Acta Adriatica 67 (2026):
https://doi.org/10.32582/aa.67.1.5

www.izor.hr

ORIGINAL ARTICLE

The Algerian coast as a seasonal corridor for the basking shark *Cetorhinus maximus*: Leveraging three decades of citizen science and bycatch data in the southwestern Mediterranean

Lotfi Bensahla-Talet[1,2*], Yahia Bouslah[3], Raouf Zaidi[4], Ouezna Mechouet[1], Noureddine Benaissa[1] and Abdennour Selama[5]

[1]*University of Oran - Ahmed Ben Bella, Faculty of Natural Sciences and Life, Department of Biology, Oran, Algeria*
[2]*University of Oran - Ahmed Ben Bella, Faculty of Natural Sciences and Life, Department of Biotechnology, Oran, Algeria*
[3]*University of Adrar Ahmed Draia, Faculty of Natural Sciences and Life, Department of Biological Sciences and Life, Adrar, Algeria*
[4]*University of Tarf Chadli Benjedid, Faculty of Natural Sciences and Life, Department of Marine Sciences, El Tarf, Algeria*
[5]*National Center for Research in Fisheries and Aquaculture, Tenès, Chlef, Algeria*

Abstract: The basking shark (*Cetorhinus maximus*), an endangered filter-feeding elasmobranch, is subject to significant anthropogenic pressures in the Mediterranean Sea. Despite its ecological importance, data from the North African coast are limited. This study presents the first multi-decadal analysis (1990-2025) of *C. maximus* occurrences in the Algerian Basin (GSA 04). A robust dataset (N=27), compiled from fisheries records, direct sightings, and citizen science contributions (33.3% of records), was used to investigate the environmental drivers of its distribution. Statistical analyses revealed a significant increase in observation frequency since 2019 (Mann-Kendall $\tau=0.362$, $p<0.001$). Occurrences exhibited a clear seasonal pattern, peaking in June. Bycatch accounted for the majority of records (63.0%), primarily associated with driftnet fisheries in the western sector. A strong positive correlation was found with sea surface temperature (Spearman's $\rho=0.68$, $p=0.021$). In contrast, a negative relationship with primary productivity ($\rho=-0.61$, $p=0.038$) suggests a "trophic lag" whereby shark presence coincides with post-bloom conditions. Sea surface salinity (SSS) was not a significant predictor ($\rho=0.12$, $p=0.45$), indicating a broad tolerance to the hydrographic gradients of the Algerian Current. These findings highlight the Algerian coast as an important seasonal migratory corridor. The observed overlap between shark presence and intensive fishing activity underscores the urgent need for conservation measures. We recommend integrating citizen science into regional monitoring programs and implementing seasonal fishing gear restrictions to reduce bycatch mortality and support the long-term persistence of this species in the Mediterranean.
Keywords: *Cetorhinus maximus*; bycatch; GSA 04; Mediterranean Sea; citizen science; phenology

Sažetak: ALŽIRSKA OBALA KAO SEZONSKI KORIDOR ZA GOLEMU PSINU (*CETORHINUS MAXIMUS*): TRI DESETLJEĆA PODATAKA DOBIVENIH PUTEM GRAĐANSKE ZNANOSTI I PRILOVA U JUGOZAPADNOM DIJELU SREDOZEMNOG MORA. Golema psina (*Cetorhinus maximus*), ugrožena filtratorna vrsta hrskavičnjača, izložena je značajnim antropogenim pritiscima u Sredozemnom moru. Unatoč svojoj ekološkoj važnosti, podaci s obale sjeverne Afrike i dalje su malobrojni. Ovo istraživanje predstavlja prvu višedesetljetnu analizu (1990.–2025.) pojavljivanja vrste *C. maximus* u Alžirskom bazenu (GSA 04). Robustan skup podataka (N = 27), prikupljen iz ribarskih evidencija, izravnih opažanja i doprinosa građanske znanosti (33,3 % zapisa), korišten je za istraživanje okolišnih čimbenika koji utječu na rasprostranjenost ove vrste. Statističke analize pokazale su značajan porast učestalosti opažanja od 2019. godine (Mann-Kendall $\tau = 0{,}362$, $p < 0{,}001$). Pojavljivanja su pokazala jasan sezonski obrazac s maksimumom u lipnju. Većina zabilježenih jedinki predstavljala je prilov (63,0%), uglavnom iz plutajućih mreža u zapadnom sektoru. Uočena je snažna pozitivna korelacija s površinskom temperaturom mora (Spearmanov $\rho = 0{,}68$, $p = 0{,}021$). Nasuprot tome, negativna korelacija s primarnom proizvodnjom ($\rho = -0{,}61$, $p = 0{,}038$) upućuje na „trofičko kašnjenje", pri čemu se prisutnost ovih morskih pasa podudara s razdobljem nakon cvjetanja fitoplanktona. Površinski salinitet nije se pokazao kao značajan čimbenik ($\rho = 0{,}12$, $p = 0{,}45$), što ukazuje na široku toleranciju vrste na hidrografske gradijente Alžirske struje. Ovi rezultati ističu alžirsku obalu kao važan sezonski migracijski koridor za golemu psinu. Uočeno preklapanje prisutnosti ove vrste i intenzivnih ribolovnih aktivnosti naglašava potrebu za hitnim mjerama očuvanja. Preporučujemo uključivanje građanske znanosti u regionalne programe praćenja te uvođenje sezonskih ograničenja ribolovnih alata kako bi se smanjila smrtnost uslijed prilova i podržala dugoročna otpornost ove vrste u Sredozemnom moru.
Ključne riječi: *Cetorhinus maximus*; prilov; GSA 04; Sredozemno more; građanska znanost; fenologija

**Corresponding author*: bensahlatalet.lotfi@univ-oran1.dz
Received: 24 February 2026, accepted: 10 April 2026
ISSN: 0001-5113, eISSN: 1846-0453

INTRODUCTION

Occupying a unique and vulnerable ecological niche, the basking shark (*Cetorhinus maximus* (Gunnerus, 1765)) is the second-largest fish in the world's oceans, surpassed only by the whale shark (*Rhincodon typus* Smith, 1828) (Ebert *et al*., 2021). Both species are large-bodied, planktivorous elasmobranchs that occupy a distinct high-trophic ecological niche (Cortés, 1999). However, while the whale shark is a facultative suction feeder typically inhabiting tropical waters, *C. maximus* is an obligate ram filter-feeder primarily found in temperate and boreal regions (Sims, 1999, 2008). This species is distributed across both hemispheres and occupies a wide vertical range in the water column, with recorded movements from the surface down to depths of 1,264 m within the mesopelagic zone (Rigby *et al*., 2021). Life-history traits further highlight its vulnerability: males reach sexual maturity at approximately 12-16 years, while females may require 20 years or more. Gestation is prolonged, lasting between 12 and 36 months (Pauly, 1978; Compagno, 2001; Sirri *et al*., 2012). The species is presumed to be oophagous, and only a single litter of six near-term pups has been documented (Ebert *et al*., 2021). These biological constraints result in low reproductive output and slow population recovery, making the species particularly susceptible to anthropogenic pressures. Consequently, the basking shark is currently listed as Endangered (EN) on the IUCN Red List under criterion A2bd, reflecting an estimated global population decline of 50-79% over the past three generations (Rigby *et al*., 2021).

