UNIVERSITAT POLITÈCNICA DE VALÈNCIA

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## Higher Polytechnic School of Gandia

# Analysis of the overlap between the apparent fishing effort and the loggerhead turtle habitat in the Western Mediterranean Sea

Master's Thesis

Master's Degree in Assessment and Environmental Monitoring of Marine and Coastal Ecosystems

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ACADEMIC YEAR: 2023/2024

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# ACKNOWLEDGMENTS

First of all, I would like to thank my advisor, Eduardo Belda, for giving me the opportunity to do this work, for helping me, and for being patient. I also want to thank Jesús Tomás, my co-advisor, for taking the time to advise me on this work. Additionally, I want to thank Sergi for teaching me and helping me with part of this work.

This work was made possible thanks to the Universitat Politècnica de València, LIFE IP INTEMARES [28-5296], the Spanish Ministry of Environment (MITECO) [16MNSV006], the Ministry of Economy, Industry and Competitiveness [CGL2011-30413], the BBVA Foundation ("BBVA Foundation Grants for Scientific Research Teams 2016"), NOAA Fisheries Pacific Islands Fisheries Science Center, and the Oceanogràfic Foundation of the Valencian Community. Also, thanks to the InGeNi-Caretta Project (Ref. I123) supported by the Fundación Biodiversidad MITECO under the Recovery, Transformation and Resilience Plan (PRTR) financed by the European Union NextGenerationEU. The Fundación Biodiversidad provided four tags funded by LIFE 15 IP ES012 INTEMARES for females. NGO Eucrante tagged 10 juvenile loggerhead turtles in 2021 under contract with the Fundación Biodiversidad within LIFE 15 IP ES012 INTEMARES, and the analysis of those satellite data was funded by that contract and the ARGOS data by the UPV. The LIFE MEdTurtle project funded several juveniles in 2021 and two adults. The Murcia Region Government provided tags and tracking data for three juveniles, and NGO ANSE provided three tags; the UPV funded the data for them. The Balearic Islands Government provided six tags, and the tracking data for these tags was paid for by the UPV. Except for the data from the Murcia Region, all tracking data was included in the AGROS program 5788 and 6297 of the UPV, and 7211 of UV.

# ABSTRACT

Incidental capture by the fishing fleet is one of the main causes of loggerhead turtle mortality in the Mediterranean. Surface longlining has always been the primary cause of incidental catches, but a change in métier now points to bottom trawling as the main culprit. The loggerhead turtle in the Mediterranean is classified as vulnerable, so understanding the distribution and habitat use of this species is crucial to comprehend how and where they interact with the fishing fleet to improve conservation efforts. To this end, satellite tracking data of 126 loggerhead turtles at different life stages, released in the Mediterranean during the period 2003-2024, and fishing effort data from AIS (Automatic Identification System) of the trawling fleet over the last 10 years were analyzed to locate areas with the highest potential risk of capture of this species. Relative densities were analyzed using post-processed state-space model locations, and the overlap method with average fishing effort was used to create potential risk maps. The highest densities of adult individuals were found in the Algerian Basin, but fishing effort data was not available. The Ebro Delta appears to be the area of highest risk for juveniles, and the Valencian Community and Murcia for adults and females. This study is fundamental for the conservation of the loggerhead turtle in the Mediterranean, as this insight can provide a basis for decision-making in marine management.



***Key words:*** *Caretta caretta; Apparent fishing effort; Bycatch; Western Mediterranean*

# INTRODUCTION

The Mediterranean Sea has an approximate area of 2,500,000 km² and is considered a semi-enclosed and oligotrophic sea (Margalef, 1985) , meaning it is an area of low primary production since nutrients are continuously lost through the deep bottom current that flows out through the Strait of Gibraltar into the Atlantic. This situation has not prevented fishing from always being associated with the Mediterranean Sea, not only for its fundamental role in the economy of coastal populations but also as an intrinsic part of their culture (FAO, 2018). However, today, fishing is considered one of the most harmful human activities for the oceans (Jackson et al., 2001).

Although the actual size of the loggerhead turtle population in the western Mediterranean, Alboran Sea, and Gulf of Cádiz is unknown, it is largely due to the ecology and migratory habits of sea turtles (Valeiras et al., 2001), the stock of turtles in the western Mediterranean has decreased as a result of incidental capture in fishing. Collisions, ingestion of debris, and chemical pollution have always been identified as threats to turtles (Margaritoulis et al., 2003), but for years now, interaction with the fishing fleet has been pointed out as probably the main threat to this species in the Mediterranean, incidentally capturing thousands of individuals each year (Aguilar, 1995;Carreras et al., 2004;Casale et al., 2007).

The geospatial characterization of marine species dependent on conservation provides crucial information for management (Foley et al., 2010). Describing the overlaps between threats and population segments allows for an understanding of the impacts on widely distributed marine megafauna populations, such as turtles (Wallace et al., 2010a). Widely distributed marine species often show variations in population dynamics, which justifies specific management for each population (Bowen et al., 2005)

Spatial-temporal overlap assessments have been used as an indicator of encounter risk between protected species and commercial fishing effort to reduce bycatch (Hatch et al., 2023a).Many studies have explored this method to aid in bycatch mitigation (Cronin et al., 2016; Hatch et al., 2016; Stepanuk et al., 2018;Baird et al., 2021;Murray, 2021). Mitigating bycatch of protected species involves understanding where and when interactions occur and how they relate to commercial fishing (Senko et al., 2013), which can lead to modifications in fishing gear or temporary closures as a strategy to reduce bycatch in fisheries (Hatch et al., 2023b).

**The loggerhead sea turtle and life cycle in western Mediterranean**

The loggerhead turtle (Caretta caretta (Linnaeus, 1758)) is the most common marine turtle species in the Mediterranean. However, regular nesting only occurs in the eastern Mediterranean (Margaritoulis et al., 2003), while the western Mediterranean is primarily used as a feeding area for immature individuals (Laurent et al., 1998; Carreras et al., 2006) that come from nesting areas in the eastern Mediterranean and northwestern Atlantic (Carreras et al., 2006). The life cycle is complex; early juveniles have an oceanic distribution but migrate to neritic habitats after reaching sexual maturity. Late juveniles and adults constantly migrate between neritic foraging areas and nesting sites (Bolten et al., 2003) The distribution of hatchlings and early juveniles is considered passive and dominated by currents (Milsom, 1975), although active swimming has been reported (Bolten et al., 2003)while adults are good swimmershat actively seek out habitat (Godley et al., 2003).

**General conservation status**

In the Mediterranean, individuals from three Regional Management Units (RMUs) coexist: the Northwestern Atlantic RMU, the Northeastern Atlantic RMU, and the Mediterranean RMU (Monzón-Argüello et al., 2010; Wallace et al., 2010) (Figure 1). Most loggerhead turtles in the region come from the Northwestern Atlantic and

Mediterranean RMUs, both of which are considered to be exposed to high threats, although the risk of extinction is currently low (Wallace et al., 2011)

The loggerhead turtle (Caretta caretta) is classified as Vulnerable by the IUCN (International Union for Conservation of Nature). It was considered "Endangered" in 1996, but in 2015, following a review of the species' status, it was reclassified as "Vulnerable." The criteria used for assessment procedures require data spanning at least three generations, which is nearly impossible to obtain for long-lived species like the loggerhead turtle. In the Mediterranean, it is listed as a species of Least Concern but dependent on conservation efforts. In Spain, the loggerhead turtle is included in Annex II of the Habitats Directive as a priority species, and Spanish legislation has listed it in the Spanish Catalogue of Threatened Species.

The main conservation efforts in the Mediterranean have focused on protecting nesting sites in Greece, Turkey, and Cyprus (Casale & Margaritoulis, 2010) with the goal of increasing the species' survival rate through nest relocation and protection (Hochscheid et al., 2022).

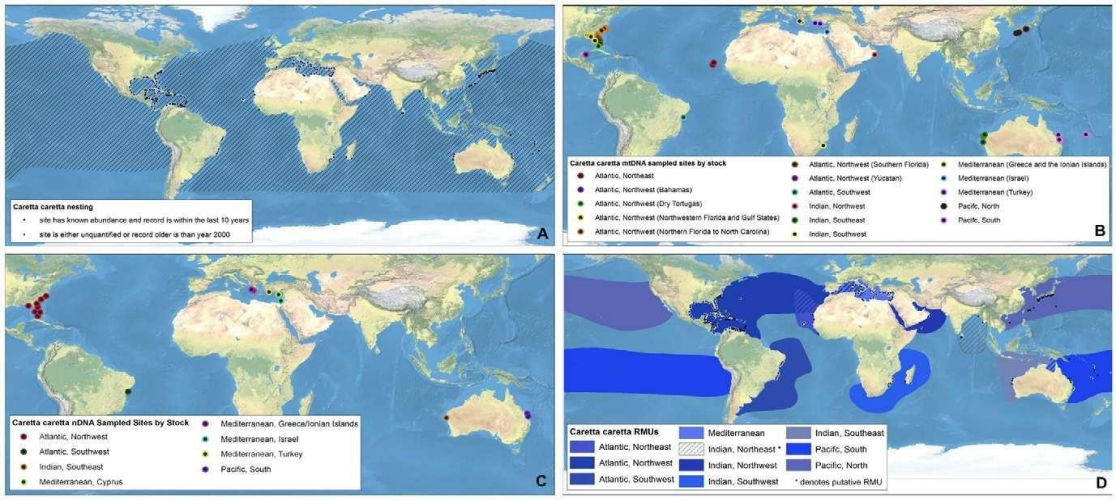


*Figure 1: multi scale regional management units for loggerhear turtles caretta caretta.* (Wallace et al., 2010b).

**Main fishing gear involved in the bycatch of loggerhead turtles in the Mediterranean.**

Fisheries by-catch and ingestion of plastic debris are considered the main causes of mortality for loggerhead sea turtles (Casale et al., 2010). Incidental capture in fisheries is recognized as the greatest threat to the conservation of the loggerhead turtle (Wallace et al., 2010a). The main limitation in estimating incidental capture rates is the lack of reliable information on fishing effort and the number of captures in small-scale fisheries (Wallace et al., 2010; Casale, 2011). The survival rate of animals after interaction with the fishing fleet is a limitation in understanding the true impact (Lewison et al., 2013a), as the number of threatened or endangered sea turtles killed by incidental capture in commercial fisheries may be significantly underestimated if decompression effects are not considered (Fahlman, 2016) .

