

	
<b>CHAPTER 2.2.1.1</b> <b>BLUE SHARK</b>	<b>AUTHORS:</b> <b>A. DOMINGO, R. FORSELLEDO, F. MAS,</b> <b>P. MILLER</b>
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### 2.2.1.1 Description of blue shark (BSH)

#### 1. Names

##### 1.a. Classification and taxonomy

**Species name:** *Prionace glauca* (Linnaeus, 1758)

**Etymology:** *Prionace* comes from the Greek word “*prión*” which means “saw”, teeth with a serrated edge. *Glauca*, from the Latin word “*glaucus*”, in turn from the Greek *γλαυκός-glaukós*: blueish white or greyish green colour (Cornejo, 2001).

**Synonyms:** *Carcharias gracilis* (Philippi, 1887); *Carcharias hirundinaceus* (Valenciennes in Müller and Henle, 1839); *Carcharias pugae* (Perez Canto, 1886); *Prionace mackiei* (Phillipps, 1935); *Squalus caeruleus* (Blainville, 1816); *Squalus glaucus* (Linnaeus, 1758); *Thalassinus rondeletii* (Moreau, 1881).

**ICCAT species code:** BSH

**ICCAT names:** Blue shark (English), Requin peau bleue (French), Tiburón azul/Tintorera (Spanish)

According to the ITIS (Integrated Taxonomy Information System), it is classified as follows:

- Kingdom: Animalia
- Phylum: Chordata
- Subphylum: Vertebrata
- Superclass: Chondrichthyes
- Class: Chondrichthyes
- Subclass: Elasmobranchii
- Superorder: Euselachii
- Order: Carcharhiniformes
- Family: Carcharhinidae

##### 1.b. Common names

List of vernacular names used in various countries according to ICCAT, FAO and Fishbase ([www.fishbase.org](http://www.fishbase.org)), in addition to other references. Although an exhaustive bibliography was used, the list of countries is not exhaustive and some local names might not be included.

**Alaska:** Blue shark.

**Albania:** Peshkagen, Peshkagen jeshil, Peshkaqen jeshil.

**Australia:** Blue shark, Blue whaler, Great blue whaler.

**Azores Islands:** Blue shark, Tintureira, Tubarão azul.

**Bermuda:** Blue shark.

**Brazil:** Cação-azul, Cação-focinhudo, Cação-mole-mole, Tintureira, Tubarão azul.

**Canada:** Blue shark.

**Canada (British Columbia):** Blue shark K'wet'thenéchte, Ksaa.

**Canada (Quebec):** Requin bleu.

<sup>1</sup> This file was initially drafted by J. Valeiras and E. Abad in September 2006 and updated by Andrés Domingo and Rodrigo Forselledo in September 2009.

**Canary Islands:** Aquella, Quella, Sarda.  
**Cabo Verde:** Guelha, Quella, Tintureira, Tubarão-azul.  
**Chile:** Azulejo.  
**China Main:** 大青鯊.  
**Chinese Taipei:** 鋸峰齒鯨.  
**Colombia:** Tiburón azul, Toyo azul.  
**Croatia:** Hajkulja.  
**Cuba:** Blue dog, Great blue shark, Tiburón azul.  
**Cyprus:** Glaukos, Karcharias.  
**Denmark:** Blåhaj.  
**Ecuador:** Aguado, Tiburón azul.  
**Faroe Islands:** Bláhávur.  
**Finland:** Sinihai.  
**France:** Bleu, Cagnot, Cagnou, Empereur, Peau bleue, Pei can, Requin bleu, Requin squale, Requin tchi, Tintourella, Verdoun.  
**Germany:** Blauer Hai, Blauhai, Großer Blauhai.  
**Greece:** Καρχαρία, Καρχαρία γλαυκός, Carcharias, Γλαυκοκαρχαρία, Glafkarcharias, Glafkokarcharias, Karcharias.  
**Ireland:** An siorc gorm, Blue shark.  
**Isle of Man:** Blue shark.  
**Israel:** Karish kakhol.  
**Italy:** Cacciueddu de mari, Cagna, Cagnizza blu, Cagnoleto, Calandrini, Can, Can da denti, Can turchin, Canesca, Celeste, Cialandrini, Cialestru, Gialestru, Moretta da denti, Musiedde, Smerije, Squalo azzurro, Verdalrola, Verdarolo, Verdesca, Verdone, Verdoro, Verdun, Virdeddru, Virdeddu, Virdisca, Virdiscu.  
**Japan:** Yoshikiri-zame, Yoshikiri, Aota, Aobuka, Guda, Mizu-zame  
**Lebanon:** Qarsh Mizraqq.  
**Madeira Island:** Tintureira.  
**Malta:** Blue shark, Huta Kahla, Kelb il-bahar, Verdesca.  
**Mauritius:** Peau bleue, Requin bleu.  
**Mexico:** Tiburón azul, Tiburón limón.  
**Micronesia:** Shark, Yeshabel.  
**Morocco:** Kalb al bhar, Mouch labhar.  
**Mozambique:** Guelha azul.  
**Namibia:** Blouhaai, Blue shark.  
**Netherlands Antilles:** Blauwe haai, Blue shark, Tribon blou.  
**Netherlands:** Blauwe haai.  
**New Zealand:** Blue shark, Mango-pouamu, Pounamu.  
**Nicaragua:** Tiburon azul.  
**Norway:** Blåhai.  
**Papua New Guinea:** Blue shark.  
**Peru:** Tiburón azul, Tintorera.  
**Philippines:** Iho, Pating.  
**Poland:** Zarłacz blekitny.  
**Portugal:** Guelha, Pas modrulj, Tintureira.  
**Romania:** Rechin albastru.  
**Russia:** акула синяя, Sinyaya akula.  
**Samoa:** Aso-polota, Malie.  
**SerbiaMontenegro:** ajkula, hajkula, hajriba, plava ajkula.  
**South Africa:** Blouhaai, Blue shark.  
**Spain:** Azujelo, Caella, Caellita, Caellón, Cuero, Lobito, Marrajo, Meona, Pez de cuero, Tiburón, Tiburón azul, Tintorera.  
**St. Helena:** Blue shark.  
**Sweden:** Blåhaj.  
**Türkiye:** Canavar balik, Maviköpek baligi, Pamuk baligi.  
**United Kingdom:** Blue dog, Blue shark, Blue whaler, Great blue shark.  
**United States:** Blue shark, Great blue shark.  
**Uruguay:** Tiburón azul.  
**Vietnam:** Cá Mập xanh.

## 2. Identification



**Figure 1.** Blue shark (*Prionace glauca* - Image taken by Domingo *et al.*, 2010. Image Credit: National Observers Program of the Uruguayan Tuna Fleet (PNOFA) DINARA/Uruguay).

### Characteristics of *Prionace glauca* (see **Figure 1** and **Figure 2**).

The maximum size records is 394 cm fork length (FL), although there are unconfirmed reports of individuals that could reach more than 450 cm. Males and females reach similar sizes (Compagno, 1984; Nakano and Stevens, 2008; Coelho *et al.*, 2018).