Historically, *C. maximus* has been heavily exploited for its liver oil (squalene), meat, and cartilage, leading to the depletion and, in some cases, local extinction of populations throughout the 20th century (Burgess *et al*. 2005; Dewar *et al.,* 2018). Although targeted fisheries have largely been prohibited following the species' inclusion in CITES Appendix II (2002) and CMS Appendices I and II (2005), contemporary populations continue to face a range of significant threats. Bycatch remains the primary source of mortality, as basking sharks are highly susceptible to entanglement in various fishing gears, including driftnets, midwater trawls, purse seines, tuna traps, and trammel nets (Cebrian *et al.,* 2010; Bradai *et al.,* 2018; Carpentieri *et al*., 2021). Their large body size and characteristic ram-feeding behavior frequently result in fatal entrapment, particularly in areas of intense fishing activity (Mancusi *et al*., 2005; Francis and Lyon, 2012). In addition, their tendency to feed near the surface for extended periods increases their vulnerability to collisions with both commercial and recreational vessels (Pirotta *et al*., 2019). Emerging threats such as marine pollution further exacerbate these risks. Due to their filtration capacity of processing up to 2,000 tons of seawater *per* hour, basking sharks are particularly exposed to the ingestion of microplastics and the bioaccumulation of persistent organic pollutants (POPs). These contaminants have been shown to cause endocrine disruption and impair reproductive function (Crespo *et al*., 2018).

In the Mediterranean Sea, the conservation status of the basking shark is of particular concern, as the basin is recognized as a global hotspot for chondrichthyan extinction risk due to the overlap of critical habitats with intensive industrial and artisanal fishing activities (Malak *et al*., 2011; Dulvy *et al*., 2014; Queiroz *et al.,* 2016). While research efforts have progressed substantially in the northern Mediterranean, the North African coast, particularly the Algerian Basin (GSA 04), remains data-deficient regarding the regional status of the species. Despite its broad global distribution, *C. maximus* is naturally rare in this region (Kabasakal, 2013). Historical records from the combined Algerian and Tunisian coasts document only 21 specimens over a 36-year period (1966-2002), underscoring its scarcity in the southwestern Mediterranean (Capapé *et al*., 2003). This rarity highlights the importance of long-term, multi-source monitoring to accurately assess its regional distribution and vulnerability to anthropogenic pressures.

The Algerian coastline is a dynamic oceanographic region influenced by the Algerian Current and the inflow of Modified Atlantic Water (MAW) (Millot, 1999). These processes have been shown to enhance productivity and promote the aggregation of planktivorous megafauna along frontal zones (Hussein and Bensahla-Talet, 2019; Bouslah *et al*., 2023). Although the ecological significance of this area as a potential migratory corridor has been suggested, systematic records of *C. maximus* along the Algerian coast remain limited and fragmented.

Establishing a robust baseline of occurrence records and anthropogenic interactions is essential for the effective implementation of regional conservation strategies and for meeting the obligations outlined in the Barcelona Convention (Annex II) (UNEP/MAP, 1995). This study aims to address this knowledge gap by compiling a comprehensive database of basking shark occurrences in Algerian waters spanning 35 years (1990-2025). The database integrates direct observations, fishery-dependent bycatch records, and citizen science contributions, allowing for a multidisciplinary approach to studying the species in the region. The objectives of this study are threefold: (i) to quantify the temporal and seasonal distribution of *C. maximus* in the southwestern Mediterranean; (ii) to identify key environmental drivers such as sea surface temperature, chlorophyll *a* concentration, and salinity associated with its occurrence; and (iii) to assess the main anthropogenic threats in order to inform targeted management and conservation strategies.

MATERIAL AND METHODS

The study encompassed the entire Algerian coastline (Fig. 1) within the southwestern Mediterranean (GSA 04; GFCM, 2018). Data on basking shark (*Cetorhinus maximus*) occurrences were collected over a 35-year

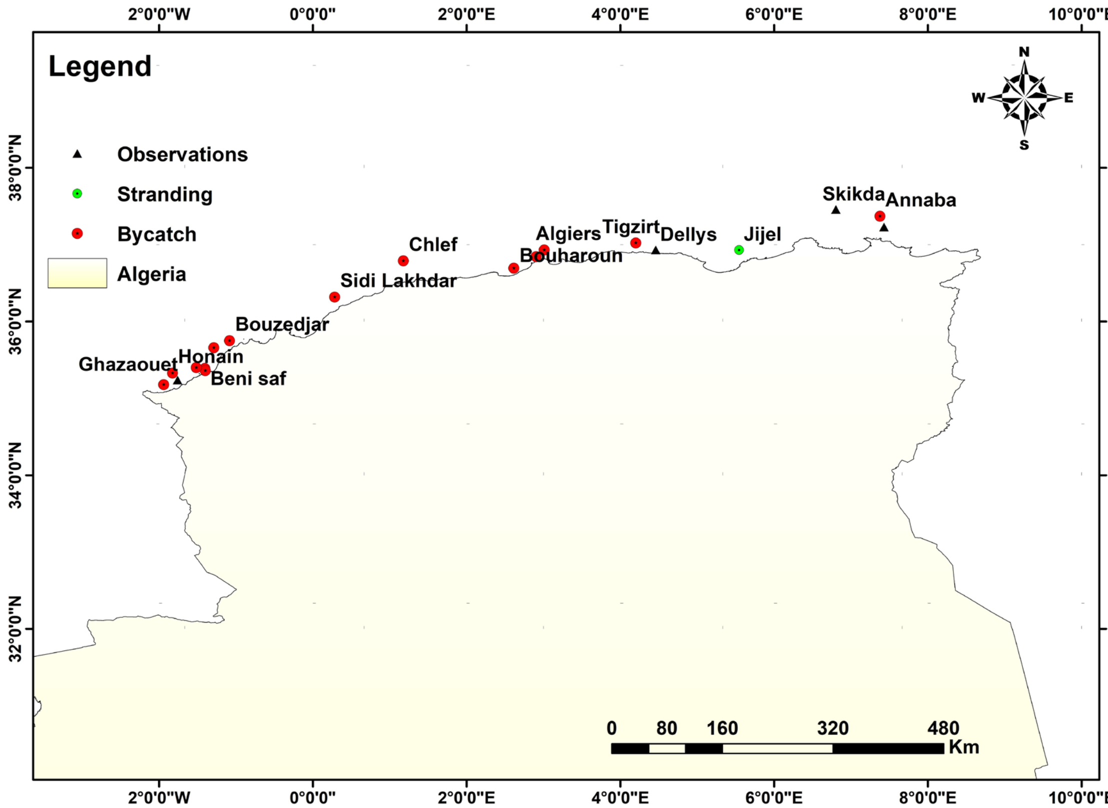

Fig. 1. Records of the basking shark *Cetorhinus maximus* mentioned from 1990 to 2025 along Algerian coastal waters with indication of record type.