Prior to 2000, surface longlining was considered the fishing gear with the highest incidental capture of loggerhead turtles in the Western Mediterranean. From that year onwards, there was a shift in the contribution of each métier to the total effort, where this gear that focused on swordfish fishing gradually shifted towards deeper semi-pelagic longlining methods that led to a significant decrease in sea turtle mortality by this gear (Báez et al., 2019). Increasing the depth of lines implemented on some vessels also significantly reduced turtle captures (Tomás et al., 2008;Báez et al., 2019). Moreover, reports reveal low levels of post-release mortality in turtles caught by surface longlines (Alvarez De Quevedo et al., 2010). Thus, the overall capture of sea turtles by surface longlines is not very high, and the mortality of incidentally caught turtles can be considered relatively low (Marco et al., 2020) so trawling fleets now pose the greatest threat to this species

Casale et al. (2004) reported high levels of sea turtle bycatch by bottom trawlers in the Adriatic Sea (eastern Mediterranean), but any evidence in northeastern Spain was scarce, and the potential bycatch there had never been quantified (Bertolero, 2003). In fact, Carreras et al. (2004) and Báez et al. (2006) reported extremely low rates of sea turtle bycatch by bottom trawlers in the Balearic Archipelago and

southern Spain, respectively, and it was generally assumed that bottom trawlers had a negligible impact on sea turtles. Several studies point to this fishing gear and other neritic gears as the causes of the high incidental capture rates and strandings along the coasts of the Western Mediterranean (Tomás et al., 2008). In 2010, studies assessing the relevance of different fishing gear in the bycatch of loggerhead turtles identified the trawling fleet as responsible for more than half of the captures of this species (Alvarez De Quevedo et al., 2010). Topographic differences along the Mediterranean coasts, with areas where trawlers would need several hours to reach the slope, force these vessels to operate on the continental shelf, where the highest incidental capture rates of loggerhead turtles have been reported with an estimated capture rate by the Spanish trawling fleet of around 500 turtles per year in this region (Domènech et al., 2015).

In this context, this study aims to evaluate the areas of the western Mediterranean where there is a higher risk of incidental capture of Loggerhead turtles by the trawling fleet, as today it seems to be the fishing gear that reports the most captures.

# METERIAL AND METHODS

Satellite-tracking data from 126 loggerhead turtles were utilized: 17 female, 11 male/unknown and 98 juveniles (early juveniles <40 cm, late juveniles > 40 cm and post-hatchlings). 76 of those loggerhead turtle specimens (62 juveniles, 3 females, and 11 males/unknown) were previously analyzed (Table 1) and reanalyzed to meet the objective of the present study. The remaining data, belonging to 36 juveniles and 14 females, are provided in this work (Table 2). The data from females were fully analyzed, and the data from juveniles had been previously analyzed without being published and were reanalyzed in this study. These turtles were opportunistically tagged during nesting events on Spanish Mediterranean beaches between 2003 and 2024. For the overlap study, the data are grouped into females, juveniles, and adults (males + females). For the study, the turtle data has been grouped into three categories: Adults with data on both male and female turtles, juveniles with data on hatchlings, early juveniles, and late juveniles, and a third category that only considers females due to their importance and vulnerability

Fishing effort data for the period 2014-2024 from fishing trawler vessels was used. These data were obtained from the Global Fishing Watch (GFW) database, which uses AIS (Automatic Identification System) data, a tracking system used by vessels worldwide. GFW has developed an algorithm that allows near real-time monitoring of fishing effort on a global scale. The algorithm classifies activities as fishing or non-fishing (transit) based on vessel movements such as speed and direction. The study focuses on FAO area 37.1, which geographically encompasses the waters of the Western Mediterranean. This region includes the coastal waters of countries such as Spain, France, Italy, Malta, Tunisia, and Algeria, where, according to the latest FAO report (2023), fishing pressure levels are still twice above the sustainable level for this sea.

Satellite tracking data and fishing effort data were combined to create bycatch risk maps for loggerhead turtles in the western Mediterranean.

*Table 1: Compilation of satellite tracking data used in the present work by life stage and data source: i) data from [dataset] Abalo-Morla et al., 2022 ii) published open access data, or iii) unpublished data provided for the thesis of Abalo-Morla et al., 2023.*

| Life Stage | n | Source | Range of deployments year |
|---|---|---|---|
| **Post-hatchlings** | 17 | [dataset] Abalo-Morla S, Belda EJ,Crespo-Picazo JL (2022) | 2015-2017 |
| **Early juveniles** | 1 | [dataset] Abalo-Morla S, Belda EJ,Crespo-Picazo JL (2022) | 2016-2018 |
| | 1 | Abalo-Morla et al., 2022 | 2011 |
| | 3 | Cardona and Hays (2018) | 2003-2005 |
| **Late juvenile** | 8 | [dataset] Abalo-Morla S, Belda EJ,Crespo-Picazo JL (2022) | 2017-2018 |
| | 9 | Abalo-Morla et al., 2022 | 2011-2016 |
| | 10 | Williard et al., 2015 | 2008-2010 |
| | 9 | Cardona and Hays (2018) | 2003-2004 |
| | 4 | Chimienti et al., 2020 | 2003-2018 |
| **Adults** | 3 female | [dataset] Abalo-Morla S, Belda EJ,Crespo-Picazo JL (2022)<br>Abalo-Morla et al., 2023 | 2016-2022 |
| | 7 male | Abalo-Morla et al., 2022 | 2012-2014 |
| | 4 male | Wiliard et al., 2015 | 2008-2009 |

*Table 2: Compilation of satellite tracking data used in the present work by life stage, ID, deployment date and tracking days. Satellite tags and satellite tracking data for these individuals were funded by different sources: InGeNi-Caretta Project (Ref. I123) supported by the Fundación Biodiversidad MITECO under the Recovery, Transformation and Resilience Pland (PRTR) financed by the European Union NextGenerationEU. Fundación Biodiversidad provided four tags funded by the LIFE 15 IP ES012 INTEMARES for females. NGO Eucrante tagged 10 juvenile loggerhead turtles in 2021 under contract by the Fundación Biodiversidad within the LIFE 15 IP ES012 INTEMARES, and the analyses of that satellite data were funded by that contract and the ARGOS data by the UPV. Project LIFE MEdTurtle funded several juveniles in 2021 and two adults. The Murcia Region Government provided tags and tracking data for three juveniles, and NGO ANSE provided three tags; the UPV funded the data for them. The Balearic Islands Government provided 6 tags, the tracking data for these tags was paid by the UPV. Except for the data from the Murcia Region, all tracking data was included in the AGROS program 5788 and 6297 of the UPV., and 7211 of UV".*

| Life Stage | ID | Name | Deployment date | Tracking days |
|---|---|---|---|---|
| **Female** | 202027 | Victoria | 30/07/2020 | 1116 |
| **Female** | 202028 | Elena | 10/07/2021 | 82 |
| **Female** | 232740 | Ana_2023 | 16/06/2023 | 249 |
| **Female** | 221927 | Diana | 18/06/23 | 247 |
| **Female** | 202563 | Borgia | 19/06/2023 | 57 |
| **Female** | 243309 | PaulaOliva | 21/06/2023 | 95 |
| **Female** | 202567 | Laura | 22/06/2023 | 24 |
| **Female** | 202564 | PoliCarmen | 36/06/2023 | 34 |
| **Female** | 202565 | Devesa | 13/07/2023 | 49 |
| **Female** | idYaiza | Yaiza | 30/06/2018 | 87 |
| **Female** | idMurcia | Murcia | 17/12/2018 | 28 |
| **Female** | idMaria | Maria | 1/07/2018 | 15 |
| **Female** | idANA | ANA | 09/07/2018 | 78 |
| **Female** | idLluna | Lluna | 18/09/2016 | 75 |
| **Juvenile** | Alfonsina | Alfonsina | 07/10/2021 | 51 |
| **Juvenile** | ANA | ANA | 09/10/2021 | 230 |
| **Juvenile** | Anibal | Anibal | 05/02/2021 | 26 |
| **Juvenile** | Ardo | Ardo | 15/10/2021 | 30 |
| **Juvenile** | Argonauta | Argonauta | 15/10/2020 | 300 |
| **Juvenile** | Arturo | Arturo | 12/10/2020 | 267 |

| | | | | |
|---|---|---|---|---|
| **Juvenile** | Bella | Bella | 01/10/2021 | 185 |
| **Juvenile** | Bobico | Bobico | 06/10/2020 | 73 |
| **Juvenile** | Careto | Careto | 06/10/2020 | 166 |
| **Juvenile** | Escipión | Escipión | 12/10/2020 | 238 |
| **Juvenile** | Fameliar | Fameliar | 04/03/2021 | 179 |
| **Juvenile** | Intemares | Intemares | 01/10/2021 | 82 |
| **Juvenile** | Intemares 2 | Intemares 2 | 22/01/2022 | 165 |
| **Juvenile** | Mar | Mar | 15/10/2021 | 172 |
| **Juvenile** | Marina_fuengirola2 | Marina_fuengirola2 | 02/11/2021 | 242 |
| **Juvenile** | Marina_Ibiza | Marina_Ibiza | 18/11/2020 | 117 |
| **Juvenile** | Patricia | Patricia | 15/10/2021 | 270 |
| **Juvenile** | Raul | Raul | 15/10/2021 | 154 |
| **Juvenile** | Savina | Savina | 07/10/2020 | 25 |
| **Juvenile** | Tanit | Tanit | 07/10/2020 | 245 |
| **Juvenile** | Vicent | Vicent | 01/10/2021 | 212 |
| **Juvenile** | Xereca | Xereca | 07/10/2020 | 178 |
| **Juvenile** | Seis | Seis | 01/09/2016 | 121 |
| **Juvenile** | Nueve | Nueve | 01/09/2016 | 37 |
| **Juvenile** | Wonder | Wonder | 03/07/2017 | 22 |
| **Juvenile** | Ali | Ali | 15/10/2018 | 82 |
| **Juvenile** | Luisa | Luisa | 15/10/2018 | 92 |
| **Juvenile** | 56459 | - | 24/10/2005 | 304 |
| **Juvenile** | 96211 | - | 27/08/2009 | 51 |
| **Juvenile** | NuevaVicenta | NuevaVicenta | 28/11/2017 | 79 |
| **Juvenile** | Princess | Princess | 13/12/2017 | 49 |
| **Juvenile** | Vistamar | Vistamar | 13/12/2017 | 62 |
| **Juvenile** | TheWorld | TheWorld | 05/07/2018 | 200 |
| **Juvenile** | Benjamin | Benjamin | 23/07/2018 | 24 |

| | | | | |
|---|---|---|---|---|
| **Juvenile** | Cuiqui | Cuiqui | 15/10/2018 | 91 |
| **Juvenile** | Kika | Kika | 19/11/2018 | 22 |

## Location data processing

Location data were obtained through the Argos satellite system that calculate a transmitter's location using the doppler effect on transmission frequency. Argos assigns a quality index (location class or LC) to each position based on the estimated accuracy in latitude and longitude. Argos does not provide an accuracy estimate for the location classes identified as LC A, LC B, and LC Z, but Hays et al. (2001) demonstrated that LC A is as accurate as LC 1 and more reliable than LC 0 or LC B (Revelles, Carreras, et al., 2007)therefore, the position data were filtered by selecting those of higher quality (precisions <1500 m, meaning LC Z were removed).

