
ARTICLE

Occurrence of the white shark *Carcharodon carcharias* in the Northeast Atlantic: new records from north-western Spain

Presencia del tiburón blanco *Carcharodon carcharias* en el Atlántico nororiental: nuevos registros en el noroeste de España

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Abstract: The Northeast Atlantic hosts several chondrichthyan species, including the iconic yet critically endangered white shark *Carcharodon carcharias* (Linnaeus, 1758), whose presence remains extremely rare, as reflected in the scarcity of records in this region. Due to the uncertainty regarding its distribution and abundance, this study compiled and updated scientifically confirmed reports of this species. A total of 24 records were identified, of which 22 derive from the scientific literature, including accounts dating as far back as the 16th century. The two remaining records correspond to the first confirmed white shark occurrences in north-western Spain, observed off the coasts of Galicia and Asturias in 2021. Given their exceptional rarity and similar size, it is hypothesized that these sightings involve the same individual. These novel records highlight the potential role of citizen science in monitoring this elusive species in the region.

Keywords: Citizen science, historical survey, Iberian Peninsula, marine conservation, Lamnidae, sightings.

Resumen: El Atlántico nororiental alberga varias especies de condricios, incluyendo el emblemático pero críticamente amenazado tiburón blanco *Carcharodon carcharias* (Linnaeus, 1758), cuya presencia es extremadamente rara, como refleja la escasez de registros en la región. Debido a la incertidumbre sobre su distribución y abundancia, este estudio ha recopilado y actualizado los registros científicamente confirmados de esta especie. Se identificaron un total de 24 citas, de las cuales 22 proceden de la literatura científica, incluyendo registros desde el siglo XVI. Los dos restantes corresponden a las primeras observaciones confirmadas del tiburón blanco en el noroeste de España, frente a las costas de Galicia y Asturias en 2021. Dada su excepcional rareza y similar tamaño, se hipotetiza que estas observaciones corresponden al mismo individuo. Estos nuevos registros destacan el potencial de la ciencia ciudadana para el seguimiento de esta esquivada especie en la región.

Palabras clave: Avistamientos, ciencia ciudadana, conservación marina, Lamnidae, Península Ibérica, revisión histórica.

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Supplementary information ↓

1. INTRODUCTION

Sharks (Class Chondrichthyes) are considered a large and diverse group of cartilaginous fishes, with 560 species described (Compagno, 2001; Weigmann, 2016; Fricke *et al.*, 2025). They play a key role in the functioning and maintenance of marine ecosystems, with their importance reinforced by their global distribution, covering a wide range of habitats from the poles to specific rivers (Compagno, 1984; Barría *et al.*, 2015; Weigmann, 2016; Dulvy *et al.*, 2021). The waters of the Northeast Atlantic are no exception, hosting approximately 119 species (Walls & Dulvy, 2021). However, as the Mediterranean Sea, this region is characterised as a hotspot for endangered species (Dulvy *et al.*, 2021; Walls & Dulvy, 2021). The most threatened species tend to be large, slow-growing, shallow-water dwellers with high migratory activity (Pacoureau *et al.*, 2021; Walls & Dulvy, 2021). A prime example is the white shark (*Carcharodon carcharias* Linnaeus, 1758), currently listed as critically endangered in both the Mediterranean and the Northeast Atlantic (Soldo *et al.*, 2015, 2016; Spaet, 2021).

The white shark is a pelagic species that typically occurs near continental and insular shelves, but dispersing individuals have also been recorded in oceanic waters (Compagno, 1984; Curtis *et al.*, 2014;

Boldrocchi *et al.*, 2017; Huveneers *et al.*, 2018). Its diving behaviour, combined with its broad global distribution in both temperate and occasionally in warm waters, complicates research efforts (Bonfil *et al.*, 2010; Duffy *et al.*, 2016; Huveneers *et al.*, 2018; Salinas-de-León *et al.*, 2024). Furthermore, its distribution appears to be discontinuous, with limited interchange across some regions (Bonfil *et al.*, 2005; Jorgensen *et al.*, 2010; Huveneers *et al.*, 2018; Wagner *et al.*, 2024).