### Colour:

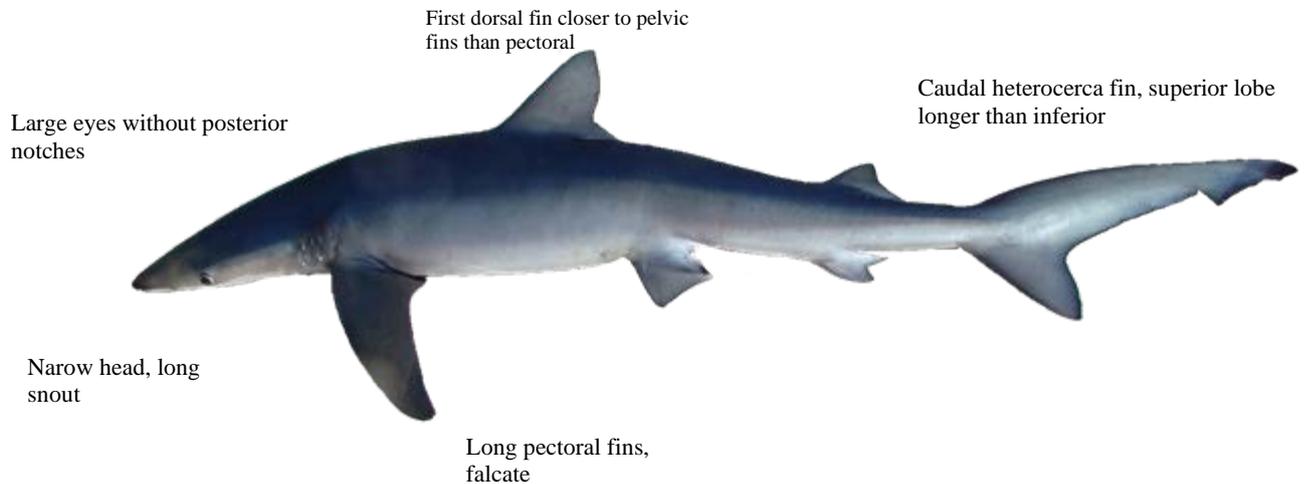
- Dorsal coloration, dark blue, abruptly bright blue on sides, white underside (fresh individual).

### External characteristics:

- Body rather slender.
- Head narrow, only moderately depressed, not trowel-shaped, long snout.
- Eyes large, without posterior notches.
- Short labial furrows.
- First dorsal fin on back closer to the pelvic fins than the pectorals.
- Second dorsal less than a third the size of the first dorsal.
- Very large pectoral fins that are long, narrow and tapered.
- Heterocercal caudal fin, upper lobe longer than inferior lobe.
- Weak keel on caudal peduncle.
- Absence of interdorsal ridge.
- Well differentiated teeth in upper and lower jaws. Upper teeth with broad, triangular, curved cusps - between straight and oblique – but not sharp, or small cusps (except in very young specimens); lower teeth, with thin cusps, that are not sharp or small cusps.

**Internal characteristics:**

- Short gillraker papillae on gill arches.



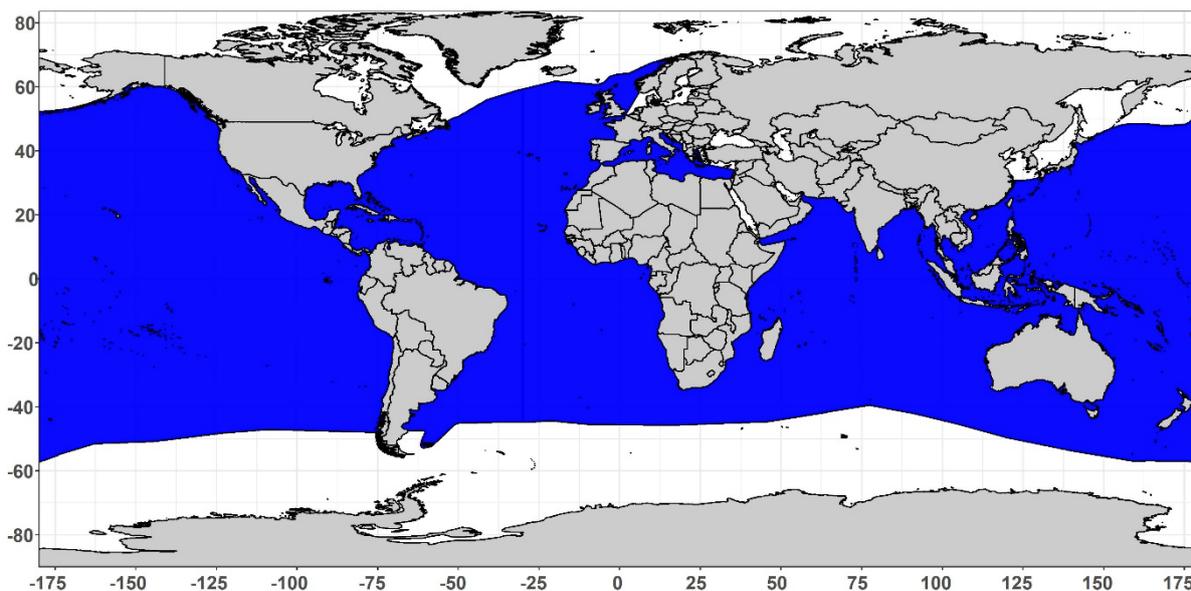
**Figure 2.** Synthesis of the most outstanding characteristics of blue shark.

**3. Distribution and population ecology****3.a. Geographic distribution**

Nakano and Seki (2003) carried out an exhaustive review of the blue shark's biology worldwide; although almost 20 years have passed since this paper was published, much of the information presented continues to be relevant and it is a reference text for this species.

The blue shark is an oceanic and epipelagic species distributed in all oceans, in tropical, subtropical and temperate waters between 62°N and 54°S (**Figure 3**). In the West Atlantic its distribution is from Newfoundland to Argentina. In the East Atlantic, from Norway to South Africa, including the Mediterranean Sea (Bigelow and Schroeder, 1948; Aasen, 1966; Compagno, 1984; Nakano and Stevens, 2008; García-Cortés *et al.*, 2016; Coelho *et al.*, 2018).

The blue shark has occupied a dominant position in the oceanic epipelagic elasmobranch taxon in recent geological history. It has the widest distribution and is one of the most abundant species in temperate and tropical waters of all the oceans (Litvinov, 2006).



**Figure 3.** Map of distribution of blue shark, *Prionace glauca*. Taken from IUCN (IUCN SSC Shark Specialist Group 2018. *Prionace glauca*. The IUCN Red List of Threatened Species. Version 2021-1).

### 3.b. Habitat preferences

Blue shark is an oceanic-epipelagic species that can be found close to the coast in some areas and at certain times, particularly where the shelf is narrow or even in ports and marinas. It is found in deep waters of tropical, warm and temperate seas from the surface to a depth of at least 1,291.1 m, with greater abundance in areas outside the platform (Castro, 1983; Hazin, *et al.* 1994a Nakano and Stevens, 2008; Campana *et al.*, 2011; Queiroz *et al.*, 2012; Mejuto *et al.*, 2014; Weigmann, 2016; Howey *et al.*, 2017). This shark is distributed mainly in waters with temperatures ranging between 12°C and 20°C, although it can be found in a greater temperature range (3.9°C - 31.3°C). Temperature preference is related to size and sex. Relative abundance decreases in equatorial waters and increases with latitude (Compagno, 1984; Nakano, 1994; COSEWIC, 2006; Nakano and Stevens, 2008; Howey *et al.*, 2017).

Some studies in the northwest Atlantic off the coast of Canada show a seasonal change in habitat use. Individuals are found in waters close to the surface for the majority of the summer and autumn, and move to deeper waters towards the end of November. Daily vertical movements were observed from an average depth of 74 m at night to an average depth of 412 m during the day. This behaviour was also observed in other areas such as the central Pacific (Campana *et al.*, 2011; Musyl *et al.*, 2011). Observations of satellite transmitter data in the North Atlantic, showed that the blue shark's dives almost always take place during the day, when most of the mesopelagic community is at depth. The dives are characterised by fast descents and slower ascents, a pattern interpreted as behaviour related to the search for prey (Braun *et al.*, 2019). Also using satellite transmitters, Nykänen *et al.* (2018) observed that two blue sharks tagged in the EEZ of Ireland spent less time in the upper layer of the water column between midnight and morning (12 a.m. - 6 a.m.) and more time at the surface in the morning and afternoon (6 a.m. - 6 p.m.). Some studies, with the use of satellite information, show periods where blue sharks are observed swimming in the surface with dorsal fins outside the water, recording up to more than seven minutes with this type of behaviour (Doyle *et al.*, 2015). Although some authors have attributed it to periods of physiological recovery, following deep dives, this behaviour varies. Doyle and collaborators (2015) observed that this type of behaviour occurred more often after dawn and this was explained on the basis that blue sharks feed on more amounts of prey at the surface at dawn, or make use of the changing conditions of light to surprise their prey that they find at the surface.