Although turtle movement may be continuous, satellite tracking provided a limited number of locations, so state-space models (SSMs) were employed. The hDCRWS model was fitted to the data; this model provides position estimates from observed data (Jonsen et al., 2013) and allows differentiation between two behavioral states: transit and areas of restricted search (ARS) (Lydersen et al., 2020) A total of 120,000 iterations were conducted in two MCMC (Markov Chain Monte Carlo) chains, with 60,000 discarded as burn-in. From the remaining iterations, every tenth sample was retained to reduce autocorrelation, resulting in estimated locations at 24-hour intervals from 6,000 MCMC samples (Abalo-Morla, Belda, Tomás, et al., 2022). The average behavioral state was estimated for each location, considering all bimodal MCMC samples, which were assigned values of 1 (transit) or 2 (ARS) for behavioral state.

## Relative density estimation

The locations obtained from the state-space model were used to calculate relative density estimates for each group of turtles. A time weighting method was employed to prevent biased towards tagging locations and to avoid overestimating long tracks in small areas, which might belong to turtles in feeding mode. This approach ensured that each animal contributed equally to generating spatial density patterns (Abalo-Morla, Belda, March, et al., 2022). Consequently, relative density maps were generated for each of the three studied groups on a 0.25 x 0.25-degree grid, which were rasterized for subsequent analysis.

## Fishing effort data acquisition

The fishing effort data were obtained from the Global Fishing Watch (GFW) database, generated from Automatic Identification System (AIS) locations. The acquired data cover the period from 2014 to July 2024 from fishing trawling vessels. The raster data are structured on a grid of 0.1- degree cells in WGS84, representing fishing effort and vessel presence measured in hours. Time is calculated by assigning a time value to each AIS detection and then summing all positions within each grid cell to obtain the cumulative sum from each AIS sensor transmitting within each cell (GFW) over a reference period, in this case one year.

## Overlap análisis using GIS

The raster data obtained for both relative turtle density and fishing effort wehere processed using Geographical Information Systems (GIS) – based techniques to obtain the overlap index analisis. First, both raster were reprojected ETRS89/ETRS-LAEA (Lambert Azimuthal Equal Area), which is the Europeam. Then, in order to co-register raster data the turtle relative density rasters were resampled using the bilinear interpolation method, changing the spatial resolution and alignment to match

the fishing effort raster. Bilinear interpolation method calculates the value of each new pixel as the weighted average of the four nearest pixels from the original raster (Serra et al., 2010).

Finally, the areas of overlap between the two rasters were identified as areas at risk of turtle capture. Multiplying the values of fishing effort and relative turtle density yields an index that correlates with the level of risk of capture. Where either fishing effort or relative density is zero, this index has no value.

# RESULTS

## Tracking data

After processing the tracking data of loggerhead sea turtles, a total of 18,046 locations were obtained (4,506 adults, 3,033 females, and 13,540 juveniles) (Figure 2) in the western Mediterranean over 21 years of monitoring, corresponding to one position per relative day of tracking period.

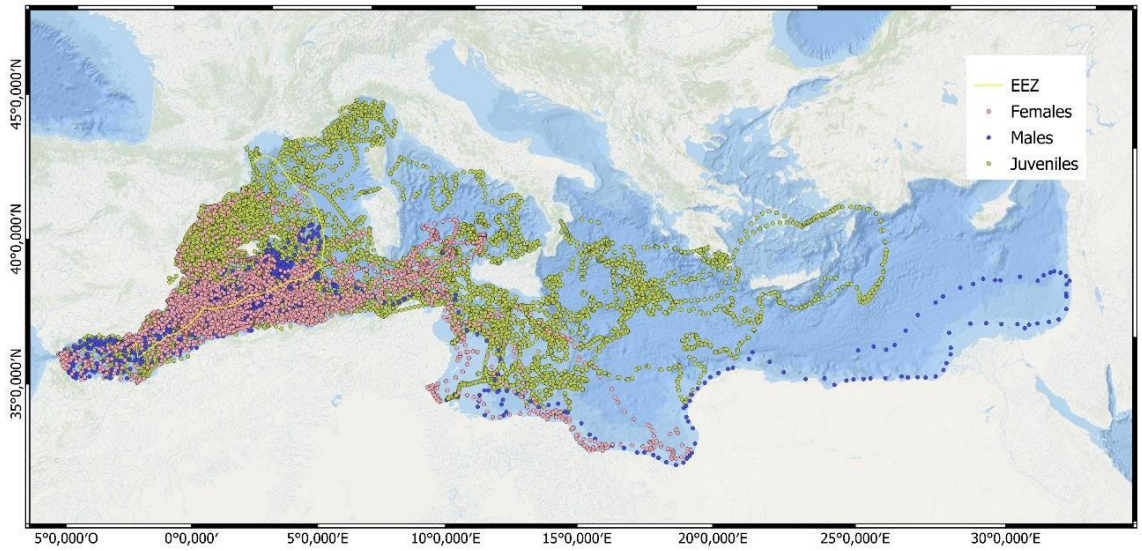


*Figure 2: Daily locations of loggerhead turtle specimens (adults, females, and juveniles) obtained through satellite tracking (ARGOS) during the study period in the western Mediterranean. The map shows the Spanish exclusive economic zone,(EEZ) marked by the 200-mile limit from the coast.*

The analysis of the tracking data shows that adult (male and female) loggerhead turtles generally concentrate in the Mediterranean basin (Figure 3) predominantly occupy neritic zones. Adult shows a concentrated distribution in the southwestern Mediterranean, with a preference for the area between Cape Nao, the southern Balearic Islands, and the Algerian Basin. Female loggerhead turtles exhibit a similar distribution to adults, with a preference for the waters off the coast of Murcia and the Algerian Basin (Figure 4). Juveniles, on the other hand, seem to concentrate in the northwestern Mediterranean, off the Catalonian and Valencian

coasts, and in the waters surrounding the Balearic Islands (Figure 5). The locations seem to show a trend in all cases of these animals preferring areas near the Algerian Basin so appears to be an important area of presence for all life stages of the loggerhead turtle in the Mediterranean.

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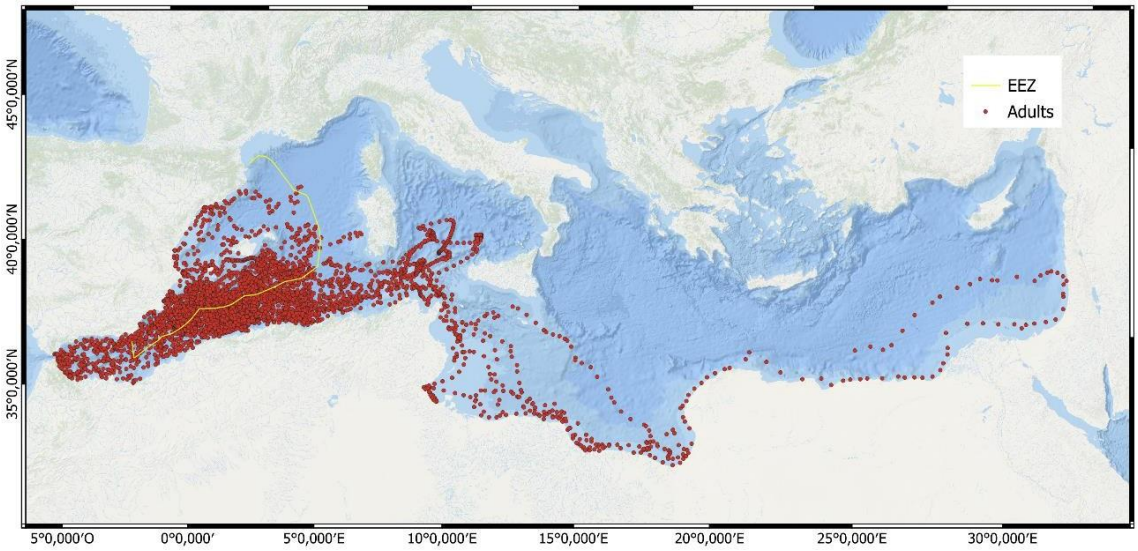


*Figure 3: Daily locations of adult loggerhead turtle specimens obtained through satellite tracking (ARGOS) during the study period in the western Mediterranean. The map shows the Spanish exclusive economic zone,(EEZ) marked by the 200-mile limit from the coast.*

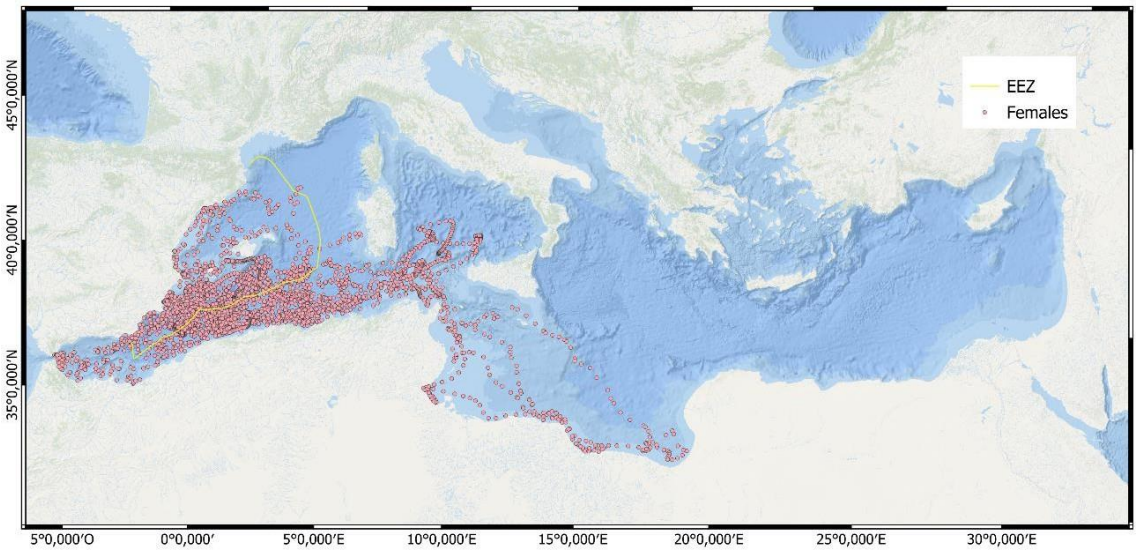


*Figure 4: Daily locations of female loggerhead turtle specimens obtained through satellite tracking (ARGOS) during the study period in the western Mediterranean. The map shows the Spanish exclusive economic zone,(EEZ) marked by the 200-mile limit from the coast.*

