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## OCCURRENCE OF LOGGERHEAD SEA TURTLES IN THE OFFSHORE AREAS OF THE CENTRAL-SOUTHERN TYRRHENIAN SEA (WESTERN MEDITERRANEAN): RESULTS OF THE FIRST FIVE YEARS OF SURVEYS USING PASSENGER FERRIES AS OBSERVATION PLATFORMS

### PRESENZA DELLA TARTARUGA MARINA COMUNE CARETTA CARETTA NELLE AREE OFFSHORE DEL TIRRENO CENTRO-MERIDIONALE (MEDITERRANEO OCCIDENTALE): RISULTATI DEI PRIMI CINQUE ANNI DI INDAGINE UTILIZZANDO TRAGHETTI DI LINEA COME PIATTAFORME DI OSSERVAZIONE

**Abstract** – *The spatial behavior of Mediterranean loggerhead sea turtles (*Caretta caretta*, Linnaeus, 1758) in offshore areas, particularly in the Tyrrhenian Sea, remains poorly understood. This study presents preliminary results from a five-year visual data collection (2019-2023) on loggerheads conducted within the FLT Med Net and LIFE Conceptu Maris Projects, using passenger ferries as observation platforms. Over 32 surveys covering about 6000 km along the Salerno-Palermo and Naples-Palermo routes, 176 specimens were sighted. Spatial analyses revealed a stable presence of turtles, with a mean sighting per km of effort of 0.03 and a significant hotspot centered ~60 km northeast of Palermo, as indicated by Kernel and Getis-Ord  $G_i^*$  statistics. Consistent with satellite-tagging studies, turtles dispersed widely in spring-summer, while concentrating in smaller areas during autumn-winter. Notably, in spring, turtles seemed to favor areas near seamounts, known to attract pelagic predators. These findings emphasize the ecological importance of the Tyrrhenian basin for loggerheads.*

**Keywords:** *conservation, human threats, marine megafauna, monitoring, spatial ecology*

**Introduction** – *Caretta caretta* (Linnaeus, 1758) is the most abundant sea turtle species in the Mediterranean, frequenting nearly all accessible areas of the basin; however, knowledge about its abundance, distribution, and ecological impacts remains limited, especially in the open sea where high operational costs and logistical challenges hinder research (Casale and Margaritoulis, 2010; Arcangeli *et al.*, 2022). The species is listed in the Annexes II and IV of the EU Habitats Directive 92/43/EEC and its conservation status in the Mediterranean was assessed as 'unfavourable-inadequate' in the 4<sup>th</sup> Italian Report (2013-2018) (La Mesa *et al.*, 2021), highlighting how the lack of a solid knowledge base undermines the effectiveness of any management action. 'Platforms of opportunity' such as passenger ferries, whose route can be contextually exploited for scientific data collection, may help address these challenges. This study analyzes five years of monitoring data (2019-2023) on loggerhead sea turtles collected by the Stazione Zoologica Anton Dohrn, using passenger ferries crossing the central-southern Tyrrhenian Sea as observation platforms. This research is strategically important, as it covers diverse coastal and offshore habitats that support a range of marine macro and megafauna species beyond *C. caretta*. Moreover, despite the recognized importance of Tyrrhenian habitats for sea turtles, the only data currently available for these areas come from a few studies that investigated the spatial behavior of some individuals using satellite tracking (e.g. Luschi *et al.*, 2018; Pasanisi *et al.*, 2022). Therefore, although preliminary, these findings offer valuable insights into the ecology of Mediterranean loggerheads, contributing to filling knowledge gaps that are

crucial for assessing their conservation status and the impact of potential threats in data-deficient offshore waters.

**Materials and methods** – Year-round data were collected along two trans-regional fixed line transects established along the Naples-Palermo (NAPA) and Salerno-Palermo (PASA) ferry routes in the central-southern Tyrrhenian Sea. Visual monitoring followed the line transect sampling method, with data gathered in passing mode (i.e. continuous search without approaching animals) according to the standard protocols of the FLT Med Net and EU Life Conceptu Maris Projects (Arcangeli *et al.*, 2022). Survey activities were conducted by a team of three to four trained observers positioned on the ferry's command deck. For each turtle sighting, the GPS location was recorded along with a list of data such as sighting time, angle, approximate distance and orientation of individual(s), life stage, sex (if identifiable), behavior, and any response to the observation platform. Data on collisions and entanglements were also collected during sightings. Survey tracks and sightings data were spatially organized in QGIS 3.30.3 and analyzed statistically with R (2023.06.0+421). A 5×5 km cell grid was applied to the study area to estimate relative abundance as SPUE (Sightings Per Unit of Effort), calculated as  $N/L$ , where  $N$  is the number of turtles sighted and  $L$  is the kilometers traveled on effort (i.e. Beaufort  $\leq 3$  and good visibility) within each cell. To map species distribution, a spatial interpolation was performed using the nonparametric Kernel Density Estimation (KDE) method, which allows for data adjustment when drawing inferences from limited datasets; areas of highest use were identified within the 25% KDE contour. The Hotspot Analysis in R calculated the Getis-Ord  $G_i^*$  statistic (Ord and Getis, 1992), a Local Indicator of Spatial Association (LISA) (Anselin, 1995), to identify statistically significant spatial clusters of high SPUE values. Spearman's rank correlation (Spearman, 1904) was used to assess the relationship between SPUE values and distance from Tyrrhenian seamounts, with the statistical dependence between the two variables strengthening as the coefficient  $\rho$  approaches  $\pm 1$ . Consequently, a result closer to  $-1$  indicates a greater abundance of turtles near these underwater features. Part of the data was also analyzed on a seasonal basis, combining autumn and winter to ensure balanced survey distribution across seasons. A minimum sampling effort of 10 km per cell for the total analysis and 5 km for the seasonal analysis was applied to avoid potential bias from uneven/insufficient survey effort.

