Black scabbardfish (Aphanopus carbo) in subareas 1, 2, 4–8, 10, and 14, and divisions 3.a, 9.a, and 12.b (Northeast Atlantic and Arctic Ocean)

Stock specific documentation of standard assessment procedures used by ICES.

Stock:	bsf_nea
Working Group:	Working Group on Biology and Assessment of Deep-sea Fisheries Resources (WGDEEP)
Created:	February of 2014 (partially revised in 2019)
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Last updated:	April 2020
Last updated by:	WGDEEP 2020

A. General

A.1. Distribution

Black scabbardfish *Aphanopus carbo* Lowe, 1839 is a widely distributed species. In the North Atlantic, the species occurs between 30ᵒN and 70ᵒN, from the strait of Denmark to Western Sahara, with greatest abundance to the South of the Faroe Islands, in the Rockall Trough, to the west of mainland Portugal, and around Madeira and the Canary archipelagos. It occurs only sporadically north of the Scotland-Iceland-Greenland ridges.

Black scabbardfish is a bathypelagic species which can be found at depths from 200 m, in the northern section of the NE Atlantic (Nakamura and Parin, 1993; Kelly *et al*., 1998), to 2300 m around the Canary Islands (Pajuelo *et al*., 2008). Despite this wide bathymetric range, it is more frequent between 800 and 1800 m in mainland Portugal (Martins *et al*., 1987), 800 and 1300 m in Madeira (Morales-Nin and Sena-Carvalho, 1996), and 400 and 1400 m of the West of the British Isles (Ehrich, 1983; Allain *et al*., 2003).

A.2. Species dynamics

Mean length and maximum length of black scabbardfish caught west of the British Isles are smaller than those caught off mainland Portugal, which in turn are smaller than those caught in Madeira. Mature or spawning individuals have never been recorded west of the British Isles or Mainland Portugal and the only known spawning locations are around Madeira, the Canary Islands the NW coast of Africa (Figueiredo *et al*., 2003; Pajuelo *et al*., 2008; Perera, 2008; Neves *et al*., 2009). Evidence from otolith microchemistry and stable isotope analysis are consistent with the fish caught west of the British Isles and Portugal having been spawned at latitudes similar to Madeira.

This leads to the hypothesis of migratory behaviour mostly driven by feeding and reproduction processes (Zilanov and Shepel, 1975; Anon, 2000; Figueiredo *et al*., 2003). According to this, spawning apparently occurs around Madeira, the Canary Islands and possibly in a few other southern areas, such as the NW coast of Africa (Figueiredo *et al*., 2003; Pajuelo *et al*., 2008; Perera, 2008; Neves *et al*., 2009). Juveniles migrate from those areas to the northernmost ones, namely Iceland, the Faroes Islands, and the west

of the British Isles, where small fish of about two years old have been caught by fisheries or by surveys. This northward migration also includes non-recruited stages up to a length of 70 cm. After having grown in northern areas for a few years, fish move southwards, namely to mainland Portugal (International Council for the Exploration of the Seas Division IXa) where they remain a few years before migrating further south to the spawning areas.

A.3. Stock definition

Although the stock structure is uncertain, in the absence of clear scientific evidence to suggest structuring it is hypothesised that a single stock exists in the NE Atlantic. Results from several studies are in agreement with this hypothesis. However, due to the differing nature of fisheries in the northern and southern areas, ICES has historically given separate advice for three assessment units. These assessment units are generally consistent with the management units used by the EU:

i) Northern (Divisions Vb and XIIb and Subareas VI and VII);

ii) Southern (Subareas VIII and IX);

iii) Other areas (Divisions IIIa and Va Subareas I, II, IV, X, and XIV).

These management units reflect the main fisheries to which the species is subjected. The Northern component comprises fish exploited mainly by trawl fisheries while the southern component by a longline fishery. In other areas the species is exploited by both longliners and trawlers, but the overall landings are very small compared with the other two management units.

In 2012, ICES Stock Identification Methods Working Group (SIMWG) recommended that the management units of Northern and Southern divisions may need revision and should be considered as one assessment unit (ICES, 2012). Consequently, a single assessment unit is now considered for this stock.

A.4. Fisheries

i) Northern (Divisions Vb and XIIb and Subareas VI and VII);

The Faroese fisheries take mostly place in Subarea Vb with minor activity in Subarea VI. The Faroese deep-sea trawl fishery started in the late 1970s as a mixed redfish, blue ling, grenadier and black scabbardfish fishery; a more directed black scabbard fishery began in the late 1980s (1988) as a result of improvements of the gear and handling of the fish. From 1993 onwards some of the otter board trawlers have targeted black scabbardfish either seasonally or throughout the year. The main fishing grounds for the species are located in the bank area southwest of the Faroes Islands. The fleet of otter board trawlers (the so called deep-sea trawlers) consist of 13 vessels >1000 HP, but only 1–3 trawlers >2000 HP are targeting black scabbardfish. Landings are mostly derived from Division Vb and the values (about 1400 t) were registered in 2001 and 2002.

In ICES Subarea VI a Scottish mixed deep-water trawl fishery included some catches of black scabbard fish since 1995. This fishery has decreased to low levels since the introduction of TACs in 2003.

Following the decline of target orange roughy Irish trawl fishery, landings of black scabbardfish derived from ICES Subareas VI and VII reached about 1000 t in 2002. In the recent years (since 2008) Irish landings have been zero.

The French deep-water fishery operates mainly in Subareas VI and VII targeting roundnose grenadier, black scabbardfish, and blue ling. Over recent years, the landings of black scabbardfish have declined but to a lesser extent than landings of other deep-water species (roundnose grenadier, blue ling, orange roughy and deep-water sharks).

The Spanish fishery in Hatton Bank started in 1996, triggered by the decline in catches in traditional fishing grounds. Durán Muñoz and Román Marcote (2001) described the beginning of this fishery and the fleet operating in Hatton. A total of 48 vessels have logged in fishing days at Hatton for the period 2002–2009, but the maximum number of vessels in the fishing grounds in any given month is 16. Most often, and on average, vessels stayed in Division VIb less than two weeks per month, but stayed in Division XII between three and four weeks.

