


Original research article

Black scabbardfish (*Aphanopus carbo*) longline fishery off the Portuguese continental coast: Spatial information in support of deep-sea fisheries regulations

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ABSTRACT

The main objective of this study is to provide, for the first time, fisheries-dependent, spatially explicit information on the activity for the black scabbard fish (*Aphanopus carbo*) longline fleet operating off the Portuguese coast. Fisheries monitoring data were analysed, covering the period 2014–2016, aiming at identifying deep-sea fishing grounds, gaining a better understanding of the fleet spatial dynamics, quantifying fishing effort and providing information on the species distribution and abundance. E-logbooks were used to define general patterns of fishing activity, while the combined analysis of Vessel Monitoring System (VMS) and Automatic Identification System (AIS) data allowed to spatially identify fishing trips and define haul-back trajectories corresponding to fishing events. A total of 19 vessels were found to be involved in this fishery, mainly operating at depths from 1000 to 1500 m, landing the black scabbard fish in two main ports located in the centre and three secondary ports in the northern region. Fishing effort and catch per unit of effort (CPUE) were estimated and mapped for the period in study and the geographic extension of the fishery in the Portuguese continental slope was highlighted. Vessels keep their activity spatially restricted, in a clear strategy to avoid competition; their areas of activity are contiguous and generally related to the closest port. Some recommendations are drawn in support of a continuous monitoring programme for this fishery.

1. Introduction

In the Northeast Atlantic, deep-sea fisheries traditionally occurred involving sub-segments of the trawl and the multi-gear fleets from different countries. Black scabbard fish is an important commercially exploited species in this area, mainly distributed at depths from 200 to 1700 m, occurring from Iceland to the Canary Islands (Gordo, 2009). Available information suggests the existence of a single stock (ICES, 2022), with a northern component mainly targeted by a French deep-sea trawl fishery, and a Southern component which is subject to deep-sea longline fisheries, either in the Portuguese continental waters (ICES subarea 9a) or off Madeira island (Fishery Committee for the Eastern Central Atlantic area - CECAF).

Portugal has a long tradition in this fishery, dating back from the 1900s in Madeira waters, through small vessels operating handlines (Leite, 1988). A longline fishery in continental waters started much

later, in the 1980's, following the fleet modernization and progressive expansion of the activity to formerly unexploited deep waters. At this time, a coastal longline fleet of 15 small vessels targeting black scabbardfish was active, with length overall (LoA) below 12 m, based on the fishing port of Sesimbra, south of Lisbon, operating at specific deep-sea fishing grounds with steep slopes located south of Cape Espichel, close to the coast (Martins et al., 1989). The annual landings in the late 80's were around 3000 tons, increasing up to 4 500 tons in the mid-90s but slowly declining to 2 500 tons in the early 2000s, when a coastal fleet of 15–20 vessels was found to be well-established, targeting black scabbardfish all year round (Bordalo-Machado et al., 2009).

By 2004 this fleet was found to operate at steep slope areas off Sesimbra and Nazaré, in the centre, on rocky bottom slopes and canyons beyond the 10 nautical miles off the coast, at depths ranging from 800 to 1200 m (Bordalo-Machado & Figueiredo, 2009). Fishing trip duration varied from 24 to 48 h, during which a longline was usually deployed,

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while the previously set longline was hauled back. The gear used followed the general technical plan in (Henriques, 1997), set in horizontal position near the bottom, with alternating floats and weights along the main line, in order to match the species vertical distribution and to prevent gear loss on hard grounds.

Data are scarce on the biology and life history of black scabbard fish; similarly to other deep-sea species, this lack of knowledge contributed to explaining the nonexistence of scientific management advice until the beginning of this century (Gordon, 2003; Haedrick et al., 2001). The observed decline in abundance indices of this species in the French deep-water trawl fishery motivated the implementation of a total allowable catch (TAC) system in 2003 (Lorance & Dupouy, 2001). Since then, management of black scabbardfish by EU vessels includes a combination of TAC and licensing systems (ICES, 2006), and definition of fishing quotas for the different countries.

Within the Common Fisheries Policy, an ecosystem-based approach to fisheries management was formally adopted, aiming at reducing the adverse impacts of fishing activities on marine ecosystems through seabed disturbance, by-catch of sensitive species and effects on marine food webs (EU Biodiversity Strategy for 2030). In 2012, the Commission proposed a trawl ban in the North-East Atlantic for species classified as deep-sea species (Regulation, 2023/2336 EU); as a result, bottom trawling was banned at depths below 800 m, from 2016 onward. The fishing effort from EU trawlers catching the black scabbardfish in the Northern Component area has been greatly reduced, with impacts on the French bottom deep-water trawl fishery (ICES, 2022). In October 2022, a new action plan entered into force under Reg. 2016/2336, to protect Vulnerable Marine Ecosystems (VMEs) at depths of between 400 and 800 m, based on scientific advice from the International Council for the Exploration of the Sea (ICES, 2023). Within this plan, a total of 87 areas, located off the coasts of Ireland, France, Spain and Portugal, were closed to all bottom fishing gears, including bottom trawls, dredges, bottom-set gill nets, bottom-set longlines, pots and traps.