period (1990-2025). A multi-source approach was adopted, integrating fishery-dependent data with opportunistic observations from sea users. Fishery-dependent data, including incidental bycatch records, were obtained through active collaboration with local fishing communities. Information was collected *via* semi-structured interviews and standardized questionnaires administered directly to fishers in key Algerian ports, following established protocols for documenting elasmobranch interactions (Lewison *et al.,* 2014). These data were complemented by citizen science contributions, including verified reports from sea users, as well as a systematic internet-based data mining process. This digital survey targeted social media platforms, aquatic life forums, and local online press archives. To ensure data quality and minimize the risk of misidentification (Soldo, 2026), only records supported by high-resolution photographic or video evidence were retained, allowing for the verification of key diagnostic morphological features (e.g., gill slits, snout shape). Each digital record underwent a rigorous validation protocol (Giovos *et al*., 2019), including verification of spatio-temporal metadata and the removal of duplicate entries across multiple platforms.

To characterize the ecological niche of the species, spatio-temporal environmental variables were cross-referenced with validated occurrence records. Daily sea surface temperature (SST) at a nominal depth of 0.2 m was extracted from the NOAA 0.25° Daily Optimum Interpolation SST (OISST) v2.1 dataset (Huang *et al*., 2021). This dataset integrates bias-corrected AVHRR satellite observations with *in situ* measurements from ships and Argo floats, providing a robust basis for identifying thermal habitat conditions. As a proxy for primary productivity, monthly mean chlorophyll *a* (Chl *a*) concentrations ($mg.m^{-3}$) were derived from the MODIS-Aqua Level 3 product at a 4 km spatial resolution, processed using the NASA standard OC3/OC4 algorithms (Hu *et al*., 2012). Finally, sea surface salinity (SSS) data were obtained from the Copernicus Marine Environment Monitoring Service (CMEMS) reanalysis. Salinity was used as an indicator of Modified Atlantic Water (MAW) inflow, enabling the characterization of the Algerian Current and associated frontal systems known to promote the aggregation of planktivorous megafauna.

Statistical analyses were conducted using Microsoft Excel Professional 2024 with the XLSTAT add-in. Long-term temporal trends (1990-2025) were assessed using the non-parametric Mann-Kendall (MK) trend test, which is well suited for environmental time series characterized by non-normal distributions and the presence of zero-observation years (Gilbert, 1987). The relationships between *C. maximus* occurrences and environmental variables (SST, Chl *a*, SSS) were examined using Spearman's rank correlation coefficient (ρ). This approach accounts for potential non-linear relationships and the non-normal distribution typical of opportunistic sighting data (Helsel *et al*., 2020).

RESULTS

A total of 27 basking shark (*Cetorhinus maximus*) records were documented along the Algerian coast between 1990 and 2025 (Table 1). The temporal distribution of occurrences revealed a significant increase in observation frequency over the 35-year study period. Records remained sporadic between 1990 and 2018, averaging approximately one occurrence *per* year, followed by a marked rise in the most recent decade. The Mann-Kendall trend test confirmed a statistically significant upward trend ($\tau=0.362$, $p<0.001$). This increase was particularly pronounced between 2019 and 2021, which together accounted for 40.7% of all records, with a peak in 2021 (n=6; 22.2%) (Fig. 2). The monthly distribution of records revealed a clear seasonal pattern within GSA 04. Occurrences were strongly concentrated in late spring and early summer, with a peak in June (n=10; 37.0%), followed by May (n=5; 18.5%) (Fig. 3). In contrast, records during winter and late summer were scarce and irregular.

Most records (Fig. 4) originated from fishery-dependent sources, with bycatch representing the dominant category and accounting for 63.0% (n=17) of all observations (Fig. 5). Direct surface observations reported by fishers and citizen scientists comprised 33.3% (n=9) of the dataset, with a notable spatial concentration in Ghazaouet Bay (Fig. 6). Stranding events were rare, representing only 3.7% (n=1) of records. The single documented stranding, recorded at Aftis Beach in January 2009, showed clear evidence of entanglement in fishing gear (Fig. 7). Monthly environmental conditions associ-

Table 1. Inventory of *Cetorhinus maximus* records documented along the Algerian coast (GSA 04) from 1990 to 2025. Total length (TL), total weight (TW).

Site	Date	GPS coordinates	n	TL (m)	TW (tons)	Obs
Ghazaouet (Sidi-ouchaa)	01/02/2017	35°08’40.4”N 1°47’08.5”W	1	-	-	Observation
Ghazaouet	3/06/2021	35°08’41.2”N 1°51’46.1”W	1	12	10.000	Bycatch
Tlemcen (Honain)	14/05/2014	35°19’51.7”N 1°49’31.8”W	1	7	1.900	Bycatch
Béni Saf	07/1990	35°23’32.1”N 1°24’20.2”W	1	11	7.600	Bycatch
	06/1994	35°23’32.1”N 1°24’20.2”W	1	7	2.100	Bycatch
	28/10/2013	35°24’04.4”N 1°30’57.6”W	1	8	2.950	Bycatch
Bouzedjar	12/06/2015	35°45’02.5”N 1°05’03.3”W	1	6	1.600	Bycatch
	26/05/2016	35°39’33.4”N 1°17’15.9”W	1	7	2.100	Bycatch
Mostaganem (Sidi Lakhdar)	10/05/2016	36°19’07.1”N 0°17’03.7”E	1	4	0.550	Bycatch
Chlef (Sidi Abderahmane)	20/04/2022	36°47’21.4”N 1°10’38.2”E	1	5.6	0.860	Bycatch
Tipaza (Bouharoun)	25/03/2019	36°41’36.8”N 2°36’52.4”E	1	5.4	0.870	Bycatch
	20/11/2023	36°49’33.8”N 2°30’31.6”E	1	5	4.000	Bycatch
	30/10/2024	36°41’36.8”N 2°36’52.4”E	1	7	8	Bycatch
	21/09/2025	36°41’36.8”N 2°36’52.4”E	1	6.6	7.9	Bycatch
Algiers	25/05/2009	36°50’40.2”N 2°54’15.7”E	1	6.3	1.450	Bycatch
	02/12/2014	36°54’58.9”N 3°16’51.7”E	1	2	0.465	Bycatch
Tizi ouzou (Tigzirt)	28/12/2012	37°01’17.3”N 4°12’02.6”E	1	10	5.600	Bycatch
Boumerdes (Dellys)	14/05/2019	37°17’45.3”N 4°10’53.4”E	1	3.5	-	Observation
Jijel (Aftis)	13/01/2009	36°55’51.6”N 5°32’44.0”E	1	7	1.500	Stranding
Skikda (Collo)	06/2019	37°27’23.2”N 6°48’12.4”E	2	1.5-4	-	Observation
Annaba	17/08/2020	37°22’46.5”N 8°11’58.3”E	1	11	7.570	Bycatch
	27/06/2021	37°22’11.6”N 7°22’38.5”E	5	1.8	0.600-0.700	Observation

