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PERSPECTIVE ON GREAT WHITE SHARKS (*CARCHARODON CARCHARIAS*) IN THE NORTHWESTERN MEDITERRANEAN AND RECOMMENDATIONS FOR FURTHER FIELD RESEARCH

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ABSTRACT

*We put into perspective the knowledge about white sharks (*Carcharodon carcharias*) in the Mediterranean Sea to identify if the northwestern part is an area of interest and the most efficient methodologies to highlight the presence of the species. We have compiled the main peer-reviewed works, officials' reports and theses, both worldwide and more specifically in the Mediterranean. We focused on studies that allow us to define a more precise framework to search the species. In the Mediterranean, a particular link has been highlighted with bluefin tuna (*Thunnus thynnus*). The northwestern Mediterranean Sea has unique characteristics compared to other parts of the sea regarding primary productivity, surface temperature, presence of tuna, and is bordered by two white sharks' hotspots. We list methodologies for detecting the species worldwide, including BRUVS and environmental DNA. We also make recommendations for field studies.*

Keywords: white sharks, Mediterranean, distribution, diet, recommendations

PROSPETTIVA SUI GRANDI SQUALI BIANCHI (*CARCHARODON CARCHARIAS*) NEL MEDITERRANEO NORD-OCCIDENTALE E RACCOMANDAZIONI PER ULTERIORI RICERCHE SUL CAMPO

SINTESI

*Gli autori hanno messo in prospettiva le conoscenze sul grande squalo bianco (*Carcharodon carcharias*) nel Mediterraneo per identificare se la parte nord-occidentale del bacino sia un'area di interesse e le metodologie più efficaci per evidenziare la presenza della specie. Hanno esaminato i principali articoli scientifici, i rapporti ufficiali e le tesi di laurea, sia a livello mondiale che più specificamente nel Mediterraneo. Si sono concentrati sugli studi che hanno permesso di definire un quadro più preciso per la ricerca della specie. Nel Mediterraneo è stato evidenziato un legame particolare con il tonno rosso (*Thunnus thynnus*). Il Mediterraneo nord-occidentale presenta caratteristiche uniche rispetto ad altre parti del bacino per quanto riguarda la produttività primaria, la temperatura superficiale e la presenza di tonni, ed è delimitato da due hotspot di squali bianchi. Vengono elencate le metodologie per il rilevamento della specie a livello mondiale, tra cui il BRUVS e il DNA ambientale. Si formulano inoltre raccomandazioni per gli studi sul campo.*

Parole chiave: squali bianchi, Mediterraneo, distribuzione, dieta, raccomandazioni

INTRODUCTION

The great white shark *Carcharodon carcharias* (Linnaeus, 1758) is a charismatic but vulnerable species at a global scale (Rigby *et al.*, 2019). Some preferred sites have been identified even though the species has a wide distribution from temperate to tropical waters (Bonfil *et al.*, 2005; Duffy *et al.*, 2012; Christiansen *et al.*, 2014). The main identified hotspots are the northeast Pacific, South Africa, Australia, New Zealand, the Mediterranean, and the east coast of the United States of America (Christiansen *et al.*, 2014).

The reasons put forward for this wide-ranging distribution are many. The first reason is food availability (Becerril-García *et al.*, 2020; Bradford *et al.*, 2020), including the productive areas attracting prey (Bradford *et al.*, 2020). The environment also impacts the species' distribution, with occupation preferences depending on temperature and depth (Boustany *et al.*, 2002; Coxon *et al.*, 2022). Breeding sites (Domeier *et al.*, 2012; Domeier & Nasby-Lucas, 2013) and nurseries also contribute to the distribution of the species (Weng *et al.*, 2007; Domeier & Nasby-Lucas, 2013; Oñate-González *et al.*, 2017). Stages of development can also induce a wide-ranging spatial distribution (Bruce, 2008). In the Mediterranean little is known about the distribution of white sharks (De Maddalena & Heim, 2012).