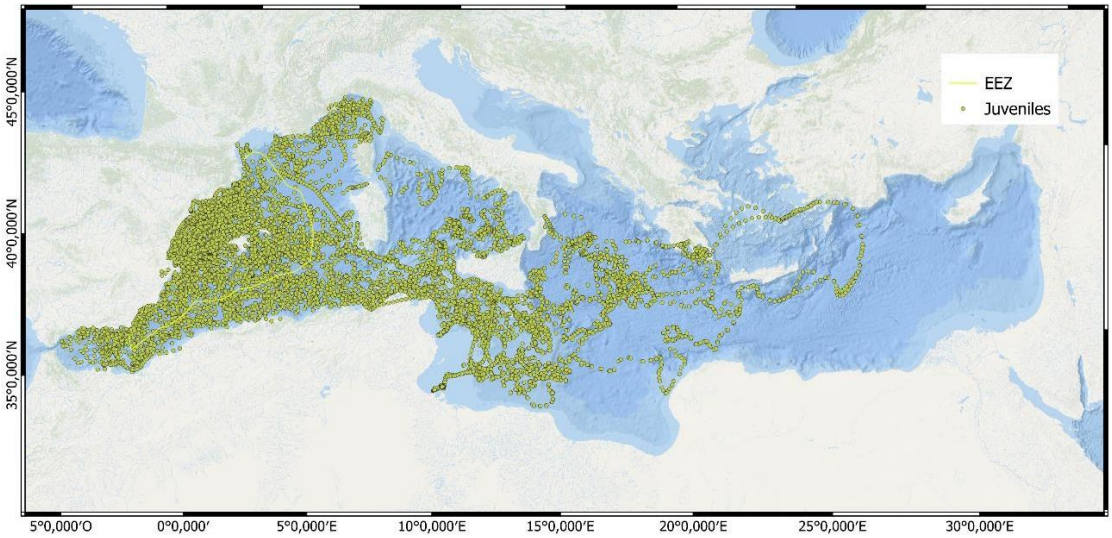


*Figure 5: Daily locations of juvenile loggerhead turtle specimens obtained through satellite tracking (ARGOS) during the study period in the western Mediterranean. The map shows the Spanish exclusive economic zone,(EEZ) marked by the 200-mile limit from the coast*

### Relative density of adult loggerhead turtles

The map shows the Algerian Basin as the area with the highest relative density of adult loggerhead turtles (Figure 6), with elevated values in oceanic zones. The Alboran Sea and the Catalan coast appear to be areas with a significant presence of this species, although in these cases, they seem to be in neritic zones. Other important areas are the submarine valleys of Mazarrón and Cabo de Palos, as well as the area near Cabo de la Nao.

On the other hand, the areas with the highest density of female loggerhead turtles are similar to those of the adults (Figure 7), showing a strong preference for the Algerian Basin and the marine area between the south of Cabo de la Nao and the Alboran Sea.

The Catalan coast south of the Gulf of Lion appears to be the area with the highest relative density of juvenile loggerhead turtles (Figure 8), extending to the Balearic Archipelago. The Algerian Basin also shows considerable levels of juvenile density. Juveniles tend to be in oceanic waters, although some points in southern Catalonia also show presence in neritic waters. However, there are no concentrations of juveniles along the rest of the Spanish Mediterranean coast.

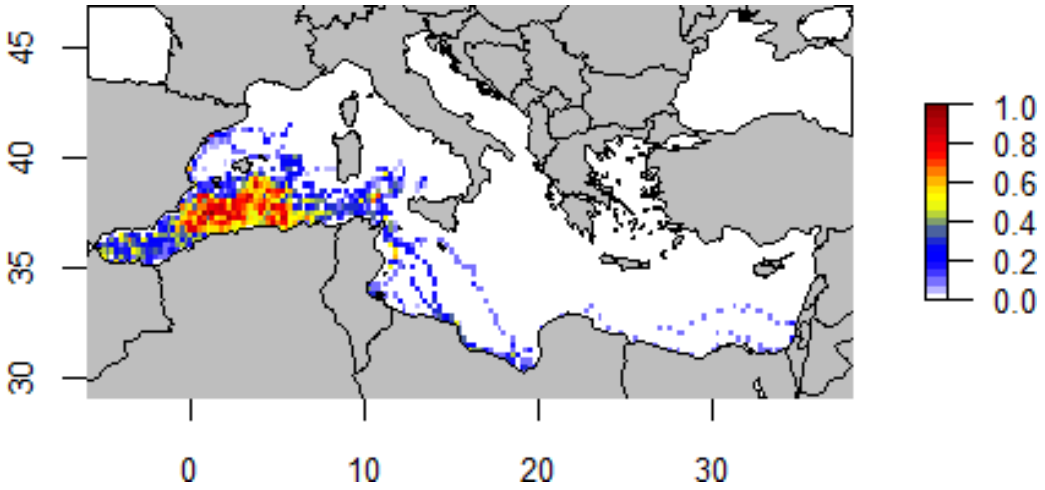


*Figure 6: Relative Density of Adult Loggerhead Turtles in the Western Mediterranean.*

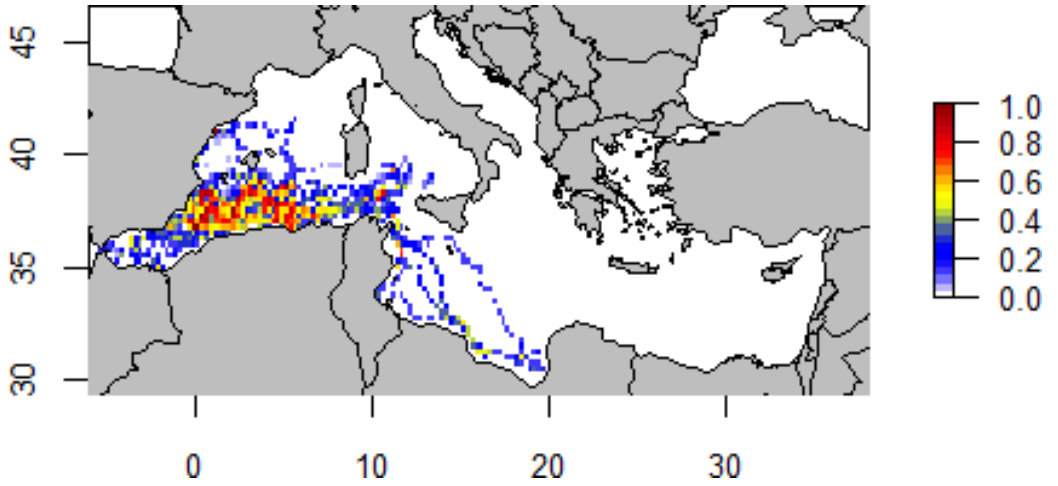


*Figure 7: Relative Density of Female Loggerhead Turtles in the Western Mediterranean.*

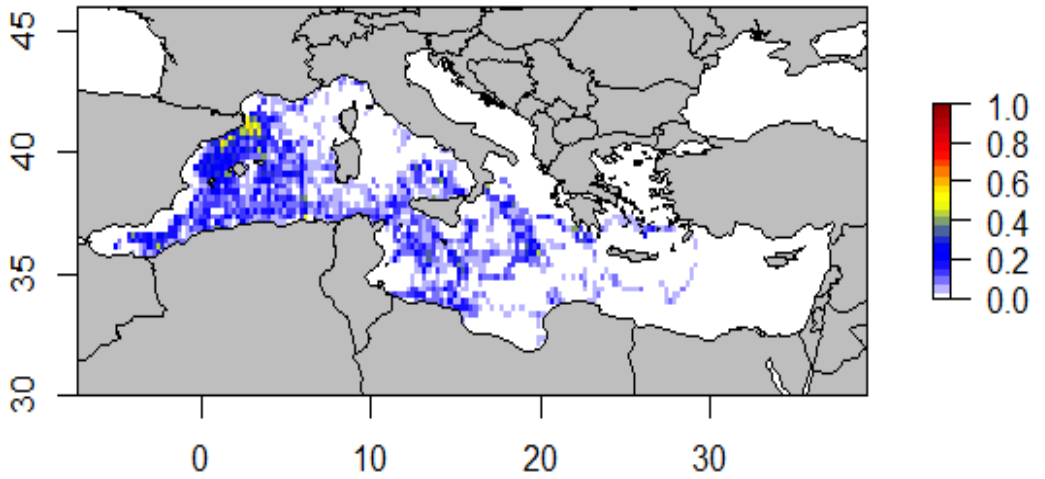


*Figure 8: Relative Density of Juvenile Loggerhead Turtles in the Western Mediterranean.*

## Fishing Effort

The map represents the average fishing effort calculated from the mean active fishing hours of trawling vessels in 0.1-degree cells for the period 2014-2024 for FAO area 37 (Figure 9).

In general, the highest fishing effort by trawling vessels occurs on/or at the edge of the continental shelf. High fishing pressure areas are evident in the Tyrrhenian Sea along the southwest coast of Italy, extending to the Ligurian Sea. The Gulf of Lion and the entire continental shelf of the Iberian Peninsula in the Mediterranean, including the Balearic Islands, are subjected to high levels of fishing effort by this type of gear. Notable areas include the north and south of the Ebro Delta, the Alicante coast, and the Mazarrón escarpments. Within area 37.1, the waters between the south of Sicily and the African continent seem to be an important point for this type of fishing. The Adriatic Sea appears to be one of the zones with the highest fishing effort by trawling in the entire Mediterranean.