### 3.c. Migrations

The blue shark is a highly migratory species, with complex movement patterns related to reproduction and to the distribution of its prey. A seasonal movement towards higher latitudes is related to the existence of highly productive areas of convergence (Nakano and Stevens, 2008). Movements of sharks in the Atlantic are known from data obtained from conventional, acoustic telemetry and satellite tagging programs, as well as fishing data and, to a lesser extent, research cruise data. Their migratory patterns are complex and encompass great distances,

with some records of distances reaching almost 7,000 km. In these studies numerous transatlantic migrations were observed (Kohler and Turner, 2008). This species undergoes seasonal latitudinal migrations on both sides of the North Atlantic (Stevens, 1976; Casey, 1985; Mejuto *et al.*, 2005; Querioz *et al.*, 2005) and in the South Atlantic (Hazin *et al.*, 1990). Seasonal movements have also been detected between the platform and the open ocean (Carey and Scharold, 1990).

Despite the great amount of investigation and extensive tagging efforts carried out in the North Atlantic, with more than 91,000 blue sharks tagged between 1962 and 2000, migratory patterns have not yet been clearly understood (Kohler *et al.*, 2002; Kohler and Turner, 2008). The tagging and recapture of individuals have shown a regular, clockwise transatlantic migratory route. Sharks tagged off the United States have been recovered in waters off Spain, in the Strait of Gibraltar, and in the equatorial north-central Atlantic, while sharks tagged in the Canary Islands have been recaptured in waters off Cuba (Compagno, 1984; Fitzmaurice *et al.*, 2005). In addition, seasonal migrations along both sides of the North Atlantic Ocean by both juveniles and adults have been detected, while smaller individuals - juveniles and neonates (50–130 cm) - stay within a more restricted area of the central Atlantic for the most part of the year. The latter group is not segregated by sex, and this only occurs after they reach the age of one and abandon the area to take part in larger-scale migrations (Vandeperre *et al.*, 2014; COSEWIC, 2016).

In the northwest Atlantic, where the stock consists mainly of juveniles of both sexes, sub-adult females and adult males, the sharks move with part of the Gulf current towards the Caribbean and northern South America at the end of the summer, autumn and spring. In addition, juvenile and sub-adult females, go deeper into the ocean; some of these probably migrate towards the east. In summer, they gather in large numbers to the south of New England, Georges Bank, Nova Scotia and Grand Banks (Casey 1985; Nakano and Stevens 2008).

In the northeast Atlantic, adult females are found in winter close to the Canary Islands and the coast of Africa, many of which were observed with pups (Casey, 1985). Adult males are found towards north of the coast of Portugal, together with juvenile and sub-adult females that are coming down from the north of Europe. In spring and summer, adult males and females mate in the area of 32–35°N. The adult females seem to have a seasonal reproductive cycle, while males and females are sexually active throughout the year (Pratt, 1979; Stevens, 1984; Nakano and Stevens, 2008). Juveniles remain in the pupping areas and do not carry out extensive migrations until they reach a size of approximately 110 - 130 cm (Stevens, 1976; Muñoz-Chápuli, 1984; Vandeperre *et al.*, 2014). In the northeast Atlantic, adult females, pregnant females and newborns occur in some seasons, for which it seems that a large part of the reproductive stock of the North Atlantic could be found in this region (Casey, 1985).

Segregation by sex can be seen in the distribution of blue shark populations. Most of the individuals tagged in the coastal waters of Ireland are females. Likewise, most of the recaptures that took place off European coasts were females (Fitzmaurice *et al.*, 2005). The northwest Atlantic is also an important area for immature males and females in addition to sub-adult females.

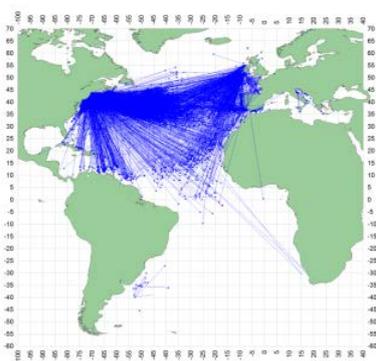
Larger individuals, and the majority of mature individuals of both sexes, are found in southern areas of the North Atlantic, with the largest average sizes for both males and females and the highest percentage of mature individuals found in the southeast North Atlantic.

More recent studies using satellite tracking support that the movement pattern of blue sharks in the northeast Atlantic is clearly influenced by seasonal changes in sea surface temperature and that juvenile and sub-adult sharks show a wider variety of movements than known, which suggests a more complex spatial dynamic and population structure (Queiroz *et al.*, 2010, 2012).

In the south Atlantic, there are at least two hypotheses on the migratory cycle of the blue shark. Hazin *et al.* (2000) proposed the existence of a model similar to that of the North Atlantic, with a clock-wise reproductive migration, where copulation would occur in the southeast-south region of Brazil. Fertilization would occur three months after copulation in the northeast region, and parturition in high latitudes. The nursery area, where the pups develop before recruiting to the adult stock, probably is located close to the coasts of Africa. The recapture of a juvenile measuring 93 cm that had been tagged in South Africa off the coast of Uruguay could support the theory of a clockwise migration, however, for the author of the theory, the data are scarce to confirm the model (Da Silva *et al.* 2010). On the other hand, Amorim (1992), Legat *et al.* (2000) and Domingo *et al.* (2008) suggested that in the southwest region of the Atlantic (20°-42°S and 20°-55°W), copulation, fertilization, gestation and parturition occur, with latitudinal migrations within the western area of the Atlantic Ocean.

Although few individuals tagged in the North Atlantic have been recaptured in the South Atlantic, some of them reached relatively high latitudes off the coast of South Africa, which shows that migratory patterns could possibly be more complex (Anon., 2020). Proof of this complexity is the recapture of individuals tagged in the Indian Ocean in the southeast and southwest Atlantic, which demonstrates that a connection also exists between the two oceans (Matsunaga and Nakano, 2009; unpublished DINARA data).

Conventional tagging and satellite studies have revealed that the movements of individuals vary widely, with some individuals tracked over dozens of thousands of miles. Individual movements have reached 42 km per day, while less mobile individuals do not exceed 18.8 km per day (Kohler and Turner, 2008; Queiroz *et al.*, 2005; Vandeperre *et al.*, 2014). In some cases, aggregations of blue sharks with less movement at certain times and in certain areas are related to feeding, capitalising on the abundance of prey to build energy reserves prior to long-distance migrations that require high amounts of energy (Howey *et al.*, 2017).



**Figure 2.** Straight displacements between release and recovery positions (apparent movement), from conventional tagging of blue sharks.

## 4. Biology

### 4.a. Growth

The age and growth of blue shark is relatively well studied in the North and South Atlantic, although there are no well validated models available. Generally, these studies indicate that the individuals can reach an age of approximately 20 years (Nakano and Stevens, 2008). Skomal and Natanson (2003) used vertebral sections to estimate age, and concluded that the maximum age was between 16 and 21 years. Other studies estimate values of up to 28.6 years; although these are theoretical estimations of longevity (Hsu *et al.*, 2011, 2012, 2015; Rice and Semba, 2014; Andrade *et al.*, 2019). Growth based on tagging and recapture was more rapid than that based on vertebral sections and similar from examination of whole vertebrae (MacNeil and Campana, 2002).

In the South Atlantic off Brazil, studies were carried out to determine the age of caught individuals based on vertebral length data. Age ranged from 3 to 12 years for males and from 4 to 9 years for females, with modal classes in age groups of 5 and 7 years, respectively (Lessa *et al.*, 2004; Hazin and Lessa, 2005). The maximum age observed by Hsu (2015) for individuals in the South Atlantic was 15 years for both males and females. The estimated theoretical longevity of blue sharks was considerably higher than the maximum observed age, reaching 21.4 and 26.6 years for males and females, respectively.

In an analysis of vertebra, Mas (2015) observed absolute minimum and maximum ages of 0.5-17.4 years for males and 1.2-14.9 years for females, with an average of 7 and 6 years, respectively, in the southern region of the southwest Atlantic.