Genetical studies based on sequencing the mitochondrial control region of Mediterranean specimens demonstrated key findings (Gubili et al., 2010). The examined specimens showed little genetic differentiation from Indo-Pacific lineages. They exhibited strong separation from geographically closer Atlantic/western Indian Ocean haplotypes. The genetic proximity of individuals from the Mediterranean to those from the Pacific lightens the origin of the population (Gubili *et al.*, 2015). Three recent studies provide a global view of this species' past and current distribution over the entire Mediterranean basin (De Maddalena & Heim, 2012; Boldrocchi *et al.*, 2017; Moro *et al.*, 2020). A census of the Mediterranean's observations and catches has been published (De Maddalena & Heim, 2012). The distribution and ecology of the species have also been studied (Boldrocchi *et al.*, 2017), and the hypothesis of the presence of several nurseries in the Mediterranean has been developed: the Sicily Channel (Fergusson, 1996; Fergusson *et al.*, 2000; Boldrocchi *et al.*, 2017), the Adriatic Sea and the Aegean Sea (Kabasakal, 2014, 2020). These studies pointed out a decline in the Mediterranean population, where the species is considered as critically endangered (Dulvy *et al.*, 2016). This phenomenon is illustrated by a reconstruction of the presence of white sharks in the Mediterranean from the 19th century to the present (Moro *et al.*, 2020).

Other studies have focused on specific sectors of the Mediterranean by carrying out analyses on a sub-regional scale. For the central part of this sea, the distribution of sightings and catches of this species was carried out off Sicily at Lampedusa (De Maddalena & Heim, 2012; Micarelli & Sperone, 2016) and Tunisia (Saïdi *et al.*, 2005; Rafrafi-Nouira *et al.*, 2015; Zaouali *et al.*, 2020). Predation on a bottlenose dolphin (*Tursiops truncatus*) has also been detected in this area (Celona *et al.*, 2006). It is not known whether this presence is linked to the narrow and compulsory passage between the two Mediterranean basins. Further east, sightings have been studied in the Adriatic Sea (De Maddalena, 2000; Soldo & Jardas, 2002; Soldo & Dulčić, 2005). A peak of presence in August and September was highlighted (De Maddalena, 2000). In the Sea of Marmara and the waters of the Bosphorus, there may be synchronicity between the decline of *T. thynnus* and *C. carcharias* (Kabasakal, 2016).

Several studies exist for the northwestern Mediterranean, where this species is recorded *e.g.* in the Balearic Islands (Morey *et al.*, 2003). Sightings in this area could be related to food availability in winter with the presence of *Thunnus thynnus* (Barrull & Mate, 2001). For the French waters of Corsica, the reports about the species are also listed (Maliet *et al.*, 2013). A study focused on observations and catches of the species more widely in the French Mediterranean (De Maddalena & Zuffa, 2009). A publication reported a large individual captured in France in 1956 and then taxidermied (De Maddalena *et al.*, 2003). However, this type of capture remains exceptional and opportunistic since this species is considered rare in the Languedoc region of southern France (Capapé *et al.*, 2000).

This study is mainly based on peer-reviewed publications on white sharks in the Mediterranean and worldwide. The work aims to be innovative by providing a different point of view on the issue of the presence of this species in this specific spatial framework. This study is divided into three parts: The first part concerns the diet of the white shark in the world, focusing on the knowledge acquired in the Mediterranean, particularly regarding the bluefin tuna. Then the second part will propose hypotheses on potential spatiotemporal frameworks for white sharks in the northwestern Mediterranean based on knowledge of prey availability and environmental data. Finally, the third part will submit realistic field ideas to highlight their presence considering the small amount of this population.

MATERIAL AND METHODS

Publications included are based on library and electronic databases containing Google Scholar, Web of Science, ResearchGate, and HAL. To find scientific studies, we used different combinations of keywords: white shark, Mediterranean, diet, food, trophic level, ecology, bluefin tuna, *Carcharodon carcharias*, *Thunnus thynnus*, BRUVS, eDNA, primary production, temperature, France, Spain, distribution, world, seamount. We recognize that electronic database research may lead to miss articles, so we used library databases and cited important works from initial findings. We have chosen works written in English, since we believe we have minimized the bias because most current studies are written in English. We also searched for articles in French or Italian, and identified reviews referring to them. We have mainly studied work that has been published in the Mediterranean. We have focused on the north-western part because it has been little studied compared to other areas and has some unique features detailed in this work. But we have also used those carried out on populations worldwide when it could bring ideas to missing knowledge in the Mediterranean. From the information available in the scientific literature, we have chosen to focus on three main parts. We have therefore gathered the information according to the white shark's diet, ecology, and effective *in situ* study methods.

RESULTS AND DISCUSSION

Our paper focuses on studies already published in peer-reviewed scientific journals and "grey" literature like reports or theses. A total of 97 published studies were included in this perspective, published between 1996 and 2023.

