, indicating focused foraging in stable yet active zones. Low sea surface height anomalies (zos) dominate, favoring productive oceanic features, while bathymetry and moderate temperatures support deep offshore presence. **Spring** sees a shift to deep coastal-shelf transitions with thermally dynamic, productive waters, likely exploiting shelf-break zones during environmental turnover. Habitat is strongly influenced by chlorophyll variability and ocean dynamics (EKE), with salinity also gaining importance. **Summer** habitat use moves toward open-water, deep, productive zones with dynamic vertical mixing. Habitat suitability is primarily driven by bathymetry and intermediate temperatures, maintaining presence in core areas but less widespread. **Autumn** targets bathymetric edges with moderate productivity and strong eddy activity, corresponding to post-summer prey redistribution. Habitat use expands, influenced by bathymetry, distance to coast, salinity, and zos, reflecting broader environmental suitability.

Habitat Directive Reporting Periods (2008–2024): over the Habitats Directive reporting periods (2008–2024), core suitable habitats remained stable in the Ligurian, Balearic, and Tyrrhenian Seas enlarging broadly towards southern regions during the last period. Initially, habitat preference was driven by chlorophyll variability and offshore distance, reflecting reliance on dynamic productivity and offshore habitats. Later periods showed a shift toward bathymetry and thermal conditions as dominant factors, with increasing importance of salinity and stable physical features like canyons, suggesting adaptation to more persistent oceanographic conditions. The combined influence of depth and productivity remains central to habitat suitability for *Physeter macrocephalus*.

Key Message:

The sperm whale (*Physeter macrocephalus*) consistently selects deep, dynamic marine habitats shaped by topographic complexity, stable thermal conditions, and high productivity. These areas support prey aggregation and are essential to the species' foraging behavior and long-term presence in the Mediterranean.

Core Suitable Areas

- Ligurian Sea
- Northern and central Tyrrhenian Sea
- Continental slope south of Sardinia
- Balearic region

These regions combine bathymetric depth, moderate temperatures, chlorophyll-rich waters, and strong oceanic dynamics (currents, eddies).

Seasonal Habitat Patterns

- **Winter:** Favors canyons and seamounts with stable temperatures and moderate productivity (e.g., Ligurian and central Tyrrhenian Seas).
- **Spring**: Moves toward shelf-break zones, with dynamic thermal and salinity conditions, likely exploiting prey during seasonal turnover.
- **Summer**: Occupies deep, offshore zones with intermediate temperatures and productive vertical mixing.
- **Autumn**: Expands distribution along bathymetric edges and dynamic waters, likely in response to post-summer prey redistribution.

Trends Across EU Habitats Directive Periods (2008–2024)

- **Core habitats remained stable in the Ligurian, Tyrrhenian, and Balearic Seas.**
- From 2013 onward, suitable areas expanded southward, linked to thermal stability, salinity, and persistent physical features like canyons.

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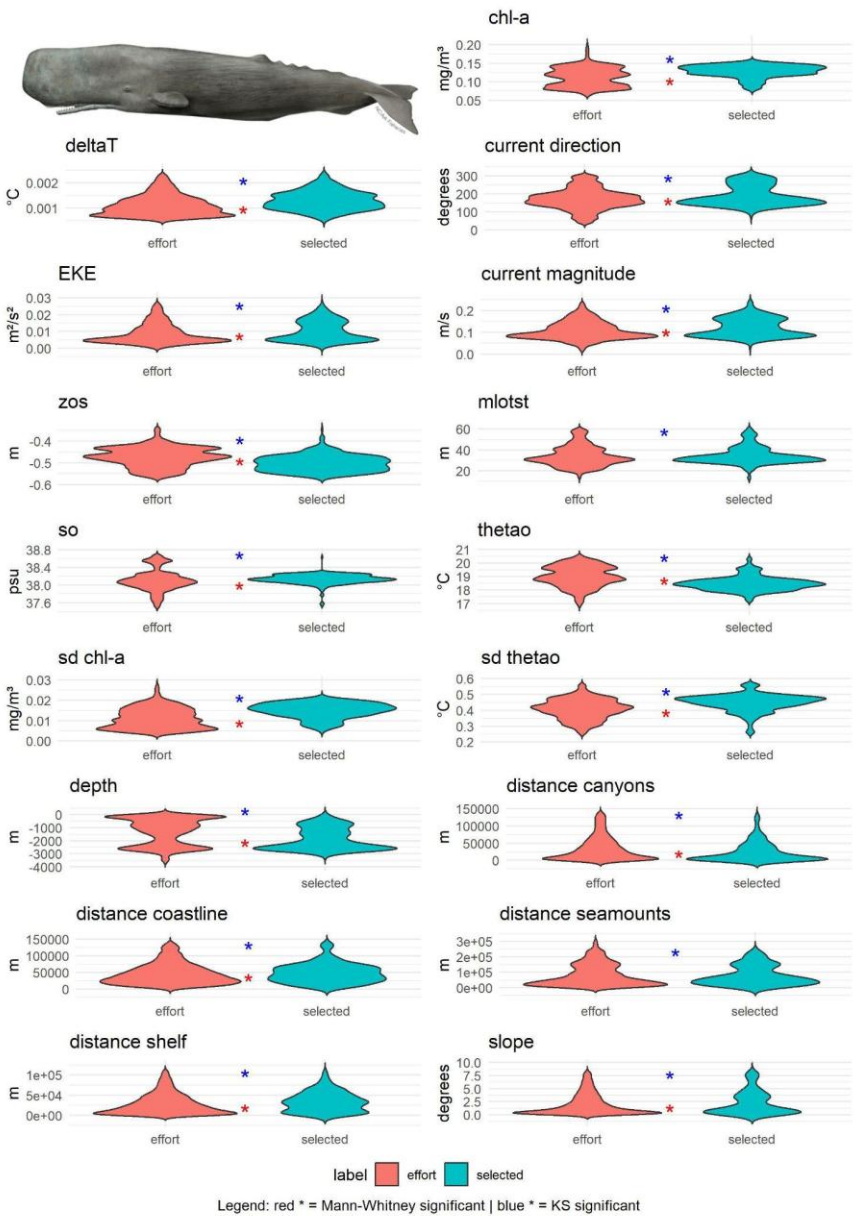
Policy Recommendations

- **Strengthen conservation in core areas (Ligurian, Tyrrhenian, Balearic), particularly in slope-associated zones where prey availability is high**
- **Prioritize deep, topographically complex areas (canyons, slopes, seamounts)** for protection.
- **Integrate seasonal and long-term shifts into spatial management plans**.
- **Monitor thermal and salinity trends as indicators of habitat change** due to climate variability..

1) Habitat Selection of *Physeter macrocephalus*. Comparison between selected environmental variable range at present locations and available range of values across the effort area.

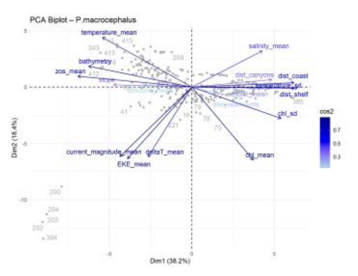
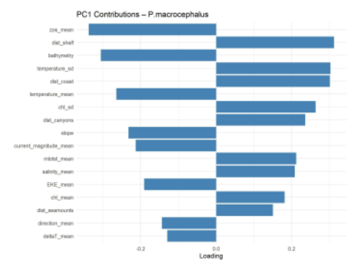
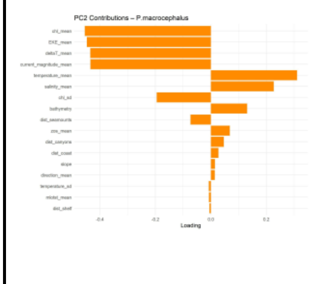
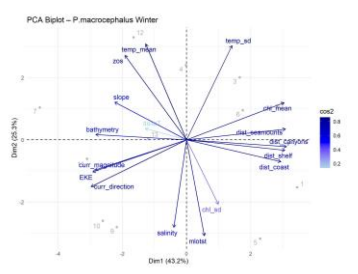
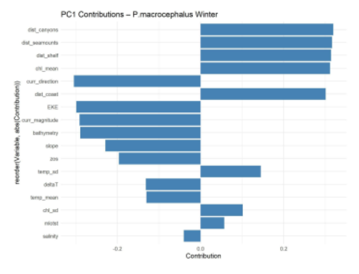
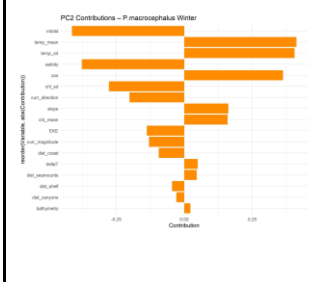
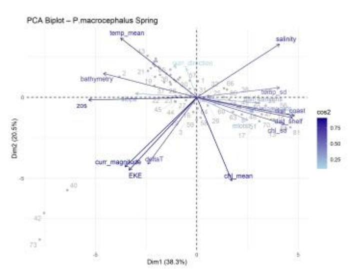
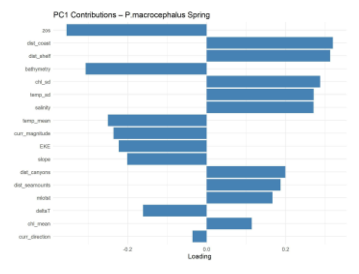
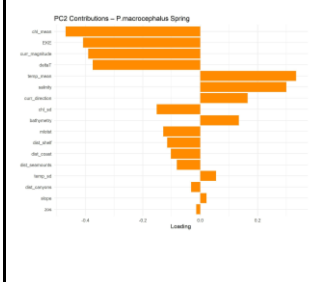
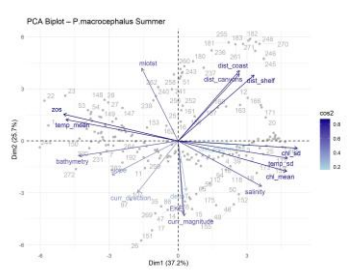
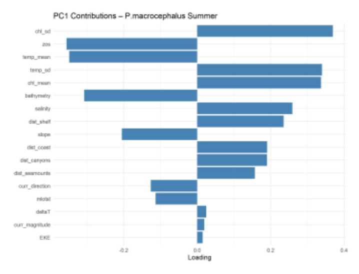
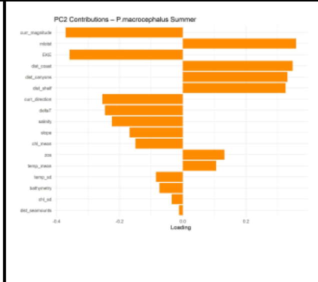
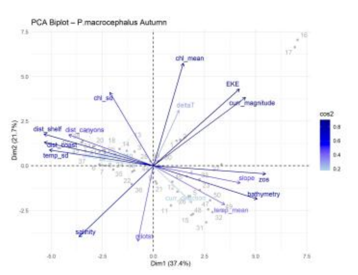
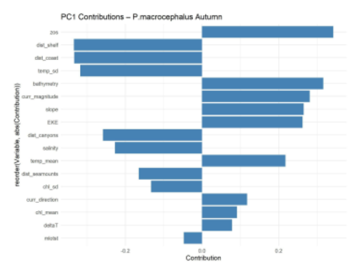
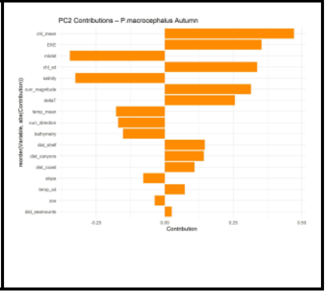


Summary:
Physeter macrocephalus appears to select for deep productive areas (e.g., higher values of chlorophyll, phytoplankton concentration, and net primary production), dynamic waters (e.g., higher current speeds and EKE), and specific salinity ranges. THe species seems to prefer medium distance from coast and shelf in areas closer to canyons with intermediate and steep slopes.

Figure 1.3.30. Habitat selection of *Physeter macrocephalus*. Distribution of environmental variable values at presence locations (left, red violin plots) and available range of values across the effort area (right, blue violin plots). Include Mann-Whitney U and Kolmogorov–Smirnov tests.

2) Principal Component Analysis (PCA) of *Physeter macrocephalus*

Table 1.3.39. *Physeter macrocephalus* PCA Biplot and Barplot of PC1 (blue) and PC2 (orange) loadings for different temporal resolutions.

Temporal res	Biplot	Loadings PC1	Loadings PC2
Entire period 56.6% explained variance			
Winter 68.5% explained variance			
Spring 58.8% explained variance			
Summer 62.9% explained variance			
Autumn 59.1% explained variance			

Over the entire period, *Physeter macrocephalus* seems to be associated with deep, steep-slope, thermally stable areas, influenced by dynamism and moderate productivity gradients. Across all seasons, *Physeter macrocephalus* shows a consistent preference for deep, thermally stable habitats shaped by topographic complexity and moderate to high oceanic dynamism. Seasonal shifts indicate the use of slope systems and frontal zones, where

vertical mixing and structural features enhance prey accessibility in offshore environments. During **winter** they use structurally complex areas (canyons, seamounts) with moderate productivity and stable temperature profiles. These conditions suggest winter foraging in stable but topographically active zones. In **spring**, *Physeter macrocephalus* is linked to deep coastal-shelf transitions with productive and thermally dynamic conditions. This pattern suggests that whales exploit shelf-break zones during seasonal turnover, when environmental mixing may push prey toward the surface or along the slope. In **summer**, instead, *Physeter macrocephalus* select deep, productive waters with dynamic vertical mixing. Temperature mean and variability have, however, strong influence on the habitat selection. This likely reflects a shift toward open-water foraging zones, where vertical mixing and productivity peaks drive prey aggregation in deeper or offshore habitats. In **autumn**, *Physeter macrocephalus* appears to target bathymetric edges with moderate surface productivity. The strong role of eddy activity and current velocity indicates that whales target energetically active frontal zones, likely linked to post-summer prey redistribution.

3) Physeter macrocephalus Species Distribution Model.

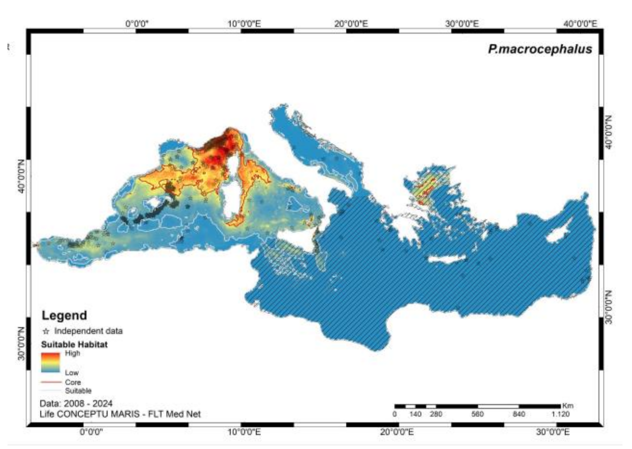
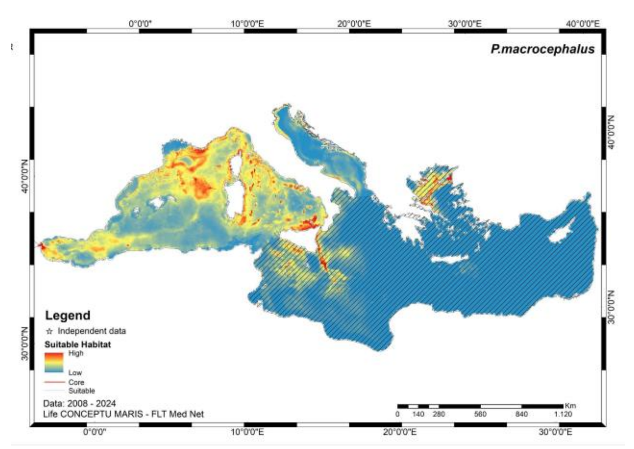
Entire period SDM *Physeter macrocephalus* (AUC train = 0.85; AUC test = 0.82)	
Maxent - avg predictions	Maxent - std
	

Figure 1.3.31. Species Distribution Model for *Physeter macrocephalus* covering the entire period from 2008 to 2024.

Table 1.3.40. Validation results of the Species Distribution Model for *Physeter macrocephalus* using an independent dataset, both within the LIFE CONCEPTU MARIS project area (western Mediterranean and Adriatic regions) and across the entire Mediterranean basin.

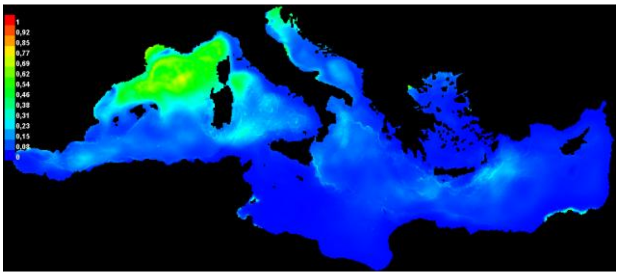
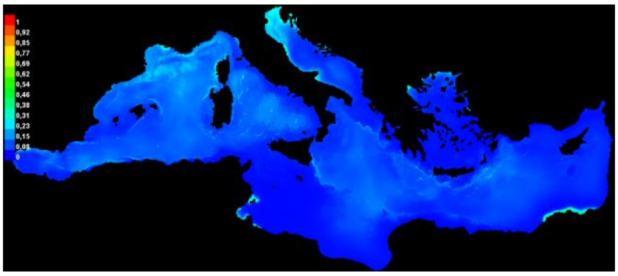
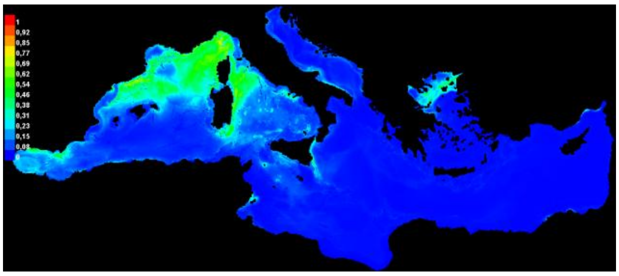
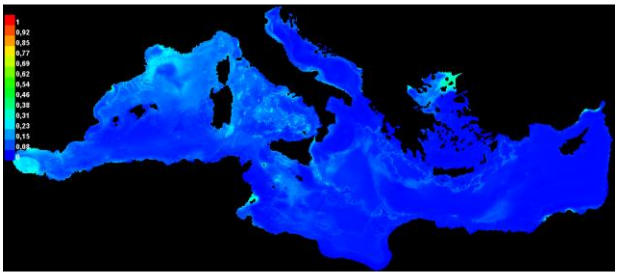
External validation with independent dataset	**W Med + Adriatic**		**Mediterranean Sea**	
	Maximum test sensitivity plus specificity Logistic threshold	Natural jenks threshold	Maximum test sensitivity plus specificity Logistic threshold	Natural jenks threshold
AUC	0.65	0.66	0.84	0.84
Precision	0.66	0.57	0.83	0.75

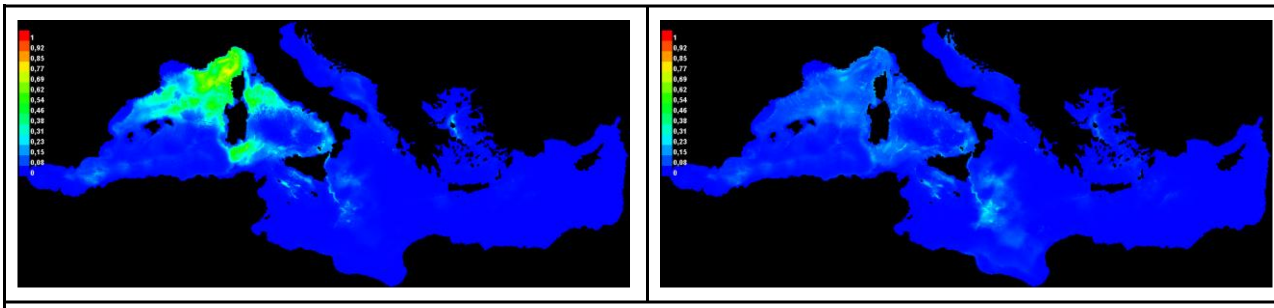
F1	0.45	0.73	0.47	0.85

Table 1.3.41. *Physeter macrocephalus* environmental variable contribution: summary of PCA loadings and Maxent output for each environmental variable over the entire period, expressed as percentage contribution and permutation importance. Top 3 values in each column are in bold.

Entire period				
Variable	PCA		SDM output	
	PC1	PC2	% contrib	per. imp
Bathymetry	-0.306	0.131	**24.4**	**22.9**
Chl_mean	0.181	-0.454	3.1	3.3
Chl_sd	0.264	-0.195	12.2	9.7
Curr.direction	-0.144	0.014	NA	NA
Curr.magnitude	-0.213	-0.434	NA	NA
deltaT	-0.130	-0.435	NA	NA
Dist.canyons	0.236	0.047	1.8	7.8
Dist.coast	0.301	0.027	6	11.1
Dist.seamounts	0.150	-0.073	3.9	9
Dist.shelf	0.312	-0.005	NA	NA
EKE	-0.191	-0.447	3	2.6
mlotst	0.212	-0.007	NA	NA
Salinity	0.208	0.227	**16.3**	**13.6**
Slope	-0.232	0.015	2.4	4.8
Temp_mean	-0.264	0.311	**24.4**	**11.9**
Temp_sd	0.303	-0.007	NA	NA
zos	-0.338	0.068	2.6	3.1

Entire period: The model identifies high suitability areas for *Physeter macrocephalus*, particularly in the northwestern Mediterranean, including the Ligurian Sea and parts of the Tyrrhenian Sea extending down along the continental slope to the southeastern corner of Sardinia. The most influential variables shaping the species' habitat were bathymetry (24.4% contribution, 22.9% importance) and mean temperature (24.4%, 11.9%) with a preference for deep, offshore waters with moderate temperatures. Salinity and chlorophyll sd also played major roles: notably, the positive response to the last indicates a preference for dynamic environments, where fluctuations in primary productivity may enhance prey aggregations. *Physeter macrocephalus* is the only species for which the model output was not strongly validated by the independent dataset, particularly in the identified core areas (F1 < 0.5 for the 'Maximum test sensitivity plus specificity logistic threshold', see Table 1.3.41). This is likely due to the predominantly pelagic sampling design, which fails to adequately capture the distinctive slope and canyon areas close to the coast of the southeastern Balearic Islands, where a semi-stable presence of *P. macrocephalus* social groups is documented in the literature (Pirotta et al, 2011). The species is known to exhibit partial habitat segregation among age and sex classes (Pirotta et al., 2011; Pace et al., 2018), with social units of female with calve preferring steep slope areas where upwelling phenomena are more likely to occur, while adult males occupy broader-ranging habitats. The sampling transects used in this study appear to capture the social unit habitats in the highly complex bathymetry of the Tyrrhenian Sea (e.g., the Pontine Archipelago) relatively well, but fail to capture the more confined social group habitats of the southeastern Balearic region. Nevertheless, although not identified as a main core area, the extended suitable habitat range is well validated and fully encompasses all presence records from the independent dataset, including those southwest of the Balearic Islands.

Seasonal SDM *Physeter macrocephalus*	
Maxent - avg predictions	Maxent - std
WINTER (AUC train = 0.89; AUC test = 0.83)	
	
SPRING (AUC train =0.87; AUC test = 0.78)	
	
SUMMER (AUC train = 0.88; AUC test = 0.84)	



AUTUMN
(AUC train = 0.9; AUC test = 0.79)

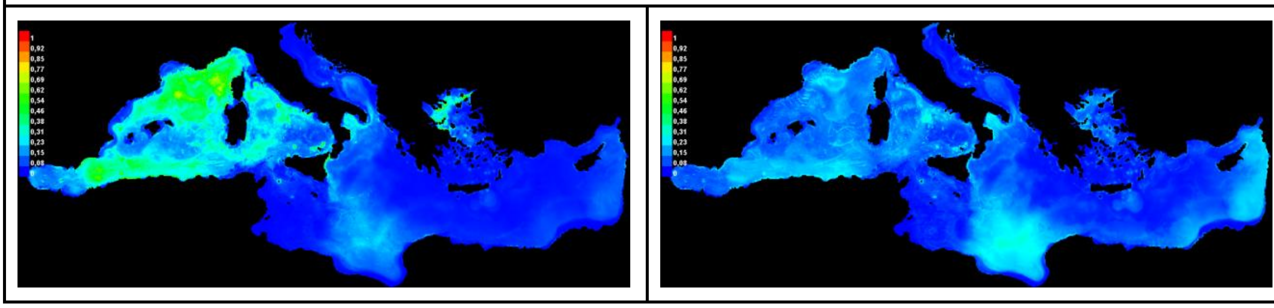


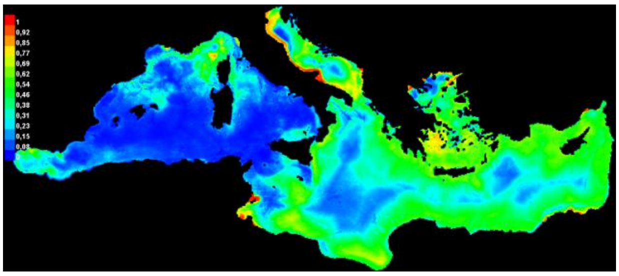
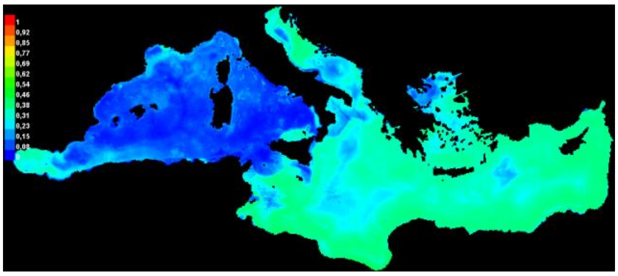
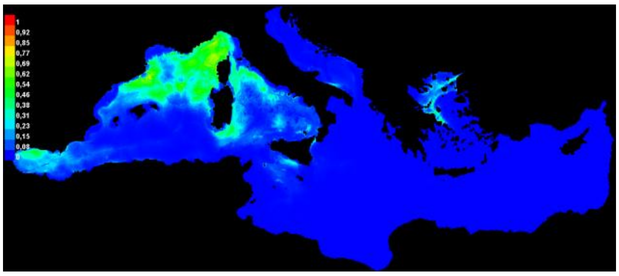
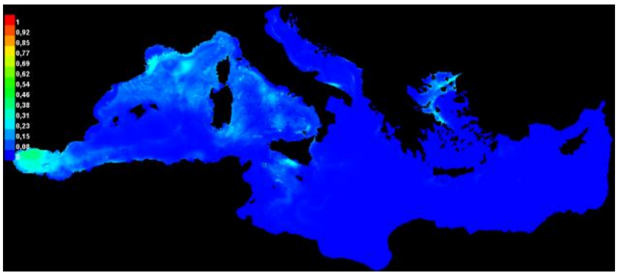
Figure 1.3.32. Species Distribution Model for *Physeter macrocephalus* during the four seasons (WIN from January to March, SPR from April to June, SUM from July to September, AUT from October to December).

Table 1.3.42. *Physeter macrocephalus* environmental variable contribution: summary of PCA loadings and Maxent output for each environmental variable over the seasons, expressed as percentage contribution and permutation importance. Top 3 values in each column are in bold.

	Winter				Spring				Summer				Autumn			
Variable	PCA		SDM output		PCA		SDM output		PCA		SDM output		PCA		SDM output	
	PC1	PC2	% contrib	perm. imp	PC1	PC2	% contrib	perm. imp	PC1	PC2	% contrib	perm. imp	PC1	PC2	% contrib	per. imp
Bathy metry	-0.290	0.022	**12.7**	9	-0.306	0.135	**16.5**	**13.8**	-0.308	-0.074	**28.3**	**28.8**	0.317	-0.152	**30.5**	**29.8**
Chl_mean	0.311	0.159	4.7	7.8	0.115	-0.469	4.1	2	0.337	-0.150	2.2	10.2	0.091	0.471	3.9	6.2
Chl_sd	0.101	-0.277	4.4	8.8	0.287	-0.152	**32.1**	**17.5**	0.370	-0.035	0.5	2.3	-0.133	0.337	7	10.6
Curr.Dir	-0.305	-0.202			-0.036	0.165			-0.126	-0.255			0.118	-0.170		
Curr.mag n	-0.291	-0.130			-0.235	-0.390			0.019	-0.371			0.281	0.314		
deltaT	-0.132	0.049			-0.161	-0.374			0.025	-0.246			0.078	0.255		
Dist. canyons	0.319	-0.029	2.3	2.7	0.199	-0.032	7.6	8.6	0.190	0.331	2.3	9.3	-0.258	0.143	5	7.4
Dist.coast	0.301	-0.094	3.9	0.8	0.320	-0.102	4.7	8.8	0.190	0.348	4.2	11	-0.333	0.109	**11.7**	8.5
Dist.seam ounts	0.316	0.046	2.8	6.7	0.187	-0.082	5	4.3	0.157	-0.012	3.7	5.3	-0.165	0.026	5.9	6.3
Dist.shelf	0.314	-0.045			0.313	-0.115			0.236	0.325			-0.334	0.146		
EKE	-0.299	-0.138	1.3	1.2	-0.222	-0.408	7.8	6.7	0.015	-0.358	5.6	3.7	0.262	0.353	5.8	5.1
mlotst	0.057	-0.413			0.167	-0.128			-0.113	0.359			-0.048	-0.346		
Salinity	-0.040	-0.377	0.2	1.2	0.271	0.300	**10.6**	**21.4**	0.259	-0.224	**19.8**	**10**	-0.227	-0.326	**10.8**	7.2
Slope	-0.229	0.162	3.6	10.1	-0.201	0.022	4.2	3.4	-0.205	-0.169	3.9	5.2	0.265	-0.078	6.3	5.4
Temp_me an	-0.130	0.412	5.1	**16.6**	-0.250	0.334	3.6	10	-0.348	0.105	**25.1**	8.4	0.218	-0.178	3.3	5.8
Temp_sd	0.145	0.405			0.271	0.055			0.340	-0.085			-0.318	0.073		

zos	-0.197	0.363	**59**	**35.1**	-0.354	-0.014	3.9	3.6	-0.355	0.132	4.5	5.9	0.342	-0.037	9.7	7.7

Seasonal patterns: In **winter**, *Physeter macrocephalus* distribution is mainly driven by zos (59% importance, 35.1% contribution) with a strong negative relationship with the species presence: areas with low zos values (often associated with productive oceanic features) are preferred habitats for the species. Bathymetry and mean temperature also influence distribution, favoring deep and moderately warm waters. High suitability areas include the Ligurian Sea, Balearic region and North Tyrrhenian Sea. In **spring**, the strongest predictor is chlorophyll variability (32.1% contribution, 17.5% importance) with preference for areas with high variability in primary productivity. Bathymetry also plays a major role, with the species favoring deep offshore waters. EKE and salinity become more relevant in spring, potentially reflecting seasonal changes. In **summer**, bathymetry dominates (28.3% contribution, 28.8% importance), confirming a preference for deep offshore areas. Intermediate sea surface temperature and moderate salinity levels are also favored. Suitable areas remain in the Ligurian, Balearic and Tyrrhenian seas, though less widespread. In **autumn** bathymetry and distance to coastline are key, with the species preferring deep waters moderately offshore. Salinity and zos regain influence. Habitat use expands, reflecting broader suitable conditions.

<table>
<tr><th colspan="2">Habitats Directive Reporting periods Physeter macrocephalus</th></tr>
<tr><td colspan="2">2008-2012
(AUC train = 0.87; AUC test = 0.80)</td></tr>
<tr><td>Maxent - avg predictions</td><td>Maxent - std</td></tr>
<tr><td></td><td></td></tr>
<tr><td colspan="2">2013-2018
(AUC train = 0.88; AUC test = 0.83)</td></tr>
<tr><td></td><td></td></tr>
<tr><td colspan="2">2019-2024
(AUC train = 0.88; AUC test = 0.79)</td></tr>
</table>

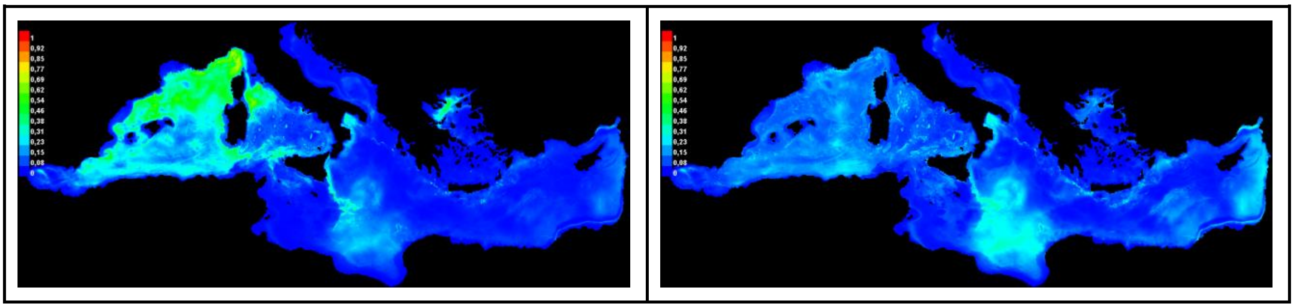


Figure 1.3.33. Species Distribution Model for *Physeter macrocephalus* covering the three Habitat Directive reporting periods (2008-2012, 2013-2018, 2019-2024).

Table 1.3.43. *Physeter macrocephalus* environmental variable contribution: summary of PCA loadings and Maxent output for each environmental variable over the reporting periods, expressed as percentage contribution and permutation importance.

	2008-2012		2013-2018		2019-2024	
Variable	SDM output		SDM output		SDM output	
	% contrib	perm. imp	% contrib	perm. imp	% contrib	perm. imp
Bathy metry	7.1	7.6	**27.8**	**17.2**	**35.3**	**26.3**
Chl_mean	13.3	4.6	2.3	2.5	17.2	15.9
Chl_sd	**25.3**	**21.8**	11.5	2.7	2.5	7.5
Curr.Dir	NA	NA	NA	NA	NA	NA
Curr.magn	NA	NA	NA	NA	NA	NA
deltaT	NA	NA	NA	NA	NA	NA
Dist. canyons	4.8	5.9	6.3	7.9	4.7	9.2
Dist.coast	**14.4**	**15.9**	7.8	**18.4**	2.7	5.8
Dist.seamounts	4.5	3.2	3.5	7.2	5.2	7.2
Dist.shelf	NA	NA	NA	NA	NA	NA
EKE	8.7	1.9	3.1	3.6	5.3	7
mlotst	NA	NA	NA	NA	NA	NA
Salinity	5.2	13.8	6.2	16.3	**14**.4	5.5
Slope	6.5	5	3	5	5.9	8.6
Temp_mean	2.5	3.4	26.3	10.4	4	3.7
Temp_sd	NA	NA	NA	NA	NA	NA
zos	7.7	**16.9**	2.2	8.7	2.8	3.3

Habitats Directive Reporting Periods: high-suitability areas of *Physeter macrocephalus* persisted in the Balearic, Ligurian and Tyrrhenian Seas, indicating a stable core habitat over time. During the **first period (2008-2012)**, *Physeter macrocephalus* distribution was primarily influenced by chlorophyll variability (25.3% contribution, 21.8% importance), indicating a preference for areas with highly variable productivity, alongside distance to coastline, suggesting a tendency for offshore habitats. Other important drivers included mean chlorophyll and zos, reflecting the role of dynamic oceanographic features. In the **second period (2013-2018)** the dominant predictor shifted to bathymetry (27.8% contribution, 17.2% importance), revealing a strong preference for deep offshore waters, while mean temperature gained importance, pointing to the role of thermal conditions. Distance to coast and canyons remained influential, while salinity became more relevant than productivity indicators, highlighting a transition toward stable physical features. Suitability concentrated in the Ligurian and Balearic regions. In the **third period (2019-2024)** bathymetry remained the leading factor (35.3% contribution, 26.3% importance), with mean chlorophyll regaining significance, underscoring the combined importance of depth and productivity. Salinity remained relevant, while the influence of temperature declined. Suitability areas extended more broadly from the northwestern Mediterranean towards southern larger regions.

Suitable habitat for *Caretta caretta*

Caretta caretta is known for its broad ecological flexibility, meaning it can use a wide variety of marine habitats. However, analyses reveal **consistent preferences for thermally stable, moderately productive environments located in transitional zones between coastal and offshore waters.** These areas often coincide with structurally complex habitats, such as seamounts, submarine canyons, and continental shelf edges, which likely enhance prey availability and ecological suitability.

Summary of Habitat Suitability: Across the full study period, the core high-suitability zones were identified in the **northern-central Adriatic** and in parts of the southwestern Mediterranean, particularly around the **Tyrrhenian Sea and Algerian coasts.** These areas combine physical complexity, coastal proximity, and dynamic but stable environmental conditions that likely support prey aggregation.

Seasonal Patterns: Seasonal distribution models show that habitat use by *Caretta caretta* is highly dynamic across the year. **In winter and autumn**, turtles are more concentrated in predictable areas like the northern Adriatic and southern Tyrrhenian Sea, while in **spring and summer** they tend to spread more widely, including offshore zones like the Ligurian Sea and the Sardinia Channel. This seasonal behavior is likely linked to changing food availability and life cycle movements.

Habitat Directive Reporting Periods (2008–2024): Looking at longer-term trends, SDMs developed over three EU Habitats Directive reporting periods reveal a **progressive northward and westward expansion of suitable habitat**, particularly between 2013–2018 and 2019–2024. The early period (2008–2012) was limited by lower data quality for this species, but later models, based on more consistent effort, clearly show an increasing presence in northern Adriatic and western Mediterranean shelf areas. This trend is likely not due to random spread but to a wider spatial availability of optimal habitats, possibly linked to rising sea temperatures that have expanded the extent of waters falling within the species' preferred thermal range (~19–21°C).

Adults: Focusing on adult turtles only, models for the most recent period (2019–2024) achieved higher predictive performance and identified more stable, spatially consistent hotspots, especially during winter and autumn. These results confirm that **adult turtles follow more predictable spatial patterns than juveniles** and support the use of adult-focused models for conservation planning. Key adult habitats include the northern Adriatic, southern Tyrrhenian, and areas along the Algerian coast.

Key Findings:

*While Caretta caretta (loggerhead turtle) shows broad ecological flexibility, long-term analyses reveal consistent preferences for **thermally stable, moderately productive environments**, often located in **transitional zones between coastal and offshore waters**, particularly around **structurally complex features** such as **seamounts, submarine canyons**, and **continental shelf edges**.*

Core Suitable Habitats:

- ***Northern-central Adriatic Sea***
- ***Southwestern Mediterranean**, especially the **Tyrrhenian Sea** and **Algerian coast***

*These areas offer a combination of **physical complexity**, **coastal proximity**, and **stable but dynamic environmental conditions** favorable for foraging.*

Seasonal Patterns

- ***Winter & Autumn:*** *Concentrated use of predictable habitats (northern Adriatic, southern Tyrrhenian).*
- ***Spring & Summer:*** *More dispersed distribution, including offshore areas (Ligurian Sea, Sardinia Channel)*

These shifts are likely linked to ***food availability*** *and* ***life-cycle movements****.*

Long-Term Trends (2008–2024)

- *From 2013 onward, models show a* ***progressive northward and westward expansion*** *of suitable habitats.*
- *This trend is likely driven by* ***rising sea temperatures****, expanding areas within the species' preferred thermal range (****~19–21°C****).*
- *Early models (2008–2012) were limited by low data availability, but recent data confirms increasing use of* ***northern Adriatic*** *and* ***western Mediterranean shelf areas****.*

Adult Turtles: Key for Planning

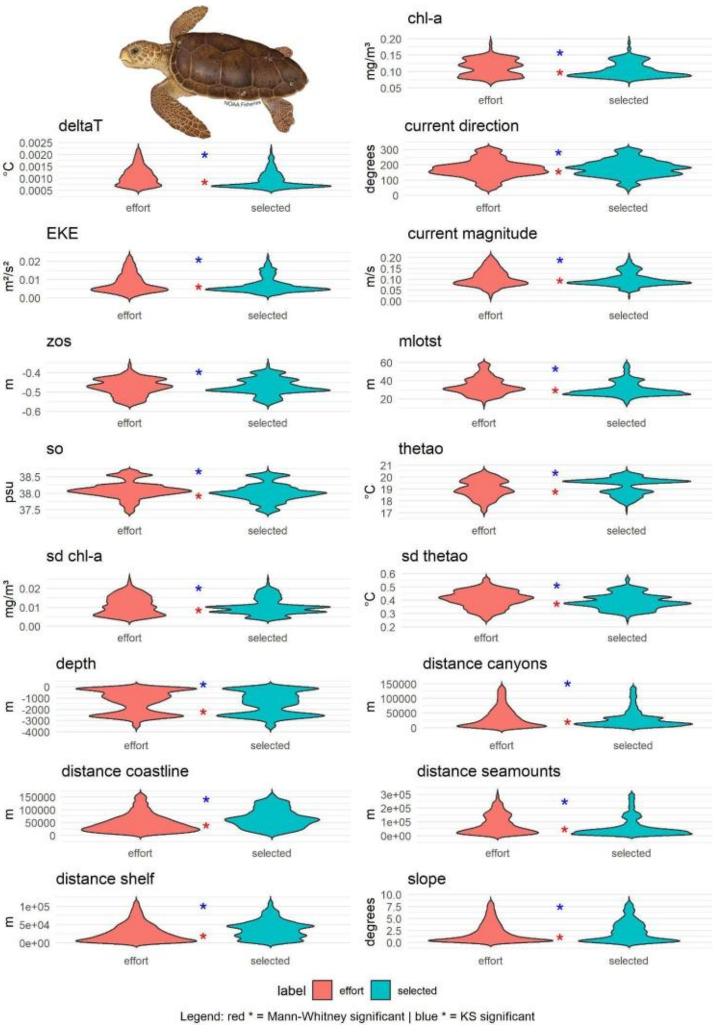
- ***Adult-only models (2019–2024)*** *show* ***higher accuracy*** *and* ***more stable habitat hotspots****, especially in winter and autumn.*
- ***Priority adult habitats: Northern Adriatic, Southern Tyrrhenian, Algerian shelf waters***
- *These consistent patterns support the* ***use of adult-focused data for effective conservation planning****.*

Policy Recommendations

- *Prioritize protection of* ***structurally complex offshore zones*** *and* ***transitional habitats****.*
- *Integrate* ***seasonal variability*** *in conservation strategies.*
- *Monitor and adapt to* ***climate-driven habitat shifts****, particularly the expansion of suitable zones northward and westward.*

Focus monitoring efforts on ***adult individuals*** *for spatially consistent conservation targeting.*

1) **Habitat Selection of *Caretta caretta*.** Comparison between selected environmental variable range at present locations and available range of values across the effort area.

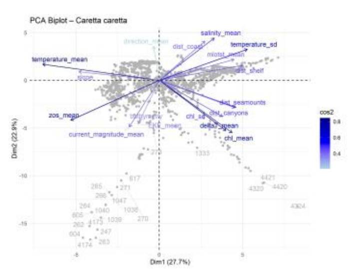
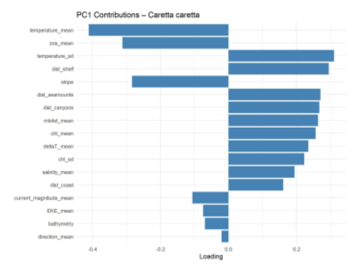
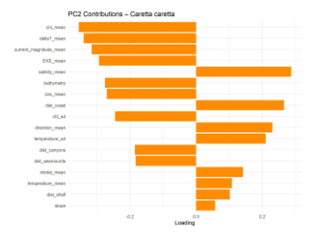


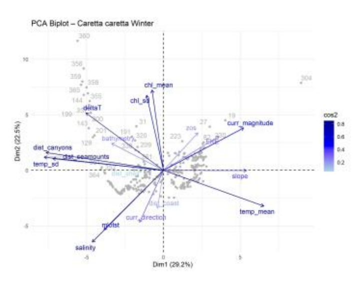
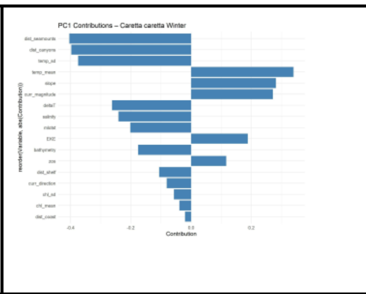
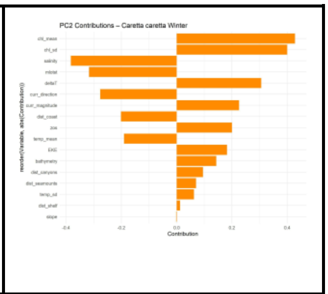
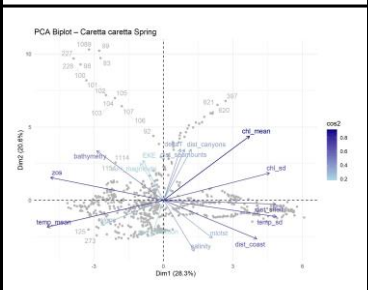
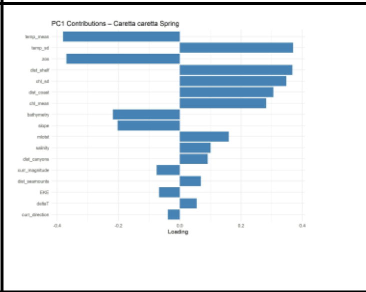
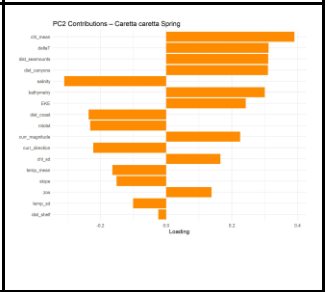
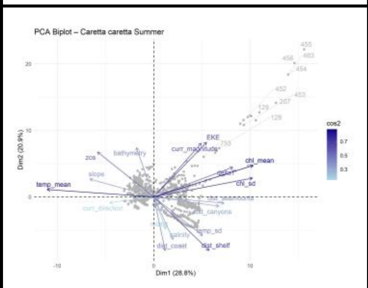
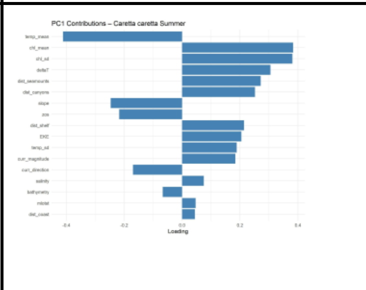
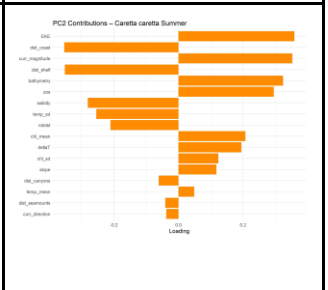
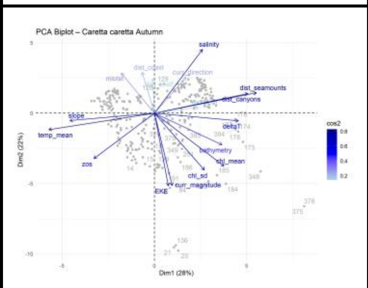
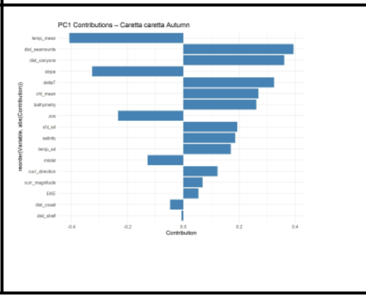
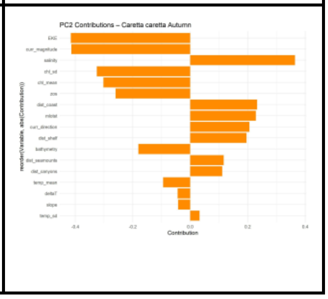
Summary.
The violin plot for the entire period indicates that *Caretta caretta* functions as a generalist species, capable of occupying a wide range of environmental conditions. This is reflected in the broad overlap between presence and effort distributions across most variables. However, ecological selectivity emerges for specific factors such as thermal stability (deltaT), chlorophyll variability (chl_sd), and proximity to coast, suggesting that while the species is flexible in habitat use, it still shows consistent preferences for thermal stable, moderate current regimes, stratified waters, and productive environments. For distance to coast, the species tends to select transitional zones, including continental shelf edges and upper slope areas, rather than open-ocean or nearshore extremes.

Figure 1.3.34. Habitat selection of *Caretta caretta*. Distribution of environmental variable values at presence locations (left, red violin plots) and available range of values across the effort area (right, blue violin plots). Include Mann-Whitney U and Kolmogorov–Smirnov tests.

2) Principal Component Analysis (PCA) of *Caretta caretta*

Table 1.3.44. *Caretta caretta* PCA Biplot and Barplot of PC1 (blue) and PC2 (orange) loadings for different temporal resolutions.

Temporal res	Biplot	Loadings PC1	Loadings PC2
Entire period 50.6% explained variance			

Winter 51.7% explained variance			
Spring 48.9% explained variance			
Summer 49.7% explained variance			
Autumn 50% explained variance			

Over the entire period, *Caretta caretta* shows a preference for areas characterized by **higher and more variable temperatures**, likely indicating favorable thermal conditions for foraging. The species is also associated with moderate **dynamic sea surface conditions** and **proximity to topographic features** such as continental shelf and slope. Additionally, zones with higher chlorophyll concentrations and ocean energy may enhance habitat suitability by increasing prey availability.

Across all seasons, *Caretta caretta* selects habitats shaped by **thermal structure, dynamic ocean features and topographic complexity**. Preference shifts between deep structured habitats (e.g. canyons, seamounts) and productive, dynamic offshore waters, likely reflecting seasonal changes in prey availability and foraging strategy, especially during mixing and stratification periods. In **winter**, *Caretta caretta* appears influenced by topographic complexity (seamounts, canyons, particularly near seamounts and canyons, in combination with thermal variability and productivity indicators (e.g. chlorophyll concentration). This suggests use of deep, structured habitats, potentially favored due to winter mixing that enhances prey accessibility. In **spring**, their distribution is shaped by thermal features, vertical dynamics, and distance from the shelf, reflecting possible shifts toward stratified environments with seasonal prey aggregations. During **summer**, the species tends to use high-productivity offshore waters, further from the shelf, with lower reliance on temperature as a limiting factor, possibly due to metabolic adaptation. Dynamic features such as strong currents and eddy activity become more relevant in this season. In **autumn**, *Caretta caretta* appears to prefer dynamic offshore habitat, with moderate productivity but also areas influenced by topography, such as proximity to seamounts and canyons. This suggests a balance between physical forcing and structural features that, again, may enhance prey aggregation.

3) *Caretta caretta* Species Distribution Model.

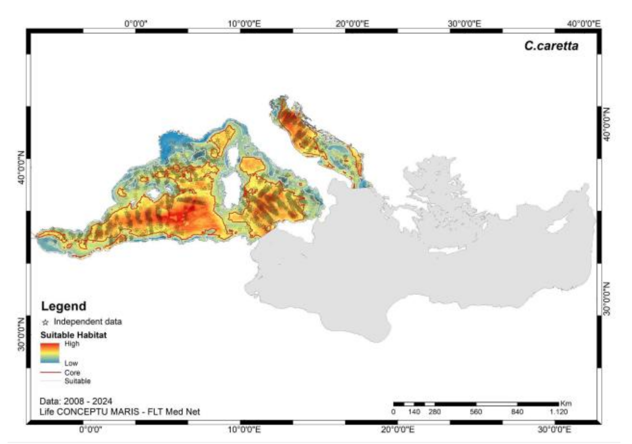
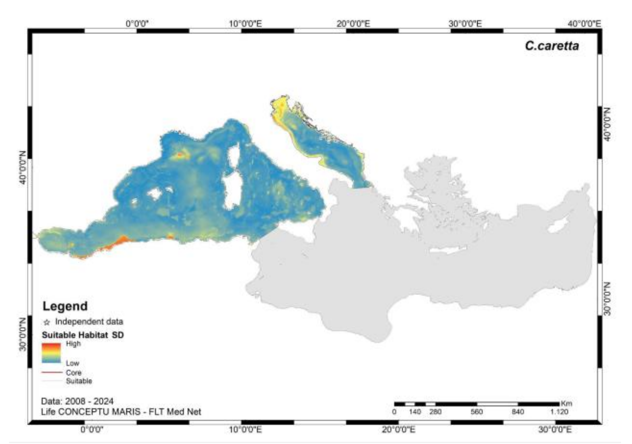
Entire period *Caretta caretta* - all life stages (AUC train = 0.72, AUC test = 0.70)	
Maxent - avg predictions	Maxent - std
	

Figure 1.3.35. Species Distribution Model for *Caretta caretta* covering the entire period from 2008 to 2024.

Table 1.3.45. Validation results of the Species Distribution Model for *Caretta caretta* using an independent dataset, both within the LIFE CONCEPTU MARIS project area (western Mediterranean and Adriatic regions) and across the entire Mediterranean basin.

External validation with independent dataset	**W Med + Adriatic**		**Mediterranean Sea**	
	Maximum test sensitivity plus specificity Logistic threshold	Natural jenks threshold	Maximum test sensitivity plus specificity Logistic threshold	Natural jenks threshold
AUC	**0.66**	**0.66**	0.52	0.51
Precision	**0.60**	**0.52**	0.53	0.50
F1	**0.66**	**0.67**	0.59	0.65

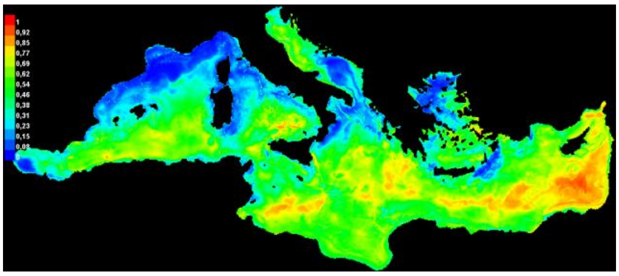
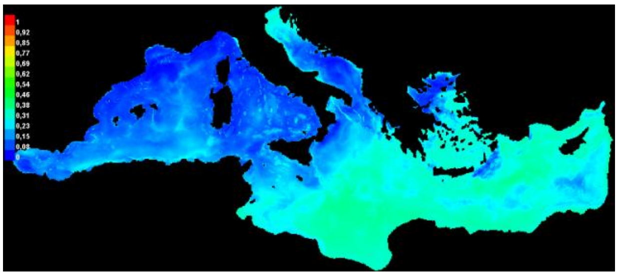
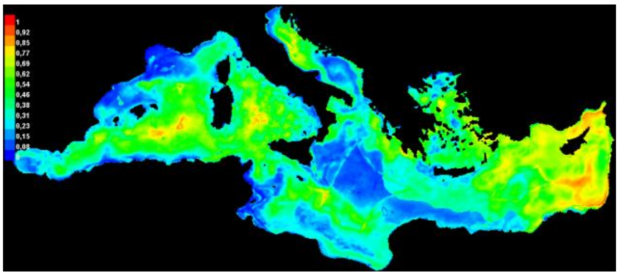
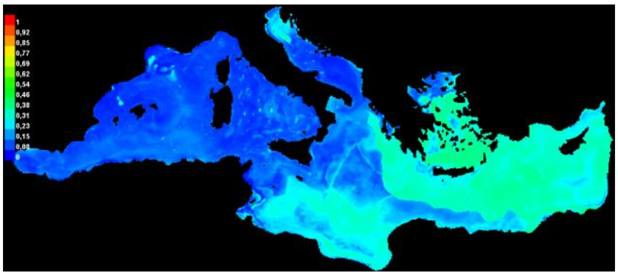
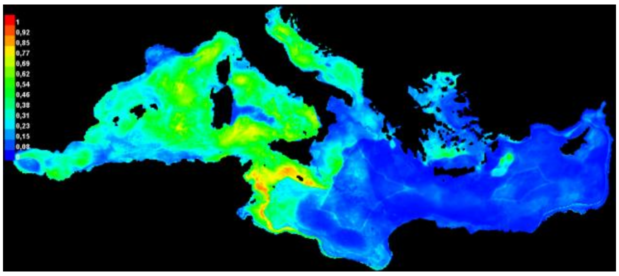
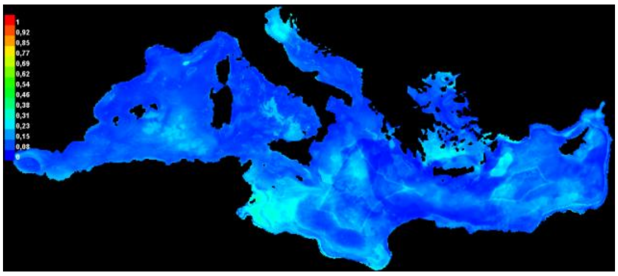
Table 1.3.46. *Caretta caretta* environmental variable contribution: summary of PCA loadings and Maxent output

for each environmental variable over the entire period, expressed as percentage contribution and permutation importance. Top 3 values in each column are in bold.

Entire period				
Variable	PCA		SDM output	
	PC1	PC2	% contrib	per. imp
Bathymetry	-0.070	-0.276	3.1	3.7
Chl_mean	0.256	-0.355	6.4	7.3
Chl_sd	0.223	-0.245	4.7	10.5
Curr.direction	-0.021	0.230	4.8	4.5
Curr.magnitude	-0.106	-0.316	1.2	1.5
deltaT	0.235	-0.340	6.8	7.8
Dist. canyons	0.267	-0.185	**12.6**	3.6
Dist.coast	0.161	0.266	**16.1**	10.4
Dist.seamounts	0.270	-0.183	4.1	4.1
Dist.shelf	0.295	0.102	NA	NA
EKE	-0.075	-0.294	NA	NA
mlotst	0.263	0.141	7.8	10.6
Salinity	0.194	0.287	6.1	12.1
Slope	-0.284	0.058	6.5	7.4
Temp_mean	-0.411	0.108	**10.9**	6.9
Temp_sd	0.310	0.210	6.1	6.3
zos	-0.312	-0.270	2.8	3

Entire period: The SDM for *Caretta caretta*, validated using an independent dataset, demonstrated a fair ability to distinguish between presence and absence of the species within the Project area (Table 1.3.45), which includes the western Mediterranean and the Adriatic Sea. Across the entire Mediterranean basin, however, the model's performance was lower and not sufficiently robust to be considered reliable; therefore, the most trustworthy model remains the one limited to the defined Project areas. Results outside of these areas are not further discussed.
The model developed for the entire study period suggests that the most suitable areas for *Caretta caretta* are associated with a complex interplay of bathymetric and oceanographic factors, including salinity and primary productivity. Suitability peaks in dynamic and structurally complex environments, which likely promote prey aggregation. The resulting predicted distribution spans all monitored regions within both the western Mediterranean and the Adriatic Sea, with core areas identified in the mid-to-northern Adriatic Sea and the southern sector of the western Mediterranean (Tyrrhenian and Algerian seas) (Figure 1.3.35). The most influential environmental variables included distance from the coast and from submarine canyons, mixed layer depth and mean surface temperature (see Table

1.3.46). Salinity also emerged as important, confirming the relevance of hydrographic gradients. These variables collectively underscore the importance of mesoscale features in shaping suitable habitats for all life stages of species.

Seasonal SDM *Caretta caretta* - all life stages	
Maxent - avg predictions	Maxent - std
WINTER (AUC train=0.84, AUC test=0.78)	
	
SPRING (AUC train =0.78, AUC test=0.73)	
	
SUMMER (AUC train=0.76 , AUC test=0.72)	
	
AUTUMN (AUC train=0.85, AUC test=0.78)	

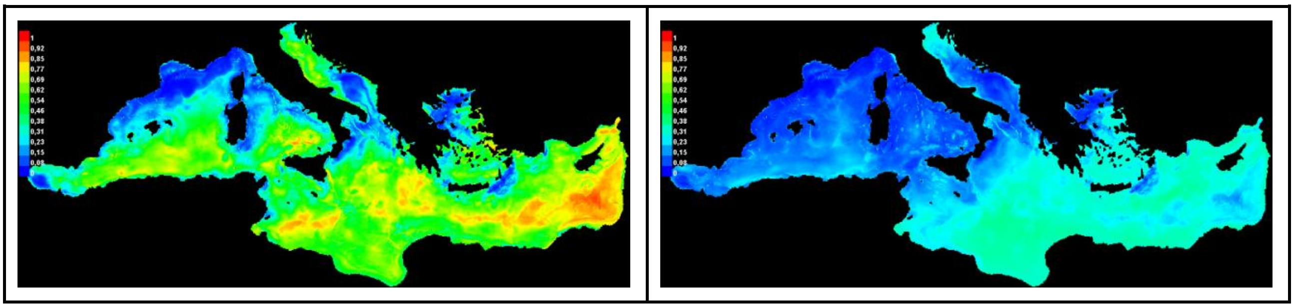


Figure 1.3.36. Species Distribution Model for *Caretta caretta* during the four seasons (WIN from January to March, SPR from April to June, SUM from July to September, AUT from October to December).

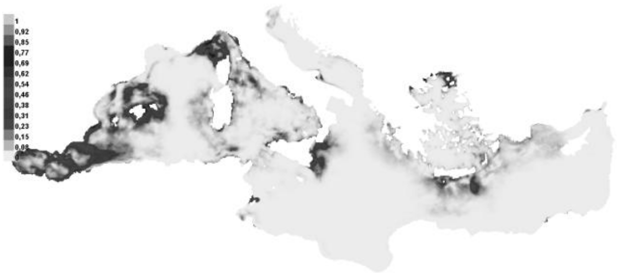
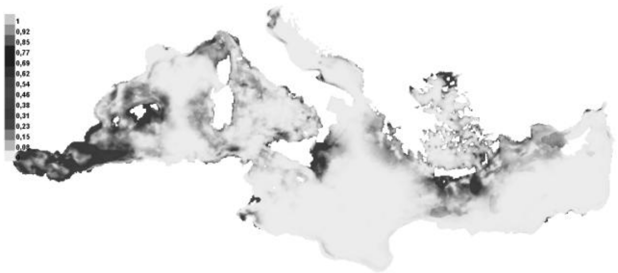
Table 1.3.47. *Caretta caretta* environmental variable contribution: summary of PCA loadings and Maxent output for each environmental variable over the seasons, expressed as percentage contribution and permutation importance. Top 3 values in each column are in bold.