The implementation of these resolutions calls for the obtention of spatially explicit information on the fishing pressure in these areas, as well as the estimation of fishing impacts on the relevant target and by-catch species. The utility of fisheries-dependent monitoring datasets providing geo-referenced data on vessels activity has been demonstrated to this purpose, through combination of VMS data with logbook catches or landings of individual vessels, to estimate the fishing effort and CPUE/LPUE (catch per unit effort/landings per unit effort) at a spatial resolution. This has been carried out mainly for towed gears, in trawl fisheries (Afonso-Dias et al., 2002; Bastardie et al., 2010; Gerritsen & Lordan, 2010; Russo et al., 2018), where georeferenced monitoring data, including catch data, are generally available; besides, the fishing activity can be associated to those sections of the vessels' trajectories characterized by low speeds, being thus generally validated through the analysis of speed registers along time. In multi-gear fisheries there has been a general lack of geo-referenced data on the fishing activity. This, along with the high diversity of fishing gears and fishing strategies, each with distinct operational requirements in terms of fishing speed and course during deployment and haul-back, along with the inherent difficulty to separate fishing from non-fishing activity and to identify haul trajectories, has strongly limited the estimation of species-directed, spatially explicit fishing effort and CPUE/LPUE.

Nonetheless, several approaches have been developed to incorporate the spatial component of the fishing activity into the development of methods for the estimation the fishing effort in static gears (Bordalo-Machado, 2006; Campos et al., 2023; Chang & Yuan, 2014; Mendo et al., 2019; Sales Henriques et al., 2023).

At present, the black scabbard fish is an extremely important species at a national level, ranking second both in landings value and weight by the multi-gear coastal fleet operating in continental waters, with 11,890 tons landed in the period from 2012 to 2016 (data in this study). The fleet operating in this period was identified by Campos et al. (2021) as a well-defined métier of the multi-gear coastal fleet, involving a fleet

component of 21 licensed vessels exclusively operating with the deep-sea longline, landing the black scabbard fish as their almost exclusive target species.

Vessel Monitoring System (VMS), reporting position, speed and heading is mandatory for these vessels. Besides, most of the fleet also reports their position through the AIS system. Since 2012, e-logbooks are also mandatory with catch discrimination at a haul level (Regulation (EU) 404/2011). In the present study, these sources of information, available for the period from 2012 to 2016, are combined for this fleet for the first time, aiming at identifying deep-sea fishing grounds, gaining a better understanding of the fleet spatial dynamics and quantifying fishing effort. Furthermore, the integration of fisheries geo-referenced information with the vessel catches registered in e-logbooks provided updated, explicit spatio-temporal information on the species distribution and abundance, including CPUE maps as a proxy to fish density. The objective is to contribute with evidence-based fishing information to be used in support of the implementation of Commission regulations in deep-sea fisheries.

2. Material and methods

2.1. Datasets used

Three types of datasets were used in this study.

- 1) Fisheries-dependent monitoring data collected by fishers during their activity, comprising; a) a landings dataset with 8068 daily sales, including the sales' date; the trip and vessel identifiers; the landing port; and, for each landed species, the common, scientific, and 3-digit FAO code along with the respective landed weight; b) Vessel Monitoring System (VMS) processed data, for a total of 19 vessels, filtered to exclude records containing empty, duplicated or erroneous values. Each observation comprises the vessel code, timestamp (date + time of day, UTC), latitude, longitude, course and speed over ground (kn); c) Electronic logbooks (e-logbooks), manually filled by fishers, comprising 11212 observations identified as fishing events, with vessel code, departure and return to port, date, time of day and respective coordinates, fishing event number, fishing gear used, reported species captured and corresponding weight; d) vessels' characteristics, including fishing license, length overall (LoA), gross tonnage (GT), engine power (kW) and year of construction;
- 2) Georeferenced data on the vessel's activity, sourced from external providers - Automatic Identification System (AIS) data, available for 14 of the 19 vessels, comprising vessel name, MMSI (Maritime Mobile Service Identity), vessel code, timestamp (date + time of day, UTC), latitude, longitude, course and speed over ground (kn);
- 3) Open-source data from two different origins: a) environmental data from the EMODnet Bathymetry Project; b) the European Fleet Register database, comprising vessel names, MMSI, vessel code, main fishing gear and subsidiary fishing gear 1 and 2.

The low time resolution of VMS records, presently recorded every 2 h, does not match the time scale of fishing operations, making this system unsuitable, when used alone, for the purpose of the identification of complete hauls' trajectories, namely gear setting, which in this fishery is a fast operation lasting between 1 and 2 h. On the other hand, AIS is a system designed for safety purposes, characterized by having the possibility of reporting at a much higher frequency; however, the vessels have the capacity to switch off this system, and this can result in vessels not reporting, or reporting at irregular emission rates, thus resulting in mis-coverage of vessels' trajectories. Gaps in coverage of AIS thus often make them inappropriate, when used alone, for absolute estimates of the fishing activity (Shepperson et al., 2018). However, VMS and AIS data sources complement each other, and their combined analysis was found to contribute to a better spatial identification of the fishing activity; as such, they have been integrated along several studies (Campos et al.,

2023; Russo et al., 2016). The integration of these two datasets, available for most of the black scabbard fish fleet, was explored in this study to improve the estimation of vessels' trajectories. However, we primarily relied on VMS registers to ensure global spatial coverage of the fleet's activity, then adding AIS information to refine the analysis, increasing the accuracy in the identification of fishing events.