Joung and collaborators (2017) suggested that blue sharks in the southeast Atlantic have a lower growth rate than individuals found in the north and southwest Atlantic.

**Table 1.** Growth parameters for *Prionace glauca* according to the Von-Bertalanffy growth model.  $L_{\infty}$ : maximum asymptotic length (cm), k: growth coefficient (years<sup>-1</sup>),  $t_0$ : theoretical age at 0 length (years).

Growth parameters			Area	Reference	Sex	Method
$L_{\infty}$	k	$t_0$				
394 (TL)	0.133	-0.801	Northeast Atlantic	Aasen (1966) <sup>1</sup>	Both	Size frequencies
423 (TL)	0.110	-1.035	Northeast Atlantic	Stevens (1975)	Females <sup>2</sup>	Full vertebrae
284 (FL)	0.140	-1.081	Northeast Atlantic	Silva (1996)	Both	Full vertebrae
376.5 (TL)	0.120	-1.33	Northeast Atlantic	Henderson <i>et al.</i> (2001)	Both	Full vertebrae
300 (FL)	0.68	-0.25	Northwest Atlantic	MacNeil and Campana (2002)	Both	Full vertebrae
302 (FL)	0.58	-0.24	Northwest Atlantic	MacNeil and Campana (2002)	Both	Cut vertebrae
343 (FL)	0.16	-0.89	Northwest Atlantic	Skomal (1990)	Males	Cut vertebrae
375 (FL)	0.15	-0.87	Northwest Atlantic	Skomal (1990)	Females	Cut vertebrae
287 (FL)	0.170	-1.430	Northwest Atlantic	Skomal and Natanson (2003)	Both	Cut vertebrae
282 (FL)	0.180	-1.350	Northwest Atlantic	Skomal and Natanson (2003)	Males	Cut vertebrae
311 (FL)	0.130	-1.770	Northwest Atlantic	Skomal and Natanson (2003)	Females	Cut vertebrae
401.5 (TL)	0.130	-0.620	Mediterranean Sea	Megalofonou <i>et al.</i> (2009)	Both	Full vertebrae
352.1 (TL)	0.157	-1.01	South-equatorial Atlantic	Lessa <i>et al.</i> (2004)	Both	Cut vertebrae
257 (FL)	0.149	-1.56	Southwest Atlantic	Montealegre-Quijano (2007)	Males	Cut vertebrae
245 (FL)	0.160	-1.55	Southwest Atlantic	Montealegre-Quijano (2007)	Females	Cut vertebrae
311.6 (TL)	0.120	-1.66	Southeast Atlantic	Jolly <i>et al.</i> (2013)	Both	Cut vertebrae
352 (TL)	0.130	-1.31	South Atlantic	Hsu <i>et al.</i> (2015)	Both	Full vertebrae
290 (FL)	0.102	-1.25	Southwest Atlantic	Mas (2015)	Both	Cut vertebrae
291 (FL)	0.102	-1.25	Southwest Atlantic	Mas (2015)	Males	Cut vertebrae
283 (FL)	0.106	-1.24	Southwest Atlantic	Mas (2015)	Females	Cut vertebrae
352.1 (TL)	0.130	-1.31	South Atlantic	Joung <i>et al.</i> (2017)	Both	Full vertebrae

TL: Total length; FL: Fork length; <sup>1</sup> Parameters from Stevens (1975) based on data from Aasen (1966); <sup>2</sup> Considered as representative of female growth since only 8 of 82 vertebrae analysed were from male individuals.

#### 4.b. Length-weight relationship, weight-weight and length-length

Published length-weight relationships for several geographic areas in the Atlantic are shown in **Table 2**.

**Table 2.** Published length-weight, weight-weight and length-length relationships for *Prionace glauca*, published data.

Equation	N	Range (cm)	Area	Reference
$LW = 3.841 \times 10^{-6} \times (FL)^{3.1313}$	4529	52-288 (FL)	Northwest Atlantic	Kohler <i>et al.</i> (1995)
$DW = 8.04 \times 10^{-7} \times (FL)^{3.232}$	354	75-250 (FL)	Northeast Atlantic	García-Cortes y Mejuto (2002)
$DW = 6.38 \times 10^{-7} \times (FL)^{3.278}$	743	120-260 (FL)	Eastern Tropical Atlantic	García-Cortes y Mejuto (2002)
$DW = 9.56 \times 10^{-7} \times (FL)^{3.209}$	164	140-245 (FL)	Central Tropical Atlantic	García-Cortes y Mejuto (2002)
$DW = 1.57 \times 10^{-6} \times (FL)^{3.104}$	166	135-250 (FL)	Southwest Atlantic	García-Cortes y Mejuto (2002)
$LW = 3.2 \times 10^{-6} \times (FL)^{3.128}$	720		Northwest Atlantic	Campana <i>et al.</i> (2005)
$DW = 1.7 \times 10^{-6} \times (FL)^{3.205}$	382		Northwest Atlantic	Campana <i>et al.</i> (2005)
$DW = 1.7 \times 10^{-3} \times (TL)^{3.0869}$	157	64-228 (TL)	Northeast Atlantic	Henderson <i>et al.</i> (2001)

$LW = 1.5 \times 10^{-6} \times (FL)^{3.2907}$			Atlantic	Coelho <i>et al.</i> (2017)
$LW = -0.315 + 14.09 \times (FF)$	99		North Atlantic	Neves dos Santos y García (2005)
$LW = 0.386 + 147.39 \times (DF)$	66		North Atlantic	Neves dos Santos y García (2005)
$LW = -0.339 + 43.387 \times (PecF)$	66		North Atlantic	Neves dos Santos y García (2005)
$LW = 0.874 + 275.723 \times (PelF)$	66		North Atlantic	Neves dos Santos y García (2005)
$LW = 3.742 + 790.176 \times (AF)$	66		North Atlantic	Neves dos Santos y García (2005)
$LW = -2.070 + 35.863 \times (CF)$	66		North Atlantic	Neves dos Santos y García (2005)
$FL = -1.2 + 0.842 \times (TL)$	792		Northwest Atlantic	Campana <i>et al.</i> (2005)
$TL = 3.8 + 1.17 \times (FL)$	792		Northwest Atlantic	Campana <i>et al.</i> (2005)
$CFL = 2.1 + 1.0 \times (SFL)$	782		Northwest Atlantic	Campana <i>et al.</i> (2005)
$SFL = -0.8 + 0.98 \times (CFL)$	782		Northwest Atlantic	Campana <i>et al.</i> (2005)
$FL = 23.4 + 3.50 \times (LID)$	894		Northwest Atlantic	Campana <i>et al.</i> (2005)
$IDL = -4.3 + 0.273 \times (FL)$	894		Northwest Atlantic	Campana <i>et al.</i> (2005)
$LW = 0.4 + 1.22 \times (DW)$	17		Northwest Atlantic	Campana <i>et al.</i> (2005)
$DW = 0.2 + 0.81 \times (LW)$	17		Northwest Atlantic	Campana <i>et al.</i> (2005)
$FW = 372.11 + 124.73 \times (BDW)$	736		North Atlantic	Mejuto y García-Cortés (2004)
$FW = 0.0888 + 65.84 \times (BW)$	184		North Atlantic	Mejuto y García-Cortés (2004)
$FW = 82.1298 + 66.1445 \times (G)$	768		North Atlantic	Lorenzo <i>et al.</i> (2010)
$FW = 48.7272 + 55.7207 \times (RW)$	768		North Atlantic	Lorenzo <i>et al.</i> (2010)
$\text{LogFW} = -8.3786 + 3.0878 \times \text{Log}(FL)$	768		North Atlantic	Lorenzo <i>et al.</i> (2010)
$DW = 0.0068 + 0.4167 \times (LW)$			Atlantic	Coelho <i>et al.</i> (2017)
$FL = -1.122 + 0.829 \times (TL)$			Atlantic	Coelho <i>et al.</i> (2017)
$PCL = -2.505 + 0.762 \times (TL)$			Atlantic	Coelho <i>et al.</i> (2017)
$FL = -1.061 + 0.8203 \times (TL)$	-		South Atlantic	Castro y Mejuto (1995)
$TL = 1.631 + 1.201 \times (FL)$	8391	78-309 (TL)	South Atlantic	Mas <i>et al.</i> (2014)
$TL = 3.549 + 1.313 \times (PCL)$	16542	78-309 (TL)	South Atlantic	Mas <i>et al.</i> (2014)
$FL = 1.956 + 1.091 \times (PCL)$	8572	64-259 (FL)	South Atlantic	Mas <i>et al.</i> (2014)
$FL = 11.27 + 0.78 \times (TL)$			Equatorial Atlantic	Hazin <i>et al.</i> (1994a)

TL: total length; FL: fork length; CFL: curve fork length; SFL: straight fork length; IDL: interdorsal length; PCL: precaudal length; LW: live weight; DW: dressed weight; FF: total weight of all the fins; DF: weight of the dorsal fins; PecF: weight of the pectoral fins; PelF: weight of the pelvic fins; AF: weight of the anal fins; CF: weight of the caudal fins; FW: fin weight; BDW: body dressed weight; BW: body weight.