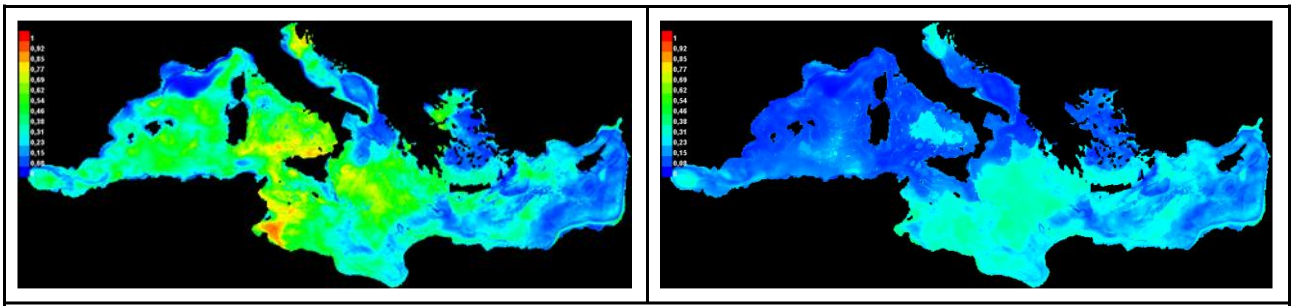
Variable	Winter				Spring				Summer				Autumn			
	PCA		SDM output		PCA		SDM output		PCA		SDM output		PCA		SDM output	
	PC1	PC2	% contrib	perm. imp	PC1	PC2	% contrib	perm. imp	PC1	PC2	% contrib	perm. imp	PC1	PC2	% contrib	per. imp
Bathymetry	-0.176	0.144	11.9	11.7	-0.218	0.300	4.7	9.3	-0.067	0.324	5.6	7.9	0.261	-0.181	11.9	11.7
Chl_mean	-0.039	0.428	3.4	5	0.282	0.390	9.1	8.6	0.384	0.207	10.9	19	0.268	-0.302	3.4	5
Chl_sd	-0.057	0.400	2.8	2.3	0.348	0.165	10.2	13.5	0.381	0.124	2.4	2.3	0.193	-0.325	2.8	2.3
Curr.Dir	-0.081	-0.276	5.2	6.5	-0.039	-0.221	3.3	2.7	-0.170	-0.038	3.3	2	0.123	0.206	5.2	6.5
Curr.magn	0.272	0.226	3	3.4	-0.076	0.225	2.7	2.5	0.184	0.352	1.9	2.9	0.069	-0.414	3	3.4
deltaT	-0.263	0.306	8.7	5.4	0.056	0.311	2	2.6	0.305	0.195	2.2	3.4	0.325	-0.044	8.7	5.4
Dist. canyons	-0.398	0.095	7.9	5.5	0.091	0.310	9.7	4.7	0.252	-0.061	3.4	5.5	0.361	0.112	7.9	5.5
Dist.coast	-0.020	-0.201	8.2	9.8	0.306	-0.235	15.7	15.9	0.044	-0.353	29.6	10.5	-0.047	0.233	8.2	9.8
Dist.seamounts	-0.404	0.070	6	8.2	0.069	0.310	9.7	10.1	0.272	-0.041	3	3.1	0.394	0.117	6	8.2
Dist.shelf	-0.106	0.013	NA	NA	0.368	-0.024	NA	NA	0.214	-0.352	NA	NA	-0.007	0.196	NA	NA
EKE	0.188	0.182	NA	NA	-0.067	0.242	NA	NA	0.204	0.359	NA	NA	0.054	-0.415	NA	NA
mlotst	-0.201	-0.317	7.8	14	0.160	-0.230	2.3	1.6	0.047	-0.210	7.8	7.7	-0.128	0.229	7.8	14
Salinity	-0.241	-0.382	2.2	2.1	0.101	-0.309	3.1	2.3	0.075	-0.281	6.2	4.1	0.186	0.364	2.2	2.1
Slope	0.281	-0.002	6.4	7.8	-0.203	-0.151	6.5	5.7	-0.247	0.117	5.9	7.4	-0.326	-0.042	6.4	7.8
Temp_mean	0.340	-0.190	1.3	1.2	-0.381	-0.163	5.9	4.6	-0.411	0.049	6.1	6	-0.408	-0.094	1.3	1.2
Temp_sd	-0.375	0.063	8.5	5.2	0.370	-0.100	11.8	9.4	0.189	-0.254	2.4	5.1	0.170	0.033	8.5	5.2
zos	0.117	0.200	16.7	11.8	-0.370	0.138	3.2	6.4	-0.217	0.295	9.3	13	-0.233	-0.260	16.7	11.8

Seasonal patterns: Seasonal SDMs revealed substantial variation in predicted habitat suitability across the year, highlighting the dynamic spatio-temporal habitat use of *Caretta caretta*. The winter and autumn models exhibited the highest performance, suggesting more stable and predictable distributions during colder months, patterns that align with the outputs from PCA analyses. In contrast, the lower performance of the spring and summer models reflects the greater spatial dispersion and ecological plasticity during the warmer season.

In winter, areas of high suitability were predicted along the northern Adriatic, particularly near coastal zones, as well as in the southern Tyrrhenian and portions of the Algerian sea. The distribution appeared more concentrated toward neritic areas or proximity to bathymetric structures. **In spring**, habitat suitability expanded broadly across the basin, with relevant values detected across large part of the Adriatic Sea and extending into the central-western Mediterranean Sea, including the Ligurian Sea and central and north Tyrrhenian Sea, suggesting seasonal expansion of suitable habitats, likely associated with pre-nesting or juvenile movements. **In summer**, predicted suitability slightly shifted, with localized hotspots in the Sardinia channel and increase in suitability in the Liguro-Provencal basin. **In autumn,** the spatial distribution of suitability closely resembled that of winter, with high values once again concentrated in the Adriatic and southern Tyrrhenian regions. This likely reflects a seasonal return to foraging or overwintering habitats following summer dispersion.

These patterns reveal a clear seasonal shift in *Caretta caretta*'s habitat use within the western Mediterranean and Adriatic seas: habitat associations are stronger and more localized in winter and autumn, driven by environmental stability and prey availability; while in spring and summer, distributions become more diffuse, likely due to broader resource distribution and possible ontogenetic or migratory movements. Key environmental variables, including bathymetry, distance to coast, sea surface height anomaly (zos), and chlorophyll-a mean concentration (Chl_mean), consistently influenced the seasonal SDMs. However, their relative importance shifted seasonally, emphasizing the species' responsiveness to dynamic oceanographic conditions within these regions.

Habitats Directive Reporting periods *Caretta caretta* - all life stages	
Maxent - avg predictions	Maxent - std
2008-2012	
	
2013-2018 (AUC train = 0.79, AUC test = 0.74)	



2019-2024
(AUC train = 0.74, AUC test = 0.71)

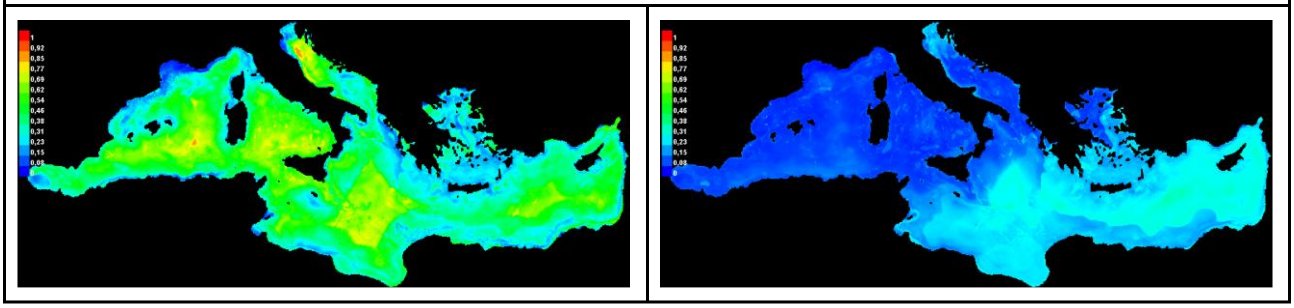


Figure 1.3.37. Species Distribution Model for *Caretta caretta* covering the three Habitat Directive reporting periods (2008-2012, 2013-2018, 2019-2024). The first period is not shown in full color as based on uneven and opportunistic data collection.

Table 1.3.48. *Caretta caretta* environmental variable contribution: summary of PCA loadings and Maxent output for each environmental variable over the reporting periods, expressed as percentage contribution and permutation importance.

	2008-2012		2013-2018		2019-2024	
Variable	SDM output		SDM output		SDM output	
	% contrib	perm. imp	% contrib	perm. imp	% contrib	perm. imp
Bathy metry	2.5	2.9	5.7	**14.9**	2.2	6.9
Chl_mean	1.1	0.9	3.4	5.7	4.8	6.8
Chl_sd	**37.8**	**36.2**	3.8	2.4	9.6	6.1
Curr.Dir	3.5	3.6	5.7	5	2.4	3.4
Curr.magn	3.6	3.9	1.7	3.2	1.2	1.8
deltaT	1.5	4.7	4.5	3.5	6.7	5.5
Dist. canyons	1.7	2.9	2.6	9.1	**15.3**	3.5
Dist.coast	5.9	7	4.7	7.5	**18.6**	**13.2**
Dist.seamounts	**13.3**	**15.6**	**10.5**	**10.5**	5.1	8.1
Dist.shelf	NA	NA	NA	NA	NA	NA
EKE	NA	NA	NA	NA	NA	NA
mlotst	1.9	3.8	3.9	3.1	3.6	**10.4**
Salinity	3.6	4.8	7.3	1.7	4.1	2.7
Slope	1.2	1.4	3.6	6.7	3.7	8.3
Temp_mean	0.7	1.6	3.1	3.1	**12.8**	3.7

Temp_sd	**19.9**	**9.1**	**30.6**	**17.7**	7.6	**16.3**
zos	1.7	1.6	**9.1**	5.8	2.3	3.4

Habitats Directive Reporting Periods: SDMs developed across the three Habitats Directive reporting periods reveal an apparent broadening of suitable areas toward the northern Adriatic Sea and the northwestern Mediterranean Sea between the second (2013–2018) and third (2019–2024) periods. **The first period** (2008–2012) should be interpreted with caution, as it was based on uneven and opportunistic data collection. Consequently, the model produced low and spatially fragmented suitability predictions, likely underestimating the full range of habitats effectively used by *Caretta caretta*. In contrast, **the second period** benefited from broader and more systematic survey coverage, resulting in a more robust model. It identified the Tyrrhenian Sea, northern Adriatic, and Tunisian shelf as key areas of high suitability. While temperature variability (Temp_sd) remained the dominant predictor, bathymetry and sea surface height anomaly (zos) increased in importance, reflecting a shift toward incorporating structural and hydrodynamic features. During **the third period,** the most influential variables included distance to coast, proximity to submarine canyons, and mean SST. Although survey effort was comparable to the previous period, the model predicted a broader spatial extent of suitable habitat. At the same time, response curves are characterized by narrower peaks, steeper slopes, and reduced tolerance ranges, indicating a shift toward more specific and consistent responses to environmental gradients. This pattern reflects greater ecological selectivity in habitat use, despite the broader geographic extent of predicted suitable areas. This implies that the observed range expansion is not the result of ecological generalism, but rather due to a greater spatial availability of optimal, well-defined habitats. For example, broader distribution may be partly driven by increasing SSTs, which have likely extended the extent of waters falling within the species' preferred thermal range (approximately 19–21°C). Additionally, warmer conditions may have enhanced habitat stability and prey availability, particularly in northern and western shelf areas, reinforcing a climate-mediated shift in habitat suitability.

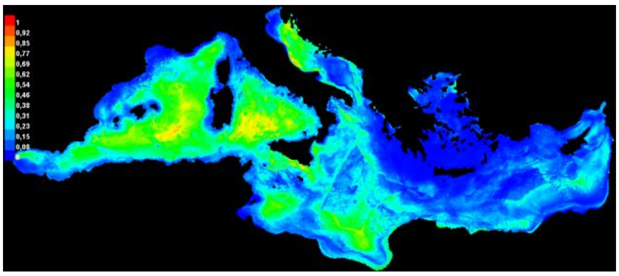
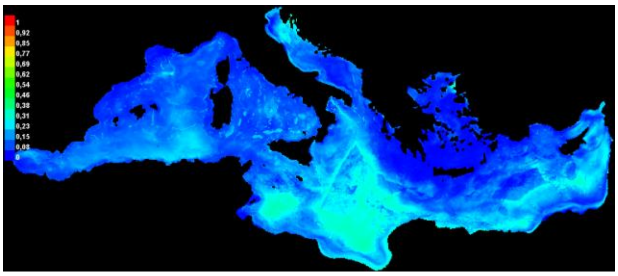
<table>
<tr><td colspan="2">Habitats Directive Reporting period - Caretta caretta - adults only
3rd period (2019-2024)
(AUC train =0.84, AUC test=0.79)</td></tr>
<tr><td>Maxent - avg predictions</td><td>Maxent - std</td></tr>
<tr><td></td><td></td></tr>
</table>

Figure 1.3.38. Species Distribution Model for *Caretta caretta* adults only during the four seasons (WIN from January to March, SPR from April to June, SUM from July to September, AUT from October to December).

Seasonal SDM - *Caretta caretta* - adults only

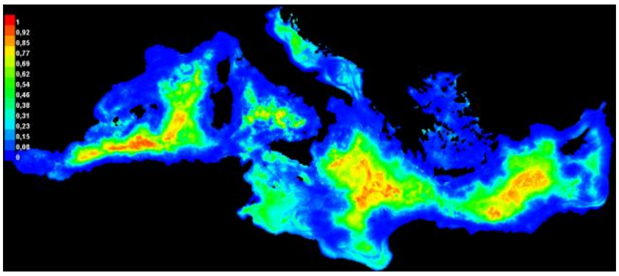
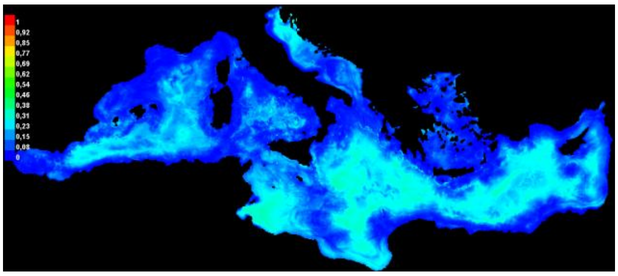
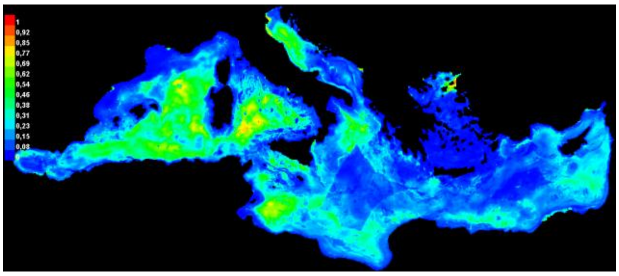
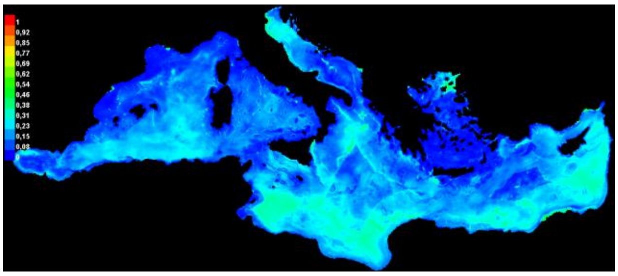
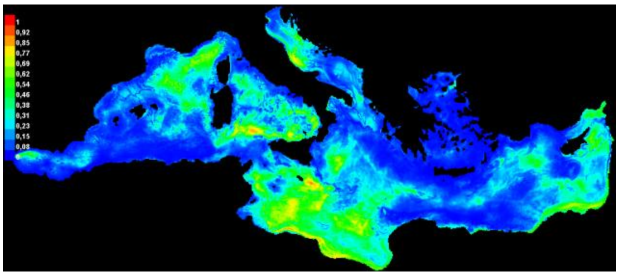
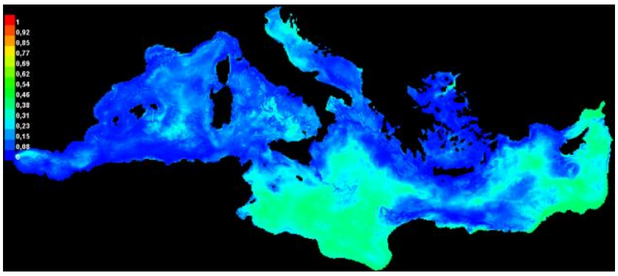
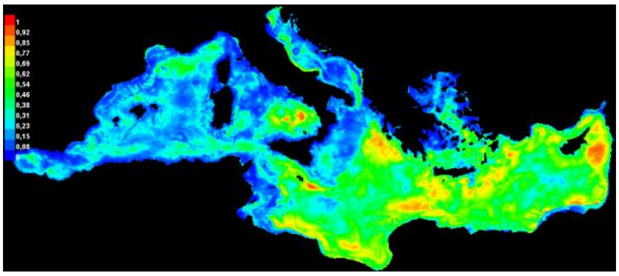
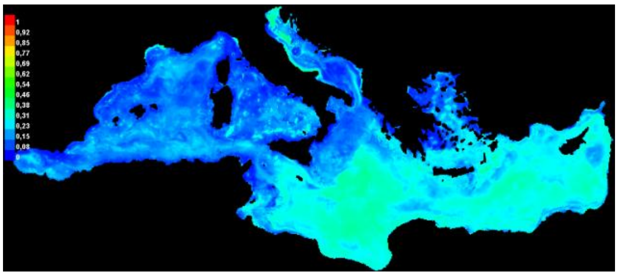
3rd period (2019-2024)	
Maxent - avg predictions	Maxent - std
WINTER (AUC train = 0.95, AUC test = 0.87)	
	
SPRING (AUC train = 0.90, AUC test = 0.82)	
	
SUMMER (AUC train =0.89, AUC test= 0.81)	
	
AUTUMN (AUC train =0.92, AUC test= 0.80)	
	

Figure 1.3.39. Species Distribution Model for *Caretta caretta* adults only covering the three Habitat Directive reporting periods (2008-2012, 2013-2018, 2019-2024).

Adult-only models: The SDMs developed for the third HD reporting period, considering only adult individuals, demonstrated greater predictive performance and spatial coherence compared to previous models that include all life stages (AUC test ≥ 0.80 all seasons). The adult-focused model yielded higher AUC score, relative to the full life stage models, indicating a more robust and reliable prediction of suitability. This improvement reflects the fact that adult turtles exhibit more targeted and consistent spatial behaviour, whereas juveniles and subadults tend to be more dispersed and opportunistic in habitat use. Spatially, the adult model shows more concentrated and seasonally consistent high-suitability areas, particularly along the northern Adriatic Sea, the southern Tyrrhenian Sea and parts of the Algerian coast. In contrast, the all-life-stages model predicted a broader and more dispersed distribution pattern, particularly during summer months likely due to greater variability in juvenile movements. This also reflects results of the variable contribution, according to which the most contributing ones were dist. coast, depth stable over the seasons, and chl mean increasing consistently in autumn. Focusing on adults only provided greater ecological resolution and operational values for conservation planning. Adult distribution is more predictable and localised especially during colder months, making these models more suitable for identifying key areas for protection.

Table 1.3.49. *Caretta caretta* environmental variable contribution: summary of PCA loadings and Maxent output for each environmental variable over the 3rd reporting periods and seasonally for adults only, expressed as percentage contribution and permutation importance.

3rd HD rep. period - adults			Winter - adults		Spring - adults		Summer - adults		Autumn - adults	
Variable	SDM output		SDM output		SDM output		SDM output		SDM output	
	% contrib	perm. imp	% contrib	perm. imp	% contrib	perm. imp	% contrib	perm. imp	% contrib	perm. imp
Bathymetry	**13.6**	**15.2**	**26.1**	**9.4**	7.8	**10.5**	**10.2**	7.9	4.2	3
Chl_mean	7	**11.9**	1.7	5.9	**11.5**	**15.1**	**14.6**	**11.2**	**40**	**26.8**
Chl_sd	**7.7**	5.1	2.3	6.5	4.9	4.9	2.4	2.6	**6.5**	**10.9**
Curr.Dir	2.5	3.4	1.4	1.3	2.2	2.8	3.1	3.1	6.2	6.9
Curr.magn	1.5	3.7	1.8	3.8	3.3	6.2	3	5.2	1.5	4
deltaT	4.7	5.2	9.3	**11.2**	2.8	4.2	5	5.8	6.4	5.6
Dist.canyons	8	7.7	**23.9**	**36.2**	**10.5**	8.3	6.8	8	6.2	7.4
Dist.coast	**22.8**	7.2	**16.9**	4.1	**28.7**	**15.6**	**21.7**	**12.5**	**7.4**	**10.8**
Dist.seamounts	4.3	8.3	1.2	1.5	4.9	4.7	5.1	**9.4**	4.8	2.9
Dist.shelf	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
EKE	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
mlotst	6.5	8.1	0.9	1.4	3	2.7	4.9	2.2	3	5.8
Salinity	7.5	2	0.5	1.6	5.4	3.4	2.6	0.8	1.3	1.9

Slope	3.1	8.2	4.8	6.1	2.5	6.7	6.5	7.8	4.4	4.3
Temp_mean	5.7	3.8	0.2	2.2	6.9	5.2	5.2	9.2	2.4	2.6
Temp_sd	3.6	**9**	3	0.6	3.6	7.3	4.2	7.6	2.3	2.9
zos	1.6	1.2	6.1	8.1	1.9	2.6	4.7	6.8	3.5	4.2

2. eDNA results

TECHNICAL SUMMARY - **Species Detection and Distribution across the Mediterranean Sea Regions and concordance with visual data:**

Using eDNA, we detected **9 species of cetaceans** (namely: *Stenella coeruleoalba, Balaenoptera physalus, Tursiops truncatus, Grampus griseus, Kogia breviceps, Ziphius cavirostris, Physeter macrocephalus, Globicephala melas, Delphinus delphis*); **187 species of bony fishes**, including nocturnal and benthic species; **11 species of elasmobranchs**. Among cetacean species, *Kogia breviceps* was not previously sighted during visual monitoring nor considered to be resident in the Mediterranean Sea.

- **Cetacean eDNA overview by species:**
- The most widespread species is ***Stenella coeruleoalba****,* whose eDNA detections are abundant in every region and throughout seasons.
- ***Tursiops truncatus*** appears to be the second most common species, with detections in the south Adriatic regions, in the Alboran Sea, in the waters off Tunisia, and in the Spanish Cetacean Migration Corridor area.
- ***Delphinus delphis*** is predominantly present in the Alboran Sea, but with sporadic detections also in the northern and southern Tyrrhenian Sea.
- ***Grampus griseus*** and ***Globicephala melas*** have been detected almost uniquely in the Alboran Sea.
- As expected, ***Balaenoptera physalus*** is mostly present in the Pelagos Sanctuary, but some detections have been found also in the Tyrrhenian Sea.
- ***Kogia breviceps*** detections are distributed across most regions of the western Mediterranean Sea.
- ***Ziphius cavirostris*** and ***Physeter macrocephalus*** are the species with less detections, reflecting smaller eDNA quantities released on the surface due to their deep-diving feeding ecology.

- **Cetacean biodiversity hotspots** (i.e. areas where multiple species were detected) emerged to be the following, in descending order: the Alboran Sea, the Spanish Cetacean Migratory Corridor, the waters off Tunisia, the Pelagos Sanctuary, and the northern Tyrrhenian Sea.

- **Fish species hotspots and distribution** appear to be concordant with the cetacean ones, highlighting how prey availability can be a major driver for habitat preference for cetaceans.

- Differences in distribution based on **seasonality** are visible, although the sampling effort was not equal across seasons, and therefore a comparison would not be reliable. However, similar seasonal distribution patterns can be identified for both cetacean and fish species, at least in terms of abundance. A more careful analysis on seasonality in fish species composition will be carried out in the next months.

- When testing **concordance between eDNA detections and visual sightings**, these were only partially overlapping (around 40%) and concordance is higher for the most common species (e.g. *Stenella coeruleoalba, Delphinus delphis, Tursiops truncatus)*

Summary of Species Distribution based on eDNA data by Effort Area

Western Mediterranean Region

The Western Mediterranean Sea resulted to be an ecologically important region for several species of cetaceans. In particular, the Alboran Sea and the Spanish Cetacean Migration Corridor are highlighted as relevant areas for their constant presence of cetaceans throughout the seasons and the biodiversity of species present. Indeed, species like *Grampus griseus* and *Globicephala melas* are almost only detected in the waters close to Gibraltar*.* The samples showing the highest cetacean-diversity (4-5 species of cetaceans molecularly detected within the same sample) were found in the Alboran region. Consistently, fish richness and abundance is high in these areas.

Ligurian Sea (Pelagos Cetacean Sanctuary)

The Pelagos region ranked **third in the incidence of cetacean-positive samples**, underscoring its ecological significance for many cetacean species, especially the fin whale and small dolphin species. Particularly biodiverse areas are the waters off Liguria and Southern France, and the Caprera Canyon area (between Corsica and Sardinia). Unfortunately, the inability to sample the area during winter does not allow for seasonal comparisons.

Tyrrhenian Sea

The Tyrrhenian Sea, although not yet considered an important area for cetacean species, exhibited particularly dense detections of species such as ***Stenella coeruleoalba, Balaenoptera physalus*** **and** ***Tursiops truncatus.*** Of the latter, a possible resident population present throughout the year was detected **in the waters of the Gulf of Tunis**.

Adriatic Region

The Adriatic region remained a marginal area for most cetacean species. The only species detected constantly in most seasons are *Stenella coeruleoalba* and *Tursiops truncatus* in the southernmost part of the region, close to the coastline of Greece and the Aegean Sea.

Overall Patterns

The western Mediterranean includes relevant areas for the presence of all cetacean species, with some of them being ubiquitous while others being detected only in specific regions. Meanwhile, the Adriatic region remains marginal for most cetaceans, with generally low or occasional presence.

SUMMARY FOR POLICYMAKERS: Key Marine Species and Priority Conservation Areas based on eDNA detections

The eDNA detection patterns of cetaceans across the western Mediterranean and Adriatic Sea highlight critical areas essential for marine biodiversity conservation and spatial planning. The observed and ecological potential ranges of key species, such as *Stenella coeruleoalba*, *Balaenoptera physalus*, *Tursiops truncatus*, *Delphinus delphis*, *Grampus griseus*, *Globicephala melas*, *Ziphius cavirostris*, *Physeter macrocephalus* and *Kogis breviceps* indicate a combination of widespread, coastal, offshore, and regionally confined distributions.

Based on eDNA data, several areas emerge as species biodiversity hotspots supporting, making them strategic priorities for adaptive marine conservation policies and spatial management; in descending order:

- **Alboran Sea and Gibraltar Region:** the most biodiverse and high-priority regions supporting the distribution of all species of cetaceans, including deep-divers, and specifically relevant for *Delphinus delphis*, *Grampus griseus* and *Globicephala melas.*
- **Spanish Cetacean Migration Corridor**: important area for the distribution of small dolphins like *Stenella coeruleoalba* and *Tursiops truncatus,* and key habitat for the distribution of *Kogia breviceps.*
- **Southern Tyrrhenian Sea and waters off Tunisia:** relevant core area for *Balaenoptera physalus*, *Stenella coeruleoalba* and *Tursiops truncatus*, with a detectable resident population close to the Gulf of Tunis.
- **Pelagos Sanctuary (Ligurian Sea):** a key habitat for several species, including *Balaenoptera physalus*, *Stenella coeruleoalba* and *Tursiops truncatus*.
- **Northern Tyrrhenian Sea:** area with unique bathymetric characteristics, relevant for deep-divers like *Ziphius cavirostris* and other species like *Tursiops truncatus* and *Kogia breviceps*.

The overlap of core habitats highlights the importance of coordinated international marine protection, improved monitoring, and focused conservation efforts within these shared ecological areas. Regional biodiversity and conservation status for multiple species may benefit from concentrated actions in these critical zones, to reach management goals and species protection.

Method. The innovative aspect of the LIFE-CONCEPTU MARIS project lies in its integration of traditional visual monitoring of cetaceans (i.e. FLT effort conducted from the ferries' deck over the past two decades) with marine biodiversity monitoring through environmental DNA (eDNA). The method relies on the detection of genetic material released into the water by marine organisms. This approach enables the assessment of the entire biological community inhabiting the waters covered by the ferry, providing up-to-date data on the presence and distribution of the entire trophic chain (fish and invertebrates), including cryptic and threatened species that generally remain poorly understood.

Although eDNA presents certain limitations, such as difficulties in pinpointing the exact geographic origin or the number of individuals contributing to the detected genetic traces, its application could offer an effective complement to visual monitoring, which is constrained by weather and sea conditions and is limited to daytime observations. This integrated approach enhances existing surveys and enables large-scale, long-term mapping of species distribution.

During the CM eDNA-collection campaign, over 400 seawater samples were collected from the engine rooms during the ferry crossings with the LIFE-CONCEPTU MARIS team onboard. To date, this represents the largest-scale collection of eDNA samples in association with observational data. Presented below are the preliminary results from the initial analysis of the eDNA data, which already highlight the considerable potential of this method to provide an additional level of resolution to traditional visual observations, with which it shows a high degree of concordance.

2.1 Samples' distribution

A total of 497 samples were analyzed using three sets of primers through next-generation sequencing (NGS) metabarcoding, targeting cetaceans, fish, and invertebrates (Figure 2.1.1). After removing the 50 extraction and PCR blanks used as negative controls, 447 valid samples remained, all of which were collected at sea. In total, 5,364 liters of marine water were filtered. Of the 447 marine eDNA samples, 393 (87.9%) were collected from operating ferries during LIFE-CM surveys, which were conducted concurrently with FLT visual observations. These samples originated from 81 Fixed Sampling Stations (FSSs, n = 364; Figure 2.1.2) or were collected shortly after sightings of rare cetacean species (n = 29). An additional 54 control samples were collected from coastal waters using smaller vessels operating in the same maritime districts covered by the ferry routes during the study period (Figure 2.1.1). The geographic distribution of all 447 sampling locations is shown in Figure 2.1.3.

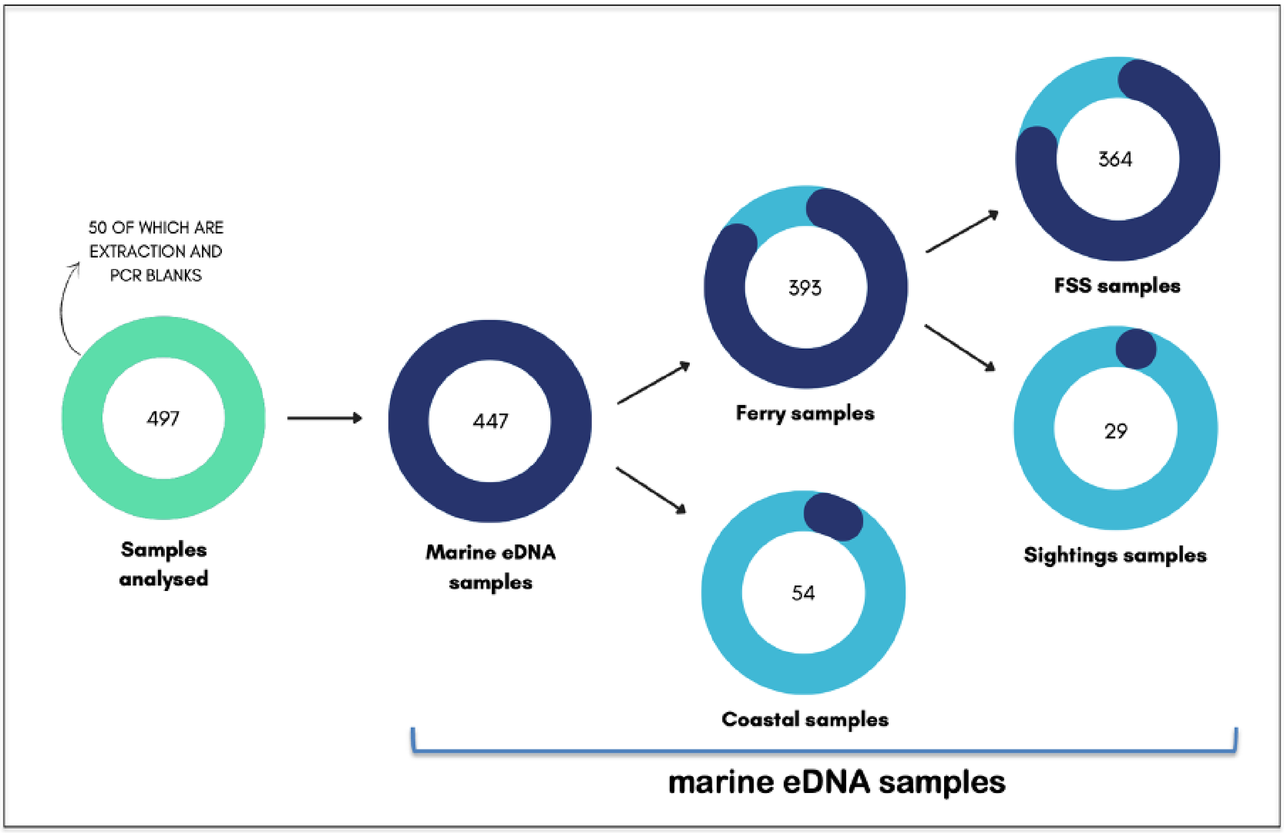


Figure 2.1.1. Total number of samples analysed during the CM project, showing specified subgroups.

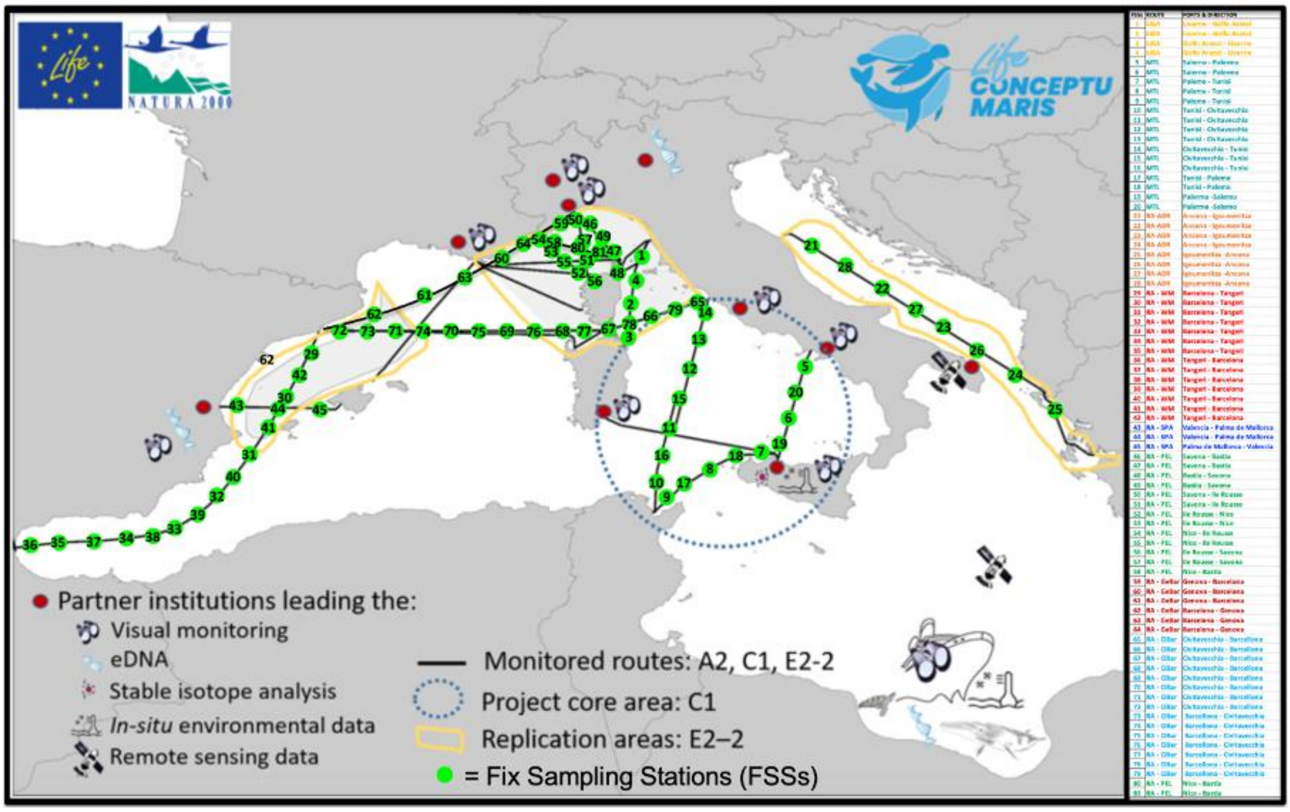


Figure 2.1.2. Map showing the 81 Fix Sampling Stations (FSSs) surveyed during the project. Not being possible to sample exactly the same point in subsequent cruise, each FSS has to be intended as a cloud of points referable to the surrounding area.

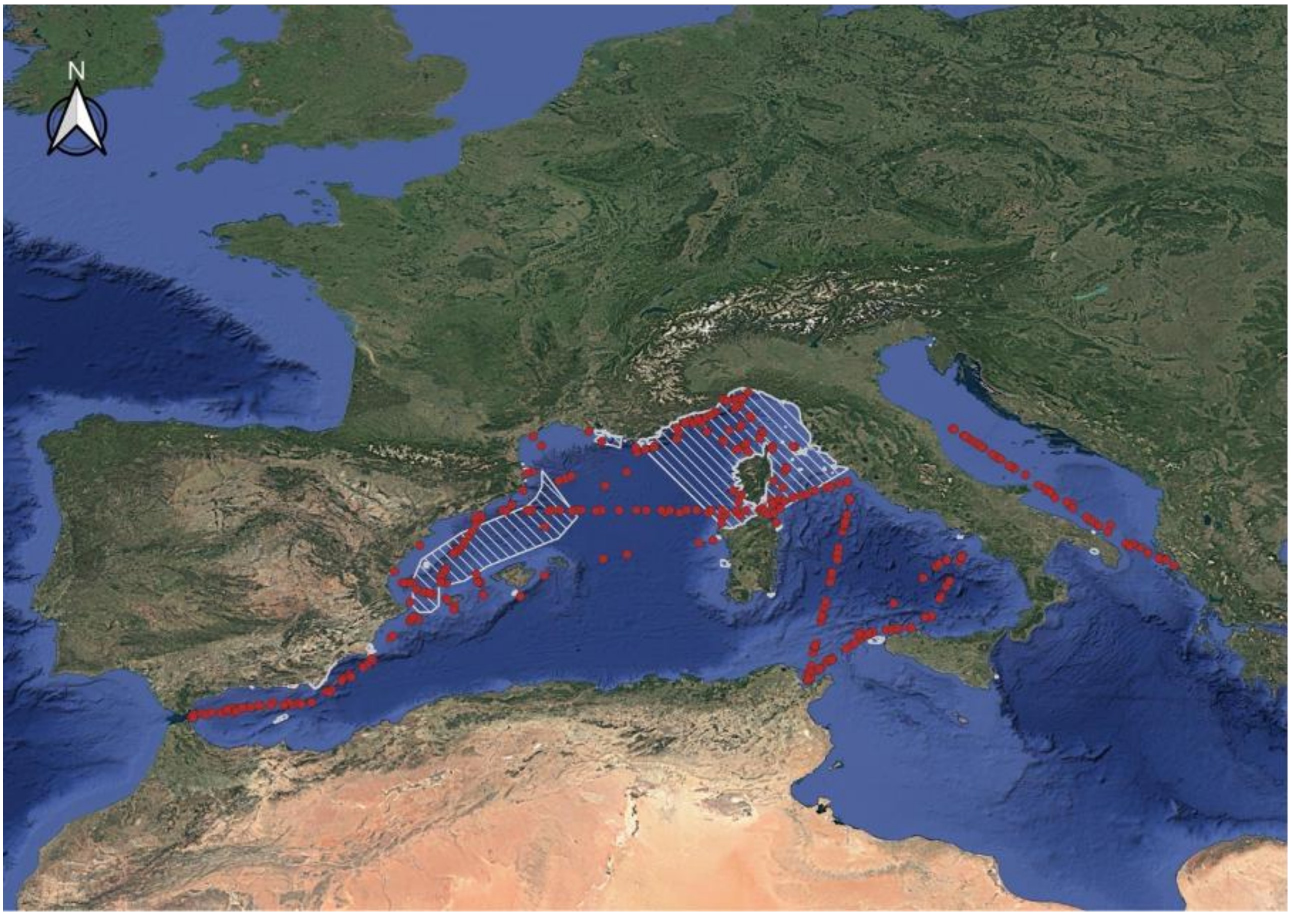


Figure 2.1.3. Geographic localization of the 447 marine eDNA samples analysed in the CM projects. Dashed lines delineate the Specially Protected Areas of Mediterranean Importance (SPAMIs, https://www.rac-spa.org/spami) (imagine created in QGIS).

Each sample consisted of 12 liters of seawater collected from the engine room. Sampling was conducted at regular intervals, including during night-time hours (n = 155; 34.8%), and during daylight hours (n = 292; 65.2%), when visual surveys were simultaneously carried out from the command deck by other members of the CM team (Figure 2.1.4).

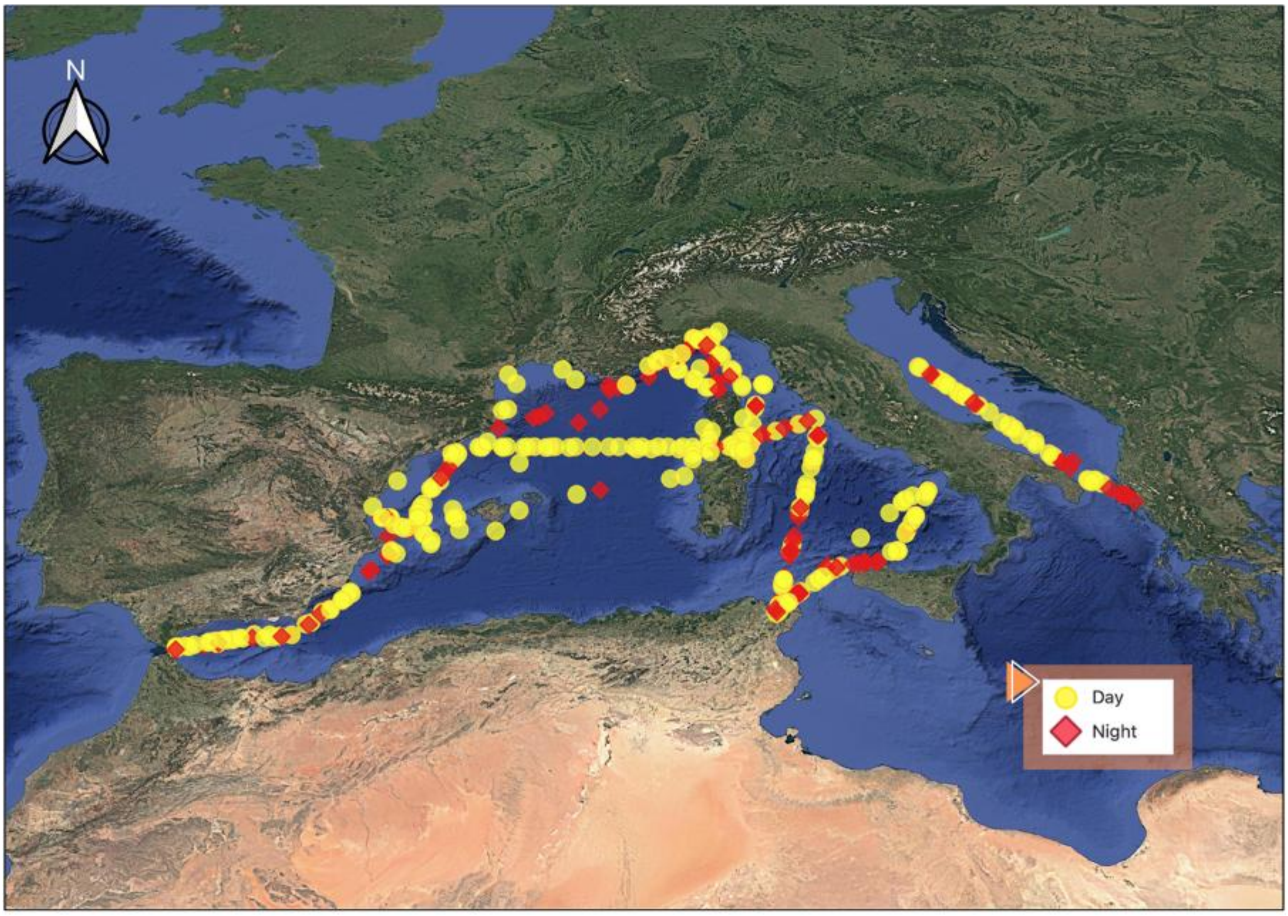


Figure 2.1.4. Distribution of daylight and nocturnal samples.

2.2 Cetacean species occurrence and diversity

To date, all samples have been analyzed for the detection of molecular traces from cetaceans and fish. A total of 467,576 reads were assigned to cetaceans, identifying nine species (Figure 2.2.1), with the striped dolphin (Stenella coeruleoalba) being the most frequently detected. The marine districts with the highest cetacean species abundance and diversity, in descending order, were the Alboran Sea, the Spanish Cetacean Migratory Corridor, the waters off Tunisia, the Pelagos Sanctuary, and the northern Tyrrhenian Sea (Figure 2.2.2).

Overall, the incidence of cetacean molecular detections was markedly higher in the Western Mediterranean sector of our sample set. For clarity, we define Western Mediterranean samples as those collected within the Spanish longitudinal range (i.e., all samples with a longitude west of 3.47°E). Although these samples represented only 28.9% (n=129) of the total dataset, they accounted for more than half (53.5%) of all positive detections for cetacean eDNA. In contrast, only one-third (32.1%) of the samples from the Central Mediterranean tested positive (Figure 2.2.3). Given the importance of the two above mentioned cetacean hotspots within Spanish waters, this report also incorporates preliminary data from a sister project, CETABIOENA, which is conducting intensified sampling in the Cetacean Migratory Corridor off the Spanish coast (see Section 2.6).

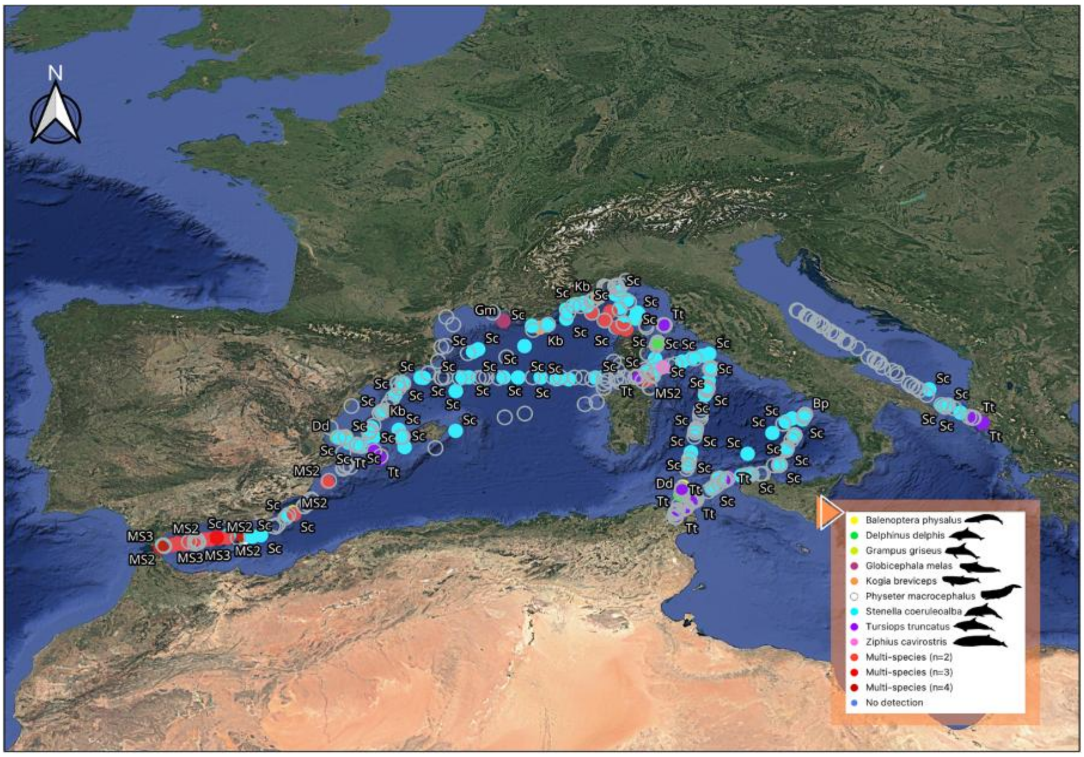


Figure 2.2.1 Distribution of detected cetacean species (solid-coloured circles). Open circles denote negative samples.

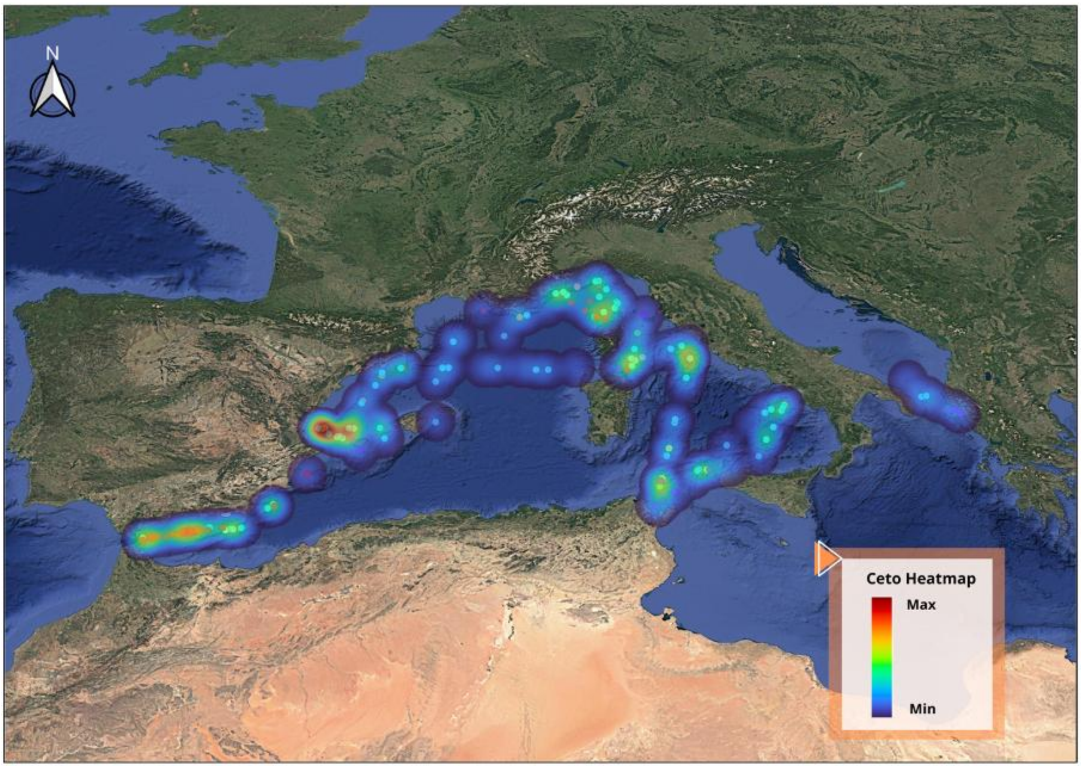


Figure 2.2.2 Heat-map of occurrence of eDNA detections referable to cetacean species. Red-orange areas highlight hot-spots for cetaceans' biodiversity.

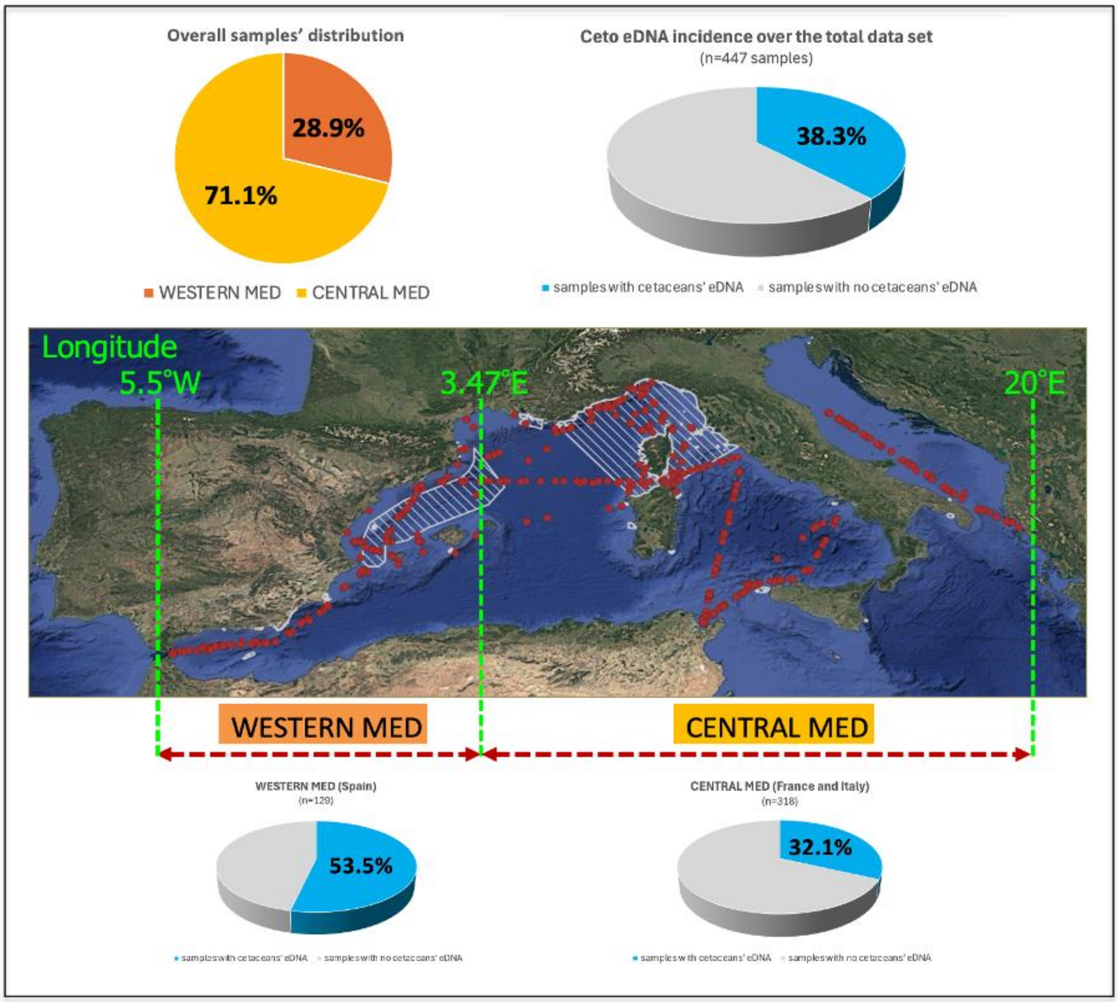


Figure 2.2.3 The grey-blue pie charts illustrate the proportion of eDNA samples testing positive for cetacean DNA within the total dataset (top right), as well as within the Western (bottom left) and Central (bottom right) Mediterranean regions.

2.3 Fish occurrence and diversity

Metabarcoding analysis assigned a total of 20,824,194 reads to fish species. A total of 198 fish taxa were identified, resolved to either species or genus level, the majority of which were bony fishes. The most frequently detected taxa are presented in Figure 2.3.1. In addition, 11 elasmobranch species (5.6% of the total) were identified (Figure 2.3.2), comprising an even representation of both Selachimorpha (sharks) and Batoidea (rays and skates).

n. reads	n. samples	taxon		
1087998	101	*Engraulis encrasicolus*	anchovy	
617057	47	*Sardinella aurita*	pilchard	
607422	69	*Hygophum hygomii*	lantern fish	N
489093	60	*Myctophum punctatum*	lantern fish	N
327255	45	*Sardina pilchardus*	pilchard	
255447	71	*Hygophum benoiti*	benoit's lantern fish	N
232380	52	*Pagellus acarne*	axillary seabream	
225357	9	*Thunnus sp*	tuna	
133959	44	*Aphia minuta*	transparent goby	
118411	18	*Scomber sp*	mackerel	
93259	29	*Auxis sp*	frigate tuna	
76034	14	*Mullus barbatus*	red mullet	B

Figure 2.3.1 List of the 12 commonest fish species detected in the total eDNA sample set. "N" and "B" denote nocturnal and benthic species respectively.

n. reads	n. samples	taxon	
12455	41	*Pteroplatytrygon violacea*	pelagic stingray
27003	12	*Mobula sp*	giant devil ray
2740	9	*Prionace glauca*	blue shark
2223	1	*Carcharhinus leucas*	bull shark
1001	2	*Mustelus manazo*	starspotted smooth-hound
421	2	*Dasyatis pastinaca*	common stingray
362	2	*Scyliorhinus canicula*	small-spotted catshark
387	1	*Galeus melastomus*	blackmouth catshark
379	1	*Isurus oxyrinchus*	mako shark
36	1	*Torpedo marmorata*	marbled electric ray
6	1	*Aetomylaeus bovinus*	bull ray

Figure 2.3.2 List of the 11 Elasmobranch species detected in the 447 marine eDNA samples surveyed in the project.

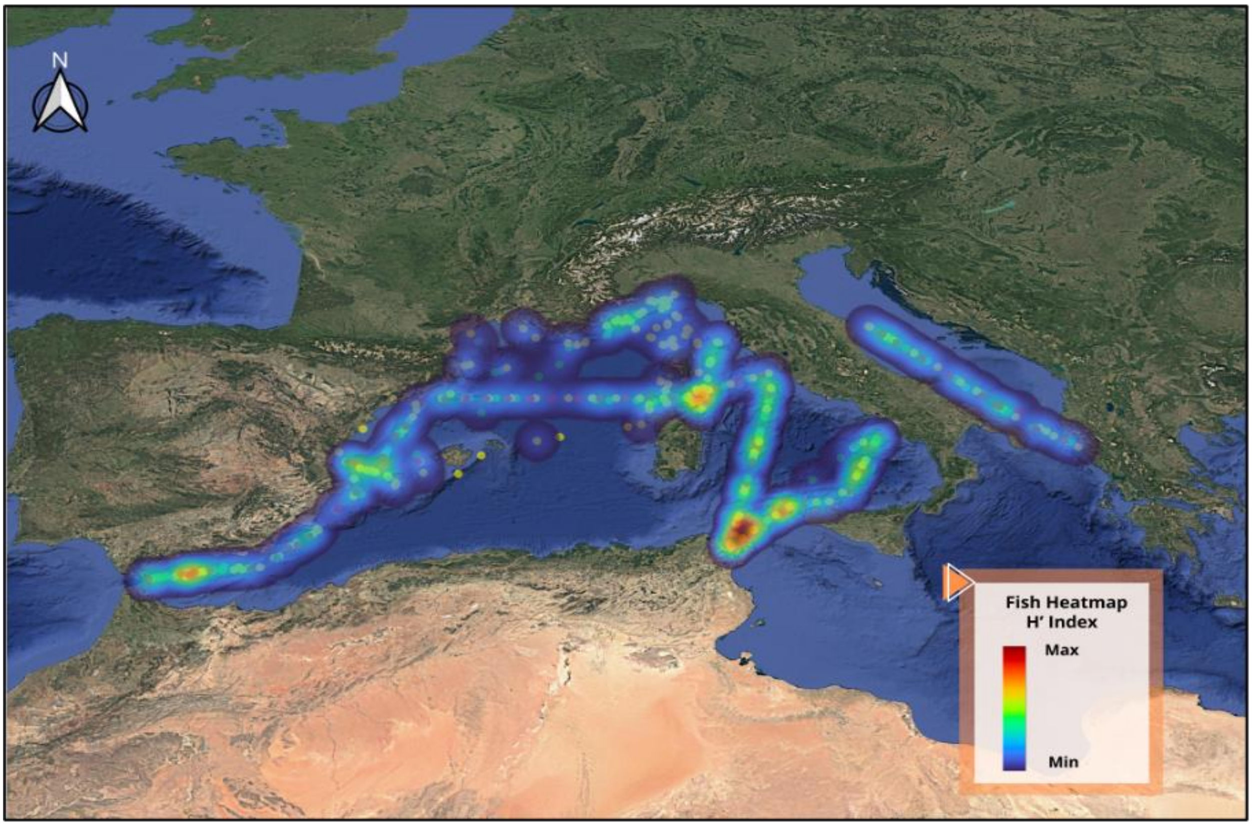


Figure 2.3.3. Heat-map of occurrence of eDNA detections referable to fish species.

Figure 2.3.3 presents overall fish diversity and abundance, highlighting the waters off the Tunisian coastline as the richest in fish biodiversity, followed by the northern Tyrrhenian Sea (based on summer records only), the Alboran Sea, and the western segment of the Spanish Cetacean Migratory Corridor.

The next step, following the retrieval of invertebrate (e.g. cephalopods, crustaceans, micro and macro plankton) data from the NGS raw sequences, will be to utilize the complete dataset to construct co-occurrence networks (e.g., Boyse et al. 2025). These networks are useful to identify correlations between all detected cetacean species and all remaining taxa, with the aim of identifying potential ecological relationships between each cetacean species and its known or potential prey. Furthermore, this analysis will support the identification of ecologically sensitive areas where such trophic networks are particularly prevalent, thereby highlighting potential key regions for targeted cetacean conservation efforts.

2.4 Seasonal variation

Samples were collected from operating ferries in all four seasons. Autumn was the most represented season, accounting for 40.5% of the samples, followed by spring (26.4%), summer (21.9%), and winter (11.2%) (Figure 2.4.1). The under-representation of the latter season can be attributed to unfavourable weather conditions that limited visual observations (always carried out simultaneously to eDNA sampling) in Winter. Figure 2.4.2 shows cetaceans and fish molecular detections split by season.