Diet of white sharks in the world and the Mediterranean

Worldwide

Adult white sharks are known to have a varied diet composed of elasmobranchs (Hussey *et al.*, 2012; Grainger, 2022), cetaceans (Hussey *et al.*, 2012; Grainger, 2022), teleosts (Hussey *et al.*, 2012; Grainger, 2022), turtles (Heithaus *et al.*, 2008), pinnipeds (Skomal *et al.*, 2012) and cephalopods (Becerril-García *et al.*, 2020; Grainger, 2022). The main food sources for adult specimens are fish for the North Atlantic (Hamady, 2014); tuna for offshore food and pinnipeds for coastal food in the northeast Pacific (Jaime-Rivera *et al.*, 2014); elasmobranchs and teleosts in Australia (Hussey *et al.*, 2012); and pinnipeds at least seasonally in the different oceans (Hussey *et al.*, 2012; Semmens *et al.*, 2013; Jaime-Rivera *et al.*, 2014; Francis *et al.*, 2015). Dietary differences are known between developmental stages and sexes (French *et al.*, 2018). Nevertheless, in general, the trophic level and the prey size will increase with the age of the shark (Estrada *et al.*, 2006; Hussey *et al.*, 2012). Thus the trophic level of an individual exceeding 278 cm is between 4.5 and 5 for individuals from the Northwest Atlantic (Estrada *et al.*, 2006). The trophic level calculated for adult individuals from South Africa is broadly similar, ranging between 4.2 and 5 (Hussey *et al.*, 2012).

The species is highly adaptable, and food sources can vary according to their availability depending on the geographical area (Hamady, 2014; Jaime-Rivera *et al.*, 2014). Indeed, white sharks are known to be highly migratory and capable of moving from one ecosystem to another (Bonfil *et al.*, 2005; Weng *et al.*, 2007; Carlisle *et al.*, 2012; Duffy *et al.*, 2012).

Mediterranean Sea

The stomach content analysis of 24 white sharks caught in the Mediterranean indicate a diverse diet (Fergusson, 1996; Fergusson *et al.*, 2000). Pelagic bony fish such as bluefin tuna *Thunnus thynnus*, Atlantic skipjack *Sarda sarda*, broad-billed swordfish *Xiphias gladius* and bullet tuna *Auxis rochei* were recorded in the diet (Fergusson *et al.*, 2000). Elasmobranchs are also found, including the blue shark *Prionace glauca*, the shortfin mako shark *Isurus oxyrinchus* and the stingrays *Dasyatis spp.* In the Mediterranean, the population diet comprises dolphins such as *Tursiops truncatus*, *Delphinus delphis* and *Stenella coeruleoalba* (Fergusson, 1996; Fergusson *et al.*, 2000). A predation mark is noted on a living bottlenose dolphin *Tursiops truncatus* in Lampedusa (Celona *et al.*, 2006), or sometimes on green turtles *Chelonia mydas* and loggerhead turtle *Caretta caretta* (Fergusson *et al.*, 2000). Finally, it is still possible to find organic or non-terrestrial waste and mollusks. Only one pinniped species exists in the Mediterranean basin, the Mediterranean monk seal *Monachus monachus*. Given the number of individuals, this critically endangered species (Aguilar & Lowry, 2010) does not seem to meet the white shark's energy needs (Semmens *et al.*, 2013). In addition, we have not identified any recent predation, and only one juvenile individual has already been identified in white shark stomach contents (De Maddalena & Zuffa, 2009). Despite recurrent predatory behaviors of white sharks on pinnipeds worldwide (Hamady, 2014), this food source cannot be predominant in the Mediterranean (Semmens *et al.*, 2013; Pethybridge *et al.*, 2014).