VMS were merged with AIS using the two common fields in the datasets (vessel code and timestamp) to increase point density in the analysis of fishing trajectories. The resulting dataset was improved by adding depth information for each record extracted from a bathymetric raster model with 150 m resolution, available through the EMODNET Bathymetry Project (<http://www.emodnet-bathymetry.eu>).

These three datasets were available only for the period between 2012 and 2016; while VMS data were not made available by the fisheries administration after that period, e-logbooks were only implemented in 2012, but not available at a regular basis during 2012 and 2013. On the other hand, VMS data were only available for 19 of the 21 vessels previously identified as the black scabbard fish fleet in Campos et al. (2021). Therefore, the fleet in study included a total of 19 vessels in the period between 2014 and 2016. Datasets in 1) were provided by the Directorate General for Natural Resources, Safety and Maritime Services (DGRM), in anonymized format, by attributing a code to each vessel.

2.2. Identification of fishing trips and fishing events

The first step in the present study was to spatially define the fishing trips. These trips were defined by partitioning the vessels' trajectories of the 19 vessels, using their geographic positions inside port as identifiers for the end of the fishing trip and beginning of the next one. Thus, each trip was spatially defined as the succession of records since the vessel leaves the port until return to the same or different port. A total of 5 662 trips were defined, with 1 503 008 georeferenced (VMS and AIS) observations, filtered to exclude records containing empty, duplicated or erroneous values.

A first attempt was carried out to identify the fishing events by collating the times of start and end of each fishing event reported in e-logbooks, with the trip spatial trajectories defined by VMS + AIS registers. However, data matching revealed impractical; the data in e-logbooks is entered by fishers at their convenience, and often individual hauls are not properly reported. A further reason preventing the identification of individual haul trajectories lies in that these events are not continuous in time. The longlines set in each trip are usually retrieved during the next or subsequent trips, remaining deployed for over 24 h, during which the vessel returns to port and starts a new trip, as referred by Bordalo-Machado and Figueiredo (2009). Thus, the fishing events defined through the information in logbooks overlap in time. On the other hand, gear setting is a fast operation with a typical duration of less than 2 h, as described in Bordalo-Machado (2006), and thus there is a risk of not being adequately recorded. This prevented the identification of fishing trajectories covering the entire fishing events; such events were thus identified in this study by linking georeferenced points corresponding to haul-back operations. This procedure can be safely adopted in bottom-set gear such as the one in study, where haul-back operations are expected to spatially coincide with gear deployment, being a good proxy for the spatial distribution of the fishery (Mendo et al., 2019).

These points were identified by plotting the frequency of vessels speed registers in VMS and AIS points (Fig. 1). Two modes could be detected, the first one at 0–2 knots, corresponding to the speed interval used during the hauling back of the gear, and a second at 8–10 knots, related to the steaming speed for these vessels when navigating between fishing grounds or to port. Intermediate speeds of 3–6 knots mostly correspond to gear setting or low-speed steaming. Haul-back points in this study were assigned to speed equal or below 2.0 knots, according to previous results in Bordalo-Machado (2006) and recently collected information from skippers at the scope of the project TecPescas

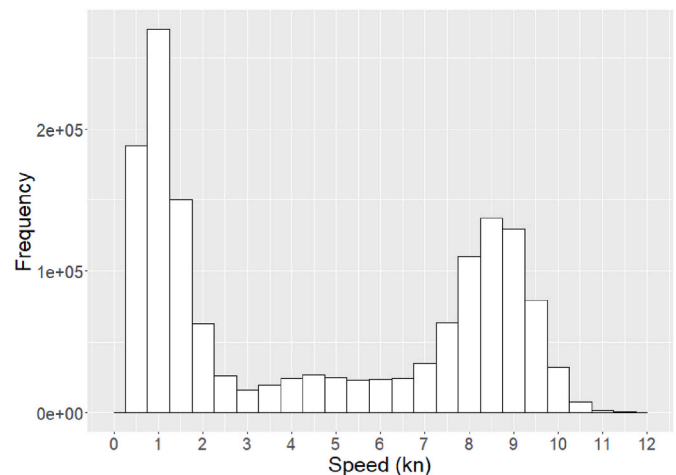


Fig. 1. Speed frequency for the 19 vessels in study. Based on the total number of VMS and AIS registers.

(unpublished data). An additional data filter was set corresponding to the minimum depth of occurrence of *Aphanopus carbo* of 500 m. A fishing event was then defined by the number of fishing points belonging to a haul-back trajectory. A total of 5648 haul-back trajectories was then identified with length up to 80 nm (Fig. 2), from which those between 5 and 20 nm were chosen, according to information collected near the skippers. The number of fishing operations selected was 4598, corresponding to 81% of the trajectories previously identified. Each trip was then merged with the port's sale record closer to the day of arrival (Fig. 3).

The information provided in e-logbooks could not be used in support to the definition of fishing trajectories; however, it was used to characterize general patterns of fishing activity, through the times associated to setting and haul-back operations. The duration of gear deployment was calculated as the time difference between setting and hauling times in consecutive trips as reported in the logbooks, being considered as a proxy of the soaking time.