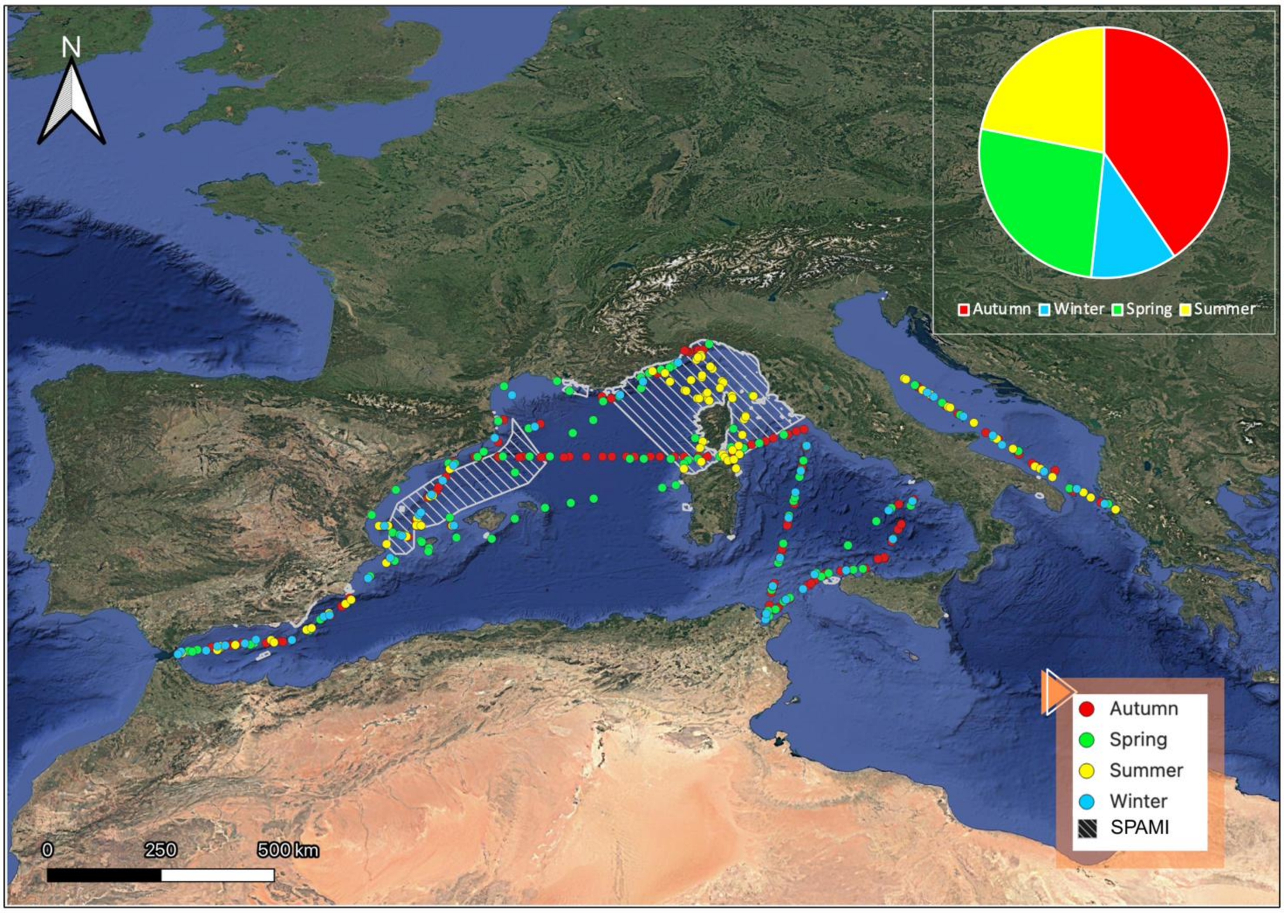


Figure 2.4.1. Seasonal distribution of eDNA traces referable to cetacean species.

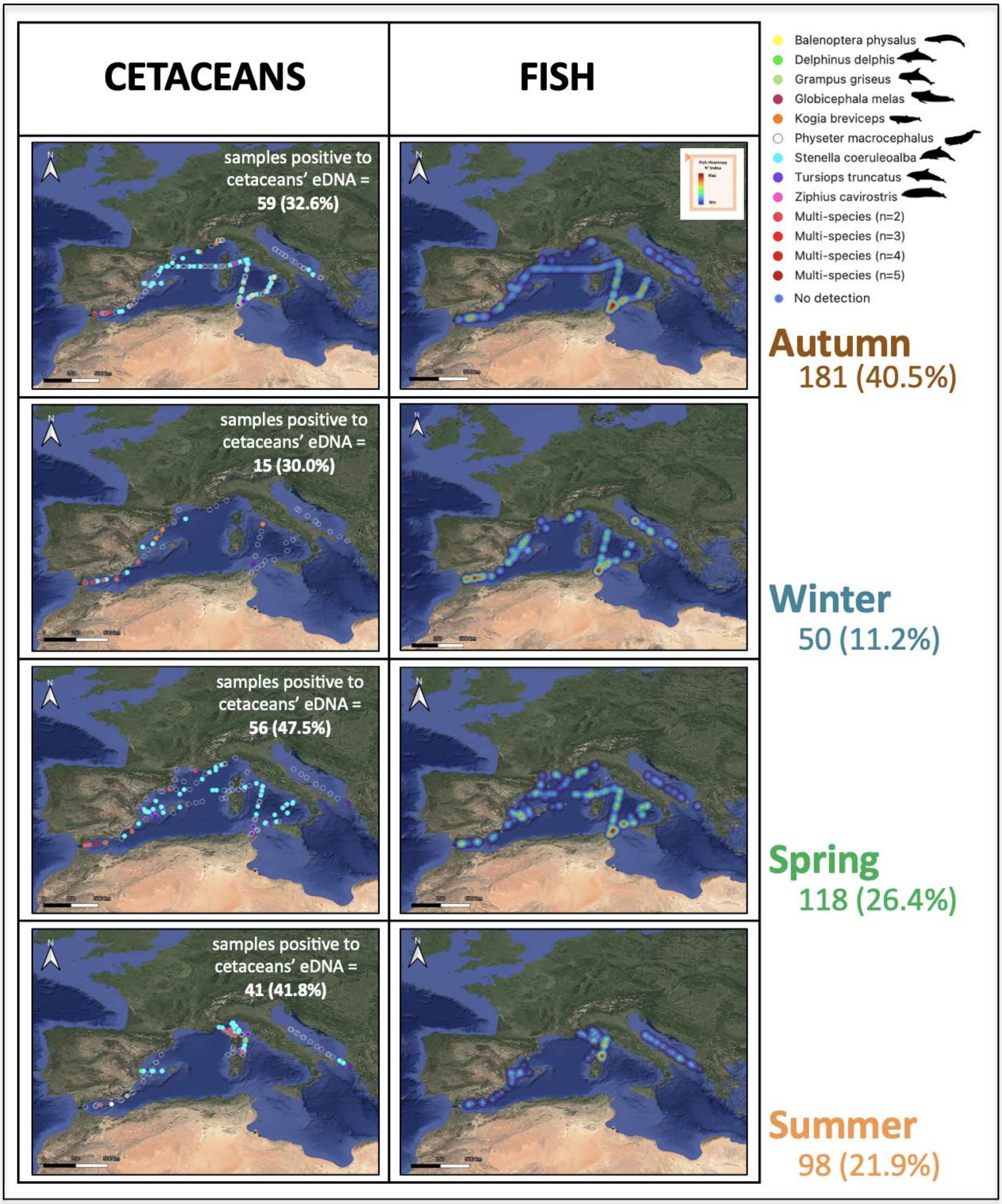


Figure 2.4.2. Seasonal distribution of eDNA reads referable to cetaceans (left) and fish (right) species. For fish data the heat-map refers to the total fish reads.

2.5 Visual - eDNA concordance

Cetacean detections obtained from the environmental DNA analysis have been compared with the visual monitoring data. To do so, we first temporally aligned the two datasets to identify any visual detection of cetaceans occurring immediately before, during or soon after the seawater collection for eDNA analysis. Since eDNA samples are mostly collected in Fixed Sampling Stations along the route, the time of collection has been used as a starting point to define a time interval within which the cetacean sightings could be compared with eDNA detections. Considering the cruising speed of the ferries during most multidisciplinary transects and the spatial and temporal information that eDNA can provide, any cetacean sighting registered 30 minutes before or after the eDNA sampling time has been included in a sub-dataset. For this purpose, eDNA samples collected during the night or on transects where visual monitoring was not active were not accounted for.

A total of 306 cetacean species detections (visual and molecular combined) constituted the sub-dataset considered for the comparison among molecular and visual concordance. Around 61.1% of those are eDNA detections, while the remaining 38.9% are visual sightings. The dataset includes 10 different species and 1 extra category, classified as “Undefined Species (U.S.)” (Figure 2.5.1). The “U.S.” category refers to cetacean specimens sighted but not identified to species level, and it is provided information only on the size of the individual (e.g. small, medium, big); therefore, this category is only present in the visual sightings database. A complete overview of the species and the number of detections included in this sub-dataset are shown in Figure 2.5.2.

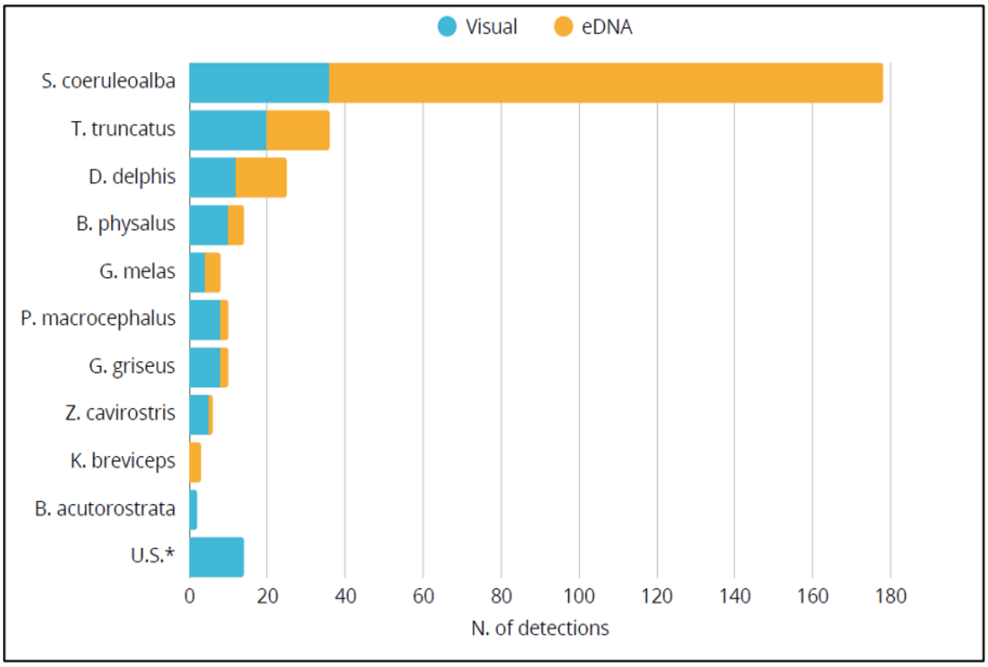


Figure 2.5.1. Stacked Bar Chart showing the number of eDNA and Visual detection for each species and for the category U.S. (*of all dimensions) included in the sub-dataset for the comparison between visual and molecular data. Note that here are not represented all visual and molecular detections (but only those spatio-temporally related).

Detections have been compared in either way, meaning both checking how many sighted species have been also identified through the analysis of eDNA, and vice versa. The results of the comparison are displayed in Figure 2.5.3 (a.-d.), where we show the percentages for:

- No concordance: the species detected with visual monitoring or eDNA has not been identified with the other method, as another species or no species has been detected by the latter.
- Concordance: the species sighted or detected with eDNA has been identified with the other method as well. This may refer to single or multiple species detections.

- Partial concordance: not all the species that have been sighted or detected with eDNA have been identified with the other method.
- Potential concordance: when an Undefined Species matches with the eDNA detected species by size, although we cannot surely affirm that the detected species is the one sighted (and vice versa).

a.

SIGHTINGS VS eDNA		
category	n.	%
No concordance	60	58.824
Concordance	31	30.392
Partial concordance	3	2.941
Potential concordance	8	7.843
total	102	

b.

% concordant species	
Stenella coeruleoalba	66.667
Tursiops truncatus	7.143
Delphinus delphis	11.905
Balaenoptera physalus	7.143
Globicephala melas	7.143
total	100

c.

eDNA VS SIGHTINGS		
category	n.	%
No concordance	69	63.303
Concordance	19	17.431
Partial concordance	12	11.009
Potential concordance	9	8.257
total	109	

d.

% concordant species	
Stenella coeruleoalba	52.632
Tursiops truncatus	7.895
Delphinus delphis	7.895
Balaenoptera physalus	7.895
Globicephala melas	5.263
Undefined species medium	2.632
Undefined species small	15.789
total	100

Figure 2.5.2. Results emerging from the comparisons of the visual and eDNA data for each category. In (a) the concordance percentage between sightings and eDNA detections, and the relative species when concordance (total or partial) has been observed (b). In (c) and (d) the percentage of concordance and the relative species for the comparison between eDNA and sightings.

As expected, the data from the visual monitoring and from the eDNA analysis are only partially overlapping (around 40% in both cases), as eDNA can detect signals from species that are present at the moment of sampling, or were present some hours before, or again are or were present somewhere close to the area of collection but not in a sighting distance from the vessel. Moreover, a series of stochastic and unforeseeable events influence eDNA detection, including: dispersion mediated by sea currents; amount of eDNA effectively released by the individual and available on the sea surface; amount of eDNA stochastically sampled during collection; chemical and physical eDNA degradation in the environment and all factors that determine the degradation process itself. Therefore, eDNA data are to be integrated with visual monitoring data as they provide different yet complementary information. Although not fully concordant, for both techniques the most detected species when monitoring and eDNA sampling are co-occurring are also the most frequently sighted and detected species in general: *Stenella coeruleoalba* and *Tursiops truncatus*.

To investigate this point further, we directly compared the complete visual sightings and eDNA detection databases, and the results obtained show a very similar situation (Fig 2.5.3). In fact, although on a different scale, species detection proportions are relatively concordant between techniques (Fig 2.5.4). In this case though, a smaller fraction of the detections is shared between visual and molecular data, as here eDNA samples collected during the night, on multidisciplinary routes where visual monitoring was not on effort, and cetacean sightings temporally distant from eDNA collection were also included. While most species were successfully identified by both methods, it is relevant to highlight that the species *Balaenoptera acutorostrata* was only sighted during visual monitoring, whilst the species *Kogia breviceps* was only detected through eDNA samples.

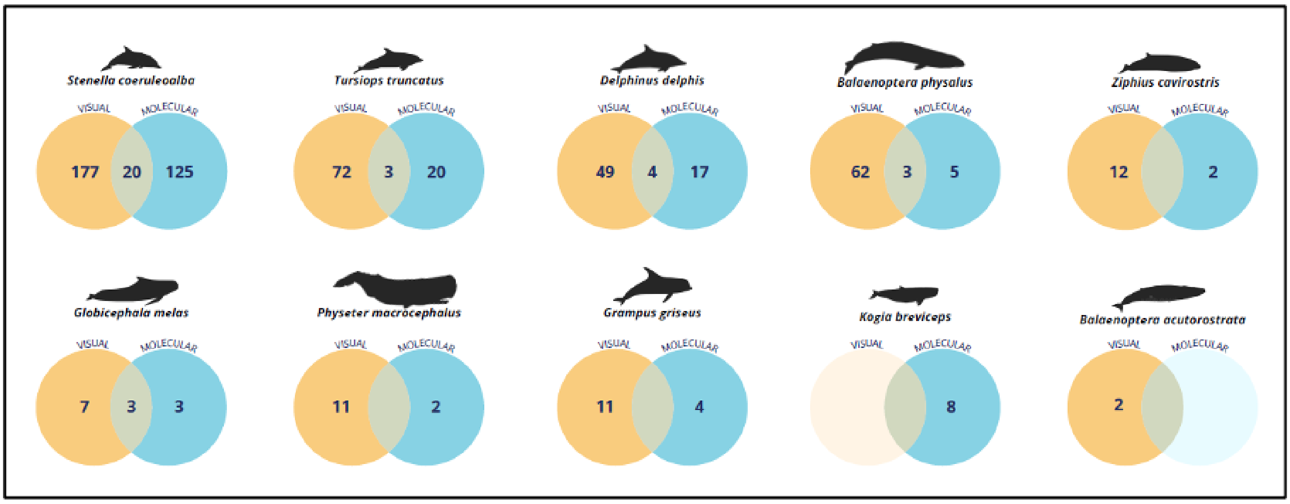


Figure 2.5.3. Number of visual and molecular detections and co-detections based on the complete visual monitoring and eDNA databases.

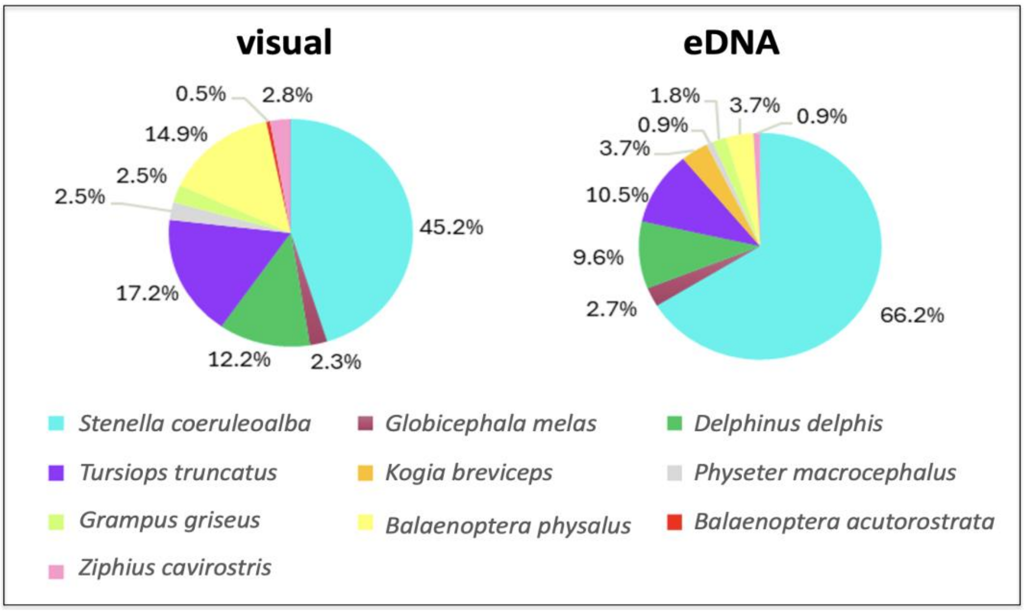


Figure 2.5.4. Comparison in species detection rates using the visual and eDNA approaches.

2.6 eDNA data for the Spanish Cetacean Migratory Corridor

In the Spanish Cetacean Migratory Corridor, a further 153 water samples (413.71 litres) were analysed with the MarVer3 primer set, which was designed to amplify ~245 bp of the mitochondrial 16S rRNA. Each sample consisted of approximately 3 litres of water and was filtered using Sterivex^{TM} 0.45µm encapsulated filters. Whenever possible, an additional one or two replicate samples were taken at each marine sampling point, although each replicate was analysed as an individual sample.

The 153 samples consisted of 138 marine samples and 15 filtering controls; sampling points are visualized in Figure 2.6.1. Each control sample consisted of 3 litres of distilled water that was filtered at the end of a marine eDNA filtration session, to account for any potential contamination of the eDNA processing area. Fifty-three (38.4%) of the 138 marine eDNA samples were acquired from 4 FSSs (one nighttime sample, VAPA1, and 3 daytime samples, VAPA2, VAPA3 and VAPA4) along the Valencia–Palma de Mallorca ferry route; samples were collected from the sea chest in the engine room during LIFE-CONCEPTU MARIS visual transect surveys. The remaining 85 marine samples (61.6%) were collected using a hand pump onboard various tourism vessels during two other research campaigns: Columbretes (*n* = 41) and MARE (*n* = 44).

Research campaign samples were collected at FSSs, singular sampling stations (SSSs) (i.e. sampling stations that were only sampled once), and during cetacean sightings. During the Columbretes research campaigns, 15 (36.6%) samples were collected along 3 FSSs and 2 SSSs, and 26 (63.4%) were collected during 13 cetacean sightings, and during the MARE campaign, 36 (81.8%) samples were collected at 18 SSSs, and 8 (18.2%) during 4 cetacean sightings.

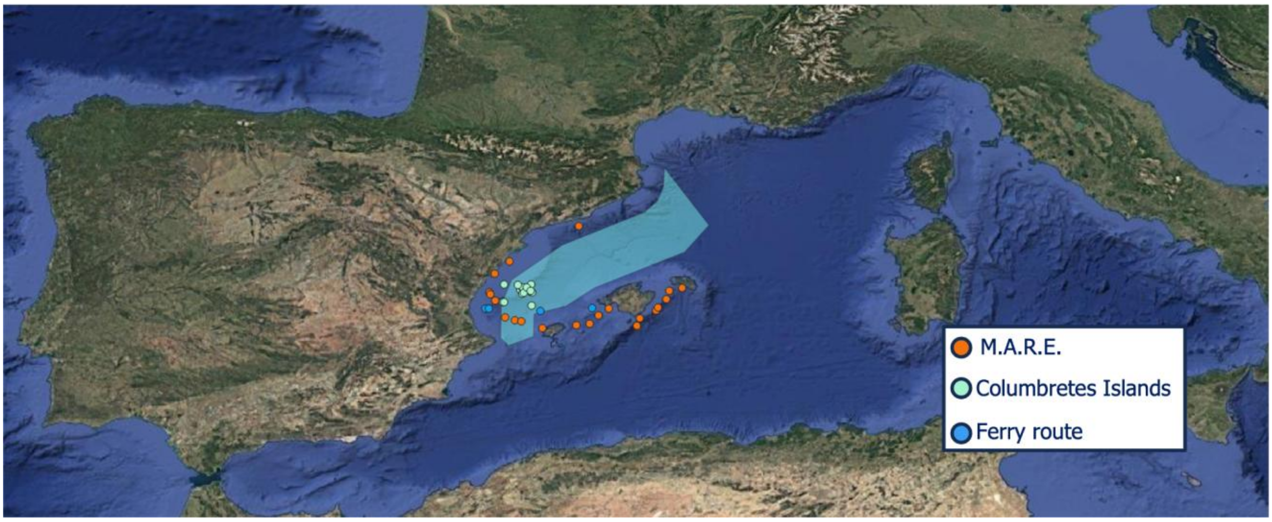


Figure 2.6.1. Water sampling locations. The shaded area shows the Spanish Cetacean Migratory Corridor MPA.

From the marine samples, a total of 74 samples (53.5%) were positive for DNA from at least one CEPTU species, and 64 (46.4%) had no molecular detection of any CEPTU species. *Stenella coeruleoalba* was the most detectable species in the area, being detected in 29 locations around the Columbretes and the Balearic Islands, the Ibiza Channel and the Mallorca Channel (Fig 2.6.2 a). DNA from *Delphinus delphis* was detected only in two sampling locations near Ibiza and off the Columbretes Islands (Fig 2.6.2. b). *Tursiops truncatus* was detected by molecular means in 10 locations around the Columbretes Islands and the Ibiza Channel (Fig 2.6.2 c). Five sampling locations were positive for *Grampus griseus* DNA and one for *Globicephala melas* and *Physeter macrocephalus*, respectively (Fig 2.6.2 c). DNA from *Balaenoptera physalus* was detected in five locations and in one location DNA from *Balaenoptera acutorostrata* (Fig 2.6.2 d). As for *Caretta caretta*, DNA from this species was detected in seven locations (Fig 2.6.2 e). Finally, in a total of 15 locations DNA identified as coming from species of the Delphinidae was also detected (Fig 2.6.2 f). In this case, specific taxonomic assignment below the family taxonomic rank was not possible because the amplified fragment is short (i.e., ca. 200 bp) and with little or no base pair differences between closely related species (e.g., *Delphinus* spp., *Stenella* spp. and *Tursiops* spp.).

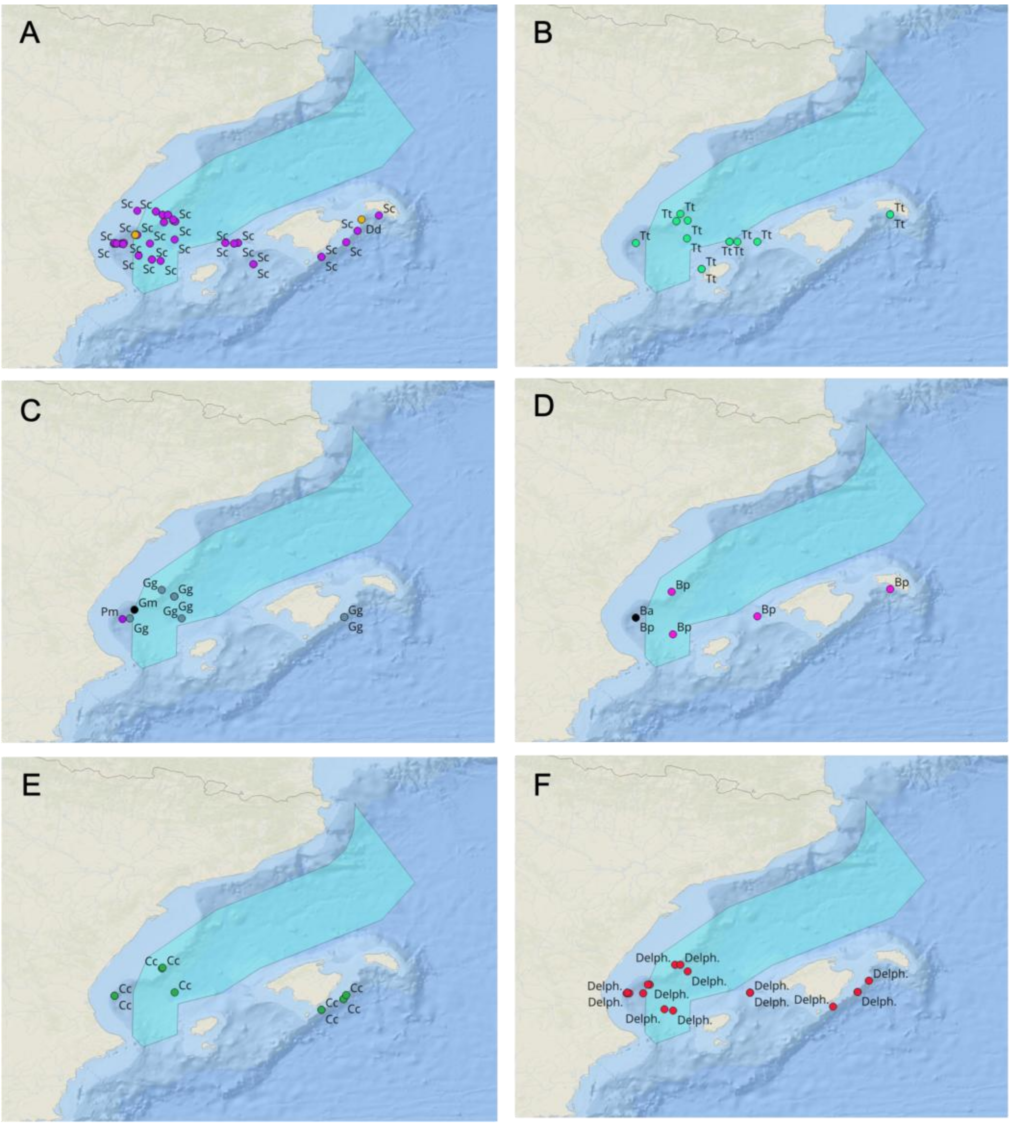


Figure 2.6.2. Molecular detection of CEPTU species through metabarcoding analysis by amplifying the mitochondrial 16S rRNA. Molecular detection of the A) *Stenella coeruleoalba* (Sc) and *Delphinus delphis* (Dd); B) *Tursiops truncatus* (Tt); C) *Grampus griseus* (Gg), *Globicephala melas* (Gm) and *Physeter macrocephalus* (Pm); D) *Balaenoptera physalus* (Bp) and *Balaenoptera acutorostrata* (Ba); E) *Caretta caretta* (Cc); and F) unidentified Delphinidae.

2.7 SDM test on *Stenella coeruleoalba* with Visual and eDNA data

For a more complete overview on cetacean presence and distribution, eDNA data will be integrated with the visual monitoring data to complement suitable habitat predictions for each species based not only on diurnal occurrence, but also on nocturnal detections. Here we present a first attempt to do so with the occurrence data of the striped dolphin (Stenella coeruleoalba).

For the purpose of this preliminary test, only the presence data were employed for modelling habitat suitability, while the setting of MaxEnt analysis remained the same employed for the previous analysis (Table 2.7.1).

Table. 2.7.1. MaxEnt setting for analysis with / without e-DNA samples for Sc

Setting	With e-DNA	Without e-DNA
Autofeatures	x	x

Output format	Log	Log
Random test %	30	30
RM	1	1
max n of background points	10000	10000
Replicates	10	10
Replicated run type	bootstrap	bootstrap
Max iter	5000	5000
Conv. threshold	0.00001	0.00001

The following results refer to just the monitored area and the HD period with e-DNA sampling of *Stenella coeruleoalba* (2019-2024) (Table 2.7.2).

3rd period (2019-2024)	
Maxent - avg predictions with e-DNA (AUC Train = 0.9015; AUC Test = 0.8963)	Maxent - avg predictions without e-DNA (AUC Train = 0.9054; AUC Test = 0.9023)

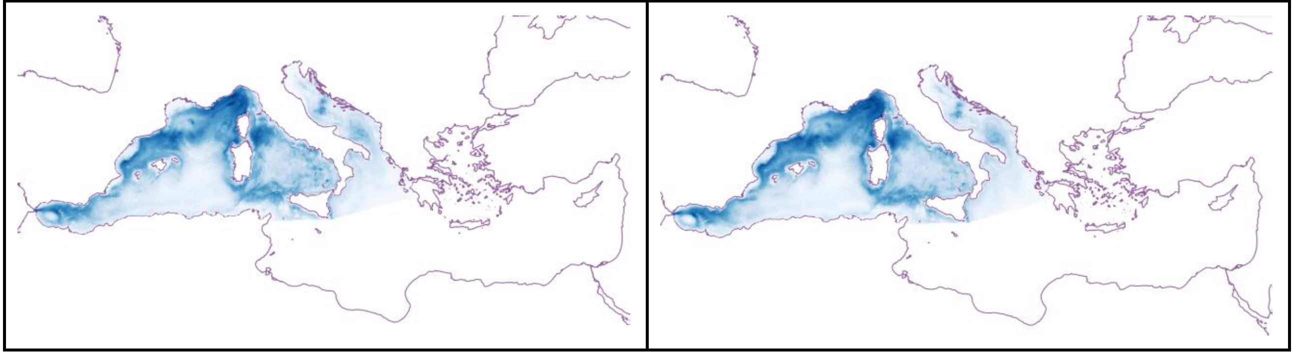


Figure 2.7.1. *Stenella coeruleoalba* model distribution with e-DNA detection (left) and without including e-DNA detection (right)

Table. 2.7.2. Summary of Maxent output for each environmental variable employed to analyse habitat suitability for HD period using FLT data alone and FLT data integrated with e-DNA ones.

Third Period (2019-2024)				
Variable	WITH e-DNA		WITHOUT e-DNA	
	% contrib	per. imp	% contrib	per. imp
Bathymetry	8.5	10.4	8.3	9
Chl_mean	50.1	24.2	49.6	29.4
Chl_sd	/	/	/	/
Curr.direction	/	/	/	/
Curr.magnitude	/	/	/	/
deltaT	0.4	2.2	0.4	2.3
Dist. canyons	4.7	0.8	4.9	2.3
Dist.coast	/	/	/	/
Dist.seamounts	3.2	2.4	3	2
Dist.shelf	0.9	2.5	1.2	2.5

EKE	1.7	3.2	1.4	3.1
mlotst	1	2.1	1	1.8
Salinity	3.4	7.5	3.8	10.1
Slope	1	1	0.6	1.1
Temp_mean	19.2	41.3	17.5	34.2
Temp_sd	/	/	/	/
zos	6.1	2.4	8.1	2.2

The SDMs created using only presence data slightly differ from those developed using both presence and absence data and presented in the previous section of the document. The models based solely on presence data show a higher concentration of suitable habitats. However, both types of models illustrate a similar pattern of habitat suitability. Additionally, the inclusion of e-DNA data enhances the model's definition. When examining the explanatory factors, the models built with and without e-DNA contributions are comparable.

3. Stable Isotopes results

Technical summary

Stable isotope analysis (SIA) doesn't track animals directly but reveals key spatial and seasonal patterns in marine biogeochemistry, especially regarding organic matter sources and nutrient cycling. By examining $\delta^{13}C$ and $\delta^{15}N$ in particulate organic matter (POM), researchers can infer primary production sources and nitrogen dynamics. Variations in $\delta^{13}C$ values reveal the relative influence of pelagic, coastal, and terrestrial sources in organic matter, helping distinguish areas with local phytoplankton production from those affected by detrital or riverine inputs. $\delta^{15}N$ values reflect patterns of nitrogen availability and recycling, serving as indicators of productivity gradients and trophic complexity. These isotopic baselines help identify likely habitats and foraging grounds for CEPTU species (cetaceans and sea turtles), offering indirect insights into their ecological niches and prey distribution.

Approach and dataset

Stable isotope analysis (SIA) of particulate organic matter (POM) was carried out in 516 seawater samples collected along three ferry based transects: the Tyrrhenian MDTL (Multidisciplinary Transect Loop) core route (231 samples) and two replication routes, ANPA (Ancona-Igoumenitsa; 96) and GEBATA (Genoa-Barcelona-Tanger; 189). To date, 190 samples (142 MDTL, 30 ANPA, 18 GEBATA) have been analysed for $\delta^{13}C$, $\delta^{15}N$ and elemental c/N ratios, providing the first synoptic, season-resolved biogeochemical baseline for the study area.

Seasonal signal in the MDTL core area

Twenty fixed stations were sampled in all four seasons.

- $\delta^{15}N$ peaked in summer (mean 7.64‰) and fell to its lowest in winter (0.73‰), indicating reduced turnover in winter.
- $\delta^{13}C$ was most depleted in spring (-24.57‰) - typical of new production during bloom onset - and relatively enriched in winter (-21.54‰), consistent with slower growth and shifts in the phytoplankton community.
- C/N ratios were lowest in summer (5.80, fresh algal material) and highest in spring (8.60 , more carbon detritus).

Seasonal isoscapes - MDTL

Regression-kriging models that incorporated sea-surface temperature, salinity, mixed-layer depth and chlorophyll-a produced high-resolution isoscapers:

- Summer $\delta^{15}N$ "hotspots" fringed the Tyrrhenian coast and central basin, while winter values were uniformly low.
- $\delta^{13}C$ showed a winter/autumn west-to-east enrichment gradient and basin-wide spring depletion.
- C/N displayed offshore summer minima and higher values in spring/autumn, reflecting post-bloom degradation.

Replication routes

ANPA - 30 analysed samples reveal moderate $\delta^{15}N$ enrichment in summer (5.61 ‰) that diminishes through autumn to winter; $\delta^{13}C$ is slightly enriched in summer; C/N rises from 7.5 (summer) to 8.3 (winter). Corresponding isoscapes point to summer nitrogen-recycling peaks along both coastal and offshore sectors and widespread carbon depletion offshore.
GEBATA - Single-season (summer) data show mean $\delta^{15}N$ = 4.21‰ ± 4.90, $\delta^{13}C$ = -22.45‰ ± 1.70, C/N = 6.27 ± 2.86 , highlighting strong trophic heterogeneity along the route.

Ecological interpretation

Higher $\delta^{13}C$ values signal zones of autochthonous phytoplankton production; elevated $\delta^{15}N$ denotes trophic enrichment and likely prey concentration; low C/N indicates fresh, nitrogen-rich organic matter. Overlaying CEPTU sighting data on these isoscapes therefore allows identification of seasonal foraging grounds and migratory corridors for cetaceans and sea turtles.

SUMMARY FOR POLICY MAKERS – Stable Isotope Baseline

- **Why it matters** - Isotopic "fingerprints" of seawater reveal where, and when, Mediterranean waters are most productive. These biochemical maps are a powerful, low-cost proxy for the quality of feeding grounds used by protected cetaceans and sea turtles.
- **Summer productivity hotspots -** The southern Tyrrhenian Sea and parts of the Adriatic-Ionian corridor show the strongest summer $\delta^{15}N$ enrichment and lowest C/N, signalling dense prey fields.
- **Winter lull** - Uniformly low $\delta^{15}N$ and enriched $\delta^{13}C$ values indicate reduced productivity, suggesting that management measures may be less critical during this season, as they would compromise less of the food supply.

Cross-border relevance - Patterns in replication areas indicate basin-scale summer peaks that span national Exclusive Economic Zones (EEZs); coordinated protection during these months would yield the greatest benefits

3.1 Relevance of seawater SIA for CEPTU species distribution and abundance assessment

In the framework of LIFE CONCEPTU MARIS, the stable isotope analysis (SIA) of seawater samples plays a pivotal role in enhancing our understanding of the ecological processes that underpin the distribution and abundance of cetaceans and pelagic sea turtles (collectively referred to as CEPTU species). While SIA does not directly track the animals themselves, it provides essential information on the spatial and temporal variability of baseline biogeochemical conditions, particularly those related to the sources and cycling of organic matter in the marine environment. By analysing the isotopic composition of particulate organic matter (POM), specifically $\delta^{13}C$ and $\delta^{15}N$, researchers can infer the dominant sources of primary production and the nature of nutrient dynamics across different areas and seasons.

This isotopic baseline is crucial for interpreting the trophic structure of the ecosystem. Variations in $\delta^{13}C$ values offer insights into the relative contributions of pelagic, coastal, and terrestrial inputs to the organic matter pool, allowing researchers to distinguish between areas dominated by *in situ* phytoplankton production and those influenced by detrital or riverine inputs. At the same time, $\delta^{15}N$ values reflect patterns of nitrogen availability and recycling, serving as indicators of productivity gradients and trophic complexity. As CEPTU species rely on a wide range of prey types and habitats, these isotopic markers provide indirect but valuable clues regarding the ecological niche/ type of habitats used by the different cetaceans and sea turtle species including potential foraging grounds, prey distribution, and the ecological conditions likely to support high megafaunal presence.

Moreover, the integration of SIA with other data sources, such as visual sightings, eDNA signals, and sensor-based measurements of physical–chemical parameters, enables a more comprehensive understanding of CEPTU species' habitat use and environmental preferences. This multidisciplinary approach enhances the spatial resolution of ecological assessments and supports the identification of offshore areas with high conservation relevance, including potential aggregation zones and migratory corridors. By linking isotopic signatures to patterns of megafaunal occurrence, SIA contributes not only to habitat characterisation but also to predictive modelling efforts aimed at informing long-term monitoring strategies and the implementation of the EU Habitats Directive. In this context, SIA emerges as a powerful and non-invasive tool for establishing ecologically meaningful baselines in regions where direct sampling of the food web is challenging or impractical.

3.2 Results overview

In the framework of a coordinated effort to characterise the biogeochemical variability along key ferry routes, a total of 516 seawater samples were collected and preserved for stable isotope analysis. Of these, 231 samples originated from the MDTL (Multi Disciplinary Transect Loop) project 'Core Area' route in the Tyrrhenian and Sardinia-Sicilian channels, while the remaining 285 were sourced from the 'Replication Areas', encompassing ANPA (Ancona-Igoumenitsa, 96 samples) and GEBATAN (Genoa-Barcelona-Tanger, 189) routes (Figure 3.2.1).

To date, 190 samples have been successfully analysed for their stable isotope composition, specifically targeting δ13C, δ15N, and elemental C/N ratios. All the other samples are currently undergoing isotopic analysis with the external contractors and will be ready in the next few months. Among the analysed samples, 142 correspond to MDTL, 30 to ANPA, and 18 to GEBATAN. These analyses provide critical insights into spatial and seasonal variations in biogeochemical processes, particularly with regard to the trophic status of the marine environment.

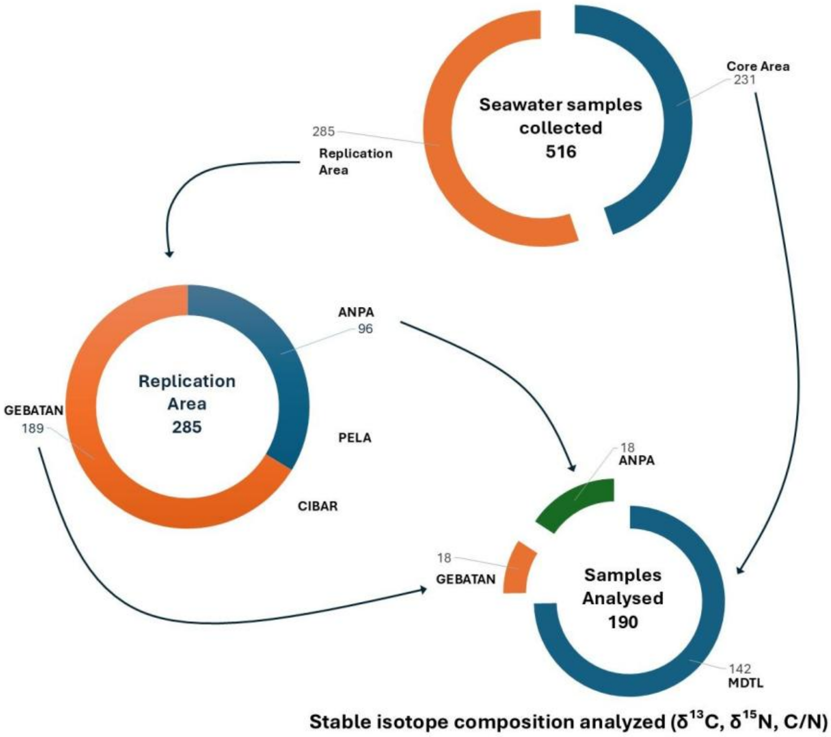


Figure 3.2.1. The total number of seawater samples collected for isotopic analysis is reported. Details about the samples already analyzed are also provided.

3.3 Seasonal and spatial patterns in the MDTL core area

Sampling within the MDTL Core Area was undertaken at 20 fixed stations throughout all four seasons. Among the 231 collected samples, to date, 142 were successfully analysed for δ13C, δ15N, and C/N.

Seasonal variability emerged clearly in the isotopic data. The δ15N values exhibited pronounced fluctuations, with the highest seasonal mean in summer (7.64‰), suggesting intensified nitrogen recycling and elevated biological productivity under stratified conditions. Conversely, the lowest values were observed in winter (0.73‰), indicating limited nutrient availability and minimal nitrogen turnover. The boxplot in Figure 3.3.1 illustrates this strong seasonal differentiation, with summer exhibits clearly elevated values compared to other seasons, while winter shows a marked decline, indicating reduced nitrogen cycling and biological activity.

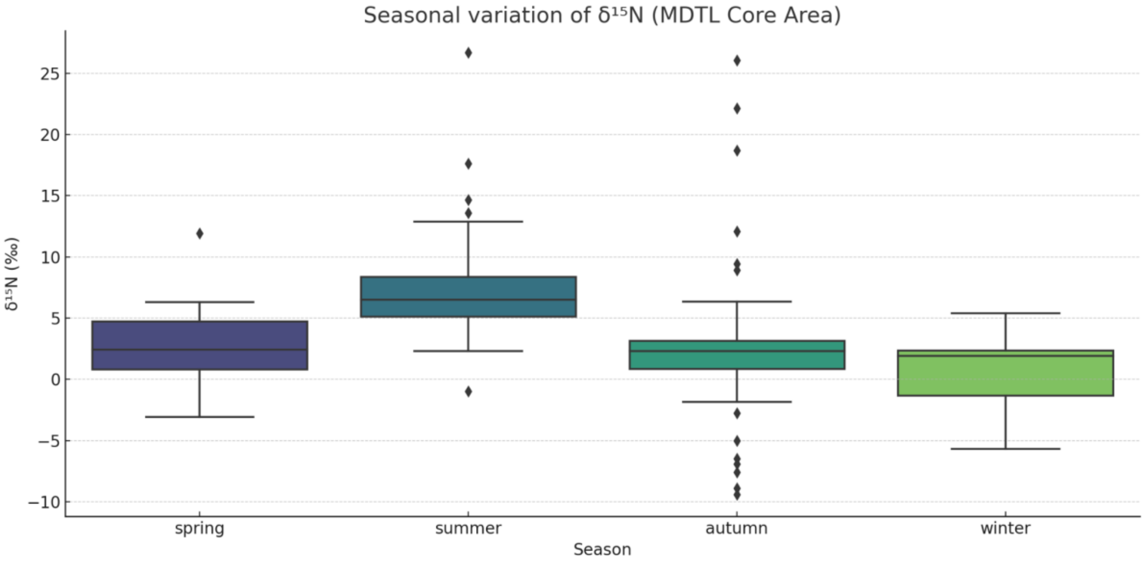


Figure 3.3.1. Seasonal variability in δ15N across the MDTL core area. Boxplot showing the distribution of δ15N values for each season.

Values of δ13C also varied by season. The most depleted average appeared in spring (–24.57‰), likely reflecting an increased contribution of newly fixed carbon and reduced isotopic fractionation. Winter values were notably more enriched (–21.54‰), possibly due to the predominance of certain phytoplankton taxa or differences in water mass origin. This is reflected in Figure 3.3.2, which displays the seasonal consistent enrichment of δ13C in winter relative to other periods.

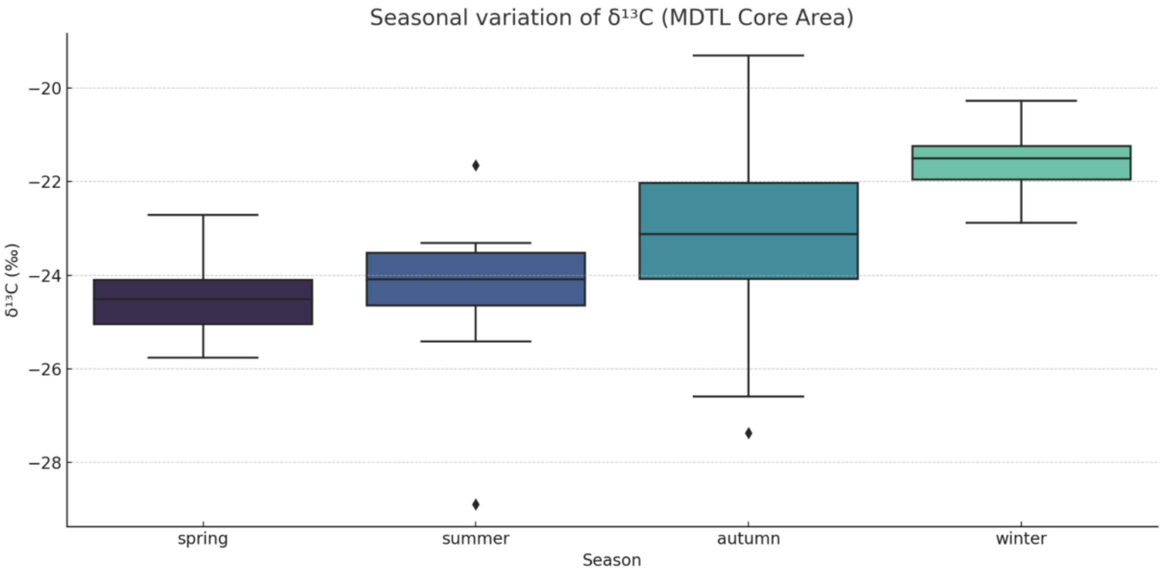


Figure 3.3.2. Seasonal variability in δ13C across the MDTL Core Area. Boxplot illustrating the seasonal distribution of δ13C values.

C/N ratios further reflected seasonal dynamics. The summer average (5.80) was the lowest, in line with nitrogen-rich organic matter from fresh algal production. In contrast, spring exhibited the highest mean ratio (8.60), implying an abundance of carbon-rich, potentially more refractory material. Autumn and winter values were intermediate, averaging around 7.5.

Seasonal Isoscape modelling - MDTL core area

To spatially represent trophic and biogeochemical indicators, seasonal isoscapes were developed for δ13C, δ15N, and C/N based on samples collected along the MDTL core area. The interpolation was performed using a regression–kriging approach over a high-resolution spatial grid, informed by data from the 20 fixed stations (see Figures 3.3.3 – 3.3.5). Environmental predictors integrated into the model included sea surface temperature (SST), salinity, mixed layer depth (MLD), and chlorophyll-a concentration. These variables, obtained from satellite and oceanographic model outputs, were temporally matched to the sampling windows. Their inclusion allowed for more ecologically meaningful interpolations, given the established relationships between these drivers and isotopic signatures in marine systems.

The resulting isoscapes revealed clear seasonal patterns. For δ15N (Figure 3.3.3), summer maps highlighted elevated values across central and coastal zones, indicative of enhanced productivity. Winter values, in contrast, were low and more uniform, reflecting reduced activity. Transitional patterns in spring and autumn showed variability likely related to coastal processes or dynamic oceanographic features.

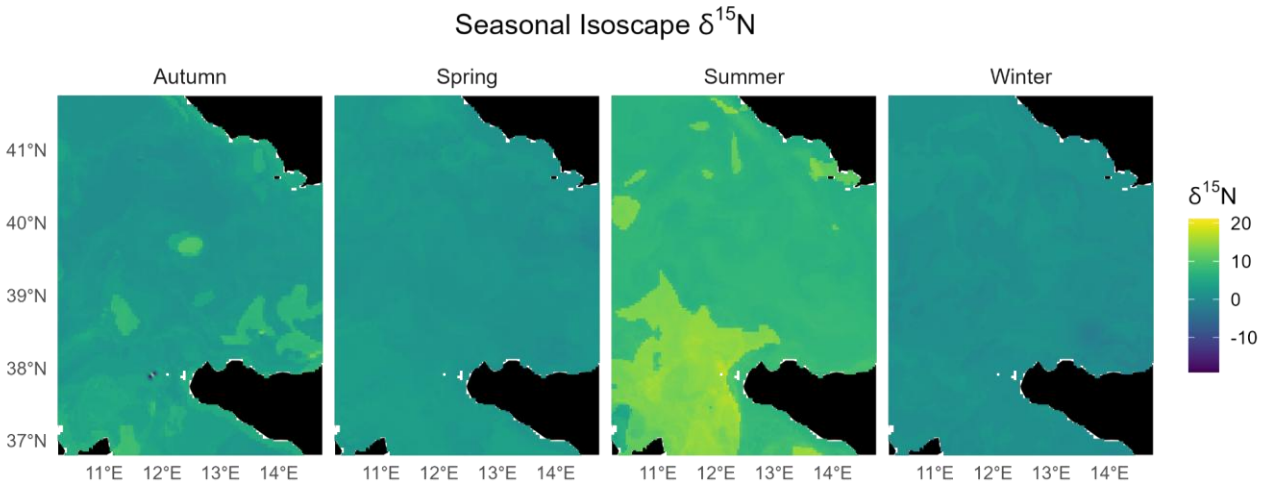


Figure 3.3.3. Seasonal δ15N isoscapes in the MDTL Core Area.

The δ13C isoscapes (Figure 3.3.4) in winter and autumn showed a west-to-east enrichment gradient, plausibly tied to light availability or phytoplankton community shifts. Spring maps displayed overall depleted values, associated with bloom onset and rapid carbon uptake.

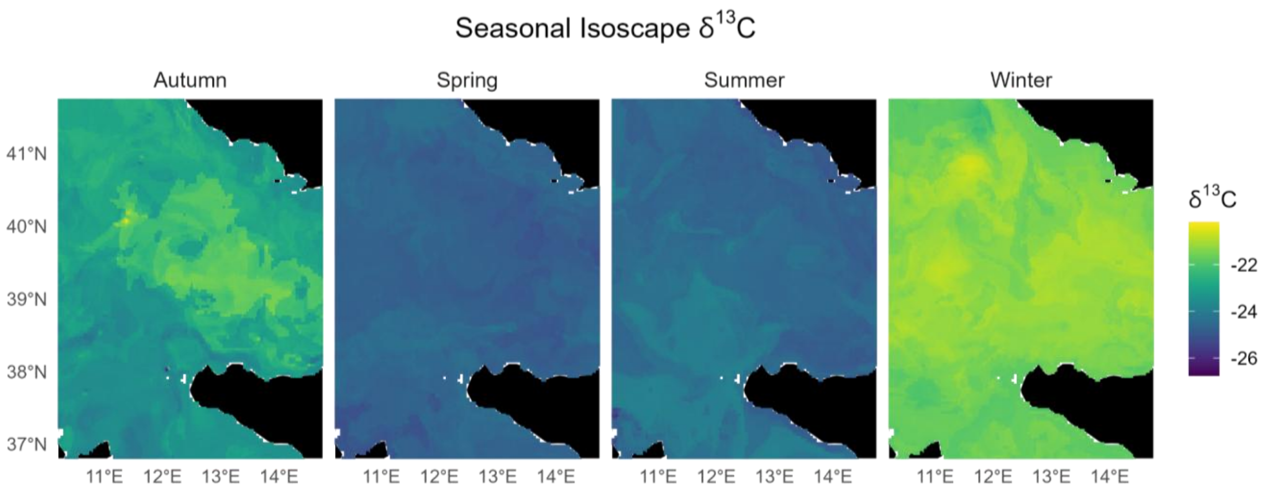


Figure 3.3.4. Seasonal δ13C isoscapes in the MDTL core area.

C/N isoscapes demonstrated offshore reductions in summer, aligned with active phytoplankton production (Figure 3.3.5). In spring and autumn, higher values suggested the presence of degraded or detritic material, consistent with post-bloom conditions. These modelled outputs provide a synoptic view of biogeochemical functioning in the southern Tyrrhenian Sea, offering a spatially explicit foundation for linking ocean productivity patterns to faunal distributions.

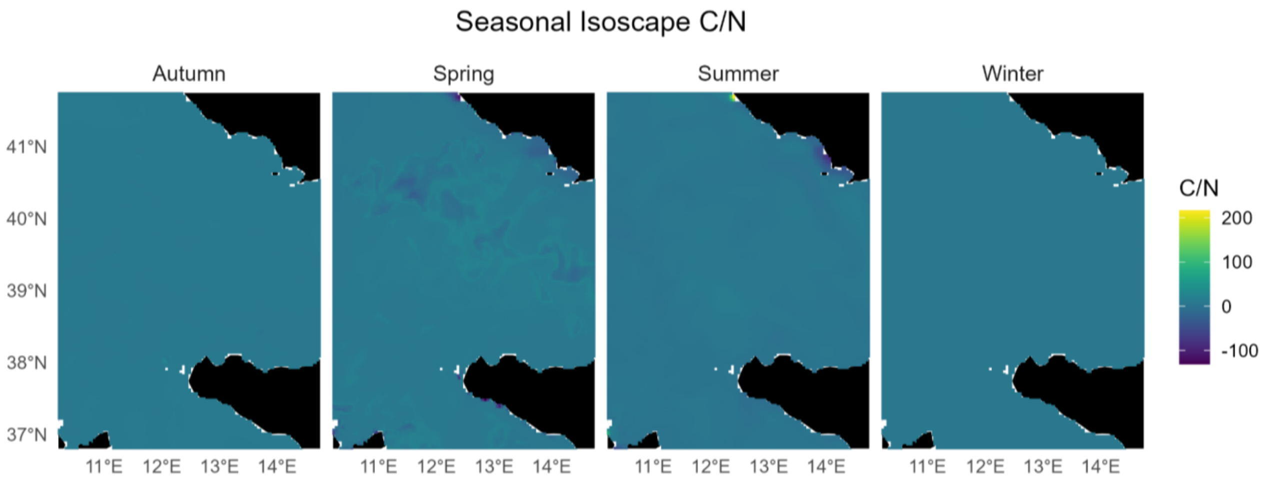


Figure 3.3.5. Seasonal C/N ratio isoscapes in the MDTL Core Area.

3.4 Seasonal and spatial patterns in the ANPA replication areas

Sampling along the ANPA ferry track was conducted during three different seasons: summer (14 samples), autumn (8 samples), and winter (8 samples), for a total of 30 valid isotopic observations. All samples were analysed for $\delta^{13}C$, $\delta^{15}N$, and C/N.

The $\delta^{15}N$ values showed moderate seasonal variability, with the highest mean recorded in summer (mean = 5.61‰), followed by autumn (4.27‰), and the lowest in winter (3.16‰). These differences may reflect variations in nitrogen source dynamics, biological productivity, or trophic structure along the ferry route. Figure 3.4.1 presents the seasonal boxplot of $\delta^{15}N$, illustrating interquartile shifts between seasons, though with overlapping ranges due to the relatively small sample size. The highest variability in summer indicates that some sites are local hotspots where productivity are very intense, possibly caused by coastal inflows or resuspension events.

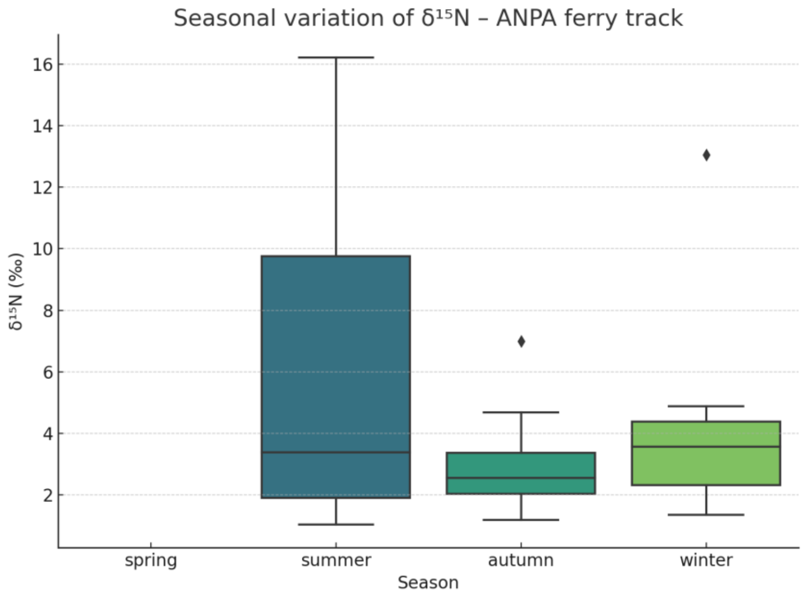


Figure 3.4.1. Seasonal variability in δ¹⁵N across the ANPA route. Boxplot showing δ¹⁵N distribution by season.

δ¹³C values were slightly more stable across seasons. The most enriched average was observed in summer (–21.15‰), while autumn and winter presented slightly more depleted values (–22.48‰ and –22.00‰, respectively). This may indicate stronger phytoplankton activity during summer and a greater influence of regenerated or detrital carbon sources in the cooler seasons (Figure 3.4.2).

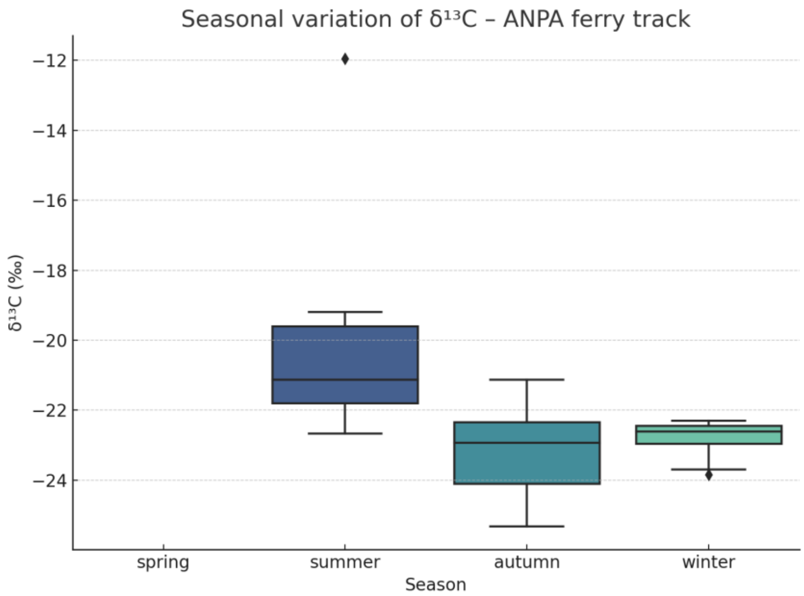


Figure 3.4.2. Seasonal variability in δ¹³C across the ANPA route. Boxplot illustrating δ¹³C values per season.

C/N ratios ranged from an average of 7.50 in summer to 8.32 in winter. These values suggest a general dominance of phytoplankton-derived organic matter, with some seasonal increase in detrital or refractory material during colder months (Figure 3.4.3).

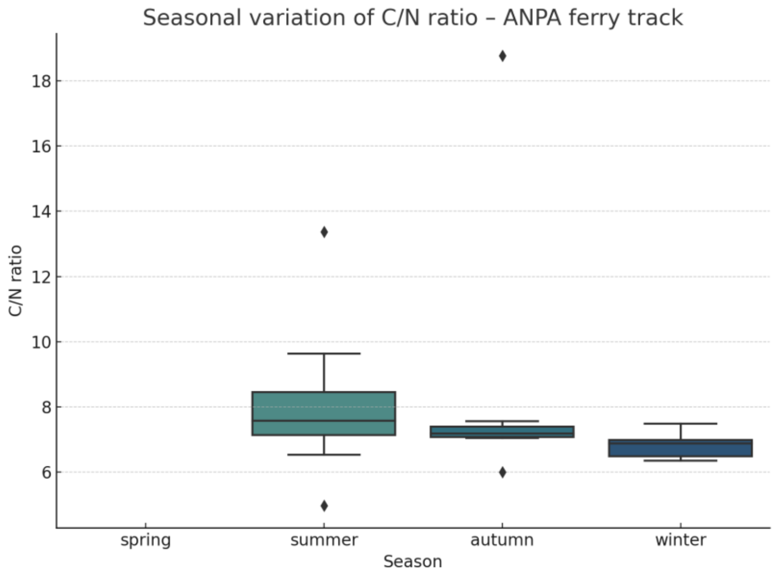


Figure 3.4.3. Seasonal variability in C/N ratio across the ANPA route.

Although the sample size is limited, the seasonal isotopic profiles along the ANPA route reveal relevant shifts in organic matter sources and trophic conditions. These variations provide valuable context for assessing spatial–temporal patterns of megafauna presence in the western Mediterranean and serve as a reference transect for comparison with the MDTL core area.

Seasonal Isoscape modelling - ANPA replication area

The δ15N isoscapes (Figure 3.4.5) highlighted consistent enrichment in summer across both coastal and offshore areas, indicative of active nitrogen recycling and enhanced trophic activity. Autumn patterns were spatially heterogeneous, with some coastal zones showing mild enrichment. Winter maps revealed uniform low δ15N values, consistent with reduced productivity and a more conservative nitrogen cycle.