Total landings from the ICES Subareas Vb and Divisions VI, VII and XII show a markedly increasing trend from 1999 to 2002 followed by a decreasing trend till 2005. There was a peak in 2006 and then there was a decrease mainly due continuous decreases of landings from ICES Divisions VI and VII.

i)   Southern (Subareas VIII and IX);

In Subarea IXa the main fishery taking place is derived from the Portuguese longliners. In the early 1980s, an artisanal longline fishery targeting this species initiated in Portuguese continental waters. The fishery takes place at grounds around Sesimbra (south of Lisboa, Latitude 38°20' N), following a series of exploratory surveys conducted by the Portuguese Institute of the Sea and Atmosphere (former IPIMAR) in close collaboration with professionals from the fisheries sector some of them from Madeira. These surveys were oriented towards the search for new fishing grounds for the species, the environmental characterization of the ocean layer where black scabbardfish occurs, the experimentation of longline fishing gears and preliminary studies on the biology of the species. Fishermen from Madeira with extensive experience in deep-sea longline fishing have greatly contributed.

The fishing method and gear used by the black scabbardfish longline fleet were developed soon after the initial fishing trials off the Sesimbra coast by fishermen from Madeira. Gear design has been modified from the one initially used (similar to the Madeira traditional longline fishing gears) to catch the species in continental waters with a different configuration; setting horizontal bottom longline, where alternating floats and sinkers occur at constant intervals on the main line. This rearrangement aims to match the intricate vertical distribution exhibited by the species in the slopes and to prevent gear loss on the hard grounds (Henriques, 1997).

At the beginning of the fishery, the fleet was composed of small artisanal vessels with an average LOA around 11 m and an average tonnage of ca. 16 GRT. In 1988, there was a slight increase in both size and engine's power of vessels. However, from 1992 to 1995, average LOA and engine's power characteristics registered the highest raise in relation to 1988; about 30%. In 2000, the fleet again underwent technological improvements, including an increase in engine power, tonnage and average LOA average. Such improvements were experienced by a limited number of vessels (4), which is reflected by the increase in standard deviation estimates.

The number of vessels in the fleet registered its highest value in 1986, but decreased from 1995 to 2004, when the fleet presented the same number of vessels exhibited twenty years before. In the period 1995–2004, the number of new vessels that entered the fleet attained its maximum in 1997 before an equal number of vessels left the fleet

in 1998. During the same period, the number of vessels that remained in the fleet has decreased from 17 to 14.

Fishing operations usually start at dusk following a well-defined pattern: vessels leave the port early in the night, carrying a previously equipped longline gear, and navigate offshore for a period that varies between one to almost six hours (depending on the vessel and location of the fishing ground). When the vessel is at the fishing ground, two fishing operations generally occur: 1) the longline gear is deployed into the sea and set, 2) another longline gear previously set in the last 24–48 hours (average around 38 hours) is recovered with the aid of a hauling winch installed on board. The occasional presence of cetaceans, whose species and numbers are still to be confirmed, can result in a great economic loss for the fishermen as these marine mammals are attracted by the catch when it reaches the surface and feed on the fish captured.

In 1800s, the fleet was composed by about 30 small artisanal vessels (<6 m length) with low engine power. The number of vessels dedicated to this fishery peaked in 1988 with a total of 95 vessels. After that period the fleet suffer a considerable reduction, mainly between 1990 and 1995, when the number of vessels dropped from 84 to 44 (Bordalo-Machado *et al.*, 2009). Between 1998 and 2000, the fleet comprised ca. 40 vessels (on average 13 m LOA, 19 GT and 150 Hp) (Reis *et al.*, 2001). Fleet size continued to decrease to around 15 vessels in the most recent years (2009–2010), with no significant changes in their technical characteristics. Landings of black scabbardfish reached a peak of 4.2 thousand tonnes in 1998 and have been steadily declining since then to 1.7 thousand tonnes in 2012.

The number of fleet vessels registered its highest value in 1986, but decreased from 1995 to 2004, when the fleet presented the same number of vessels exhibited twenty years before. In the period 1995 – 2004, the number of new vessels that entered the fleet attained its maximum in 1997 before an equal number of vessels left the fleet in 1998. During the same period, the number of vessels that remained in the fleet has decreased from 17 to 14.

The number of hooks by fishing gear varied since the beginning of the fishery till present days. In the first years of the fishery, gears used 3600 to 4000 hooks (Martins, et al., 1989), while, in 1996, its number ranged from 4800 to 5400 (Henriques, 1997). More recently in 2004, the number of hooks by gear varied between 4000 and 10000. The No. 5 Hook has been commonly used in fishing gears since the beginning of the fishery. The most common bait of the gear is sardine (*Sardina pilchardus*), however, chub mackerel (*Scomber japonicus*) can also be used when sardine is less available or its market price increases. The process of gear preparation, including disentangling, baiting and coiling of the main line into the tubs is carried out ashore by people hired for these tasks and by crewmen when they are not at sea (Henriques, 1997). All the work is performed by hand and is very intensive and laboriously.

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Fishing takes place on hard bottoms along the slopes of canyons at depths normally ranging from 800 to 1200 m and may attain 1450 m.

The French bottom-trawlers operating in Subareas mainly VI and VII have a small marginal activity in Subarea VIII.

i)   Other areas (Divisions IIIa and Va Subareas I, II, IV, X, and XIV).

In ICES Division IXa2 (Azorean EEZ), black scabbardfish fisheries have received sporadic experimental activity despite previous indications that a potential for a fishery exists (Vinnichenko, 1998; Hareide and Garnes, 2001). The absence of a local market and the complexity of the gear and labour requirements for its operation have thus far limited the development of the fishery. Two species of Trichiuridae occur in the Azores, *Aphanopus. carbo* and *Aphanopus intermedius.* Landings in Subarea X may contain a mixture of these two species.

