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BITE MARKS OBSERVED ON A LARGE FEMALE WHITE SHARK *CARCHARODON CARCHARIAS* OFF CAMARGUE, FRANCE PROVIDE POTENTIAL INSIGHTS INTO THE REPRODUCTION OF THE MEDITERRANEAN POPULATION

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ABSTRACT

The ecology of the great white shark Carcharodon carcharias *in the Mediterranean remains largely unknown due to its rarity and population decline, despite its role as the region's apex predator. In September 2022, we documented a rare adult female displaying distinct bite marks, swimming off the coast of the Camargue. From spring to autumn, the Gulf of Lion, particularly in the adjacent waters of the protected area of the Parc Naturel Régional de Camargue, experiences a significant increase in biodiversity. Our observations suggest that this region may serve as a key late-summer feeding area for female great white sharks following copulation.*

Key words: white shark, Gulf of Lion, reproduction, bite marks, conservation

SEGNI DI MORSI OSSERVATI SU UNA GRANDE FEMMINA DI SQUALO BIANCO *CARCHARODON CARCHARIAS* AL LARGO DELLA CAMARGUE, IN FRANCIA, FORNISCONO POTENZIALI INDICAZIONI SULLA RIPRODUZIONE DELLA POPOLAZIONE MEDITERRANEA

SINTESI

L'ecologia del grande squalo bianco Carcharodon carcharias *nel Mediterraneo rimane in gran parte sconosciuta a causa della sua rarità e del declino della popolazione, nonostante il suo ruolo di superpredatore nella regione. Nel settembre 2022, gli autori hanno documentato una rara femmina adulta che mostrava segni di morsi distinti, nuotando al largo della costa della Camargue. Dalla primavera all'autunno, il Golfo del Leone, in particolare nelle acque adiacenti all'area protetta del Parc Naturel Régional de Camargue, registra un significativo aumento della biodiversità. Queste osservazioni suggeriscono che la regione può servire come area di alimentazione tardo-estiva per le femmine di squalo bianco dopo l'accoppiamento.*

Parole chiave: squalo bianco, Golfo del Leone, riproduzione, segni di morsi, conservazione

INTRODUCTION

Carcharodon carcharias (Linnaeus, 1758) (Lamniformes: Lamnidae) is one of the largest coastal and oceanic macro-predators (Ebert & Dando, 2020; Ebert *et al.*, 2021). Six genetically distinct and geographically isolated philopatric populations have been identified worldwide: Australia, South Africa, the Northwest Atlantic, the North-East Pacific, Japan, and the Mediterranean (Huveeners *et al.*, 2018; Villafaña *et al.*, 2020; Ebert *et al.*, 2021). The migrations of *C. carcharias* are influenced by environmental conditions, reproduction, and prey availability (Milankovic et *al.*, 2021).

The Mediterranean population has been identified as genetically distinct (Gubili *et al.*, 2012). The species is classified as critically endangered by the IUCN Red List (Soldo *et al.*, 2016). As a top predator, it preys on large pelagic fish such as bluefin tuna *Thunnus thynnus* and swordfish *Xiphias gladius*, as well as elasmobranchs and marine mammals in its Mediterranean area (Fergusson, 1996; De Maddalena & Heim, 2012; Boldrocchi *et al.*, 2017). Since the 1600s, most of our knowledge about the species has relied on rare opportunistic observations of live individuals, historical surveys, and bycatch data (Morey *et al.*, 2003; De Maddalena & Heim, 2012; Maliet et *al.*, 2013; Kabasakal, 2014; Boldrocchi *et al.*, 2017; Moro *et al.*, 2020; Deysson *et al.*, 2024; Jambura *et al.*, 2025).

In the Mediterranean, the research to improve understanding of the life history of the Mediterranean population and especially its reproduction remains a huge challenge currently producing very few results even if involving long term indepth monitoring (Micarelli *et al.*, 2023; Ferretti *et al.*, 2024). This is likely due to a critical decline of over 90% and the marked fragmentation of the original population (Moro *et al.*, 2020; Ferretti *et al.*, 2024).