Particular attention is given to bluefin tuna, which have been found most often in the stomachs of Mediterranean white sharks (Boldrocchi *et al.*, 2017). Large numbers of white sharks have been caught in tuna traps, including 27 individuals in 38 observations in the Balearic Islands, Italy, and France (Morey *et al.*, 2003; De Maddalena & Heim, 2012). A sighting in continental France even mentions a school of tuna followed by a shark (De Maddalena & Heim, 2012). It is noted that tuna is identified as the primary diet for white sharks in the northeastern Pacific (Jaime-Rivera *et al.*, 2014). Therefore, the relationship between wild bluefin tuna and white sharks has already been studied and highlighted (De Maddalena, 2000; Barrull & Mate, 2001; Soldo & Jardas, 2002; De Maddalena & Heim, 2012; Kabasakal, 2014, 2016; Boldrocchi *et al.*, 2017; Moro *et al.*, 2020). An adult white shark diet hypothesis was suggested based essentially on the bluefin tuna *Thunnus thynnus* in the Mediterranean in the face of a poor choice of prey (Moro *et al.*, 2020). Isotopic analysis of two individuals shows that this population may feed mainly on fish and cephalopods rather than marine mammals (Bevacqua *et al.*, 2021). So we focus on the exploited bluefin tuna species to identify possible hunting areas on hotspots, but we do not consider that this shark feeds exclusively on it. The problem of the drastic reduction in bluefin tuna numbers has allowed the accumulation of new research on this species, in particular for the French Mediterranean.

Productive waters and frameworks of the bluefin tuna (*Thunnus thynnus*) in the northwestern Mediterranean

Mediterranean bioregions can be classified according to non-coastal phytoplankton developments from satellite data (Lavigne *et al.*, 2013). It shows only one non-coastal bloom bioregion in the Mediterranean: the "Bloom North-West" bioregion covering the Liguro-Provencal basin. It's the most productive non-coastal area in primary production (Lavigne *et al.*, 2013). Therefore, there is a significant and transient development of biomass from March to May. The attraction of bluefin tuna to another upwelling area of the Mediterranean is known (Battaglia *et al.*, 2022). From Spring to Fall, the Pacific bluefin tuna (*Thunnus orientalis*) has been located in areas with the highest primary productivity levels available in the California Current ecosystem (Boustany *et al.*, 2010). It is, therefore, likely to find bluefin tuna in the "Bloom North-West" bioregion in the Spring, which is in agreement with the known distribution of the species (Cermeño *et al.*, 2015). A key area of high presence of bluefin tuna was identified (Fromentin & Lopuszanski, 2014; Bauer *et al.*, 2017) and is located at coordinates 4–6 °E and 43–41 °N. A greater dispersion of animals in this sector was noted for the Spring season. It is noted that a possible fidelity of bluefin tuna to its tagging site may be a bias in the representation of the movements of tuna from other regions visiting these waters. In contrast, the Gulf of Lion is a feeding habitat for bluefin tuna (Druon *et al.*, 2011), where adults are less abundant than individuals in their maturing stages (Bauer *et al.*, 2015).

Possible spatial and temporal frameworks of the white shark *(Carcharodon carcharias)* in the northwestern Mediterranean

Possible link with bluefin tuna distribution

To suggest potential habitat zones, we used the knowledge acquired on populations worldwide. The inshore behaviors of white sharks are consistent with a pinniped hunting strategy (Weng *et al.*, 2007). While their behavior in offshore waters is hypothesized to be at least partially related to pelagic prey (Jorgensen *et al.*, 2012). From this information applied to the context of the Mediterranean basin, we can hypothesize a link between the habitat of bluefin tuna and the white shark in offshore waters (De Maddalena & Heim, 2012). We note that the western Mediterranean sectors are important for the reproduction and feeding of bluefin tuna (Cermeño *et al.*, 2015). This species and the white shark (*Carcharodon carcharias*) are both apex predators, and it could be interesting for them to move to areas with significant prey biomass for energy reasons (Korsmeyer & Dewar, 2001; Semmens *et al.*, 2013). Moreover, the demography of the great white shark could be linked to one of its main prey (Moro *et al.*, 2020). Understanding the spatial and temporal distribution of the studied bluefin tuna in the "Bloom North-West" bioregion can restrict the search areas of white sharks. A recent statistical analysis of the observations identifies three hotspots in the Mediterranean: the Balearic Islands, Corsica, and Malta (Moro *et al.*, 2020). Two of these three hotspots border the "Bloom North-West" bioregion. Because of the diet supposedly based mainly on bluefin tuna and the recorded presence of the white shark, we suspect the Provencal basin to be a frequented sector. The presence of the white shark at least seasonally seems likely during the Spring bloom based on historical observations, which does not mean this is still the case today.