A Faroese exploratory trawl fishery took place in 2008 in the Mid-Atlantic Ridge area. This fishery was mainly targeting at orange roughy and black scabbard fish, and was undertaken in the period 13 February to 9 March 2008 in ICES Areas X and XII according to a resolution adopted at the 26th Annual Meeting of NEAFC on management measures for orange roughy. The fishery was performed by one trawler (M/S Ran TG0752) which had many years participation in the Faroese orange roughy fishery. The gear used was a bottom trawl. Locations of catches of black scabbardfish are shown in Figure 1.
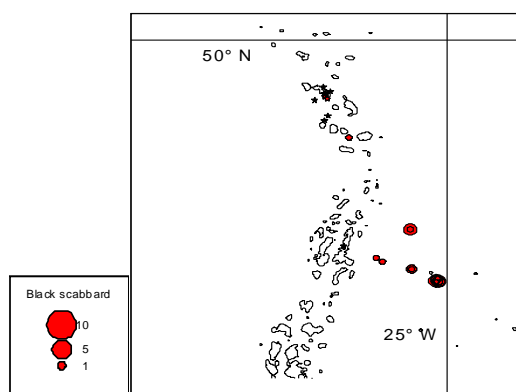

Figure 1. Faroese exploratory survey total catches of black scabbardfish (tonnes).

Outside the ICES area, black scabbardfish is being exploited in Madeira and the Canaries. In Madeira, the drifting deep-water longline targeting black scabbardfish is the main fishery activity. It probably started in the early 1800s when local fisherman were targeting "oil fish". This fishery was kept almost unaltered for over one century, when in 1982 hemp was replaced by monofilament drifting longline and the number of hooks per line increased (Martins and Ferreira, 1995). This change in fishing gear, along with better equipped boats that helped local fisherman searching for new fishing grounds such as seamounts, significantly improving their yields (Martins and Ferreira, 1995). The fleet now exploits new areas, especially located SE of Madeira, as far as 150–200 nautical miles from the fishing port. The fishery is mostly developed inside the Madeira Exclusive Economic Zone, included in the CECAF 34.1.2 area, all year round. Sporadically fishing sets are made, by the vessels with higher autonomy in the vicinity of the Madeira EEZ.

A.5. Ecosystem aspects

i)   Northern (Divisions Vb and XIIb and Subareas VI and VII);

A large proportion of deep-water trawl catches (upwards of 50%) can consist of unpalatable species and numerous small species, including juveniles of the target species, which are usually discarded (Allain *et al*., 2003). Baird's smoothhead (*Alepocephalus bairdii*) is the main discarded species of the trawl fishery but a large number of other non-marketable bentho-pelagic species are also discarded. The survival of these discards although unknown, it is believed to be virtually zero because of fragility of these species and the effects of pressure changes during retrieval (Gordon, 2001). Therefore such fisheries have the potential to deplete the whole fish community biomass. A study of the impacts of deep-water fishing to the west of Britain using historical survey data found some evidence of changes in size spectra and a decline in species diversity between pre- and post-exploitation data, but the scarce and unbalanced nature of the time-series hampered firm conclusions (Basson *et al*., 2001).

Catch, bycatch and discards of sharks in deep-sea fisheries have been an issue of concern (Stevens *et al*., 2000). Deep-sea sharks are frequent bycatch of black scabbardfish longline and trawl fisheries (Clarke *et al*., 2005; Bordalo-Machado, 2009; Muñoz *et al*., 2011; Piñeiro *et al*., 2001) and their commercial exploitation has recently increased. It is recognized that trawls and longlines catch varied quantities of different deep-sea shark species and size frequencies in different locations (Clarke *et al*., 2005; Coelho *et al*., 2003). However, the global magnitude of the problem is still unknown. It has been recognized that the bycatch of deep-sea sharks in trawls is lower than for longlines in many locations (Piñeiro *et al.,* 2001; Hareide & Garnes 2001; Clarke *et al.,* 2005) but post catch survival is likely to be higher in longlining (Coelho and Erzini, 2008). Some solutions may exist to reduce deep-sea shark bycatch in longlines such as increasing the distance of the hooks from the seabed (Coelho *et al*., 2003) or use artificial baits; but still need to be tested.

The effects of fishing on the benthic habitat relates to the physical disturbance by the gear used. This includes the removal of physical features, reduction in complexity of habitat structure and resuspension of sediment. More attention has been paid to biogenic habitat that occurs along the slope, mainly the cold-water coral. The main reef building species is *L. pertusa*. Any long-lived sessile organisms that stand proud of the seabed will be highly vulnerable to destruction by towed demersal fishing gear. There are a number of documented reports of damage to Lophelia reefs in various parts of the Northeast Atlantic by trawl gear where trawl scars and coral rubble have been observed (e.g. Hall- Spencer, *et al.,* 2002). Damage can also be caused on a smaller scale by static gears such as gillnets and longlines (Grehan *et al*., 2003).

In Divisions VI, VII and XIIb there are a number of known areas of cold-water corals. These include the shelf break to the west and north of Scotland, Rockall Bank, Hatton Bank and the Porcupine Bank. The best known site is the Darwin Mounds, located at 1000 m to the south of the Wyville Thompson Ridge. Some of these areas have been heavily impacted by deep-water trawling activities in the past (Hall-Spencer, 2002; Grehan *et al*., 2003) but all are now closed to bottom contacting fishing gears.

i)   Southern (Subareas VIII and IX);

The Bay of Biscay and Iberian Coast region is situated in temperate latitudes with a climate that is strongly influenced by the inflow of oceanic water from the Atlantic Ocean and by the large scale westerly air circulation which frequently contains low pressure system. The bottom topography of region is highly variable, from

continental shelf to abyssal plain. Some remarkable topographic features such as seamounts, banks and submarine canyons can be found. The coastline is also highly diversified with estuaries, rias and wetlands, which all support extremely productive ecosystems.

In Subarea VIII there are historic records of impacts on deep‐water ecosystems, in particular corals (Joubin, 1922).