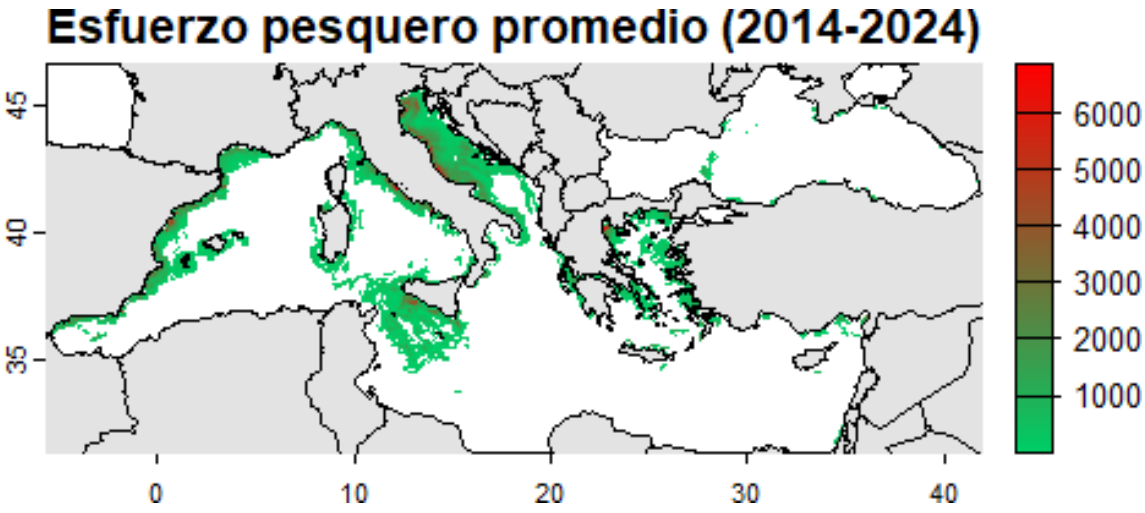


*Figure 9: Fishing effort calculated from the mean active fishing hours of trawling vessels in 0.1 degree cells for the period 2014-2024 for FAO area 37.*

## Higher risk áreas of loggerhead sea turtle by-catch in the Western Mediterranean

Figure 10 shows the areas of highest risk of incidental capture of adult loggerhead turtles by the trawling fleet operating in the western Mediterranean, calculated from the spatial overlap between the relative density of adult individuals (Figure 11) and the average fishing effort shows in Figure 9.

The areas near the submerged coastal strip of the Region of Murcia (Special Area of Conservatión, ZEC) at the coastal boundary between the Mar Menor and the Valencian Community appear to be an important potential risk area for the capture of adult loggerhead turtles. The neritic waters north of Cabo de la Nao appear to be the areas with the highest risk of incidental capture of loggerhead turtles in the Valencian Community, although there is moderate risk along the entire coastline. In Catalonia, the northern part of the Ebro Delta is considered a moderate-high risk area for the capture of loggerhead turtles by the fishing fleet in the Mediterranean. The Algerian Basin and the waters surrounding the Balearic Islands do not seem to be significant encounter points.

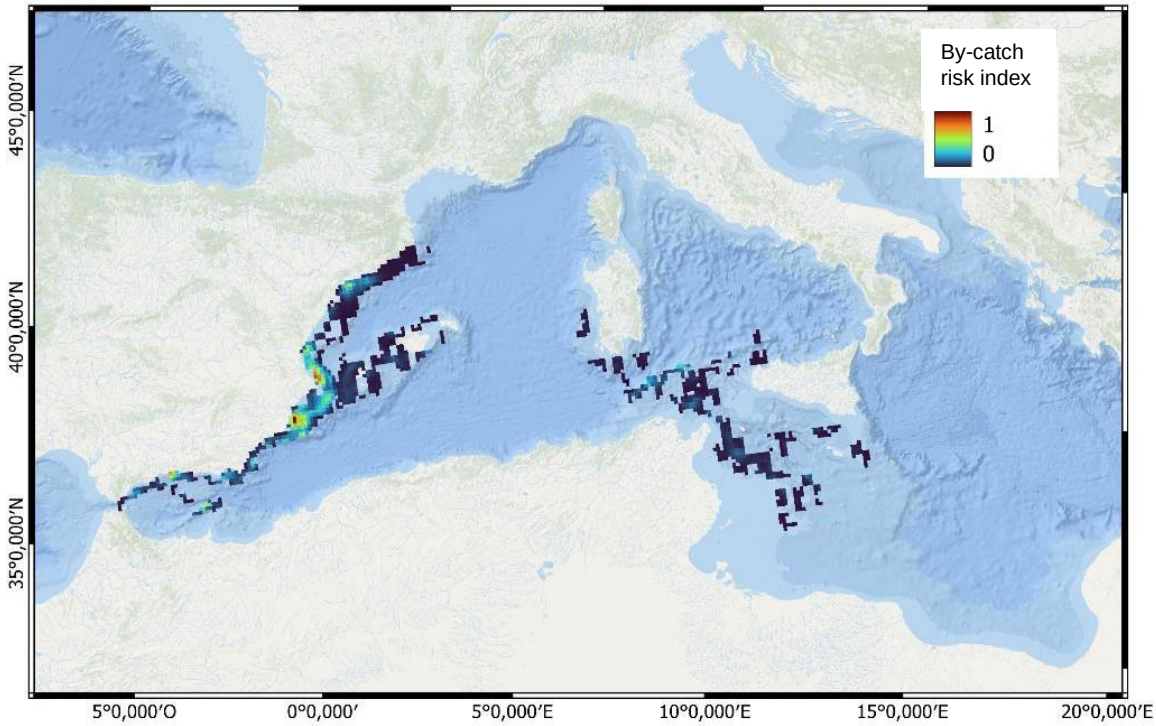


*Figure 10: higher risk areas of incidental capture of adult loggerhead turtles by trawling fleet in the Mediterranean sea.*

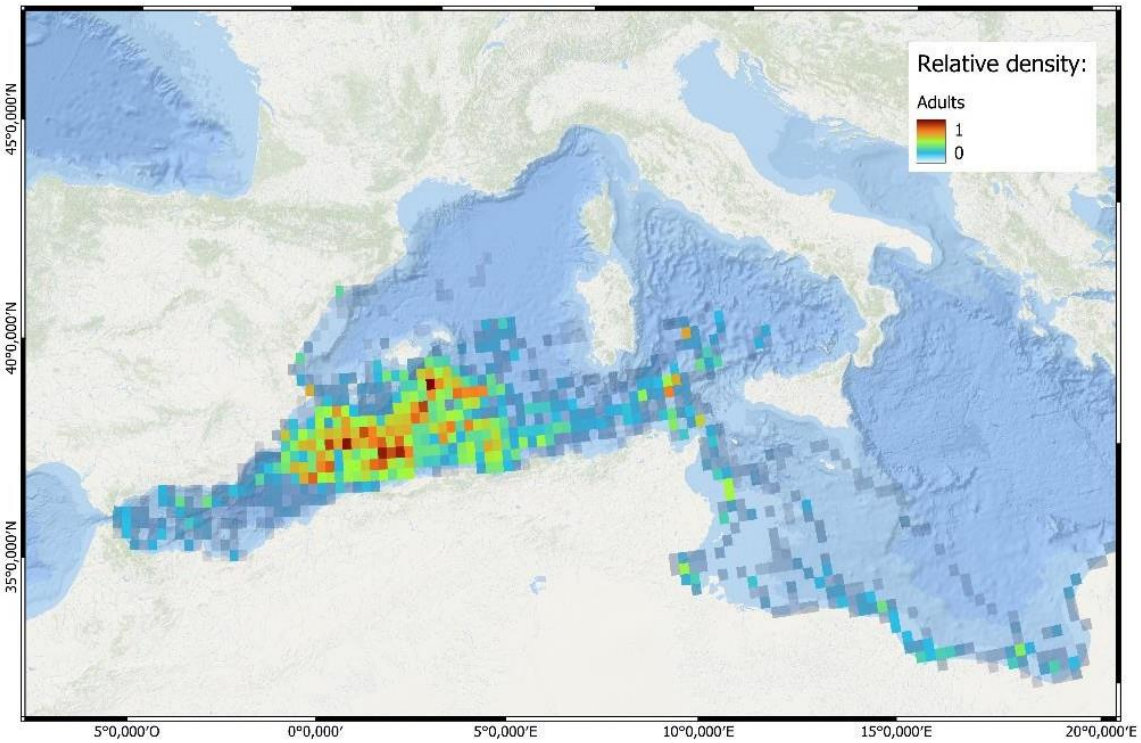


*Figure 11: Relative density of adult loggerhead turtle in the Mediterranean procesed by Geographican Information System (GIS).*

The areas of highest risk of incidental capture of female loggerhead turtles by the trawling fleet operating in the western Mediterranean, calculated from the spatial overlap between the relative density of female individuals and the average fishing effort are on Figure 12. Figure 13 shows relative density of females turtles.

The bycatch risk zones for female loggerhead turtles are similar to those for adults, this result is expected since 75% of the locations in the adult study belong to females. The neritic zones north of the Ebro Delta, north of Cabo de la Nao, and the waters off the Natural Park of Las Lagunas de La Mata in Torrevieja appear to be areas with the highest potential risk of capturing female loggerhead turtles. Figure 14 shows the deployment locations of 11 of the 17 analyzed female turtles for which information was available

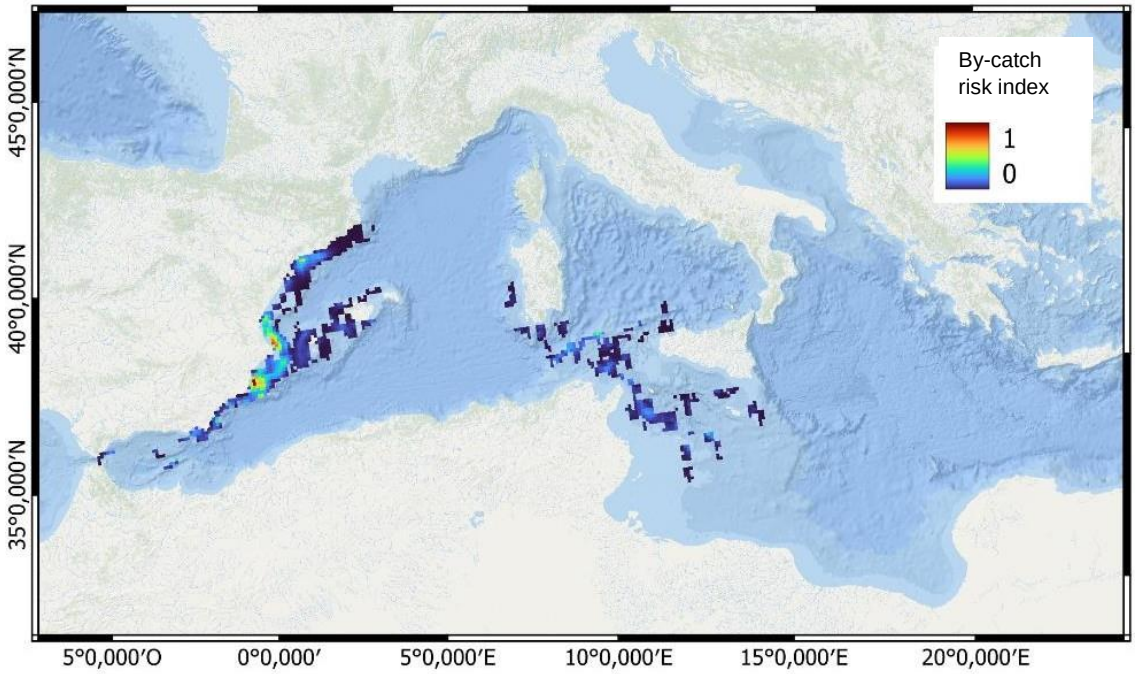


*Figure 12: higher risk areas of incidental capture of female loggerhead turtles by trawling fleet in the Mediterranean sea.*