Data from scientific literature also support the hypothesis of a seasonal presence in the Provencal basin. Thus in the Balearic Islands, catches of white sharks are more important just before Spring (Morey *et al.*, 2003) in neighbouring waters of the "Bloom North-West" bioregion. One study speculated that sightings in the Balearic Islands were related to food and appeared to occur in winter (Barrull & Mate, 2001). During this season, bluefin tuna are present on the north coast of Mallorca, according to a study of Bauer *et al.* (2017), when a greater presence of white sharks was identified in these months in historical data (Barrull & Mate, 2001). The migratory character of bluefin tuna (Richardson *et al.*, 2016) is known for its high energy requirements (Brill, 1996). The bioregion "Bloom North-West" could be important at least seasonally. This presence in the western Mediterranean is perhaps partially linked to the area's environmental characteristics.

Movements related to environmental variables and possible bias in the observations

The white shark Mediterranean population is genetically distinct from the Atlantic (Gubili *et al.*, 2010), and evidence of migration has already been provided in other parts of the world for males (Boustany *et al.*, 2002) and females (Bonfil *et al.*, 2005). The hypothesis of movements only within the Mediterranean Sea remains the most credible to explain this genetic distinction but is not yet confirmed. Individuals could have differences in spatial occupancy depending on sex or age, like for example in South Africa (Kock *et al.*, 2013) or Australia (Robbins & Booth, 2012). Therefore, sexual and size segregation may exist in the Mediterranean Sea in relation to environmental variables.

The temperature range in which the world's great white sharks evolve is wide, tolerating 5 to 25°C (Boustany *et al.*, 2002; Bonfil *et al.*, 2010; Skomal *et al.*, 2017; Ebert *et al.*, 2021). It is noted that the northwestern Mediterranean sector is unique for its low sea surface temperature (SST) in Spring compared to the entire basin (Pisano *et al.*, 2020). The Mediterranean can offer a wide range of temperatures, as shown by the great diversity of ingested prey feeding on habitats of different types (Boldrocchi *et al.*, 2017). A movement pattern of white sharks following a latitudinal distribution has already been observed (Skomal *et al.*, 2017); it is unknown if the same happens in the Mediterranean. The numerous observations in the south-central Mediterranean is, therefore, not in opposition to the presence of hotspots in the northwestern Mediterranean (Moro *et al.*, 2020), due to the thermal amplitude of the two areas. In addition, the northwest sector could instead be a seasonal feeding sector for adults, while the central-south (Fergusson, 2002; Saïdi *et al.*, 2005) and Turkish waters (Kabasakal, 2020) could be considered as nurseries sectors. Site fidelity and seasonality are reported for white sharks in the northeast Pacific (Jorgensen *et al.*, 2009). Offshore migration is also known in Spring for eastern North Pacific sharks (Weng *et al.*, 2007). It could be helpful to conduct a statistical study combining the satellite data monitoring white sharks worldwide with their environmental data. This analysis could highlight the compatibility between the waters of the northwestern Mediterranean and the habitat of white sharks. Thus it would be possible to say whether the surface temperature in these areas is similar to the regions visited by this species in the other parts of the world according to a potential latitudinal distribution.

We can hypothesize about promising areas within the northwest bioregion in Spring (Fig. 1). Fine-scale structures in the open ocean (Wurtz & Rovere, 2015) must be checked first in these areas because of an increasing fish concentration effect (Fiori *et al.*, 2016; Baudena *et al.*, 2021). Balearics are interesting during February according to the seasonal increase in observations (Morey *et al.*, 2003), with possible fine-scale structures such as Sóller, Bertran and Cresques seamounts. Just after the bloom, the more offshore part of the high-use area of bluefin tuna in May has unique conditions in the Mediterranean of low SST and tuna-rich waters. Possible fine-scale structures are Aragó seamount, La Renaixença hills, Felibres hills and Calypso hills. Finally, offshore Corsica's west coast during April-May is of interest because of the proximity of this hotspot (Moro *et al.*, 2020) with productive and cool waters.

We should have bycatch or recent observations if white sharks were present annually in French Mediterranean waters. However, today's low fishing pressure in the Provencal basin (Micheli *et al.*, 2013) and the important reduction of individuals (Moro *et al.*, 2020) may explain the subsided proportion of white shark catches. The contemporary observations are more numerous in the south-central Mediterranean than in the Gulf of Lion (Moro *et al.*, 2020). Hypotheses can be formulated to explain this phenomenon, but without confirmation so far: attraction for a nursery in the south-central Mediterranean (Fergusson, 2002), more coastal behavior in the south-central Mediterranean like in South Africa (Johnson *et al.*, 2009), change in behavior or number comparing to the past distribution in northwestern Mediterranean, important historical fishing leading to the disappearance of nurseries in Europe as in Croatia (De Maddalena & Heim, 2012) in favor of North African nurseries, the historical disappearance of pinnipeds from the french Mediterranean coast (Karamanlidis *et al.*, 2016), more observation or fishing effort in the