**Results** – Between August 2019 and June 2023, 32 surveys were conducted, covering 6150 km over 180 hours of navigation, with the NAPA and PASA routes each including half of the sampled transects. Survey distribution was as follows: 3 in 2019, 2 in 2020, 11 in 2021, 13 in 2022, and 3 in 2023. Of these, 6 were in spring, 16 in summer, 6 in autumn, and 4 in winter. A total of 176 turtles were observed, over half of which were juveniles (i.e. curved carapace length  $\leq 70$  cm); 37 sightings occurred in spring, 87 in summer, 22 in autumn, and 30 in winter. Most turtles were either resting ( $n = 82$ ) or swimming ( $n = 82$ ), with fewer observed feeding ( $n = 3$ ) or in a mating/courtship event ( $n = 2$ ). Approximately 57% of turtles remained indifferent to the passage of the ferry, while 32% attempted to escape. About 22% ( $n = 38$ ) experienced collisions, and some showed signs of poor health ( $n = 3$ ) or entanglement/proximity to floating debris or fishing devices ( $n = 7$ ). Overall, turtle distribution along the transects was fairly uniform, with a mean SPUE of  $0.03 \pm 0.03$  individuals per km of effort (Fig. 1a). The KDE analysis identified a high-abundance area centered approximately 60 km northeast of Palermo, confirmed by significant hotspots identified there through the Getis-Ord  $G_i^*$  statistic ( $g_i > 0$ ;  $0.01 \leq p \leq 0.1$ ) (Fig. 1b-c). Seasonal analysis revealed the highest mean SPUE in autumn-winter ( $0.031 \pm 0.028$ ), followed by spring ( $0.029 \pm 0.04$ ) and summer ( $0.013 \pm 0.009$ ). Consistent with this, turtles were more evenly distributed in

spring and especially summer, also at higher latitudes, while autumn-winter data indicated a concentration in the southern half of the transects (Fig. 1d-f). Significant moderate correlations between SPUE values and distance from Tyrrhenian seamounts were observed in spring ( $\rho = -0.54$ ;  $p < 0.05$ ) and summer ( $\rho = 0.56$ ;  $p < 0.005$ ), with opposite trends, while no significant correlation was detected during autumn-winter ( $\rho = -0.13$ ;  $p > 0.5$ ).