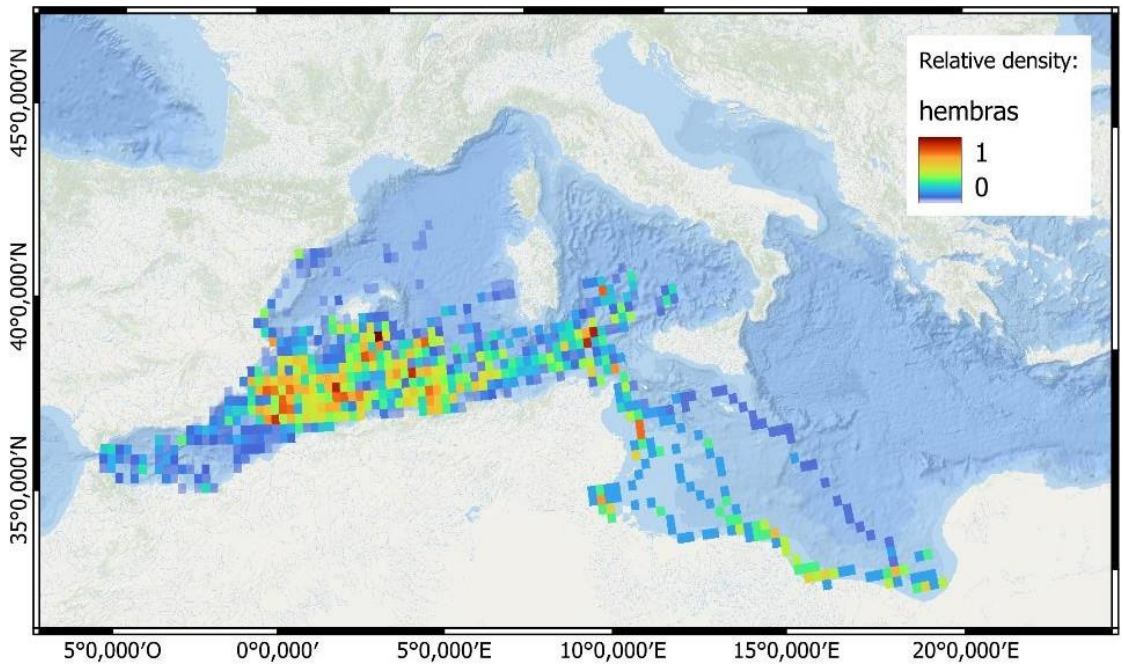


*Figure 13: Relative density of female loggerhead turtle in the Mediterranean procesed by Geographican Information System (GIS).*

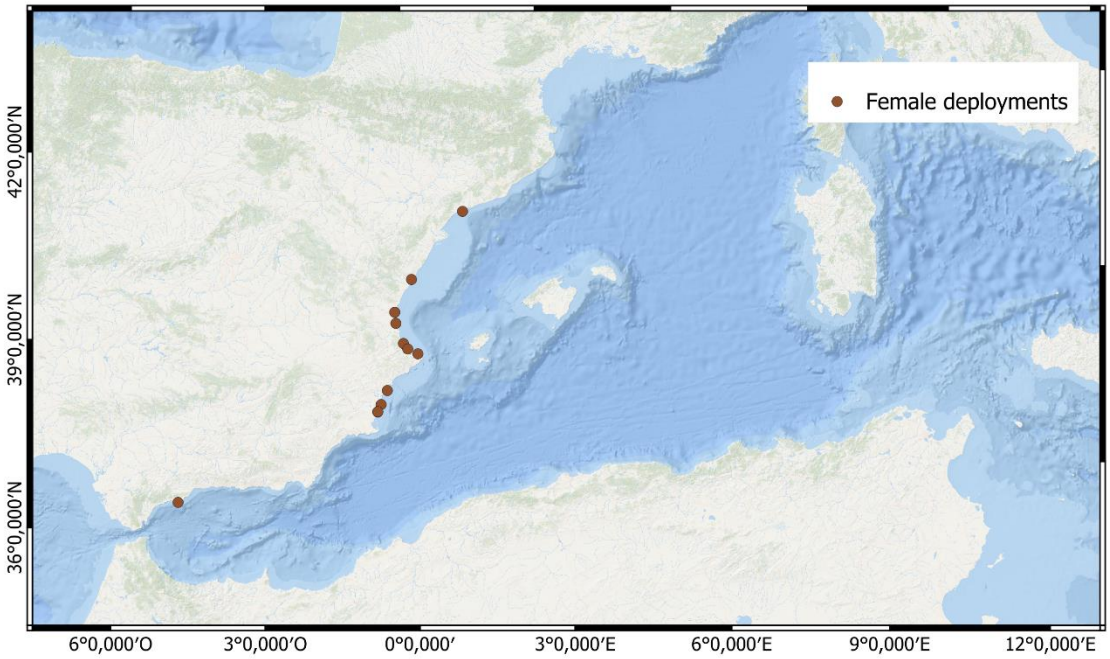


*Figure 14: Deployment sites of 11 of the female analyzed form Table 2, which were oportunistically tagged on the beaches of the Western Mediterranean.*

Figure 15 shows the areas of highest risk of incidental capture of juvenile loggerhead turtles by the trawling fleet operating in the western Mediterranean, calculated from the spatial overlap between the relative density of juvenile individuals (Figure 16) and the average fishing effort.

The waters surrounding the Ebro Delta show the highest risk of incidental capture of juvenile loggerhead turtles by trawlers. The northernmost area also appears to be a region with significant risk, as do the neritic zones to the north and south of Alicante and certain points in the Murcia region.

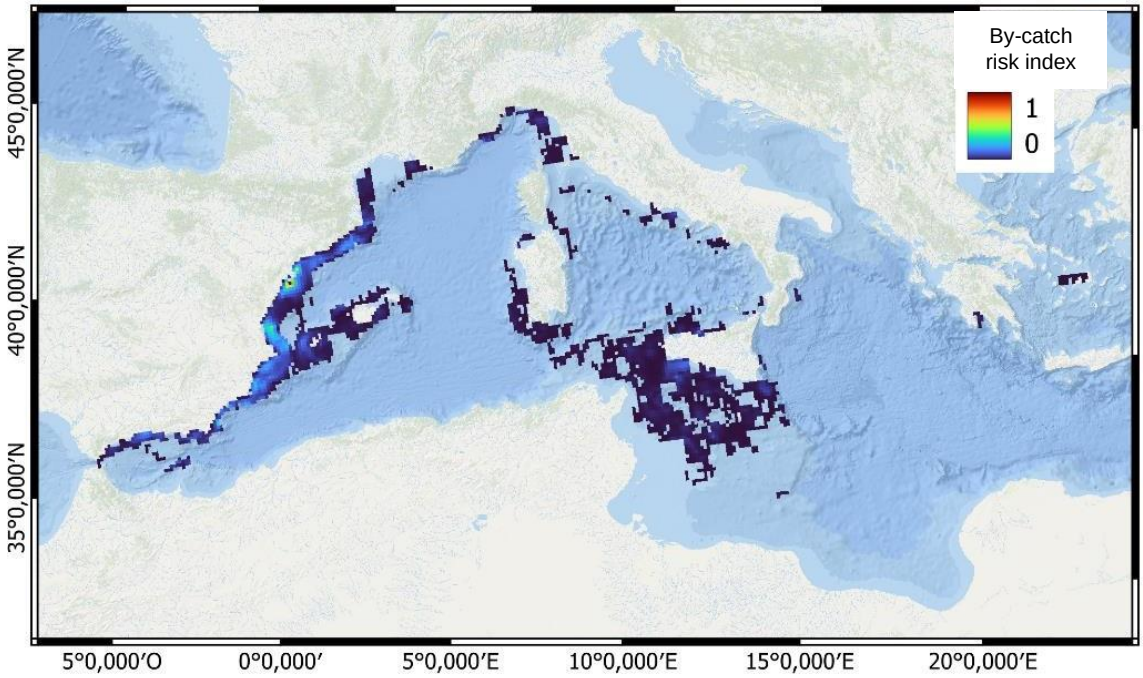


*Figure 15: higher risk areas of incidental capture of juvenile loggerhead turtles by trawling fleet in the Mediterranean sea.*

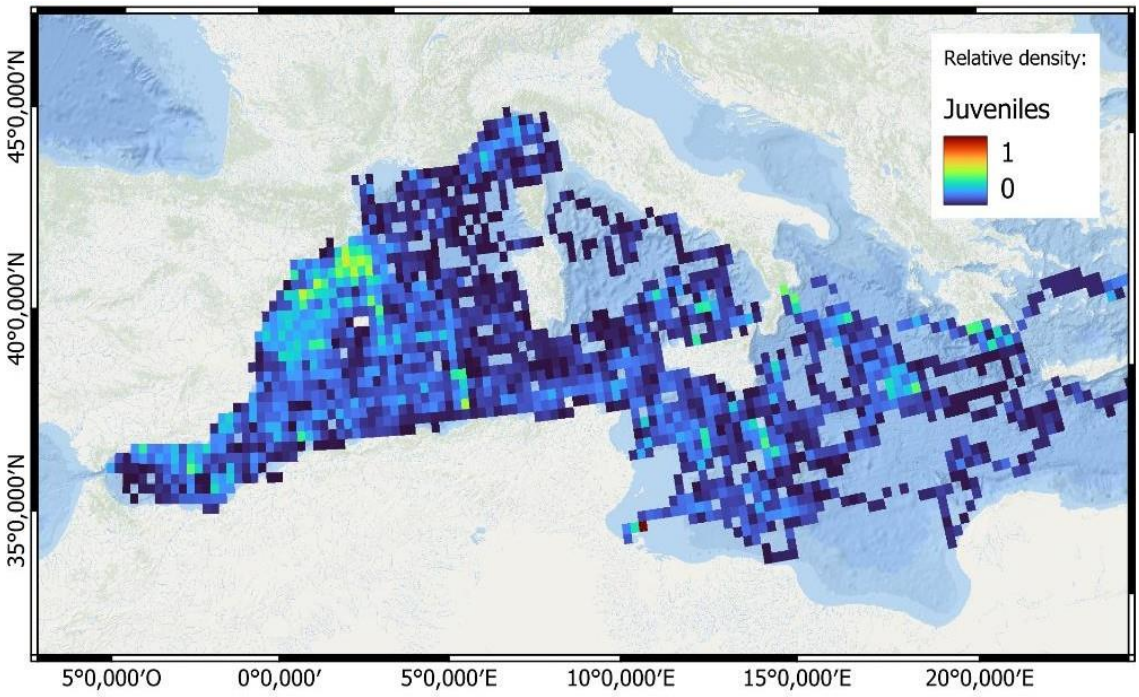


*Figure 16: Relative density of juvenile loggerhead turtle in the Mediterranean procesed by Geographican Information System (GIS).*

# DISCUSSION

## Relative density áreas

Loggerhead turtles generally concéntrate in the Western Mediterranenan basin, as previously demonstrated by Abalo-Morla et al., (2022) in their study on the spatial distribution of this species in the western Mediterranean. In the adult and sub-adult phases, loggerhead turtles predominantly occupy neritic zones in search of food (Bolten et al., 2003; Febrer Mesquida, 2017), with a greater concentration on the continental shelf than in oceanic waters as we observed.