In Division IXa some sporadic information available suggests the existence of coral and sponges. The topography of the region reveals the existence of seamount and canyons usually considered as VME´s

B. Data

B.1. Commercial catch

i)   Northern (Divisions Vb and XIIb and Subareas VI and VII);

In ICES Divisions VIb1 and XIIb the landings from Spanish trawling fleet operating on the Northern and Western Hatton Bank are available since 2004.

Landings from other fleets in the northern area are available from 1989 onwards, which is believed to correspond to the entire history of the fisheries.

i)   Southern (Subareas VIII and IX);

Landing data from Subareas VIII and IX are available to WGDEEP. Almost all landing are derived from the Portuguese longline fishery that takes place in Subarea IXa. Data are available from 1989 which is believed to correspond to the entire history of the fishery.

Data are not currently available for fisheries outside the ICES area including Madeira and the Canaries.

DISCARDS

i)   Northern (Divisions Vb and XIIb and Subareas VI and VII);

Discard data from Spanish bottom otter trawl métiers operating Hatton Bank (ICES Divisions VIb1 and XIIb) are available from the `Spanish observer Programme' carried out by the IEO since 1996. Trip was the sampling unit, being raised to fleet level using fishing effort as auxiliary variable.

Discarding information from the French fisheries west of the British Isles is collected by French observers. Discards of this species are very low comprising only individuals that are damaged.

i)   Southern (Subareas VIII and IX);

The artisanal segment of the commercial fishing fleet of mainland Portugal is responsible for the largest landings' quantities of deep-water species. The onboard discard sampling for longline Portuguese commercial fleet started in mid 2005 and is integrated in the Portuguese Discard Sampling programme, included in the EU DCR/NP. Onboard sampling in longline commercial vessels is carried out in a monthly basis to get discards and trip information.

B.2. Biological

Since 2003, French length data of back scabbardfish by depth are available based on data from on-board observations of French trawlers.

Length on data from Soviet exploratory fishing surveys at late 1970s at Lauzy Bank, Anthon-Dorn Bank and Anthon-Dorn Bank and the Hatton-Rockall Plateau showed that the size range of the species (70–130 cm with higher frequencies at lengths varying between 96–110 cm) do not greatly differ among areas (Vinnichenko *et al.*, 2003).

In Division IXa length frequency and biological samples from Portuguese landing port at Sesimbra have been collected on a monthly basis since 2000.

LHC	BEST ESTIMATE	DERIVED FROM	OTHER ESTIMATES
Maximum observed length	1510 mm	Figueiredo *et al.,* 2003	
Fecundity, egg size etc	73-373 oocytes g^{-1} female (Madeira). Vitellogenic oocytes ranged from 0.60 to 1.50 mm.	Neves *et al.,* (2009)	

Ageing - Studies on age and growth on age and growth of the black scabbardfish have been carried out at different areas (Table 3).

Table 3. Von Bertalanffy growth parameter estimates from different studies carried out in the NE Atlantic, including otolith age reading method and clearing solution. F: female, M: male, SD: standard deviation.

Area	Method	Clearing	Sex	N	Total length range (cm)	Age range (year)	$L_{inf} \pm SD$ (cm)	k (year^{-1})	t_0 (year)	Source
W. British Isles	Thin sections in epoxy resin	Alcohol	both	230	75–120	4–32	*NA*	0.1	*NA*	Kelly et al. 1998
Mainland Portugal	Thin sections in epoxy resin	1:1 glycerin-alcohol	F	248	64–131	5–13	135 ± 4	0.2	−2.0	Vieira et al. 2009
			M	206		4–10	124 ± 3	0.2	−1.7	
Madeira	Surface	Glycerol	F	334	58–151	0–8	142	0.3	−2.1	Morales-Nin and Sena-Carvalho 1996
			M	357	58–132		155	0.2	−3.3	
			both	649	58–151		139	0.3	−2.3	
	Thin sections in epoxy resin	1:1 glycerin-alcohol	F	200	125–148	8–15	159 ± 4	0.1	−2.3	Vieira et al. 2009
			M	163		8–14	146 ± 1	0.1	−1.4	
	Surface	1:1 glycerin-alcohol	F	554	100–140	6–14	136 ± 5	0.2	−4.2	Delgado et al. 2013
			M				132 ± 5	0.2	−3.1	
Canary Islands	Surface, burned	50% glycerol	F	196	100–148	2–12	149 ± 2	0.2	−4.7	Pajuelo et al. 2008
			M	102	104–134	2–8	141 ± 4	0.3	−3.5	
			both	298	100–148	2–12	148 ± 2	0.2	−4.6	

NA: not available.

The maximum age estimated by Morales-Nin and Sena-Carvalho (1996) corresponded to a male of 130 cm and a female of 150 cm total length. These ages were probably underestimated because, when using whole otoliths in larger specimens from this species, the growth increments closer to the border are very difficult to identify (Vieira *et al.*, 2009). On the contrary, the maximum age assigned by Kelly *et al.*, (1998) using thin otolith sections was most likely overestimated since, with this preparation technique, the number of visible rings is very high and the authors reported problems

in their interpretation. Regarding age estimations in Madeira and the Canary Islands in studies prior to 2008, when caught specimens started being routinely separated by species, the possible mixing of black scabbardfish and intermediate scabbardfish (*A. intermedius*) specimens could also explain the differences found between regions and should be taken into consideration (Farias *et al.*, 2013).

Excluding Kelly *et al.*, (1998) the growth parameters estimated based on the von Bertalanffy growth equation showed a relatively rapid growth rate for the black scabbardfish (Table 3). The low estimate of growth rate obtained by Kelly *et al.*, (1998) for the west of the British Isles is not in agreement with the predominance of young immature specimens in this area, commonly characterized by high growth rates.