2.2.1. Definition of effort and CPUE

The fishing effort, E , was estimated, for each fishing event, as the length, in nautical miles, of the haul-back trajectory associated to that event, given by the number of georeferenced fishing points. The fishing effort was then computed per year, during the period in analysis, by summing up the lengths of all the fishing trajectories L_e , according to

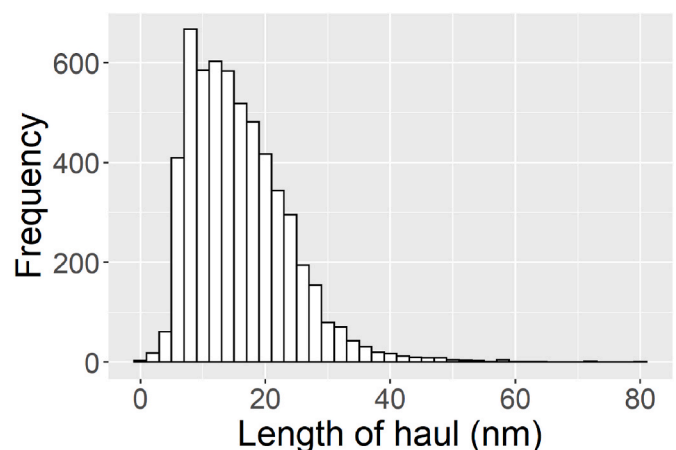


Fig. 2. Length of hauls Defined by the fishing points belonging to haul-back trajectories. A total of 5648 trajectories is represented, each corresponding to a fishing trip.

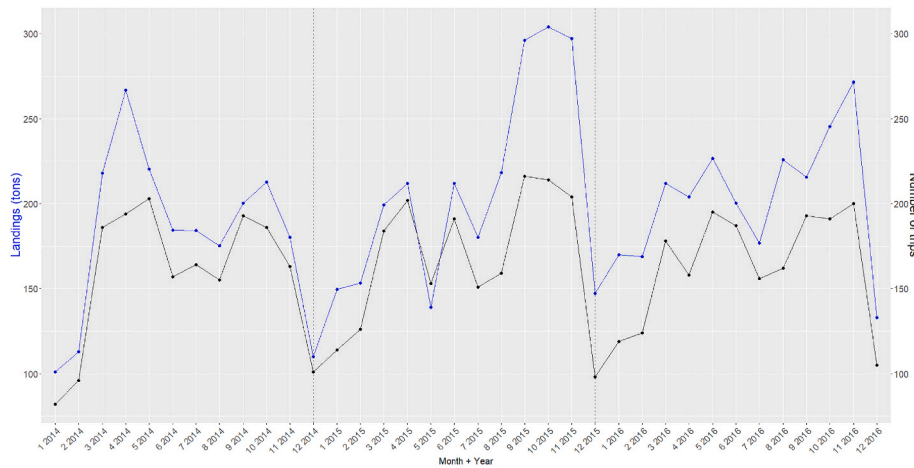


Fig. 3. Monthly variation in total landings and in the number of fishing events. Based on the 4598 fishing events in total (1396–2014, 1566–2015 and 1636–2016).

(Eq. (1)), where nt is the number of fishing events:

$$E_{year} = \sum_{e=1}^{nt} L_e \tag{Eq. 1}$$

whereas the landing per unit effort, $LPUE$, was computed according to (Eq. (2)), where n is the number of fishing events e , carried out during each year, C_e the total landing in the event e and E_e the respective effort.

$$CPUE_{year} = \frac{1}{n} \sum_{e=1}^n \frac{C_e}{E_e} \tag{Eq. 2}$$

2.2.2. Mapping fishing effort and CPUE

Fishing effort and CPUE were mapped using a 0.05° grid (~3NM) adapted to the specific spatial extent (the Portuguese continental coast) and intensity characteristics of the fishing operations with this gear type. Since the spatial trajectories of fishing events may cross multiple grid cells, the fishing effort and catches were allocated proportionally to the lengths of fishing trajectories within each cell (Bastardie et al., 2010). Therefore, the fishing effort in each cell is calculated by summing up the lengths of all the fishing events within that cell. On the other hand, the CPUE in each cell is estimated as the average of the individual CPUEs assigned to the fishing events in that same cell (Eq. (3)).

$$CPUE_{cell} = \frac{1}{n} \sum_{e=1}^n CPUE_e \tag{Eq. 3}$$

3. Results

The deep water bottom longline fleet that targets the black scabbardfish involves 19 vessels with an average length of 17 m and engine power of 169 kW, mostly built in the late 80’s/early 90’s (Table 1); all the vessels in this fleet are above 12 m in length and thus VMS and e-logbooks are mandatory, while AIS registers were available for 14 of these vessels. The 19 vessels operating remained the same over the three years in study, with the exception of one vessel operating only in the first two years.

Table 1
Main technical characteristics of the black scabbard fish fleet in study. Standard deviations in brackets for LoA, engine power and gross tonnage.