The same behavior is observed in the juvenile group, which includes hatchlings and early and late juveniles, with a higher predominance in the western Mediterranean basin, although with greater dispersion towards the eastern area compared to adults. This is consistent with recent studies that have shown that, despite the belief that the species' life cycle included an initial oceanic phase where post-hatchlings during their first year of life passively drifted due to oceanographic factors, post- hatchlings and small juveniles do exhibit active dispersion (Febrer Mesquida, 2017). The juvenile group comprises individuals up to the adult phase (> 10 years), so it is considered normal for the results to show both neritic and oceanic distribution, as this group spans different life stages. The locations seem to show a trend in all cases of these animals preferring areas near the Balearic Islands and the Algerian Basin, areas considered of great importance for loggerhead turtle conservation according to previous studies (Cardona et al., 2005; Revelles,et al., 2007;Casale et al., 2012;Hays et al., 2014).

Algerian Basin is an important area for adult and loggerhead turtles. This result is expected, as the Algerian Basin is considered to be one of the regions with the highest densities of this species in the entire Mediterranean Sea (DiMatteo et al., 2022) although it was previously considered solely a foraging area for juvenile individuals (Cardona & Hays, 2018). The presence of some adult loggerhead turtles in the oceanic foraging grounds of the Algerian Basin supports the

hypothesis that certain individuals may reach adulthood while remaining at their juvenile foraging grounds (Piovano et al., 2011). Other important locations include the submarine valleys of Mazarrón and Cabo de Palos, the northern part of the Ebro Delta, Cabo de la Nao, and various points in the Alboran Sea, consistent with the results obtained by Abalo-Morla et al. (2022).

The Algerian Basin is also an importan area for female loggerhead turtles. It could be a feeding area, as studies highlight the importance of this region in the feeding ecology of the species due to the high presence of pelagic prey (Tomas et al., 2001; Revelles et al., 2007). However, it would be necessary to analyze future data based on the time of year to better understand why they concentrate there, as several authors suggest that during nesting periods, turtles tend to aggregate in limited areas during incubation and/or inter-nesting periods (Abalo-Morla et al., 2022) this, in turn, would pose a significant potential risk of incidental capture for these females.

The highest densities of juvenile loggerhead turtles are found between the Balearic Archipelago and the Catalan coast south of the Gulf of Lion. This coincides with previous studies indicating that this area is heavily used by juvenile loggerheads, particularly during the autumn months (Pina Cubells, 2022). However, sightings and bycatch of juvenile loggerheads around the Balearic Archipelago occur year-round (Carreras et al., 2004).

The area with the highest density of young individuals corresponds to the Protected Marine Area of the Mediterranean Cetacean Corridor, as noted by Abalo-Morla et al. (2022), being the most visited zone by hatchlings and juveniles. The map clearly shows that there are no significant relative densities of juveniles along almost the entire coastal area of the peninsula. However, juveniles seem to show interest in the coasts of the Algerian basin, with a greater preference for oceanic waters where one of the highest bycatch rates in the world is experienced (Mayol et al., 1988; Witzell & Cramer, 1995;Camiñas et al., 2006) in line with the hypothesis that immature loggerhead turtles in that region likely have a

preference for oceanic habitats (Cardona et al. 2005; Revelles et al. 2007; Eckert et al., 2008).

This appears to conflict with capture-tagging-recapture studies indicating that immature loggerhead turtles seem to spend long periods off the eastern coast of the Iberian Peninsula (Bertolero 2003; (Revelles et al., 2008), being residents of the continental shelf rather than vagrants from nearby oceanic areas. However, our results may be biased by the weighting method used to calculate relative densities, where less importance was given to longer tracks. This is because an individual in a specific area could show similar values to those observed if there were several individuals, potentially skewing the perceived bycatch risk.

**By-catch risk áreas**

Fisheries bycatch is recognised as the greatest threat to their conservation (Wallace et al. 2010) and is considered a moderate or high threat to more than 75% of all Regional Marine Turtle Management Units worldwide (Wallace et al. 2011, Lewison et al., 2013)

The main limitation in bycatch estimates is the lack of reliable and complete information on total fishing effort, bycatch in small-scale fisheries (Wallace et al. 2010, Casale 2011) and survival rate of released animals (Chaloupka et al., 2004; Mangel et al., 2011).

Prior to 2000, the fishing gear that reported the highest bycatch of loggerhead turtles in the Mediterranean was the surface longline. From that year onwards, there was a shift in the contribution of each métier to the total effort, where this gear that focused on swordfish fishing gradually shifted towards deeper semi-pelagic longlining methods that led to a significant decrease in sea turtle mortality by this gear (Baez et al., 2019). Currently, the bottom trawl fleet operating in the western Mediterranean is the largest bycatch of turtles, estimated at around 500 turtles per year (Domenech et al., 2015).

Trawlers typically operate between 50 and 200 m depth. Turtles are therefore vulnerable to this type of fishing gear on the continental shelf since in many areas they are most of the time at depths of less than 100 m (Hochscheid et al., 2005) and the maximum depth of immersion for this species is about 230 m (Spotila, 2004).

Bottom trawling and other neritic fishing gears have already been considered as a potential threat to this species (Tomás et al. 2008). In addition, studies based on necropsies of stranded specimens did not reveal interactions with boats or driftnets, so it was already hypothesised that trawls were the cause of these deaths.

Most of the data on bycatch by fishing gear are known from landings of this species in ports, but it should be noted that many of the catches are not known because the animals are thrown back to the sea dead or alive at the time of capture. Sea turtles can spend 90% of their lives in apnoea (Lutcavage & Lutz, 2017) and are the longest and deepest diving air-breathing marine vertebrates (Byles, 1988; Sakamoto et al., 1990; Houghton et al., 2008), but this condition does not exempt them from drowning as the most common cause of death when caught in nets. A 2014 study of loggerhead sea turtles that were accidentally caught in trawl nets showed that even as apnoeic diving vertebrates they had developed gas embolism (García-Párraga et al., 2014). Gas embolism may have no visible symptoms so that the practice of releasing the animal by the vessel that caught it may result in the animal's death later and undetected, meaning that the number of individuals that die from bycatch in fisheries is underestimated (Fahlman et al., 2017).

The relative density map of adult loggerhead turtles highlighted the southern area of the Levantine-Balearic demarcation and the Algerian Basin as points of highest density of adult individuals of this species. However, these do not seem to be areas with a potential risk of incidental capture of loggerhead turtles by trawlers when combined with fishing effort hours. This may be due to the fact that the

Global Fishing Watch database calculates apparent fishing effort using AIS detections, a system that is not always used.

In Spain, according to Annex II, Part I, Point 3, of Directive 2002/59/EC, fishing vessels with a total length of more than 15 meters must be equipped with an automatic identification system that functions properly and meets the performance standards approved by the International Maritime Organization under the 1974 SOLAS Convention (Regulation (EU) No 1224/2009). Therefore, the vast majority of Spanish trawlers are obliged to use AIS. As of May 31, 2014, all EU-flagged fishing vessels over 15 meters in length had to be equipped with AIS.

However, the waters of the western Mediterranean are shared with Algeria, where the fishing situation differs both in the capacity of its fishing fleet and in the regulations associated with this practice. In 2022, the total number of Algerian fishing vessels rose to 6,000 units, representing a positive growth of 3.1% compared to the previous year. Vessels under 6 meters in length (43.8%) comprise the majority of the fleet, although recent studies by the Ministry of Fisheries and Marine Resources raised this percentage to 52%. Additionally, three main segments are distinguished: small-scale vessels (61.3%), sardine boats (28.7%), and trawlers (9.5%).

Fishing effort maps seem to indicate that this detection system is not being implemented in these waters, as it is estimated that only 1/3 of the continental shelf surface is trawlable according to the General Fisheries Commission for the Mediterranean, and 20% of the fleet is normally dedicated to bottom trawling (200-400 m), although recently also to pelagic trawling (Massutí et al., 2004). The Algerian trawling fleet consists of 285 small vessels, between 11 and 20 meters, concentrated from Algiers to the border with Morocco (FAO, 2018). This means that even if these vessels were to implement the recommendations of the SOLAS Convention without being a member state of the International Maritime Organization (IMO), the vast majority of their fleet would not be required to have the AIS system installed due to not reaching 15 meters in length.

It is therefore important to note that although the Algerian Basin does not appear to be an area with a significant risk of incidental capture of loggerhead turtles in the western Mediterranean, it is an area that requires more detailed study due to the high density of individuals of this species at all stages of their life cycle. The overlap results could be biased by the fishing effort calculation method based on AIS detections if vessels do not use it.

The waters off the province of Castellón have the largest continental shelf in the Spanish Mediterranean. Studies mention it as an important neritic feeding ground for loggerhead turtles (Domenech et al., 2015) attracted by trawling discards in the area (Tomas et al., 2001). This area is used by trawlers from Castellón and southern Catalonia (Álvarez de Quevedo et al., 2010). For this reason, Domenech et al., (2015) considered it as a hotspot for the interaction between loggerhead turtles and bottom trawling. However, our data do not seem to support this theory, at least in the case of adult loggerhead turtles, so it would be interesting to analyse whether the fishing fleet that used to fish in the waters off the port of Castellón now devotes its fishing effort to other areas where there really seems to be a greater risk of capture, such as the waters off the town of Valencia or to the north of the Ebro Delta. On the other hand, these results could reflect a decrease in the relative density of turtles, as the maps do not seem to consider the area as a point of significant density. Likewise, further analysis should be carried out taking into account the origins of the populations studied.