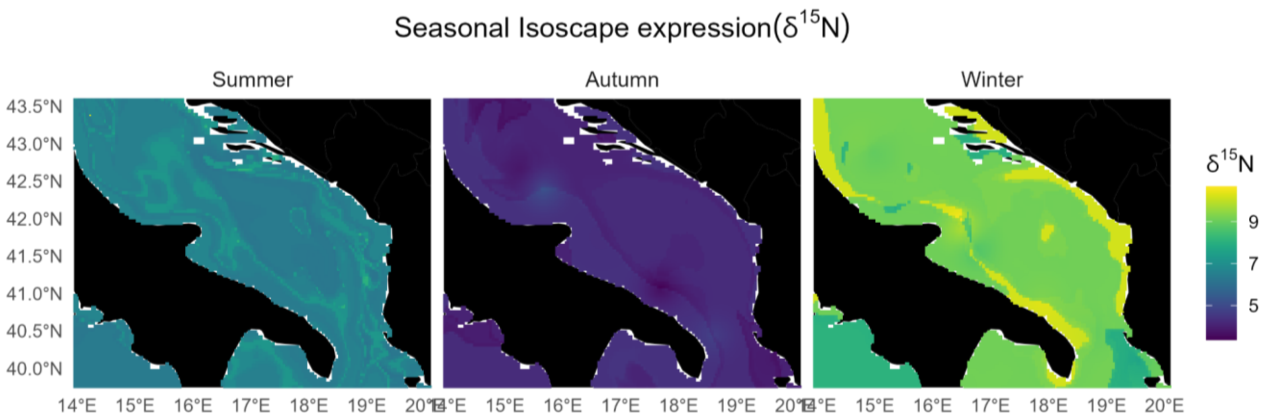


Figure 3.4.5. Seasonal δ15N isoscapes in the ANPA route.

The δ13C isoscapes (Figure 3.4.6) for the ANPA area showed a clear depletion in summer, particularly in offshore zones, suggesting high rates of primary production and fractionation under stratified conditions. In contrast, autumn values increased slightly across the domain, while winter showed a broader enrichment, especially near the coast, possibly linked to shifts in phytoplankton composition or physical mixing.

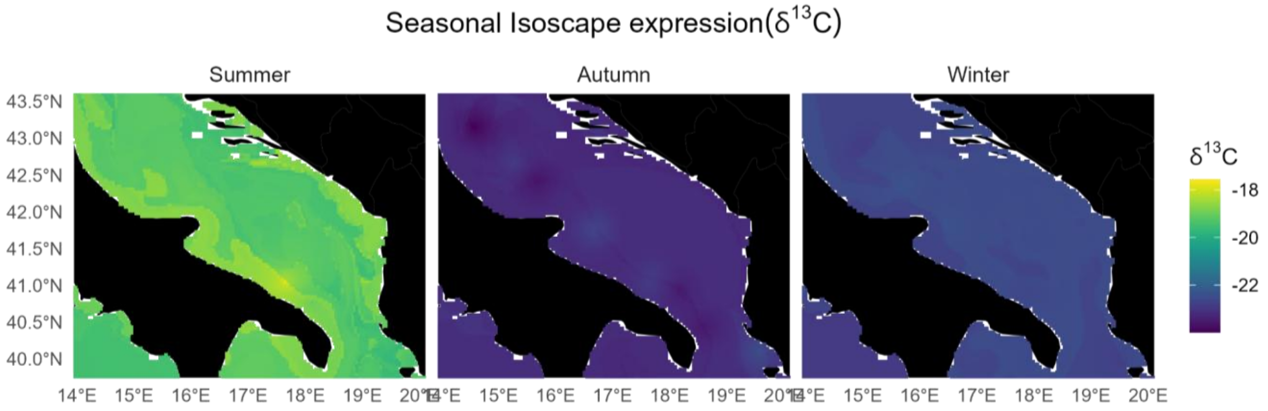


Figure 3.4.6. Seasonal δ13C isoscapes in the ANPA route.

C/N isoscapes (Figure 3.4.7) illustrated summer minima across much of the basin, aligned with recent phytoplanktonic organic matter deposition. Autumn maps showed patchy increases in C/N ratios, reflecting more degraded material or detrital inputs. In winter, values remained moderately elevated and homogeneous, indicating sustained input of refractory organic matter and reduced new production.

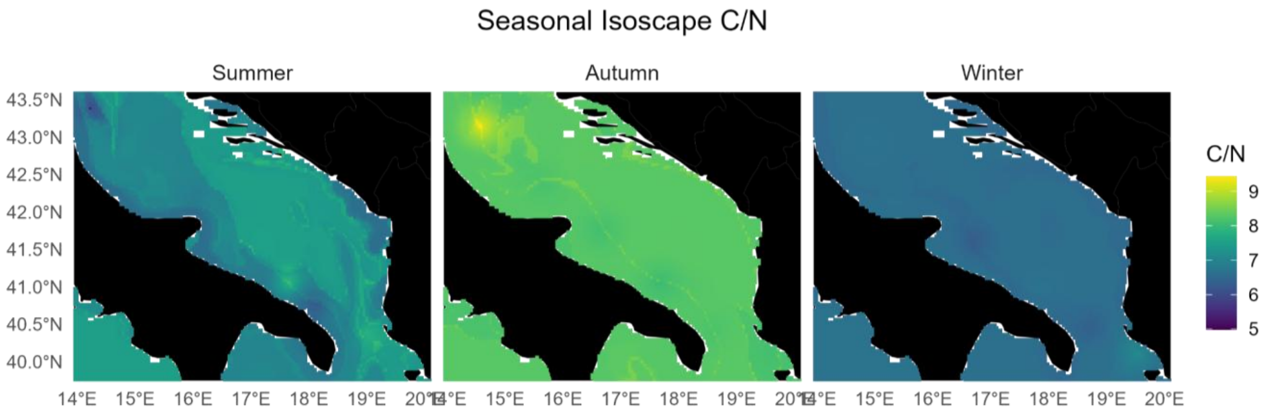


Figure 3.4.7. Seasonal C/N ratio isoscapes in the ANPA route.

3.5 Isotopic results - GEBATA replication area

Sampling along the GEBATA ferry route was conducted during the summer season. A total of 189 seawater samples were collected, of which 18 were successfully analysed for $\delta^{13}C$, $\delta^{15}N$, and C/N.

The mean $\delta^{15}N$ value was 4.21‰ (±4.90), indicating a moderately enriched trophic signal, with high variability across stations. This suggests the presence of spatially heterogeneous nitrogen sources or differing levels of biological activity along the transect.

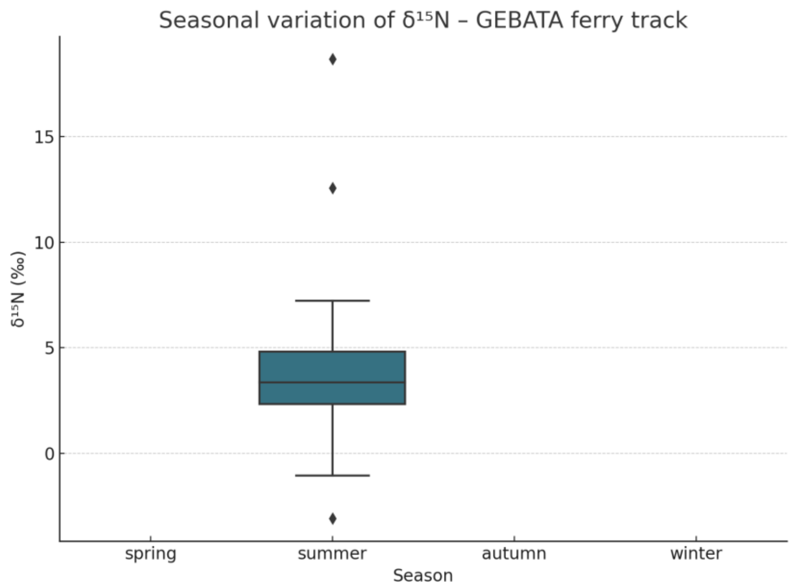


Figure 3.5.1. Distribution of $\delta^{15}N$ values – GEBATA ferry track (summer).

The mean $\delta^{13}C$ value was –22.45‰ (±1.70), moderately depleted and indicative of phytoplankton-based carbon sources. The relatively narrow range points to a more consistent carbon cycling regime compared to $\delta^{15}N$.

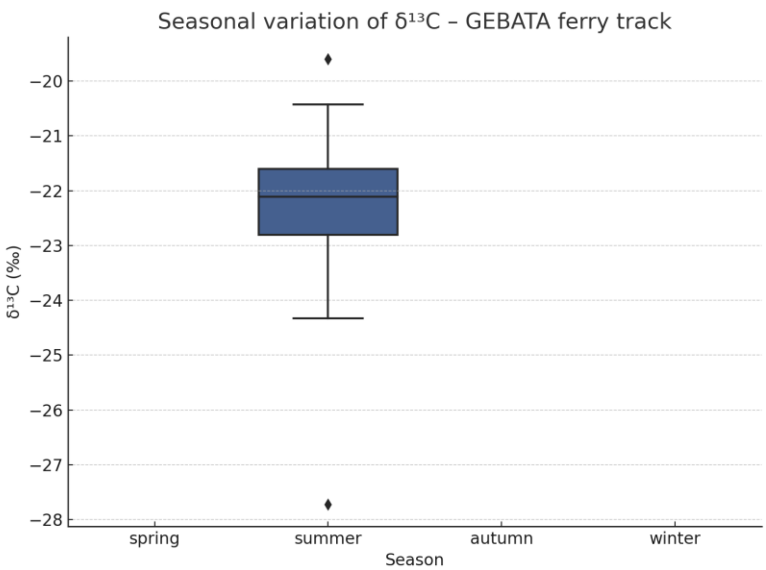


Figure 3.5.2. Distribution of $\delta^{13}C$ values – GEBATA ferry track (summer).

C/N ratios averaged 6.76 (±2.86), suggesting a mix of fresh phytoplanktonic organic matter and some contribution of more refractory material. The variability observed may indicate the coexistence of recent primary production and degraded organic matter.

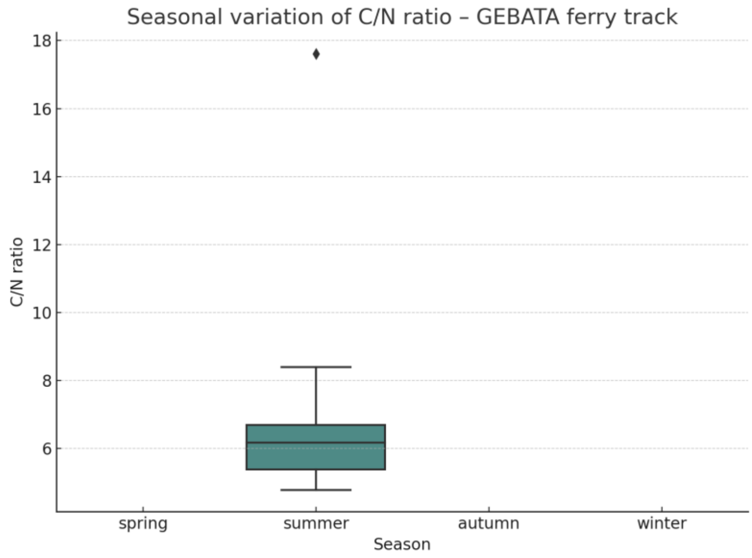


Figure 3.5.3. C/N ratio distribution – GEBATA ferry track (summer).

Although limited to a single season, the isotopic data from the GEBATA route highlight trophic variability and provide a spatial reference point for interpreting regional patterns in relation to megafauna presence.

3.6 Interpretation of seasonal Isoscapes and relevance to megafauna

The isoscapes of δ13C, δ15N, and C/N deliver robust spatial and seasonal information about ecosystem processes, organic matter sources, and trophic pathways. These indicators may prove valuable when interpreted alongside data on cetacean and sea turtle sightings.

- Higher δ13C values are generally indicative of autochthonous carbon sources, such as pelagic phytoplankton. In contrast, lower values may point to terrestrial or macroalgal detritus, potentially of riverine or coastal origin. If megafauna sightings occur in areas with enriched δ13C, this may signal foraging in regions of active production and short trophic chains. Low δ13C zones could reflect utilisation of detritus-based or more complex food webs.

- The δ15N marker offers insights into trophic positioning. Elevated values suggest trophic enrichment, aligning with predatory feeding habits and zones of high prey biomass. Lower values indicate proximity to the base of the food web or areas with reduced productivity. Cetacean and turtle distributions in δ15N-rich zones may thus correlate with dense prey fields and efficient energy transfer.

C/N ratios help distinguish the nature of organic matter. Low ratios (<7) imply fresh, nitrogen-rich material typical of algal production, whereas high values (>10) suggest detritus or refractory carbon sources. Faunal presence in low C/N areas may indicate high prey quality and recent production, while associations with high C/N regions might reflect feeding on detrital aggregates, benthic sources, or areas with persistent organic accumulations.

4. Vulnerability index

The **EU Habitats Directive**, through the **Natura 2000 network**, forms the primary legislative tool for the spatial protection of marine species such as cetaceans and sea turtles within European waters. Natura 2000 designates **Special Areas of Conservation (SACs)** to protect essential habitats, supporting the conservation and recovery of vulnerable species and contributing to EU biodiversity goals. International frameworks like the **CBD Kunming-Montreal Framework** and the **EU Biodiversity Strategy** have set ambitious targets to protect at least **30% of marine habitats by 2030**, emphasizing the urgent need for effective spatial protection. Current conservation initiatives, including **IUCN Important Marine Mammal Areas (IMMAs)**, and **ACCOBAMS' Conservation and Management Plan for Cetaceans (CCH)**, contribute to these efforts.

However, ensuring effective spatial protection for wide-ranging migratory species such as cetaceans and sea turtles remains particularly challenging. Their movements and habitat use are highly dynamic, shaped by **seasonal cycles** and **climate-driven variability**, which can shift the location and importance of key habitats throughout the year. **Different species and even the same species at different times may require protection in distinct areas**, complicating the identification of stable and consistent conservation priorities. These challenges are further intensified by **climate change**, which is accelerating oceanic shifts and altering species distributions, with profound consequences for marine biodiversity (IPCC AR6).

In this context, there is a critical need to enhance the prioritization of spatial protection areas through a **standardized and objective approach** to support **flexible and adaptive management strategies**. To address these challenges, we applied a vulnerability index to assess seasonal and interannual shifts in priority areas across 10 key Mediterranean sites. These areas have been consistently monitored by the FLT Med Network and the Life CONCEPTU MARIS project from 2008 to date. Based on a long-term dataset (2008–2024) comprising 12,642 cetacean sightings over 573,000 km of survey effort, the index integrates key biological indicators essential for cetacean conservation

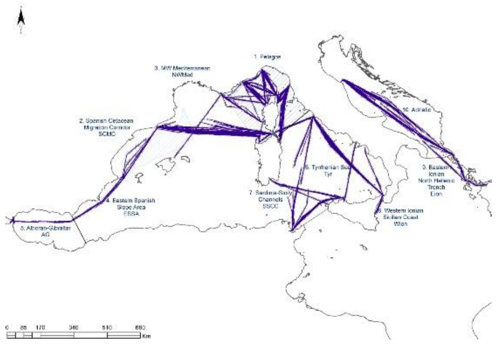
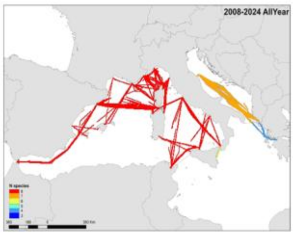
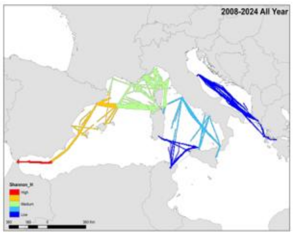
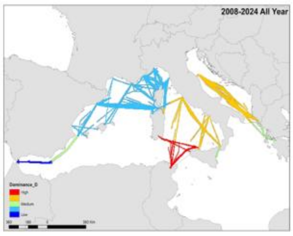
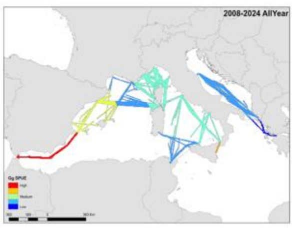
4.1 Overall priority areas

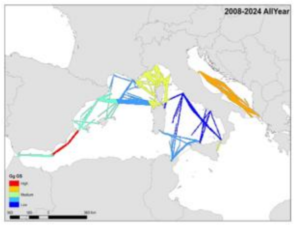
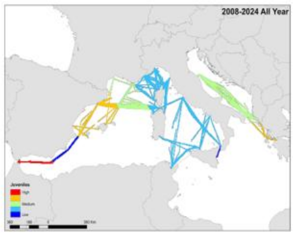
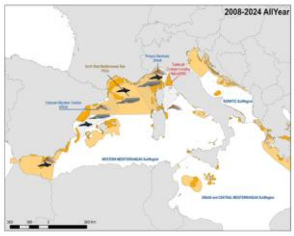
Following the approach outlined in the LIFE CONCEPTU MARIS Deliverable C1.2 – *Report on Identified Indicators to Evaluate the Conservation Status of CEPTU Species* (Arcangeli et al., 2025), a suite of ecological indicators has been applied to provide a comprehensive understanding of species distribution, abundance, and ecological significance, based on *in situ* data collected within the area of effort.

Indicator values have been used as proxy representations for the 10 main areas. To assess and compare priority areas over time and seasons, multiple indicators related to cetacean biology, ecology, and vulnerability were integrated into a single index. This index includes key traits such as species richness, diversity, dominance, abundance (SPUE), mean group size, juvenile presence, and rare species occurrence, providing a comprehensive measure of area importance for conservation.

Table 4.1.1 presents the ecological significance of each indicator, the criteria and thresholds used to score the positive or null contribution of each indicator, and a map showing the relative importance of each area for the respective indicator.

Table 4.1.1. Priority areas based on a single criteria (indicator)

<table>
<tr><td colspan="2">The 10 main areas:</td><td colspan="3">
</td></tr>
<tr><td>Ecological significance of indicator / ecological priority criteria</td><td>Indicator</td><td>Threshold</td><td colspan="2">Priority areas based on single indicator/criteria</td></tr>
<tr><td rowspan="3">Species Richness, Shannon-H and dominance indices assess community structure and biodiversity health: Species Richness indicates the number of species; Shannon-H reflects how evenly individuals are distributed; Dominance highlights if a few species dominate.</td><td>Species richness</td><td>More than 50% of the number of Mediterranean population species</td><td colspan="2">
</td></tr>
<tr><td>Shannon-H</td><td>Over the half Shannon maximum value (on sightings)</td><td colspan="2">
</td></tr>
<tr><td>Dominance_D</td><td>Below the half value of Dominance (on sightings)</td><td colspan="2">
</td></tr>
<tr><td>SPUE and mean Group Size (GS) served as proxies for relative abundance, density, and habitat use. SPUE standardizes sightings by effort, while GS reflects population density, social structure, and</td><td>SPUE</td><td>Higher than the mean SPUE recorded in all the areas together (by season) (e.g., Gg)</td><td colspan="2">
</td></tr>
</table>

behavioral responses to the environment.	Group size	Higher than the mean GS recorded in all the areas together (by season) (e.g., Gg)	
Sightings with juveniles were used as a proxy for breeding or nursery grounds, which are critical to assess the reproductive value of an area and long-term population viability.	Juvenile presence	Over the percentage of tot sightings with juv. pres. over all areas-seasons (>0.07)	
Rare species presence is a measure of conservation value of areas essential to the survival of the most range-restricted species	Range-restricted species occurrence	If the species is present in less than 5 areas considering all season's score =1 where it is present	

Each indicator identifies conservation priority based on a single criterion, which may highlight different areas as important depending on the specific aspect being assessed (e.g., species richness, abundance, or juvenile presence). The analysis clearly demonstrates that determining the overall conservation importance of an area requires the integration of multiple indicators / ecological criteria. Relying on a single indicator can indeed result in a fragmented or limited view of area conservation value. By combining these various indicators / ecological criteria into a composite index, a more robust and holistic assessment of conservation priorities across regions is achieved (Figure 4.4.1).

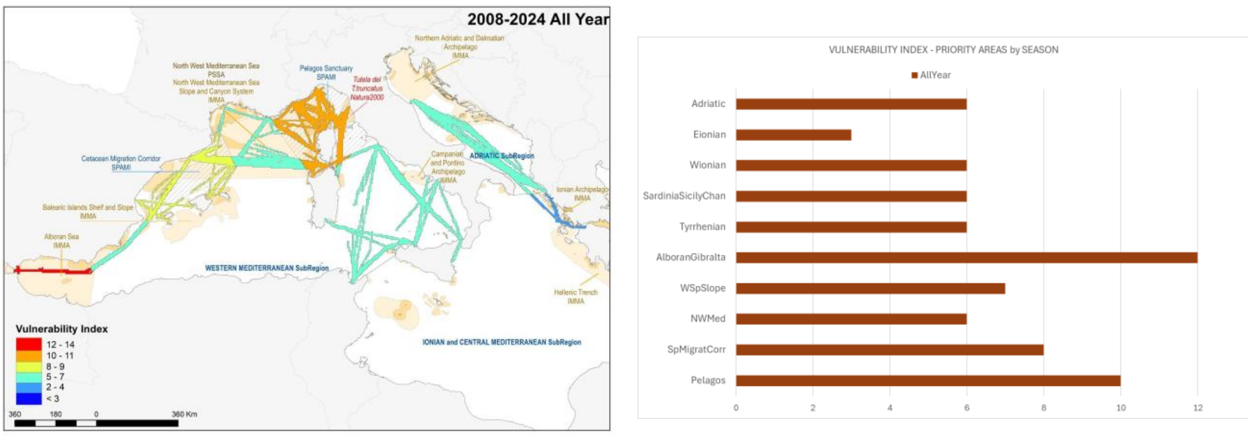


Figure 4.1.1. Overall priority area based on the combined index resulting from 10 indicators/ecological criteria.

Table 4.1.2. Details of the indicators, criteria, thresholds, and scores used to calculate the vulnerability index and identify priority areas.

ALL YEAR		Pelagos	SpMigratCorr	NWMed	WSpSlope	AlboranGibralta	Tyrrhenian	SardiniaSicilyChan	Wionian	Eionian	Adriatic
Indicators	**Criteria**										
N of species	>4	1	1	1	1	1	1	1	1		1
Shannon_H	0,74	1	1	1	1	1	1	1	1	1	1
Dominance_D	0,28										
Presence of Juveniles	>7% of tot sightings		1			1				1	1
SPUE	> mean SPUE :										
Sc	0,010	1	1			1			1		
Bp	0,002	1									
Tt	0,002										
Dd	0,002					1					
Pm	presence	1	1	1	1	1	1	1	1		1
Zc	presence	1	1	1	1	1	1	1		1	1
Gg	presence	1	1	1	1	1	1	1	1		1
Gm	presence	1	1	1	1	1	1	1			
GROUP SIZE	> mean GS :										
Sc	9,2	1			1	1			1		
Bp	1,2										
Tt	5,4					1					
Dd	8,3					1					
Pm	1,6										
Zc	2,0										
Gg	4,6										
Gm	5,5	1									
Rare sp. Pres	presence										
INDEX		10	8	6	7	12	6	6	6	3	6

The Alboran-Gibraltar, Pelagos, and Spanish Migratory Corridor (SpMigratCorr) emerge as the most critical areas for cetacean conservation in the Mediterranean, each for different reasons. Alboran-Gibraltar stands out for hosting higher frequency of juveniles and encounter rate and group size of *Stenella coeruleoalba* (Sc) and the rare *Delphinus delphis* (Dd). It also shows higher group sizes of *Tursiops truncatus* (Tt). Pelagos is notable for the highest concentrations of *Balaenoptera physalus* and *Stenella coeruleoalba*, as well as larger group sizes of *Globicephala melas*. The Spanish Cetacean Migratory Corridor (SpMigratCorr) is one of the few areas that host higher frequency of juveniles, together with Alboran-Gibraltar, eastern Ionian and Adriatic. It also hosts among the highest abundance of *Stenella coeruleoalba*. Almost all areas host at least half of the more common Mediterranean cetacean species, and have at least one recorded occurrence of the four rarer species (*Physeter macrocephalus, Grampus griseus, Globicephala melas, and Ziphius cavirostris*).

4.2 Seasonal priority areas

Seasonality plays a crucial role in the ecology, biology, and habitat use of cetacean species. As a result, vulnerability is strongly shaped by ecological processes, leading to the emergence of distinct priority areas.

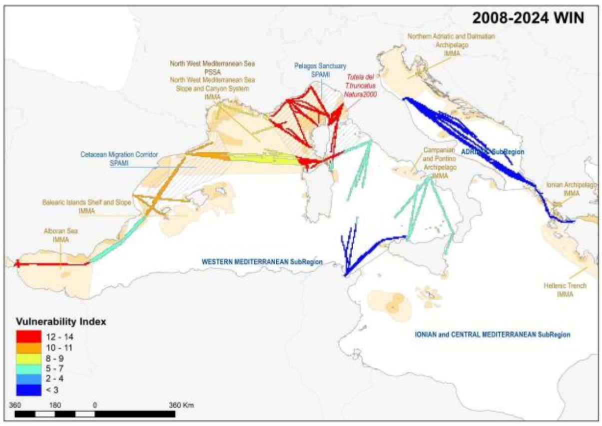
Table 4.2.1. Details of the indicators, criteria, thresholds, and scores used to calculate the vulnerability index and identify priority areas by season (Winter: January-March; Spring: April-June; Summer: July-September; Autumn: October-December).

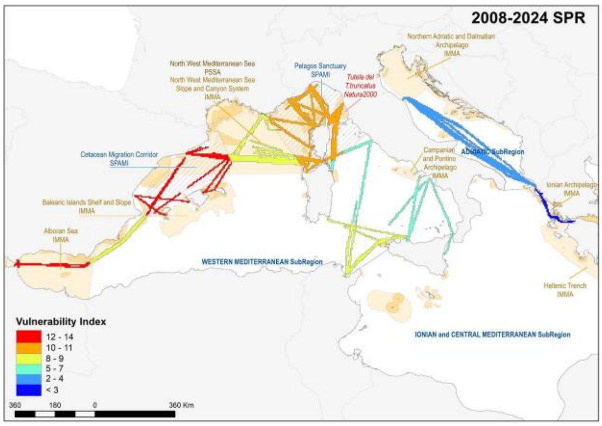
WINTER		Pelagos	SpMigratCorr	NWMed	WSpSlope	AlboranGibralta	Tyrrhenian	SardiniaSicilyChan	WIonian	EIonian	Adriatic
Indicators	Criteria										
N of species	>4	1	1	1		1	1				
Shannon_H	0,72	1	1	1	1	1	1		1		1
Dominance_D	0,32					1					
Presence of Juveniles	>7% of tot sightings		1			1					
SPUE	> mean SPUE :										
Sc	0,010		1		1	1			1		
Bp	0,002	1		1							
Tt	0,003					1		1	1		
Dd	0,003					1			1		
Pm	presence	1	1	1							
Zc	presence	1	1			1	1				
Gg	presence	1	1	1	1	1					
Gm	presence	1	1	1	1	1	1				
GROUP SIZE	> mean GS :										
Sc	6,6	1			1	1					
Bp	1,2	1	1	1							
Tt	5,6					1			1		
Dd	6,4	1			1	1		1			
Pm	1,5		1	1							
Zc	1,7		1				1				
Gg	3,3	1		1							
Gm	2,9	1				1	1				
Rare sp. Pres	presence	*Zc, Pm*	*Zc, Pm*	*Pm*		*Zc*	*Zc*				
INDEX		12	11	9	6	14	6	2	5	0	1

SPRING		Pelagos	SpMigratCorr	NWMed	WSpSlope	AlboranGibralta	Tyrrhenian	SardiniaSicilyChan	WIonian	EIonian	Adriatic
Indicators	Criteria										
N of species	>4	1	1	1	1	1	1	1			
Shannon_H	0,67	1	1	1	1	1	1	1	1		1
Dominance_D	0,28								1		
Presence of Juveniles	>7% of tot sightings	1	1			1					1
SPUE	> mean SPUE :										
Sc	0,009	1	1	1		1					
Bp	0,003	1	1	1							
Tt	0,004				1	1			1		
Dd	0,005					1			1		
Pm	presence	1	1	1	1	1	1	1			
Zc	presence	1	1	1			1				1
Gg	presence	1	1	1	1	1	1	1			
Gm	presence	1	1	1	1	1					
GROUP SIZE	> mean GS :										
Sc	10,4				1	1					
Bp	1,5							1			
Tt	5,8			1		1			1		
Dd	7,8		1			1	1	1			
Pm	2,2				1			1			
Zc	1,8	1	1								1
Gg	5,3		1				1	1			
Gm	6,1	1				1					
Rare sp. Pres	presence										
INDEX		11	12	9	8	13	7	8	5		4

SUMMER		Pelagos	SpMigratCorr	NWMed	WSpSlope	AlboranGibralta	Tyrrhenian	SardiniaSicilyChan	WIonian	EIonian	Adriatic
Indicators	Criteria										
N of species	>4	1	1	1	1	1	1	1			
Shannon_H	0,90	1	1	1	1	1	1	1	1	1	
Dominance_D	0,30				1						
Presence of Juveniles	>7% of tot sightings		1	1		1				1	1
SPUE	> mean SPUE :										
Sc	0,012	1				1			1		
Bp	0,002	1		1							
Tt	0,002					1		1	1	1	1
Dd	0,001					1					
Pm	presence	1	1	1			1	1	1		
Zc	presence	1	1	1		1	1	1		1	1
Gg	presence	1	1	1	1	1	1	1	1		1
Gm	presence	1	1	1	1	1		1			
GROUP SIZE	> mean GS :										
Sc	10,3	1			1	1			1		
Bp	1,2	1		1			1	1			
Tt	5,0				1	1	1		1		
Dd	10,5	1			1	1	1				
Pm	1,3		1	1				1			
Zc	2,2				1	1					1
Gg	5,0			1			1	1			
Gm	5,8	1				1					
Rare sp. Pres	presence										
INDEX		12	8	11	9	14	9	10	7	4	5

AUTUMN		Pelagos	SpMigratCorr	NWMed	WSpSlope	AlboranGibralta	Tyrrhenian	SardiniaSicilyChan	WIonian	EIonian	Adriatic
Indicators	Criteria										
N of species	>4	1	1	1	1	1	1	1			
Shannon_H	0,76	1	1	1	1	1	1	1	1	1	1
Dominance_D	0,26										
Presence of Juveniles	>7% of tot sightings	1	1		1	1	1			1	
SPUE	> mean SPUE :										
Sc		1	1		1	1			1		
Bp		1		1							
Tt			1	1				1		1	1
Dd					1	1					
Pm	presence	1	1	1	1	1	1	1	1		1
Zc	presence	1	1	1	1	1	1			1	
Gg	presence	1	1	1	1	1	1	1			
Gm	presence	1	1	1		1					
GROUP SIZE	> mean GS :										
Sc	6,7	1		1		1					1
Bp	1,2	1		1			1				
Tt	4,0		1	1	1	1					
Dd	8,6					1					
Pm	1,7				1			1			
Zc	1,8					1					
Gg	5,5	1		1				1			
Gm	5,7			1		1					
Rare sp. Pres	presence	*Gm*	*Gm*	*Gm*		*Gm*					
INDEX		12	10	13	10	14	7	7	3	4	4





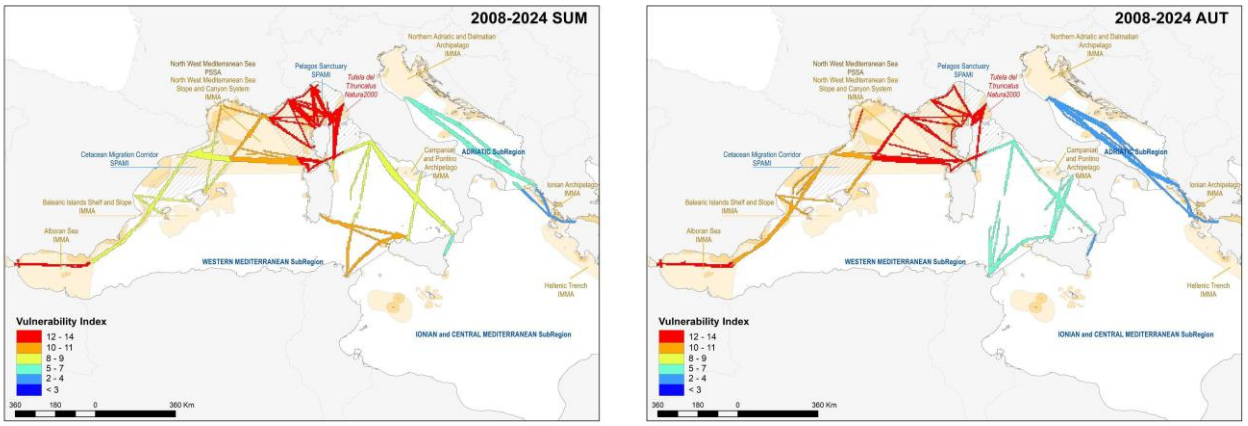


Figure 4.2.2. Overall priority area by season based on the combined index resulting from 10 indicators/ecological criteria. (Winter: January-March; Spring: April-June; Summer: July-September; Autumn: October-December).

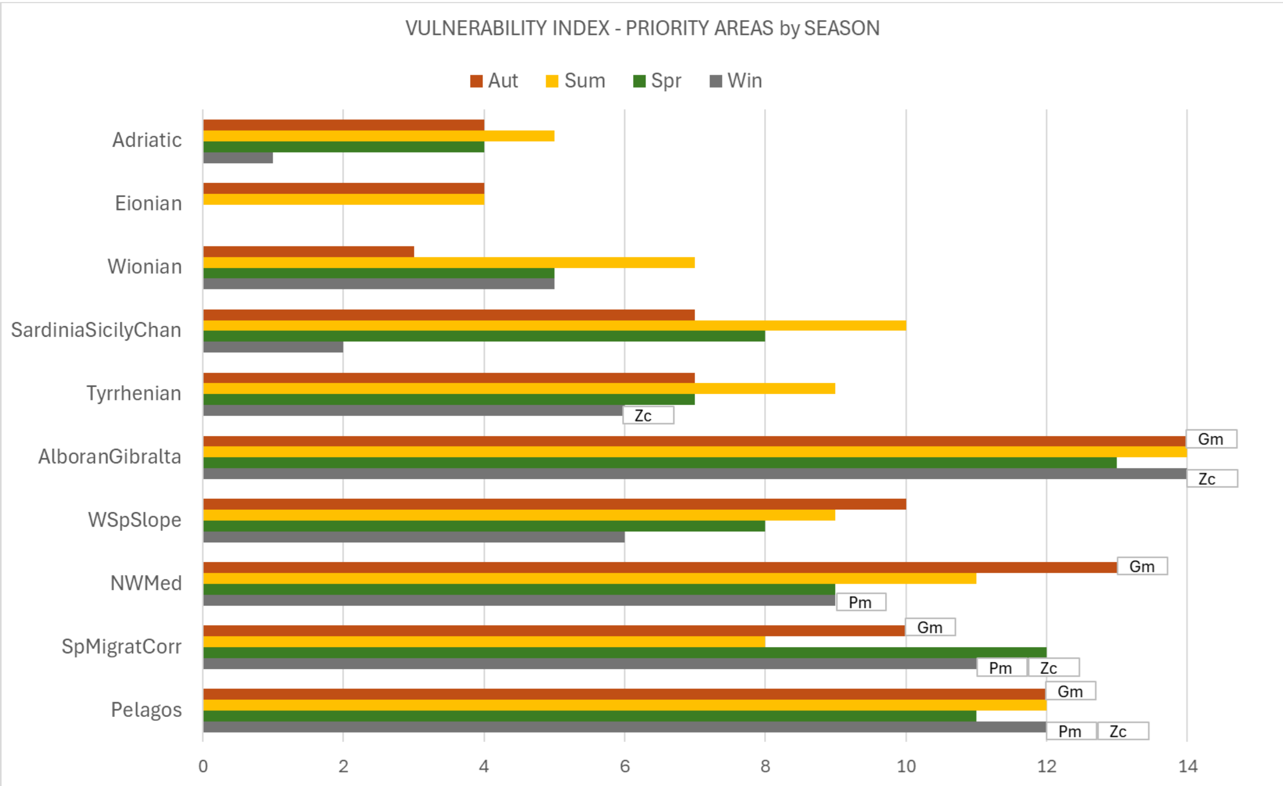


Figure 4.2.3. Overall priority area by season based on the combined index resulting from 10 indicators/ecological criteria. (Winter: January-March; Spring: April-June; Summer: July-September; Autumn: October-December). The species detected in few areas (criteria of range-restricted species) are indicated at the end of the bar.

Seasonal and temporal variations revealed significant shifts in conservation priority areas. In general, the maps show seasonal variation in the importance of different Mediterranean areas for cetacean conservation, based on a vulnerability index from 2008 to 2024. The red-colored routes indicate the highest vulnerability, meaning these areas are the most critical for conservation. In general, the Alboran-Gibraltar region remains of highest importance, showing a higher frequency of juveniles throughout all seasons. It is also among the few areas that host *Ziphius cavirostris* in winter and *Globicephala melas* in autumn. Apart from this region, in **winter**, the areas of highest vulnerability are generally concentrated in the western Mediterranean especially in the Pelagos Sanctuary and the Spanish Migratory Corridor. These are also among the few areas that, during this season, both *Physeter macrocephalus* and *Ziphius cavirostris*. Other than in the Alboran-Gibraltar, highest juvenile frequency is recorded during winter in the Spanish Migratory Corridor too. In **spring**, there is a clear expansion of high-vulnerability zones across the western Mediterranean, including firstly the Spanish Migratory Corridor, then Pelagos and the Northwestern Mediterranean, and then the western Spanish slope and the Sardinia-Sicilian channels. Notably, higher group size of *Globicephala melas* are recorded during spring in Pelagos, while social groups of *Physeter macrocephalus* are recorded in the western Spanish slope and Sardinia-Sicilian channels. **Summer** is the season with the highest overall vulnerability. Highest values are concentrated in the upper western Mediterranean, the Pelagos and northwestern Mediterranean areas, followed by the Sardinia-Sicilian channels, Tyrrhenian and western Spanish slopes. Juveniles' high frequency are spread among five areas, including the Alboran-gibraltar, Spanish Migratory Corridor and northwestern Mediterranean, eastern Ionian and Adriatic. During **autumn**, the higher vulnerability is again spread among the more western areas with higher balance than during spring, though slightly less intense than in summer. Globicephala mes is confined to four areas only (Alboran-Gibraltar, Spanish migratory Corridor, northwestern Mediterranean and Pelagos) High-vulnerability routes are again found in the northwestern basin, while the eastern regions show limited but still present activity. Juveniles higher frequency is the most spread among areas, reaching higer values in six of them including Alboran-Gibraltar, western Spanish slopes, Pelagos, Tyrrhenian, and eastern Ionian.

Overall, the western Mediterranean consistently appears as the most important area for cetacean conservation, with peak vulnerability in the summer. The eastern and central Mediterranean show more seasonal variation, with some regions becoming important primarily in spring and autumn.

In more detail, the **Alboran-Gibraltar** region maintained high conservation value year-round, standing out due to high frequency of juveniles in all the seasons, high counts and group size of *Delphinus delphis* (Dd), high group size of *Tursiops truncatus,* and *Globicephala melas* (Gm) and rare species presence such as *Ziphius cavirostris* in winter and Gm in autumn. The **Pelagos Sanctuary** consistently stands out as an important area, particularly due to the high frequency and large group sizes of *Stenella coeruleoalba* (Sc) and *Balaenoptera physalus* (Bp). It also hosts notably larger group sizes of the rarer species: *Delphinus delphis* (Dd) in winter and summer, *Grampus griseus* (Gg) in autumn and summer, *Globicephala melas* (Gm) in winter, spring, and summer, and *Ziphius cavirostris* (Zc) in spring. The area hosts the highest juvenile presence in spring and autumn. The **Spanish Cetacean Migration Corridor** showed peak importance in spring, followed by winter and autumn, mostly driven by the rare presence of Pm and Zc in winter, and Gm in autumn. As all the Western Mediterranean, also the **northwestern Mediterranean Sea** hosts some of the rarer species but especially stands out for the high concentration of Bp during all the seasons, and high juvenile frequency in summer. Among the other areas, the **Tyrrhenian** shows high group size of Dd and Gg during spring and summer, and juveniles in autumn while the **SardiniaSicilianChannels** hosts among the highest group size especially of Gg during all the seasons but winter and Dd during winter and spring.

High frequency of **juveniles** is spread in 6 out of 10 areas during autumn, but are recorded with high frequency almost in all the seasons, confined to the westernmost area of the Spanish Cetacean Migration Corridor and Alboran-Gibraltar area during winter. While a few **dominant species** shaped patterns across areas and seasons, a more balanced species diversity emerged in winter in the Alboran-Gibraltar, spring in the western Ionian Sea, and summer in the western Spanish Slope.

5. Anthropogenic pressures

In addition to species data, information on anthropogenic pressures is essential for a comprehensive assessment of marine biodiversity. In line with the requirements of the Habitats Directive (Art. 17) and the **Marine Strategy Framework Directive (MSFD)**, spatially explicit data on human pressures are critical for evaluating exposure risks and supporting assessments of conservation status and environmental health.

For this reason, two key anthropogenic pressures were analysed: **floating macro marine litter (FMML)** and **maritime traffic (MT)**. These specific pressures were selected because they represent some of the most direct and widespread threats to marine megafauna, particularly cetaceans and sea turtles. FMML, mostly composed of plastics, poses ingestion and entanglement risks and degrades surface habitat quality. MT contributes to disturbance, habitat fragmentation, continuous noise and vessel collisions, and is increasingly recognised as a major factor influencing species distribution and survival. These pressures were also selected because they allow for the integration of *in situ* data, collected during the Conceptu Maris surveys, with additional sources such as AIS-based datasets for MT , enabling robust and spatially consistent exposure assessments.

The results also provide a solid basis for the risk assessment outlined in the next chapter (6. Risk Exposure Analysis of CEPTU species to main anthropogenic pressures) and support the development of targeted mitigation strategies, fully aligned with the MSFD framework for pressure–impact analysis and the conservation objectives of the Habitats Directive.

5.1 Floating Marine Macro Litter spatial analysis

SUMMARY ON FLOATING MARINE MACRO LITTER DISTRIBUTION

The spatial analysis of **floating marine macro litter (FMML)** densities (≥ 20 cm) in the Western and Central Adriatic sea over the EU reporting period 2019-2024, based on standardised ***in situ* observation**, revealed a mean density of 1.2 ± 1.4 items/km². This analysis allowed for the identification of both persistent accumulation zones and statistically significant hotspots.

The results reveal stable high-density areas (>3 items/km²) in the **Central Adriatic**, the **Southern Tyrrhenian**, and the **Ligurian/Liguro-Provencal Seas**. Additionally, although less prominent over the entire period, the **Alboran Sea, Strait of Sicily, and Sardinia Channel** show significant concentrations during specific seasons.

A clear seasonal pattern emerged, with lower densities and limited hotspot extent in autumn and winter (0.9 ± 1.3 and 0.9 ± 1.4 items/km² respectively), followed by a sharp increase in both density and spatial distribution during spring and summer (mean values 1.2 ± 1.6 and 1.1 ± 1.4 respectively). In these warmer seasons, pronounced hotspots are particularly evident in the Ligurian/Liguro-Provencal Seas, the southern-central Tyrrhenian Sea, and the Sardinia Channel.

Method. Data on Floating Marine Macro Litter (FMML, size ≥ 20 cm) were collected concurrently with cetacean and sea turtle monitoring onboard ferries, using a strip transect sampling methodology within a fixed-width strip (MILESTONE C1.1b – Data Acquisition in the Core Area and DELIVERABLE E2.2.). For this study, data from the third EU reporting period (2019–2024) were used to ensure alignment with the subsequent risk analysis and to match the latest monitoring cycle under the Habitats Directive (HD). For the spatial analysis, we followed the method described in Arcangeli et al., 2019.

- Floating litter data were used to estimate item density by overlaying observations onto the EU standard 5 × 5 km grid. A buffer was created along each survey transect, corresponding to the effective strip width defined by the observation protocol. These buffered transects were intersected with the grid cells to calculate, for each cell: 1) the total sampled area; 2) the number of floating litter items ≥ 20 cm; 3) the density for each cell calculated as D=n.objects/total sampled ares

- The spatial distribution of plastic density was analysed using Kernel Density Estimation (KDE) to identify seasonal accumulation zones. The analysis was performed on grid cells with a sampled area ≥ 0.25 km², ensuring sufficient sampling effort. Additionally, extreme density values (upper limit of the upper whisker threshold, defined as Q3 + 1.5 × IQR) were excluded to reduce the influence of potential outliers (Table 5.1.1.)

- KDE was applied both for the entire period (2019–2024), and for each season separately, using per-cell density values as weights. The estimation used a bandwidth of 50 km, a quartic kernel function, and an output resolution of 500 m, implemented in QGIS. To delineate areas of highest accumulation, 95th and 99th percentile isopleths were extracted from the KDE surface. To detect statistically significant spatial clusters of high plastic density, we applied the Getis-Ord Gi* statistics to the same filtered dataset using the “spdep” package in R. Cells with a z-score greater than 1.96 were classified as hotspots, corresponding to a significance level of 95%.

Table 5.1.1. Upper limits used as thresholds for outlier removal by temporal resolution

Temporal res		**Q1**	**Q3**	**IQR**	**upper_whisker**
Entire period		0.0	2.3	2.3	5.8
spring		0.0	2.5	2.5	6.3
summer		0.0	2.3	2.3	5.7
autumn		0.0	2.0	2.0	5.0
winter		0.0	1.9	1.9	4.8

Results

The spatial analysis of FMML densities over the third EU reporting period (2019–2024) revealed **consistent patterns of accumulation across the Western and Central Mediterranean basins**. Using Kernel Density Estimation (KDE) and Getis-Ord Gi* hotspot analysis, the study identified both persistent high-density zones and statistically significant clustering, offering insights into spatial and seasonal dynamics.

Over the entire period, stable accumulation hotspots are evident in the central Adriatic Sea (especially in the northern sector), the Southern Tyrrhenian, the Ligurian Seas, and, secondarily in the Alboran Sea, Sicily and Sardinia Channels (Figure 5.1.1). These patterns likely reflect the combined influence of rivers, coastal urbanisation, dominant currents and maritime traffic intensity.

A clear seasonal pattern also emerges (Figure 5.1.2):

- **Winter** is characterised by generally lower densities (Table 5.1.2) and limited extent of hotspots, although the Adriatic remains a consistent accumulation area.
- **Spring** shows a sharp increase in both density and spatial distribution, with hotspots emerging in the Ligurian/Liguro-Provencal Seas, southern-central Tyrrhenian Sea, near Palermo, in the Sardinia Channel, and along the northern Alboran Sea (from Valencia to Murcia, Figure **5.1.2**).
- **Summer** maintains high densities across all areas identified in spring, with a notable intensification particularly in the Sardinia and Sicily Channels and the Ligurian Sea;
- **Autumn** sees a general decline in density, although persistent clusters remain in the Adriatic, and off the coasts of Tunisia and Palermo.

Table 5.1.2 Descriptive statistics of litter density (number of objects per km²) measured per 5x5 km cells across different temporal resolutions. Outliers were removed using the upper threshold method based on the interquartile range (IQR), to reduce the influence of extreme values on summary statistics.

Temp.res.	Area sampled (km2)	N. cells	Mean (n.obj/km2)	Sd	Min	Max
Entire period	12,382	3551	1.2	1.4	0.0	5.8
Winter	2,219	1725	0.9	1.2	0.0	4.8
Spring	3,195	2274	1.2	1.6	0.0	6.3
Summer	4,184	2253	1.1	1.4	0.0	5.7
Autumn	2,219	1880	0.9	1.3	0.0	5.0

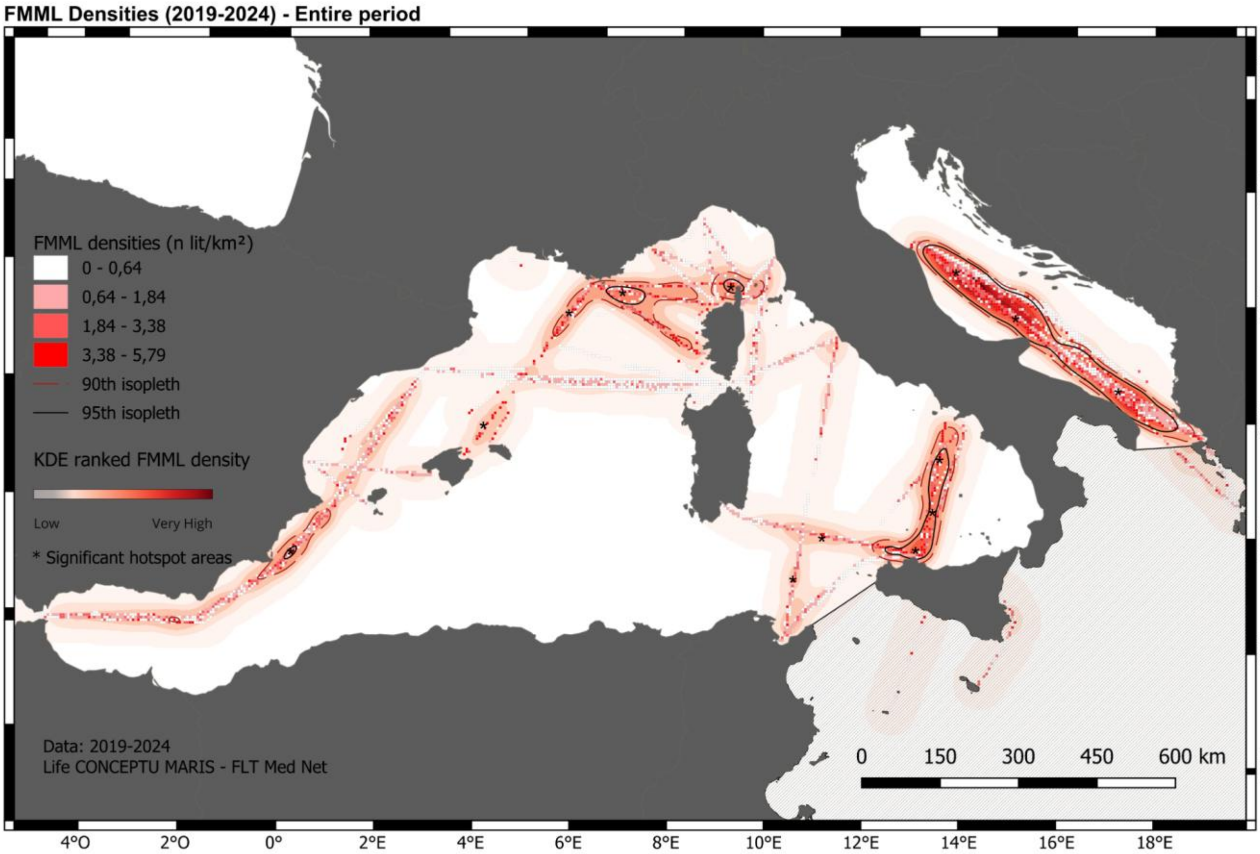
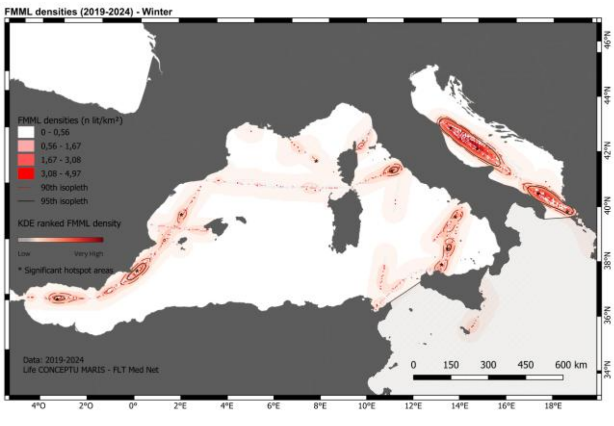
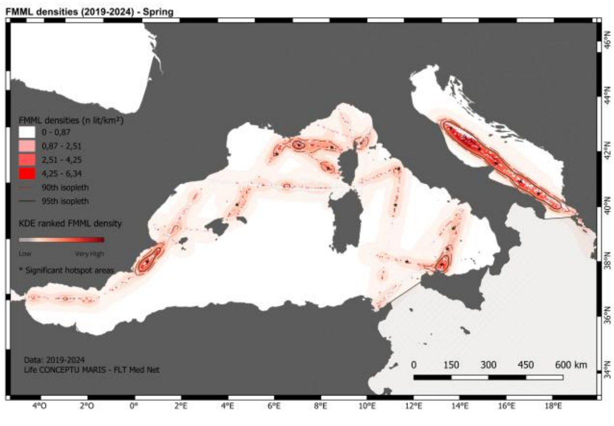


Figure 5.1.1 Spatial distribution of FMML densities across the study area during the last HD reporting period (2019–2024). Background shading shows observed FMML densities (items per km²), while the KDE surface highlights distribution patterns. Contours represent areas exceeding the 90th and 95th percentiles of KDE values, with the 95th percentile shown in black. Asterisks (*) indicate statistically significant hotspots of FMML density based on Getis-Ord Gi analysis ($p < 0.05$).

WINTER	SPRING
	
SUMMER	**AUTUMN**

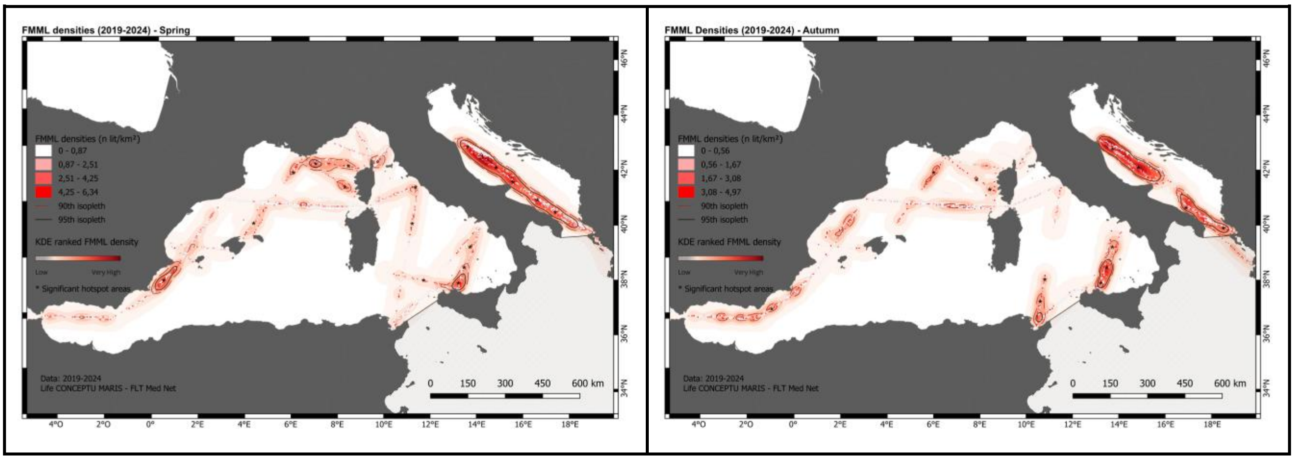


Figure 5.1.2 Spatial distribution of FMML densities across the study area during the last HD reporting period (2019–2024) sorted by the four seasons. Background shading shows observed FMML densities (items per km²), while the KDE surface highlights distribution patterns. Contours represent areas exceeding the 90th and 95th percentiles of KDE values, with the 95th percentile shown in black. Asterisks (*) indicate statistically significant hotspots of FMML density based on Getis-Ord Gi analysis ($p < 0.05$).

5.2 Maritime Traffic

SUMMARY ON MARITIME TRAFFIC DATA

The assessment of maritime traffic in the Mediterranean Sea was based on the integration of two main data sources; the AIS (Automatic Identification System) data, which provide comprehensive coverage of medium to large vessels (≥300 GT) and In situ observations from ferry-based surveys, which offer insight into the density and distribution of leisure vessels (small to medium recreational boats not detected by AIS)

The analysis of maritime traffic in the Mediterranean Sea from 2019 to 2024, based on AIS route density data, reveals a highly structured network concentrated along two main corridors: west–east (from the Strait of Gibraltar to the Suez Canal) and north–south (linking Europe and North Africa). High-intensity routes include the Strait of Gibraltar, Tyrrhenian, Adriatic Sea, Sicily Channel, and Aegean Sea. Traffic is dominated by cargo (44.3%) and tanker vessels (19.0%), with activity peaking in spring and summer, especially in coastal and island areas.

Complementary *in situ* data collected through Point Count Transect (PCT) surveys from ferries (2018–2024) allowed the modelling of leisure vessel distribution, typically untracked by AIS. This form of traffic is strongly coastal, concentrated near ports, anchorages, and shallow waters, and shows clear seasonal peaks in summer, particularly near touristic zones.

Combining AIS data with in situ observations allows for a broader understanding of maritime traffic patterns across vessel types and environments. While AIS data provide robust coverage of commercial traffic, especially in offshore waters where large vessels dominate, in situ data offer valuable complementary information on leisure vessel activity, particularly in coastal areas and touristic zones. These observations help fill spatial and seasonal gaps not captured by AIS, supporting a more complete interpretation of maritime pressures across the Mediterranean.

Findings from AIS data

Method. AIS data, provided as route density by EMODnet, were downloaded at monthly resolution from 2019 to 2024. The data include multiple vessel types as classified in the AIS system (e.g., cargo, tanker, passenger, fishing, and others). The International Maritime Organization's International Convention for the Safety of Life at Sea requires AIS to be fitted aboard international voyaging ships with 300 or more gross tonnage (GT), and all passenger ships regardless of size. Those data were then averaged over different temporal resolutions, entire period and seasonal, and gridded onto the standard European 5x5 km grid, in line with the approach used for SDM analyses and environmental variables.

Route densities spatial patterns across the study areas

The analysis of AIS route density maps indicates that maritime traffic in the Mediterranean Sea is highly organized along well-defined corridors and shows marked seasonal variation, partly depending on vessel type. Two main axes of movement can be identified: a west–east corridor from the Strait of Gibraltar through the Sicily Channel and the Aegean Sea to the Suez Canal, and a north–south corridor connecting Italy with North Africa and Greece with Egypt. The most prominent and consolidated routes include the Strait of Gibraltar, the coastal corridor along Morocco, Algeria, and Tunisia, the connection between Spain and Italy, the Sicily Channel and Malta area, the Tyrrhenian arc along the Italian coast, the Adriatic Sea, the western coast of Greece, and the route through the Suez Canal.

In general, total traffic is more intense during spring and summer, with routes showing wider spatial dispersion and activity extending further into coastal and island areas (Figure 5.2.1). During autumn and winter, a decrease in overall traffic is observed, especially for vessel categories not directly involved in commercial transport.

A quantitative overview of traffic composition and intensity further supports these patterns. Across the Mediterranean, maritime traffic is dominated by cargo and tanker vessels, which together account for approximately 63.3% of all AIS-detected routes (44.3% cargo and 19.0% tanker, Figure 5.2.7). Among the MSFD sub-regions, the Adriatic Sea shows the highest average route density, with a mean of 24.4 routes per km², reflecting the concentration of both commercial and regional traffic. When considering national Exclusive Economic Zones (EEZs), the Spanish EEZ records the highest average traffic density, with a mean of 18.4 routes per km², followed by Italy and France (Figure 5.2.6).

Regarding vessel types, cargo traffic remains stable and regular throughout the year, with a slight increase in spring and summer in the Adriatic and eastern Ionian Seas (Figure 5.2.3). This category is only marginally affected by seasonality, showing a structured and consistent pattern. Tanker routes are similar to cargo but more concentrated towards Libya, Egypt, and the Black Sea. Seasonal variation in both these is limited (Figure 5.2.3). Passenger traffic is strongly seasonal, with peak activity during summer along touristic routes in the Aegean, Adriatic, and along the Italian coast. In winter, many of these routes show minimal or no activity (Figure 5.2.4). Fishing vessels operate mainly in coastal areas, with regional differences. Their activity increases in spring and summer, especially in the Adriatic, the Sicily Channel, and the Aegean, and declines in autumn and winter (Figure 5.2.5), likely due to seasonal closures such as biological rest periods or meteorological constraints. The "Other" category, which includes service vessels, recreational boats, and military units, presents more variable spatial and temporal patterns (Figure 5.2.6). These vessels are generally more active in summer and in coastal areas, likely due to increased recreational boating (mainly large sailing vessels or large yachts) during this period.