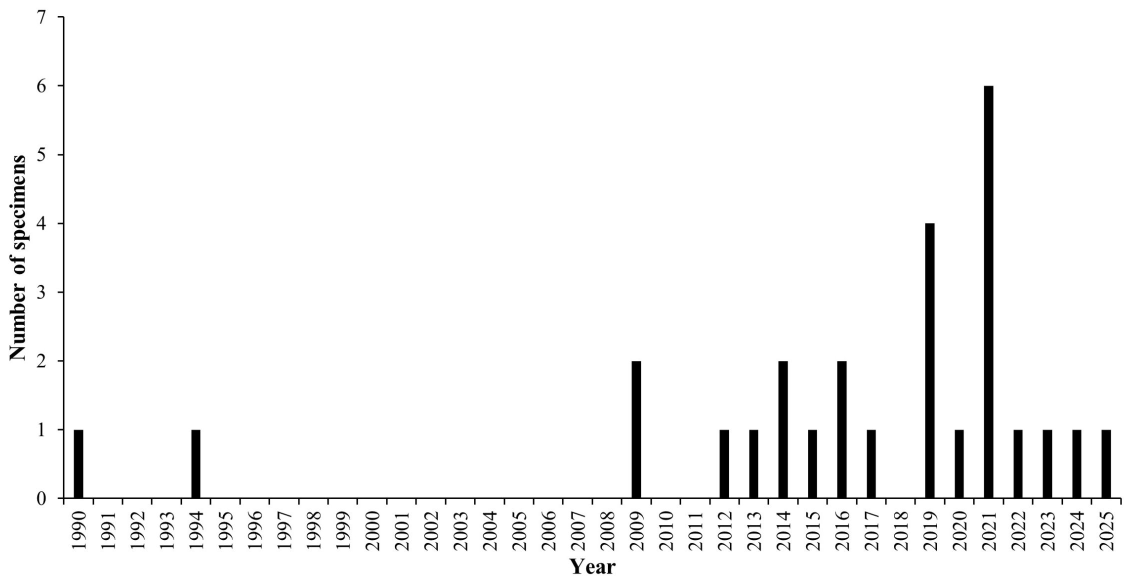

Fig. 2. Annual frequency of *Cetorhinus maximus* records.

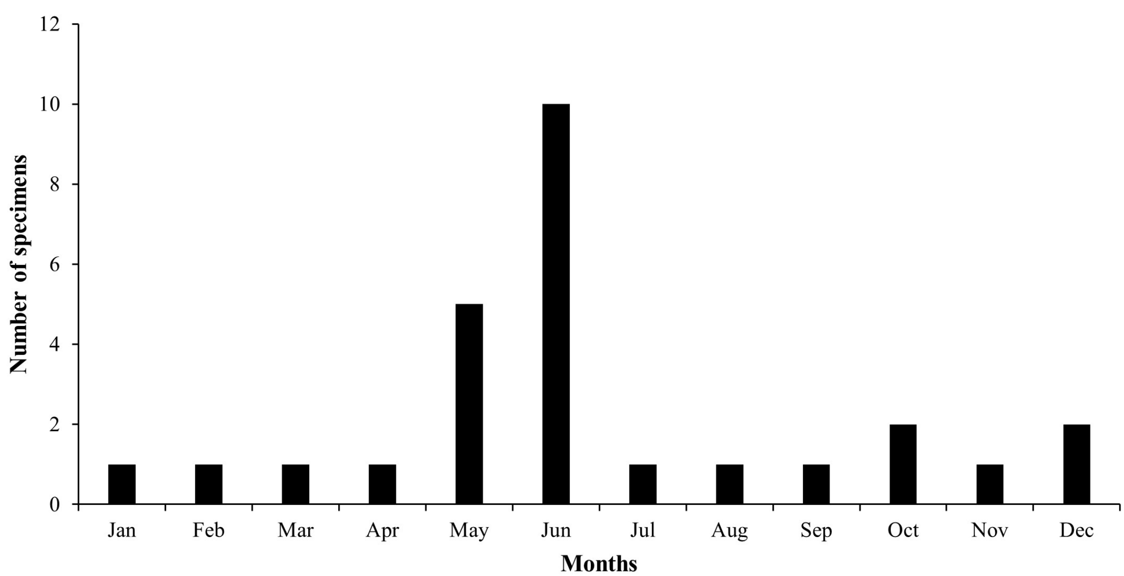

Fig. 3. Monthly frequency of *Cetorhinus maximus* records.

ated with basking shark occurrences are summarized in Table 2, which integrates sea surface temperature (SST), chlorophyll *a* concentration, salinity, and occurrence frequency. Observations were predominantly associated with a narrow thermal range, with 55.5% of records occurring between 18 °C and 21 °C, corresponding to the May-June period. Correlation analysis based on monthly data (Table 2) revealed a significant positive relationship between basking shark occurrence and sea surface temperature (SST) (Spearman's ρ=0.68, p=0.021). In contrast, chlorophyll *a* concentration was significantly negatively correlated with occurrence frequency (ρ=-0.61, p=0.038). No significant relationship was detected between shark occurrence and sea surface salinity (SSS) (ρ=0.12, p=0.45).