Regarding the reproduction of the species, the central basin of the Mediterranean Sea is well known as a parturition and nursery area for *C. carcharias* (Saïdi *et al.*, 2005; by Kabasakal, 2014; Boldrochi *et al.*, 2017; Zaouali *et al.*, 2020; Jambura *et al.*, 2025). It is established that females reach maturity at a total length of 450 to 500 cm and males reach maturity at a total length of 350 to 400 cm (Francis, 1996; Ebert & Dando, 2020).

In this context, we report an extremely rare observation of an alive adult female great white shark exhibiting bite marks, suggesting recent mating. This observation contributes valuable insight into timing and dynamics of the poorly known reproductive cycle of the Mediterranean *C. carcharias* population.

MATERIAL AND METHODS

The data presented here concerns a large shark sighted by three anglers in Camargue waters (NW Mediterranean), recorded on video and reported to the Groupe Phocéen d'Étude des Requins (GPER), Marseille, France, along with all sighting details and precise GPS coordinates. No GPER researchers were on board. The animal was observed on September 22, 2022, at 8 AM (GMT+1), 6 NM from the coast (43°16'05.6 "N 4°35'04.1 "E), using the Beauduc lighthouse as a reference. None of the three anglers were fishing, and no bait was in the water. No other boats were in the observation area at the time, according to the sighters. The boat was cruising at moderate speed when it came across the large shark, which surfaced at the same time. With the boat stopped, the shark turned for five minutes at a distance of 10 m before diving towards the coast in the direction of the Parc Naturel Régional de Camargue (PNRC). The observers reported to the GPER, Marseille, France an estimated total length (TL) of the shark exceeding 500 cm when the tip of the animal's snout was at bow level when swimming parallel to the boat. It was a 683 cm long recreational fishing vessel BOSTON WHALER 220 OUTRAGE. The sky was clear at sunrise, the sea was calm, and visibility was good. The surface water temperature was 25 °C. The animal circled the boat during five minutes before disappearing, swimming 10 m below the surface. A juvenile swordfish *X. gladius* was observed in the area just before the shark appeared to the surface near the vessel. The boat's depth sounder detected numerous large fish. It swims in the direction of the coastal area of the PNRC (Fig. 1).

RESULTS

The large shark was estimated to measure between 500 cm and 600 cm in total length (TL). According to the reported observations (Fig. 2) the individual has a massive, fusiform body with a dark grey dorsal coloration, interspersed with shades of brown, sharply contrasting with its marked white belly. The pectoral fins are large and curved (Figs. 2B, C). The left gill area is wide but bare, lacking protective tegument (Figs. 2A, B). The first dorsal fin is large, triangular, and curved backward (Figs. 2D, E, F). Its posterior margin is clearly concave (Fig. 2F). The absence of claspers was also noted (Fig. 2F). The large, sighted shark has thus been identified as an adult female great white shark (GWS) (Ebert & Dando, 2020; Barone *et al.*, 2022).

DISCUSSION AND CONCLUSIONS

We identified an adult female great white shark *Carcharodon carcharias* "GWS", estimated to be between 500 cm and 600 cm in total length