The north-eastern basin of the peninsula is considered an area of great interest when studying turtle-fisheries interactions, as both the abundance of loggerhead turtles and fishing activity are important. The Ebro Delta is an important area of high ecological value in the region where a stable population of loggerhead turtles was found to be present throughout the year (Bertolero, 2003). Studies have shown a strong preference of loggerhead turtles for specific areas such as the Ebro Delta, which is reflected in the density maps. It is true that the areas close to this region are not the most important in the western Mediterranean in terms of numbers of individuals, but this area does stand out in comparison with the

entire coast north of Cabo de la Nao, where it is practically the only point with a significant density of these animals.

The supply of fresh water from the Ebro River together with the productivity of the waters at the mouth of the delta, due above all to the upwelling of deep waters, rich in salts and inorganic phosphorous, caused by the so-called estuary effect (San Feliu, 1974), result in a positive influence on the recruitment of demersal species, which makes the adjacent waters an important point for trawling.

When a high density of individuals of a species and a large number of vessels dedicated to fishing by a non-selective method come together, the risk of by-catch increases. This situation occurs in the waters near the Ebro Delta where we can see how it is an important area of risk of capture for adults of this species on the Spanish Mediterranean coast.

The Alicante trawling fleet is the largest in the Community, doubling in number that of Valencia, making encounters with these animals more likely in the area. However, in this area, there are mainly slope areas close to the coast, and the Alicante trawlers do not usually operate on the wide platform at depths of less than 200 meters, which would directly affect the passage areas of the turtles (Domenech et al., 2015). This could be because in this part of the Mediterranean, turtles seem to prefer oceanic habitats (Cardona et al., 2005; Revelles et al., 2007).

The Alboran Sea does not seem to be an area frequented by female loggerhead turtles, at least not as a regular nesting area, as the only recorded nest of this species was reported in Málaga in 2020 (Báez et al., 2020). Continuous nesting by female turtles on beaches in the western Mediterranean is relatively recent. Since 2010, sand temperatures on these beaches exceeded 25ºC for 80 days; the threshold for successful egg incubation (Cardona et al., 2024) due to global warming. All loggerhead turtle nests in Spain have been located within the Mediterranean biogeographical region (Camiñas et al., 2020). It would be interesting to analyse the data according to the time of year. It is true that although

the highest overlap rates coincide with areas of medium-high density and high fishing effort, a more detailed analysis would be useful to show whether the risk of bycatch is more pronounced during the nesting season in these areas.

Juvenile loggerhead turtles concentration on Catalan coast is evident. This behaviour has already been reflected by Cardona et al. (2009) where more than 90% of the turtles studied used the continental shelf with a strong preference for the Ebro Delta. Bearing in mind that juvenile loggerhead turtles spend less time at the surface when they are on the continental shelf (Cardona et al. 2005; Revelles et al. 2007) and that this is the area with the largest continental shelf, the data on juvenile density seem to be closer to reality, as it would be expected that satellite detectability would be lower in this area.

The marine area of the Ebro Delta was established as a Special Protection Area for Birds (ZEPA) because it is one of the most important feeding areas for seabirds in the whole of the Mediterranean. The Delta de l'Ebre - Illes Columbretes ZEPA extends between the provinces of Tarragona and Castellón. This area appears to be an important recruitment area for juvenile loggerhead turtles in the western Mediterranean (Figure 17), in line with the study by Sara-Abalo et al., (2022) on the habitat use of juvenile loggerhead turtles where they observed that the Ebro Delta was the second Marine Protected Area with the second highest residence rate. As it is designated as a special conservation area for birds, it has no specific measures for the protection and management of vulnerable species such as loggerhead turtles, and therefore remains an important fishing ground for the trawler fleet.

The Ebro Delta, as mentioned above, is an important coastal area for demersal fisheries. The average fishing effort map highlights this area as one with the highest values of fishing hours per km2. The high rates of juvenile turtles in an area heavily exploited by bottom trawlers suggest that it is considered to be one of the areas with the highest risk of by-catch of juvenile loggerhead turtles in the western Mediterranean.

Although trawling appears to be the main threat to this species in all life stages, the loggerhead turtle is susceptible to interacting with any other fishing gear used in these waters. Therefore, the potential risk of bycatch is not limited to trawling but extends to any other non-selective fishing gear

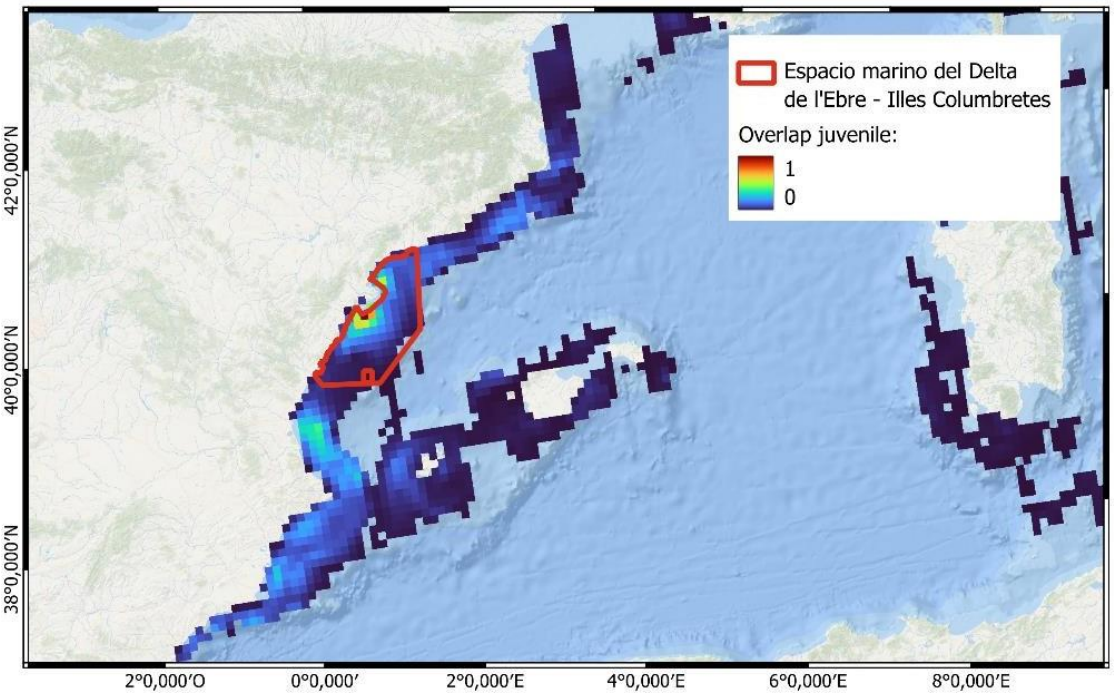


*Figure 17: Risk of bycatch of juvenile loggerhead turtles within the Ebro Delta Marine Area (ZEPA).*

# CONCLUSIONS

The description of overlaps between threats and the population segment of interest provides crucial information for developing management tools and establishing measures to help protect vulnerable species reliant on conservation efforts, such as the loggerhead turtle in the Mediterranean.

Quantifying the actual fishing effort in the Western Mediterranean remains a challenge due to the confluence of this sea with various countries that have different fishing regulations. This poses a limitation in more accurately estimating the areas with a high risk of by-catch of the loggerhead turtle, such as the Algerian Basin.

Satellite tracking of vulnerable species provides valuable information for understanding the behavior of these species, thereby improving protection measures.

The trawling fleet focuses its efforts on the continental shelf of the peninsular coast and the Balearic Islands. The Ebro Delta, the coast of Alicante, and the Mazarrón escarpments appear to be the most important trawling points along the coast.

In general, the tagged loggerhead turtles in the Mediterranean coast continue to inhabit the waters of the Western Mediterranean during the tracking period. The highest density of adult and female loggerhead turtles is recorded in the Algerian Basin. Juveniles are concentrated south of the Gulf of Lion, off the Catalonian coast.

There is a risk of incidental capture of adult loggerhead turtles across almost the entire continental shelf of the Valencian Community. Alicante is the province with the highest by-catch risk, notably the northern area of Cabo de la Nao and the area between Torrevieja and the Mar Menor. The northern part of the Ebro Delta is a potentially critical point for incidental capture.

The areas with the highest risk of by-catch of female loggerhead turtles are similar to those for adults, although the data may be biased by the high density of females in the adult data. The areas with the highest risk of incidental capture of females seem to correlate somewhat with the usual nesting areas on the western Mediterranean coast.

The highest risk of capture of juvenile loggerhead turtles is found in the waters surrounding the Ebro Delta, where a wide continental shelf, a high presence of juveniles, and significant fishing pressure converge. This area is designated as a Special Protection Area for Birds (ZEPA) without any measures for the protection of this species.

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# SUSTAINABLE DEVELOPMENT GOALS (ODS)

The analysis of the overlap between apparent fishing effort and loggerhead turtle habitat in the Western Mediterranean Sea can be related to several Sustainable Development Goals (ODS):

**ODS 14:**

One of the targets of this goal is to effectively regulate fishing and eliminate overfishing, illegal, unreported, and unregulated fishing, and destructive fishing practices. This study helps identify high-risk areas where fishing can negatively impact loggerhead turtle populations. By highlighting these areas, the work can assist in implementing more effective regulations and developing strategies to reduce incidental capture of loggerhead turtles, which is a form of destructive and unsustainable fishing.

Another target within this goal is to conserve at least 10% of coastal and marine areas through protected areas and other effective measures. Thus, this work can inform the need to establish new protected areas or improve management in existing ones to protect loggerhead turtle habitats. Identifying areas where loggerhead turtles are at risk due to fishing can help prioritize these areas for conservation and the implementation of effective protection measures.

| Objetivos de Desarrollo Sostenibles | Alto | Medio | Bajo | No Procede |
|---|---|---|---|---|
| ODS 1. **Fin de la pobreza.** | | | | - |
| ODS 2. **Hambre cero.** | | | | - |
| ODS 3. **Salud y bienestar.** | | | | - |
| ODS 4. **Educación de calidad.** | | - | | |
| ODS 5. **Igualdad de género.** | | | | - |
| ODS 6. **Agua limpia y saneamiento.** | | | | - |
| ODS 7. **Energía asequible y no contaminante.** | | | | - |
| ODS 8. **Trabajo decente y crecimiento económico.** | | | - | |
| ODS 9. **Industria, innovación e infraestructuras.** | | - | | |
| ODS 10. **Reducción de las desigualdades**. | | | | - |
| ODS 11. **Ciudades y comunidades sostenibles**. | | | - | |
| ODS 12. **Producción y consumo responsables.** | | - | | |
| ODS 13. **Acción por el clima.** | | | - | |
| ODS 14. **Vida submarina.** | - | | | |
| ODS 15. **Vida de ecosistemas terrestres.** | | - | | |
| ODS 16. **Paz, justicia e instituciones sólidas.** | | | | - |
| ODS 17. **Alianzas para lograr objetivos.** | | | | - |