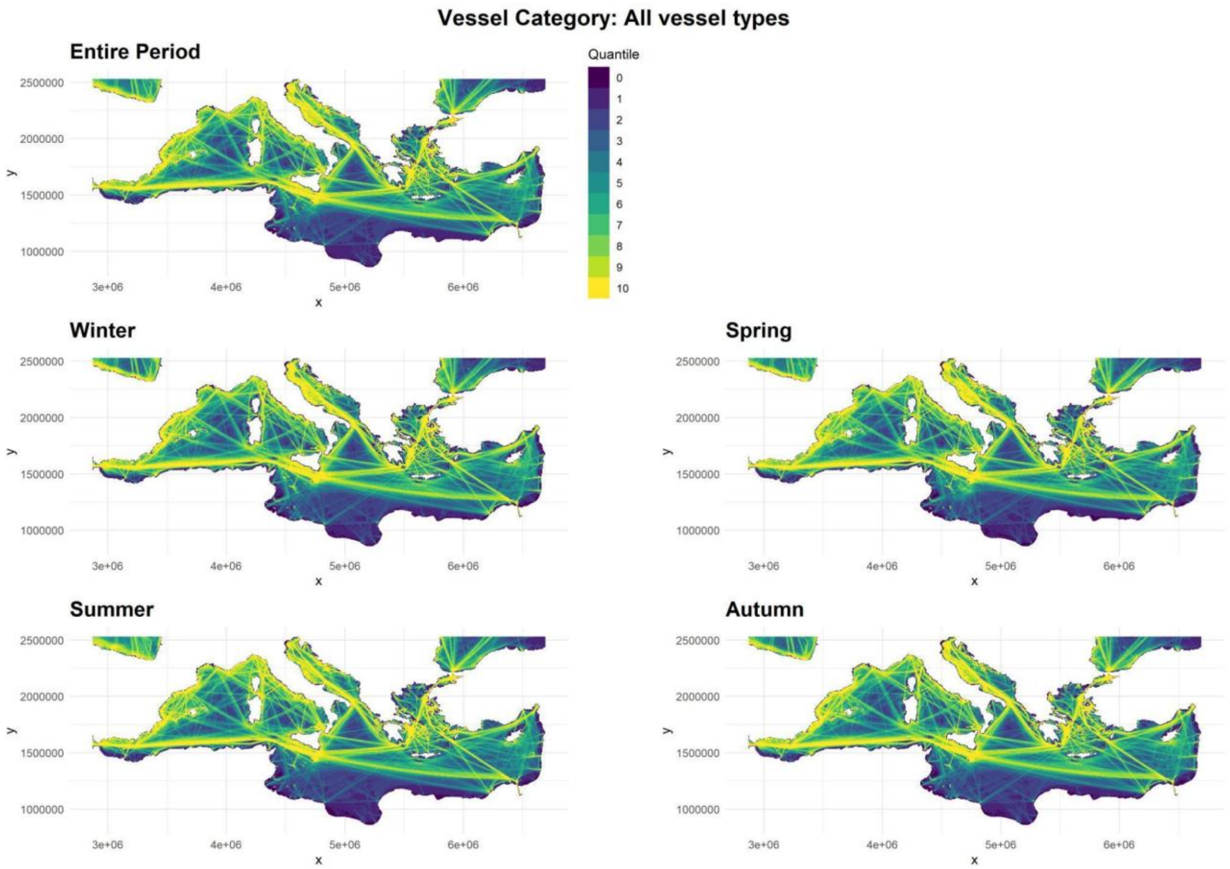


Figure .5.2.1 Average AIS route density for all vessel types across the Mediterranean Sea (2019–2024).

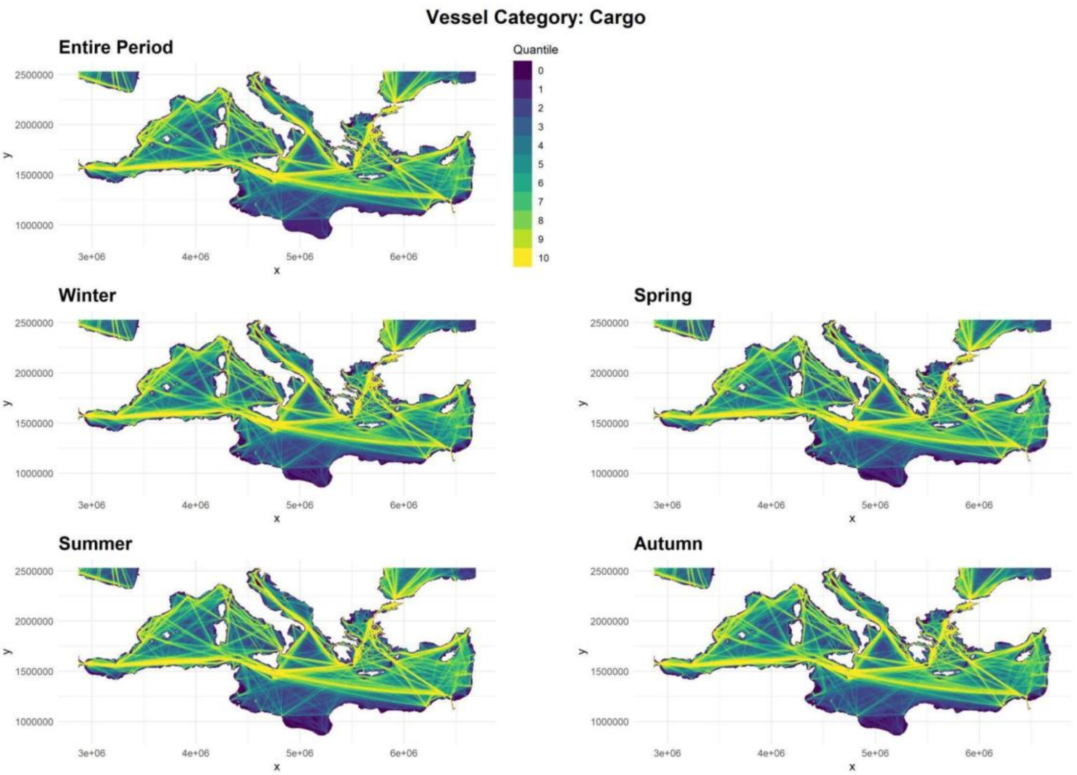


Figure 5.2.2 Average AIS route density for Cargo vessels across the Mediterranean Sea (2019–2024).

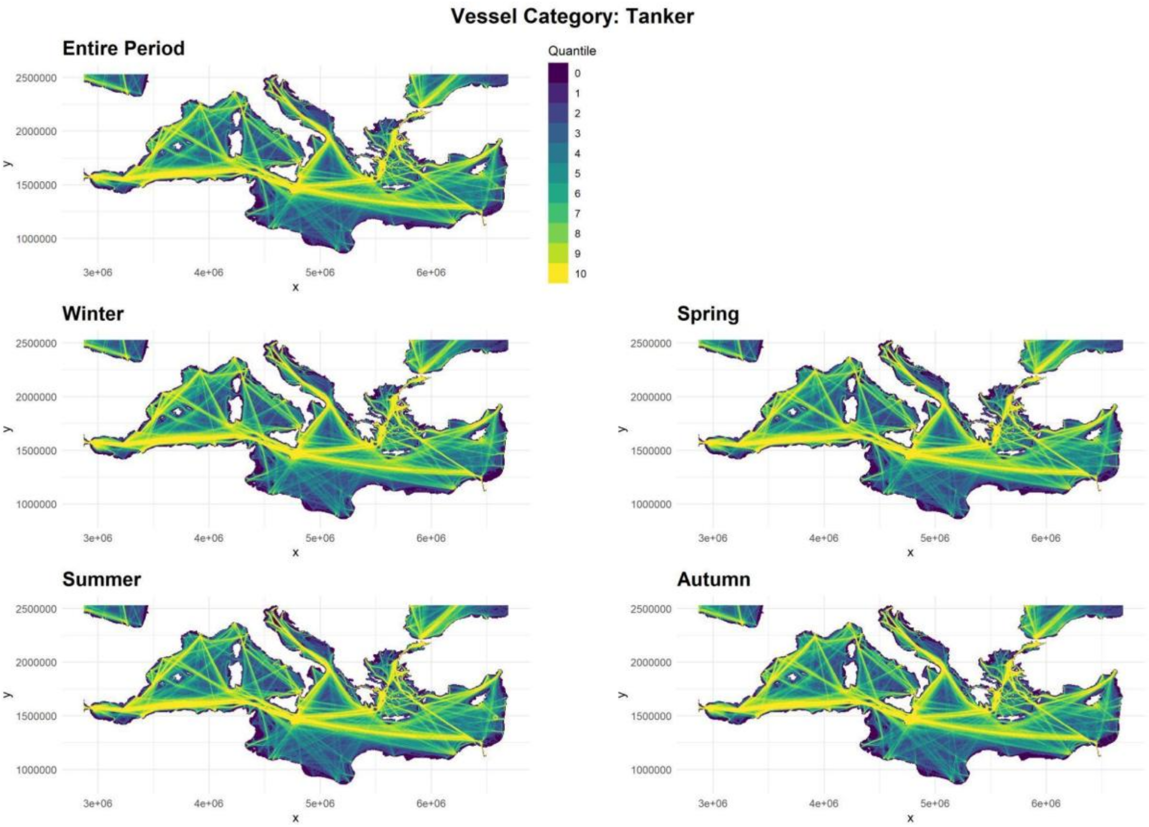


Figure 5.2.3. Average AIS route density for Tanker vessels across the Mediterranean Sea (2019–2024).

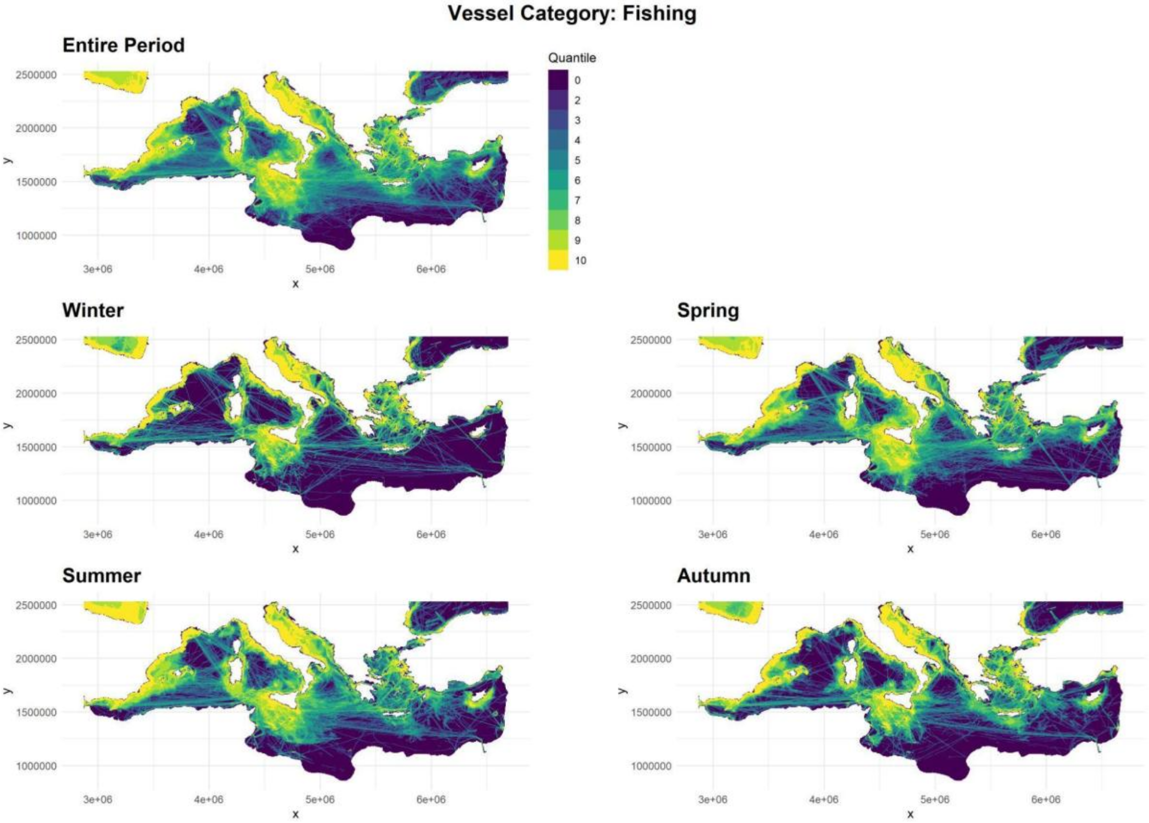


Figure 5.2.4 Average AIS route density for Fishing vessels across the Mediterranean Sea (2019–2024).

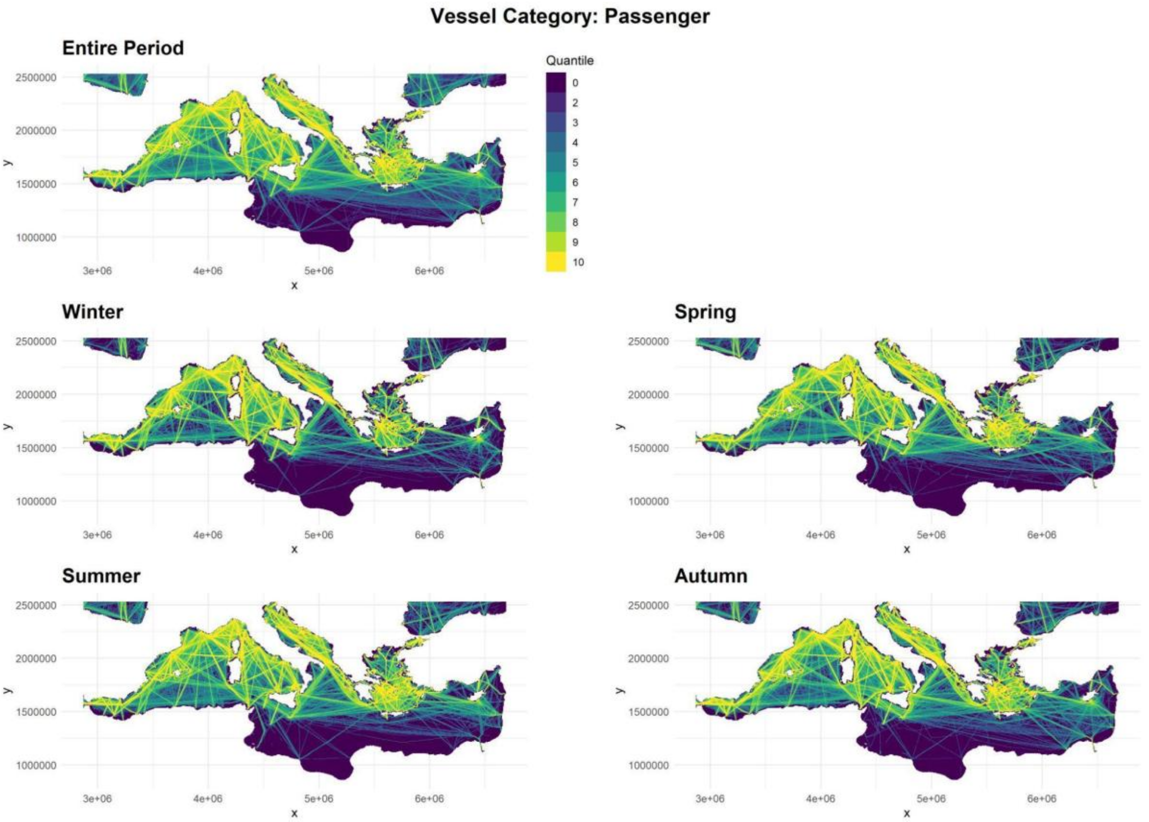


Figure 5.2.5 Average AIS route density for Passenger vessels across the Mediterranean Sea (2019–2024).

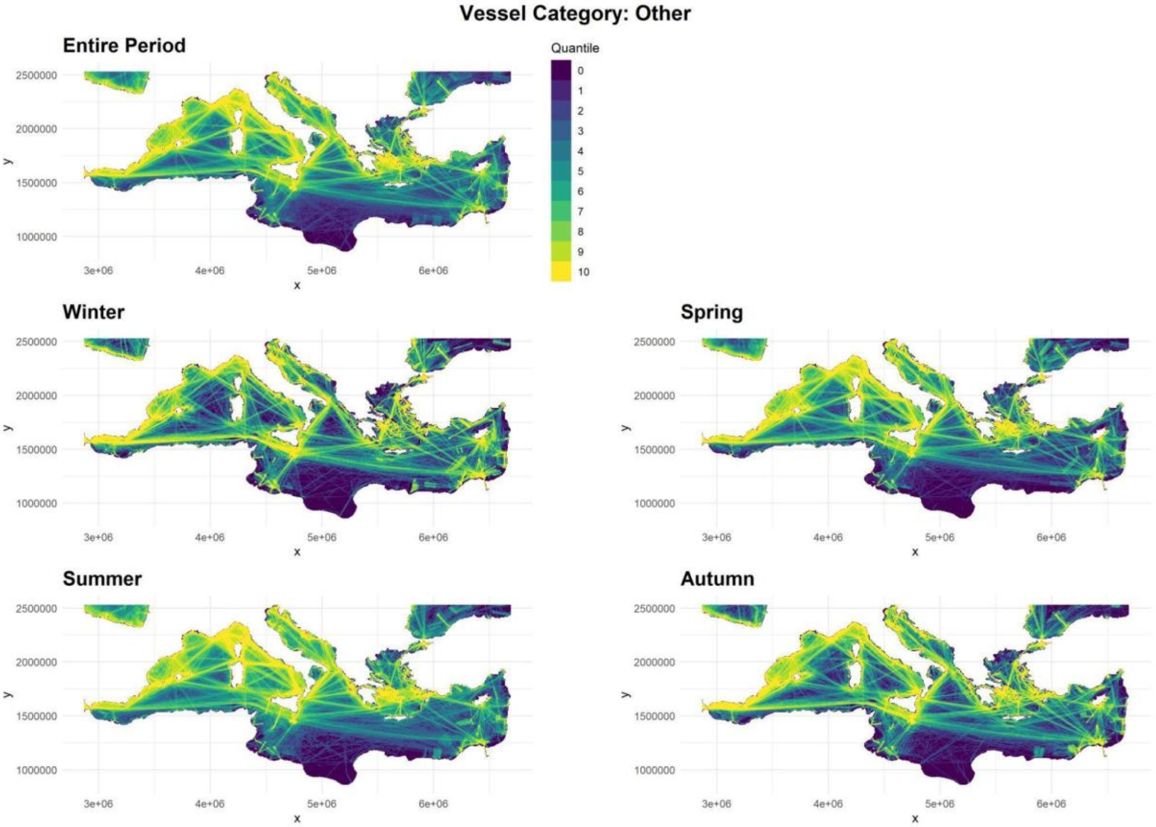


Figure 5.2.6. Average AIS route density for Other vessel types across the Mediterranean Sea (2019–2024).

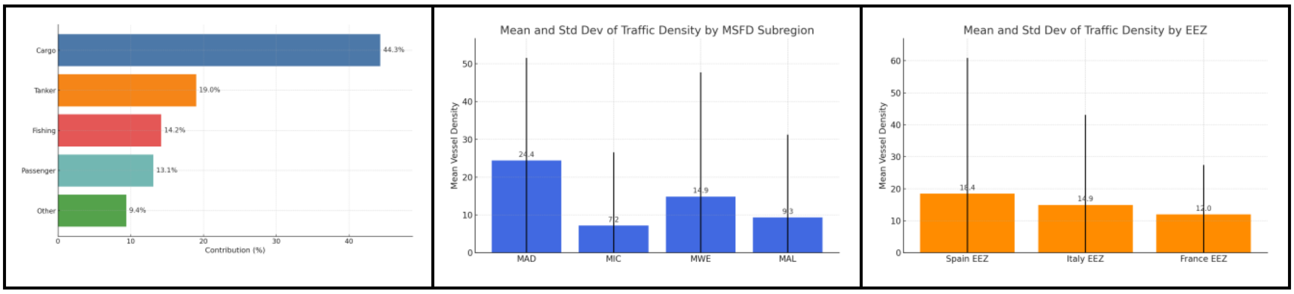


Figure 5.2.7. Bar plot showing: (left) the percentage composition of all maritime traffic types; (middle) average route densities across different MSFD sub-regions; and (right) average route densities within the Exclusive Economic Zones (EEZs) of Spain, Italy, and France.

Findings From *in-situ* data: leisure vessels

AIS is not required on leisure vessels, but yet some vessels, mainly the larger ones, are equipped with it. However, most leisure traffic is represented by medium to small boats, which cannot be tracked with an automatic device at sea. Therefore, there is no global map showing the distribution of the density of this activity at sea, including large and small leisure vessels. From the *in-situ* data collected by the FLT Med Network & Life Conceptu Maris, a first trial of modelisation of this activity at sea has been made, focusing on the north-western Mediterranean Sea.

Method. The data used for this study were collected using the Point Count Transect (PCT) method during ferry surveys (MILESTONE C1.1b – Data Acquisition in the Core Area and DELIVERABLE

E2.2.), here presented for the northwestern Mediterranean Sea, over the period 2018-2024 (excluding 2020). Leisure vessels counted included all types, from large to small, sailing to motorboat. All leisure vessels were counted 360° around the platform of observation (the ferry), until the horizon. The first step was to define the diameter of this surface sampled, by creating a buffer zone around the coordinates of the ferry from which the observations were run, at each counting event. The radius of this zone was calculated using the theoretical horizon formula:

$$\sqrt{(2 \times Rt \times (Hboat+Hobs))}$$

with Rt = radius of the Earth = 6 364 181 (in m), Hboat the height of the platform where the observers are, and Hobs the observer's eye height set at 1.60 (m). Table 5.2.1 shows the value of the command deck height for each ferry, and the result of the calculation of the associated theoretical horizon. This allows us to calculate the surface sampled for each PCT sample.

Table 5.2.1: List of ferries with their platform height and theoretical horizon (in meters)

Ferry	Command deck (Platform) height (m)	Theoretical horizon (m)
CORFÚ	19	16192.72
Catania	19	16192.72
Corsica Marina Seconda	15	14535.85
Corsica Sardinia Vera	15	14535.85
Corsica Victoria	12	13226.36
Cristal	22	17339.74
Cruise Ausonia	23	17736.60
Cruise Barcelona	29	19741.66
Cruise Bonaria	24	18130.76
Cruise Roma	29	19741.66
Cruise Smeralda	21	16936.33
Denia Ciudad Creativa	23	17736.60
Dimonios	20	16534.81
EUROPA PALACE	23	17736.60
Excellent	25	18519.62
Excelsior	25	18519.62
GNV Antares	24	18130.76
GNV Aries	24	18130.76
Hedy Lamarr	20	16534.81
Ikarus Palace	21	16936.33
Majestic	21	16936.33
Martin i Soler	17	15337.71
Mega Andrea	25	18519.62
Mega Express	20	16534.81
Mega Express 2	20	16534.81
Mega Express 3	20	16534.81
Mega Express 4	22	17339.74
Mega Express 5	22	17339.74
Mega Regina	29	19741.66
Mega Smeralda	25	18519.62
Mega Victoria	12	13226.36
Pascal Lota	22	17339.74
Sardinia Regina	12	13226.36
Sardinia Vera	15	14535.85
Sicilia	25	18519.62
Smeralda	21	16936.33
Tom Sawyer	21	16936.33
Visborg	20	16534.81
Zeus Palace	21	16936.33

The second step was to eliminate duplicates, that is, two sampling zones partially overlapping, with the same boat actually being counted twice. Thus, for the samples (=counting events) along the same transect that had overlapping buffer zones, only one has been kept. This roughly corresponds to keeping counts spaced 50 minutes apart, but it depends on the speed and the height of the platform. Then for each PCT sample, the number of boats has been mapped. Knowing those numbers and the surface of each sample, a density of leisure vessels at each sampling location could be calculated.

The spatial distribution of the density of leisure vessels was modeled over the north-western Mediterranean Sea, using a Log-Gaussian Cox Process (LGCP) model, particularly suited to spatialized count data. This model assumes that the observations follow a random Poisson process, intensity of which varies spatially according to a latent random field. The intensity function of the process $\lambda(s)$ can be modeled as:
$\lambda(s) = \exp(\eta(s))$ with $\eta(s)$ being the linear predictor defined by:

$$\ln(\lambda(s)) = \eta(s) = \beta_0 + W(s) + \sum_j \beta_j \times x_j(s)$$

with β_0 the model intercept, $W(s)$ a latent spatial field modeled as a Gaussian field with a Matérn structure, $x_j(s)$ the covariates, and β_j their effects.
The spatial field $W(s)$ is represented numerically using the SPDE (Stochastic Partial Differential Equation) method, which approximates a continuous Gaussian field on a triangular mesh, while reducing computational costs. Bayesian estimation of the parameters is performed using the INLA (Integrated Nested Laplace Approximation) method.

The data were first associated with **covariates** that could potentially be linked to the distribution of the density of leisure vessels as :
• Bathymetry
• Distance to the coast
• Distance to the nearest port weighted by its capacity.
• Distance to anchorage areas, which were defined by selecting the bathymetry with a depth between 0 and 15 m
• Protected areas: Natura 2000 sites and Nationally Designated Areas
• Seabed type classified into four categories: rock, gravel, sand, soft earth (clay and silt).
Distance data were measured against the centroids of the sighting areas.

The combination of covariates resulting in the best possible model was determined by comparing the DIC (Deviance Information Criteria) of several models ($DIC = \bar{D} + (\bar{D} - \hat{D})$ with $\bar{D}$ being the mean of the posterior distribution and $\hat{D}$ being the deviance calculated at the mean of the posterior distribution).

Results
The map showing the samples highlights that this anthropogenic activity is merely coastal, with a gradient from coast to offshore (Fig. 5.2.8).

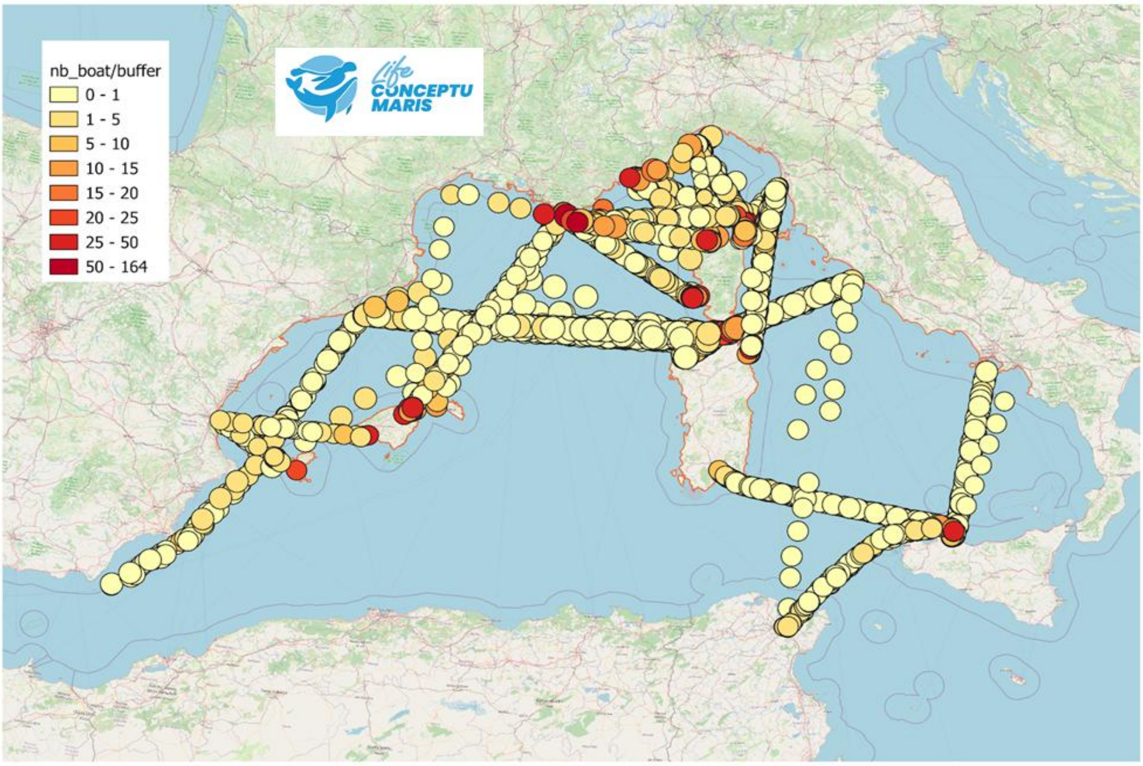


Figure 5.2.8: Number of leisure boats per area covered at each Point Count Transect sample, from ferry, 2018-2024

The combination of variables resulting in the best model is therefore: distance from the coast, distance from the nearest ports, distance from anchorages, protected areas NDA and seabed types (rock, sand and gravel) (distance from the coast and seabed type (sand) were not significant but nevertheless allowed a slight decrease in the DIC).

The resulting map of the predicted distribution of the density of leisure vessels is shown in Figure 5-2-9. It highlights the very coastal nature of this activity, with high densities along the coasts of the mainland, but with some also more offshore.

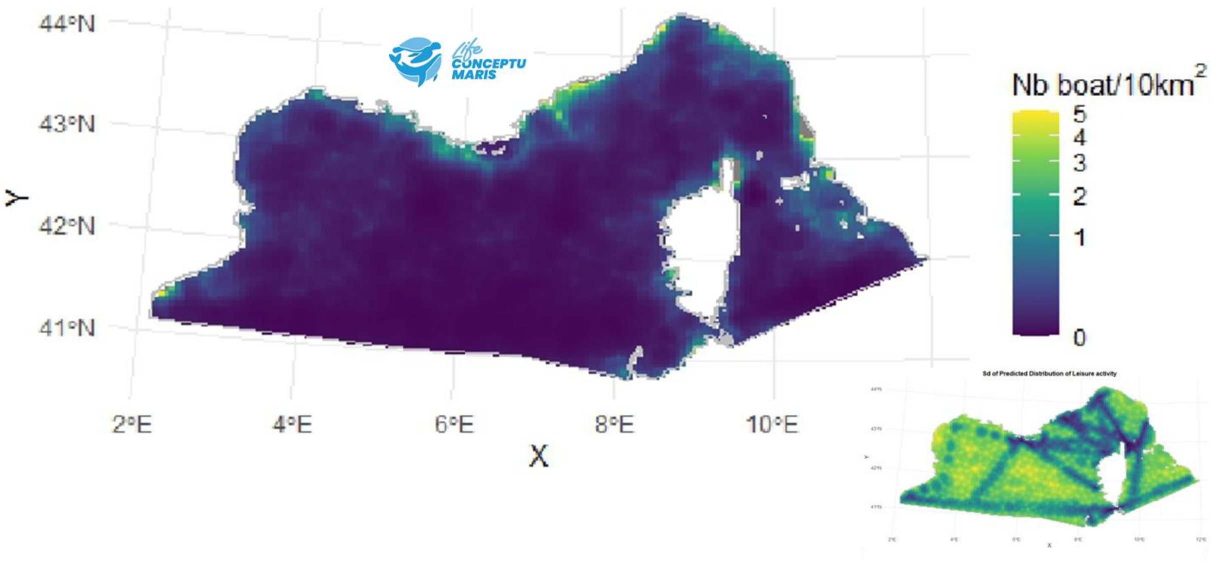


Figure 5.2.9: Map of the predicted distribution of the density of leisure vessels from Point Count Transect from ferry, 2018-2024 and the standard deviation (right bottom)

6. Spatial Risk Exposure Analysis of CEPTU species to main anthropogenic pressures

Spatial Risk Assessment Methodological approach

Risk analysis, in this context, refers to a multi-step process that integrates species data with data on anthropogenic pressures to identify where and when marine species are most exposed or potentially affected by specific human activities.
Although such analyses are increasingly required for effective conservation planning, a clear and standardized methodological framework has historically been lacking, especially for open-sea environments.
To address this, the project began with a systematic review of methodological approaches for spatial risk assessment (Arcangeli et al., 2024). This review served as the scientific foundation for the analytical framework adopted in the present study.
It is important to clarify a key distinction within this framework: exposure risk refers to the probability that a species is present in the same location and time as a given anthropogenic pressure. This co-occurrence does not automatically imply that the species is affected or harmed. In contrast, actual risk goes further by incorporating the likelihood that the exposure results in negative impacts on the species. While estimating actual impacts is methodologically complex and often limited by data availability, assessing exposure risk remains a fundamental first step. When integrated with expert knowledge and data on potential harm, exposure analysis becomes a powerful tool to inform conservation strategies and support evidence-based management.

In applying this approach, we developed a unified methodological framework that was used consistently across both pressures considered in the study: floating marine litter and maritime traffic. For both, species presence was represented using Sightings Per Unit Effort (SPUE - expressed per kilometer). This metric provides a standardized proxy of relative abundance or species activity based on visual observations during ferry-based surveys.

Pressure layers were derived from two sources: Floating marine litter densities (n. objects/km^2) were obtained from *in-situ* observations conducted as part of the Conceptu Maris program (see paragraph 5.1.1), while maritime traffic densities (n. routes per km^2) was calculated from AIS data provided by the EMODnet platform and processed by CMCC project partner.

Different steps were followed for spatial analysis:

- Study areas was overimposed with EEA standard 5x5 grid:
- The exposure index for each species and pressure was calculated as the product of the ranked SPUE and ranked density of the pressure layer (litter or traffic) for each grid cell, highlighting areas of spatial co-occurrence between species presence and human pressure. Resulting index values range from 0 (no overlap) to 16 (maximum potential exposure). To minimize the influence of extreme values, outliers in litter density were removed seasonally by excluding values above the upper whisker threshold (Q3 + 1.5×IQR) before classification.
- To evaluate cumulative risk across species, we summed the species-specific pressure exposure indices for each grid cell. This allowed us to assess overall exposure for cetaceans as a group, for a subset of low-density cetacean species (*Ziphius cavirostris, Grampus griseus, and Globicephala melas*), for sea turtles alone (*Caretta caretta*), and for cetaceans and turtles combined. These cumulative layers reveal areas of multispecies overlap under high pressure from plastic pollution.

- For spatial refinement, we applied two methods: Kernel Density Estimation (KDE) and the Getis-Ord G* statistics. KDE was applied to grid cell centroids using a quartic kernel with a 50 km bandwidth and a 500 m output resolution, producing continuous surfaces of spatial intensity. The Getis-Ord G* statistic was calculated on the exposure index to detect statistically significant spatial clusters of high values (Gi > 1.96*, $p < 0.05$), using a fixed spatial neighborhood of 25 km. These complementary approaches helped identify statistically significant exposure hotspots. For mapping purposes seasonal isopleths of 90th percentile, were extracted for each group of species/species.

The same approach described above for traffic risk has been applied also for Passenger traffic only to evaluate the highest exposure areas from this specific maritime activity for all CEPTU species. These latter analyses allows, particularly for large and medium-sized cetaceans (*B.physalus, P.macrocephalus, Z.cavirostris, G.griseus, G.melas*), to be compared with spatial results of observed Near-Miss Events (NME) recorded by the FLT Med Network (see dedicated paragraph 6.3).

6.1 High Risk Exposure Areas to Floating Marine Litter

SUMMARY ON MAIN RISK EXPOSURE AREAS TO FLOATING MARINE LITTER FOR CEPTU SPECIES

The analysis of FMML exposure risk across CEPTU species reveals distinct spatial and seasonal patterns throughout the Western Mediterranean and Adriatic Sea.

Among cetaceans, **the Ligurian–Provençal Basin** stands out as the most prominent and statistically consistent hotspot, marked by high cumulative risk and persistent seasonal overlap, **particularly in spring and summer**.
The Alboran Sea also emerges as a recurrent exposure zone, **especially for low-density cetacean species** such as *Ziphius cavirostris, Grampus griseus, and Globicephala melas*, with significant clusters across winter, spring, and autumn. Additional seasonal hotspots for cetaceans are found in the southern Tyrrhenian and Adriatic Seas, although no year-round statistically significant clusters are present outside the northwestern basin.

For sea turtles (*Caretta caretta*), exposure is more concentrated and persistent **in the Adriatic and Central Tyrrhenian Seas**, with stable risk patterns observed throughout the year. Seasonal expansion is evident in spring and summer, with additional hotspots in the Sardinia Channel, Balearic Sea, and northwest of Corsica. In autumn, the extent of exposure contracts, resembling the winter distribution. Minor but relevant risk areas are also noted in the northern Alboran Sea and along the southeastern French coast.

Species-specific analysis confirms and refines cumulative patterns, with the Ligurian–Provençal Basin emerging as a key risk area for *B. physalus, S. coeruleoalba, Z. cavirostris, and P. macrocephalus*. Other species show more localized exposures: *T. truncatus* in the Adriatic and Tunisian coasts, *D. delphis* in the Alboran Sea, and low-density species like *G. griseus and G. melas* in the Alboran, Balearic, and Ligurian Seas.

Overall, these results highlight both year-round exposure zones and seasonally dynamic hotspots, emphasizing the need for targeted and time-sensitive mitigation strategies to reduce marine litter impacts across target Mediterranean species.

Summary for policymakers: Key Risk Areas from Floating Marine Litter (FMML) for CEPTU Species
The analysis of FMML exposure (2019–2024) reveals distinct spatial and seasonal patterns across the Western Mediterranean and Adriatic Seas, with implications for both cetaceans and sea turtles.

For cetaceans, the **Ligurian–Provençal Basin** stands out as the most consistent and statistically significant risk area. It shows strong cumulative exposure, especially in **spring and summer**, for key species including *Balaenoptera physalus*, *Stenella coeruleoalba*, *Physeter macrocephalus*, and *Ziphius cavirostris*.
The **Alboran Sea** is another important risk zone, particularly for low-density species such as *G. griseus*, *G. melas*, and *Z. cavirostris*, with notable exposure during **winter, spring, and autumn**. Smaller, seasonal hotspots also appear in the **southern Tyrrhenian** and **Adriatic Seas**, though no year-round clusters exist outside the northwestern basin.
For sea turtles (*Caretta caretta*), exposure is highest and most consistent in the **Adriatic** and **Central Tyrrhenian Seas**, with stable risk throughout the year. In **spring and summer**, exposure expands to include the **Sardinia Channel**, **Balearic Sea**, and waters **northwest of Corsica**. Risk areas shrink again in **autumn and winter**, following turtle movement patterns. Minor but relevant exposure zones are also found in the **northern Alboran Sea** and **southeastern France**.
Species-level analysis further refines these patterns:

- *Tursiops truncatus*: persistent exposure in the **Adriatic** and near **Tunisian ports**.
- *Delphinus delphis*: localised risk in the **Alboran Sea**.
- *G. griseus* and *G. melas*: exposure in the **Alboran**, **Balearic**, and **Ligurian Seas**.

Implication for mitigation measures:

- The **Ligurian–Provençal Basin** is a high-priority area for reducing FMML impact on multiple cetacean species.
- The **Adriatic** and **Central Tyrrhenian Seas** are critical year-round exposure zones for **sea turtles**.
- Seasonal shifts in exposure call for **dynamic, time-sensitive mitigation**, including seasonal clean-up efforts, improved waste management at sea and ports, and enhanced monitoring.
- Localised exposure patterns highlight the need for **species-specific actions** to reduce FMML impacts, especially for less abundant species.

FMML Risk for all cetacean species

The most prominent and statistically robust hotspot remains centred in the Ligurian–Provençal Basin, where high cumulative REA index values and dense seasonal hotspot contours (particularly in spring and summer) reveal sustained overlap between cetacean presence and litter accumulation (Figure 6.1.1). The presence of multiple Gi* significant clusters confirms this region as a year-round high-risk zone.
In the Alboran Sea, seasonal hotspots are consistently observed across winter, spring, and autumn, with significant clustering particularly along the Spanish coast. This reaffirms the western Mediterranean as a key exposure region, even for mobile and spatially diffuse cetacean populations.
In contrast, no year-round statistically significant clusters were detected in the Tyrrhenian or Adriatic Seas. However, seasonal clusters are evident, particularly in winter and autumn in the southern Tyrrhenian and north-central Adriatic, and throughout all seasons in the southern Adriatic and Ionian basins, indicating temporally limited yet spatially relevant patterns of exposure.

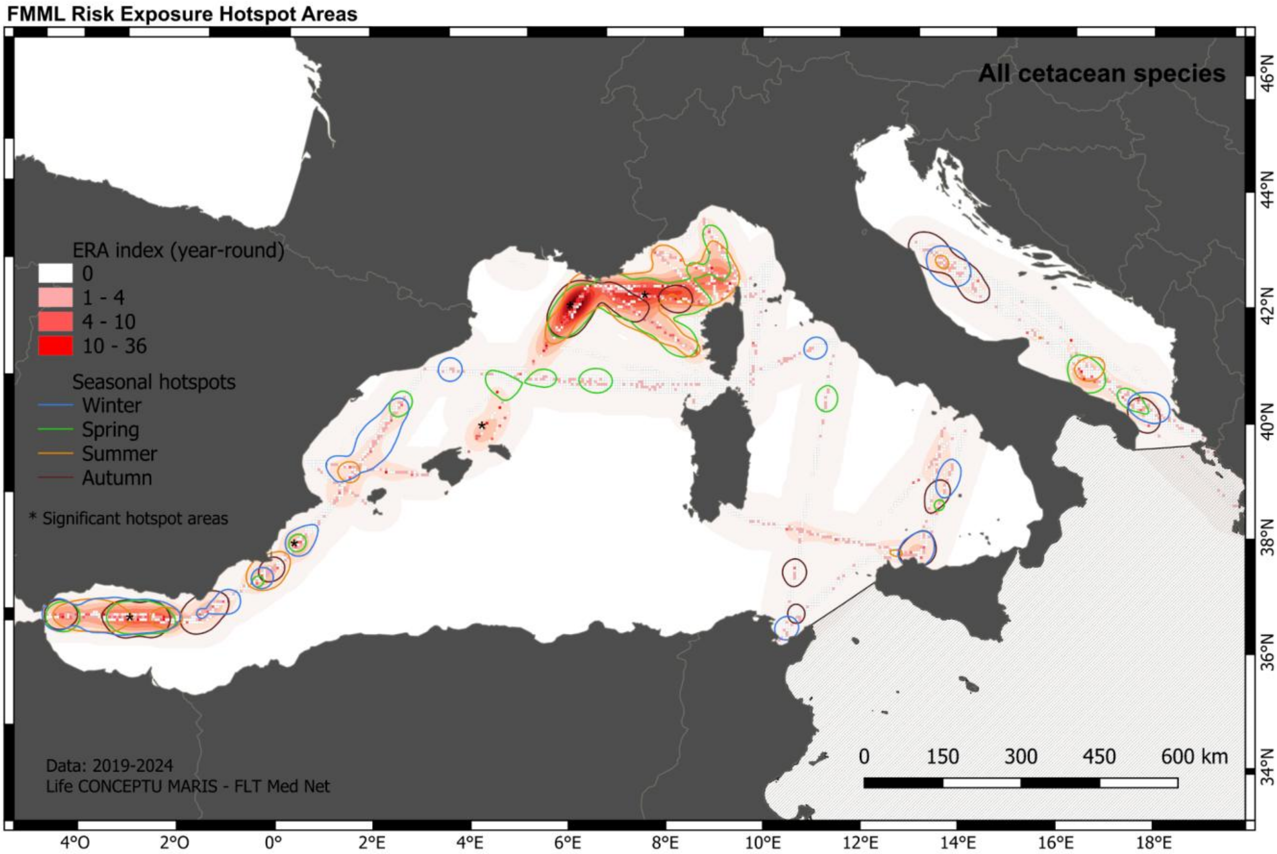


Figure 6.1.1. Hotspot areas of cumulative exposure to Floating Marine Macro Litter (FMML) for all cetaceans species over the study period (2019–2024). Background shading shows Risk Exposure Assessment index (REA), with the Kernel Density Estimator (KDE) risk output indicating areas of intensified risk. Contours represent seasonal hotspots above the 90th percentile, while asterisks mark statistically significant clusters of high values within 25 km (Getis-Ord Gi, $p < 0.05$).

FMML Risk for low-density cetacean species

Although these species occur at low densities, they are repeatedly exposed to FMML in localized but ecologically relevant areas, particularly along western Mediterranean basins and transition zones between deep and shelf waters. Despite the generally sparse presence of these species (*Z.cavirostris, G.melas and G.griseus*), the map reveals a clear zone of concentrated exposure risk, particularly in the Alboran Sea, where an intense and statistically significant cluster is visible throughout the year. This area stands out with high REA index values and consistent seasonal hotspots, especially during winter and summer, suggesting a critical overlap between cetaceans' presence and litter accumulation (Figure 6.1.2).

A second notable cluster is found off the Gulf of Lion and Ligurian Sea, where multiple overlapping seasonal hotspots (spring, summer, autumn) suggest recurrent exposure. While REA index values are lower than in the Alboran Sea, the presence of statistically significant Gi* hotspots indicate consistent spatial clustering through the year. Additional seasonal hotspots are observed in the Sardinia Channel, off Palermo (Sicily) in summer and off Campania coast in winter.

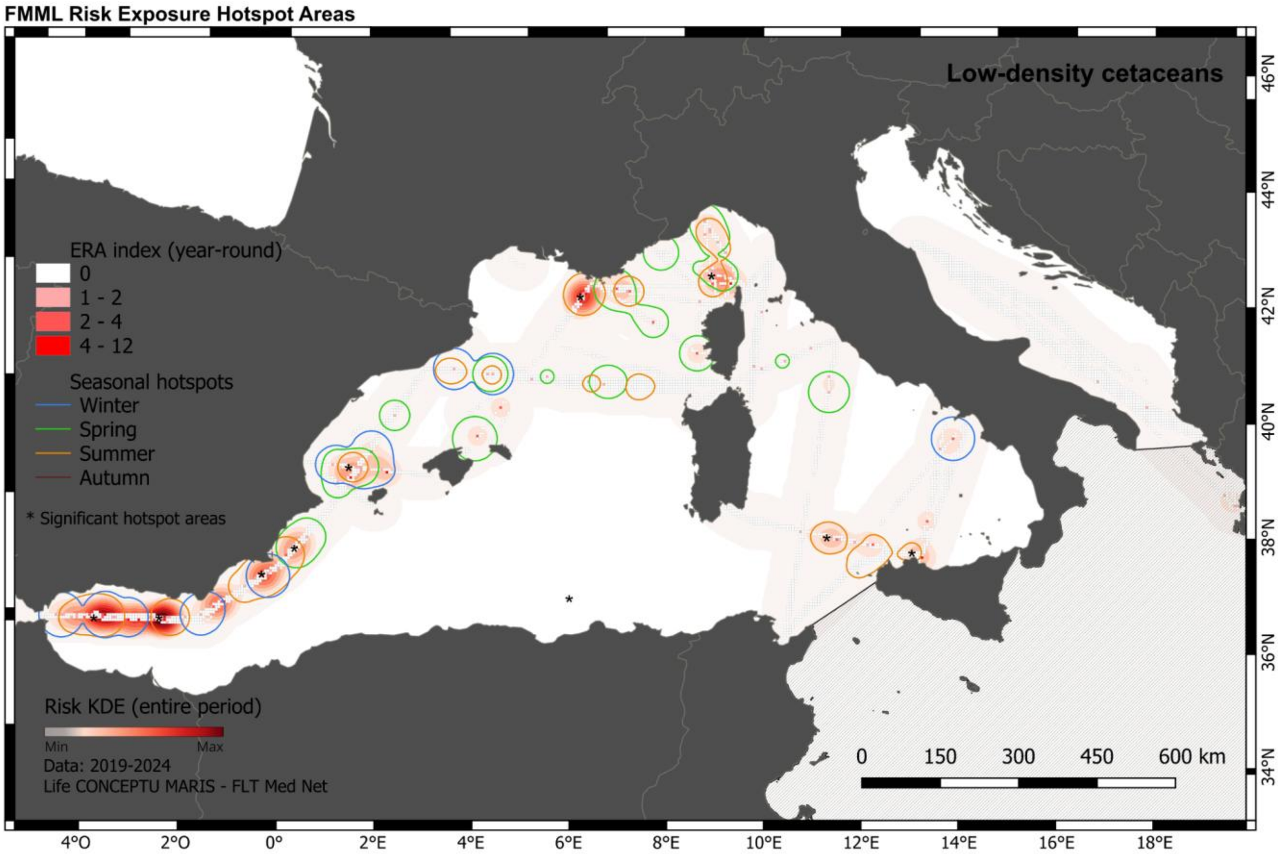


Figure 6.1.2. Hotspot areas of cumulative exposure to Floating Marine Macro Litter (FMML) for Low-density cetaceans (*G.griseus, G.melas, Z.cavirostris*) over the study period (2019–2024). Background shading shows Risk Exposure Assessment (REA) index, with the Kernel Density Estimator (KDE) risk output indicating areas of intensified risk. Contours represent seasonal hotspots above the 90th percentile, while asterisks mark statistically significant clusters of high values within 25 km (Getis-Ord Gi, $p < 0.05$).

FMML Risk for sea turtles (*Caretta caretta*)

Risk Exposure Analysis revealed significant hotspots of exposure to FMML for *Caretta caretta* in the Central Tyrrhenian and Adriatic Seas throughout the year, along with minor but significant hotspots in the northernmost sector of the Alboran Sea and along the south-eastern coast of France (Figure 6.1.3). In winter, hotspots are relatively localized, primarily concentrated in the Central Adriatic, with smaller areas of elevated risk in the southern Adriatic, the southern Tyrrhenian (offshore of Sicily), and the Alboran Sea. In spring, risk areas expand, encompassing the mid-central Tyrrhenian, the area northwest of Corsica, and the Balearic Sea. These regions become more prominent in summer, when stable and persistent hotspots in the Tyrrhenian Sea intensify, particularly in the Sardinia Channel and off the Campania coast. In autumn, the extent of exposure contracts, reverting to a spatial pattern more similar to winter.

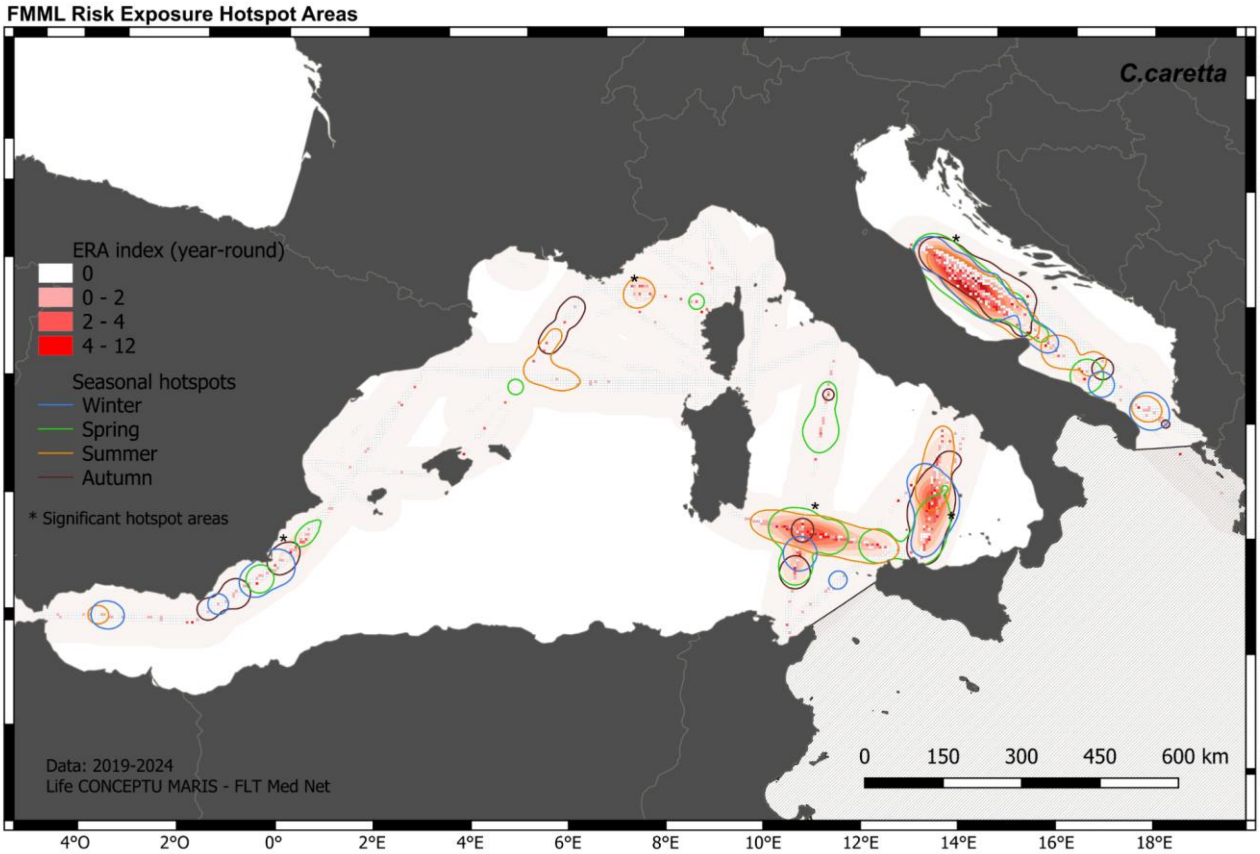


Figure 6.1.3. Hotspot areas of exposure to Floating Marine Macro Litter (FMML) for sea turtles (*Caretta caretta*) over the study period (2019–2024). Background shading shows raw Risk Exposure Assessment (REA) values, with the Kernel Density Estimator (KDE) risk output indicating areas of intensified risk. Contours represent seasonal hotspots above the 90th percentile, while asterisks mark statistically significant clusters of high values within 25 km (Getis-Ord Gi, $p < 0.05$).

FMML Risk for CEPTU species

The Adriatic Sea emerges as a consistent high-risk area throughout the year, particularly in winter and summer, where both the intensity of exposure and statistical clustering are evident (Figure 6.1.4). In the Tyrrhenian Sea, exposure is also persistent, with a notable summer intensification in the Sardinia Channel and along the Campania coast. Smaller but significant hotspots appear in the Alboran Sea, especially along the Spanish coastline in winter and autumn. In spring and summer, the risk areas expand, with the emergence of hotspots in the Sicily Channel, the southern Ionian Sea, and the Ligurian Sea, where summer exposure resurfaces in areas largely absent in other seasons. The spatial and seasonal distribution of these hotspots highlights both persistent and dynamic zones of risk, driven by the overlap between species presence and FMML density.

FMML Risk Exposure Hotspot Areas

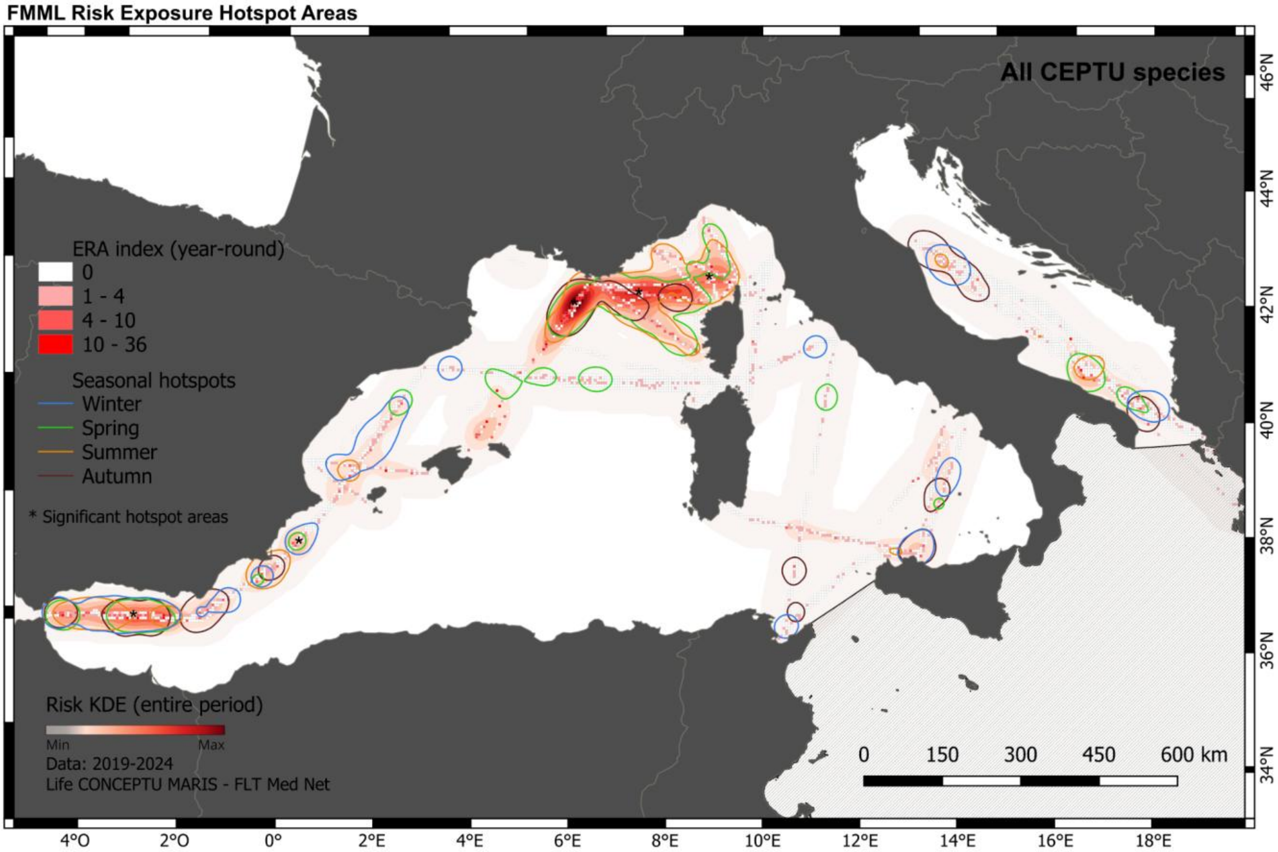


Figure 6.1.4. Hotspot areas of cumulative exposure to Floating Marine Macro Litter (FMML) for all CEPTU species (cetaceans & sea turtles) over the study period (2019–2024). Background shading shows raw Risk Exposure Assessment (REA) values, with the Kernel Density Estimator (KDE) risk output indicating areas of intensified risk. Contours represent seasonal hotspots above the 90th percentile, while asterisks mark statistically significant clusters of high values within 25 km (Getis-Ord Gi, $p < 0.05$).

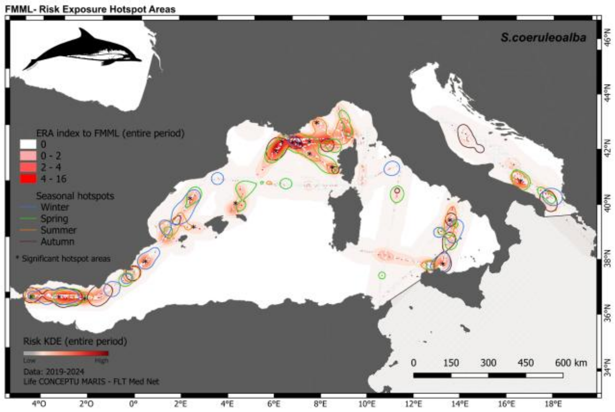
Cetacean Specie-specific Exposure Risk Assessment to FMML

The species-specific spatial analysis of cetacean exposure revealed additional, more refined insights that complement the cumulative FMML risk patterns previously described (Figure 6.1.5). As outlined in the cumulative analysis, the Ligurian–Provençal Basin remains the most prominent and statistically robust hotspot across species. This finding is further supported when evaluating individual species distributions, with high exposure areas in the Pelagos Sanctuary especially for *Balaenoptera physalus*, *Stenella coeruleoalba*, *Physeter macrocephalus*, and *Ziphius cavirostris*. For the latter, the risk appears more spatially restricted, particularly within the Ligurian Sea between Corsica and the Genoa coastline.

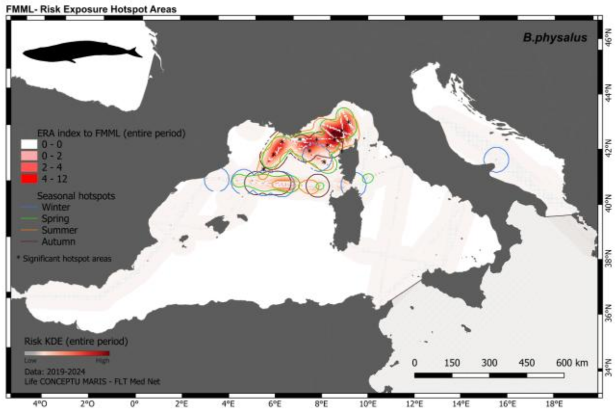
Species-specific results also reinforce patterns observed in the Adriatic and Tyrrhenian Seas, where year-round significant cumulative hotspots for cetacean's species were not detected. However, at the species level, *Tursiops truncatus* exhibits persistent exposure in the northern-central Adriatic and around Tunisian ports throughout all seasons. On a seasonal basis, results indicate that the species is potentially more exposed during spring and summer near the Balearic Islands and along the Corsican coast.

Regarding other species, areas where risk exposure is high for *Delphinus delphis* are limited to the Alboran Sea and a smaller area between mainland Spain and the Balearic Islands. For *Stenella* *coeruleoalba* on the other side, exposure is high across widespread areas of the Mediterranean, due to its broader distribution and mobility. For *Grampus griseus*, areas of high-exposure are in the Alboran, Balearic, and Ligurian Seas, as well as in the southern Tyrrhenian Sea off the coast of Palermo. Finally, consistent with the cumulative findings for low-density species, *Globicephala melas* and *Ziphius cavirostris* are potentially more exposed to FMML in the Alboran and Ligurian Seas, the Balearic basin, and the Sardinian Channel, highlighting localized yet ecologically meaningful exposure zones even for less abundant taxa.