DISCUSSION

The most prominent pattern emerging from this study is the marked seasonal peak in basking shark (*Cetorhinus maximus*) occurrences during May and June, which accounted for 55.6% of all records (Fig. 3). This

Fig. 4. Specimens of *Cetorhinus maximus* caught as bycatch along Algerian coasts (2009-2023): Ghazaouet June 3rd, 2009 **(A)**; Tigzirt December 18th, 2012 **(B)**; Béni-Saf October 28th, 2013 **(C)**; Honain May 14th, 2014 **(D)**; Ain Benian May 12th, 2014 **(E)**; Bouzedjar May 26th, 2016 **(F)**; Mostaganem May 8th, 2016 **(G)**; Bou Haroun March 25th, 2019 **(H)**; Annaba August 17th, 2020 **(I)**; Bou Haroun November 21st; 2023 **(J)**.

pronounced phenological signal likely reflects a biologically meaningful response to seasonal ecosystem dynamics rather than random variability. Across the Mediterranean basin, basking sharks display a clear seasonal pattern, with the highest number of observations generally reported from early spring to early summer. A substantial body of research, including regional database analyses, indicates that most Mediterranean records are concentrated between March and June (Kabasakal, 2013), highlighting a consistent basin-wide temporal trend. Similar patterns have also been documented in the eastern Mediterranean, where a high proportion of sightings occurs during late spring and early summer (Carlucci *et al.,* 2014; Kabasakal *et al.,* 2017). This synchrony, observed across the western, central, and eastern Mediterranean basins, suggests that the Algerian coast forms part of a broader, environmentally driven migratory system rather than representing an isolated or

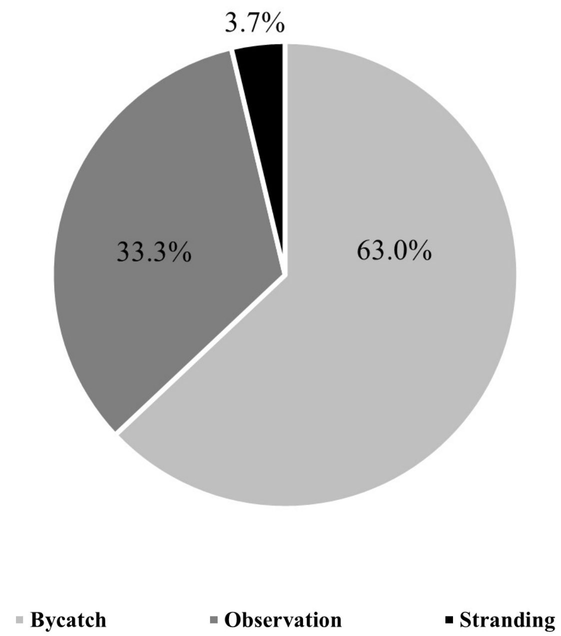

Fig. 5. Percentage of record types for *Cetorhinus maximus*.

Fig. 6. Sighting of *Cetorhinus maximus* in Ghazaouet Bay (July 2017).

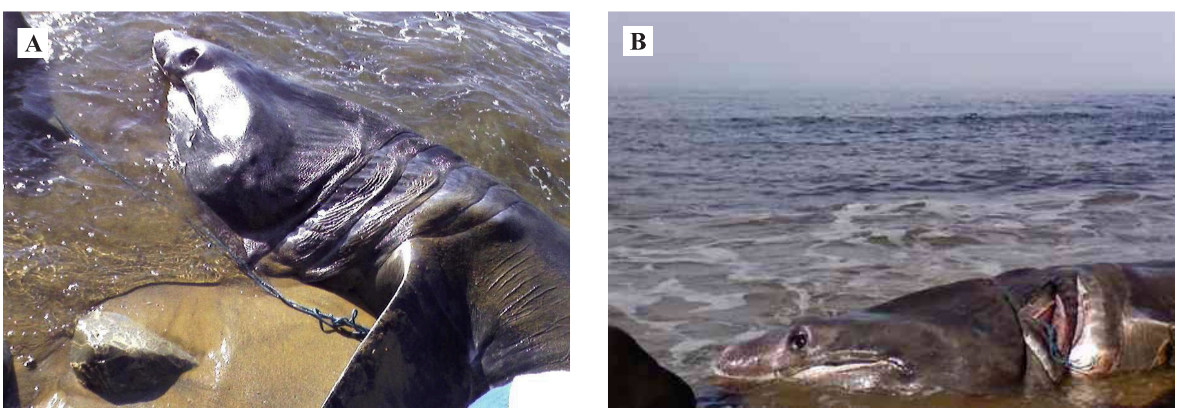

Fig. 7. Stranded basking shark (*Cetorhinus maximus*) recorded at Aftis Beach (Jijel, Algeria) in January 2009. Lateral view of the head showing the characteristic conical snout and large gill slits **(A)**; detailed view of the gill region showing entanglement with blue synthetic rope (polyethylene) **(B)**.

permanent habitat (Sims *et al.,* 2003). A similarly pronounced seasonal pattern has also been reported in the north-eastern Atlantic, where basking shark occurrences peak during the summer months and are closely linked to cycles of plankton productivity (Witt *et al*., 2012). This geographic consistency across regions supports the hypothesis that basking shark occurrence is strongly associated with predictable pulses in prey availability, particularly following seasonal phytoplankton blooms that promote increased zooplankton abundance (Siokou-Frangou *et al.,* 2010; Merlivat *et al*., 2022).

The thermal preference identified in this study (18-21 °C) provides further support for this ecological interpretation. Temperature has long been recognized as a key driver of basking shark distribution, both directly and indirectly through its influence on plankton dynamics. Studies from different oceanic regions have shown that basking sharks preferentially occupy waters within specific thermal ranges, often associated with frontal systems, stratified water columns, and elevated chlorophyll *a* concentration (Siders *et al*., 2013; Finucci *et al*., 2021). This pattern, here referred to as "thermal windows", appears to be particularly relevant in the Mediterranean, where it likely corresponds to periods of enhanced vertical stratification. Such stratification can promote the concentration of zooplankton in surface

Table 2. Monthly oceanographic conditions (1990-2025), *Cetorhinus maximus* occurrence frequency, and Spearman rank correlations with environmental variables in the Algerian Basin (GSA 04). Sea surface temperature (SST), chlorophyll *a* (Chl *a*), sea surface salinity (SSS).

Month	SST (°C) [1]	Chl *a* (mg/m³) [2]	SSS [3]	Records (n=27)
January	15.2	0.28	37.1	1
February	14.8	0.35	37.2	1
March	15.1	0.42	37.4	1
April	16.5	0.38	37.5	1
May	18.2	0.25	37.6	5
June	**20.8**	**0.18**	**37.8**	**10**
July	23.5	0.12	37.9	1
August	25.1	0.09	38.0	1
September	24.2	0.11	37.8	1
October	21.5	0.15	37.5	2
November	18.8	0.19	37.3	2
December	16.4	0.22	37.2	1
Correlation (ρ)	0.68	-0.61	0.12	--
p-value	0.021**	0.038*	0.45 (ns)	--

Data Sources: [1] NOAA Optimum Interpolation SST (OISST); [2] MODIS-Aqua (Chlorophyll *a*); [3] Copernicus Marine Service (CMEMS - SSS); ** $p < 0.01$; * $p < 0.05$; ns = non-significant. Bold font denotes environmental parameters corresponding to peak species observations

layers, thereby creating favorable feeding conditions for this obligate filter feeder. Accordingly, the temperature range observed in Algerian waters is consistent with broader ecological patterns and supports the hypothesis that basking shark occurrence is largely governed by the availability of trophic resources.