Ribeiro Santos (2013) compared two alternative methods for the interpretation of growth increments in sectioned otoliths. The more conservative interpretation, which was preferred, gave ages in the range of 0 to 15 years and 0 to 13 years respectively, for females and males from the west of the British Isles. In Madeira, the age ranged between 8 and 19 for females and 6 and 24 years (only one fish over 18 years) for males. Growth parameters for the west of the British Isles were: males, L_{inf} = 117 (SE = 4), k = 0.238, t_0 = 3.65; female, L_{inf} = 140 (SE = 8), k = 0.248, t_0 = 3.65 and for Madeira: males L_{inf} = 124 (SE = 6), k = 0.131, t_0 = 3.35; female, L_{inf} = 149 (SE = 6), k = 0.081, t_0 = 3.35.

Females, particularly those from Madeiran waters, had a lower growth rate than those from Mainland (ICES Subarea IXa). This reduction in the growth rate seems to be related to the reproductive effort. The differential growth pattern between the females from mainland Portugal (non-reproductive females) and Madeira (reproductive females) may reflect the optimisation of the energetic balances (Vieira *et al.*, 2009).

Maturity - In ICES Subarea IXa only immature and early developing specimens have been observed (Figueiredo, 2009 WD). Mature individuals only occurred in Madeira (Figueiredo *et al.*, 2003) and, in Canary Islands (Pajuelo *et al.*, 2008) and the northwest coast of Africa although it is possible that two species may occur in these areas.

The black scabbardfish is an iteroparous species, since it can spawn multiple times throughout its life, and is also a total spawner, as it spawns in one single event (Pajuelo *et al.*, 2008; Ribeiro Santos *et al.*, 2013).

Mature and spawning adults have only been observed in the last quarter of the year in Madeira (Figueiredo *et al.*, 2003; Neves *et al.*, 2009; Ribeiro Santos *et al.*, 2013), the Canaries (Pajuelo *et al.*, 2008), and the northwest coast of Africa (Perera, 2008).

An increase in the relative weight of the liver just before the increase in weight of gonads in females was very conspicuous in Madeira, but it could also be perceived in mainland females. Such strategy is typical of thin fishes in which the majority of the energy necessary to maturity is stored in the liver and, after the maturation is reached, the HSI present a sharp decrease. In males, the HSI did not follow the same conspicuous pattern shown in females since the energy needed for their reproduction has lower energy costs than females'. The HSI revealed a correlation with GSI in females but not in males and no relation of the Fulton's condition factor with the reproduction in both sexes was perceived.

Length of first maturity - Estimated female length at first maturity (L50) was 103 cm around Madeira (Figueiredo *et al.*, 2003) and 114 cm around the Canary Islands (Pajuelo *et al.*, 2008). Once again, the possible mixture of black and intermediate scabbardfish specimens in the samples may have biased these results. In a more recent work, female L50 was estimated to be 111 cm for Madeira and 116 cm when also including specimens from the west of the British Isles (Ribeiro Santos *et al.*, 2013). The latter values are

probably overestimated because the estimation did not include specimens from Madeira smaller than 92 cm in total length (Farias *et al.,* 2013).

Fecundity - Black scabbardfish has a determinate fecundity strategy the relative fecundity estimates ranged from 73 to 373 oocytes/female weights (g). Skipped spawning was also considered to occur in this species; the percentages of non-reproductive females between 21% and 37% (Vieira *et al.,* 2009).

B.3. Surveys

Survey data on the species are available both from Scottish and Irish surveys. The former is conducted by the Marine Scotland - Science [formerly Fisheries Research Services, (FRS)] along the continental shelf/slope to the northwest of Scotland. The survey was initiated in 1996 with strictly comparable data available between 1998 and 2008. The core area is surveyed between 55–59°N, with trawling undertaken at depths ranging from 300 to 1900 m with most of the hauls being conducted at fixed stations, at depths of around 500 m, 1000 m, 1500 m and 1800 m. Further hauls have been made on seamounts in the area, and on the slope around Rockall Bank, but these are exploratory, irregular and not included in the survey dataset.

The Irish deep-water trawl survey sampled the fish community of the continental shelf slope to west and northwest of Ireland between 2006 and 2009. Sampling methodology and trawl gear were standardised in accordance with the Scottish deep-water survey with trawling at fixed stations around 500 m, 1000 m, 1500 m and 1800 m. This survey has been discontinued.

No fisheries-independent survey is available for the Portuguese mainland fishery.

B.4. Commercial cpue

An lpue dataseries for black scabbardfish is estimated for the French deep-water fleet based upon the French tallybooks (Pawlowski *et al.*, WD 2009). The tally book (from skipper own logbooks) database provided by the French industry (PROMA/PMA a producers organization and EURONOR a ship owner), has the advantage in relation to logbook of having the records on a haul by haul resolution and on having fishing depth available (Pawlowski *et al.*, WD 2009).

A GAM model is adjusted where landing is the response variable and fishing time, depth, month, vessel identity (vessel.id), rectangle, year and area are the explanatory variables:

log(E[landings]) = s(haul duration) + s(depth) + month + vessel.id + rectangle + year:area

where E[] denotes expected value, s() indicates a smooth nonlinear function (cubic regression spline). The haul duration is used as an explanatory variable to avoid non-proportional relationship between landings and fishing time.

The fit is done assuming a Tweedie distribution with a log-link function using the mgcv package in R (Wood, 2006; Lorance *et al.,* 2010). All hauls in areas edge6 and other6 in the depth range 500–1500 m of duration between 30 min and 5 h were selected. In the case, all fishing hauls in a given depth range can be selected as the depth factor and the rectangle factor implies that the targeting is handled (i.e. in given rectangle, fishing at a given depth implies fishing for one or some species). In the case of logbooks it was necessary to select fishing subtrips with a threshold proportion of black scabbardfish in the landings in order to exclude hauls targeting other (and possibly shelf) species.

Taking a 10% threshold implies that in a substrip where black scabbardfish is below this threshold most of the fishing effort of the subtrip (i.e. the majority of the hauls) was directed to other species or that black scabbardfish was a minor bycatch.