#### 4.c. Reproduction

Reproduction is viviparous and gestation lasts for between 9 and 12 months. The reproduction cycle is annual or biennial and females are ready to ovulate and gestate soon after parturition. Litters contain 4 to 135 embryos (generally 25 to 35), with a size at birth of 35 to 60 cm TL (Pratt, 1979; Stevens, 1984; Hazin *et al.*, 1994; Nakano, 1994; Hazin and Lessa, 2005). It is one of the most productive species with a mean population doubling time of 3.1 years (Aires da Silva and Gallucci, 2007). Age at maturity is variable in the Atlantic Ocean, from 5 to 7 years of age for females and 4 to 6 years of age for males. The estimated generation length is 10 years (Nakano, 1994; Skomal and Natanson, 2003; Jolly *et al.*, 2013). Although embryos usually occur in the same relative stage of development during gestation, they are occasionally found in completely distinct stages (Hazin and Lessa, 2005). Legat and Vooren, 2008 find that in the South West Atlantic region parturition is annual and occurs in a single period.

#### Parturition and pupping

In the warm waters of the central Atlantic, adult specimens were observed with a high percentage of females with signs of having been fertilized, and pregnant females with relatively small embryos. The North and South Atlantic are regions that have a lower prevalence of females in the stage of reproduction than the central Atlantic region, though some females with large embryos are found. A possibly higher number of juveniles and sub-

adults are found at high latitudes than in the central Atlantic region. The central Atlantic region appears to be used preferentially for gestation, and not for parturition. Recent studies carried out in the Cabo Verde region mainly observed relatively large adult specimens (Coelho *et al.*, 2020). In view of the size of the embryos observed in the different regions, the final stages of embryo development and birth, at least for a part of the female population, would probably take place in the temperate water zones of the North or South, where there is more food available. Mejuto and García-Cortés (2005) suggest an abundance of juveniles and sub-adults of both sexes in some temperate areas of the North Atlantic, although these waters are also inhabited by some adult females. Juveniles and neonates reach coastal areas off NW Galicia-Spain, particularly in summer for the purpose of their development (Mejuto *et al.*, 2014; Bañón *et al.*, 2016). Other studies suggest the existence of an important nursery area for small juveniles in spring in the Azores (Aires da Silva *et al.*, 2008), and the presence of gestating females with fully developed embryos between 36.5 and 59 cm TL (average =  $51.4 \pm 3.5$  cm TL) in May could suggest that at least parturition takes place in this area (Vandepierre *et al.*, 2014, 2014a). This would explain the wide-ranging and complex migratory pattern observed in this species. On the basis of this thesis, the animals might carry out two migrations, in opposite directions, during the mating-gestation or gestation-parturition processes. In addition, the presence of concentrations of juveniles in highly productive temperate zones with an abundance of available food, as occurs in some of the regions of the North and South Atlantic, help support this thesis.

A high percentage of gravid females in catches has also been noted in other regions such as the Caribbean - approximately 25% - which means that this area plays an important role in the reproduction of blue sharks (Arocha *et al.*, 2005).

In the South Atlantic, Hazin and Lessa (2005) suggest that female blue sharks would be moving from southeast Brazil, where copulation occurs, to the northeast, where ovulation takes place, and from there to the Gulf of Guinea, where females in early pregnancy are found from June to August (Castro and Mejuto, 1995). More recent studies show the distribution of embryos in more coastal areas in the Gulf of Guinea, with recently pregnant females from November to December and females with more advanced embryos between August and September (Kouamé *et al.*, 2019). The parturition area is unknown, but based on data available from other oceans (Nakano, 1990), it would probably be located between the southern coast of Africa where upwelling occurs and the subtropical convergence. On the other hand, various authors (Amorim, 1992; Legat *et al.*, 2000; Bornatowski and Schwingel, 2008; Domingo *et al.*, 2008) support a more complex scheme where all the reproductive processes (mating, fertilization, embryonic development, parturition and pupping) would take place in different parts of the South Atlantic.

In South and Southeast Brazil, a large number of adult individuals were found with oocytes in the uterus from December to July, some females showing signs of recent parturition in July and another with at-term embryos (45.2 cm) (Bornatowski and Schwingel, 2008). Other researchers suggest that this region (South and Southeast Brazil and Uruguay) is a nursery area and juveniles of both sexes remain here until they reach 130 cm FL. This is attributed to the nutritional richness found in the Brazil-Malvinas Confluence Zone (Montealegre-Quijano and Vooren, 2010).

There is little information regarding the Mediterranean Sea. Some studies highlight its importance as a nursery area, mainly the eastern zone (Leone *et al.*, 2017). Nonetheless, gravid females have occasionally been found in the western Mediterranean off the coast of Valencia, Spain (257 cm TL and 65 embryos) (Penadés-Suay *et al.*, 2017).

Some neonates measuring between 50 and 70 cm found off the coast of Montenegro in the Adriatic, locate this zone as a pupping and nursery area, alongside the Ionian Sea (Megalofonou *et al.*, 2009; Četković *et al.*, 2019). Observations off the coast of Algeria, which would be a mating area, suggest that fertilised females probably migrate to southern areas such as the Gulf of Gabes and northern areas such as the Italian coast to give birth (Hemida and Capape, 2003).

### *Maturity*

In the Northwest Atlantic, 50% of males are mature at a size of 218 cm (TL), although some reach maturity at 182 cm, and 50% of females at 221 cm (TL) (Pratt, 1979). Later studies regarding nearby areas found that 50% of males are mature at 201 cm, varying between 193 and 210 cm (Campana *et al.*, 2005). These are lower than previous values.

Maturity at age in the equatorial east Atlantic off the coast of Guinea is reached at 5 years. In the same area it was observed that 50% of the females were pregnant at a size of 217 cm (Castro and Mejuto, 1995). Studies carried out based on specimens caught by the Chinese Taipei longline fleet in this area, estimated the maturity sizes (50%) of females and males at 191.7 and 197.5 cm (FL), respectively (Wu *et al.*, 2020).

In the western equatorial Atlantic and Caribbean off the coast of Venezuela a size of 213 cm was estimated to reach 50% of the pregnant females, with pregnant specimens from 152 cm (Tavares and Arocha, 2008).

In the southwest Atlantic, off Brazil, female sexual maturity is reached at about 228 cm TL, at about 5 years. Males attain sexual maturity at approximately 225 cm TL and show a seasonal fluctuation in sperm production (Hazin *et al.*, 1994; Hazin *et al.*, 2000). Subsequent studies estimate a size of maturity of 171.2 cm (FL) for females and 180.2 cm (FL) for males (Montealegre-Quijano *et al.*, 2014; Da Silva *et al.*, 2021). Based on Uruguayan fishery data, Mas (2015) estimated later ages at first maturity, at 8 years for males and 7 for females.

In the eastern zone of the South Atlantic, Jolly *et al.* (2013) estimated much lower average length at 50% maturity in the southwest Atlantic for both males and females, at 201.4 cm TL and 7 years of age and 194.4 cm TL and 6 years of age, respectively.