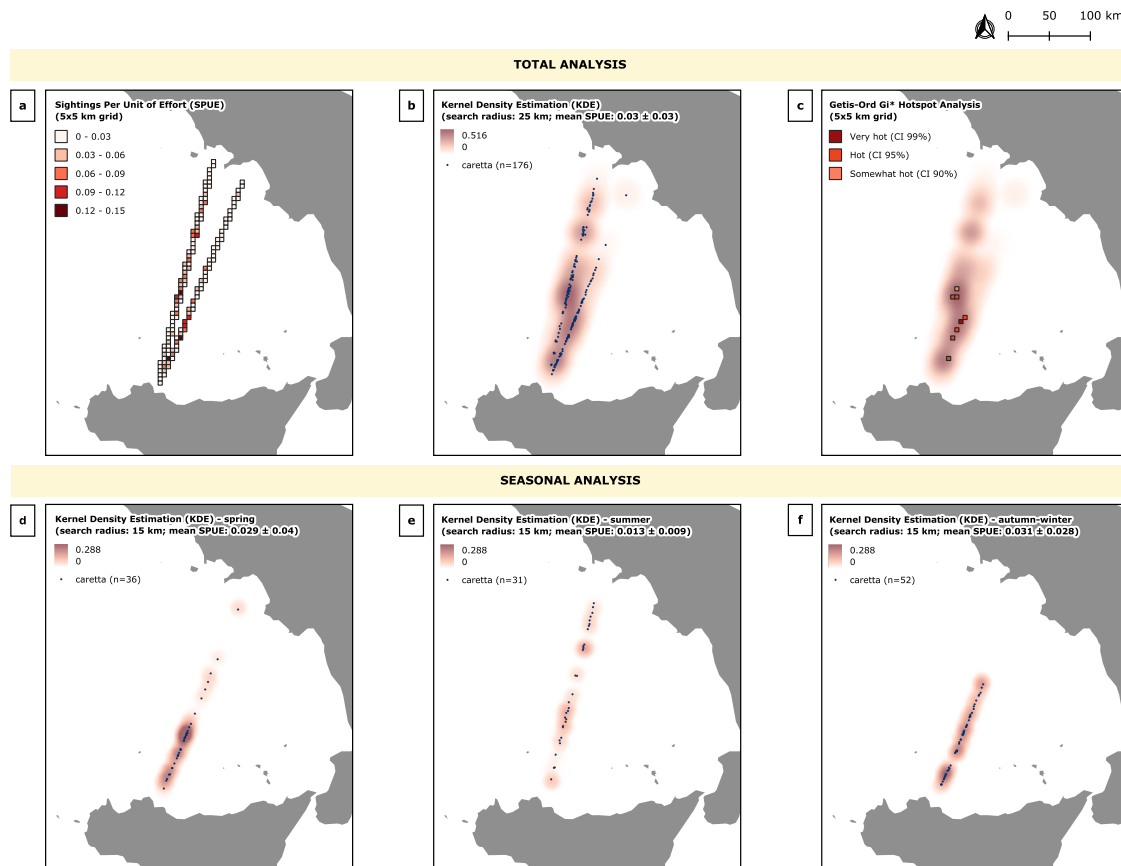


Fig. 1 - (a) Total SPUE (Sightings Per Unit of Effort) of *C. caretta* over the 5x5 km cell grid. (b) Turtle distribution based on Kernel Density Estimation (KDE); the individuals detected along the transects are marked as dots. (c) Getis-Ord  $G_i^*$  analysis output, highlighting hotspots in red cells. (d-f) KDE seasonal results.

(a) SPUE totale di *C. caretta* sulla griglia di celle 5x5 km. (b) Distribuzione delle tartarughe basata sulla Stima della Densità Kernel (KDE); gli individui rilevati lungo i transetti sono indicati come punti. (c) Risultato dell'analisi Getis-Ord  $G_i^*$ , con le celle rosse che rappresentano gli hotspot. (d-f) Risultati stagionali della KDE.

**Conclusions** – The spatial analyses indicated a stable presence of *C. caretta* across the study area and throughout the seasons, underscoring the ecological importance of the Tyrrhenian Sea as a foraging, overwintering as well as breeding area for the species, as supported by the observation of a probable mating event in its offshore waters. To our knowledge, this is the first time that the hotspot located about 60 km northeast of Palermo has been identified as potentially significant for loggerhead turtles. The seasonal patterns observed align with previous findings (Pasanisi *et al.*, 2022) showing the highest relative abundances in autumn-winter, when turtles display preferences for specific areas, and the lowest in summer, when they exhibit broader dispersion. These distribution shifts may be influenced by the strong seasonality in the local circulation of the Tyrrhenian Sea, which affects food availability, particularly during summer when active anticyclonic eddies lead to a more widespread distribution of resources (Iacono

*et al.*, 2021). The Spearman's correlation analysis indicated that turtles tend to concentrate near seamounts during spring, consistent with their potential role as hotspots of pelagic biodiversity (Morato *et al.*, 2010). This finding is in line with that of Luschi *et al.* (2018), where it was observed that the core areas of tracked turtles were within 20 km of, or passed over, several Tyrrhenian seamounts. Similarly, Pasanisi *et al.* (2022) identified areas with the highest mean values of loggerhead occurrence within 50 km northwest of Marsili's peak. In summer, the significant positive correlation suggests that turtles may select different habitats, possibly due to changes in food availability or movements for reasons other than foraging, such as breeding and nesting. This aligns with the results of the spatial analysis, which suggests a broader distribution of sightings during summer without a clear preference for specific areas. Although further analyses, including those with larger datasets or broader spatial scales, are needed to confirm the influence of seamounts on turtle movements, this study provides preliminary evidence to inform future studies exploring the importance of these underwater features for the management of *C. caretta* in the Mediterranean. Approximately a quarter of sighted turtles experienced likely collision events with ferries, highlighting the significant risk this activity poses to the species, including life-threatening injuries. This supports the hypothesis that vessel collisions are underestimated in the open sea, where turtles are more vulnerable than those in shallow areas, as they surface for extended periods to rest and warm up after long, deep dives in cold waters (Hochscheid *et al.*, 2010). The high speed of ferries (~33 km/h) likely contributes to the high collision rate by reducing the time turtles have to detect and avoid approaching vessels; indeed, more than half of the turtles observed showed no reaction. Assessing the likelihood of offshore collision events and characterizing the behavioral responses of sea turtles to vessels are crucial, particularly in regions like the Tyrrhenian Sea, where maritime activities (i.e. transport, fishing) heavily overlap with areas of high turtle occurrence (Pasanisi *et al.*, 2022). To conclude, the present study corroborates the effectiveness of using passenger ferries as platforms of opportunity for systematic offshore surveys of *C. caretta*, enabling the collection of diverse types of data on this threatened species, whose ecology is still partially unknown, thereby limiting effective conservation planning beyond coastal environments.

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