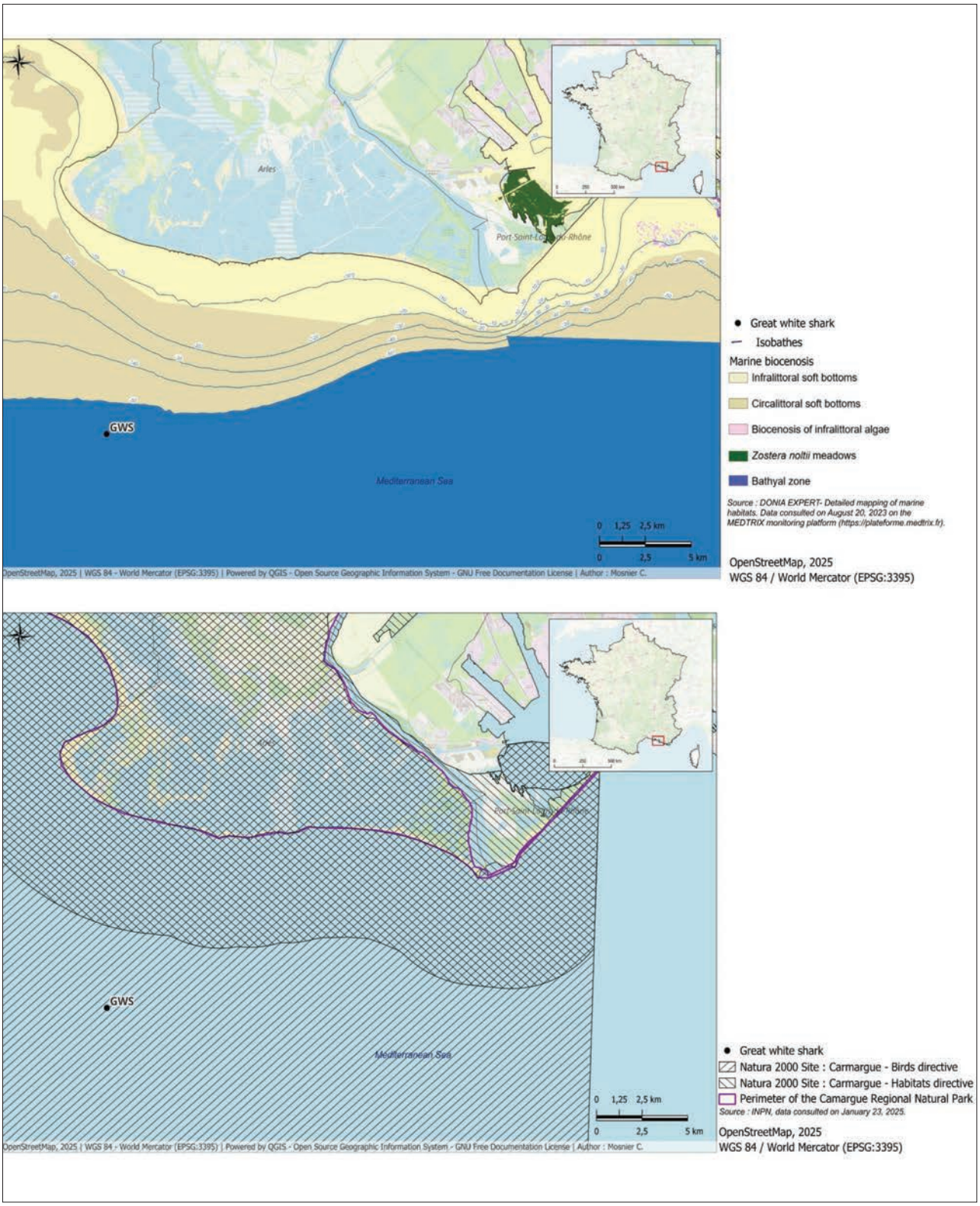

Fig. 1: Geolocation of the shark in Camargue waters. Seabed composition off coastal areas (above). Identification of Natura 2000 protected sites (below).
Sl. 1: Geolokacija morskega volka v vodah okoli Camargua. Sestava morskega dna ob obalnih območjih (zgoraj). Identifikacija zavarovanih območij Natura 2000 (spodaj).