Although several studies have recently been carried out on the biology and ecology of this species (Colefax *et al.*, 2020; Kanive *et al.*, 2021; Lee *et al.*, 2021), much remains unknown (Huveneers *et al.*, 2018; Ferretti *et al.*, 2024). This is notable given that the white shark is one of the most iconic and emblematic shark species (Klimley, 1994; Kempster & Collin, 2014; Aich *et al.*, 2021; Whitenack *et al.*, 2022). Major aggregations tend to occur near highly productive habitats, where large concentrations of marine mammals and other groups they prey upon are found (Compagno, 1984; Skomal *et al.*, 2012; Boldrocchi *et al.*, 2017; Huveneers *et al.*, 2018). Many studies are focused on regions with high white shark abundances, such as California (Goldman & Anderson, 1999; Dewar, 2004; Chapple *et al.*, 2011), South Africa (Compagno, 1991; Hussey *et al.*, 2012; Hewitt *et al.*, 2018), New Zealand (Francis *et al.*, 2015), or Australia (Bruce *et al.*, 2006, 2019; Spaet *et al.*, 2020). When analysing the species' general distribution, the North Atlantic Ocean also emerges as an important location (Compagno, 1984; Casey & Pratt, 1985; Huveneers *et al.*, 2018). Nevertheless, the vast majority of the records are reported in the Northwest Atlantic (Curtis *et al.*, 2014). In contrast, although the presence of white sharks in the Northeast Atlantic dates back to the Pleistocene (Bor & Peters, 2015), confirmed records are almost non-existent in comparison with other regions (i.e., California, South Africa and Australia), with most references representing anecdotal observations (Fergusson, 1996).

The white shark may have played the ecological role of an apex predator since the Pleistocene (Bor & Peters, 2015). However, despite the potential importance of the Northeast Atlantic region for the species, the ecological role of large predatory sharks in this area remains poorly understood, as broader patterns of shark population status and ecosystem function in the region are incompletely resolved (Walls & Dulvy, 2021). In the present day, several lamnid species (Lamnidae family), including the porbeagle shark *Lamna nasus* (Bonaterre, 1788) and the shortfin mako shark *Isurus oxyrinchus* (Rafinesque, 1810), are known to occur in the region (Bañón *et al.*, 2010; Biais *et al.*, 2017), while the presence of the critically endangered white shark in this area remains largely undocumented (Soldo *et al.*, 2015, 2016; Spaet, 2021). Thus, the goal of this study is to compile all scientifically recorded data on the presence of the white shark in the Northeast Atlantic, including, for the first time, confirmed sightings of the species off the coast of Galicia and Asturias in north-western Spain.

2. MATERIAL AND METHODS

To examine the presence of the white shark in the Northeast Atlantic, a bibliographic review was carried out from 2023 to 2025 using Scopus, Web of Science and Google Scholar, aiming to collect scientifically reported occurrences of this species in this region over the last 100 years (Fig. 1; Table 1). In addition to the academic databases, citizen science platforms (i.e., iNaturalist and GBIF) and social media (i.e., YouTube, Facebook, Instagram, and Twitter/X) were also examined for records not published in peer-reviewed journals. However, these sources were approached with caution due to the potential risk of false records, particularly in the absence of images or other verifiable information. Consequently, records from scientific publications were prioritized over those from social media and citizen science platforms. The main information extracted from these records was the date, location and source of the observations.