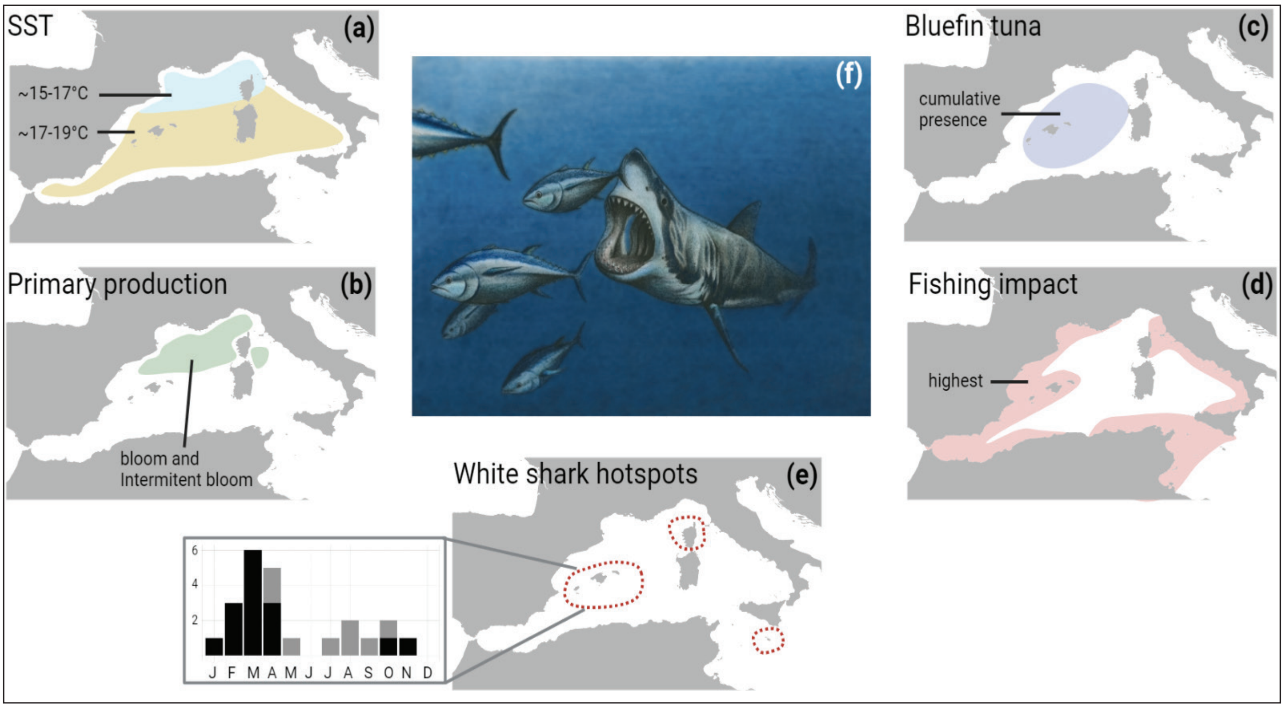

Fig. 1: Variables of interest in the northwestern Mediterranean to better understand the distribution of white sharks** (Carcharodon carcharias)**. (a) Mean sea surface temperature (SST) field (ºC) from 1982 to 2018 in the Copernicus Marine Environment Monitoring Service (CMEMS) Mediterranean area (inspired by Pisano** et al.**, 2020). (b) Spatial distribution of the non-costal bloom and intermittent bloom obtained from the DR09 methodology applied on a weekly climatology calculated from a 16-year database (inspired by Mayot** et al.**, 2016). (c) Utilization Distributions of tagged bluefin tuna** (Thunnus thynnus) **(inspired by Cermeño** et al.**, 2015). (d) Spatial distribution of the highest cumulative fishing impact (all fishing types combined) (inspired by Micheli** et al.**, 2013). (e) Hotspots of white sharks (inspired by Moro** et al.**, 2020) with histograms of observations for the Balearic Islands (data from Morey** et al.**, 2003). Black: white sharks catches. Grey: attacks upon cetaceans or turtles). (f) Biological illustration of a white shark hunting a school of bluefin tuna. Illustration by Juliette Vallin, digital improvements by Tanguy Carpaye-Taïlamée.