Unstandardized cpue series were determined for the Spanish trawlers operating Hatton Bank using the available data on annual catch and nominal effort (number fishing days). Figure 2 cpue estimates were presented for Subdivisions VIb1 and XIIb separately, as well as, for the two combined.
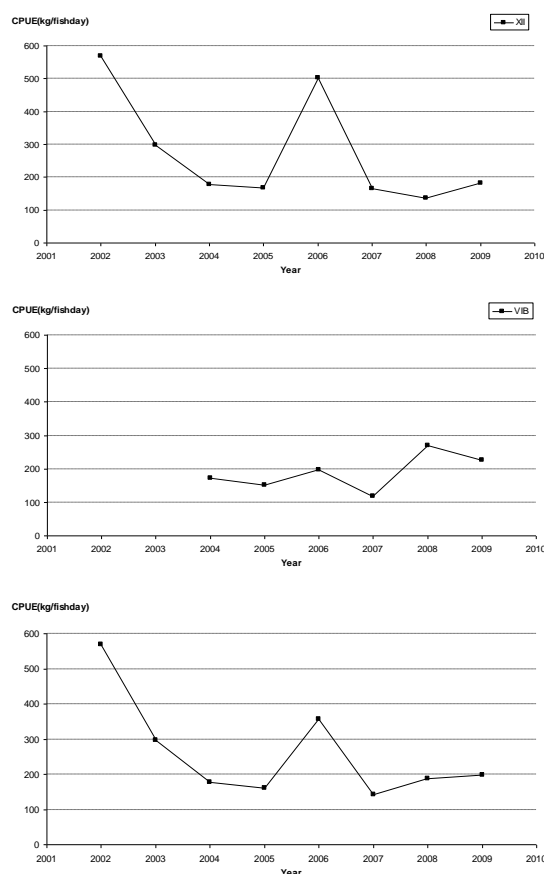

Figure 2. Black scabbard fish cpue (kg/fishing days) in VIb (upper left). XIb (upper right) and the two Subareas combined (center) from Spanish trawlers.

A LPUE dataseries for black scabbardfish is estimated for the Portuguese longline fishery operating in Portugal mainland (ICES Subarea IXa). The commercial daily landings from Portuguese longline vessels are used to derive black scabbardfish monthly LPUE values. Data has been provided by the Portuguese General Directorate of Fisheries and Aquaculture.

Monthly LPUE are calculated for each vessel as the *ratio* total landed weight (kg) / number of fishing trips. Only vessels having total monthly landings ≥ 1000 kg and a monthly number of fishing trips ≥ 5 were considered in the analysis.

Although there is no information on the number of hooks used per trip, it is known from interviews with the fishermen that each vessel uses the same number of hooks on each trip (Bordalo-Machado and Figueiredo, 2009). Hence, the effect of the number of hooks on the effort estimates is extracted from the model when we extract the effect of the vessel.

Standardized monthly LPUE is estimated based on the adjustment of GLM model. Factors considered are YEAR, MONTH and VESSEL and the model is expressed as:

$$g(LPUE_{ijkl}) = \alpha_i YEAR_i + \beta_j MONTH_j + \lambda_k VESSEL_k + \varepsilon_{ijkl,} \qquad (1)$$

where α_i (i = 1995,…, lastyear), β_j (j = 1,…,12) and λ_k (k = 1,…,33) are coefficients to be determined. The most appropriate distribution the expected or a function of the expected response variable is chosen among the exponential family group of distributions. The quality of the model adjustment is evaluated by quantile residuals analysis.

B.5. Other relevant data

Information from the fishery, particularly the abundance index, cpue, indicates the existence of a seasonal trend in abundance, both in BI and in P: lesser abundance is usually registered from March to August of any year (here referred as the 1st semester) and higher abundances are mostly registered from September to December of an year and January and February of the following year (here referred as the 2nd semester). These fluctuations in abundance are considered to be associated with the migratory processes and as a consequence, the time unit adopted to analyse the dynamics of the population is the semester defined as before and denoted by s.

C. Assessment: data and method

Data

The input data for the model are

- the number of specimens landed in each semester (defined as mentioned above) by the French trawlers and the Portuguese longliners partitioned into two length groups $70 \leq C2 < 103$ cm and $C3 \geq 103$ cm. The time-series covered is from 1999 to 2012;
- Standardized total fishing effort for each of the two fleet for the time period from 1999–2012.

The input data for the model are in turn dependent on data availability on:

- Length–frequency distributions from onboard observers from the French trawlers;
- Monthly landings of the Portuguese longline fishery by commercial longline category;
- Length–frequency distributions from landing sampling program;
- Weight–length relationship;
- Standardized cpue for each of the two fleets.

Model used

The model used consists of two state space models, one for part of the population in the BI and the other for part of the population in P. In both cases the state vectors are partitioned into four groups defined according to criteria to length size (C2 or C3) and the fishing status (fished, F, or not fished, $\overline{F}$).

In each semester s, the population abundance in BI and in P is given, respectively, by the state vectors $n_{BI;s}$ and $n_{P;s}$, with the following components

$$\boldsymbol{n}'_{BI,s} = \left(n_{BI,C2,s}(\overline{F}),\ n_{BI,C3,s}(\overline{F}),\ n_{BI,C2,s}(F),\ n_{BI,C3,s}(F) \right)$$

$$\boldsymbol{n}'_{P,s} = \left(n_{P,C2,s}(\overline{F}),\ n_{P,C3,s}(\overline{F}),\ n_{P,C2,s}(F),\ n_{P,C3,s}(F) \right),$$

where ($\overline{F}$) represents those components including only specimens that have survived fishing while (F) refers to those that were fished, $n_{BI;C2;s}$ and $n_{BI;C3;s}$ are the number of individuals belonging, respectively, to C2 and C3 inhabiting BI and $n_{P;C2;s}$ and $n_{P;C3;s}$ are the number of individuals be belonging, respectively, to C2 and C3 inhabiting P.

Two state-space models are considered, one for BI and one for P, these models run separately but not independently since the one for BI is linked to that of P through a migration subprocess.

In each model, the state process is subdivided into subprocesses which translate the main features of the species life cycle and migration pattern. The state process is assumed to be a first order Markov process. It is also assumed that all the individuals in the population act identically and independently (IID hypothesis) of each other and that the parameters of the distribution functions depending on the subprocesses remain constant over time.