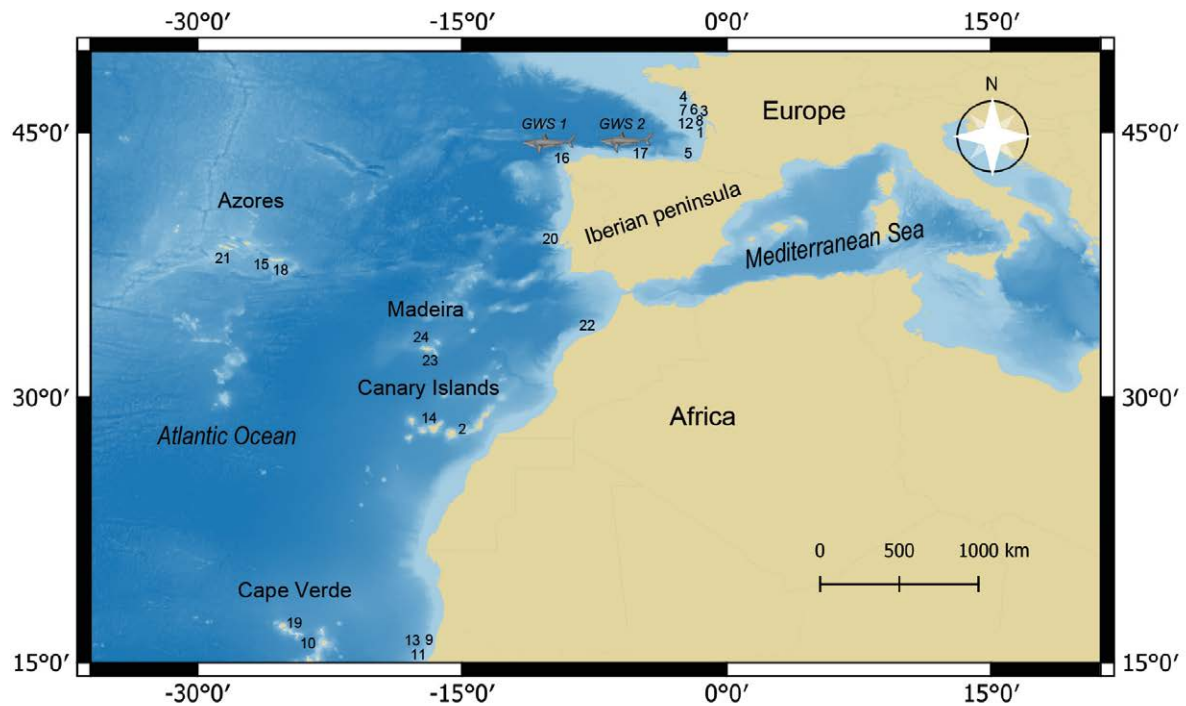


Fig. 1. Map showing scientifically confirmed white shark (*Carcharodon carcharias* Linnaeus, 1758) records in the Northeast Atlantic Ocean reported over the last 100 years; numbers correspond to Table 1.

Fig. 1. Mapa de los registros científicamente confirmados del tiburón blanco (*Carcharodon carcharias* Linnaeus, 1758) en el océano Atlántico nororiental reportados en los últimos 100 años; los números corresponden a la Tabla 1.

Table 1. Compilation of scientifically confirmed white shark (*Carcharodon carcharias* Linnaeus, 1758) records in the Northeast Atlantic, including the new occurrences documented in this study through citizen science (italicised).

Tabla 1. Recopilación de registros científicamente confirmados del tiburón blanco (*Carcharodon carcharias* Linnaeus, 1758) en el Atlántico nororiental, incluyendo las nuevas observaciones documentadas en este estudio a través de ciencia ciudadana (en cursiva).

Nº	Location	Date	Reference
1	Saintonge, France	16 th century	Quero <i>et al.</i> (2011)
2	San Cristóbal, Gran Canaria, Spain	1799	Bellon & Mateu (1931)
3	La Rochelle, France	1821	Quero <i>et al.</i> (2011)
4	Loire-Inférieure, France	1843	Quero <i>et al.</i> (1978)
5	Bay of Biscay, France	1851	Quero <i>et al.</i> (1978)
6	Charente et Vendée, La Rochelle, France	1866	Quero <i>et al.</i> (1978)
7	La Rochelle, France	1872	Quero <i>et al.</i> (2011)
8	Coast of Charente-Inférieure, France	March 1880	Quero <i>et al.</i> (2011)
9	Dakar, M'Bodiene Village, Senegal	1945	Cadenat & Blache (1981)
10	Cape Verde	1953	Cousteau & Dumas (1953)
11	Île de Gorée, Dakar, Senegal	1957	Cadenat & Blache (1981)
12	Near La Rochelle, France	24 May 1977	Quero <i>et al.</i> (2011)
13	Dakar, Senegal	1982	Barrull & Mate (2002)
14	Tenerife, Spain	1987	Fergusson (1996)