In the Mediterranean Sea (Adriatic Sea, Ionian Sea, Aegean Sea and the Levantine Basin) the mean length at 50% maturity was estimated at 202.9 cm TL for males and 214.7 cm TL for females, corresponding to 4.9 and 5.5 years of age, respectively (Megalofonou *et al.*, 2009)

#### *Fecundity*

The number of pups varies from 4 to 135 per litter. This variation could be due to the size of the female (Compagno, 1984; Nakano, 1994). Normally, fecundity is about 30-40, and the females are ready for a new ovulation and pregnancy soon after parturition (Hazin and Lessa, 2005; Montealegre-Quijano *et al.*, 2014). Castro and Mejuto (1995) found fecundity in the Atlantic of 38 embryos, based on the number of female pups produced per year, from the number of pups in one litter, with a 1:1 embryonic sex ratio. Pups are born with a size of 35-50 cm TL, and although the embryos are at the same stage of development, occasionally there could also be some embryos in other, completely distinct stages of development (Hazin *et al.*, 1994; Hazin *et al.*, 2000).

#### **4.d. Diet**

Blue shark feeds mainly on relatively small prey, principally cephalopods and bony fish. Additionally, due to its opportunistic nature, its prey also includes invertebrates, small sharks, cetaceans, marine mammals and sea birds (Compagno, 1984; Clarke *et al.*, 1996; Henderson *et al.*, 2001). Cephalopods are a very important prey of these sharks and account for approximately 80% of diet biomass in some areas (Clarke *et al.*, 1996; Mendonça, 2009; Biton-Porsmoguer, 2015). Although the composition of the consumed cephalopods is highly variable, the vertical migrant *Histioteuthis* spp. predominated in some areas (Vaske Junior *et al.*, 2009). In the northeast Atlantic, cephalopods from the genus *Histioteuthis* were the main prey of pre-adult individuals, while the genus *Sepiolidae* constituted the main prey of juveniles (Biton-Porsmoguer, 2015). Studies carried out in the Mediterranean with stable isotopes also confirmed the dietary preference for cephalopods (Cardona *et al.*, 2012) and the importance of *Sepiolidae* (Kabasakal, 2011).

In some areas or at times when cephalopods are less abundant, small teleost fishes are the main prey (M<sup>c</sup> Cord and Campana, 2003), although larger prey such as escolar (*Lepidocybium flavobrunneum*) have been found as a secondary dietary item in the southwest Atlantic (Vaske and Rincón, 1998).

#### **4.e. Physiology**

Although ambient temperature is a physiological regulator in all ectothermic sharks, meaning that they seek physiologically optimal temperatures, it was observed that females occupied much colder temperatures than mature and immature males. This has been observed on the continental shelf, which suggests that temperature has sex-specific biological significance in this species. Female blue sharks have thicker skin than males, presumably as a result of aggressive mating strategies. However, this could also allow them to occupy cooler temperatures and, ultimately, a larger niche (Howey *et al.*, 2017).

It is a resistant species and individuals have been observed with two or more hooks in the mouth (Campana *et al.*, 2009; Penadés-Suay, *et al.* 2017; unpublished DINARA data). Some experiments have shown an important resilience at the time of catch, estimating that around 30% of the specimens survive after being caught by longline during 8 hours (Poisson *et al.*, 2010) and 95% after 3 hours (Braccini *et al.*, 2012). Predictive models that used satellite tags and blood samples suggest that it is likely that blue sharks caught in apparently healthy conditions, survive in the longer term if they are released (Moyes *et al.*, 2006).

It is one of the few chondrichthyan species where significant malformations such as diprosopus (duplication of craniofacial structures) have been observed (Lamarca *et al.*, 2017).

#### **4.f. Natural mortality**

There are no estimates of natural mortality (M) for the blue shark and it has few known predators. There are no known predators of adult blue sharks. There are some records of predation on sub-adults and juveniles by other species. They have been recorded in the diet of some lamnid sharks such as the shortfin mako (*Isurus oxyrinchus*) and the white shark (*Carcharodon carcharias*). There are also records of attacks on blue sharks by bony fish such as the swordfish, brown fur seals (*Arctocephalus pusillus*) on the South African coast and Californian sea lions (*Zalophus californianus*) (COSEWIC, 2006; Fallows *et al.*, 2015; Penadés-Suay *et al.*, 2017).

Natural mortality has been inferred based on relationships between the growth rate, mortality rate and/or longevity. The range of inferred M spans from 0.07 to 0.48, with an overall average of 0.23 (Campana *et al.*, 2005).

Subsequent studies by Montealegre-Quijano and Vooren (2009) obtained similar results, with an estimated natural annual mortality of 0.256 for females and 0.243 for males. The authors also obtained the age-specific natural mortality of females, which decreased as age increased from 0.417 in the first year of life to 0.173 in the twelfth year of life, the maximum age observed.

Aires da Silva and Gallucci (2007) obtained natural survival via six indirect methods, and average natural mortality was 0.27.

### **5. Fisheries biology**

#### **5.a. Stocks / Stock structure**

Based on extensive tagging data, Fitzmaurice *et al.* (2005) considered that there is a single blue shark stock in the North Atlantic. At the time, these data also led to the conclusion that there was a stock to the South of 4°N, as very few individuals tagged in the North Atlantic were recaptured in the South. The small number of sharks tagged in the Atlantic and recaptured in the Mediterranean Sea led to the decision to consider the stock in that sea as a separate stock. Consequently, the ICCAT Sharks Species Group assumes the existence of three stocks: North Atlantic, South Atlantic and Mediterranean (Anon, 2005). Based on data obtained in satellite tagging and conventional tagging programmes carried out in recent decades, a larger number of individuals have been seen to cross the limits established for both North-South stocks (Vandeperre *et al.*, 2014a; Wögerbauer *et al.*, 2016). Furthermore, recent genetic studies indicated genetic homogeneity throughout the entire Atlantic basin (Verissimo *et al.*, 2017). These results go against the currently assumed distinction of northern and southern populations. The majority of evidence collected to date indicates that the blue shark exhibits dispersion with gene flow over very large spatial scales, and little or no philopatry in the sampled nursery areas. Nonetheless, in the case of blue sharks where the population size is very large, levels of genetic divergence associated with migration rates that could lead to demographic connectivity (~ 10%) could be difficult to detect using traditional molecular markers. In these cases, the precautionary approach in conservation and fisheries management would be to consider each nursery area as independent, with potentially different demographic parameters and vulnerability to fishing pressure (ICES, 2017). Additionally, using satellite tags, Vandeperre *et al.* (2014a) found that the nursing area located between the Azores and the Great Meteor Seamount is used by juveniles of both sexes, at least during the first year of life, and that there is a high degree of loyalty to this site with individuals in almost all life stages returning to the region. Such a complex spatial structure and philopatric behaviour would have important consequences for management and conservation of the blue shark. In the Northwest Atlantic, Howey *et al.* (2017) observed that blue sharks mainly used highly productive areas with chlorophyll concentrations of > 1 mg/m<sup>3</sup> and exhibited lower rates of movement during aggregation than during migration, which suggests that primary productivity promotes site loyalty.

Genetic analyses in the Mediterranean revealed significant signs of genetic structure for the blue shark (Mediterranean and adjacent Atlantic), with several frequent mtDNA haplotypes exclusive to the Mediterranean and others shared with samples from the Atlantic population (Leone *et al.*, 2017).

Other studies demonstrate generalised genetic homogeneity with similar levels of allelic richness in the Mediterranean Sea, the North Atlantic and the Pacific. These results reflect large-scale panmixia, i.e., random mating on a global scale or that any deviation from random mating occurred too recent to have left a mark on the genome. However, the authors interpret that their analysis requires more data to confirm their theory and recommend a conservative, concerted and global conservation and management plan until in-depth analysis makes it possible to confirm the homogeneity or delineation of differentiated demographic groups and/or populations (Bailleul *et al.*, 2018). More modern techniques (DArTseq), which use a specific genome scanning method, found significant differences between northern regions (Mediterranean and North Atlantic) and southern regions (South East Atlantic, Indian Ocean and South East Pacific). Significant values, although low, were also found between locations of different regions within the Atlantic Ocean (North vs Northeast vs Southeast Atlantic (Nikolic *et al.*, 2020).