The Markovian assumption assures that, at each time point s, the process is totally defined if the distribution of the process conditional on the process state in the previous time point is known, $\mathbf{n}_s \overset{d}{=} H_s[\mathbf{n}_{s-1}]$.

State space model for BI

The temporal evolution of the population in BI area is divided into four stochastic subprocesses:

M_s - Survival to natural mortality

T_s - Class transition

D_s - Displacement by migration - entrances and departures

F_s - Survival to fishing:

The model assumes that the subprocesses are discrete and succeed in time always in the same order, each of which depending exclusively on the subprocess that occurred immediately before

$$M_s \rightarrow T_s \rightarrow D_s \rightarrow F_s$$

For the first subprocess, survival to natural mortality, a binomial distribution is assumed for the number of survivors in BI, with probability of survival $p_{M;BI}$, common to both length groups,

$$\boldsymbol{u}^M_{BI,s} \sim \boldsymbol{H}^M_{BI,s}(\boldsymbol{n}_{BI,s-1}) : \begin{cases} u^M_{BI,C2,s} & \sim & \mathrm{Bi}\left(n_{BI,C2,s-1}(\overline{F}), p_{M,BI}\right) \\ u^M_{BI,C3,s} & \sim & \mathrm{Bi}\left(n_{BI,C3,s-1}(\overline{F}), p_{M,BI}\right) \end{cases}$$

In the subprocess class transition, the distribution of the number of C2 elements that evolve to length group C3 is binomial with parameter $p_{23;BI}$,

$$\boldsymbol{u}_{BI,s}^{T} \sim \boldsymbol{H}_{BI,s}^{T}(\boldsymbol{u}_{BI,s}^{M}) : \begin{cases} u_{BI,C2,s}^{T} &= u_{BI,C2,s}^{M} - X[u_{BI,C2,s}^{M}], \\ &\text{with } X[u_{BI,C2,s}^{M}] \sim \mathrm{Bi}\left(u_{BI,C2,s}^{M}, p_{23,BI}\right) \\ u_{BI,C3,s}^{T} &= u_{BI,C3,s}^{M} + X[u_{BI,C2,s}^{M}] \end{cases}$$

The subprocess displacement by migration, Ds, differs according to whether s corresponds to a first or second semester. In the second semester, a contingent of new recruits is admitted to be added to the C2 length group of BI, part of which have just arrived from their migration from south and the others, being already present in BI, only then attained the recruitment size and enter into C2 length group. It is further assumed that the number of entries in BI is binomial distributed over the number of C2 fishes existing there with probability $p_{r;BI}$.

$$\boldsymbol{u}_{BI,s}^{D} \sim \boldsymbol{H}_{BI,s}^{D}(\boldsymbol{u}_{BI,s}^{T}) \quad : \begin{cases} u_{BI,C2,s}^{D} &= u_{BI,C2,s}^{T} + E_{C2,s} \\ &\text{with } E_{C2,s} \sim \mathrm{Bi}\left(u_{BI,C2,s}^{T}, p_{r,BI}\right) \\ u_{BI,C3,s}^{D} &= u_{BI,C3,s}^{T} \\ \text{if } s \text{ corresponds to a second semester.} \end{cases} \quad ,$$

Emigration from BI is admitted to occur during the first semester and the specimens exiting belong either to C2 or C3. The number of exits in the two length groups are considered to have independent binomial distributions with the same parameter $p_{E;BI}$.

$$\boldsymbol{u}_{BI,s}^{D} \sim \boldsymbol{H}_{BI,s}^{D}(\boldsymbol{u}_{BI,s}^{T}) \quad : \begin{cases} u_{BI,C2,s}^{D} &= u_{BI,C2,s}^{T} - I_{C2,s} \\ &\text{with } I_{C2,s} \sim \mathrm{Bi}\left(u_{BI,C2,s}^{T}, p_{E,BI}\right) \\ u_{BI,C3,s}^{D} &= u_{BI,C3,s}^{T} - I_{C3,s} \\ &\text{with } I_{C3,s} \sim \mathrm{Bi}\left(u_{BI,C3,s}^{T}, p_{E,BI}\right) \\ \text{if } s \text{ corresponds to a first semester.} \end{cases}$$

The subprocess of survival to fishing, denoting by ϕ_{BI} the probability of one element in BI being fished, the distributions of the number of survivors to fishing in each length group are considered to be independent binomials with probability complementary to the one mentioned

$$\boldsymbol{n}_{BI,s} = \boldsymbol{u}_{BI,s}^{F} \sim \boldsymbol{H}_{BI,s}^{F}(\boldsymbol{u}_{BI,s}^{D}) : \begin{cases} n_{BI,C2,s}(\overline{F}) &\sim \mathrm{Bi}(u_{BI,C2,s}^{D}, 1 - \phi_{BI,s}) \\ n_{BI,C3,s}(\overline{F}) &\sim \mathrm{Bi}(u_{BI,C3,s}^{D}, 1 - \phi_{BI,s}) \\ n_{BI,C2,s}(F) &= u_{BI,C2,s}^{D} - n_{BI,C2,s}(\overline{F}) \\ n_{BI,C3,s}(F) &= u_{BI,C3,s}^{D} - n_{BI,C3,s}(\overline{F}) \end{cases}$$

State space model for P

Five subprocesses are considered, the first of which is deterministic, while the others are stochastic, is:

I_s - Immigration from BI

M_s - Survival to natural mortality

T_s - Class transition

E_s - Emigration

F_s - Survival to fishing.