15	Ponta Garça, São Miguel, Azores, Portugal	10 February 1990	Fergusson (1996)
16	Punta Langosteira, Galicia, Spain	29 September 2021	This study (GWS 1)
17	Ribadesella, Asturias, Spain	21 October 2021	This study (GWS 2)
18	São Miguel, Azores, Portugal	undated	Fergusson (1996)
19	Sant Vincent Island, Cape Verde	undated	Fergusson (1996)
20	Portugal	undated	Fergusson (1996)
21	Faial, Azores, Portugal	undated	Fergusson (1996)
22	Moroccan coast, Morocco	undated	Fergusson (1996)
23	Madeira, Portugal	undated	Fergusson (1996)
24	Madeira, Portugal	undated	Fergusson (1996)

Two sightings in Spanish waters were further analysed (Fig. 2A-E), reported on September 29th 2021 near Punta Langosteira, Galicia (43.344965° N, 8.516042° W) (GWS 1; Fig. 2A-B), and on October 16th 2021 near Ribadesella, Asturias (43.572028° N, 5.033112° W) (GWS 2; Fig. 2C-E). These were respectively reported by a port worker and by fishermen, and both were uploaded to the citizen science platform “Observadores del Mar” (Sea Watchers: www.seawatchers.net). To validate the identification of the species in both observations, key morphological characteristics were examined, including the fusiform and robust body, conical snout, and broadly triangular serrated teeth (Compagno, 2001; Ebert & Dando, 2021; Soldo & Bakiu, 2024).

This study complied with all applicable international and national environmental legislation in Spain: it was non-invasive, adhering to national regulations by observing the white sharks without disturbance.

3. RESULTS

Since 1931, a total of 24 scientifically confirmed records of white sharks in the Northeast Atlantic have been collected through an analysis of the scientific literature ($n = 22$) and additional sources (i.e., social media and citizen science platforms) ($n = 2$) (Fig. 1; Table 1). The northernmost report occurred in France, while the southernmost was located on the continental shelf off Senegal. Insular reports were also recorded from the Macaronesian islands, including the Azores, Madeira, Canary Islands, and Cape Verde (Table 1). Of the 22 records documented from the scientific literature, only 15 were dated. These were primarily concentrated in the 19th and 20th centuries ($n = 6$ and 7 respectively), while the remaining two corresponded to the 16th and 18th centuries ($n = 1$ each) (Table 1). On the other hand, the only two records documented in the 21st century corresponded to opportunistic sightings off the Atlantic coast of the Iberian Peninsula in Spanish waters (Fig. 2A-E; Table 1). Both sightings were uploaded to the citizen science platform “Observadores del Mar” (Sea Watchers), and subsequently to GBIF.

The first sighting (GWS 1) occurred on September 29th 2021 at approximately 15:00 hours (GMT+1) near Punta Langosteira (dockland), Galicia, Spain (43.344965° N, 8.516042° W) (Fig. 2A-B). Sea conditions were very good, with fair visibility (0-1 on the Douglas sea scale). The sighting, made by a port worker, lasted only a few minutes. The shark was initially observed from the shore (Fig. 2B) and later alongside a 3.5 m boat (Fig. 2A). The second sighting (GWS 2) was made by fishermen on October 16th 2021 at approximately 07:00 hours (GMT+1), 10 miles north of Ribadesella, Asturias, Spain (43.572028° N, 5.033112° W) (Fig. 2C-E). Sea conditions were again very good, with fair visibility (0-1 on the Douglas sea scale). According to the fishermen and the accompanying images (Fig. 2C-E), the shark swam around the boat for approximately 2 hours. Both sightings were uploaded to the citizen science platform “Observadores del Mar” (Sea Watchers), and also to GBIF. The morphological characteristics of the individuals sighted (Fig. 2A-E) were consistent with descriptions of the species documented in the scientific literature (Compagno, 2001; Ebert & Dando, 2021). In particular, the shape of the body, head, and snout, together with the large size of the individuals, allowed for confident validation of species identification.