N° vessels	Mean LoA (m)	Mean Engine power (kW)	Mean Gross tonnage	Mean year of construction
19	17.04 (2.51)	169.07 (60.89)	41.48 (34.26)	1987 (1950–2001)

This fleet carries out three weekly trips with average duration of 18 h, landing the black scabbard fish as their almost exclusive target species, with extremely low landing fractions corresponding to deep-sea sharks. Monthly landings and the corresponding number of trips are presented in Fig. 2 for the 19 vessels analysed, over the three years in study, showing that this is an all-year round fishery with no marked seasonal patterns, with the exception of the period from December to February in which a decrease in the number of events and corresponding landings is observed due to limitations to vessels’ activity caused by bad weather. In interviews conducted at the scope of the project TecPescas (2022, unpublished data) in the port of Sesimbra the skippers reported average gear length and number of hooks of 24 km and 7000 approximately, with distance of 4.5 m between snoods, deployed for a period of around 30 h, at a setting speed close to 5 knots and haul-back speed around 1 knot. The bait commonly used is chub mackerel (*Scomber japonicus*).

The fleet’s activity was based in two main ports, Sesimbra and Peniche, which accounted for 82% of the total number of landings (Appendix 1), while Aveiro, Matosinhos and Figueira da Foz are secondary ports, altogether accounting for 17%. These vessels are licensed for a total of 7 gear types; the different combinations of fishing licenses and those actually used are shown in Appendix 2, showing that nearly all vessels were found to exclusively use bottom longline (LLS). General information on the number of active vessels, daily sales, fishing trips and fishing events is provided in Table 2. Mean trip duration was found to be around 20 h, covered by an average of 255 VMS/AIS registers, from which one half approximately corresponds to fishing registers.

The total landings of black scabbardfish by the fleet in study attained around half of the fishing quota established for the entire Portuguese fleet, including vessels operating in continental waters and CEECAF area, during the period in analysis, with a mean landed weight per trip between 1 100 and 1 300 kg (Table 3). The black scabbardfish is virtually the only species landed, nevertheless, small amounts of deep-sea sharks totalling 98 tons were reported in the landings, including the Portuguese dogfish and the leafscale gulper shark (*Centrophorus squamosus*).

3.1. Fishing operation patterns

Frequency distributions representing start of both gear deployment and gear haul-back (as reported in e-logbooks) and soak times for all fishing events carried out with bottom longline are shown in Fig. 4(a)–(c).

Two modes can be identified for the setting time, a clear mode at 03:00h and a second, smaller one between 13:00 and 17:00h. For the hauling time, two modes at 03:00 and 16:00 h are observed. However,

Table 2

General information on the number of vessels, fishing trips and fishing events targeting black scabbard fish over the study period, based on e-logbook information.

Year	N° active vessels	N° landings = daily sales	N° of fishing events	Mean trip duration (h)	Mean haul duration (h)	Mean n° of fishing registers per haul	Mean length of haul (nm)
2014	15	1451	1396	19:43	11:24	122	11.72
2015	19	1637	1566	20:11	11:30	126	11.76
2016	17	1679	1636	19:58	11:11	103	12.01
Total		4767	4598				

Table 3

General information on the black scabbard fish landings in Portuguese continental waters for this fleet over the study period. The total fishing quota is shared by vessels operating in continental waters, Azores and Madeira.

Year	PT fishing quota (t)	Total landed weight of black scabbard in PT continental waters (t)	Total revenue (€ x 10 ⁶)	Mean landed weight/trip (kg)	Mean trip revenue (€)	Total landings (t)
2014	3659	1585	4.53	1135	3245	1664
2015	3659	2048	5.96	1308	3806	2067
2016	3659	2065	6.03	1262	3686	2070
Total	10977	5698	16.52			5801

high variation is recorded indicating that this gear can be set or retrieved along the 24 h. High variation is also visible for the soaking time, with several modes, two clear ones at 36 and 48 h (corresponding to 1.5 and 2.0 days respectively), and two other small modes at 60 and 72 h (2.5 and 3.0 days).

The 19 vessels in analysis were found to operate along the continental coast from Póvoa de Varzim, in the north, to Sesimbra, in the south (Fig. 5), in fishing grounds confined to areas of the slope, mainly at depths from 1 000 to 1 500 m. Mapping the vessels' individual activity allowed to observe that each vessel tends to concentrate its activity in a small, well-defined area, with only three vessels operating between Póvoa de Varzim and Figueira da Foz, in the north, three between Figueira da Foz and Peniche, in the centre, and other three between Peniche and Cascais. The remaining 10 vessels concentrate their activity between Cascais and Sines, in the fishing grounds off Sesimbra.

This progressive increase in fishing activity towards southern fishing grounds is visible in Fig. 6a), where the fishing effort is depicted. Catch per unit of effort CPUE is shown in Fig. 6 b), with higher CPUE values attaining 300 kg per unit gear length (nm) north of Peniche, while towards south CPUE was found to be generally below 200 kg/nm.

4. Discussion

Spatially-derived fisheries indicators have mostly been applied to trawl fleets, where VMS are currently operating. Most vessels belonging to multi-gear fleets are exempted from this obligation since they are under 12 m length and trip duration is less than 24 h. This is the case for the Portuguese multi-gear coastal fleet above 9 m in length, where approximately two thirds of the vessels are not reporting georeferenced data. The deep-sea black scabbard longline fleet in study is an exception; from the 21 vessels identified to be active during the period in study, a total of 19 were reporting their activity in VMS system. Most of these vessels were also reporting in the Automatic Identification System (AIS). Thus, a global coverage of the fleet activity was possible, allowing the estimation of absolute effort and CPUE estimates at a high spatial resolution.