A detailed examination of the temporal trends in the dataset revealed a marked increase in sightings after 2019, a pattern that warrants careful interpretation. Although this trend may indicate a recent rise in local occurrence, the potential influence of observation effort and reporting intensity must also be considered. The expansion of digital platforms, growing public awareness, and the increasing contribution of citizen science have likely enhanced detection probability in recent years. Similar discrepancies between historical and contemporary datasets have been reported in other regions, where apparent increases in sightings were at least partly attributed to improved monitoring and reporting rather than true population recovery (McInturf *et al*., 2022).

When compared with historical records from the southwestern Mediterranean, which documented only sporadic occurrences over several decades, the increase observed in the present dataset likely reflects a combination of ecological and methodological factors. Environmental changes, including rising sea surface temperatures and shifts in plankton phenology, may be modifying habitat suitability and influencing the spatial distribution of basking sharks. At the same time, improvements in reporting mechanisms and increased observer coverage have enhanced our ability to detect and document these events. Consequently, the shift from rare historical observations to more frequent contemporary records should be interpreted with caution, as it does not necessarily indicate a corresponding increase in population size.

The relatively high proportion of bycatch records (63.0%) documented in this study indicates a substantial interaction between basking sharks and fishing activities in the Algerian Basin. This pattern differs from that reported in most other Mediterranean regions, where basking sharks are only sporadically represented in fisheries data. It likely reflects a stronger spatial overlap in this area between zones of fishing effort and areas used by sharks. Such overlap may be particularly pronounced during peak seasonal periods, when basking sharks aggregate in productive habitats that also attract intensive fishing activity. From a conservation perspective, this pattern is especially concerning, as basking sharks are highly vulnerable to incidental capture due to their large body size, slow swimming behavior, and frequent use of surface waters.

Across the Mediterranean, assessing the impacts of bycatch remains challenging because of limited data availability and persistent underreporting. Nevertheless, the available evidence consistently identifies fisheries interactions as a major threat to large pelagic elasmobranchs in the region. The relatively high bycatch rate documented in this study may therefore reflect both a genuine ecological overlap and localized fishing pressure, underscoring the need for region-specific management measures. In addition, the low frequency of natural strandings in our dataset further suggests that anthropogenic factors, rather than natural mortality, are the primary drivers of basking shark records in Algerian waters.

Despite these limitations, the contribution of citizen science to this study (33% of records) highlights its growing importance in marine ecological research. In data-limited regions such as the Mediterranean, opportunistic observations provided by fishers, divers, and the general public represent a valuable source of information on species occurrence and distribution. Recent studies have shown that, when supported by photographic evidence and rigorous validation procedures, citizen-generated data can achieve a high level of reliability and substantially strengthen monitoring efforts (Bargnesi *et al*., 2020). In this context, citizen science should not be viewed as a secondary source of information, but rather as an essential component of contemporary conservation strategies, particularly for rare and wide-ranging species.

Overall, our results identify the Algerian coast as an important component of the broader Mediterranean network of basking shark habitats, characterized by marked seasonality, strong environmental coupling, and significant anthropogenic pressure. The overlap between ecological drivers and human activities in this region presents both opportunities and challenges, underscoring the need for targeted conservation measures. Given the relatively predictable timing of peak occurrences, dynamic management approaches such as seasonal fishing closures or spatially explicit mitigation measures could help reduce bycatch risk while minimizing impacts on fisheries.

At a broader scale, the transboundary movements of basking sharks call for coordinated international management efforts. Tracking studies have shown that individuals can undertake extensive migrations across multiple jurisdictions, underscoring the need for basin-wide conservation strategies (Skomal *et al*., 2009). In this context, collaboration among regional fisheries management organizations and conservation bodies will be essential to ensure the long-term protection of the species. By placing local observations within a Mediterranean-wide framework, this study contributes to a more integrated understanding of basking shark ecology and provides a foundation for evidence-based management in a rapidly changing marine environment.

CONCLUSION

Our 35-year survey provides the first statistically robust baseline for the basking shark in the southwestern Mediterranean. The increase in recorded occurrences after 2019, together with the identification of a clear phenological peak in June, highlights the Algerian coast as an important and regularly used area for this endangered elasmobranch. Citizen science proved to be an effective tool for filling historical data gaps; however, the high frequency of bycatch underscores the urgent need for targeted mitigation measures within the Algerian fishing sector. Future research should focus on aerial surveys and satellite telemetry to better understand three-dimensional habitat use and transboundary movements. Integrating these findings into regional management frameworks will be essential to ensure the long-term conservation of the world's second-largest shark in an increasingly human-impacted Mediterranean ecosystem.

ACKNOWLEDGEMENTS

The authors would like to extend their sincere appreciation to the local fishing communities along the Algerian coast, especially Mr. Mimoun, for their remarkable cooperation in documenting bycatch occurrences. We also thank all the sea users and citizen scientists whose real-time observations considerably improved our dataset. Additionally, we acknowledge the administrators of specialized social media platforms and regional ecological groups for playing a vital role in aiding the reporting and verification of *Cetorhinus maximus* occurrences.

REFERENCES

Bargnesi, F., Lucrezi, S., Ferretti, F. 2020. Opportunities from citizen science for shark conservation, with a focus on the Mediterranean Sea. The European Zoological Journal, 87(1), 20-34. https://doi.org/10.1080/24750263.2019.1709574

Bouslah, Y., Bensahla-Talet, L., Hussein, K. B., Benaissa, N., Gheribi, T. 2023. Records of ocean sunfish *Mola mola* (Linnaeus, 1758) along the Algerian coast, 2014-2021. Cahiers de Biologie Marine, 64(2), 129-136. https://doi.org/10.21411/CBM.A.C814A453

Bradai, M. N., Saidi, B., Enajjar, S. 2018. Overview on Mediterranean sharks' fisheries: Impact on the biodiversity. *In* Marine ecology: Biotic and abiotic interactions (eds. M. Türkoğlu, U. Önal, A. Ismen). IntechOpen. pp. 161-181. https://doi.org/10.5772/intechopen.74923

Burgess, G.H., Beerkircher, L.R., Cailliet, G.M., Carlson, J.K., Cortés, E., Goldman, K.J., Grubbs, R.D., *et al.* 2005. Is the collapse of shark populations in the Northwest Atlantic Ocean and Gulf of Mexico real? Fisheries, 30(10), 19-26. https://doi.org/10.1577/1548-8446(2005)30[19:ITCOSP]2.0.CO;2

Capapé, C., Guelorget, O., Barrul, J., Mate, I., Hemida, F., Seridji, R., Bensaci, J., *et al.* 2003. Records of the bluntnose six-gill shark, *Hexanchus griseus* (Bonnaterre, 1788) (Chondrichthyes: Hexanchidae) in the Mediterranean Sea: A historical survey. Annales, Seria historia naturalis, 13(2), 157-166.