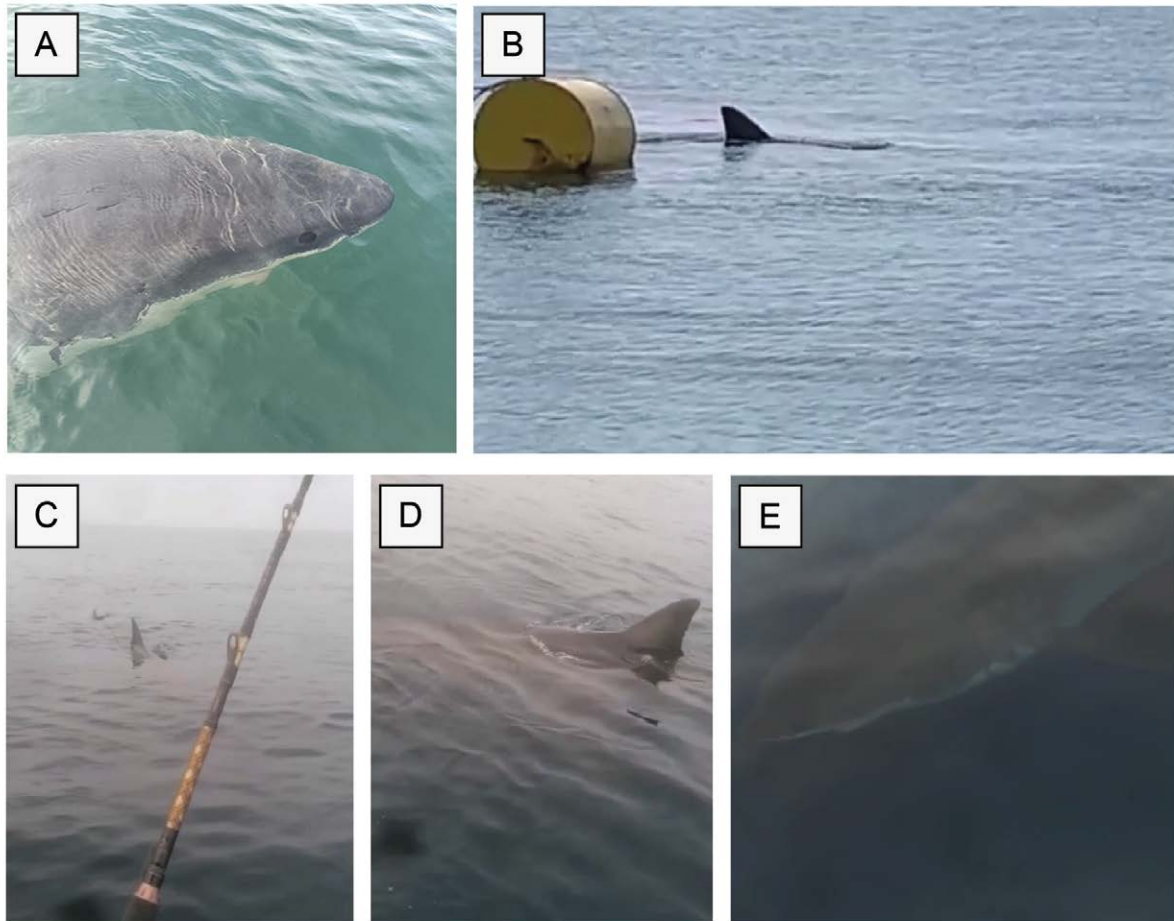


Fig. 2. North-western Spain observations of white sharks (*Carcharodon carcharias* Linnaeus, 1758). (A) Close-up of GWS 1. (B) GWS 1 circling a buoy in Punta Langosteira (dockland), Galicia. (C) GWS 2 approaching a boat in Ribadesella, Asturias. (D) GWS 2 circling the boat. (E) Close-up of GWS 2. Images (A–B) show GWS 1, recorded on 29th September 2021 by José María Méndez Laza; images (C–E) show GWS 2, recorded on 16th October 2021 by Juan Carlos González.