The registers from the VMS mandatory system for fishing vessels with systematic emission rates were crucial in the spatial and temporal definition of fishing trips and fishing events. However, the low frequency of VMS data acquisition does not match the time scale of fishing

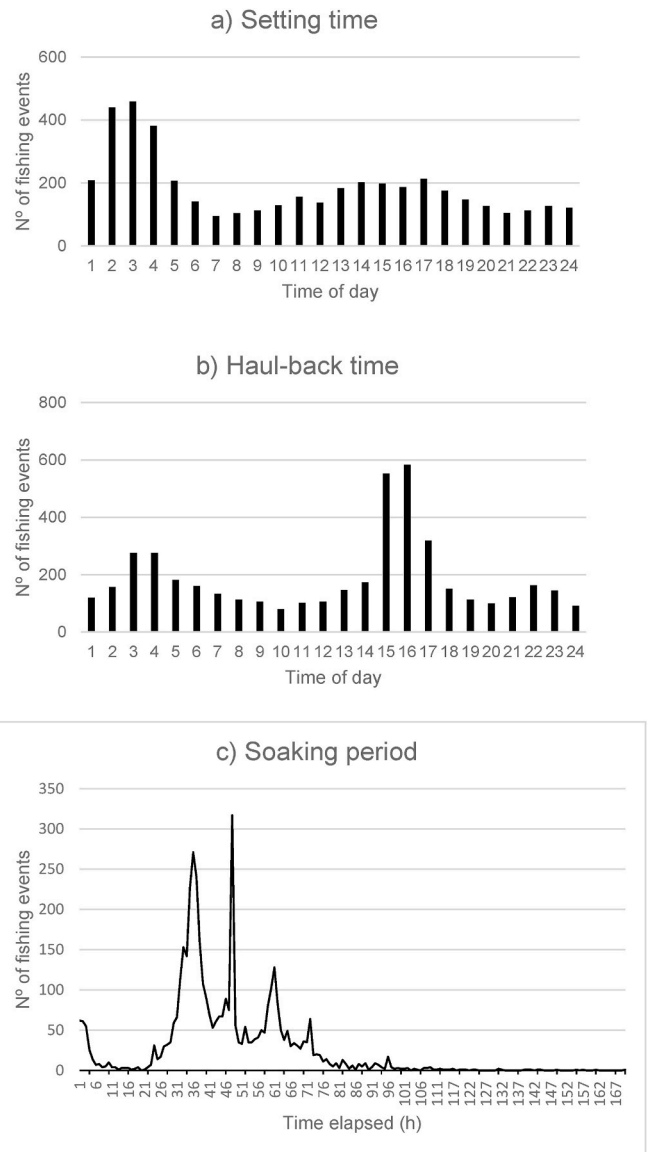


Fig. 4. Details on fishing operations. Based on 4598 fishing events recorded in e-logbooks.

operations; a further reason for this misidentification is that black scabbardfish longlines are set and retrieved during two consecutive trips, being deployed for over 24 h, during which the vessel returns to port and starts a new trip. These issues were found to compromise the identification of fishing trajectories; to circumvent this problem, fishing events were identified only by their haul-back points, which are unequivocally linked to a fishing trip and respective landing. Haul-back trajectories were thus further assumed to provide a measure of the total gear length, which was considered as a proxy of the fishing effort; and the landings for each fishing trip, originated from one single event,