As for the BI model it is also admitted that the subprocesses succeed in time always in the following order,

$$I_s \rightarrow M_s \rightarrow T_s \rightarrow E_s \rightarrow F_s.$$

The first subprocess to be considered is immigration from BI. The entrance in P of immigrants from BI, is admitted to occur at the beginning of the second semester. It is assumed that specimens arrive at P with a constant delay from their departure from BI estimated to be around 3 semesters. This time interval roughly corresponds to the age difference of specimens with modal length caught in the northern and southern areas, respectively, 94 cm and 106 cm. It is also considered that during the migration time period, both natural mortality and class transition occur. So, when s corresponds to a second semester, the number of immigrants to the group C2 of P, iC2;s, is given by the following product,

$$i_{C2,s} = E[I_{C2,s-3}] \, p^2_{M,BI} \, (1 - p_{23,BI})^2.$$

where E[I$_{C2;s-3}$] is the estimated mean number of those that have left the group C$_2$ of BI at the end of semester s-3, and p^2 $_{M;BI}$ and (1-p$_{23;BI}$)^2 are, the posterior estimates of the probability of surviving, and the probability of remaining in group C2, during two semesters of migration. The third semester of migration is supposed to occur already in the P area.

Similarly, the number of immigrants to the group C3 of P, iC3;s is given by,

$$i_{C3,s} = E[I_{C2,s-4}] \, p^2_{M,BI} \, (1 - (1 - p_{23,BI})^2) + E[I_{C3,s-3}] \, p^2_{M,BI}$$

where E[IC3;s@3291] represents the survivors of the estimated mean number of elements leaving the group C3 of BI. The corresponding expressions are

$$u^I_{P,s} \quad \sim \quad \boldsymbol{H}^I_{P,s}(\boldsymbol{n}_{P,s-1}):$$
$$\begin{cases} u^I_{P,C2,s} &= n_{P,C2,s-1}(\overline{F}) + (1 - p_{23,BI})^2 p^2_{M,BI} i_{C2,s-3} \\ u^I_{P,C3,s} &= n_{P,C3,s-1}(\overline{F}) + p^2_{M,BI} i_{C3,s-3} \\ &+ \quad (1 - (1 - p_{23,BI})^2) p^2_{M,BI} i_{C2,s-3} \end{cases}$$
$$\text{if } s \text{ corresponds to a second semester.}$$

The next state processes (Survival to natural mortality, Class transition, Emigration, Survival to fishing) are defined similarly to the corresponding BI subprocess but with parameters assigned to P area.

The prior distributions for the parameters in the model were selected in a way that each of them incorporates as much information as available for the species. Non-informative gamma were chosen for the prior distributions of the dispersion of the observation errors as this is the common choice for dispersion parameters.

The quality of the fitting is evaluated for each model separately. For the BI model, the catch estimates for the C2 and C3 length groups, in semester s, i.e. the components of

$\hat{Y}_{BI,s}$ are the median of the distributions of the state process vector components corresponding to the two shed subpopulations, in that semester. For the P model, the catch estimates in semester s were obtained, in the same way and are denoted by $\hat{Y}_{PI,s}$. The evaluation of the model's adequacy is based on the expected deviance and also on visual inspection of the credible intervals. Contrarily to the confidence intervals, the latter are intervals in the domain of the posterior probability distributions.

Software used

The estimation of these models, both parameters and states, is done via the Bayesian paradigm, implying non-trivial integration of these several probability density functions, which is accomplished through sequential Monte Carlo. Two state models were considered in order to estimate the BI and P abundances, being estimated by sequential importance sampling according to Liu and West (2010) algorithm. The necessary computations were run in R.

Model Options chosen

The prior distributions for the parameters in the models were selected in a way that each of them incorporates as much information as available for the species (Table 4). Non-informative gamma were chosen for the prior distributions of the dispersion of the observation errors as this is the common choice for dispersion parameters.

Table 4. Priors distributions adopted for the parameters in each model defined based on the mean and standard deviation shown in two right columns

Parameter	Prior Distribution	Mean	Standard Deviation	
$p_{M,BI}$	Beta(16.56,1.11)	0.937	0.06	
p_{23BI}	Beta(1.15,5.92)	0.16	0.1	
p_{rBI}	Beta(1,1)	0.5	0.29	
$p_{E,BI}$	Beta(3.91,10.41)	0.27	0.11	
q_{BI}	Log-normal($-5.44, 0.83$)	0.006	0.006	
ψ_{BI}	Gamma(0.4,0.25)	0.10	0.16	
$p_{M,P}$	Beta(16.56,1.11)	0.937	0.06	
p_{23P}	Beta(1.09,1.35)	0.45	0.27	
$p_{E,P}$	Beta(4.39,18.48)	0.19	0.08	
q_P	Log-normal($-3.59, 0.83$)	0.039	0.039	
ψ_P	Gamma(0.4,0.25)	0.10	0.16	

D. Biological Reference Points

In view of the probable linkage between the Portuguese and British Isles fishery components, it is considered essential that the status of the stock as a whole should be considered when giving management advice for either fishery component. However, given the presumed sequential nature of the exploitation pattern, management should also take into consideration trends occurring in the separate areas.

The harvest control rule proposed by WKDEEP 2104 is therefore to adjust catches in both areas according to recent trends in total abundance for the two areas combined as estimated by the state space model (estimated by a regression fitted to the posterior median estimates of abundance of the most recent five years). This will be applied in

combination with a simple harvest control rule that specifies that catch advice should only increase when the abundance trends for both fishery components are increasing. If either is stable or decreasing, the advised catch for both areas should be adjusted according to the rate of change in the area showing the decrease.

E. Other Issues

E.1. Historical overview of previous assessment methods

The previous assessment trials were done taking into consideration a unique stock in NE Atlantic. However due to the different nature of fisheries in the northern and southern areas and lack of information on migration, the stock has traditionally been divided into northern and southern components for management purposes.

Year	Assessment type[3]	Assessment method(s) used	Assessment package/ program used	Reference
1998	Exploratory	Scheafer Production model	CEDA	WGDEEP 1998
2006	Exploratory	Dynamic Production model	ASPIC	WGDEEP 2006
2006	Exploratory	Bayesian approach to Production model	Winbugs	WGDEEP 2006

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[3] Exploratory, Benchmark (to identify best practise), Update (repeat of previous years' assessment using same method and settings but with the addition of data for another year).

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