Sl. 1: Ključne spremenljivke v severozahodnem Sredozemlju za boljše razumevanje porazdelitve belega morskega volka** (Carcharodon carcharias)**. Legenda: a) Polje srednje površinske (ºC) temperature morske vode od 1982 do 2018 v sredozemskem območju Kopernikove službe za spremljanje morskega okolja (CMEMS) (po vzoru Pisano in sod., 2020). b) Prostorska porazdelitev cvetenja stran od obale in občasnega cvetenja na podlagi metodologije DR09 in tedenske klimatologije, izračunane iz 16-letne baze podatkov (prirejeno po Mayot in sod., 2016). C) Razširjenost modroplavutega tuna** (Thunnus thynnus) **(prirejeno po Cermeño in sod., 2015). D) Prostorska porazdelitev največjega kumulativnega ribolova (vse vrste ribolova skupaj) (prirejeno po Micheli in sod., 2013). E) Vroče točke pojavljanja belih morskih volkov (po Moro in sod., 2020) z opazovanji na Balearih (po Morey in sod., 2003). Črna: ulovi belih morskih volkov. Siva: napadi na kite ali želve. F) Biološka ilustracija belega morskega volka, ki lovi jato modroplavutega tuna (ilustracija Juliette Vallin, digitalna izboljšava Tanguy Carpaye-Taïlamée).

south-central Mediterranean (Micheli *et al.*, 2013), the poor transmission of historical data in south-central Mediterranean countries.

Suggestions for field research

Choice of methodologies

We are entitled to question the veracity of the hypotheses proposed above. To verify or reject them, we can rely on several complementary methodologies that highlight the presence of shark species (Boussarie *et al.*, 2018). Thus we can use methodologies based on environmental DNA, baited remote underwater videos (BRUVs), opportunistic underwater visual census, opportunistic observations census by participatory sciences (Bargnesi *et al.*, 2020) and fisheries registration (Baum & Blanchard, 2010). These last three techniques require considerable sampling effort to increase the number of current observations. We will focus on methodologies with a better chance of achievement depending on their cost and chances of success. Therefore, the two methodologies selected are environmental DNA and BRUVS.

Use of environmental DNA

Environmental DNA has a proven track record for detecting shark species (Bakker *et al.*, 2017). This methodology could highlight the presence of this unidentified species in these sectors as they were identified in the Sicilian Channel (Jenrette *et al.*, 2023). Increasing the eDNA sampling effort could make it possible to detect species in the sector where it was not yet detected (Boussarie *et al.*, 2018).

Today different methods exist for eDNA sampling, but the method of filtration is the most adapted to our situation in offshore waters (Tsuji *et al.*, 2019). The eDNA of this fish is most likely to be captured by 1-10 µm pore size filters (Turner *et al.*, 2014). Glass microfiber can be used to increase the efficacy of eDNA collection (Tsuji *et al.*, 2019). A first water sampling method could be a Niskin rosette sampler with a CTD attached that can take samples from great depths (Truelove *et al.*, 2019). Another possibility in water sampling could be using a remotely controlled vehicle (ROV) equipped with Niskin collection bottles (Truelove *et al.*, 2019). A water pump could be another possibility with adequate pressure, flow rate and water volume (Thomas *et al.*, 2018) applied to offshore waters.

In any case, there could be no detection of a species of interest with a low amount of DNA in the ocean environment because of DNA degradation (Jenrette *et al.*, 2023). Therefore, it is necessary to play on several variables to maximize the chances of results to overcome this problem. The constraints on field variables are e.g. calm meteorological conditions before and during sampling without strong currents, having a large number of replicas, the depth of sampling in the water column (Andruszkiewicz *et al.*, 2017; Curtis *et al.*, 2021).

It is possible to change the sampling depth, targeting the probable locations and depths of appearances of adult white sharks in offshore waters. Several depths of interest are mentioned in the literature: 300-500 m depth range during the day and in the 50-250 m range at night (Nasby-Lucas *et al.*, 2009), 100-600m depth range (Skomal *et al.*, 2017), 200-900 m depth range (Bonfil *et al.*, 2005). Depths corresponding to temperatures between 20-22.5°C are also interesting (Nasby-Lucas *et al.*, 2009). Surface waters could be occupied even if there are no pinnipeds (Bonfil *et al.*, 2005). More globally, the mesopelagic zone is known to be a major feeding habitat for white sharks (Le Croizier *et al.*, 2020). These depths remain suggestions without confirmation of the presence of genetic material in the Mediterranean Sea.