Fig. 2. Observaciones de tiburones blancos (*Carcharodon carcharias* Linnaeus, 1758) en el noroeste de España. (A) Plano cercano de GWS 1. (B) GWS 1 rodeando una boya en la zona portuaria de Punta Langosteira, Galicia. (C) GWS 2 aproximándose a una embarcación en Ribadesella, Asturias. (D) GWS 2 rodeando la embarcación. (E) Plano cercano de GWS 2. Las imágenes (A–B) muestran a GWS 1, registrado el 29 de septiembre de 2021 por José María Méndez Laza; las imágenes (C–E), a GWS 2, registrado el 16 de octubre de 2021 por Juan Carlos González.

Due to the absence of previous confirmed records on the Spanish peninsular coast of the Atlantic Ocean (Table 1), the 2021 sightings represent the first and latest white sharks recorded in this region (Fig. 2A–E). Although neither of the two white sharks could be directly measured, information provided by the present bystanders and specific circumstances, such as GWS 1 being larger than the boat from which it was sighted (3.5 m), led to the estimation that both GWS 1 and GWS 2 measured approximately 5 m in total length (TL) (Fig. 2A–E). Additionally, both sharks exhibited a calm behaviour and maintained a continuous swimming pattern without rapid movements (Fig. 2B–D). Notably, GWS 2 brushed past the boat twice, according to the fisherman's report.

4. DISCUSSION

The white shark population in Europe is currently listed as Critically Endangered and moderately depleted (Soldo et al., 2015, 2016; Spaet, 2021; Walls & Dulvy, 2021), reflecting both the species' vulnerable characteristics (Walls & Dulvy, 2021), and the generally low number of confirmed records across the region. Our review only found 24 records (Table 1), with 22 coming from a bibliographic search and

2 records contributed by citizen science (Fig. 2A-E; Table 1). Despite the scarcity of confirmed records, there are other unverified reports that suggest its permanent presence in the region. Specifically, Rodríguez Solórzano *et al.* (1983) referenced a potential sighting: “É moi raro no noso litoral. Vimos seis exemplares nunha ocasión na lonxa da Coruña capturados nos palangres do marraxo” (“It is very rare on our coast. We saw six specimens on one occasion in the A Coruña fish market caught on the mako shark longlines”). Furthermore, López Seoane (1887) reported that: “Algunas veces llega á las costas de Galicia el tiburón. Ni Cornide, ni Alonso citan esta especie como observada en su tiempo” (“Some sharks occasionally reach the coasts of Galicia. Neither Cornide nor Alonso mentioned this species as having been observed in their time”). These references do not unambiguously confirm the presence of white sharks in the region, as the vague descriptions provided by López Seoane (1887) and Rodríguez Solórzano *et al.* (1983), together with the unknown fishing area and absence of photographic evidence in the latter case, preclude a reliable identification. Therefore, there is no conclusive evidence that the specimens described corresponded to white sharks. They were probably records of similar species, such as the porbeagle shark or mako sharks (*Isurus* spp.), which have been recorded in the area (Bañón *et al.*, 2010).

Additionally, there are no confirmed records of white sharks off the United Kingdom or in the North Sea, where sea surface temperatures are likely too cold for the species’ preferences (Bor & Peters, 2015). Historical records also show a lack of reliable evidence: Day (1884) noted that although the white shark had been included in works on British fishes, the available descriptions, such as those from the Cornish coast or off the Orkneys, do not appear to correspond to specimens from these localities. Based on social media, several unconfirmed records suggest the sporadic presence of white sharks in these regions (Baldwin, 2019). One of the best known potential sightings occurred off Lybster (Scotland), on July 15th 2003 (Carter, 2008), where a large shark (TL estimated at 5.5 m) got entangled in a net while fishing for codling, and a single photograph was taken while it was being disentangled (Carter, 2008; Baldwin, 2019). Despite the alleged evidence, this particular record and several others remain inconclusive and were therefore excluded from this study, as they were not scientifically validated due to the lack of clear supporting data and the possibility of potential misidentifications with porbeagle and mako sharks (Fergusson, 1996). This underscores the challenges in validating sightings of elusive species like the white shark (Huveneers *et al.*, 2018; Fontaine *et al.*, 2022; Soldo & Bakiu, 2024; Soldo, 2026).