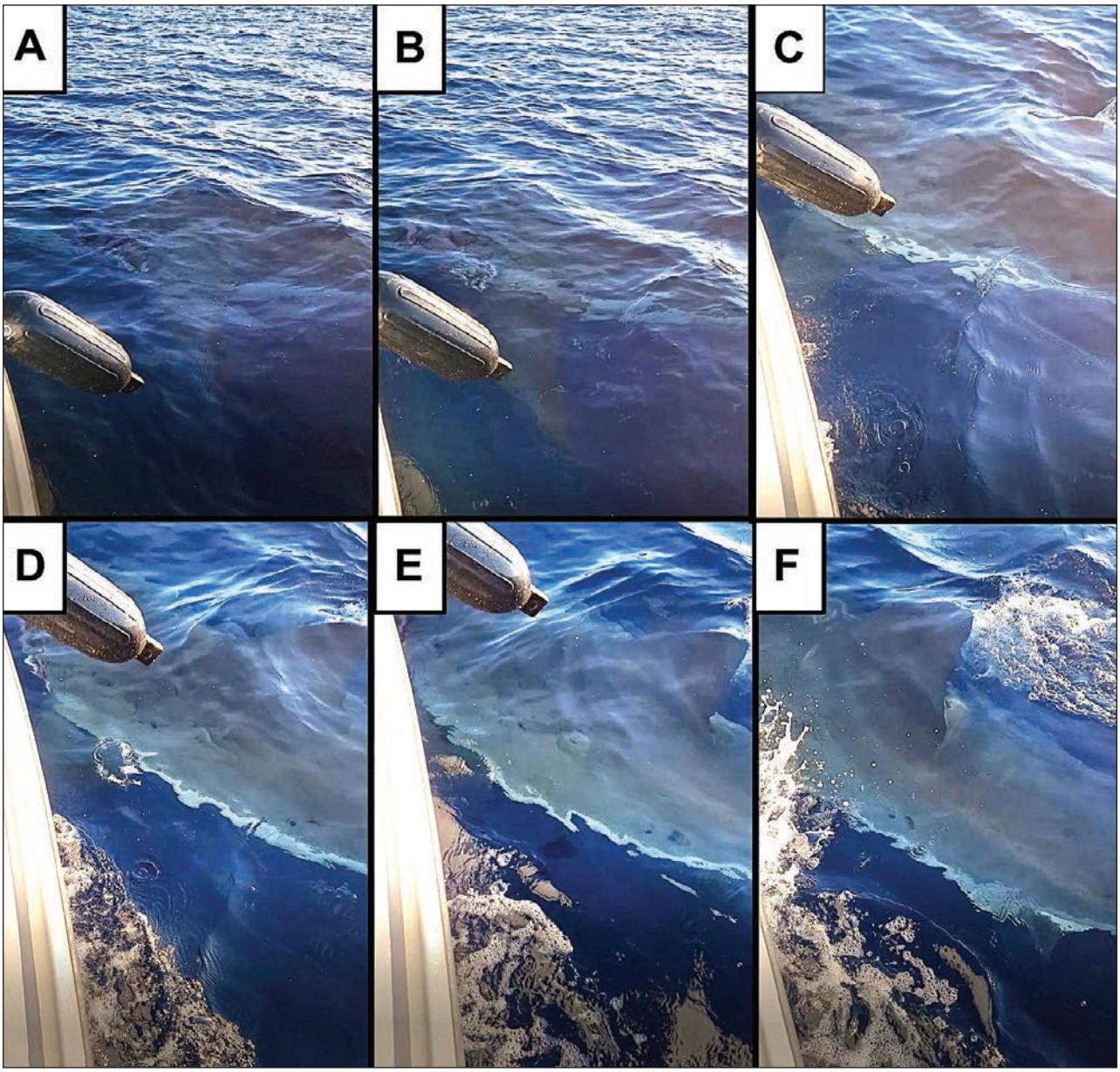

Fig. 2. Species identification of the great white shark (GWS). The visible absence of claspers confirms it is a female (F).
Sl. 2: Identifikacija vrste velikega belega morskega volka (GWS). Vidna odsotnost klasperjev potrjuje, da gre za samico (F).

(TL). The shark was observed swimming along the continental shelf (Fig.1). Furthermore, the shark was geolocated swimming in the direction of the coastal areas of the Rhone Delta (Fig. 1), the wildest most protected and most nutrient-rich area of the PNRC in terms of alluvial discharge (Monaco *et al.*, 2009; Parc National Regional de Camargue, 2012).