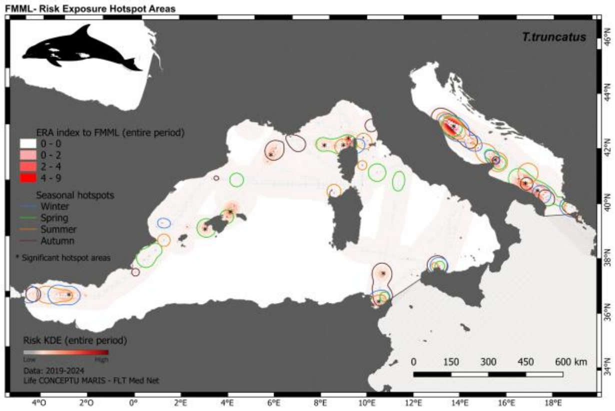
Stenella coeruleoalba



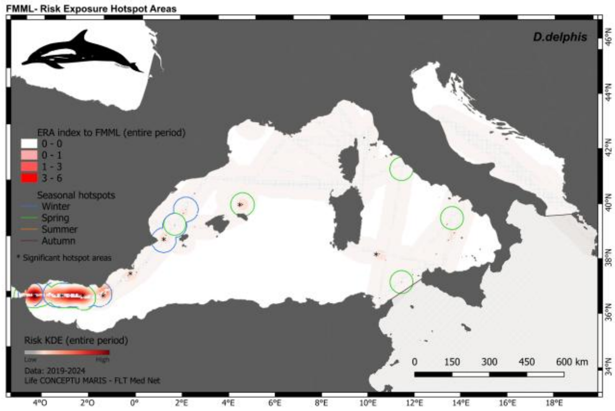
Balaenoptera physalus



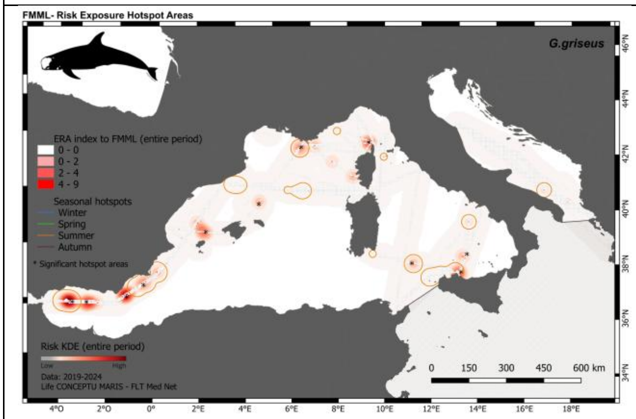
Tursiops truncatus



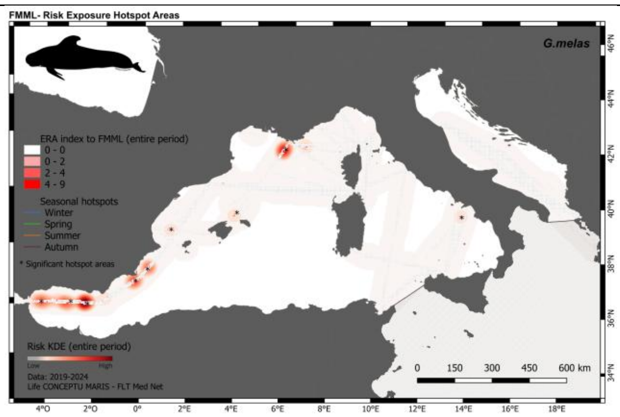
Delphinus deplphis



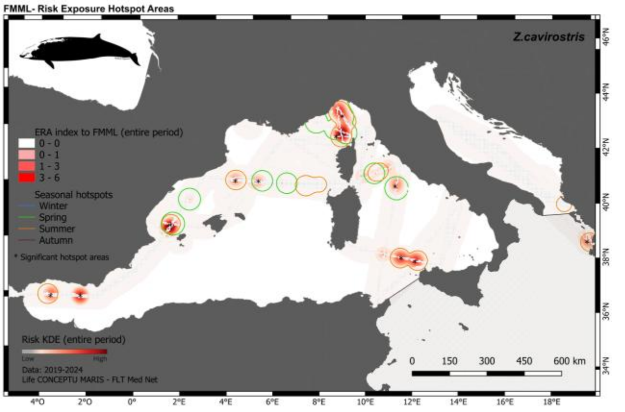
Grampus griseus



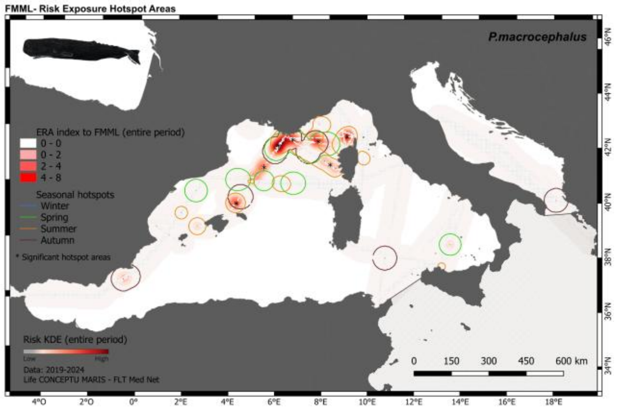
Globicephala melas



Ziphius cavirostris



Physeter macrocephalus



Caretta caretta

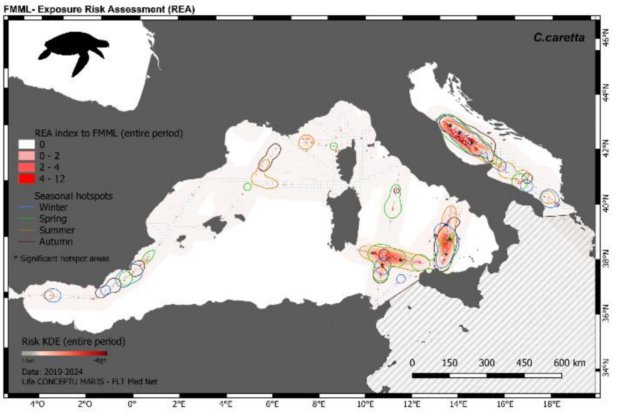


Figure 6.1.5. Hotspot areas of exposure to Floating Marine Macro Litter (FMML) for each cetacean species over the study period (2019–2024). Background shading shows raw Risk Exposure Assessment (REA) values, with the Kernel Density Estimator (KDE) risk output indicating areas of intensified risk. Contours represent seasonal hotspots above the 90th percentile; when contours are not visible, it indicates that the 90th percentile could not be determined, likely due to low or zero density values; asterisks mark statistically significant clusters of high values within 25 km (Getis-Ord Gi, p < 0.05).

6.2 High Risk Exposure Areas to Maritime Traffic

SUMMARY ON MAIN RISK EXPOSURE AREAS TO ALL MARITIME TRAFFIC FOR CEPTU SPECIES

The analysis of species-specific and cumulative exposure to maritime traffic (2019–2024) reveals clear spatial risk patterns across the Mediterranean, shaped by the overlap of observed species encounter rates with maritime traffic intensity from AIS data.
The **Alboran Sea and Strait of Gibraltar** clearly stand out as **the most critical high-risk exposure areas** for all CEPTU groups, both cetaceans (including rare species) and sea turtles (*Caretta caretta*). These areas show consistently high exposure levels throughout the year, confirmed by multiple analysis (Risk Exposure Assessment (REA) and Kernel Density Estimation values of REA index). The results highlight not only a strong overlap between species presence and human pressures, but also statistically significant risk high-exposure areas, making these zones priorities for conservation.

Among **all cetaceans**, additional seasonal hotspots are observed along the **southern Spanish corridor** and within the **Pelagos Sanctuary**, especially during spring and summer.

For **low-density cetaceans** (*Z. cavirostris, G. melas, G. griseus*), exposure is **more geographically limited** but still centers on the **Alboran–Gibraltar region**. Additional, more localised hotspots appear in **northern Pelagos sanctuary**, **off Savona**, and **near the Bonifacio Strait**, especially during spring and summer.

For ***Caretta caretta***, exposure is strongest in the **Adriatic Sea**, especially in the **central-northern sector**, with seasonal hotspots extending along the **Apulian and Greek coasts**. An additional seasonal hotspot emerges **off the Gulf of Tunis** during autumn-winter, likely driven by both intense traffic and ecological relevance for pelagic adults, particularly in these seasons.

While based on all maritime traffic, a separate analysis of passenger vessels reveals partially distinct patterns, with reduced exposure in the Alboran Sea and higher exposure in the Pelagos Sanctuary, Tyrrhenian Sea, Balearic ferry corridors, and the Adriatic (notably for *C. caretta and T. truncatus*).

In conclusion, t**he Alboran–Gibraltar region** stands out as the most consistent and statistically significant multispecies exposure hotspot to all maritime traffic in the Mediterranean. **The Adriatic Sea** represents another key risk area, especially for sea turtles. Additional risk in the Western Mediterranean are generally weaker, species-specific, and more seasonally variable, reflecting the influence of species mobility and the dynamic nature of maritime traffic. However, when the analysis is rescaled by traffic type, as in the case of **passenger vessels**, higher exposure levels are revealed for several species in areas such as the **Pelagos Sanctuary, the Balearic corridor, and the Tyrrhenian Sea**.

Summary for policymakers: Key Risk Areas from Maritime Traffic for CEPTU Species (2019–2024)
Recent analysis of species-specific and cumulative exposure to maritime traffic across the Mediterranean (2019–2024) identifies clear high-risk zones for both cetaceans and sea turtles, shaped by the overlap between species presence and shipping activity (based on AIS data).
The Alboran Sea and Strait of Gibraltar emerge as the most critical and consistent exposure hotspots for all CEPTU groups, including rare cetaceans and sea turtles like *Caretta caretta*. These areas show high exposure levels year-round and are strongly supported by multiple risk assessment methods. They should be treated as top priorities for conservation action.
Seasonal hotspots also appear:

- Along the **southern Spanish coast** and within the **Pelagos Sanctuary** (especially in spring and summer) for several cetacean species.

- For low-density cetaceans (e.g., *Ziphius cavirostris*, *Globicephala melas*, *Grampus griseus*), risk is more localized, mainly around the Alboran–Gibraltar region, and seasonally in parts of the northern Pelagos, off Savona, and near the Bonifacio Strait.
- For **sea turtles**, the **central-northern Adriatic** is the main risk zone, with additional seasonal exposure along the Apulian and Greek coasts, and off the **Gulf of Tunis** during autumn and winter, likely due to ecological importance for adult turtles in these areas.

When looking specifically at **passenger vessel traffic**, patterns shift slightly:

- **Lower risk** is seen in the Alboran Sea.
- **Higher exposure** is found in the **Pelagos Sanctuary**, **Tyrrhenian Sea**, **Balearic ferry corridors**, and parts of the **Adriatic**—particularly relevant for *Caretta caretta* and *Tursiops truncatus*.

Implication for mitigation:

- **The Alboran–Gibraltar region** is the most critical multispecies exposure hotspot and should be a top conservation priority.
- **The Adriatic Sea** is a key risk zone, especially for sea turtles.
- Other areas, such as the **Pelagos Sanctuary**, show **seasonal and species-specific exposure**, requiring targeted and adaptive management.
- **Traffic type matters:** policy measures should consider vessel categories (e.g., passenger vs cargo) to more effectively mitigate risks.

All maritime Traffic Risk for all cetacean species

For all cetaceans' species, the most persistent risk hotspots with maritime traffic are located in the **Alboran Sea** along the Spanish coastline, and within the Strait of Gibraltar, where both Risk Exposure Assessment (REA) index values and the Kernel Density Estimator (KDE) intensities are the highest (Figure 6.2.1). These areas also include multiple statistically significant clusters of high values, indicating consistent exposure across all seasons. Additional seasonal hotspots are visible along the southern part of the Spanish migratory corridors. Another hotspot, though more localized and less intense, is found along the French coast near the commercial port of Toulon. In the Pelagos Sanctuary area, seasonal hotspots emerge mainly during spring and summer. In the Adriatic Sea, non-significant but recurring seasonal hotspots are observed, more northerly in winter and autumn, and shifting southward along the Apulian and Greek coasts during spring and summer.

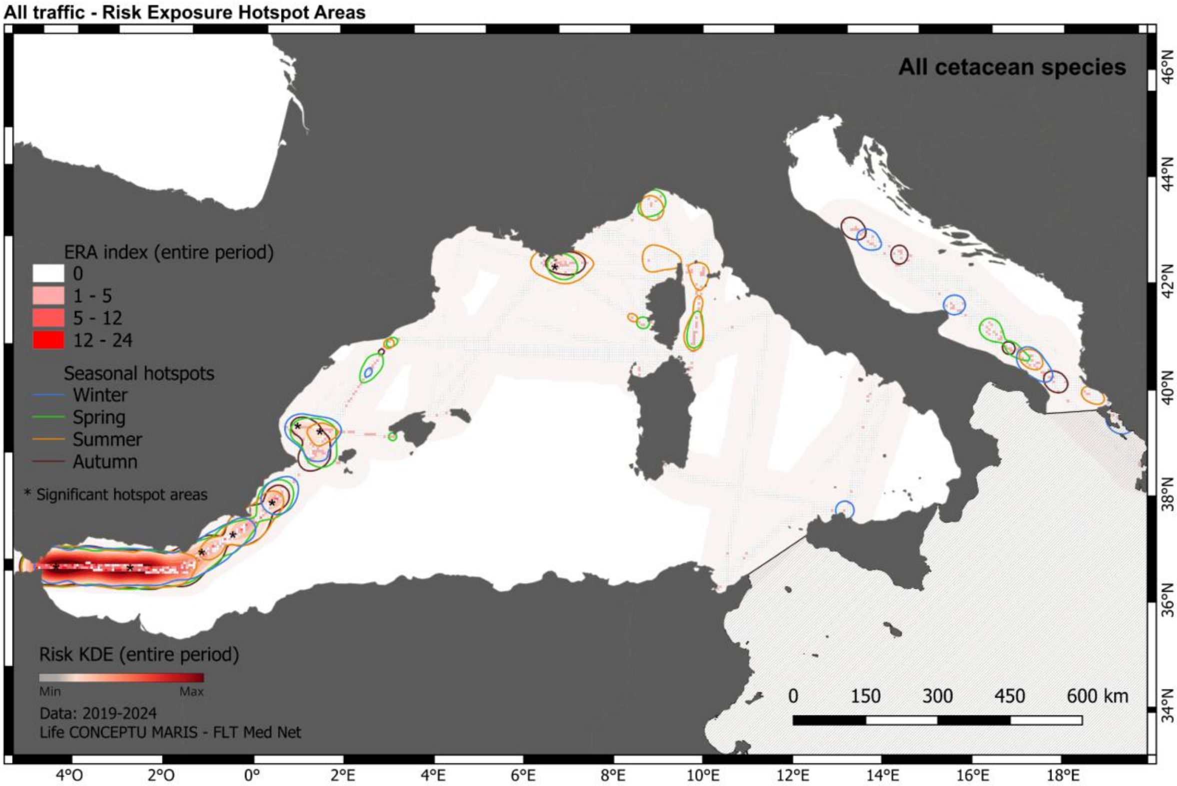


Figure 6.2.1. Hotspot areas of cumulative exposure to All Maritime Traffic for all cetacean species over the study period (2019–2024). Background shading shows raw Risk Exposure Assessment (REA) values, with Risk of the Kernel Density Estimator (KDE) output indicating areas of intensified risk. Contours represent seasonal hotspots above the 90th percentile, while asterisks mark statistically significant clusters of high values within 25 km (Getis-Ord Gi, $p < 0.05$).

All maritime Traffic Risk for low-density cetaceans

The focus on low-density species indicates that, although the Alboran Sea, the Strait of Gibraltar, and the southern Spanish migratory corridor consistently emerge as the highest-risk areas from maritime traffic, reflecting the patterns shown in Figure 6.2.1, overall exposure for these species is less spatially concentrated and more geographically restricted, though still relevant. **The Alboran Sea** remains the primary exposure hotspot throughout the year. Only a few other regions show seasonal contours, mostly during spring and summer, in scattered parts of the **Pelagos Sanctuary** and near the **Strait of Bonifacio**, or in the area **off Savona (Italy)** and the **French coast near Toulon** (Figure 6.2.2). However, these areas do not display statistical significance in the year-round cluster analysis, indicating that the associated risk is limited to specific seasons.

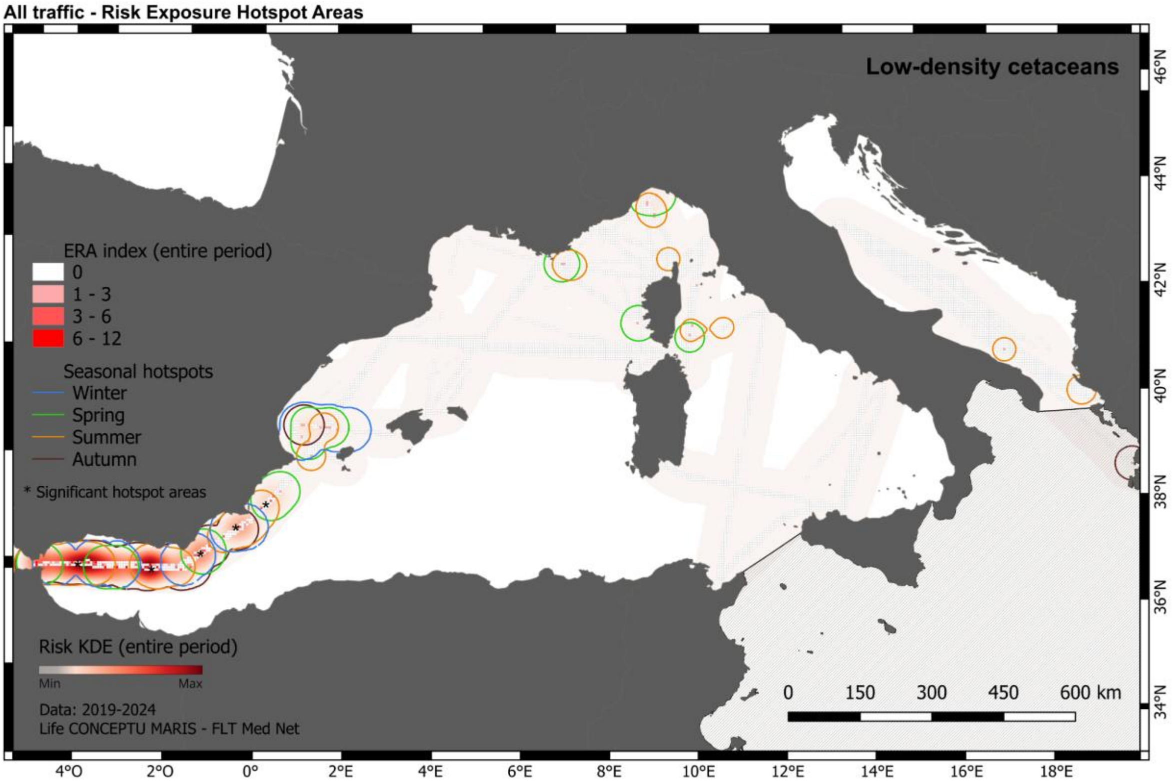


Figure 6.2.2. Hotspot areas of cumulative exposure to All Maritime Traffic for Low-density cetaceans (*G.griseus, G.melas, Z.cavirostris*) over the study period (2019–2024). Background shading shows raw Risk Exposure Assessment (REA) values, with the Kernel Density Estimator (KDE) output indicating areas of intensified risk. Contours represent seasonal hotspots above the 90th percentile, while asterisks mark statistically significant clusters of high values within 25 km (Getis-Ord Gi, $p < 0.05$).

All maritime Traffic Risk for Sea turtles

The most prominent exposure areas are once again the **Alboran Sea and the Strait of Gibraltar**, followed by the **Adriatic Sea** (Figure 6.2.3). In the Adriatic, statistically significant hotspots are located mainly in the central-northern sector, while seasonal hotspots are distributed across the entire surveyed area. An additional noteworthy seasonal hotspot appears **off the Gulf of Tunis**, larger in winter and more confined in autumn. This pattern is expected, as the area lies along a major maritime route connecting the western and eastern Mediterranean basins, and is also ecologically important for *Caretta caretta*, particularly for pelagic adult individuals, in line with SDM-based results.

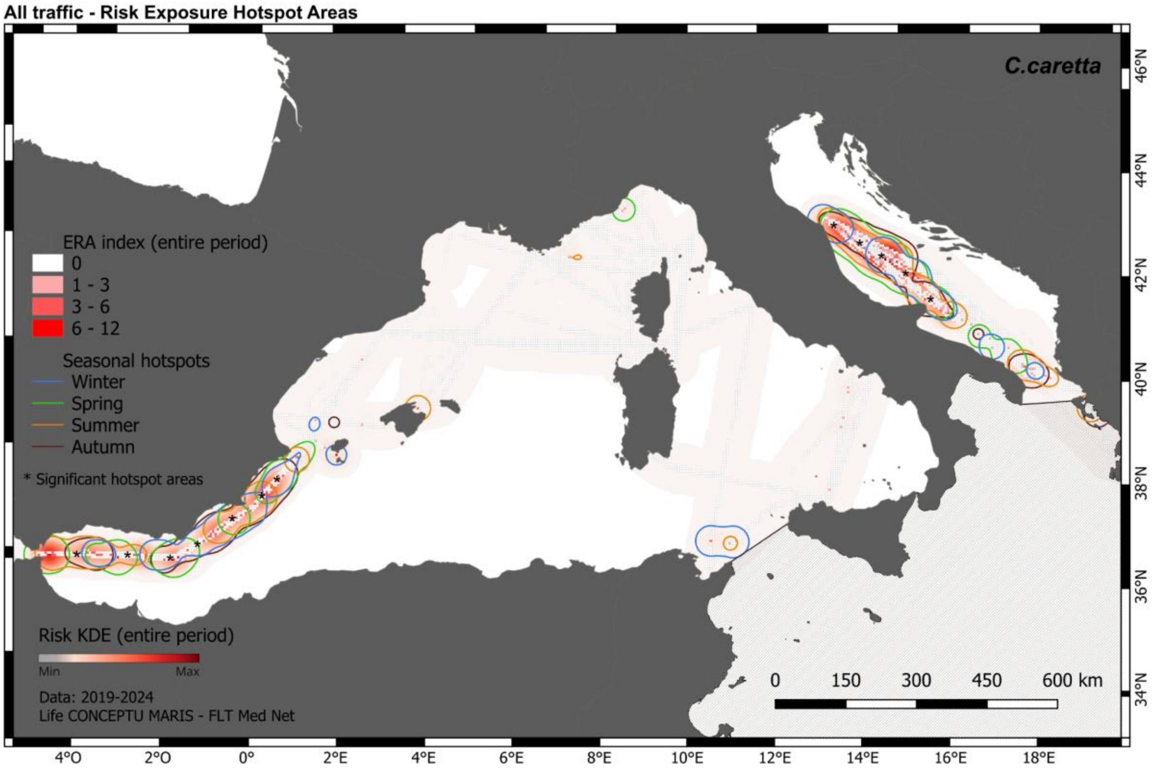


Figure 6.2.3. Hotspot areas of exposure to All Maritime Traffic for Sea turtles (*Caretta caretta*) over the study period (2019–2024). Background shading shows raw Risk Exposure Assessment (REA) values, with the Kernel Density Estimator (KDE) output indicating areas of intensified risk. Contours represent seasonal hotspots above the 90th percentile, while asterisks mark statistically significant clusters of high values within 25 km (Getis-Ord Gi, p < 0.05).

All maritime Traffic Risk for all CEPTU species

The cumulative risk exposure analysis to all maritime traffic for CEPTU species (cetaceans and *Caretta caretta*) revealed spatial patterns driven by both species' distributions and vessel activity across the Mediterranean. The **Alboran Sea** and the **Strait of Gibraltar** consistently emerge as the most prominent and statistically significant high-risk areas, highlighted by elevated Risk Exposure Assessment (REA) index values, intense Kernel Density Estimator (KDE) outputs, and overlapping seasonal hotspots, as evident from previous maps. This pattern is visible across all groups, cetaceans, turtles, and their combination, underscoring the ecological and navigational importance of this region.

In the **Adriatic Sea, particularly due to *C. caretta*,** high Risk Exposure Assessment (REA) values and multiple significant hotspots are concentrated in the central-northern sector, while seasonal hotspots extend further south along the Puglia and Greek coasts. When cetaceans and turtles are considered together, this Adriatic risk relevance remain visible, although overall intensity appears slightly diffused compared to single-species/groups maps.

Overall, the CEPTU cumulative risk map reflects a synthesis of species patterns: the Alboran–Gibraltar region stands out as a persistent multispecies exposure hotspot, while other risk areas appear more fragmented and season-dependent, shaped by the mobility of species and the dynamic footprint of maritime traffic.

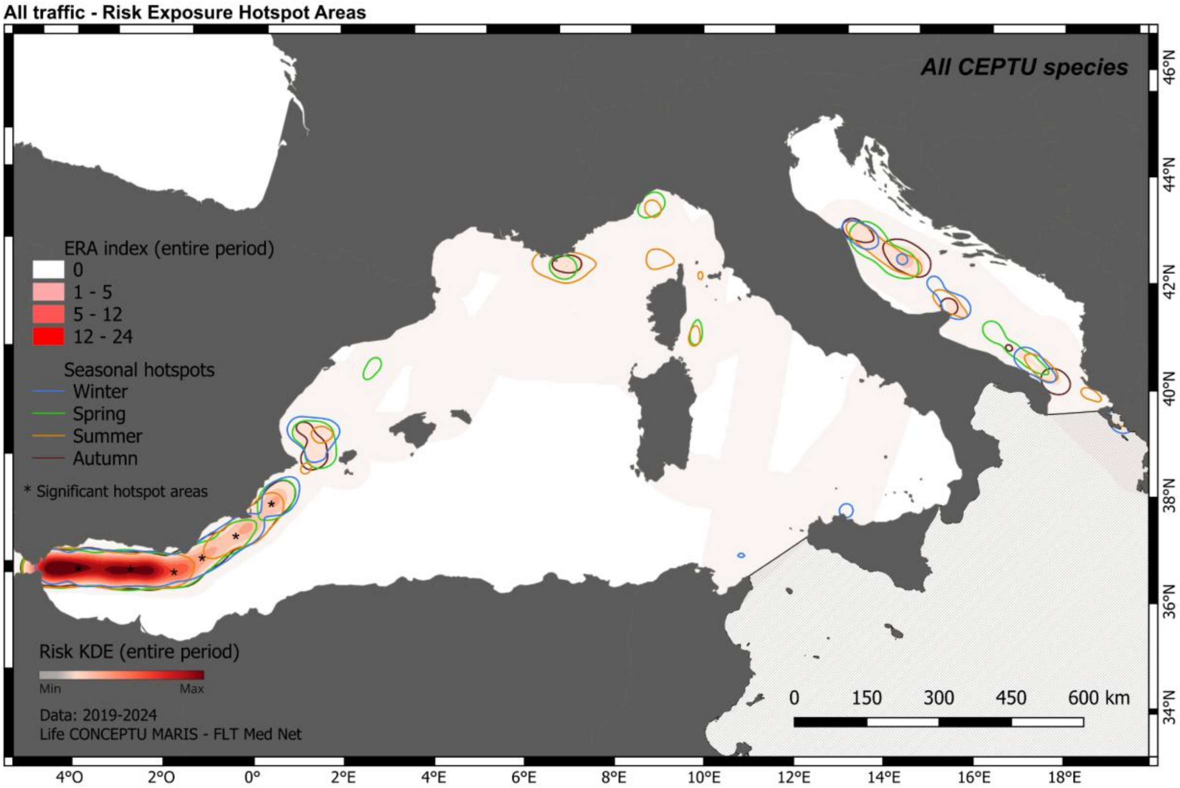


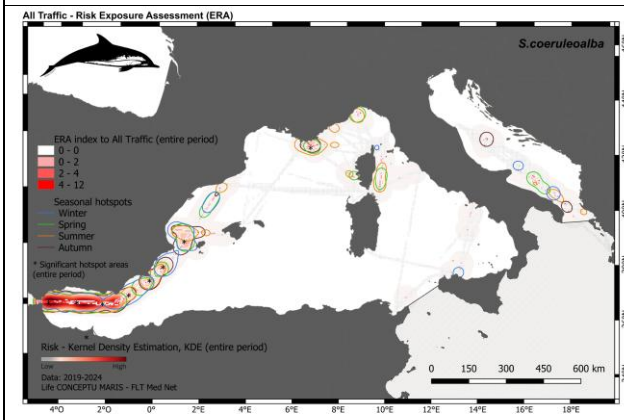
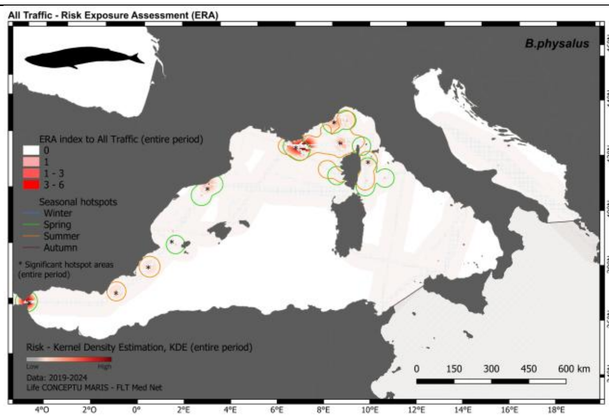
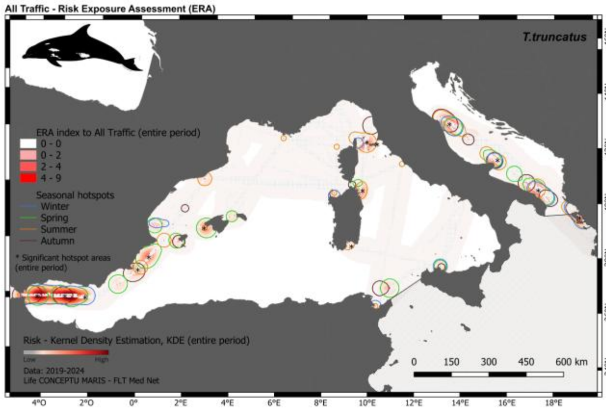
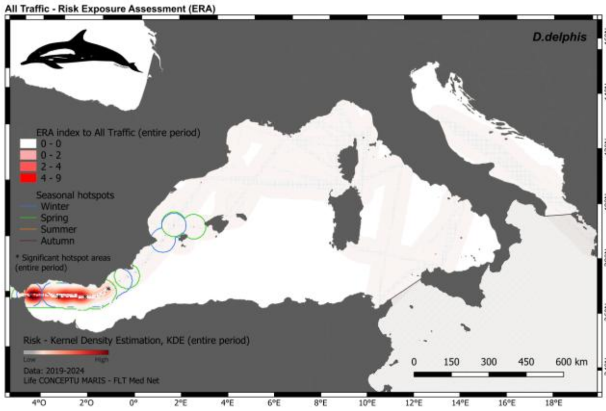
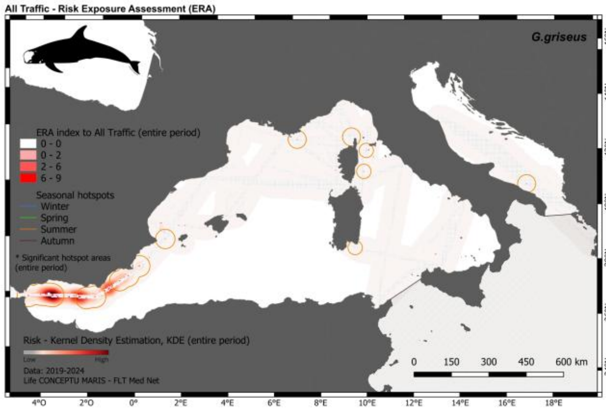
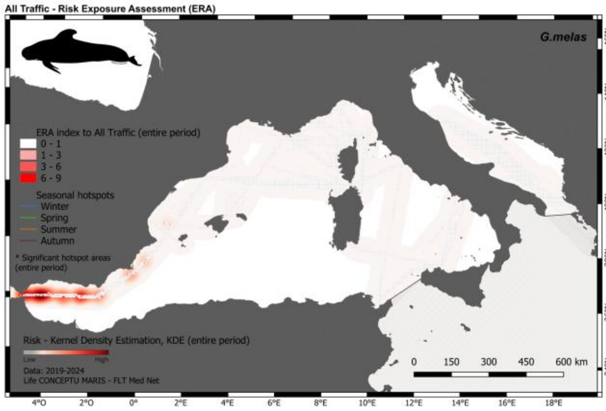
Figure 6.2.4. Hotspot areas of cumulative exposure to All Maritime Traffic risk for all CEPTU species over the study period (2019–2024). Background shading shows raw Risk Exposure Assessment (REA) values, with KDE output indicating areas of intensified risk. Contours represent seasonal hotspots above the 90th percentile, while asterisks mark statistically significant clusters of high values within 25 km (Getis-Ord Gi, $p < 0.05$).

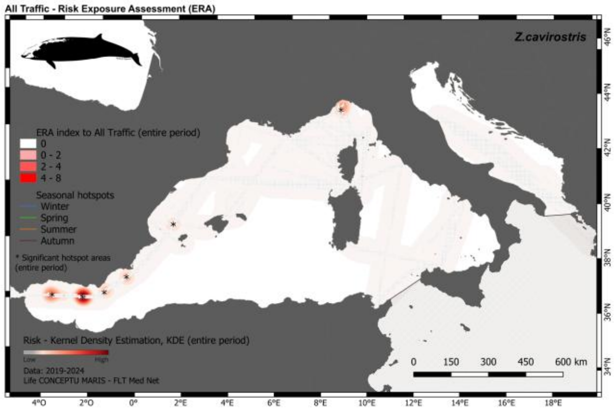
Cetacean Specie-specific Risk Exposure Assessment to All Traffic

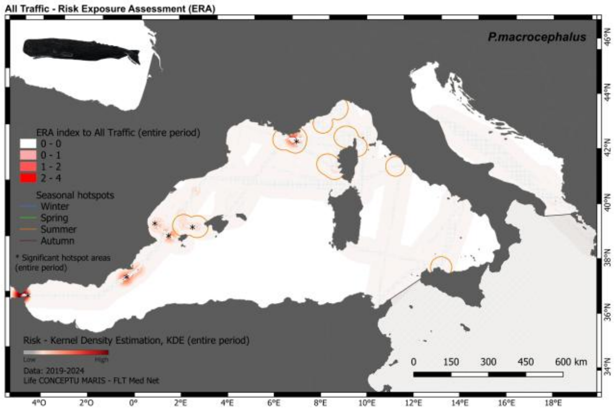
While the Alboran Sea clearly emerged as a key hotspot in the overall cetacean group analysis, the species-specific assessments provide additional spatial detail (Figure 6.2.5). By rescaling the analysis to individual species, other relevant exposure areas become evident, some of which may be masked in the cumulative maps. These insights highlight the value of disaggregating risk patterns, revealing distinct seasonal hotspots and region-specific vulnerabilities that vary considerably among species.

While species like *Delphinus delphis, Globicephala melas, Grampus griseus, and Stenella coeruleoalba* are mostly exposed in the Alboran Sea, other species are exposed in broader or more spatially distinct areas. For example, the *Balaenoptera physalus* is exposed not only in the Strait of Gibraltar, but also along the French and Italian coasts, particularly in the Ligurian-Provençal Basin and the northern Tyrrhenian Sea, especially during spring and summer. Additional seasonal exposure is observed off Barcelona in spring, as well as in the Alboran Sea.
Ziphius cavirostris is exposed in both the Alboran Sea and the Gulf of Genoa. *Physeter macrocephalus* are primarily exposed in the Strait of Gibraltar, with localized hotspots between mainland Spain and the Balearic Islands, especially during summer. Other exposure zones include off the coast of Toulon, the Ligurian-Provençal Basin, the northern Tyrrhenian Sea, and off Palermo.
Tursiops truncatus is exposed not only in the Alboran Sea, but also around the Balearic Islands, northern Sardinia, and northern Corsica, overlapping with Natura 2000 sites designated for this species. Additional seasonal clusters of exposure are evident in the Adriatic Sea throughout the year, as well as in the Gulf of Corfu.

These results confirm the need also for species-specific and area-based management approaches, as the degree and timing of exposure to maritime traffic may vary significantly among species.

<table>
<tr><td>Stenella coeruleoalba</td><td>Balaenoptera physalus</td></tr>
<tr><td>
</td><td>
</td></tr>
<tr><td>Tursiops truncatus</td><td>Delphinus deplphis</td></tr>
<tr><td>
</td><td>
</td></tr>
<tr><td>Grampus griseus</td><td>Globicephala melas</td></tr>
<tr><td>
</td><td>
</td></tr>
<tr><td>Ziphius cavirostris</td><td>Physeter macrocephalus</td></tr>
</table>





Caretta caretta

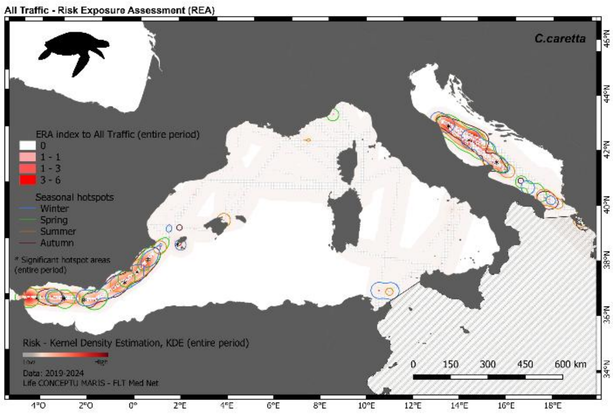


Figure 6.2.5. Hotspot areas of exposure to All Maritime Traffic for each cetacean species over the study period (2019–2024). Background shading shows REA values, with the KDE risk output indicating areas of intensified risk. Contours represent seasonal hotspots above the 90th percentile; when contours are not visible, it indicates that the 90th percentile could not be determined, likely due to low or zero density values; asterisks mark statistically significant clusters of high values within 25 km measured over the entire period (Getis-Ord Gi, p < 0.05).

Specie-specific Spatial Risk Exposure Assessment to Passenger Traffic only

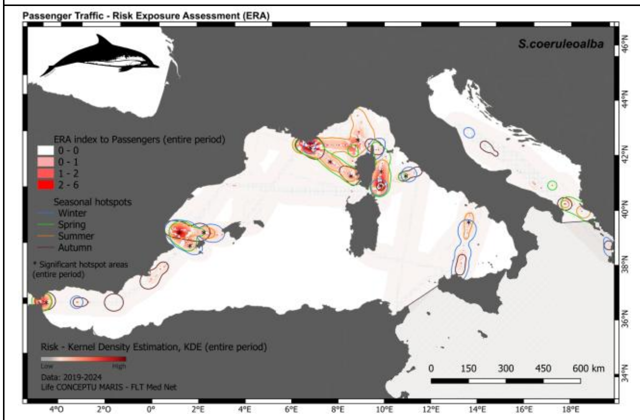
To also evaluate the highest exposure risk from passenger vessels for large and medium-sized cetaceans (*B.physalus, P.macrocephalus, Z.cavirostris, G.griseus, G.melas*) as well as for smaller delphinids (*Stenella coeruleoalba, Delphinus delphis, Tursiops truncatus*) and the sea turtle *Caretta caretta*, a species-specific spatial analysis was conducted to identify the areas most affected by this specific category of maritime traffic (Figure 6.2.6).

The species-specific maps highlight marked differences in spatial exposure patterns to passenger vessel traffic for different species. Overall, the Alboran Sea shows a reduced level of exposure under passenger traffic, losing importance compared to total traffic patterns. In contrast, other areas such as the **Pelagos Sanctuary** (for *P. macrocephalus, S. coeruleoalba, G. griseus, T. truncatus, Z. cavirostris, B. physalus*), **the Tyrrhenian Sea** (for *C. caretta, Z. cavirostris, B. physalus*), and **the Balearic ferry routes** (for *D. delphis, Z. cavirostris, S. coeruleoalba, G. griseus, T. truncatus, P. macrocephalus*), and the **Adriatic Sea** (for *C. caretta* and *T. truncatus*) emerge as key exposure zones under passenger traffic. At the same time, the Alboran Sea and the Strait of Gibraltar remain important exposure areas for certain species, particularly *G. melas, G. griseus, D. delphis, P. macrocephalus, S. coeruleoalba, and T. truncatus*, albeit at lower exposure levels compared to total traffic patterns.

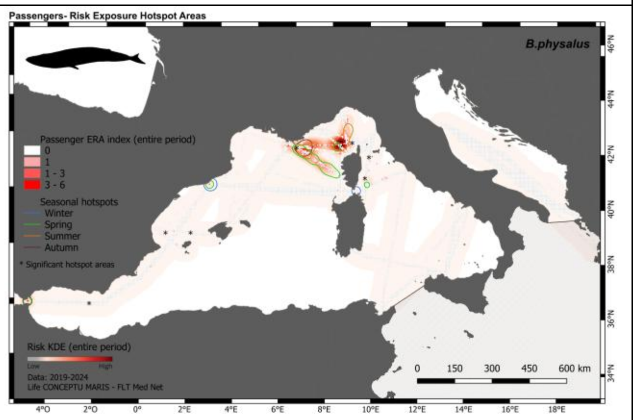
In the case of *Caretta caretta*, the passenger traffic-specific assessment confirms the Adriatic Sea as a primary area of exposure. Interestingly, however, the Tyrrhenian Sea, rather than the Alboran, emerges as the second most relevant zone.

These refined spatial patterns support a more targeted understanding of species-specific vulnerabilities to specific traffic activity, essential for assessing and mitigating the impacts of maritime traffic.The spatial patterns derived here are also used to inform the discussion on observed Near Miss Events (NMEs) recorded by the FLT Med Network (see Section 6.3) on board ferries (passengers) with regard to large-medium cetaceans.

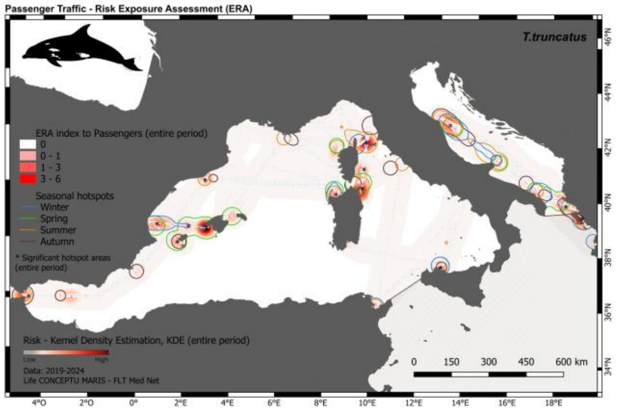
Stenella coeruleoalba



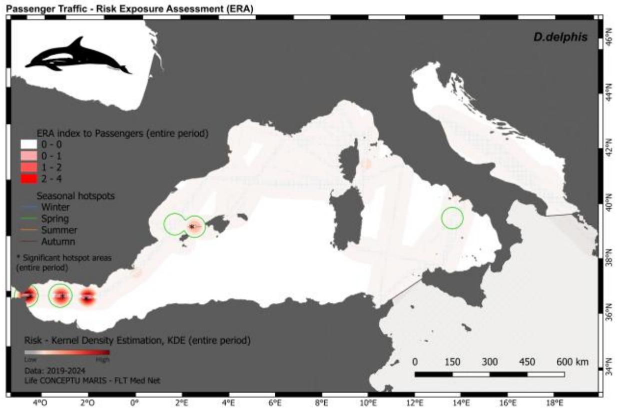
Balaenoptera physalus



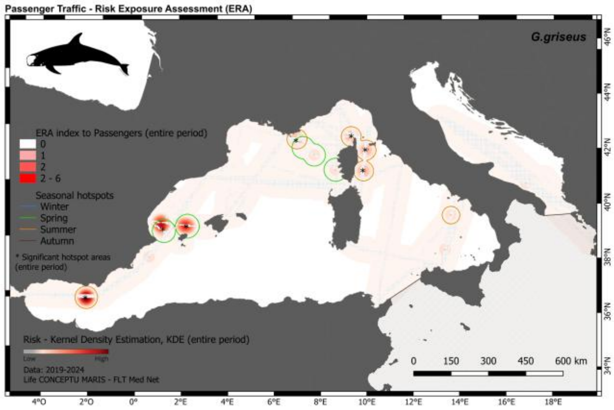
Tursiops truncatus



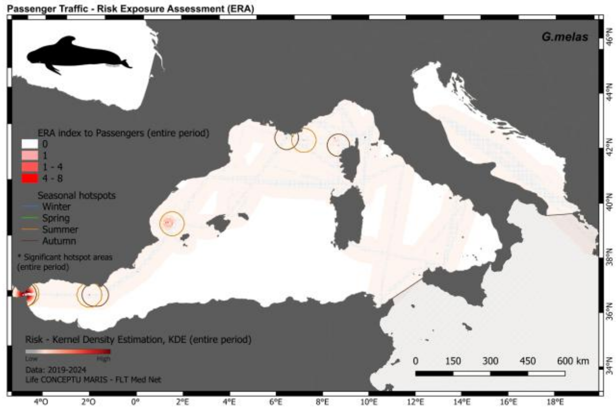
Delphinus deplphis



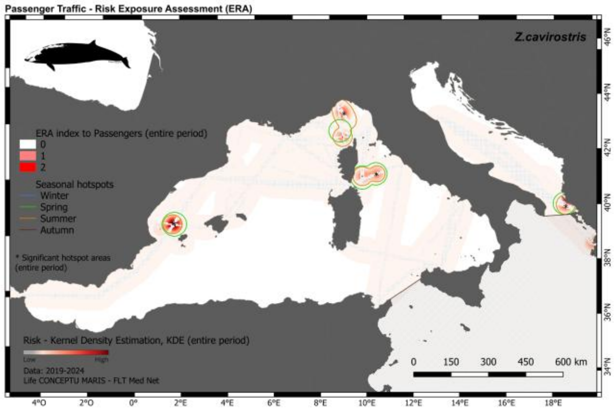
Grampus griseus



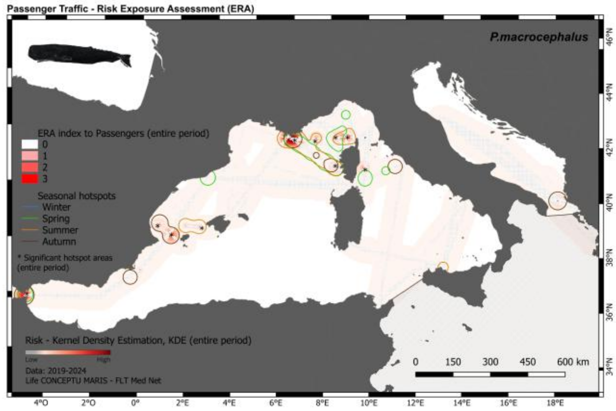
Globicephala melas



Ziphius cavirostris



Physeter macrocephalus



Caretta caretta

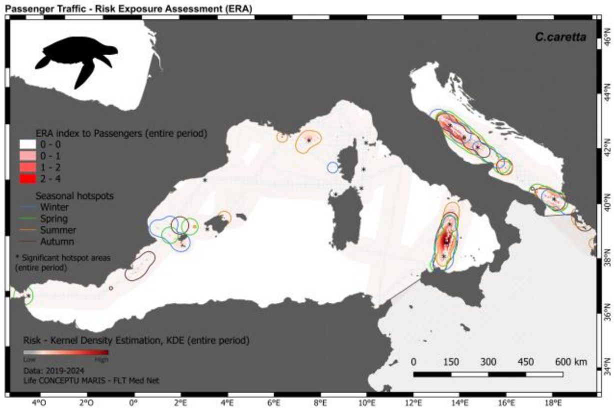


Figure 6.2.6. Results of the Risk Exposure Assessment (REA) to passenger traffic for all species over the entire study period. The background shows the Kernel Density Estimation (KDE) of the exposure index (cumulative), while contours represent the 90th percentile of seasonal kernels (95th just for Dd, Gm, Gg, Zc, Pm). The risk index refers to the full period (2019–2024). Statistically significant clusters of high values within 25 km identified by the Getis-Ord Gi* analysis ($p < 0.05$) are marked with an asterisk (*).

6.3 Near Miss Event

TECHNICAL SUMMARY: Near Miss Event definition has been chosen to be very close to the ferry so it can be used as a proxy for ship strike, for large and medium species. Since 2008, for 630 000 km in effort and over 4585 sightings of large and medium cetaceans, 101 NME were recorded with 5 different species: 73 with *Balaenoptera physalus*, 10 with *Ziphius cavirostris*, 9 with *Physeter macrocephalus*, 5 with *Globicephala melas* and 4 with *Grampus griseus*.
NME occurred on almost all routes monitored. For *Balaenoptera physalus*, NMEs occurred mainly in the north-western Mediterranean Sea and the NME area through KDE seems stable over summer and winter.
There is a significant correlation (p-value < 0.05) between ER (number of sighting.km-1) and ER of NME, confirming that the more the presence of species, the more the risks. In the meantime, one NME happened in the Sicily channel where the species is rarely seen, leading to the conclusion that the zero risk does not exist. For *Ziphius cavirostris* and *Physeter macrocephalus* the same results appeared, with a correlation of location and number of NMEs with areas and high or medium presence of species, even if it is not highly significant statistically (p-value=0.07) due to the low number of NME. Gathering NME areas of all species highlight the north-western Med Sea as the place where this biodiversity is the most threatened and confirm the importance of the newly designated PSSA. On the other hand, our results highlight also new areas where large and medium cetaceans are at risk: Gibraltar and Alboran Sea, the Balearic channel and the Sicily channel, which is probably linked to the high intensity of maritime traffic.
The reasons for NME cannot easily be linked to initial behaviour of animals, cycle within the day, season, response to the vessel, but Encounter Rate of the species and speed of vessel play a major role. Indeed, within NME only very few were engaged in feeding and resting behaviour, the main of them were traveling or emerging close to the vessel, apparently indifferent to it and escaping it at the end. And at least for *Balaenoptera physalus*, the speed of the ferry appears to be significantly higher for NMEs than for all other sightings.
The maps of the Kernel Density Estimation of the Encounter Rate of observed Near Miss Events match the high Risk Exposure Areas obtained from the analysis with AIS data of passenger vessels with the observed occurrence of the species. Therefore, the observed NME helps to validate the risk maps and approach.

SUMMARY FOR POLICYMAKERS: Near Miss Event

- Overall Status: NMEs occur on almost all routes monitored. The five large and medium species of cetaceans are concerned, mainly *Balaenoptera physalus*, *Physeter macrocephalus* and *Ziphius cavirostris*. NME happens mainly in summer (April to September) but also in winter.
- Geographic Patterns:
    - The whole north-western Mediterranean Sea is the place with the most species threatened, in summer and winter, confirming the importance of the newly designated PSSA.
    - New areas where large and medium cetaceans are at risk were also highlighted: Gibraltar and Alboran Sea, the Balearic channel and the Sicily channel, which is probably linked to the high intensity of maritime traffic.
    - The maps of the observed NME validate the Exposure Risk Analysis approach
- Explanatory factors:
    - NMEs occurred in areas with high and medium Encounter Rate of the species, the two are correlated.
    - The reasons for NME cannot be linked to any specific initial behaviour of animals, nor cycle within the day, season, response to the vessel, as many animals were mainly traveling, emerging close to the vessel, indifferent to it or escaping it, from dawn to evening.
    - Speed of the vessel was significantly higher for NMEs than for sightings for Fin whale.
    - Policy Implications

● The PSSA is the good place and tool to mitigate the ship strikes with large and medium cetacean species if the Associated Measures of Protection are applied by the vessels.
● New areas could benefit from protection through speed reduction like the Balearic channel (between Ibiza and mainland Spain) and the Alboran Sea
● Cross-border collaboration between France, Italy, and Spain is essential to ensure mitigating ship strike risks.
● Continued long-term monitoring of NME is crucial for raising the knowledge, raising awareness of crew, assessing the efficiency of any conservation measures or tool, and informing adaptive management strategies.

Methods. Near Miss Event (NME) is defined when the animal is sighted at a minimum distance of 50 m in front of the bow of the ferry and 25 m on the side, unaware of the approaching ship, so not taking into account species that usually show an approaching behaviour (e.g., bow-riding dolphins). The distances to the ferry have been chosen very close in order to use those NMEs as proxy for ship strike.

Encounter Rate of NME (number of NME.km-1 ; ER_NME) has been calculated per 10x10 km cell. Those values were then used for interpolation using the Kernel Density Estimation (KDE) method (Qgis software via the "Heat Map" module). This method interpolates the known values to estimate the unknown values in other neighboring cells within a smoothing radius Rb (table x) as :

$$Rb = 0.9 * \left(\sqrt[SD]{\frac{1}{ln\ (2)}} * Dm \right) * n^{-0.2}$$

Where :

- Rb= Core bandwidth radius (in m)
- Sd= Standard distance (a single summary measure of the distribution of features around their geometric mean center)
- Dm= Median distance to mean center (distance of each point of observation relative to the barycenter of the points cloud)
- N=number of observations (=number of cells with effort)

The weight assigned to each point is the ER_NME. Sd and Dm are calculated using the "Spatial point pattern analysis" processing tool in QGis.

Table 6.3.1. Results of the calculation of smoothing radius distance for the KDE analysis

	No cells (N)	Radius in meters (Rb)
All seasons	2 059	78 954
Summer	1 794	79 502
Winter	1 571	87 266

The isoline highlighting the areas with ER_NME positive values, obtained by the interpolation, were defined as values > ⅕ of the mean, the rest are values near zero. The NME can imply one animal, barely two, so the comparison has been made with sightings only, not individuals.

Results

Number of NMEs and ratio over sightings: In total, 101 NMEs have been observed during all the surveys, with five different species: the *Balaenoptera physalus*, the *Physeter macrocephalus* the *Ziphius cavirostris*, the *Globicephala melas* and the *Grampus griseus* (table 6.3.1). Most of them (88) happened during the summer (April to September) but still some (13) happened also during winter (November to March). The Fin whale has been seen the most in such events (73 cases over 101), then *Ziphius cavirostris* and *Physeter macrocephalus* were involved 10 and 9 times in NME respectively, whereas the two other species only 5 times (*Globicephala melas*) and 4 times (*Grampus griseus*). Those few events for the two last species will prevent some analysis and results should be taken with caution. Only *Balaenoptera physalus* and *Globicephala melas* were involved in NME in winter.

Table 6.3.2 : Number of Near Miss Events (NME) observed per cetacean's species during summer (April to September) and winter (November to March) per project areas. Bp: *Balaenoptera physalus*, Pm: *Physeter macrocephalus*, Zc: *Ziphius cavirostris*, Gm: *Globicephala melas*, Gg: *Grampus griseus*

Project areas	Summer						Winter		
	km	NME Bp	NME Pm	NME Zc	NME Gm	NME Gg	km	NME Bp	NME Gm
Alboran Gibraltar	4 920	1	1		1		5 275	0	2
Eastern Spanish slope	3 273						4 724	0	
Spanish Cetacean Mitigation	30 660	5	2	2			18 538	0	1
Sard-Balearic seas	50 038	9	2			1	28 347	3	1
Pelagos	232 852	46	4	8		1	56 551	5	
Tyrrhenian	43 492	3				1	16 772	0	
Sardinia Sicily channels	49 312						19 522	1	
Western Ionian	2 146					1	444	0	
Adriatic	25 327						26 650	0	
Eastern Ionian North	7 326						7 959	0	
Total	**449 345**	**64**	**9**	**10**	**1**	**4**	**184 783**	**9**	**4**

The ratio of NME over the number of sightings is between 2% and 3.6% depending on the species, and from 1.1 to 8.3 seasonally (table 6.3.3). If the ratio is very stable between seasons for the *Balaenoptera physalus* around 2%, it is highly different for the *Globicephala melas.*

Table 6.3.3 : Ratio between the number of NME and the total number of sightings for the 5 species, globally and per seasons (summer, from April to September and winter from November to March)

Ratio of NME over total sightings	*Fin whale*	*Sperm whale*	*Ziphius cavirostris*	*Pilot whale*	*Risso's dolphin*
Entire period	2	2.2	3.3	3.6	2.9
summer	2.1	2.6	3.6	1.1	3.7
winter	1.8			8.3	

Encounter rates of NME

Comparing the Encounter Rate of sightings and that of NME per project areas (Fig. 6.3.1) shows a clear correlation between both indices in several areas of the project for the *Balaenoptera physalus*, at both seasons. At least for 4 areas where the species is present and frequent (Spanish cetacean Migratory corridor, Sard-Balearic Seas, Pelagos and Tyrrhenian), and for the areas where the species is almost absent as Adriatic, eastern and western Ionian. On the other hand, two areas show a high ER_NME compared to their ER of *Balaenoptera physalus*, the Alboran-Gibraltar and the Sardinia Sicily channel. Indeed, in Gibraltar, only 2 sightings of *Balaenoptera physalus* were made in summer within the whole period surveyed and one ended as NME whereas in Sicily only one *Balaenoptera physalus* has been encountered, in winter, and this was also a NME. This implies that a NME needs only one animal and one vessel, and the “Zero risk” does not exist.

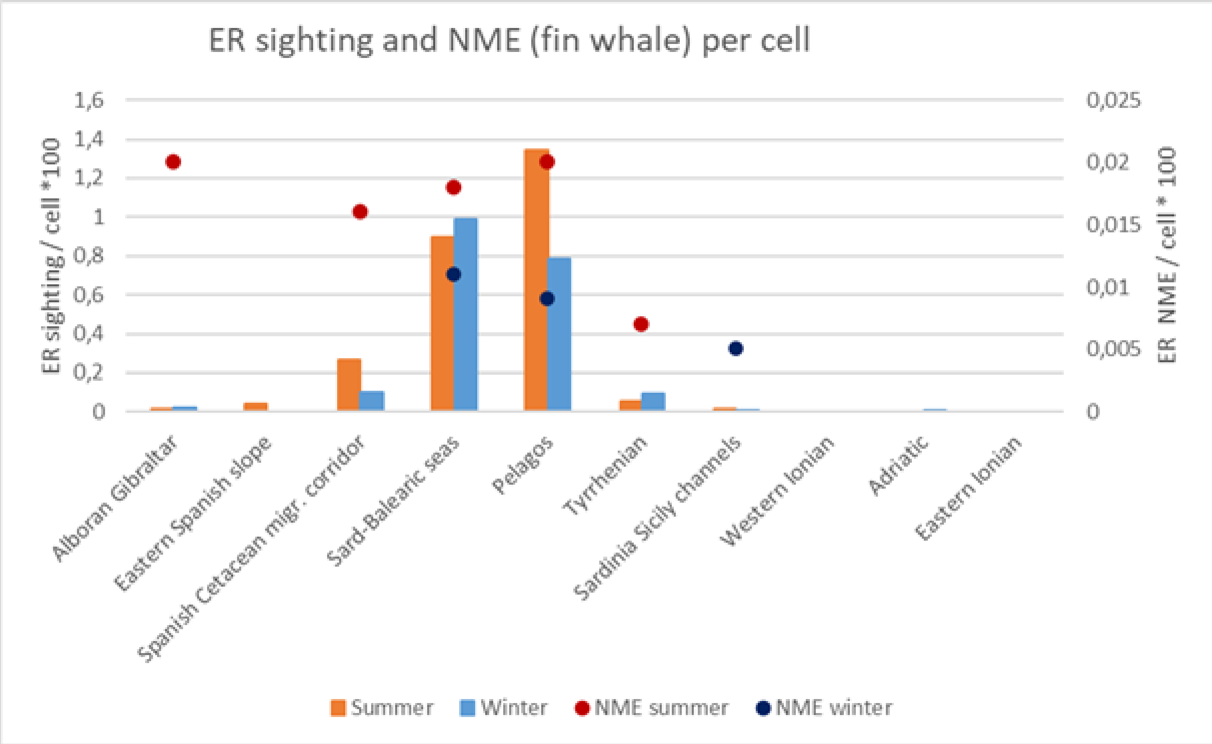


Figure 6.3.1 : Encounter rate of sightings and NME per 100 km for *Fin whale* per project areas and seasons

Indeed, for *Balaenoptera physalus* the correlation between ER and ER_NME is strong (Figure 6.3.2) per project area (r=0.93, p-value> 0.05, Spearman's rank correlation test) as well as per route (N=39, r=0,63, p-value>0.05). Those results stated that the more the abundance of a species within an area, the more the NMEs and subsequently, the higher the risk of ship strike.

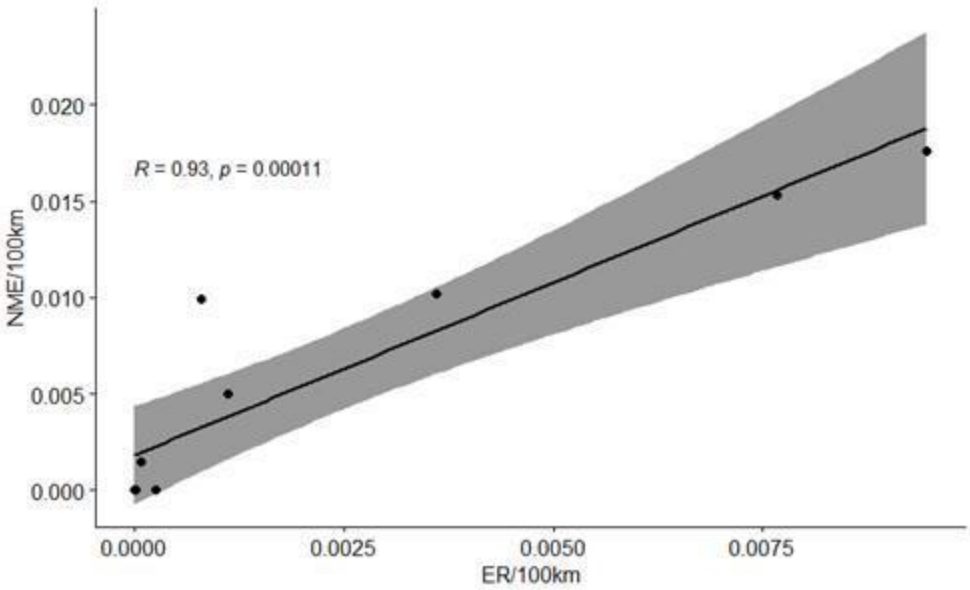


Fig 6.3.2 Correlation between ER and ER_NME for *Balaenoptera physalus* per project areas

For the *Physeter macrocephalus*, NMEs occurred in areas and the season with medium and high presence of the species (Figure 6.3.3, at least 0.35 sighting.100 km-1), but the correlation between ER and ER_NME is not statistically significant per area (Spearman test, S = 68.112, rho= 0.587, p-value = 0.0743). .

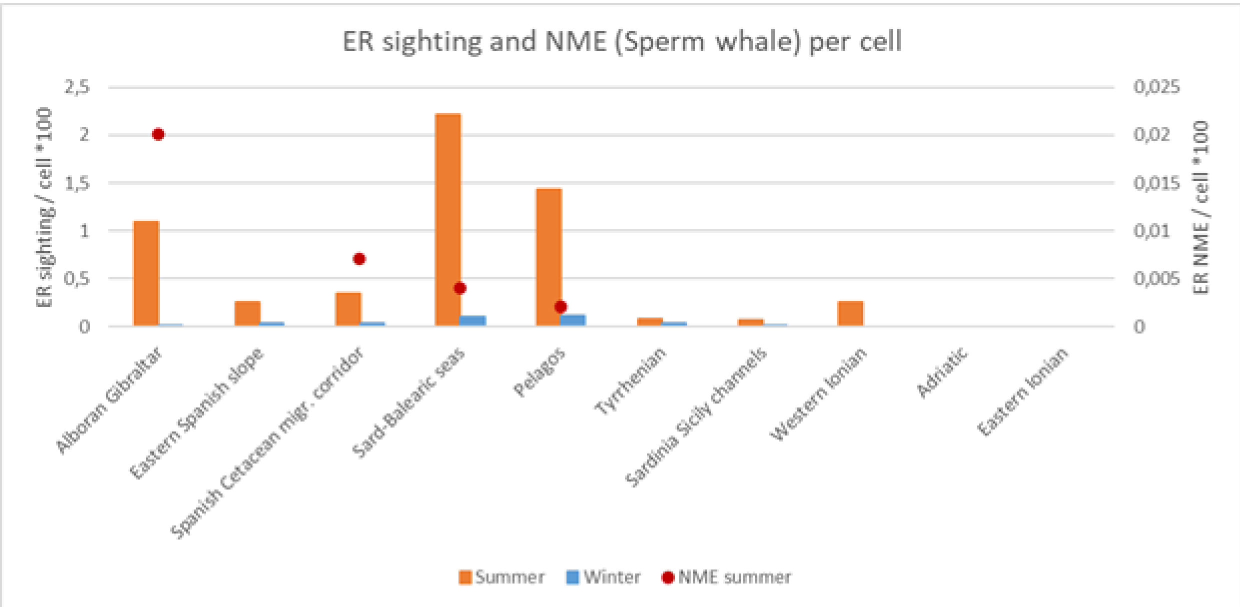


Figure 6.3.3 : Encounter rate of sightings and NME per 100 km for *Physeter macrocephalus* per project areas and seasons

Finally, for *Ziphius cavirostris*, the correlation between ER and ER_NME per area is weak (Spearman, S = 5402.9, r=0.45, p-value = 0.0038), leading to the fact that other factors may raise the risk : intensity of maritime traffic, distribution (Figure 6.3.4).