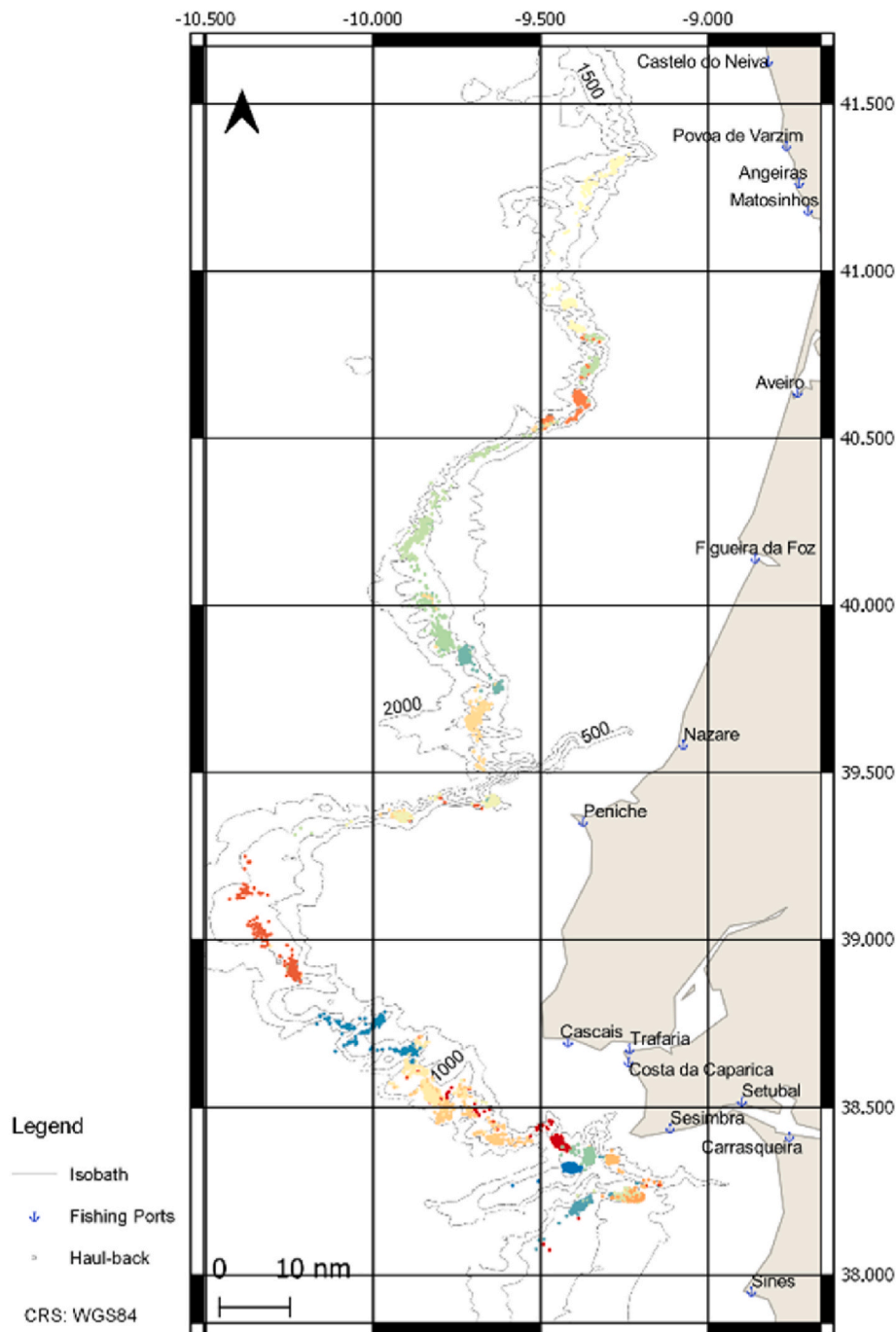


Fig. 5. Details on the spatial extent of fishing operations by the 19 vessels analysed in the period 2014–2016. A total of 4598 fishing points is depicted, each corresponding to the starting position of a fishing event; each colour represents one vessel.

were used to estimate CPUE in that event.

Notwithstanding the difficulties in using the information provided in e-logbooks in support to the definition of fishing trajectories, that information was here used, similarly to [Campos et al. \(2019\)](#), in support to the global characterization of the fishing operations, including time of gear deployment, gear haul-back and soaking time, while operational speeds were characterized from VMS and AIS registers. The results obtained here concerning setting and haul-back times, as well as vessels' speeds, agree with previous results in [Bordalo-Machado and Figueiredo \(2009\)](#), as well as with results from interviews to fishers at the scope of this study (unpublished data). The main mode at around 36 h estimated here for the soaking time also agrees with the previous studies, where this value was estimated to be around 38 h, and does not much differ

from values obtained at the scope of this study (30 h); the sharp peak corresponding to a soaking time of 48 h can be attributed either to hauls where the gear was set before the weekend or to biases in e-logbooks filling. E-logbooks are manually filled, often at the end of the trip, and thus the information provided is not completed correctly, as pointed out in recent studies ([Leitão et al., 2024](#)). The only information considered important is the declared catch, that can be matched with landings by port authorities. In this study, the high number of soak time with precise values such as 48 h, strongly points to a red flag.

Recently, [Sales Henriques et al. \(2023\)](#), using AIS data, proposed a general method to quantify and map the fishing effort, as soak time, of fishing gears used by 84 vessels of the Portuguese coastal multi-gear fleet. Soak time was found to vary much, from 90 min to 20 days, in