In line with the studies by Amorim (1992), Hazin *et al.* (1994; 2000), Castro and Mejuto (1995), Legat *et al.* (2000) and Legat and Vooren (2000), which present various scenarios of the blue shark stock structure and its reproductive cycle, Domingo *et al.* (2008) discuss the possible existence of two fishing management units in the South Atlantic Ocean: one in the equatorial area and another in the southwestern area, between 19° and 41°S latitude. These findings are supported by Amorim *et al.* (2020) who suggest that the entire reproductive cycle of the species is developed in southeastern Brazil. On the other hand, although Teixeira (2011) found different haplotypic frequencies using nucleotide sequences of the mitochondrial DNA (D-loop) control region between the regions of the Brazilian coast, from the South to the Equator (2°-30°S), he identified moderate genetic population structuring, therefore it should be considered as one stock in fisheries management.

As part of a joint study by scientists from ICCAT and the Indian Ocean Tuna Commission (IOTC), Coelho *et al.* (2018) analysed information from several observer programmes and obtained distribution patterns for approximately 400 thousand blue sharks in the Atlantic Ocean in a size range of 36 to 394 cm FL. The smallest specimens tended to be caught in more temperate waters, while larger specimens were more frequently caught in tropical waters, particularly between West Africa and the Caribbean Sea. With regard to distribution by sex for the analysed data (a total of 353 thousand individuals), the authors observed a ratio of 1.14 males for each female. More immature blue sharks were caught, including young born that year (0 years) and the smallest individuals (1 year), in the Northeast (Bay of Biscay), central East (Azores) and Southwest (south of Brazil and Uruguay) Atlantic, while adults were more abundant in the equatorial eastern and tropical regions, in the Gulf of Guinea and closer to the Cabo Verde archipelago.

In addition to these stock structure approaches, there is also the possibility of connectivity between the Indian Ocean and the Atlantic around the coast of South Africa. This connectivity has been observed in several species, and there are records of catches in the Atlantic, in the eastern area as well as the western area, of blue sharks tagged in the Indian Ocean (Matsunaga-Nakano, 2009; unpublished DINARA data).

### **5.b. Description of fisheries: catches and effort**

Pelagic sharks form an important part of the bycatch of the longline fisheries that target tuna, billfish and swordfish. The blue shark are caught by various gears in the Atlantic Ocean, Gulf of Mexico, the Caribbean Sea and the Mediterranean Sea including longline, gillnet, handline, rod and reel, trawl, purse seine, troll, and harpoon, but they are mostly caught as bycatch in the pelagic longline fisheries or as target species. The blue shark is the most frequently caught elasmobranch species in pelagic surface longline fisheries, and can account for more than 50% of total fish catch and from 85 to 90% of total elasmobranch catch (Lordan and Clarck, 1998; Coelho *et al.*, 2013). The blue shark is the most commonly caught pelagic shark, with annual landings worldwide estimated at 109,000 t in 2019 (FAO, 2021), figures that are underestimated. Detailed catches of this species have been recorded in the ICCAT database since 1997. Reports are scarce prior to this date (Anon, 2016).

Although longline fishing was developed since the second half of the 20th century, some coastal countries on the Atlantic Ocean and Mediterranean Sea already had fisheries targeting tuna and tuna-like species. The United States fished tuna using longline in the 1940s and Spain had coastal longline fisheries in the 15th century. Longlines called *marrajeras* have been used in part of the Iberian Peninsula (Mediterranean and Atlantic Ocean) since the 19th century. They designated boats fishing shortfin mako (*Isurus oxyrinchus*) (Domingo *et al.*, 2014).

Deep-set longline began to develop in 1955 with the first trips made by Japanese boats that investigated and explored tuna resources. However, it was from 1957 onwards that the fleet's activity started to increase strongly, mainly operating in areas of the tropical Atlantic (Domingo *et al.*, 2014). In the 1960s, other nations such as Spain, the USA, Canada and the Faroe Islands used longline gear to fish tuna, swordfish and sharks, taking blue sharks as bycatch. New exploitation patterns have arisen in the past 20 years in response to the reduction of international tuna and swordfish quotas. In particular, effort has turned to blue shark both for meat and the fin trade. Shark meat markets have developed particularly strongly in Europe and certain poor countries (Aires da Silva *et al.*, 2008a; Bornatowski *et al.*, 2018).

In the North Atlantic, 13 fisheries (EU-Spain, EU-Portugal, Japan, Canada, United States-longline, Chinese Taipei, EU-France, Belize, Panama, United States-purse-seine, China (P.R), Korea (Rep.) and Venezuela) made 99% of the total landings between 1990 and 2014. The majority (except for US sport fishery, EU-France unclassified gear) are purse seine fisheries. In the South Atlantic, nine longline fisheries (EU-Spain, EU-Portugal, Chinese Taipei, Namibia, Brazil, Japan, Uruguay, China (P.R.) and South Africa) made 99% of the total landings between 1990 and 2014 (Anon., 2016a).

There are several reasons why fleets have increased their effort and catch of blue shark, from an increase in the value of this product and catch limitations on other pelagic species to the abundance of this resource in certain areas at certain times (Bornatowski *et al.*, 2018).

The Spanish surface longline fishery targeting swordfish has been operating in the Mediterranean and Atlantic Ocean for centuries. Blue shark was the most significant shark species taken as incidental catch in the North Atlantic. On average, this species accounted for 87% of combined pelagic shark landings made by the Spanish surface longline fleet operating in Atlantic regions combined between 1997 and 2006. This proportion could be slightly higher in recent years following the implementation of several regulations regarding other shark species (García-Cortes *et al.*, 2016). Spanish longliners operating in coastal waters make trips lasting one to two weeks and mainly target blue shark (Biton Porsmoguer, 2015). Other fleets in the North Atlantic, such as the Canadian fleet, discard large numbers of blue shark taken as bycatch (Fowler and Campana, 2009; Campana *et al.*, 2015).

The Chinese Taipei longline fishery has been operating in the Atlantic Ocean since the late 1960s. However, incidental catch of sharks taken by Chinese Taipei tuna longliners was not reported until 1981 due to the species' low value compared to tunas. From 1981 to 2002, only a single "shark" category was recorded in the logbook. The "shark" logbook category was split into four subcategories, one of them being blue shark, which is the main shark species taken as incidental catch by the Chinese Taipei longline fishery (Wen-Pei and Liu, 2015).

In Venezuelan industrial longline fisheries targeting tunas and swordfish, blue shark is the main species taken as bycatch (Arocha *et al.*, 2005).

Although longliners on the Southeast and South coast of Brazil mainly target swordfish (*Xiphias gladius*), the blue shark has also become a target species for longliners due to growing demand for its meat and fins. Many of these sharks are juveniles, with individuals of under 150 cm accounting for the majority of catches (Pol-Mayer and Andrade, 2005; Quaggio *et al.*, 2008).

In addition to industrial and artisanal fisheries, the blue shark is also caught by recreational fisheries in several areas of the Atlantic Ocean and Mediterranean Sea. Some of the main countries where these can be found are Canada, the United States, Ireland, Mexico and the United Kingdom (Anon., 2005). Blue shark is one of the largest marine sport fishes in Ireland and it is considered one of the most valued species caught by angling (Green *et al.*, 2009). In 1952, a sport shark fishery was established in Cornwall. The main species caught was the blue shark. The fishery caught a total of 53,780 blue sharks from 1958 to 1972 (Vas, 1990). Recreational fisheries targeting blue sharks in the English Channel are open from June to September and catch between 200 and 600 individuals per year (Mitchel *et al.*, 2014).