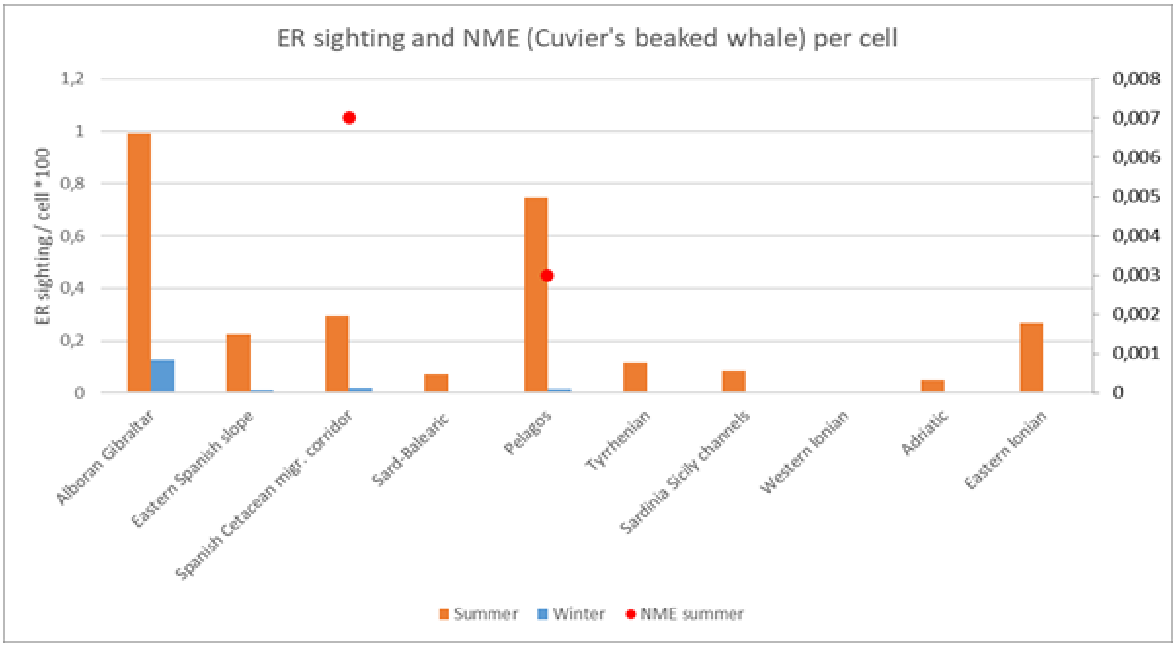


Figure 6.3.4: Encounter rate of sightings and NME per 100 km for *Ziphius cavirostris* per project areas and seasons

The relationship between ER and NME_ER is not obvious for *Grampus griseus* (Figure 6.3.5), whereas it seems obvious for *Globicephala melas* for which the NME happened in the Alboran Sea at both seasons (Figure 6.3.6).

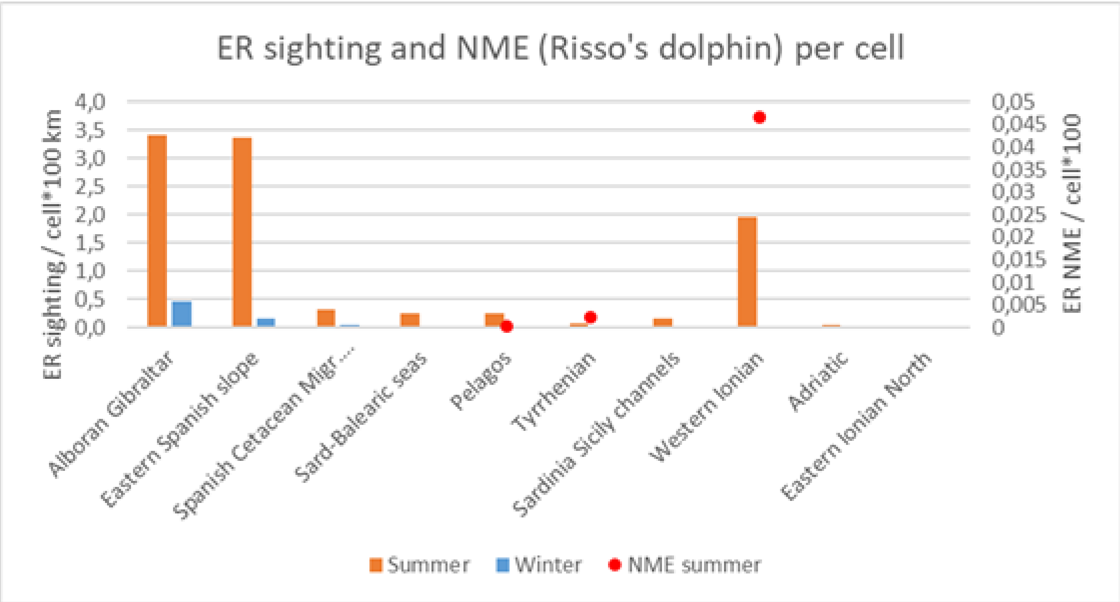


Figure 6.3.5: Encounter rate of sightings and NME per 100 km for *Grampus griseus* per project areas and seasons

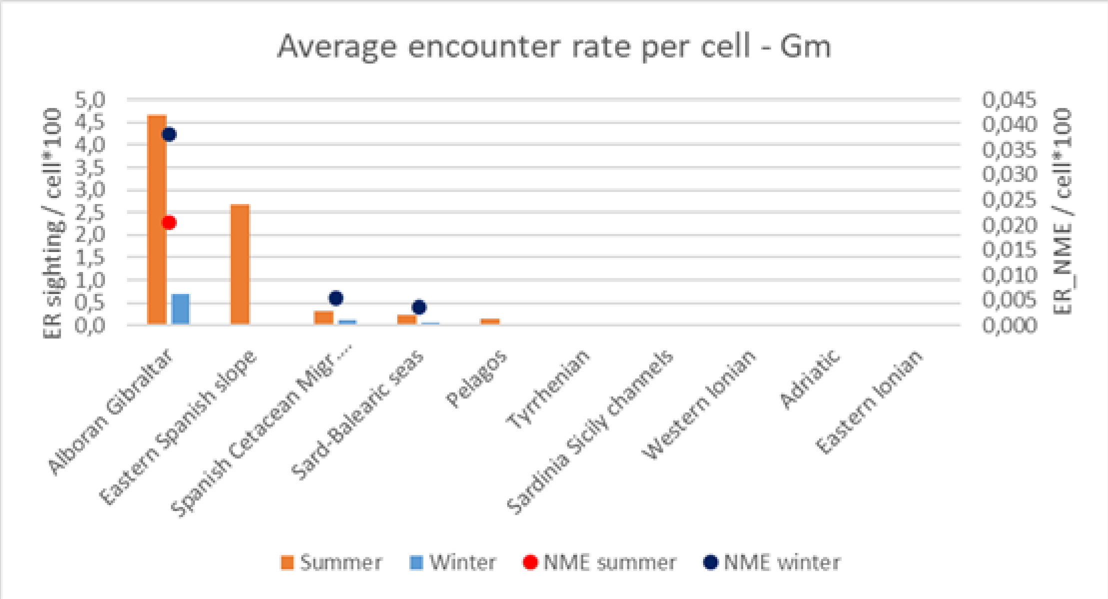


Figure 6.3.6 : Encounter rate of sightings and NME per 100 km for *Globicephala melas* per project areas and seasons

In general, during summertime, a NME with a *Balaenoptera physalus* may occur each 7000 km of travelled distance of a ferry, and for *Ziphius cavirostris* and *Physeter macrocephalus* this distance is 45 000 km and 50 000 km respectively (Figure 6.3.7). More than twice those distances should be travelled to put at risk a *Risso's dolphin* and even more for *Pilot whales*.

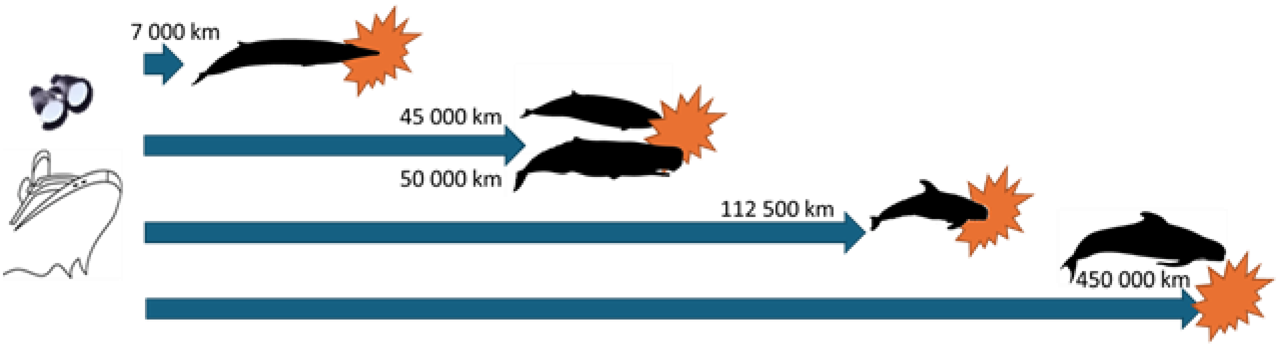


Fig 6.3.7 : Mean travelled distance for a ferry to be involved in a Near Miss Event with cetacean species in the Mediterranean Sea in summertime (April to September). From top to bottom: *Balaenoptera physalus, Ziphius cavirostris, Physeter macrocephalus, Grampus griseus* and *Globicephala melas*.

Distribution and interpolation

The distribution of the NMEs for *Balaenoptera physalus* match clearly the distribution of sightings and are widespread over the area, merely offshore over deep areas (Figure 6.3.8). All routes beyond the shelf had at least one NME, even several, in the north-western Mediterranean Sea. On the other hand, in Gibraltar, only 2 sightings were made in summer and one ended as NME whereas in the Sicily only one *Balaenoptera physalus* has been encountered, in winter, and this was also a NME. This indicates that even if the probability of NMEs are higher in areas where the species is frequent, NME can occur everywhere, and this may probably also depend on the intensity of the maritime traffic at the location.

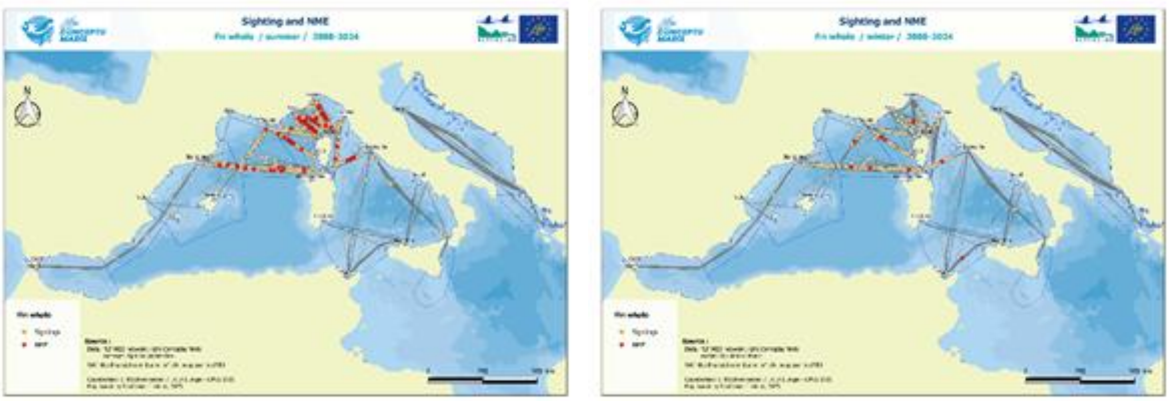
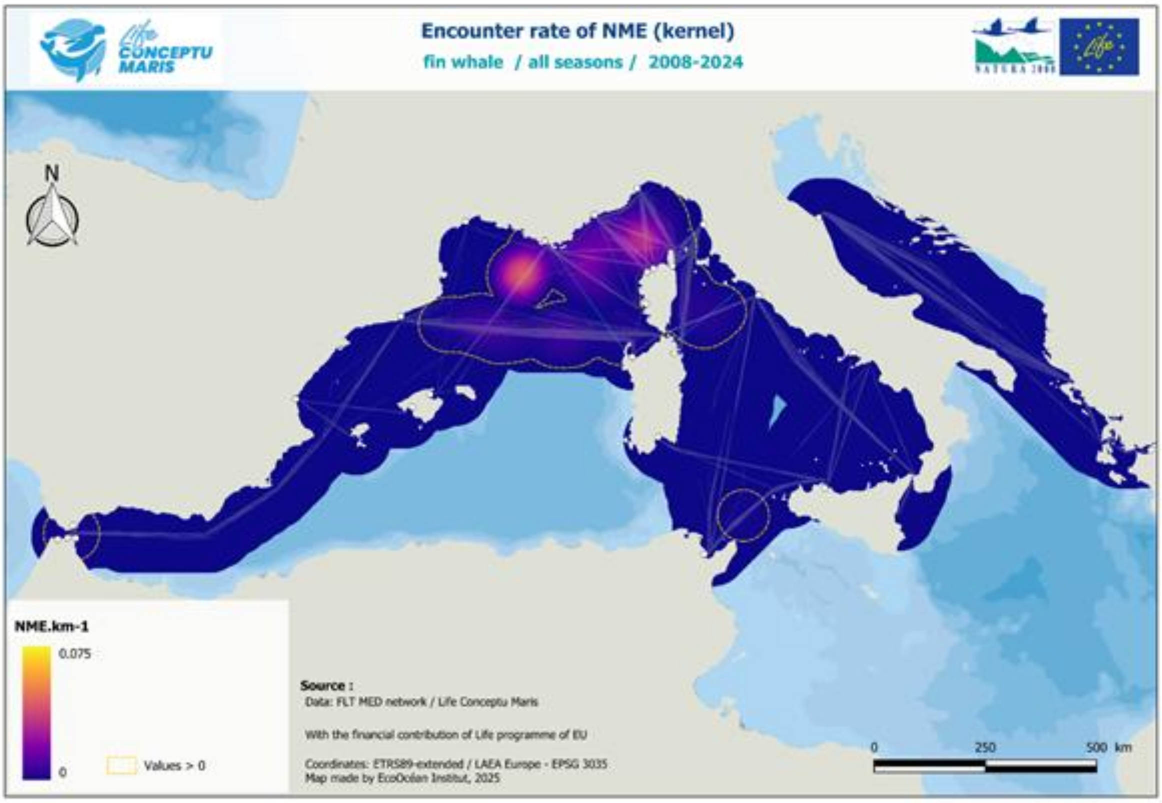


Figure 6.3.8: Distribution of effort, sightings and Near Miss Events of *Balaenoptera physalus* in summer (April to September) and winter (November to March).

The interpolated Encounter Rates of NME maps for *Balaenoptera physalus* (Figure 6.3.9) highlight that the species may be at risk in the entire north-western basin, at both seasons, from the north Tyrrhenian Sea (east of Corsica, Bonifacio Strait) to offshore the gulf of Lion, including the Ligurian Sea. Other hotspots appear in the Strait of Gibraltar (summer) and the Sardinian Sicily channel (winter). The areas highlighted for NME are rather similar in both seasons.



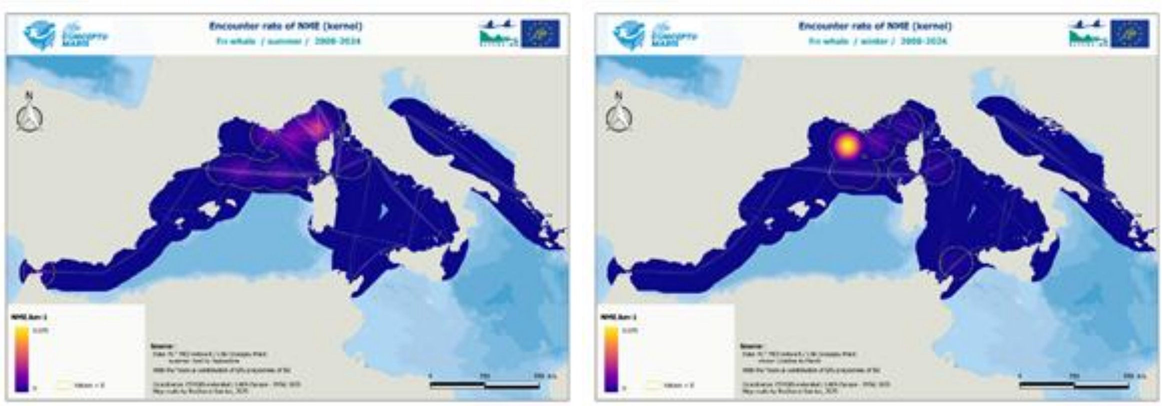


Figure 6.3.9: Kernel interpolated Encounter Rate of Near Miss Events of *Balaenoptera physalus* for the entire period, the summer (April to September) and the winter (November to March).

The NMEs involving *Physeter macrocephalus* (Figure 6.3.10) are located either offshore and over deep areas as in more coastal areas over the continental slope like in the Ligurian Sea, the north Tyrrhenian Sea (east of the Bonifacio Strait) and the Strait of Gibraltar.

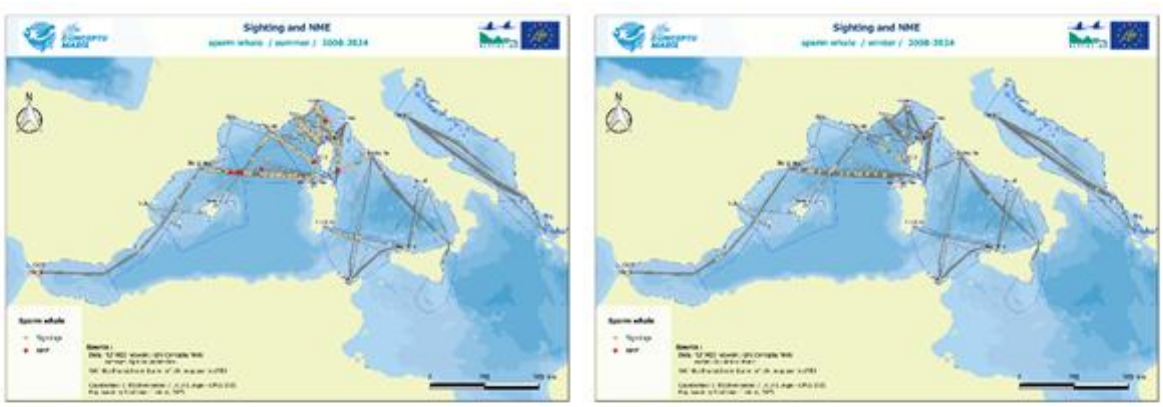


Figure 6.3.10: Distribution of effort, sightings and Near Miss Events of *Physeter macrocephalus* in summer (April to September) and winter (November to March).

The interpolated ER_NME maps for *Physeter macrocephalus* (Figure 6.3.11) show that NMEs occurred more in the north-western Mediterranean Sea, as well as in Gibraltar.

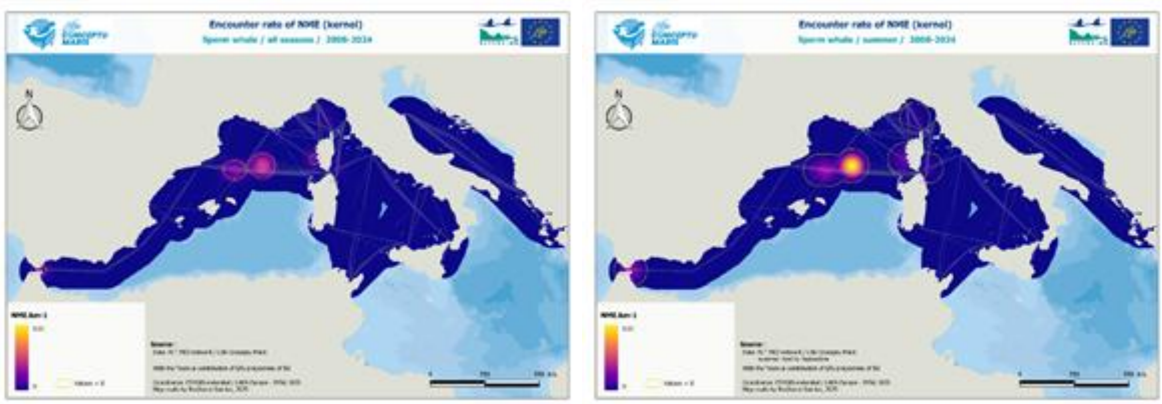


Figure 6.3.11: Kernel interpolated Encounter Rate of Near Miss Events of *Physeter macrocephalus* for the entire period and the summer (April to September).

The *Ziphius cavirostris* NMEs occurred only in summer and were in areas with numerous encounters of the animals. Indeed, many NME occurred in the Ligurian Sea (Figure 6.3.12), then one occurred in the north Tyrrhenian Sea and one along the Spanish continental slope offshore Barcelona. On the other hand, one NME occurred in the strait between the Balearic Island Ibiza and mainland Spain, whereas there are few sightings of the species. This again may indicate that NMEs can occur almost everywhere, even if the probability is higher in areas with more encounters of the species. It may probably depend on the intensity of the maritime traffic too.

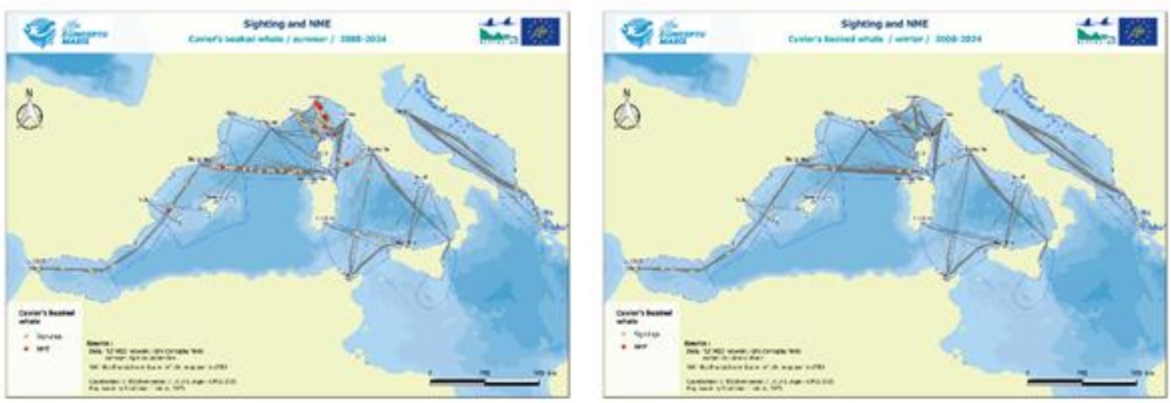


Figure 6.3.12 : Distribution of effort, sightings and Near Miss Events of *Ziphius cavirostris* in summer (April to September) and winter (November to March).

The interpolated ER_NME maps for *Ziphius cavirostris* (Fig 6.3.13) highlighted the Ligurian Sea, north Tyrrhenian Sea and also some parts of the Spanish continental slope.

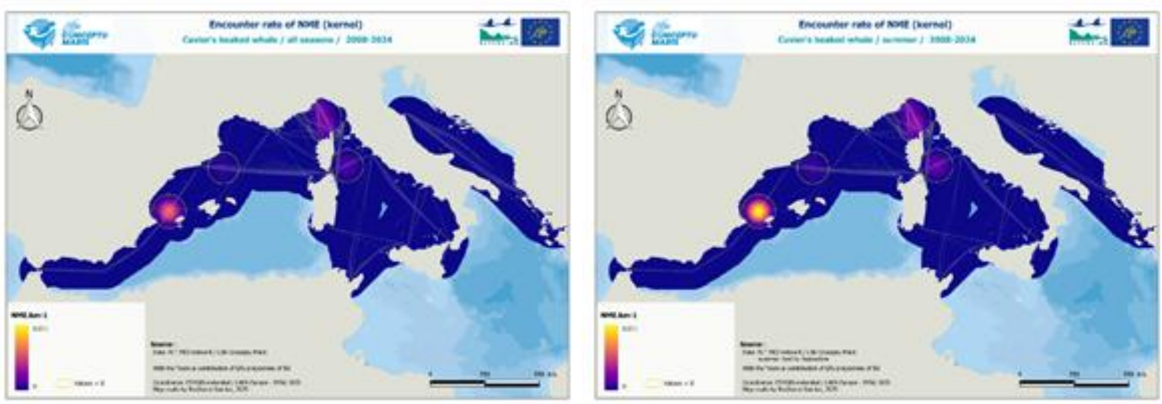


Figure 6.3.13: Kernel interpolated Encounter Rate of Near Miss Events of *Ziphius cavirostris* for the entire period and the summer (April to September).

Globicephala melas NMEs are located (Figure 6.3.14 and Figure 6.3.15) in Gibraltar (summer and winter), and in the Alboran Sea and offshore the gulf of Lion (in winter). Those events happened in areas where there are numerous or few encounters, and until now never occurred in summer in the Pelagos area despite the large number of sightings made there.

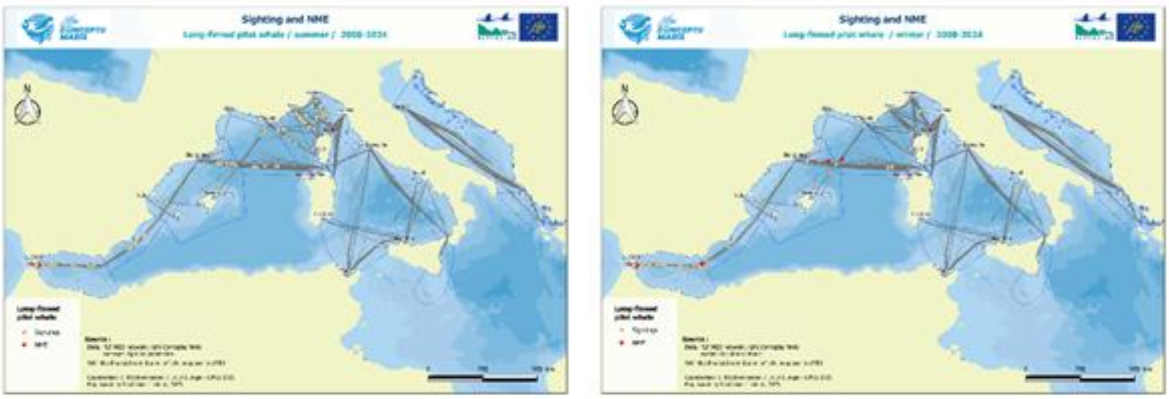


Figure 6.3.14: Distribution of effort, sightings and Near Miss Events of *Pilot whale* in summer (April to September) and winter (November to March).

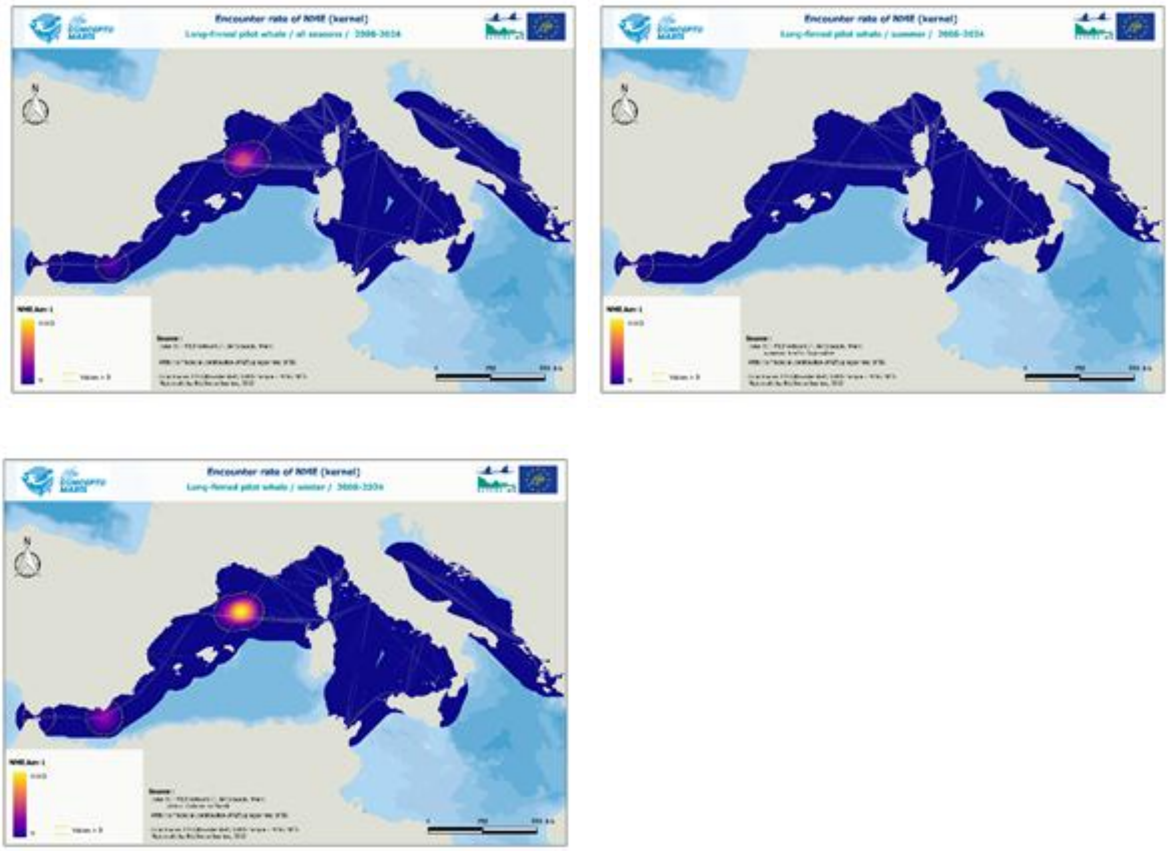


Figure 6.3.15: Kernel interpolated Encounter Rate of Near Miss Events of *Globicephala melas* for the entire period, the summer (April to September) and the winter (November to March).

Grampus griseus NME seems not located in areas where they are the most sightings of the species (Figure 6.3.16 and Figure 6.3.17). They were witnessed only in summer, either in coastal areas or over the slope (in the neighbourhood of Sicilia) as well as in deep offshore areas (north-western Mediterranean Sea).

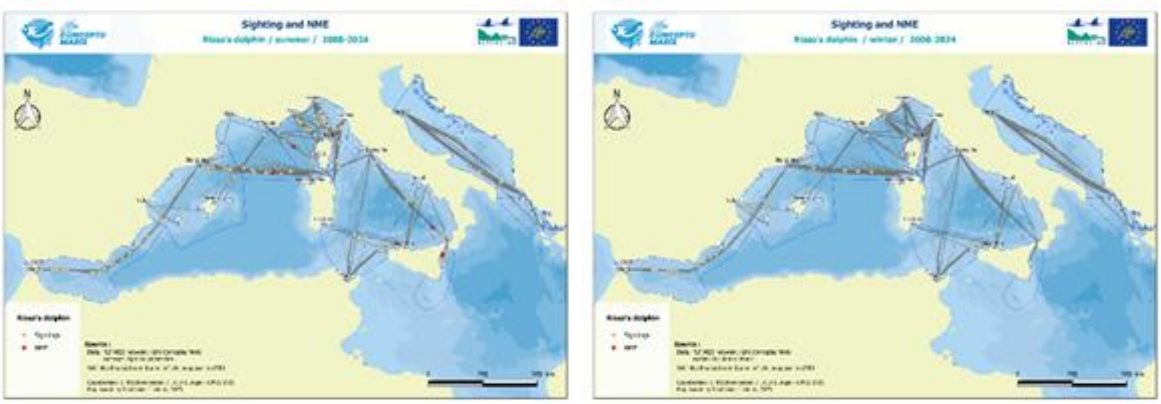


Figure 6.3.16: Distribution of effort, sightings and Near Miss Events of *Grampus griseus* in summer (April to September) and winter (November to March).

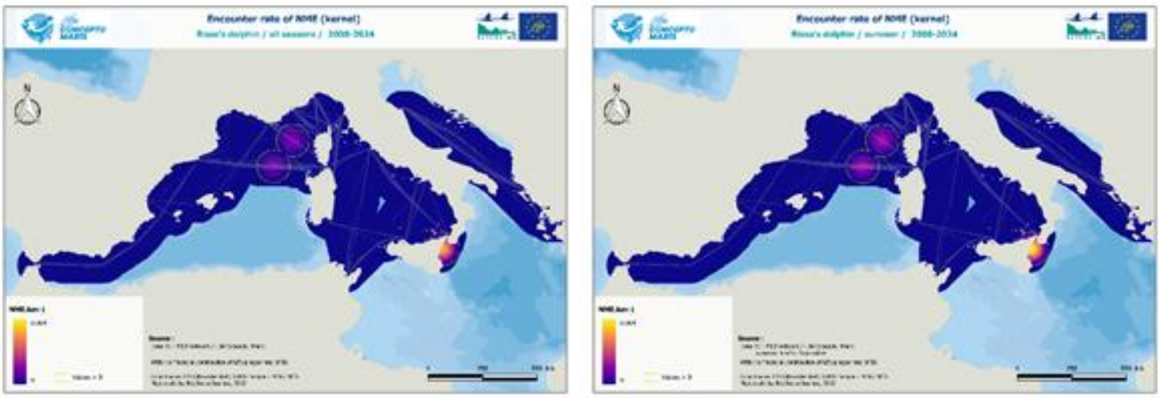


Figure 6.3.17: Kernel interpolated Encounter Rate of Near Miss Events of *Grampus griseus* for the entire period, the summer (April to September) and the winter (November to March).

After having detailed the NMEs for each species, a map considering the NME areas of all species together has been built (Figure 6.3.18). The area with the most different species (3 to 4) involved in NME is the offshore **Gulf of Lion, north of the Balearic Islands Minorca**. Then **Gibraltar** appears to be an important risk area for cetacean species (3), followed by the **Ligurian Sea** and the **north Tyrrhenian Sea** (2 species). The **summer** seems to be the season with the **most risks** for the cetacean's community with up to 3 species with their NME areas in the same place.

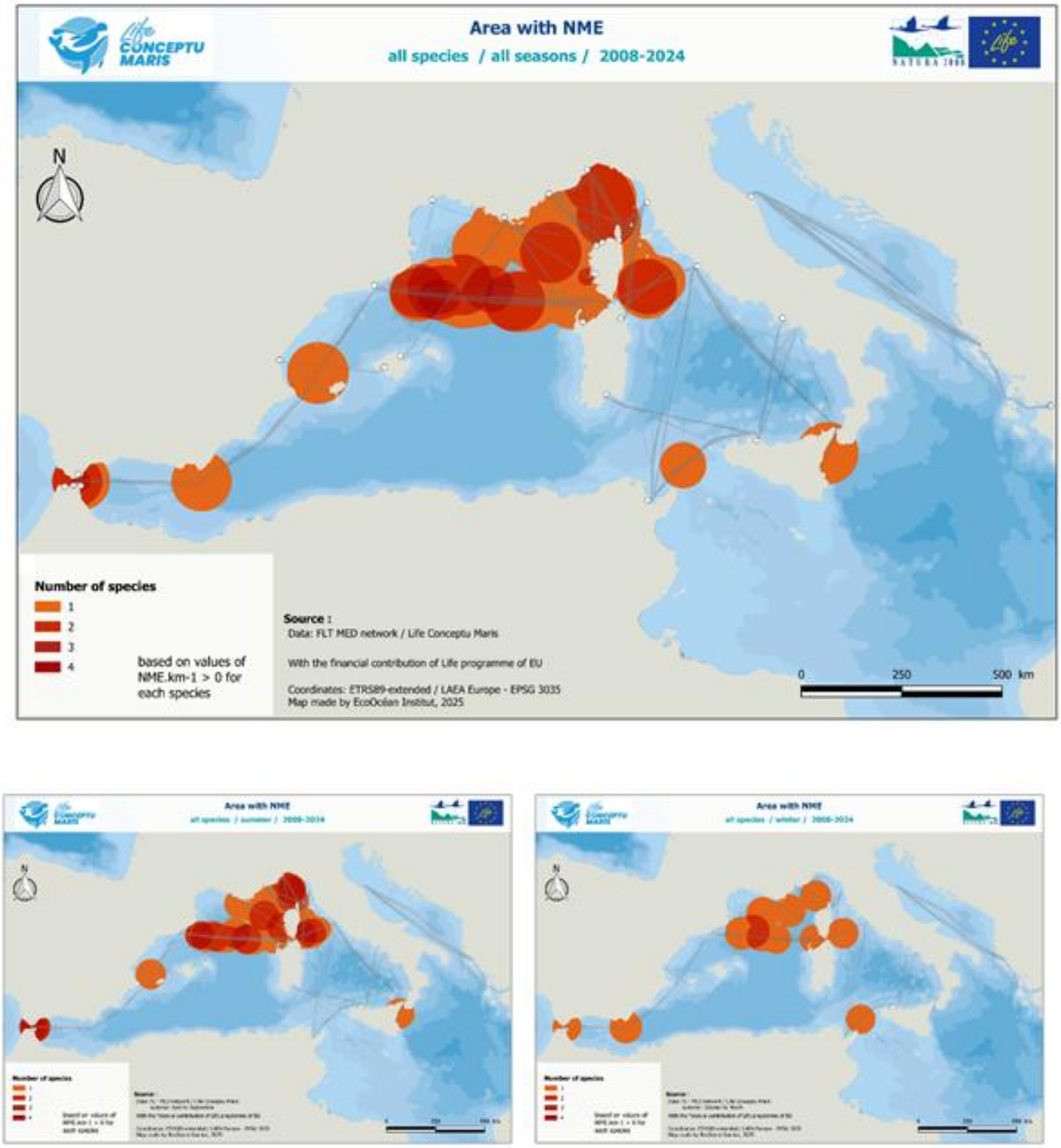


Figure 6.3.18: Areas where Near Miss Events of different species of cetaceans occurred, for the entire period, the summer (April to September) and the winter (November to March).

Comparing the maps from the spatial analysis of observed NME with those from the Risk Exposure Analysis (REA) of Passenger Traffic from AIS for large and medium-sized cetaceans from observed occurrence (see paragraph 6.2), resulted globally in a good match. Indeed, the main risk areas highlighted by the REA *for Balaenoptera physalus, Physeter macrocephalus* and *Ziphius cavirostris* (Table 6.2.1) are coherent with where the NMEs occur the most. Still some NMEs occurred also in medium predicted risk areas. The NME dataset is the only one of this type and reveals tremendous value to better understand the phenomenon and validate the Risk Exposure Analysis approach developed in this project.

Factors influencing NMEs

Seven variables were used to explain the 101 NMEs of the five species, using the PCA mixed chart of squared loadings for quantitative and qualitative variables method: 3 numerical ones : ER of the species over the transect where the NME occurred, number of animals in the group in which the NME occurred and the speed of the ferry at the time of the NME.4 categorical variables:

- Cycle (dawn is before 9h, morning between 9-12h, midday between 12h-14h, afternoon 14h-18h, evening is after 18h)

- Season : spring, summer, autumn and winter

- Behaviour of the animal at initial (travel, feed, rest, socialise and unknown)

- Response of the animal to the ferry (indifferent, escape, approach)

The variables explained only 27% of the variance (Fig 6.3.19), with 15% explained by the first dimension and almost 12% for the second. ER, behaviour, speed and cycle contribute the most at the 1rst dimension, whereas cycle, number and response contribute the most at the 2nd dimension (Fig 6.3.20 and 6.3.21).

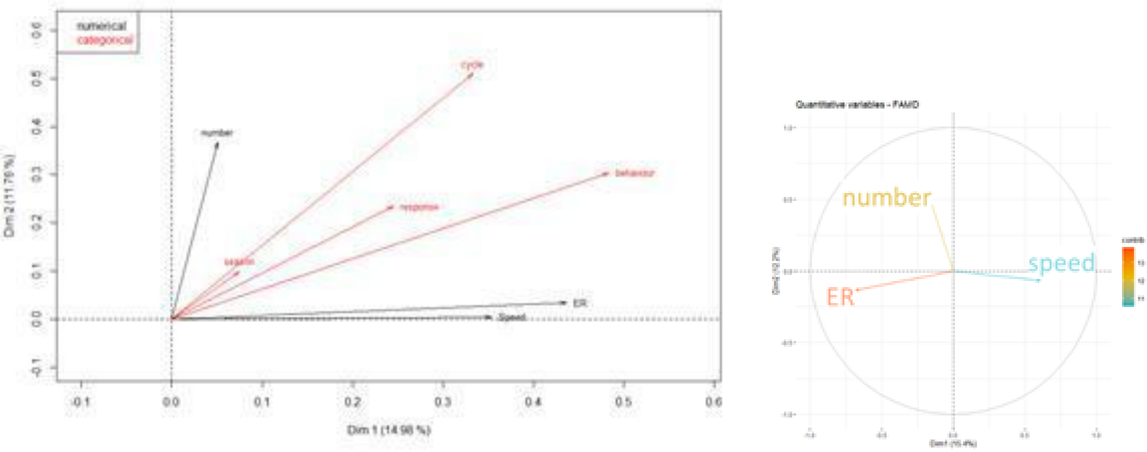


Figure 6.3.19: Results of the PCAmix for 101 NMEs from 5 species of cetaceans and 7 variables, left, and contributions of the 3 numerical variables (right)

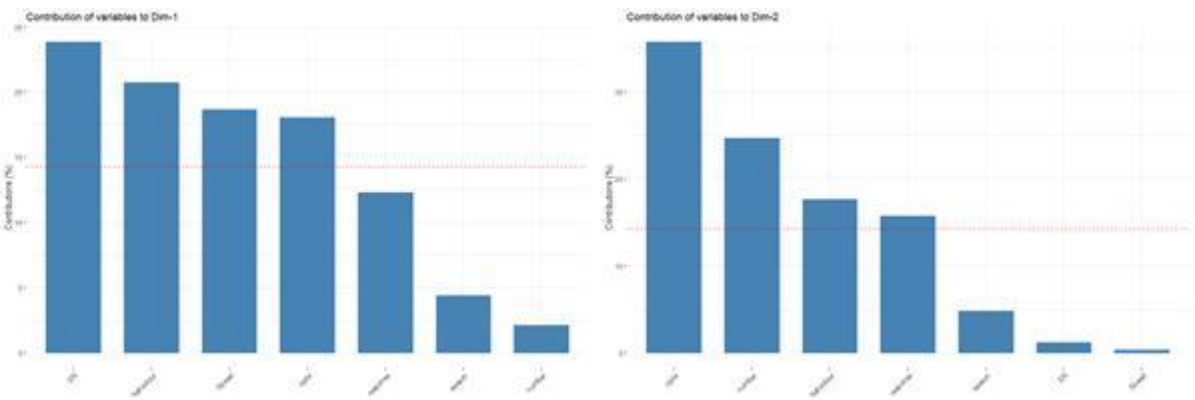


Figure 6.3.20: Contribution of the variables to the 1rst dimension of the PCAmix (left) and to the 2nd dimension (right)

Considering the behaviour (Figxx), in 28% of the NME cases it was unknown, then a majority of animals were travelling (41%), whereas only 8% were resting (1 *Risso's dolphin*, 1 *Pilot whale*, 1 *Sperm whale* and 2 *Ziphius cavirostris* and 3 *Fin whale*) and 1% feeding (1 *Fin whale*). So, at first, we can conclude that most animals involved in NME are not resting or feeding, but merely travelling. The influence of this variable in the PCA highlighted differences but that cannot lead to a generalisation or explanation.

Considering the cycle of the day (Figxx), again, some differences appear, with cases happening at dawn or in the afternoon, but this cannot be used to draw a global picture, as many NMEs occurred at all the other periods of the day, from morning to dusk (Figx). And the repartition of NMEs between cycles is almost the same as for all sightings, so there is no difference (p-value > 0.05).

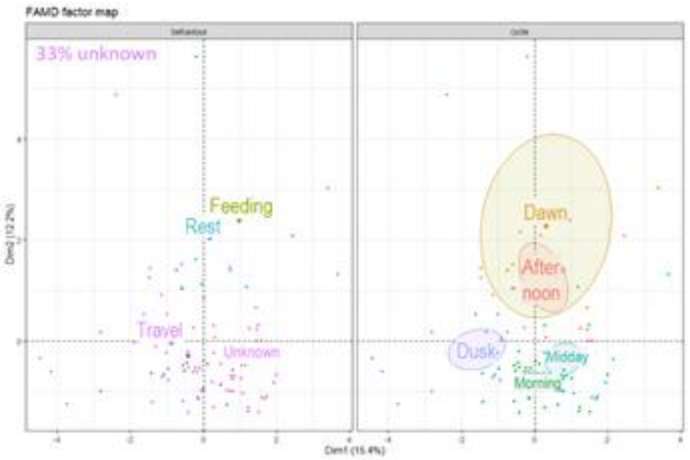


Fig 6.3.21: Distribution of 101 NME cases on the PCAmix first and second dimensions for the "behaviour" and the "cycle".

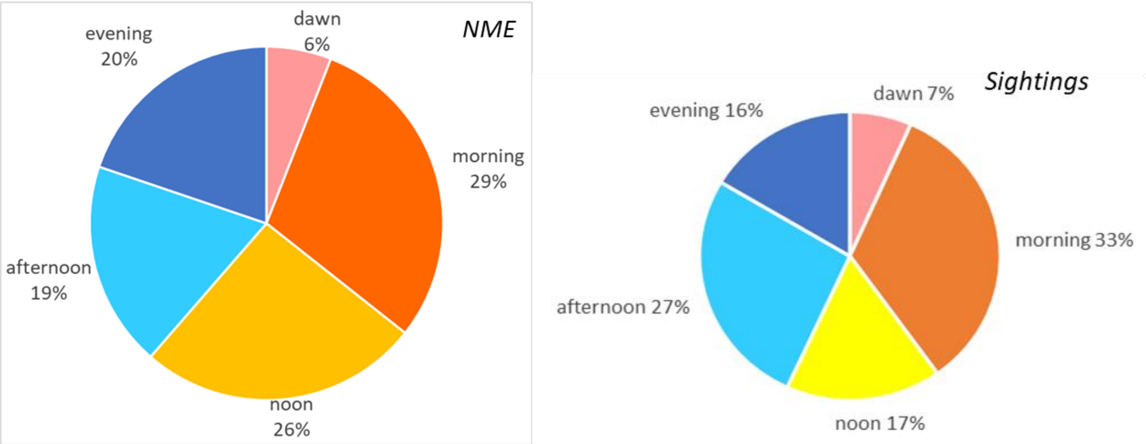


Fig 6.3.22: repartition of NME (left) and sightings (right) between the different cycles of the day

Considering only NME with *Balaenoptera physalus* (N=73), it appears that the majority of animals were travelling and a significant portion emerged close to the vessel, which left little or no time for the crew to maneuver (Figure 6.3.23). And also the majority 59% of animals seemed to escape the vessel, whereas 37% seemed indifferent to it and only 3% headed toward the vessel.

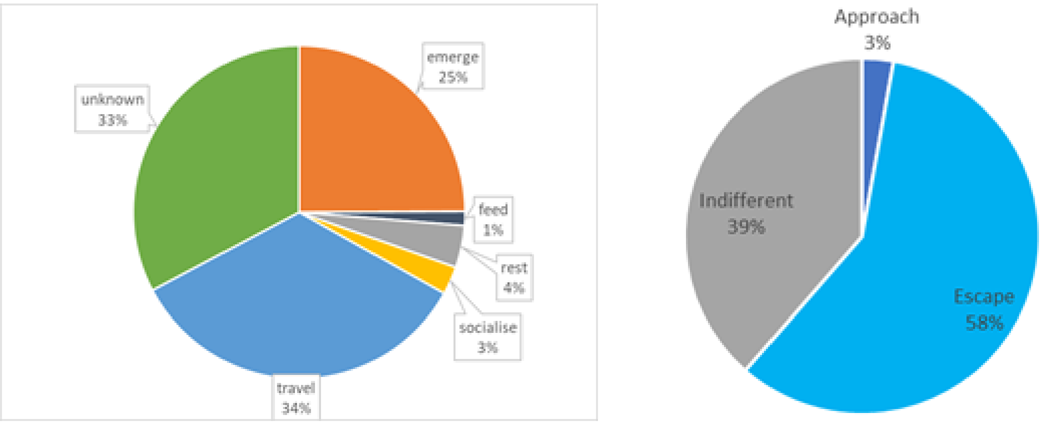


Fig 6.3.23 : Initial behaviour of fin whale involved in NME (left) and response to the ferry (right)

Finally, considering the speed of the vessel for the 101 NME, compared to the speed for all the sightings (4585), no significant statistical difference is highlighted (Welch Two Sample t-test, t = -1.2981, df = 101.52, p-value = 0.1972).

On the other hand, the same test for the *Balaenoptera physalus* NMEs do show that there is a significant difference in speed for NME cases versus all *Balaenoptera physalus* sightings (Two Sample t-test, t = -2.2651, df = 3611, p-value = 0.02357), with a speed higher for NMEs (Figure 6.3.24).

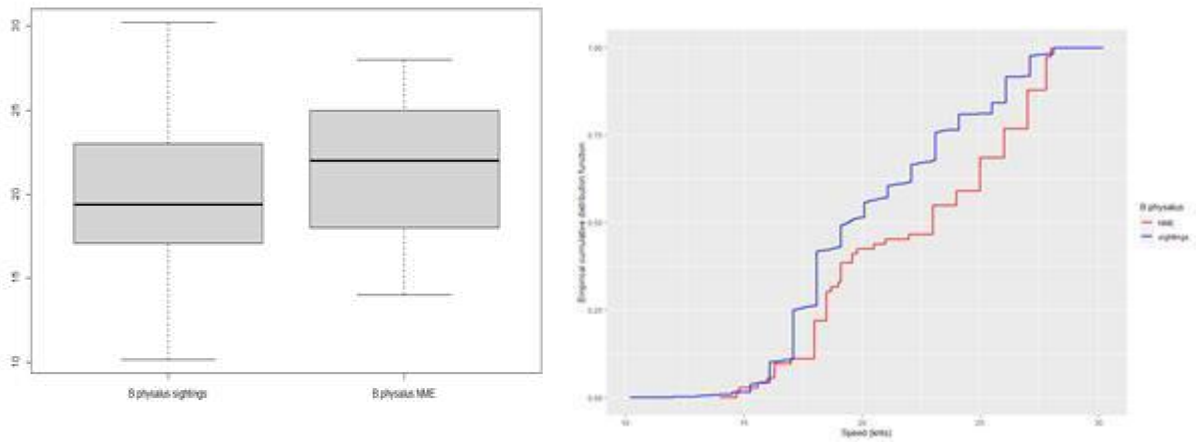


Fig 6.3.24 : boxplot of the speed of the ferry during sightings and NME of *Balaenoptera physalus* (left) and empirical cumulative distribution function (left)

In conclusion, by recording NMEs through real-time observations made by on-board qualified and trained ferry observers, it was possible to identify high-risk areas, some already known were then confirmed and also new ones were highlighted. Despite our effort, the reasons for NME cannot be linked to any specific behaviour of animals, neither cycle within the day, nor season and response to the vessel. But clearly, Encounter Rate of the species and speed of ferry may play a major role.

7. Executive summary on CEPTU Species Important and risk areas

"Deliverable C1: Identification of important offshore CEPTU areas and risk areas in Western Mediterranean (WMED) and Adriatic and Ionian (ADRION) marine regions", details a comprehensive study on the conservation of Cetaceans and Pelagic Sea Turtles (CEPTU species) in the Mediterranean. It identifies crucial habitats and areas of risk for nine specific species, including various dolphins, whales, and the loggerhead sea turtle. The report utilizes visual sightings, environmental DNA (eDNA) analysis, and stable isotope analysis (SIA) to assess population trends, distribution ranges, and habitat suitability, factoring in seasonal and long-term variations. Furthermore, it examines anthropogenic pressures like floating marine macro litter and maritime traffic, assessing their spatial and seasonal overlap with CEPTU presence to identify vulnerability and risk exposure areas, including "Near Miss Events" with vessels, ultimately informing conservation strategies.

The methodology includes:

1. **Preliminary analysis of environmental variable correlation:** Identifying and selecting non-redundant environmental variables (e.g., bathymetry, chlorophyll concentration, sea surface temperature, distance to canyons/seamounts, salinity, Eddy Kinetic Energy - EKE) that influence species presence.
2. **Habitat Selection Analysis:** Comparing environmental variable distributions at species presence locations versus available effort locations to reveal specific habitat preferences using statistical tests (Mann–Whitney U and Kolmogorov–Smirnov tests) and visualization (violin plots). For example, *Stenella coeruleoalba* prefers dynamic, productive waters near canyons and seamounts, while *Tursiops truncatus* favors coastal and continental shelf areas.
3. **Principal Component Analysis (PCA):** Reducing dimensionality and identifying underlying environmental gradients that shape species distribution. This helps to understand how species respond to broad ecological conditions.
4. **Species Distribution Models (SDMs) using MaxEnt:** Implementing SDMs to predict suitable habitats based on selected environmental variables and presence data. These models are run for the entire study period, seasonally, and for each Habitat Directive reporting period to capture dynamic shifts.
5. **Model validation with independent datasets:** Crucially, the models are validated using extensive independent datasets (over 24,000 records) to ensure their robustness and generalizability to real-world scenarios. Thresholds like "Maximum test sensitivity plus specificity logistic threshold" and "Natural Jenks threshold" are used to delineate core and extended suitable areas.

Environmental DNA (eDNA): plays an innovative and complementary role in monitoring CEPTU species and marine biodiversity within the LIFE CONCEPTU MARIS project. It involves detecting genetic material released by marine organisms into the water, providing a broad assessment of the entire biological community, including cryptic and threatened species that are difficult to observe visually. **Concordance with Visual Sightings:** While eDNA offers a powerful complementary tool, its detections only partially overlap with traditional visual sightings (around 40% concordance). This is attributed to factors like eDNA dispersion by currents, variable amounts of DNA released by animals, stochastic sampling, and degradation processes. eDNA can detect species that were present hours before or were in the vicinity but not within visual range, including nocturnal species. Conversely, visual sightings might detect species whose eDNA signals are transient or dilute.

Stable Isotope Analysis (SIA) reveals patterns in marine biogeochemistry by analyzing $\delta^{13}C$, $\delta^{15}N$, and C/N ratios in particulate organic matter (POM). **$\delta^{13}C$** indicates the **relative influence of carbon sources (pelagic, coastal, terrestrial)** and local vs. external organic matter input, with higher values suggesting active phytoplankton production and shorter food chains while lower values could indicate the utilization of detritus-based or more complex food webs, or an influence from terrestrial/riverine inputs.. **$\delta^{15}N$** reflects nitrogen cycling and trophic complexity, with elevated values indicating **trophic enrichment and likely prey concentration**. CEPTU distributions in $\delta^{15}N$-rich zones can correlate with **dense prey fields and efficient energy transfer** while lower values indicate proximity to the base of the food web or areas with reduced productivity. **C/N ratios** distinguish between fresh algal material (low ratios <7) and older, detrital organic matter (high ratios >10).These isotopic markers **act as low-cost proxies for** i**dentifying highly productive areas** for CEPTU species.

7.1 CEPTU important areas

The project identifies important areas for CEPTU species through a multi-step framework that integrates environmental niche analysis and Species Distribution Models (SDMs), rigorously validated with independent datasets, and innovative techniques such as eDNA.

Visual and eDNA complementary Information: The partial overlap highlights that eDNA and visual monitoring provide different yet complementary information. eDNA analysis successfully detected nine cetacean species, 187 bony fish species, and 11 elasmobranch species. The most frequently sighted species (e.g., *Stenella coeruleoalba*, *Tursiops truncatus*) are also the most commonly detected by eDNA, reinforcing their widespread presence. However, some species, like *Balaenoptera acutorostrata* (minke whale), were only sighted visually, while *Kogia breviceps* was exclusively detected by eDNA, demonstrating the unique value of each method. Notably, *Kogia breviceps* (pygmy sperm whale), a species not previously sighted or considered resident in the Mediterranean, was detected via eDNA across various Western Mediterranean regions. In general, the integration of eDNA data with visual monitoring data enhanced suitable habitat predictions, especially by incorporating nocturnal detections and identifying trophic relationships between cetaceans and their prey.

In general, either the visual and the eDNA detections consistently showed the **western Mediterranean importance for cetaceans' species** compared to the Central Mediterranean and Adriatic regions, reinforcing its ecological importance for these species. The most consistently **important areas for *Caretta caretta* are the northern-central Adriatic Sea and the southwestern Mediterranean, particularly the Tyrrhenian Sea and Algerian coasts**, with seasonal and long-term shifts influencing the broader distribution.

The visual and eDNA results consistently highlight **key areas for cetacean** species like the **Alboran Sea and Gibraltar region, Pelagos Sanctuary, Spanish Cetacean Migratory Corridor, Tyrrhenian Sea**, and the **Sardinian basin** and the **waters off Tunisia** as ecological hotspots supporting multiple species**. These hotspots often align with high fish species richness and abundance detected by eDNA techniques, suggesting a link between prey availability and cetacean habitat preference**.

Overall Priority Areas (Vulnerability Index)

A comprehensive vulnerability index, integrating indicators such as species richness, diversity, abundance, group size, juvenile presence, and rare species occurrence, identifies the following as the **most critical areas for cetacean conservation in the Mediterranean**:

- **Alboran-Gibraltar region**: This area is notable for a **higher frequency of juveniles** and **higher encounter rates and group sizes of *Stenella coeruleoalba*** (striped dolphin) and the **rare *Delphinus delphis*** (common dolphin). It also hosts larger group sizes of *Tursiops truncatus* (bottlenose dolphin).
- **Pelagos Sanctuary**: This sanctuary stands out for the **highest concentrations of *Balaenoptera physalus*** (fin whale) and *Stenella coeruleoalba*, as well as **larger group sizes of *Globicephala melas*** (pilot whale).
- **Spanish Cetacean Migration Corridor (SpMigratCorr)**: This area is one of the few regions, alongside Alboran-Gibraltar, that exhibits a **higher frequency of juveniles**. It also hosts some of the highest abundances of *Stenella coeruleoalba*.

Most other areas also host at least half of the more common Mediterranean cetacean species and have recorded occurrences of rarer species like *Physeter macrocephalus* (sperm whale), *Grampus griseus* (Risso's dolphin), *Globicephala melas*, and *Ziphius cavirostris*.

Seasonal Vulnerability:

Alboran-Gibraltar maintains its high conservation value **year-round**, consistently showing a high frequency of juveniles. It also hosts *Ziphius cavirostris* in winter and *Globicephala melas* in autumn.

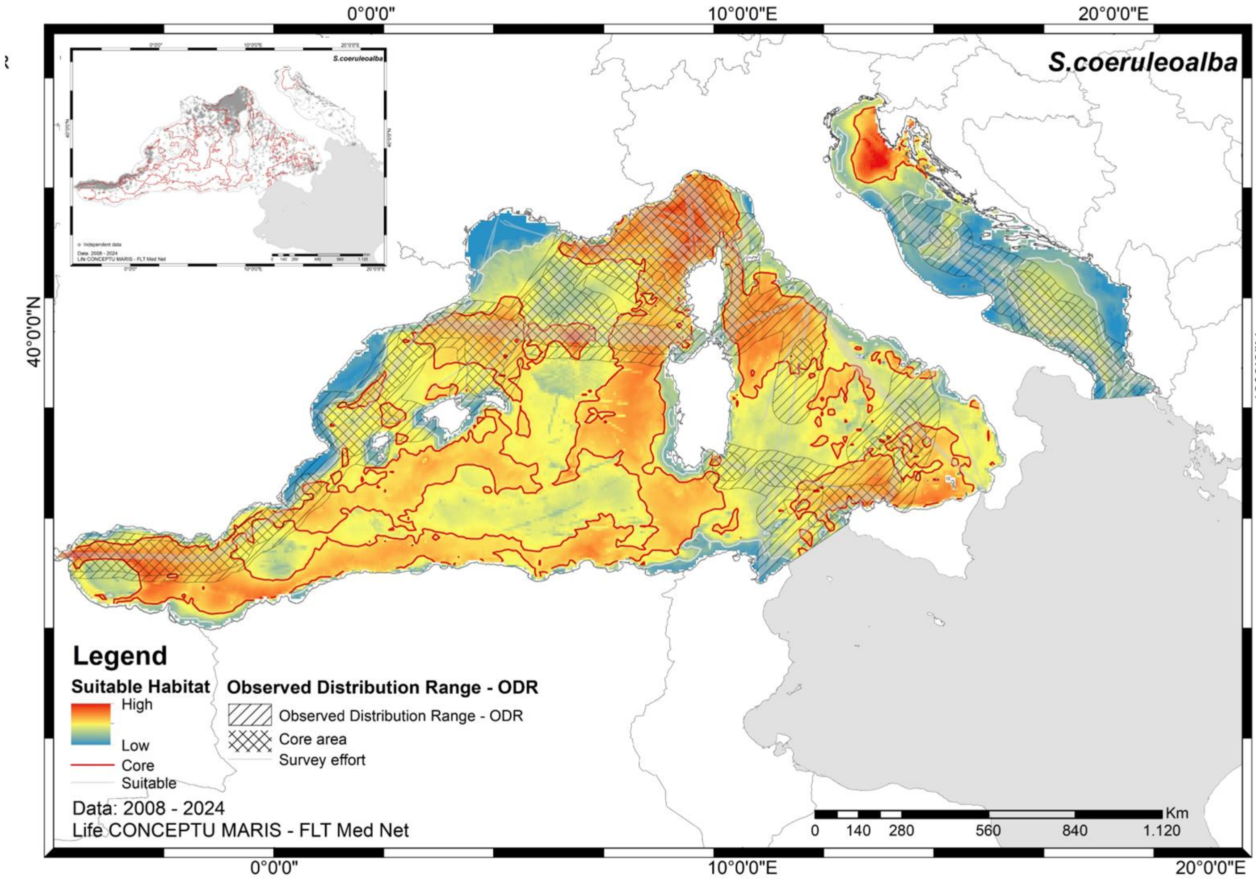
- In **winter**, high-vulnerability zones are concentrated in the **western Mediterranean**, specifically the **Pelagos Sanctuary** and the **Spanish Migratory Corridor**, which host *Physeter macrocephalus* and *Ziphius cavirostris* during this season.
- In **spring**, high-vulnerability zones **expand across the western Mediterranean**, including the **Spanish Migratory Corridor**, **Pelagos**, **Northwestern Mediterranean**, and the **western Spanish slope** and **Sardinia-Sicilian channels**.
- **Summer** is the season with the **highest overall vulnerability**, particularly in the **upper western Mediterranean**, **Pelagos**, and **northwestern Mediterranean areas**, followed by the **Sardinia-Sicilian channels**, **Tyrrhenian**, and **western Spanish slopes**. High juvenile frequency is spread across five areas during this season.
- In **autumn**, high vulnerability is again widespread in the **western areas**, though slightly less intense than in summer.