Nonetheless, based on the current climate change scenario, there is a possibility that the North East Atlantic could become suitable for white sharks (Skubel *et al.*, 2018; Franks *et al.*, 2021; Osgood *et al.*, 2021). Salinas-de-León *et al.* (2024) documented one specimen in the Galápagos, likely influenced by the 2021 La Niña ENSO event. This particular occurrence, in conjunction with other studies, suggests that the species’ presence may be linked to specific temperature ranges, potentially shifting its distribution towards higher latitudes to match their thermal requirements, as projected by climate change models (Bor & Peters, 2015; Franks *et al.*, 2021; Lee *et al.*, 2021; Osgood *et al.*, 2021). Furthermore, climate change may indirectly influence white sharks by altering the distribution and abundance of their prey, thereby shaping their movements and habitat use (Skomal *et al.*, 2012; Huveneers *et al.*, 2018; Soldo & Turan, 2025). In certain regions, such as the Mediterranean Sea, a northward shift linked to changes in sea surface temperature and the distribution of bluefin tuna *Thunnus thynnus* (Linnaeus, 1758) has been hypothesised (Soldo & Turan, 2025). However, in nearby regions, such as France and the Bay of Biscay (~46.0° N), close to the area where the two observations described in this study were recorded, a significant number of observations of white sharks have been reported (Quero *et al.*, 1978, 1995) (Fig. 1; Table 1). Fossil records of this species have also been documented in citizen science databases (e.g., GBIF), which may influence the total count of records in this region. Nevertheless, similar to the alleged records in British waters discussed earlier, these records were also excluded from the overall count of this study, given the uncertainty regarding their provenance.

Considering the highly migratory behaviour and the great distances white sharks can travel (Bonfil *et al.*, 2005; Jorgensen *et al.*, 2010; Franks *et al.*, 2021), it is plausible to consider their occasional presence in Spain, despite their rarity, particularly along the Eastern Atlantic coast. Notably, the last confirmed record of an adult white shark in Spain was in the Mediterranean Sea in 1992 (Barrull & Mate, 2001; Morey *et al.*, 2003). However, more recent evidence, including a confirmed record of a juvenile

individual in 2023 off the coast of Alicante (Spain), indicates that the species still occurs sporadically in Spanish waters, albeit extremely rarely (Báez *et al.*, 2026). This rarity, in addition to the lack of previous records in this area, combined with facts like the swimming speed of approximately 3.2 km/h (Strong *et al.*, 1996) and the size of both sighted white sharks (≈ 5 m TL), it is likely that GWS 1 and GWS 2 are actually the same individual, as the distance between both sighting points is approximately 400 km (Fig. 1). Considering the estimated TL of both observations and the size at sexual maturity of this species, 3.1–4.1 m TL and 4–5 m TL for males and females respectively (Pratt, 1996; Compagno, 2001; Tanaka *et al.*, 2011), it can be concluded that the sighted individual was a mature white shark.