We noted numerous deep and well-defined lesions all over the body of GWS (Figs. 2, 3). The shape of these lesions suggests injuries due to bites by a large macropredatory shark that have wide homodont jaws and large sharp teeth, given their well-defined elliptical shape (Fig. 3), exhibiting bite marks on its flank and on its left ventral area (Figs. 2, 3A, B, C, D). Notably, the left gills appeared to be devoured (Figs. 2A, B, D, 3E). The most plausible explanation for these observations is that another adult conspecific repeatedly bit or gripped the gills with its jaws.

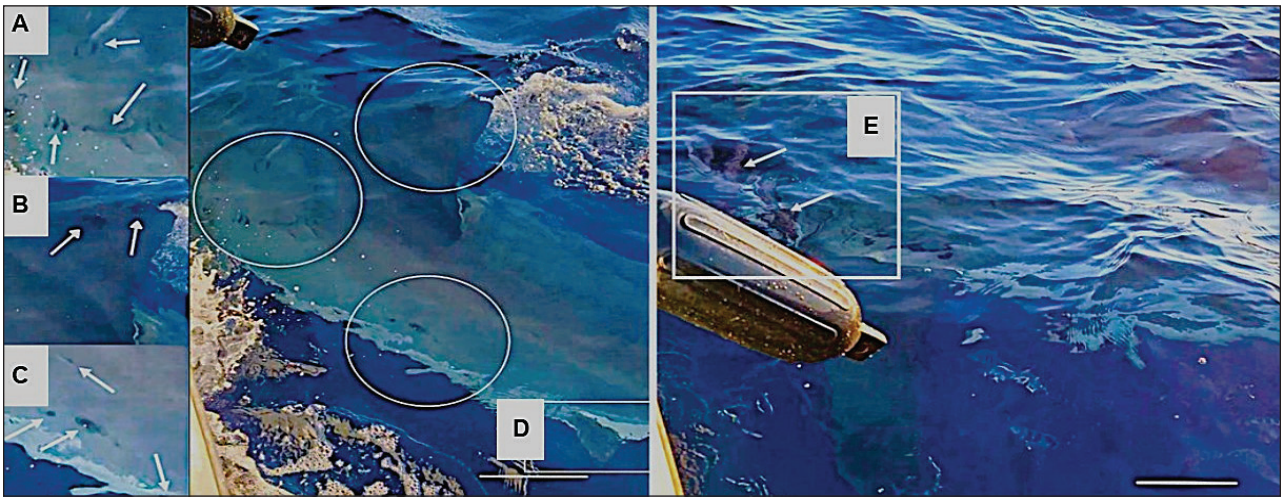

Fig. 3. Presence of large elliptic and deep isolated lesions (white arrows) visible on the left flank (Figs. 3A, B, C, D) of GWS. Damaged first dorsal fin (Fig. 3B). Fig. 3E: Focus on the devoured GWS's left gills. Scale bar indicates 40 cm.
Sl. 3: Prisotnost velikih eliptičnih in globokih izoliranih poškodb (bele puščice), vidnih na levem boku (slike 3A, B, C, D) samice. Poškodovana prva hrbtna plavut (slika 3B). Slika 3E: Osredotočite se na požrte leve škrge samice. Merilna vrstica kaže 40 cm.

The presence of these fresh, non-healing bite scars further supports the hypothesis that these wounds were sustained recently. These bite marks were observed in late September, a period that coincides with the breeding season for the species in the Mediterranean (De Maddalena & Heim, 2012; Boldrocchi *et al.*, 2017). These bite marks are consistent with the so-called "love bites" or «mating scars» observed in other shark species during copulation attempts (Celona *et al.*, 2005; Ritter & Amin, 2018; De Maddalena *et al.*, 2023; Rangel *et al.*, 2023; Barry *et al.*, 2025). Thus, one adult male conspecific grips the body of a female to permit the copulation (Pratt & Carrier, 2001; Hibbit *et al.*, 2017; Santos *et al.*, 2022). Some of the bites can be inflicted by the male on or around the ventral area of the female's cloaca (Rangel *et al.*, 2023). These are suggested to stimulate the ovulation before the copulation in macropredatory sharks (Rangel *et al.*, 2023). During the copulation the male penetrates and inseminates the female by the cloaca using only single one erected of its two claspers (Pratt & Carrier, 2001; Hibbit *et al.*, 2017; Santos *et al.*, 2022). At the end of mating, the male releases the female from his jaws. This is the post-copulatory state for the female.