Overall, the **western Mediterranean consistently appears as the most important area for cetacean conservation, with peak vulnerability in the summer.**

Seasonal Stable Isotope Analysis (SIA) reveal **strong spatial-temporal variability in productivity and trophic dynamics**. **Summer** hotspots in the southern Tyrrhenian and Adriatic-Ionian areas show high $\delta^{15}N$ and low C/N, signalling dense prey and key CEPTU foraging grounds. In contrast, **winter** shows low $\delta^{15}N$ and enriched $\delta^{13}C$, indicating reduced productivity. Isotopic patterns span national borders, supporting coordinated, cross-border summer protection efforts.

The following maps highlight the **key important areas for each species** where:

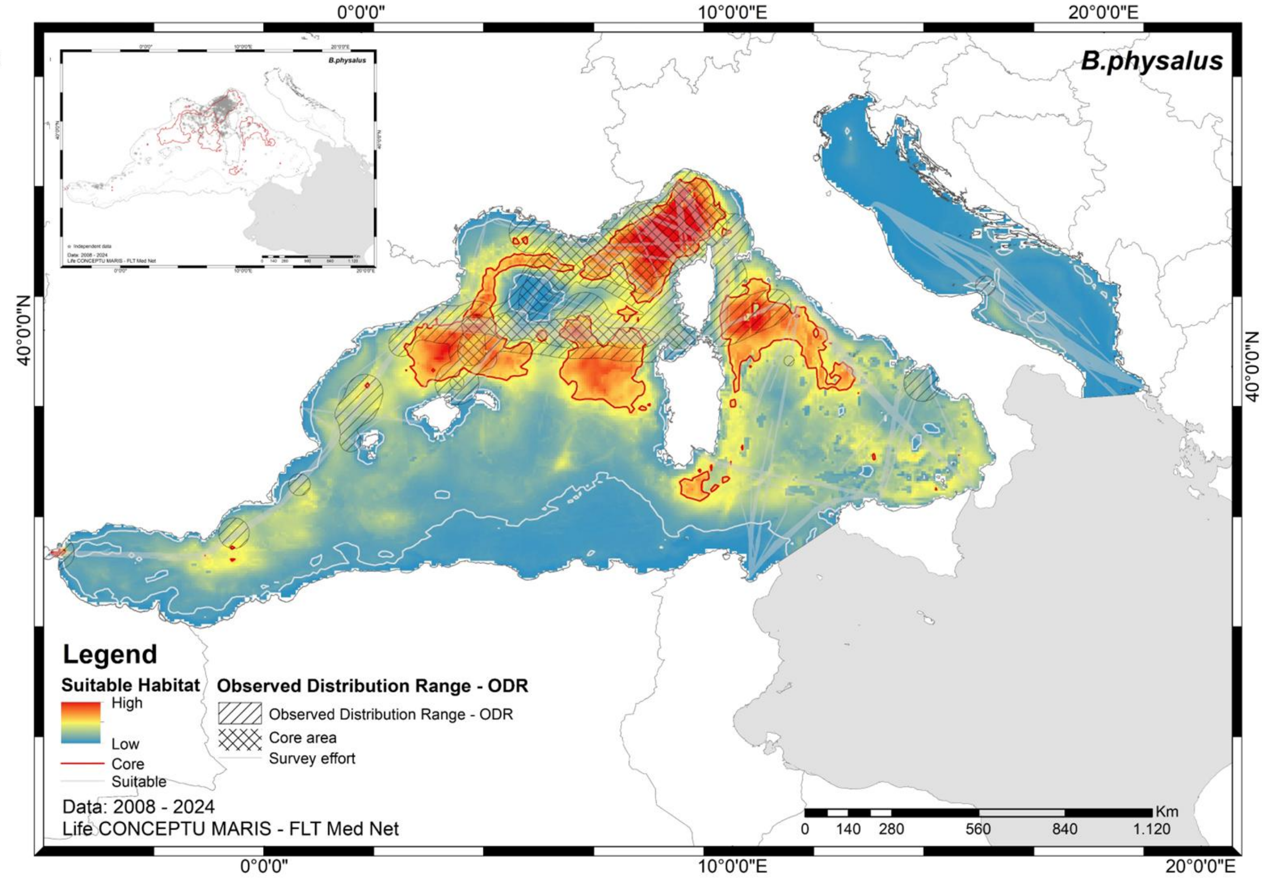
- **Observed species Distribution Range (ODR)** is delineated through a kernel density estimator applied to visual sightings. The resulting Observed Distribution Range (ODR) includes cross-hatched areas (////), indicating the general extent of observed presence, and densely hatched areas (XXXX), identifying core areas with consistently high densities of sightings.
- **Survey effort** is shown as light grey lines, representing the spatial coverage of data collection activities, which is considered relatively homogeneous across the study area.
- **Ecological Potential Range (EPR)** is represented using a colour gradient, where values range from low suitability (blue) to high suitability (red and dark orange). This gradient is derived from environmental variables and species occurrence data, providing a spatial representation of potential habitat quality. Areas of high suitability are likely to be important for key ecological functions such as feeding or transit, and they generally overlap with the observed core distribution areas.
- **Independent data points**, marked with stars (☆), represent external sightings or detections used to validate both the modelled habitat suitability and the observed distribution patterns.



Distribution: Striped dolphin (*Stenella coeruleoalba*) is **widespread across most monitored areas in both the Western Mediterranean and Adriatic Sea, with a preference for deeper offshore regions**. Its Ecological Potential Range (EPR) extends throughout pelagic waters. Core areas are primarily concentrated in the **Pelagos Sanctuary, Tyrrhenian Sea**, **the waters off western and southern Sardinia, around the Balearic Islands, the Alboran Sea, and the northern coast of Africa**.

Habitat Characteristics: *Stenella coeruleoalba* prefers **dynamic, deep, and productive offshore areas**, often near seamounts and canyons. It selects areas with **stronger currents, elevated Eddy Kinetic Energy (EKE), high chlorophyll concentration, phytoplankton abundance, and primary productivity**. Depth is the most influential predictor (45.6%), followed by mean sea surface temperature (SST, 13%). Habitat suitability increases with chlorophyll levels up to a certain threshold and prefers SST around 18°C.

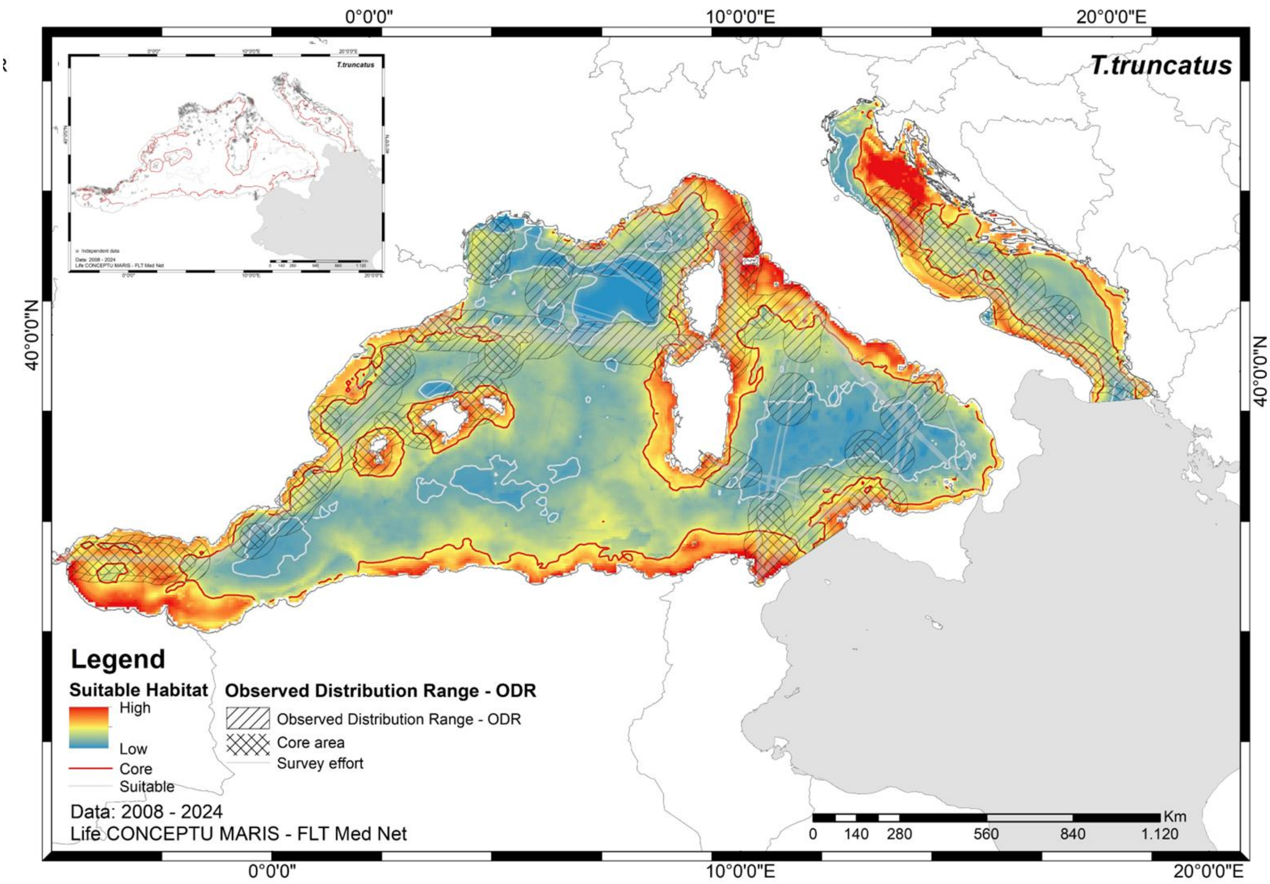
Trend and seasonality: From 2008 to 2024, *Stenella coeruleoalba* habitat suitability was shaped by hydrographic, bathymetric, and productivity-related factors, with shifting influence over time. Thermocline depth was key early on, depth became dominant mid-period, and salinity gained importance later. Suitable habitats remained widespread across Mediterranean sub-basins, with some westward expansion. Overall, the **range of suitable habitats became slightly more extended**, suggesting a widespread of favorable conditions and potentially a larger ecological niche, possibly driven by changing oceanographic conditions



Distribution: Fin whale (*Balaenoptera physalus*) Observed Distribution Range (ODR) is primarily concentrated in the **northwestern region of the monitored areas and along the Spanish Cetacean Migration Corridor**. The Ecological Potential Range (EPR) indicates a potential distribution mostly covering the Western Mediterranean, with limited extension into the Adriatic Sea. Core areas align with the observed range, particularly in **the Pelagos Sanctury,** the **northwestern Mediterranean and the waters of the Sardinia-Balearic basin,** the **Spanish migration corridor,** the **central Tyrrhenian Sea, and** the waters surrounding **Sardinia Island**.

Habitat Characteristics: *Balaenoptera physalus* consistently prefers **deep, cold, productive pelagic habitats**, especially in the northwestern basin, with strong habitat suitability in the Corso-Ligurian-Provencal Basin and the central Tyrrhenian Sea. These areas are marked by high productivity, dynamic oceanographic processes, and complex bathymetry. **Bathymetry is the most influential variable**, with a preference for intermediate to deep waters, often near seamounts and far from the continental slope. Other key predictors include **moderate sea surface temperature, chlorophyll concentration, salinity, and EKE**, indicating reliance on upwelling zones and frontal systems associated with krill aggregations.

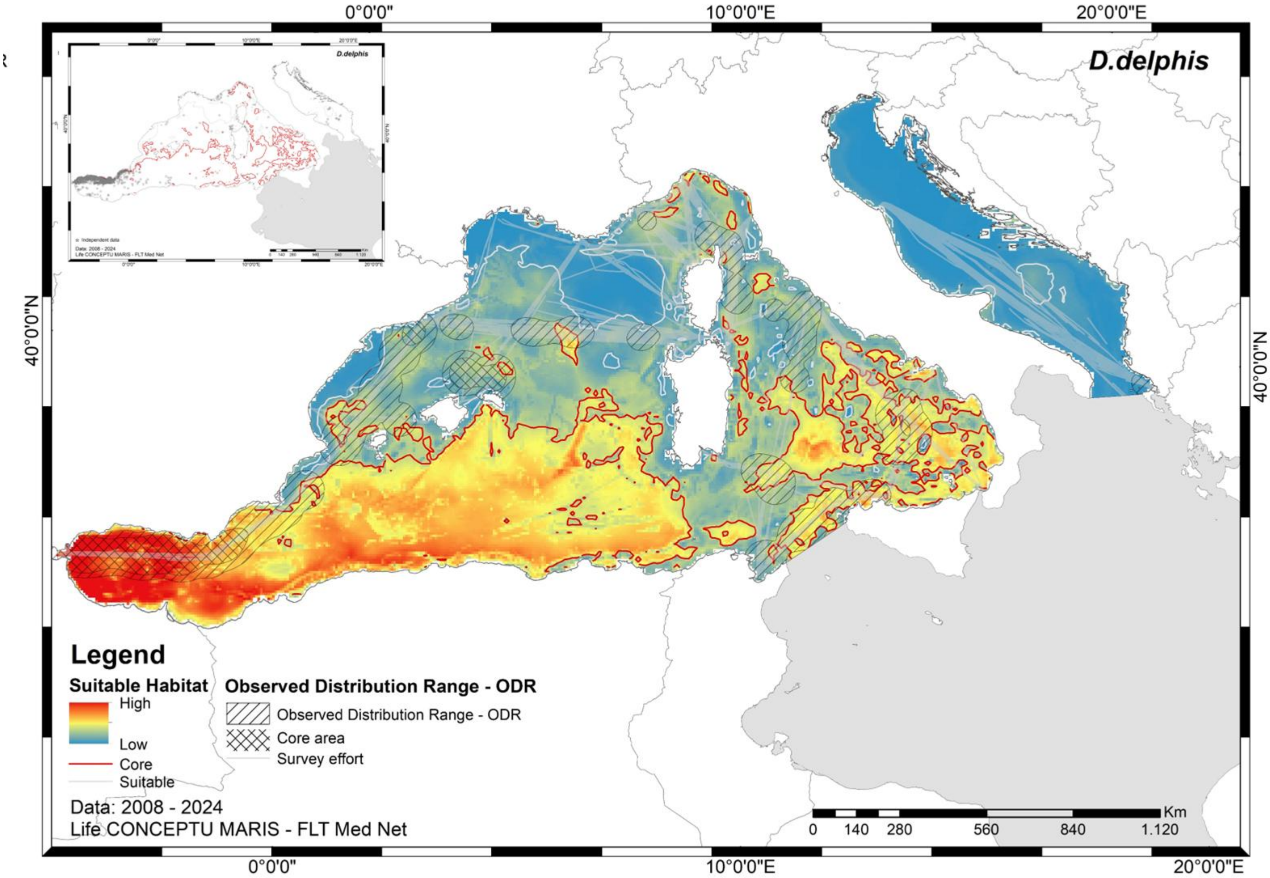
Trend and seasonality: While the **northwestern Mediterranean Sea consistently emerged as a key habitat** across all three reporting periods, a **progressive spatial contraction of suitable areas of *Balaenoptera physalus* was observed over time.** Seasonal patterns indicate that while core suitable areas remain stable, habitat suitability varies slightly in spatial extent and environmental drivers across seasons



Distribution: Bottlenose dolphin (*Tursiops truncatus*) has a **widespread Observed Distribution Range (ODR)** throughout the western Mediterranean and Adriatic sea**, with core areas located closer to the coast**. Its Ecological Potential Range (EPR) shows a preference for **coastal areas and the upper continental shelf of the Adriatic region**, but also extends into pelagic waters, excluding the most remote offshore areas. Key stable areas include the **Alboran Sea, the Balearic Islands, Gulf of Lion**, **Tyrrhenian coastlines, the Tunisian shelf, and the Adriatic Sea**.

Habitat Characteristics: *Tursiops truncatus* favors **dynamic environments, primarily coastal and shelf areas using more offshore areas during summer and autumn**. Preferred conditions include **intermediate depth, proximity to the coast, and moderate levels of temperature and chlorophyll**. Bathymetry, distance to coast, temperature variability, and mean chlorophyll are the most influential predictors. Salinity also plays a meaningful role, particularly in spring and summer.

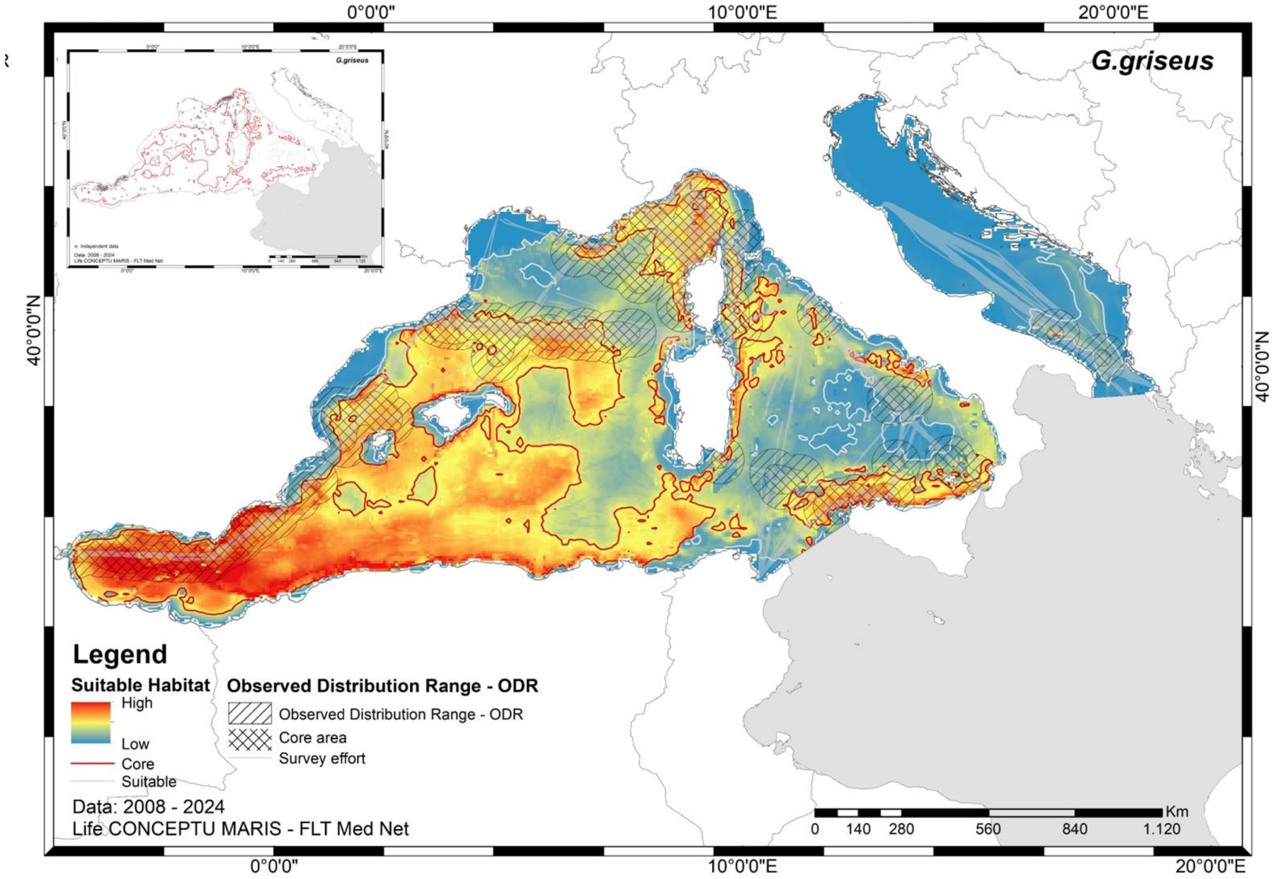
Trends and seasonality: *Tursiops truncatus* showed an **overall stability** in its presence and range, with some regional and **temporal fluctuations** in its habitat suitability**. Key environmental drivers (bathymetry, coastal proximity, thermal variability, sea surface height, moderate productivity) remained consistent across all periods.** It exhibits **seasonal plasticity in habitat use, expanding in spring and summer and contracting in autumn and winter, combined with spatial consistency in its ecological preferences**



Distribution: Common dolphin (*Delphinus delphis*) Observed Distribution Range (ODR) is scattered across the Western Mediterranean, becoming rarer at higher latitudes. A more continuous core area is evident in the **Alboran–Gibraltar region**. The Ecological Potential Range (EPR) confirms a predominantly southern distribution within the Western Mediterranean, with an extended core area stretching from Gibraltar to the Sardinian Channel, and more scattered suitable areas in the **southern Tyrrhenian Sea and the Sicily Channel**. Localized spots also appear in the Pelagos Sanctuary.

Habitat Characteristics: *Delphinus delphis* prefers **dynamic, productive waters near the continental shelf, canyons, and seamounts**, especially in the Alboran Sea and the southern latitudes of the Western Mediterranean Sea. **Salinity** is consistently identified as the most influential environmental predictor across all seasons and reporting periods, with a strong preference for **intermediate values** often associated with frontal zones and water mass mixing. Other important factors include **Eddy Kinetic Energy (EKE)**, which supports prey aggregation dynamics, and **proximity to complex seafloor features** like canyons and seamounts. Chlorophyll plays a secondary but seasonally significant role, especially in spring and summer.

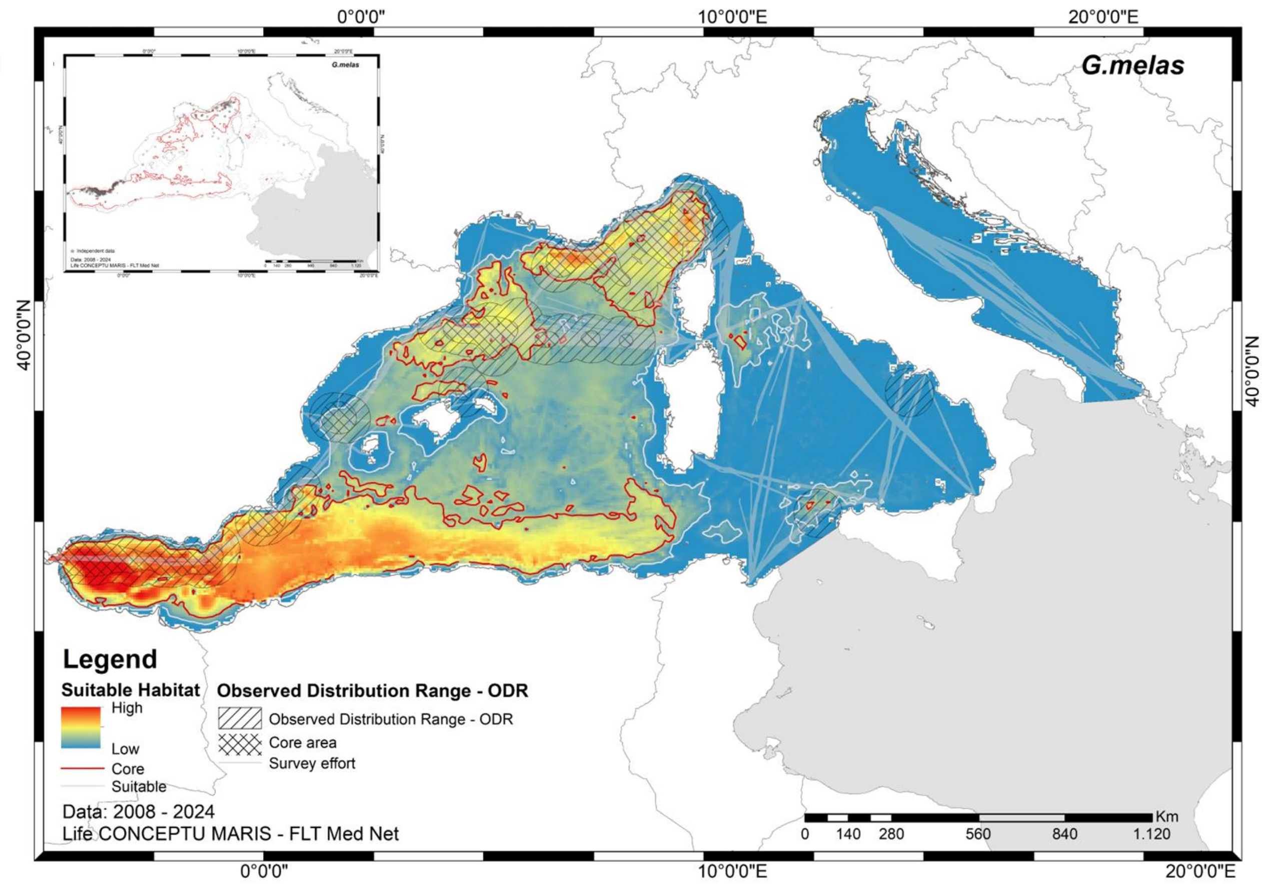
Trends and seasonality: *Delphinus delphis* **remained almost stable in the Western Mediterranean region with slightly sign of spatial restriction in recent years. Seasonal habitat suitability varies**, with salinity and EKE driving **winter patterns in the Alboran Sea. In spring and autumn,** salinity remains key, with habitats **expanding eastward and into the Tyrrhenian Sea. Summer** sees a shift to warmer, shallow **coastal zones, with temperature and depth** becoming more influential**.**



Distribution: Risso's dolphin (*Grampus griseus*) Observed Distribution Range (ODR) extends broadly across the Western Mediterranean monitored areas, with scattered presence around the shelf areas of the Tyrrhenian Sea and occasional sightings in the southern Adriatic region. Core areas are primarily located in the **Ligurian Sea and around the Balearic Islands, extending southward to the Alboran Sea**. It is also distributed within the Pelagos Sanctuary and around the shelf areas of the Tyrrhenian Sea.

Habitat Characteristics: *Grampus griseus* is a **flexible marine species that utilizes a wide range of habitats** but shows consistent preferences for specific environmental conditions. Its displays preferences for **dynamic, productive areas, particularly those with high currents,** Eddy Kinetic Energy (**EKE), and chlorophyll concentrations**. It favors regions close to seafloor features such as **canyons and seamounts**, reflecting a reliance on structurally complex and oceanographically active habitats. Across all periods, **bathymetry is the most influential predictor**, followed by salinity, chlorophyll concentration, and proximity to underwater features.

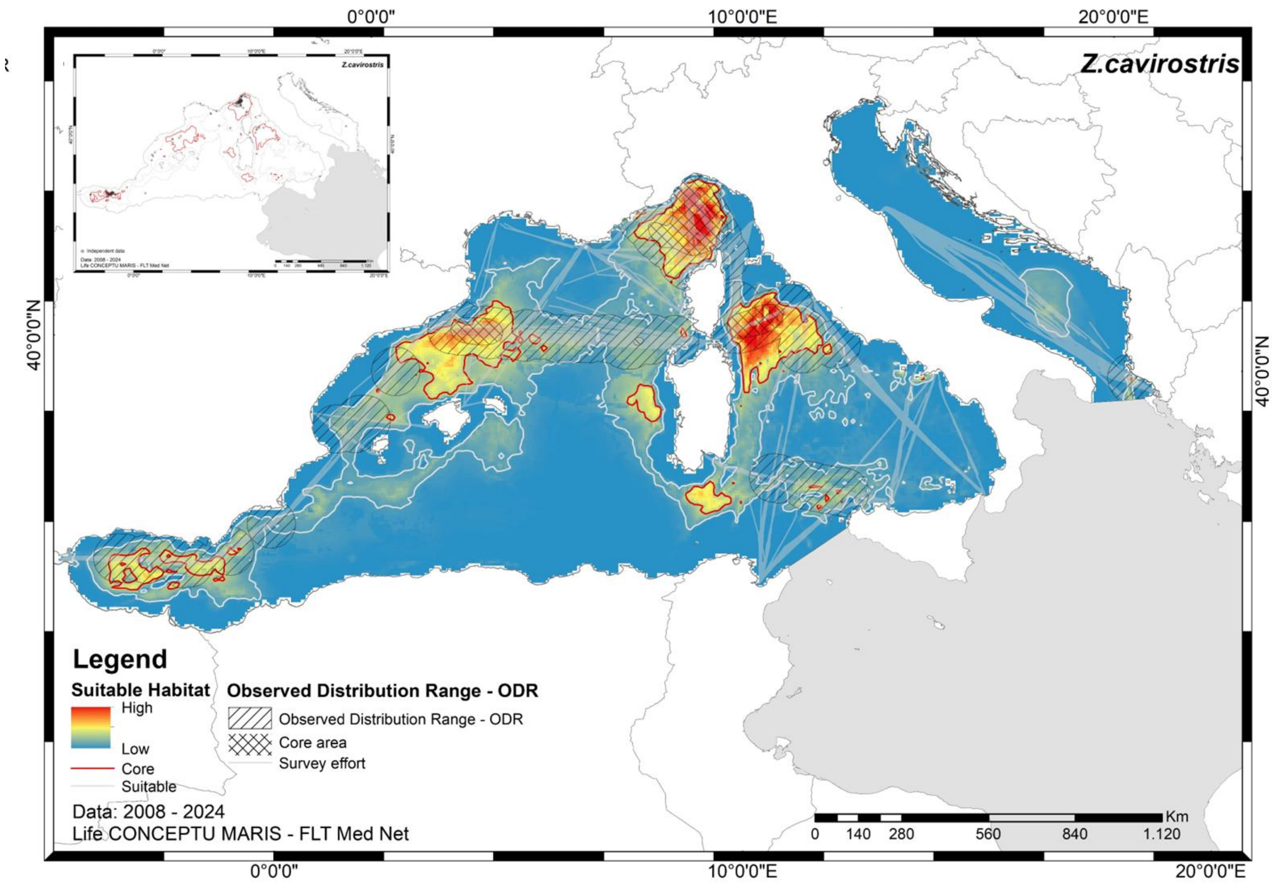
Trends and seasonality: *Grampus griseus* range **remained almost stable in the Western Mediterranean region but the habitat used has become more extensive over time, shifting towards more offshore and southwestern areas.** It consistently utilizes structured, productive offshore environments, especially those with moderate salinity and dynamic ocean conditions but **habitat use varies seasonally**, with **winter** favoring deep, moderately saline offshore areas near seamounts. In **spring** and **summer**, the species prefers productive, dynamic waters influenced by bathymetry, salinity, and primary productivity. **Autumn** use spans deep and shallower offshore zones, driven by bathymetry, canyon proximity, and trophic variability.



Distribution: Pilot whale (*Globicephala melas)* Observed Distribution Rante (ODR) is mostly confined to the **westernmost part of the Western Mediterranean with a few exceptions near the Campanian and Pontine Archipelagos and the Egadi Islands west of Sicily**. The Ecological Potential Range (EPR) confirms this westernmost distribution, extending west of Corsica and Sardinia, with core areas in the **northwestern region and primarily in the southern sector, stretching from the Alboran Sea to the northern African coast**. Key regions include the **Alboran Sea (most critical and consistent refuge, especially in autumn), the northwestern Mediterranean, the Balearic Sea, the Ligurian Sea, and the Algerian Basin** (where suitable habitats expanded southward recently). Areas near seafloor structures throughout the Western Mediterranean are also important.

Habitat Characteristics: *Globicephala melas* shows strong preferences for **dynamic, productive, and topographically complex environments**, with high chlorophyll concentrations, current dynamics, and seafloor features. The most influential variable is **chlorophyll mean** (33%), highlighting the importance of moderately productive waters. Salinity, bathymetry, and Eddy Kinetic Energy (EKE) also play a major role, indicating a preference for dynamic, less saline areas with intermediate depths.

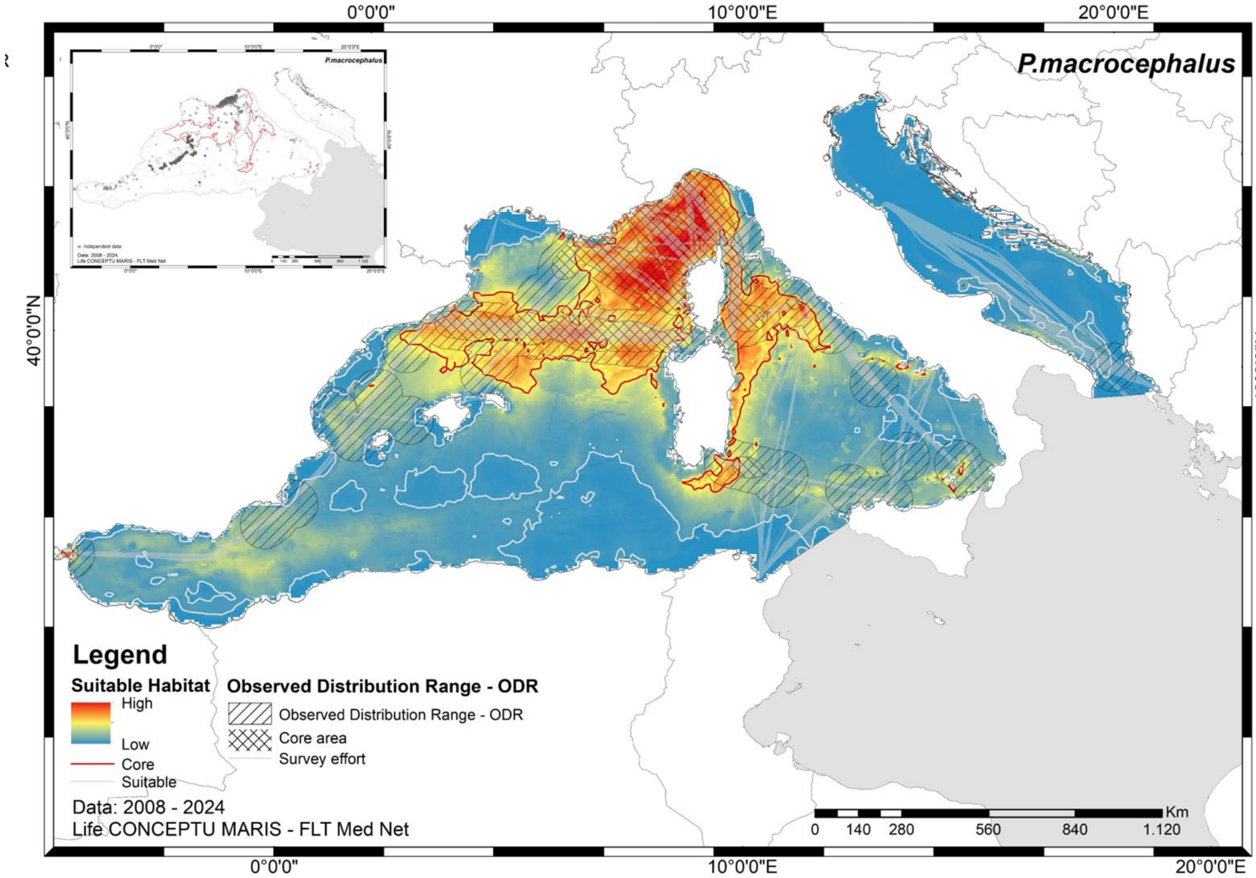
Trends and seasonality: *Globicephala melas* **range stayed stable in the western Mediterranean**, with strong reliance on productivity and dynamic processes. Recently, salinity's importance has grown, indicating sensitivity to climate-driven ocean changes*. Globicephala melas* shows **strong seasonal habitat shifts. Winter and** spring habitats are driven by EKE and productivity near canyons and seamounts. **In autumn, suitable areas contract to the Alboran Sea,** where salinity and bathymetric complexity dominate.



Distribution: *Ziphius cavirostris* Observed Distribution Range *(ODR)* is scattered primarily across the **northwestern Mediterranean, with a few occurrences in the Ionian Sea**. Core areas are concentrated in the **central Ligurian Sea, the central Tyrrhenian Sea, and northern Balearic islands**. The Ecological Potential Range (EPR) aligns with this confined distribution, also including offshore Barcelona and the Alboran Sea. These areas are typically associated with **steep slopes and canyon systems**.

Habitat Characteristics: *Ziphius cavirostris* strongly and consistently prefers **deep, offshore habitats characterized by both structural complexity and dynamic oceanographic conditions**. It favors areas with **higher productivity (elevated chlorophyll, variable net primary production) and is typically found in regions with lower temperatures and a very narrow range of salinity**. It is closely associated with **deep-sea features such as submarine canyons and seamounts**. **Bathymetry** (28.8% contribution) and **mean temperature** (22.5%) are the most influential variables.

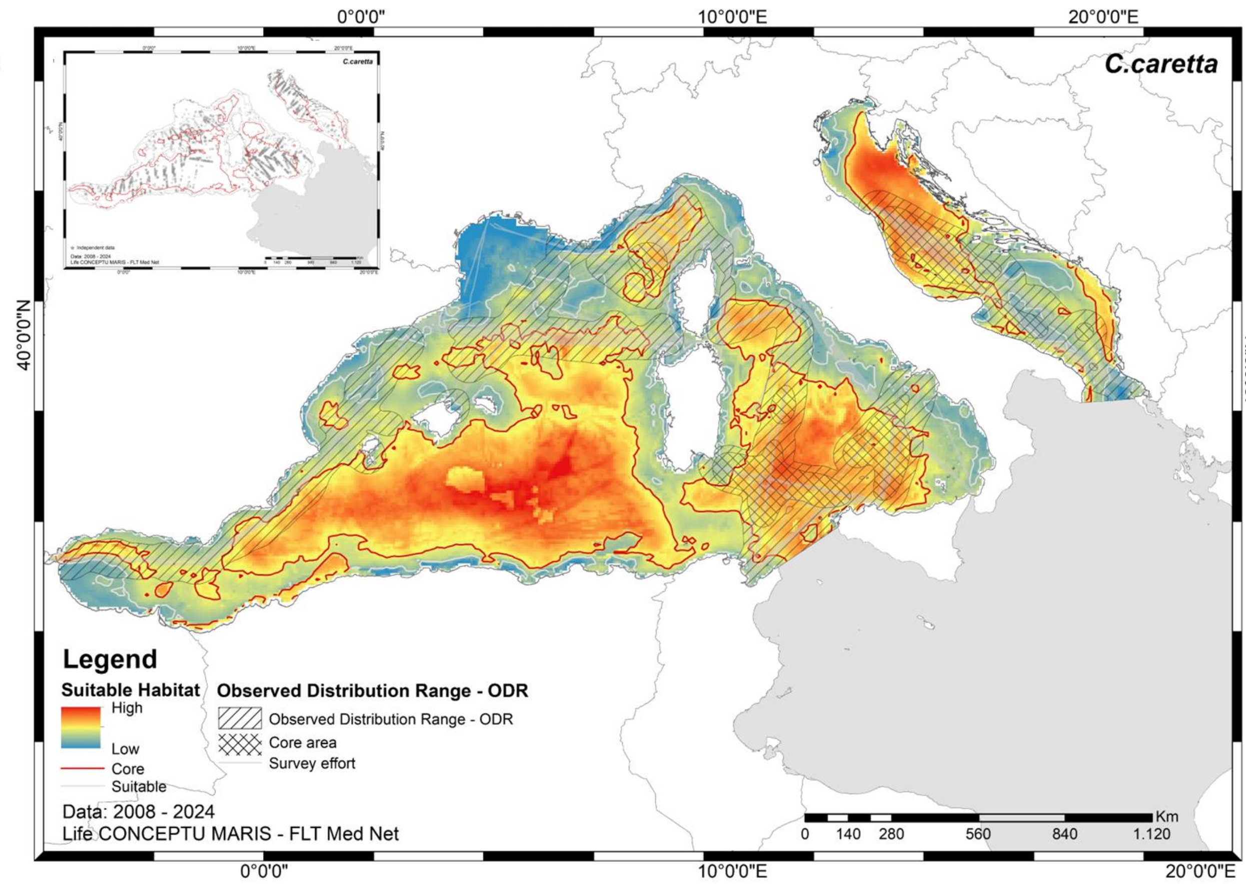
Trends and seasonality: *Ziphius cavirostris range* ***remained almost stable with*** **a slightly contraction over time and an increasing reliance on the Tyrrhenian and Ligurian areas*.*** The species **consistently favours deep, productive offshore areas near seamounts and canyons year-round**. **Winter** and **spring** habitats are driven by seamounts, canyons, and bathymetry, while **summer** habitats contract around core areas influenced by temperature and seamounts. In **autumn**, the range expands coastward, still relying on underwater features.



Distribution: Sperm whale (*Physeter macrocephalus)* Observed Distribution Range (ODR) is mostly confined to the **northern portion of the monitored areas in the Western Mediterranean**, with exceptions in southeastern Sardinia and the southern Adriatic region. The Ecological Potential Range (EPR) reflects a predominantly Western Mediterranean distribution, with an extended core area in the **northern part within the Pelagos Sanctuary, northern Balearic Islands, and central Tyrrhenian Sea**. Other hotspots include **near the Ischia Islands and north of Sicily**.

Habitat Characteristics: *Physeter macrocephalus* consistently selects **deep, productive, and dynamic marine habitats** characterized by **higher chlorophyll, phytoplankton concentration, and net primary production, alongside strong currents and** Eddy Kinetic Energy **(EKE)**, within specific salinity ranges. It prefers deep, steep-slope, thermally stable areas shaped by topographic complexity and moderate to high oceanic dynamism. **Bathymetry and mean temperature are the most influential environmental factors**. Salinity and chlorophyll variability also play significant roles, emphasizing affinity for dynamic environments that promote prey aggregation.

Trends and seasonality: *Physeter macrocephalus* range **remained almost stable with core suitable habitats in the Ligurian, Balearic, and Tyrrhenian Seas, but with a slightly contraction and a shift towards southern regions during the last period.** The species **seasonally shifts** between slope systems and productive frontal zones to follow prey availability. **Winter** favors complex canyons and seamounts with stable conditions, while **spring** and **summer** target productive coastal transitions and deep waters. In **autumn**, habitat expands to bathymetric edges with increased eddy activity and moderate productivity.



Distribution: *Caretta caretta* Observed Distribution Range (ODR) spans all monitored areas in both the Western Mediterranean and Adriatic regions. Core areas are primarily located in the **southern part of the Western Mediterranean and the northern Adriatic**. The Ecological Potential Range (EPR) shows extended core areas in the **Tyrrhenian Sea (especially the southern part including Sardinia-Sicilian channels), the Algerian basin up to Balearic Islands, the central Ligurian Sea, and the northern Adriatic region**.

Habitat Characteristics: *Caretta caretta* exhibits **broad ecological flexibility**, but consistently prefers **thermally stable, moderately productive environments located in transitional zones between coastal and offshore waters**. These areas often coincide with **structurally complex habitats, such as seamounts, submarine canyons, and continental shelf edges**, which likely enhance prey availability. **Distance from the coast, distance from submarine canyons, mixed layer depth, and mean surface temperature** are influential environmental variables. It tends to select transitional zones rather than open-ocean or nearshore extremes. The species is highly dynamic in habitat use, spreading more widely in spring and summer and concentrating in predictable areas like the northern Adriatic and southern Tyrrhenian in winter and autumn.

Trends and seasonality: *Caretta caretta's* range stayed stable in the Adriatic but significanly expanded northward and westward in the western Mediterranean, likely due to warming seas extending its preferred 19–21°C thermal range.*Caretta caretta* shows **dynamic habitat use throughout the year**, concentrating in stable, prey-rich areas during **winter** and autumn, influenced by topography and thermal variability. In **spring** and **summer**, it spreads into offshore zones like the Ligurian Sea and Sardinia Channel. This seasonal shift reflects changing resource distribution and possible migratory movements.

Populations and trends of key CEPTU species assessed in the Mediterranean

The LIFE CONCEPTU MARIS project assesses populations and trends of key CEPTU species using distribution data, ecological ranges, and population density indices. Population density indices were calculated for Balaenoptera physalus, Stenella coeruleoalba, Ziphius cavirostris, and Physeter macrocephalus using two indices: D_sight (sightings per unit effort) and D_animals (animals per unit effort), based on observations from passenger ferries. These calculations factor in the **effective strip width (ESW)**, which varies depending on the ferry type.

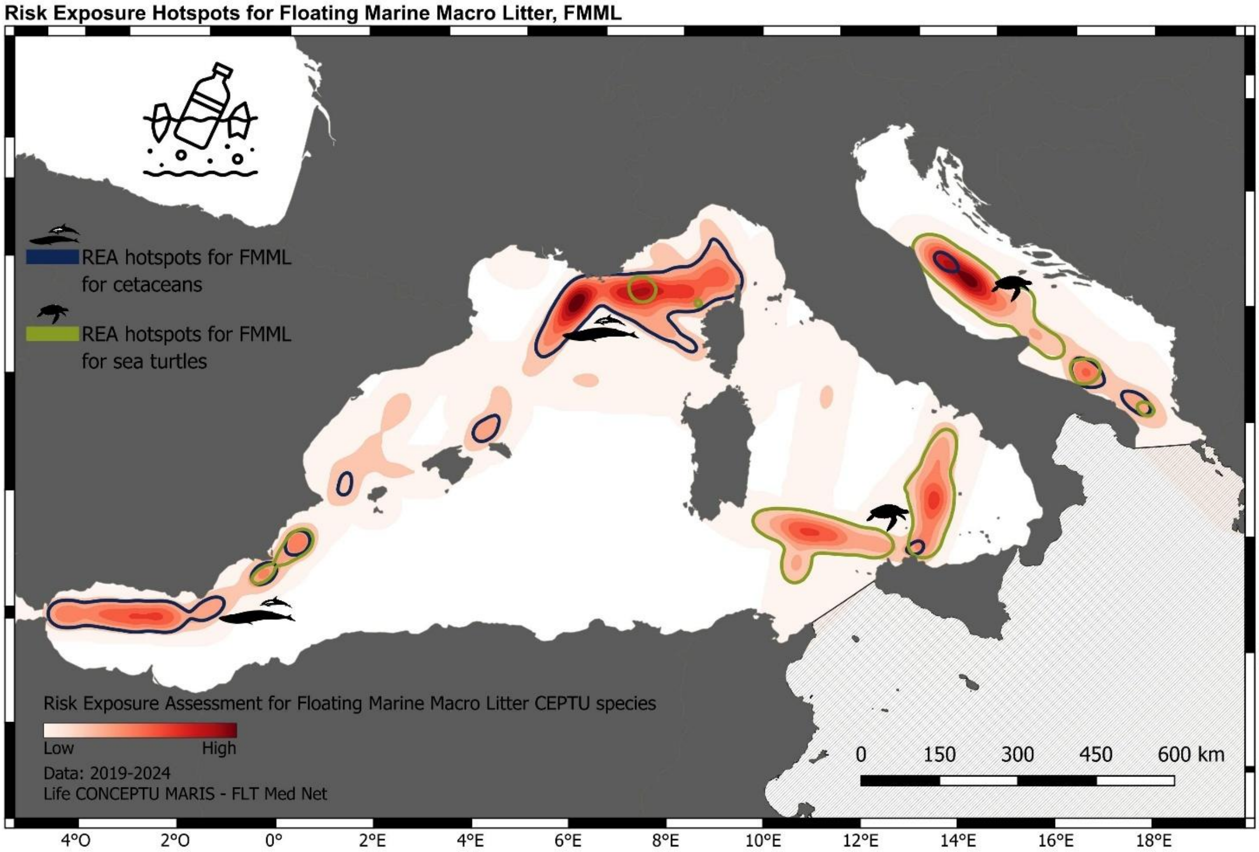
Balaenoptera physalus generally shows a stable presence in the Western Mediterranean but is rare in the Adriatic, with a significant increasing trend observed in the most recent reporting period (2019-2024), particularly in the Pelagos Sanctuary. In contrast, ***Stenella coeruleoalba*** experienced a decline from 2010 to 2016 but has since shown a more stable phase, with an increase in group size in Italian waters. ***Ziphius cavirostris*** shows an overall increasing trend, especially in the last five years, with higher densities in French and Italian EEZs. ***Physeter macrocephalus*** generally exhibits stable presence with marked interannual variability, and higher densities in French waters. These assessments inform policy implications, recommending targeted monitoring, mitigation, and cross-border collaboration to ensure regional population stability.

7.2 CEPTU Risk Exposure Areas

Anthropogenic pressures, specifically Floating Marine Macro Litter (FMML) and maritime traffic (MT), significantly impact the distribution and vulnerability of marine species such as cetaceans and pelagic sea turtles (CEPTU species) in the Mediterranean Sea. These pressures are considered direct and widespread threats, posing risks like ingestion, entanglement, habitat degradation, disturbance, habitat fragmentation, continuous noise, and vessel collisions. Understanding these pressures is crucial for evaluating exposure risks and supporting conservation status assessments under directives like the EU Habitats Directive and Marine Strategy Framework Directive.

Floating Marine Macro Litter (FMML) Impacts and Risk

Risk Exposure Hotspots for Floating Marine Macro Litter, FMML



Nature and Distribution of FMML: FMML (items ≥ 20 cm) is a significant threat, primarily composed of plastics, which can be ingested by marine animals or cause entanglement, degrading the quality of their surface habitat.

- **Overall Density and Hotspots:** A mean density of 1.2 ± 1.4 items/km² was observed in the Western and Central Adriatic Sea between 2019 and 2024. **Stable high-density areas** (over 3 items/km²) include the **Central Adriatic, the Southern Tyrrhenian, and the Ligurian/Liguro-Provençal Seas**. The Alboran Sea, Strait of Sicily, and Sardinia Channel also show significant concentrations during specific seasons.
- **Seasonal Patterns:** FMML densities are lower in autumn and winter (around 0.9 items/km²) but **sharply increase in spring and summer** (around 1.1-1.2 items/km²). During warmer seasons, pronounced hotspots are particularly evident in the Ligurian/Liguro-Provençal Seas, the southern-central Tyrrhenian Sea (near Palermo), and the Sardinia Channel.

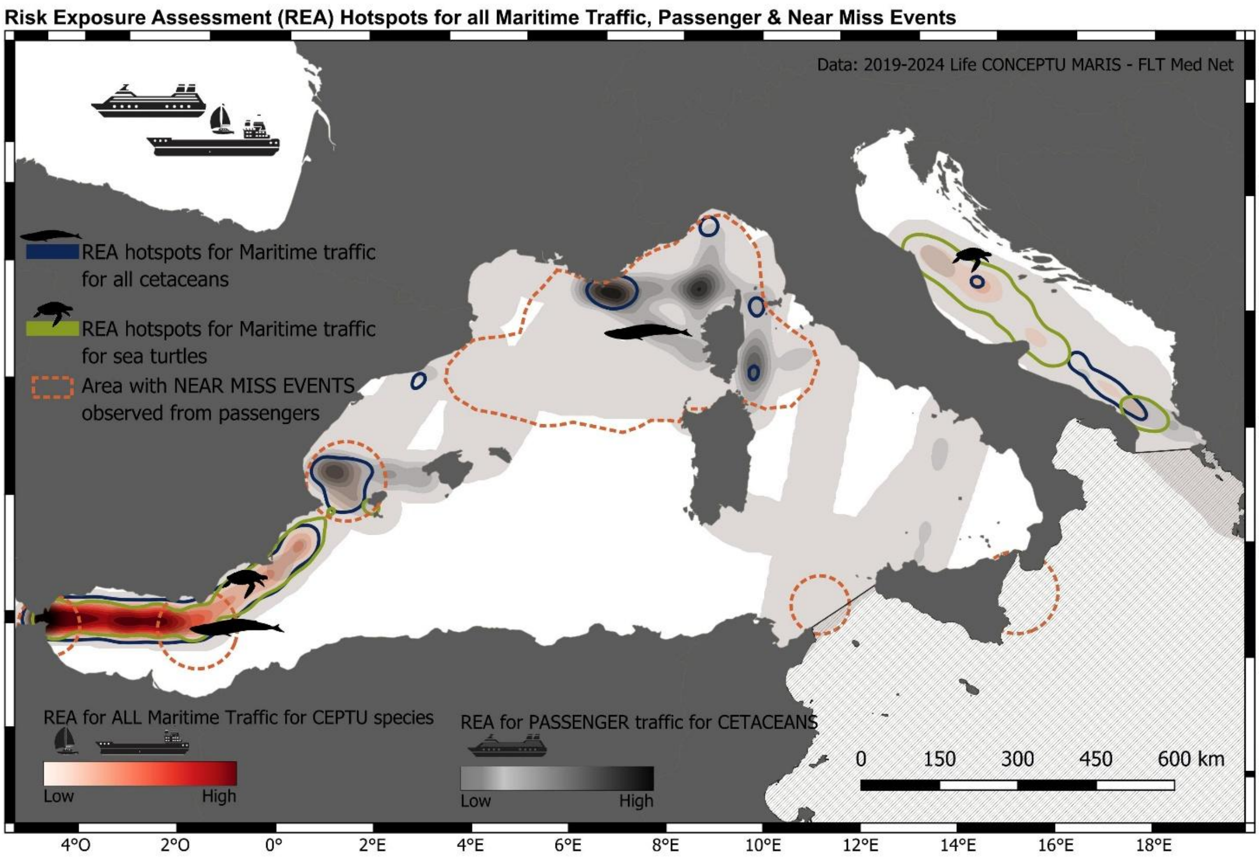
Risk Exposure to FMML for CEPTU Species: The analysis of FMML exposure risk reveals distinct spatial and seasonal patterns across the Western Mediterranean and Adriatic Sea.

- **All Cetaceans:** The **Ligurian–Provençal Basin** is identified as the most prominent and statistically consistent hotspot for all cetaceans, showing high cumulative risk and persistent seasonal overlap, especially in spring and summer. The **Alboran Sea** is another recurrent exposure zone, with significant clusters across winter, spring, and autumn. Seasonal hotspots also appear in the southern Tyrrhenian and Adriatic Seas.
- **Low-Density Cetaceans** (*Ziphius cavirostris, Grampus griseus, Globicephala melas*): Exposure is more localized but ecologically relevant. The **Alboran Sea** is a primary exposure hotspot throughout the year. Other notable clusters are found off the Gulf of Lion and Ligurian Sea (spring, summer, autumn), and seasonally in the Sardinia Channel, off Palermo, and off the Campania coast.
- **Sea Turtles** (*Caretta caretta*): Exposure is most concentrated and persistent in the **Adriatic and Central Tyrrhenian Seas**, with stable risk patterns year-round. Seasonal expansion occurs in spring and summer, with additional hotspots in the Sardinia Channel, Balearic Sea, and northwest of Corsica. Minor risk areas also include the northern Alboran Sea and southeastern French coast.
- **All CEPTU Species Combined:** The **Adriatic Sea** consistently emerges as a high-risk area, particularly in winter and summer. In the **Tyrrhenian Sea**, exposure is persistent with a summer intensification in the Sardinia Channel and along the Campania coast. Smaller but significant hotspots appear in the Alboran Sea, and in spring/summer, new hotspots emerge in the Sicily Channel, southern Ionian Sea, and Ligurian Sea.

Policy Implications for Floating Marine Macro Litter (FMML) Mitigation:

- The **Ligurian–Provençal Basin** is a high-priority area for reducing FMML impact on multiple cetacean species.
- The **Adriatic and Central Tyrrhenian Seas** are critical year-round exposure zones for sea turtles.
- Mitigation strategies should be dynamic and **time-sensitive**, including seasonal clean-up efforts, improved waste management at sea and in ports, and enhanced monitoring.
- Localized exposure patterns necessitate **species-specific actions**, especially for less abundant species.

Maritime Traffic (MT) Impacts and Risk



Nature and Distribution of MT: Maritime traffic contributes to disturbance, habitat fragmentation, continuous noise, and vessel collisions, which are increasing factors influencing species distribution and survival.

- **Overall AIS Traffic:** Maritime traffic in the Mediterranean is highly structured along two main corridors: **west–east** (Strait of Gibraltar to Suez Canal) and **north–south** (linking Europe and North Africa). High-intensity routes include the Strait of Gibraltar, Tyrrhenian Sea, Adriatic Sea, Sicily Channel, and Aegean Sea.
    - Traffic is dominated by **cargo (44.3%) and tanker (19.0%) vessels**, with overall activity peaking in spring and summer, especially in coastal and island areas.
    - The **Spanish EEZ** records the highest average traffic density (18.4 routes per km²), followed by Italy and France.
- **Leisure Vessels (*In-situ* Data):** AIS typically does not track most leisure vessels. *In-situ* observations from ferries reveal that leisure traffic is strongly coastal, concentrated near ports, anchorages, and shallow waters, with clear **seasonal peaks in summer** (2018–2024 data for the northwestern Mediterranean).

Risk Exposure to MT for CEPTU Species: Maritime traffic analysis identifies clear spatial risk patterns shaped by the overlap of species presence with shipping activity.

- **All CEPTU Groups (Cetaceans and Sea Turtles):** The **Alboran Sea and Strait of Gibraltar** consistently emerge as the **most critical and consistent high-risk exposure areas**, showing high exposure levels year-round for all CEPTU groups.

- **All Cetaceans:** Persistent risk hotspots are in the **Alboran Sea along the Spanish coastline and within the Strait of Gibraltar**. Additional seasonal hotspots appear along the southern Spanish migratory corridors and within the **Pelagos Sanctuary**, especially during spring and summer.
- **Low-Density Cetaceans** (*Ziphius cavirostris, Grampus griseus, Globicephala melas*)**:** Exposure is more geographically limited but still centres on the **Alboran–Gibraltar region**. Localized seasonal hotspots appear in parts of the northern Pelagos Sanctuary, off Savona, and near the Bonifacio Strait during spring and summer.
- **Sea Turtles** (*Caretta caretta*): Exposure is strongest in the **Adriatic Sea** (central-northern sector). An additional noteworthy seasonal hotspot appears off the **Gulf of Tunis** during autumn-winter, likely due to both intense traffic and its ecological importance for pelagic adult turtles.
- **Passenger Vessel Traffic Only:** This analysis reveals partially distinct patterns compared to total traffic.
    - **Higher exposure** is found in the **Pelagos Sanctuary**, **Tyrrhenian Sea**, **Balearic ferry corridors**, and parts of the **Adriatic** (particularly relevant for *Caretta caretta* and *Tursiops truncatus*).

Near Miss Events (NMEs)

Definition and Occurrence: A Near Miss Event (NME) is defined when an animal is sighted unaware of an approaching ship at a minimum distance of 50 m in front of the bow and 25 m on the side, serving as a **proxy for ship strike**.

- From 2008 onwards, over 630,000 km of effort and 4,585 sightings of large and medium cetaceans, **101 NMEs were recorded**.
- Five species were involved: ***Balaenoptera physalus* (73 NMEs), *Ziphius cavirostris* (10), *Physeter macrocephalus* (9), *Globicephala melas* (5), and *Grampus griseus* (4)**.
- Most NMEs (88) occurred during **summer** (April to September), but some (13) also happened during winter (November to March).
- NMEs occurred on almost all monitored routes. The ratio of NME over total sightings ranges from 2% to 3.6% depending on the species.

NME Distribution and Correlation with Risk Areas:

- The **north-western Mediterranean Sea** is the area where most species are threatened by NMEs, confirming the importance of the newly designated Particularly Sensitive Sea Area (PSSA).
- For *Balaenoptera physalus*, NMEs occurred mainly in the north-western Mediterranean Sea, with areas like the north Tyrrhenian Sea (east of Corsica, Bonifacio Strait) to offshore the Gulf of Lion, including the Ligurian Sea. There is a **significant correlation between Encounter Rate (ER) and ER of NME**, indicating that **higher species abundance leads to higher NME risks**.
- However, NMEs can also occur in areas with rare species presence, like the Sicily Channel (one *Balaenoptera physalus* NME from a single sighting) and Gibraltar (one *Balaenoptera physalus* NME from two sightings), highlighting that "zero risk" does not exist.
- New areas of risk for large and medium cetaceans were also highlighted: **Gibraltar and Alboran Sea, the Balearic Channel, and the Sicily Channel**, likely linked to high maritime traffic intensity.

- The maps of observed NME distribution **globally match the high Risk Exposure Areas obtained from the analysis with AIS data of passenger vessels**, thus **validating the Risk Exposure Analysis approach**.

Factors Influencing NMEs:

- The reasons for NMEs cannot be easily linked to initial animal behavior (most were travelling, not resting or feeding), cycle within the day, season, or response to the vessel (many were indifferent or escaping).
- However, **Encounter Rate of the species and speed of the vessel play a major role**. For *Balaenoptera physalus*, the speed of the ferry was significantly higher during NMEs compared to all other sightings.

Policy Implications for Maritime Traffic Mitigation:

- The Alboran–Gibraltar region is the most critical multispecies exposure hotspot and should be a top conservation priority.
- The Adriatic Sea is a key risk zone, especially for sea turtles.
- Other areas, such as the Pelagos Sanctuary, show seasonal and species-specific exposure, requiring targeted and adaptive management.
- Policy measures should consider specific vessel categories (e.g., passenger vs. cargo) to more effectively mitigate risks.

Policy Implications from Near Miss Event (NMEs):

- The PSSA is an important tool for mitigating ship strikes if associated protection measures are applied.
- New areas like the Balearic Channel (between Ibiza and mainland Spain) and the Alboran Sea could benefit from protection through speed reduction.
- Continued long-term monitoring of NMEs is crucial for enhancing knowledge, raising crew awareness, assessing conservation measure efficiency, and informing adaptive management strategies.

In conclusion, both marine litter and maritime traffic exert significant and dynamic pressures on Mediterranean marine species. While specific risk hotspots vary by pressure type and species, integrated approaches combining visual observations, eDNA, stable isotope analysis, and robust risk assessment methodologies are essential for identifying critical conservation areas and developing effective, adaptive, and cross-border protection strategies.

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