Use of BRUVs

BRUV stations are used worldwide for white shark studies (Harasti *et al.*, 2019). Pelagic stereo or mono BRUVs are alternative sampling methods that are non-intrusive and non-lethal (Santana-Garcon *et al.*, 2014). Some studies contradict each other on their efficiencies: complementarity with other so-called "standard" methods has already been identified (Boussarie *et al.*, 2018). Conversely, comparable proportions of species of the family Carcharhinidae have already been shown using specific procedures (Santana-Garcon *et al.*, 2014). However, BRUVs are known to have highlighted the presence of juvenile white sharks on the coast of Australia (Harasti *et al.*, 2019). Stereo-BRUVs allow continuous behavioral recordings for the target species or other mobile animals (Santana-Garcon *et al.*, 2014). In our case, standardization is interesting over broad spatiotemporal scales and to determine the relative abundance of the species (Santana-Garcon *et al.*, 2014).

BRUV could be interesting to use in areas of great depth and far from shore, which differs from what has already been done in Australia for juveniles. Tuna, particularly tropical, are known to aggregate under "fish aggregating devices" (FAD) (Pérez, 2021) and placing BRUVs on these FADs could be another option to increase the likelihood of identifying white sharks. This kind of device equipped with a camera may be an idea to develop, the attracted tuna acting as live bait. Due to the remoteness of the study site in the Mediterranean, there are many constraints for multiple monthly deployments, unlike coastal studies (Harasti *et al.*, 2019). Pelagic low-cost BRUVs have been proposed for pelagic sharks, but we must retrieve the device before and after (Torres *et al.*, 2020). Because of the possibility of a strong swell with the winds causing seasonal bloom, equipment must be waterproof and solid to resist.

In a favourable environment for observations in Australia, one shark was recorded approximately every 15 hours (Harasti *et al.*, 2019). We therefore assume that in our unfavourable situation the required deployment time should be much longer to obtain a single sighting. It will also be possible to verify the presence of declining species like other large sharks.

CONCLUSIONS

There is no spot with a strong coastal presence of white sharks in the Mediterranean compared to other areas worldwide. We had to make assumptions about this species to define plausible spatial and temporal frameworks, including the assumed main diet. We do not know if the species' current distribution is representative of historical observations due to strong anthropogenic impacts. Despite all the precautions, the chances of identifying white shark DNA in the offshore environment are probably very low. However, this remains the most efficient and cheapest identification technique for an effective long-term study of this rare species in some areas of the Mediterranean (Jenrette *et al.*, 2023). It would therefore be interesting to carry out this type of analysis on the observation hotspots in the Mediterranean, namely the Balearic Islands, Corsica and Malta (Moro *et al.*, 2020). However, the main priority in the Mediterranean remains the reduction of threats to the conservation of the species (Huveneers *et al.*, 2018).

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POGLED NA VELIKEGA BELEGA MORSKEGA VOLKA (*CARCHARODON CARCHARIAS*) V SEVEROZAHODNEM SREDOZEMLJU IN PRIPOROČILA ZA NADALJNE TERENSKE RAZISKAVE

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POVZETEK

*Avtorji so preiskali znanje o belih morskih volkovih (*Carcharodon carcharias*) v Sredozemskem morju, da bi ugotovili, ali je severozahodni del območja zanimiv in analizirali najbolj učinkovite metode za ugotavljanje prisotnosti vrste. Analizirali so vsa razpoložljiva recenzirana dela, uradna poročila in teze tako v svetovnem merilu kot tudi na nivoju Sredozemskega morja. Osredotočili so se na raziskave, ki so omogočale določitev natančnejšega okvira pojavljanja vrste. Še posebej je bila poudarjena povezava z modroplavutim tunom (*Thunnus thynnus*) v Sredozemskem morju. Severozahodni del bazena ima v primerjavi z drugimi deli edinstvene značilnosti kot so primarna produkcija, površinska temperatura in pojavljanje tunov, poleg tega pa meji na dve vroči točki pojavljanja belih morskih volkov. Avtorji navajajo metode za odkrivanje vrste po vsem svetu, vključno z metodami BRUVS in okoljske DNK. Poleg tega podajajo priporočila za terenske raziskave.*

Ključne besede: beli morski volkovi, Sredozemsko morje, razširjenost, prehrana, priporočila

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