Carlucci, R., Battista, D., Capezzuto, F., Serena, F., Sion, L. 2014. Occurrence of the basking shark *Cetorhinus maximus* (Gunnerus, 1765) (Lamniformes: Cetorhinidae) in the central-eastern Mediterranean Sea. Italian Journal of Zoology, 81(2), 280-286. https://doi.org/10.1080/11250003.2014.910275

Carpentieri, P., Nastasi, A., Sessa, M., Srour, A. (eds.). 2021. Incidental catch of vulnerable species in Mediterranean and Black Sea fisheries- A review. Studies and Reviews No. 101 (General Fisheries Commission for the Mediterranean). FAO, 338 pp. https://doi.org/10.4060/cb5405en

Cebrian, D., De Juan, S., Limam, A. 2010. The Mediterranean Sea biodiversity: State of the ecosystems, pressures, impacts and future priorities. UNEP-MAP RAC/SPA, 100 pp.

CITES. 2002. Inclusion of basking shark (*Cetorhinus maximus*) on Appendix II. Proposal 12.36, Convention on International Trade in Endangered Species of Wild Fauna and Flora, Santiago, 12 pp.

CMS. 2005. Inclusion of the basking shark (*Cetorhinus maximus*) on Appendices I and II of the Convention. Convention on the Conservation of Migratory Species of Wild Animals, Eighth meeting of the Conference of the Parties (CoP8), Nairobi (Kenya). https://www.cms.int/en/species/cetorhinus-maximus (accessed 8 April 2026).

Compagno, L.J.V. 2001. Sharks of the world: An annotated and illustrated catalogue of shark species known to date. Volume 2. Bullhead, mackerel and carpet sharks (Heterodontiformes, Lamniformes and Orectolobiformes). FAO Species Catalogue for Fishery Purposes. FAO, 269 pp.

Cortés, E. 1999. Standardized diet compositions and trophic levels of sharks. ICES Journal of Marine Science, 56(5), 707-717. https://doi.org/10.1006/jmsc.1999.0489

Crespo, G.O., Dunn, D.C., Reygondeau, G., Boerder, K., Worm, B., Cheung, W., Tittensor, D.P., *et al*. 2018. The environmental niche of the global high seas pelagic longline fleet. Science Advances, 4(8), eaat3681. https://doi.org/10.1126/sciadv.aat3681

Dewar, H., Wilson, S.G., Hyde, J.R., Snodgrass, O.E., Leising, A., Lam, C.H., Domokos, R., *et al.* 2018. Basking shark (*Cetorhinus maximus*) movements in the eastern North Pacific determined using satellite telemetry. Frontiers in Marine Science, 5, 163. https://doi.org/10.3389/fmars.2018.00163

Dulvy, N.K., Fowler, S.L., Musick, J.A., Cavanagh, R.D., Kyne, P.M., Harrison, L.R., Carlson, J.K., *et al.* 2014. Extinction risk and conservation of the world's sharks and rays. eLife, 3, e00590. https://doi.org/10.7554/eLife.00590

Ebert, D.A., Dando, M., Fowler, S. 2021. Sharks of the world: A complete guide. Princeton University Press, 608 pp.

Finucci, B., Duffy, C., Brough, T., Francis, M., Milardi, M., Pinkerton, M., Petersen, G.L., *et al.* 2021. Drivers of spatial distributions of basking shark (*Cetorhinus maximus*) in the Southwest Pacific. Frontiers in Marine Science, 8, 665337. https://doi.org/10.3389/fmars.2021.665337

Francis, M.P., Lyon, W.S. 2012. Review of commercial fishery interactions and population information for eight New Zealand protected fish species. National Institute of Water and Atmospheric Research, 82 pp.

GFCM. 2018. GFCM Data Collection Reference Framework (DCRF) (Version 23.2). General Fisheries Commission for the Mediterranean. FAO, 176 pp.

Gilbert, R.O. 1987. Statistical methods for environmental pollution monitoring. Wiley & Sons, New York, 320 pp.

Giovos, I., Stoilas, V.O., Al-Mabruk, S.A., Doumpas, N., Marakis, P., Maximiadi, M., Moutopoulos, D., *et al.* 2019. Integrating local ecological knowledge, citizen science and long-term historical data for endangered species conservation: Additional records of angel sharks (Chondrichthyes: Squatinidae) in the Mediterranean Sea. Aquatic Conservation: Marine and Freshwater Ecosystems, 29(6), 881-890. https://doi.org/10.1002/aqc.3089

Helsel, D.R., Hirsch, R.M., Ryberg, K.R., Archfield, S.A., Gilroy, E.J. 2020. Statistical methods in water resources. Techniques and Methods 4-A3. U.S. Geological Survey, 458 pp. https://doi.org/10.3133/tm4A3

Hu, C., Lee, Z., Franz, B. 2012. Chlorophyll *a* algorithms for oligotrophic oceans: A novel approach based on three-band reflectance difference. Journal of Geophysical Research: Oceans, 117(C1), C01011. https://doi.org/10.1029/2011JC007395

Huang, B., Liu, C., Banzon, V., Freeman, E., Graham, G., Hankins, B., Smith, T., *et al*. 2021. Improvements of the Daily Optimum Interpolation Sea Surface Temperature (DOISST) Version 2.1. Journal of Climate, 34(8), 2923-2939. https://doi.org/10.1175/JCLI-D-20-0166.1

Hussein, K.B., Bensahla-Talet, L. 2019. A preliminary inventory of biodiversity and benthic habitats of "Plane" Island (Paloma) in Oran Bay, north western Algeria (western Mediterranean). Journal of the Black Sea/Mediterranean Environment, 25(1), 49-72.

Kabasakal, H. 2013. Rare but present: Status of basking shark, *Cetorhinus maximus* (Gunnerus, 1765) in eastern Mediterranean. Annales, Seria historia naturalis, 23(2), 17-22.