September aligns with the peak of adult great white shark occurrence in the Mediterranean (Boldrocchi *et al.*, 2017). This suggests that the wounds may be indicative of a recent mating event. The observation of bite marks serves not only as an indicator of reproductive behaviour but also offers an opportunity to better understand the timing of mating events through the study of skin regeneration and healing patterns (Borucinska *et al.*, 2020).

A large proportion of the GWS female's tissues are damaged (Figs. 2A, B, 3E). Its presence swimming close to the PNRC may be explained by a potential foraging behaviour after a possible post copulatory state. Late September in the Rhone Delta is the peak productivity period of the year in the Gulf of Lion (Monaco *et al.*, 2009). The PNRC serves as nursery, foraging and breeding site for many marine species (Parc Naturel Régional de Camargue, 2012). The favorite preys of the Mediterranean great whites: *T. thynnus, X. gladius* and the Delphinidae are mainly abundant at the end of summer in the area (Fromentin & Lopuzanski, 2014; Di-Méglio *et al.*, 2015; Rouyer *et al.*, 2021). This late September 2022, a high abundance of juvenile bluefin tunas were present throughout the Gulf of Lion, notably in the Gulf of Aigues-Mortes (France Bleu Gard Lozère, 2022). The presence of Mediterranean *C. carcharias* is highly correlated with that of *T. thynnus* (Boldrocchi *et al.*, 2017).

The Gulf of Lion may also constitute a key area for the foraging of the species in late summer due to its high productivity (Monaco *et al.*, 2009; Roos, 2012; Stambler, 2013; Strady *et al.*, 2015) and high prey abundance (De Maddalena & Heim, 2012; Rouyer *et al.*, 2021).

This study presents the first footage from the Mediterranean of an adult female *C. carcharias* with possible «mating scars» or so-called «love bites» as the bite

marks caused during pre-copulation. Such mating scars are critical for understanding the reproductive dynamics of the species (Rangel *et al.* 2023, Barry *et al.*, 2025). Future observations will be crucial in confirming our preliminary hypotheses. Firstly, the sighting of other females with obvious bites from the ventral pelvic region to the cloacal region would support our hypothesis that the Northwestern Mediterranean could be a mating site for *C. carcharias*. Then, the coastal waters of the Gulf of Lion could be feeding grounds for females in their post-copulatory state.

Given the critically endangered status of the Mediterranean great white shark and the pressure they face from fishing, a deeper understanding of the species' life history is essential to ensuring their conservation. Our study also higlights the value of citizen as a tool for uncovering new, albeit preliminary, knowledge to improve protection of such large elusive critically endangered species.

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SLEDOVI UGRIZOV NA VELIKI SAMICI BELEGA MORSKEGA VOLKA *CARCHARODON CARCHARIAS* PRI CAMARGU (FRANCIJA) KAŽEJO NA MOŽNO RAZMNOŽEVANJE SREDOZEMSKE POPULACIJE

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POVZETEK

*Ekologija belega morskega volka (*Carcharodon carcharias*) v Sredozemskem morju kljub vlogi te vrste kot največjega plenilca v regiji ostaja slabo poznana zaradi njegove redkosti in upada populacije. Septembra 2022 so avtorji popisali primer redke odrasle samice z izrazitimi sledovi ugrizov ob obali Camargue. Od pomladi do jeseni se v Lyonskem zalivu, zlasti v vodah okoli zavarovanega območja Parc Naturel Régional de Camargue, znatno poveča biodiverziteta. Na podlagi lastnih opazovanj domnevajo, da bi lahko ta regija pozno poleti služila kot pomembno prehranjevalno okolje za samice belega morskega volka po kopulaciji.*

Ključne besede: beli morski volk, Lyonski zaliv, razmnoževanje, sledovi ugrizov, varovanje

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