The last exhaustive review of blue shark catches took place as part of the blue shark data preparatory meeting in 2015 (Anon., 2016a). Catches in the ICCAT Convention area in 2018 ascended to 68,220 t (**Figure 4**). Non-retained blue shark catches could reach up to 15% of total catches in some cases (Mas *et al.*, 2016). Even though a large number or the majority of these specimens are released alive, there are no clear discard survival estimates. Despite this, it is believed that most individuals survive (ICES, 2017). For example, the discard survival rate is estimated to be approximately 60% in longline fisheries and 80% in rod and reel fisheries (Campana *et al.*, 2005).

Catches in the Mediterranean are mainly taken in longline fisheries targeting swordfish and are more abundant in the western region, Alborán Sea and Northeast region (Valeiras and De la Serna, 2003; Damalas and Megalofonou, 2010). Blue shark accounts for approximately 90% of total shark catch in these fisheries (De la Serna *et al.*, 2002) and, in general, all specimens are retained as there is market demand (Megalofonou *et al.*, 2005).

### 5.c. State of the stocks

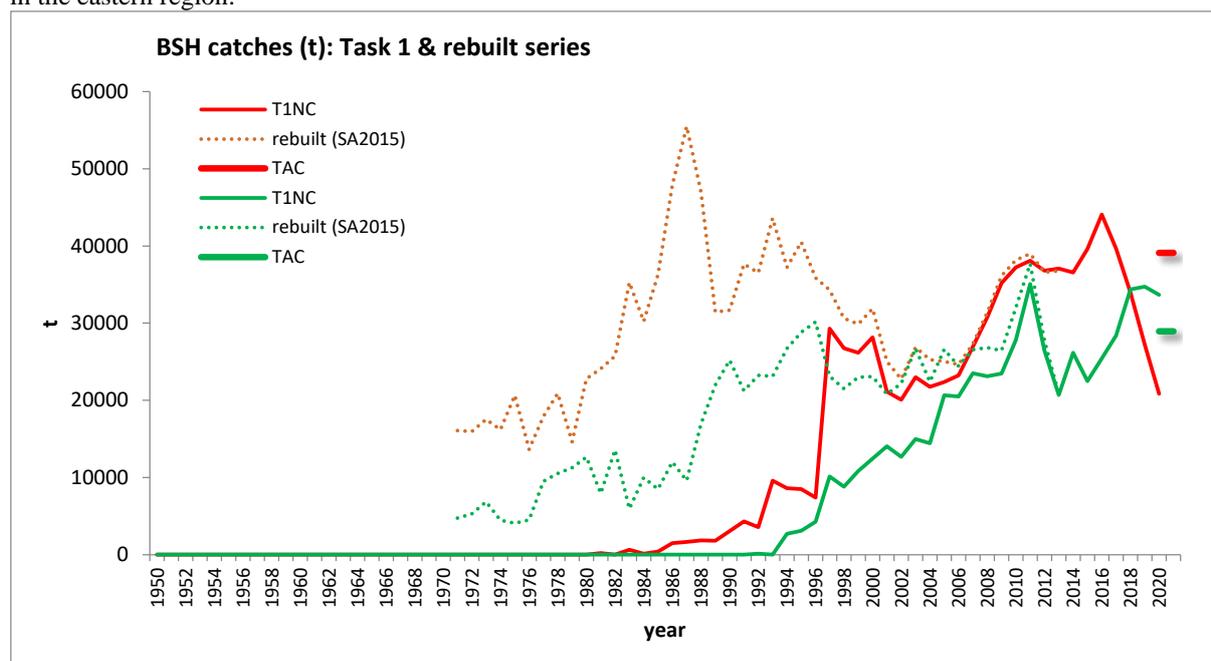
As a consequence of the historically low economic value of shark products compared to other fish, for many years investigation and conservation related to sharks were given much less priority than other fish species that traditionally had a higher value (Carvalho *et al.*, 2010).

The last stock assessment of blue sharks in the Atlantic was carried out by ICCAT in 2015 (Anon., 2016a). In the last assessment, considerable progress was made in data integration and modelling approaches. Uncertainty in data inputs and model configuration were worked on through sensitivity analysis. Despite this general progress, the results of the assessment must be interpreted with caution.

For the North Atlantic stock, scenarios with the Bayesian surplus production (BSP) model estimated that the stock was not overfished ( $B_{2013}/B_{RMS}=1.50$  to 1.96) and that overfishing was not occurring ( $F_{2013}/F_{RMS}=0.04$  to 0.50). Estimates obtained with the Stock Synthesis (SS3) model varied more widely, but still predicted that the stock was not overfished ( $SSF_{2013}/SSF_{RMS}=1.35$  to 3.45) and that overfishing was not occurring ( $F_{2013}/F_{RMS}=0.15$  to 0.75). For the South Atlantic stock, scenarios with the BSP estimated that the stock was not overfished ( $B_{2013}/B_{RMS}=1.96$  to 2.03) and that overfishing was not occurring ( $F_{2013}/F_{RMS}=0.01$  to 0.11) (Anon., 2016a). The high uncertainty in past catch estimates and deficiency of some important biological parameters, particularly for the South Atlantic, were identified as obstacles for obtaining more reliable estimates of the state of stocks (Anon., 2016b).

Ecological Risk Assessments were carried out for pelagic sharks in the Atlantic Ocean in 2008 and 2012, and showed that the blue shark had an intermediate level of vulnerability, characterised for being the most productive pelagic shark species and highly susceptible to longline fisheries (Cortés *et al.*, 2010, 2015).

ICCAT has not performed any assessment in the Mediterranean. The only study carried out are the IUCN risk assessments. Although this species is mainly taken as bycatch, it has accounted for 20% of swordfish surface longline fleet's landings in some years. In addition, some Spanish artisanal fleets target blue shark, mainly the Andalusian and, to a lesser extent, the Catalanian fleets (Biton-Porsmoguer and Lloret, 2017). Catches of this species are higher in the western Mediterranean, probably due to the species' greater abundance in this area than in the eastern region.



**Figure 5.** Nominal catch of blue shark in the Atlantic Ocean reported to ICCAT (t).

### ***Relationship with the environment***

It should be noted that the modern structure of the elasmobranch taxon in oceanic waters was established very recently. The blue shark took on a dominant position just a few hundred years ago. In the past, millions of years back, it occupied a subordinate position and shortfin mako (*Isurus oxyrinchus*) was the dominant species. This change in dominant species was sudden and quick, and the moment of the event can be calculated based on the density of tooth fossils on the ocean floor and tooth replacement rate. Therefore, the structure of the oceanic system is highly fragile and the balance can be easily disrupted (Litvinov, 2004).

As a top predator and an oceanic, highly migratory species, the blue shark can be used as an environmental indicator given that several chemical pollutants from the persistent organic pollutants (POP) family can be detected in individuals, including polychlorinated compounds, perfluorinated compounds and various trace and heavy metals (Storelli *et al.*, 2011). One of the most widely studied and regulated of these pollutants is mercury deposited in the sea, mainly coming from the energy industry, coal and waste incineration, as well as from mining. Its transport capacity means that it can be found very far from the area where it was produced. Once deposited in water, bacteria can convert mercury (Hg) into methylmercury (CH<sub>3</sub>Hg), which poses an even greater risk as it can be absorbed through membranes in this state and accumulate in tissues. This causes biomagnification of Hg throughout the trophic chain, which leads to significant levels of mercury in the muscle tissue of some top predators, such as blue shark, and increases with the size and weight of individuals (Gustinelli *et al.*, 2014; Alves *et al.*, 2016; Biton-Porsmoguer *et al.*, 2018). Pelagic sharks are generally the main predators exposed to the accumulative effects of metallic oligoelements (Biton-Porsmoguer, 2015).

High lead concentrations have also been found in blue shark, which means that, in some cases, its consumption could pose a risk to human health (López *et al.*, 2013).

Plastic waste affects marine species to varying degrees. Plastic waste from fishing activity, such as gear parts or bait packaging, are a potential cause of mortality (Colmenero *et al.*, 2017). In the North Atlantic, 0.21% of blue sharks contained plastic waste (Mucientes and Queiroz, 2019).

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