Given the absence of aggregations in the Northeast Atlantic, it is unlikely that the presence of the individuals described in this study in Spanish waters is part of a reproductive migration. Instead, it may instead be related to disorientation or feeding behaviours. Observations in other regions, such as the Pacific Ocean, show that the white shark exhibits regular migratory patterns, typically approaching coastal areas to feed during the summer, autumn, and early winter (Carlisle *et al.*, 2012; Skubel *et al.*, 2018). Therefore, it is plausible that the reported white sharks were pursuing potential prey, such as schools of fish, cetaceans, other elasmobranchs, or large teleost fishes, such as tuna and swordfish, that inhabit north-western Spanish waters (Borja *et al.*, 2019). With increasing size and age, the diet of large white sharks (> 3 m) tends to preferentially favour marine mammals, including pinnipeds, small cetaceans, and large whale carcasses (Cliff *et al.*, 1989; Curtis *et al.*, 2006; Kim *et al.*, 2012; Skomal *et al.*, 2012). Additionally, the presence of small pinnipeds in the vicinity of the shark sightings or the increase of large tunids (*Thunnus* spp.) in the zone at the same time may be contributing factors (Covelo *et al.*, 2011; López *et al.*, 2017; Borja *et al.*, 2019; Sandoval, pers. comm., 2021). Similar behaviours have been reported off the coast of Massachusetts, where the number of adult sharks increases as the seal pup season approaches, providing higher prey availability (Skomal *et al.*, 2012). This pattern has also been observed at Guadalupe Island (Mexico) and in the Mediterranean Sea, where white sharks feed on tunids (Morey *et al.*, 2003; Soldo & Dulcic, 2005; Domeier, 2009; Boldrocchi *et al.*, 2017). The eastward displacement of individuals, rather than southward migration, may be related to the presence of orcas (*Orcinus orca* Linnaeus, 1758) off the coast of Portugal and north-western Spain contemporary to shark sightings (CEMMA, 2021), given that orcas can act as predators of white sharks and influence their distribution (Jorgensen *et al.*, 2019; Towner *et al.*, 2022; Hammerschlag *et al.*, 2025). In the presumed absence of a resident population in the Northeast Atlantic, it is most likely that the white sharks sighted in this area originate from the western side of the Atlantic, and undertake transoceanic migrations (Bonfil *et al.*, 2005). This species typically moves further north in the Atlantic during the latter part of the year, particularly in the regions of New Jersey and Canada (Curtis *et al.*, 2014; Skomal *et al.*, 2017; Franks *et al.*, 2021).

Regardless of the drivers behind the presence of white sharks in Spanish waters, gaining insight into their distribution in the Northeast Atlantic is a priority, primarily due to data scarcity and the critical conservation status of this species (Smart *et al.*, 2013; Soldo *et al.*, 2015; Walls & Dulvy, 2021). While we cannot definitively conclude whether the white sharks have come to stay on the Iberian coast, alternative methodologies should be employed to further determine their distribution and abundance. Adopting a similar approach to the Mediterranean white shark strategy described by Ferretti *et al.* (2024) would be desirable. This strategy combines traditional tools (e.g., collaboration with fishing communities and underwater recording systems) with novel methods such as environmental DNA and predictive modelling analyses (Pikitch, 2018; Jenrette *et al.*, 2023; Ferretti *et al.*, 2024; Panunzi *et al.*, 2025). Beyond these actions, citizen science might also play an important role in tracking rare and threatened species like white sharks (Fontaine *et al.*, 2022; Carrasco-Puig *et al.* 2025; Soldo, 2026). Such methods may facilitate a more accurate assessment of their presence in the Northeast Atlantic (Huveneers *et al.*, 2018; Pikitch, 2018; Ferretti *et al.*, 2024). This will require a cooperative approach between scientific, governmental, and local communities (Jorgensen *et al.*, 2022), in order to fill pervasive knowledge gaps on the biology and ecology of such an iconic species, particularly as it becomes increasingly vulnerable to extinction in certain areas, including the Northeast Atlantic.

Supplementary information ↑

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Supplementary material

Not applicable.

Data availability

Not applicable.

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Authorship contribution statement

Claudio Barría: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Project administration, Resources, Software, Validation, Visualization, Writing – original draft, Writing – review & editing.

Ana I. Colmenero: Conceptualization, Data curation, Formal analysis, Writing – original draft, Writing – review & editing.

Alfredo López: Investigation, Resources, Writing – review & editing.

Pablo Covelo: Investigation, Resources, Writing – review & editing.

Xabier Vázquez-Pumariño: Investigation, Resources, Writing – review & editing.

Pol Carrasco-Puig: Investigation, Software, Visualization, Writing – original draft, Writing – review & editing.

Gonzalo Mucientes: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Resources, Software, Validation, Writing – review & editing.

Competing interests

The authors of this article declare that they have no financial, professional or personal conflicts of interest that could have inappropriately influenced this work.

Statement on the use of Artificial Intelligence

Not applicable.

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