Kabasakal, H., Karhan, S.Ü., Sakınan, S. 2017. Review of the distribution of large sharks in the seas of Turkey (Eastern Mediterranean). Cahiers de Biologie Marine, 58, 219-228. https://doi.org/10.21411/cbm.a.96d9f948

Lewison, R.L., Crowder, L.B., Read, A.J., Freeman, S.A., Woodberry, S.D., Sullivan, J.B., Moore, J.E., *et al.* 2014. Global patterns of marine mammal, seabird, and sea turtle bycatch reveal taxa-specific and cumulative megafauna hotspots. Proceedings of the National Academy of Sciences, 111(14), 5271-5276. https://doi.org/10.1073/pnas.1318960111

Malak, D.A., Livingstone, S.R., Pollard, D., Polidoro, B.A., Cuttelod, A., Bariche, M., Bilecenoglu, M., *et al.* 2011. Overview of the conservation status of the marine fishes of the Mediterranean Sea. IUCN Global Species Programme, Gland & Malaga, 61 pp.

Mancusi, C., Clò, S., Affronte, M., Bradaï, M.N., Hemida, F., Serena, F., Soldo, A., *et al.* 2005. On the presence of basking shark (*Cetorhinus maximus*) in the Mediterranean Sea. Cybium, 29(4), 399-405.

McInturf, A.G., Muhling, B., Bizzarro, J.J., Fangue, N., Ebert, D., Caillaud, D., Dewar, H. 2022. Spatial distribution, temporal changes, and knowledge gaps in basking shark (*Cetorhinus maximus*) sightings in the California Current Ecosystem. Frontiers in Marine Science, 9, 818670. https://doi.org/10.3389/fmars.2022.818670

Merlivat, L., Hemming, M., Boutin, J., Antoine, D., Vellucci, V., Golbol, M., Lee, G.A., *et al*. 2022. Physical mechanisms for biological carbon uptake during the onset of the spring phytoplankton bloom in the northwestern Mediterranean Sea (BOUSSOLE site). Biogeosciences, 19, 3911-3920. https://doi.org/10.5194/bg-19-3911-2022

Millot, C. 1999. Circulation in the Western Mediterranean Sea. Journal of Marine Systems, 20(1-4), 423-442. https://doi.org/10.1016/S0924-7963(98)00078-5

Pauly, D. 1978. A critique of some literature data on the growth, reproduction and mortality of the lamnid shark *Cetorhinus maximus* (Gunnerus). ICES Council Meeting Paper, 1978H:17, Pelagic Fish Committee, 10 pp.

Pirotta, V., Grech, A., Jonsen, I.D., Laurance, W.F., Harcourt, R.G. 2019. Consequences of global shipping traffic for marine giants. Frontiers in Ecology and the Environment, 17(1), 39-47. https://doi.org/10.1002/fee.1987

Queiroz, N., Humphries, N.E., Mucientes, G., Hammerschlag, N., Lima, F.P., Scales, K.L., Miller, P.I., *et al.* 2016. Ocean-wide tracking of pelagic sharks reveals extent of overlap with longline fishing hotspots. Proceedings of the National Academy of Sciences, 113(6), 1582-1587. https://doi.org/ 10.1073/pnas.1510090113

Rigby, C.L., Barreto, R., Carlson, J., Fernando, D., Fordham, S., Francis, M.P., Herman, K., *et al*. 2021. *Cetorhinus maximus* (amended version of 2019 assessment). The IUCN Red List of Threatened Species 2021: e.T4292A194720078. https://doi.org/10.2305/IUCN.UK.2021-1.RLTS.T4292A194720078 (accessed 26 March 2026).

Siders, Z.A., Westgate, A., Johnston, D., Murison, L.D., Koopman, H. 2013. Seasonal variation in the spatial distribution of basking sharks (*Cetorhinus maximus*) in the lower Bay of Fundy, Canada. PLoS ONE, 8(12), e82074. https://doi.org/10.1371/journal.pone.0082074

Sims, D.W. 1999. Threshold foraging behaviour of basking sharks on zooplankton: Life on an energetic knife-edge? Proceedings of the Royal Society of London, Series B: Biological Sciences, 266(1427), 1437-1443. https://doi.org/10.1098/rspb.1999.0798

Sims, D.W. 2008. Sieving a living: A review of the biology, ecology and conservation status of the plankton-feeding basking shark *Cetorhinus maximus*. Advances in Marine Biology, 54, 171-220. https://doi.org/10.1016/S0065-2881(08)00003-5

Sims, D.W., Southall, E.J., Richardson, A.J., Reid, P.C., Metcalfe, J.D. 2003. Seasonal movements and behaviour of basking sharks from archival tagging: No evidence of winter hibernation. Marine Ecology Progress Series, 248, 187-196. https://doi.org/10.3354/meps248187

Siokou-Frangou, I., Christaki, U., Mazzocchi, M.G., Montresor, M., Ribera d'Alcalá, M., Vaqué, D., Zingone, A. 2010. Plankton in the open Mediterranean Sea: A review. Biogeosciences, 7, 1543-1586. https://doi.org/10.5194/bg-7-1543-2010

Sirri, R., Scarpa, F., Zanatta, M., Zaccaroni, A., Scaravelli, D. 2012. Age determination in a basking shark *Cetorhinus maximus* (Gunnerus, 1765) by radiographic and histological approach. *In* Where to go and what to eat? (eds. D. Scaravelli, A. Zaccaroni). Aracne Editrice. pp. 157-164.

Skomal, G.B., Zeeman, S.I., Chisholm, J.H., Summers, E.L., Walsh, H.J., McMahon, K.W., Thorrold, S.R. 2009. Transequatorial migrations by basking sharks in the western Atlantic Ocean. Current Biology, 19(12), 1019-1022. https://doi.org/10.1016/j.cub.2009.04.019

Soldo, A. 2026. When citizen science becomes speculation: Evaluating the reliability of lamnid shark identification from photographic records in the Mediterranean. Journal of Marine Science Engineering, 14(2), 173. https://doi.org/10.3390/jmse14020173

UNEP/MAP. 1995. Protocol concerning Specially Protected Areas and Biological Diversity in the Mediterranean. Annex II: List of Endangered or Threatened Species. Amended in 2009. Barcelona Convention. United Nations Environment Programme, Mediterranean Action Plan. 327-345.

Witt, M.J., Hardy, T., Johnson, L., McClellan, C., Pikesley, S.K., Ranger, S., Richardson, P.B., *et al.* 2012. Basking sharks in the northeast Atlantic: Spatio-temporal trends from sightings in UK waters. Marine Ecology Progress Series, 459, 121-134. https://doi.org/10.3354/meps09737