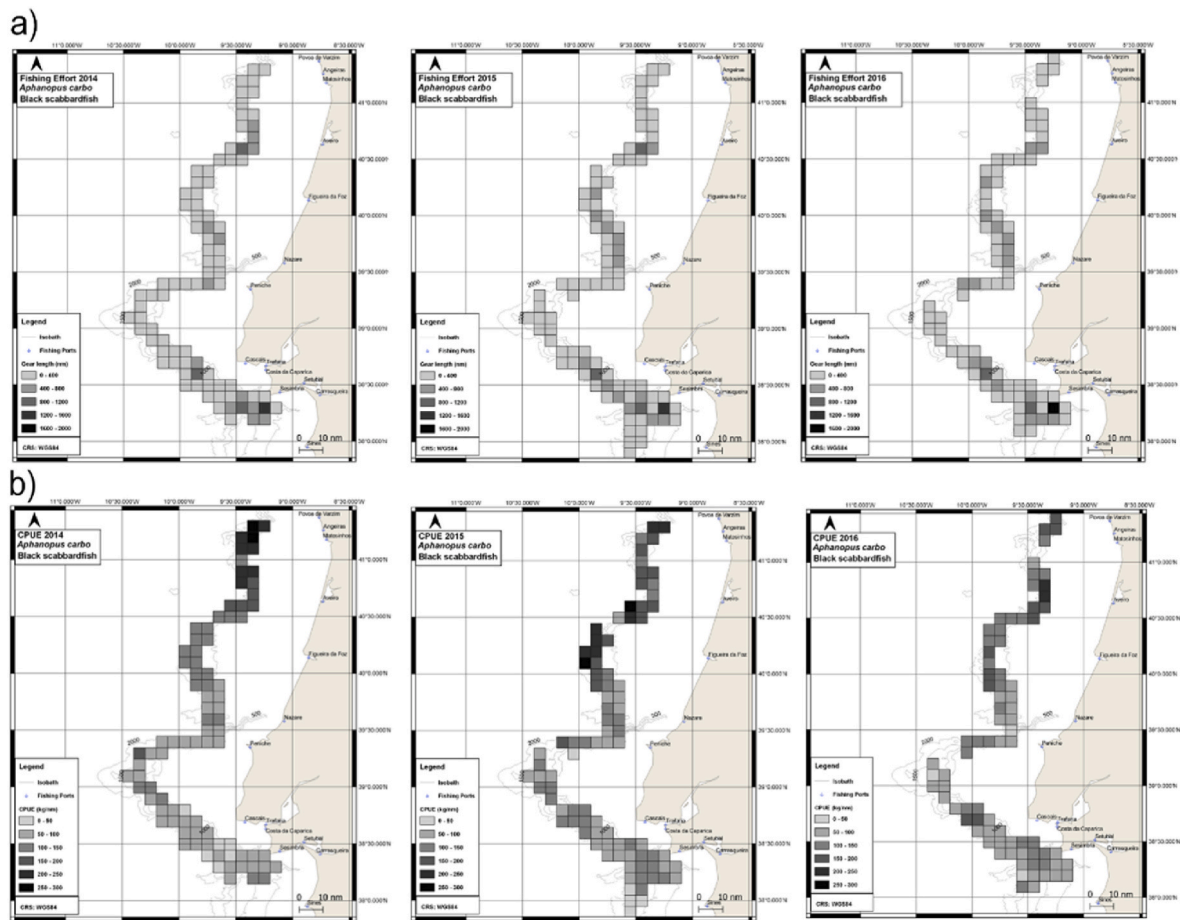


Fig. 6. Annual fishing effort (a) and CPUE (b) Based on a total of 4 598 hauls: 1 396 (2014); 1 566 (2015); 1 636 (2016).

vessels using nets, pots and traps; however, longlines are not included in this study. Considering that soak time does not vary much within the fleet in study, the effort estimates given here as gear length, as well as the estimates of CPUE as catch per unit of gear length, are good proxies for these two indicators.

In the early 2000's, this fleet was operating in two distinct geographic areas, one northern area from Nazaré to Peniche, and a southern one from Cabo da Roca to Sesimbra, corresponding to two different fishing grounds associated to the ports of Peniche and Sesimbra (Bordalo-Machado et al., 2009). The observation of plotted VMS data of the fishery enabled the delimitation of three distinct groups of fishing grounds as shown by Bordalo-Machado (2006). The fishery has undergone substantial geographic expansion since then, as shown in the present study, with vessels' activity attaining areas off Matosinhos, in the north, to Sines, in the southwestern coast, and spatial segregation among fishing vessels' activity. This segregation was formerly reported in fleets involved in multispecies fisheries by Poos et al. (2010) as a response to differences in the spatial distribution of target species; and by Turner et al. (2013) as a result of the allocation of informal property rights. This seems to be the case in this fishery, where there is anecdotal evidence that vessels' activity is based on gentlemen's agreements. Similar coverage expansion towards fishing grounds located in international waters SE of the Azores, off the Canaries and over seamounts of the Madeira-Tore was reported by Delgado et al. (2018) in the deep-sea fishery carried out by vessels of Madeira fleet, traditionally concentrated off the islands of Madeira and Porto Santo, from 2005 onwards, following a decrease in the abundance of the resource in traditional fishing grounds.

In this fishery, the vessels tend to keep their activity spatially

restricted, possibly following a strategy to avoid competition, their areas of activity being contiguous in space and generally related to the closest port, to reduce the steaming time and fuel expenses. This contributes to explaining the higher fishing effort towards the area off Sesimbra, where the fishing grounds are distant only approximately 1 h from the port. Notwithstanding the fact that CPUE values in this area are much lower, this proximity is probably associated to a strategy to keep the vessels' profit as high as possible, since Sesimbra is the main landing port, where sales occur; black scabbardfish landed in other ports is transported to Sesimbra.

Fishing effort was estimated by Bordalo-Machado and Figueiredo (2009) as the number of monthly trips or monthly hooks used for the period 2000–2004. Monthly CPUE was also calculated as the ratio between species weight (kg) landed and the monthly number of trips or hooks deployed. The average landings per trip estimated in the present study, around 1 250 kg, do not much differ from the previous figures of 900–1 200 kg per trip presented by these authors. Although the catch per hook represents the most accurate estimate of CPUE for this type of gear, the lack of information in e-logbooks concerning the number of hooks used in each deployment prevented us from this estimation, as this number can greatly vary. However, indicative values around 150 g/hook are obtained when the average number of hooks per trip is assumed to be around 7 000, according to enquires collected in port. This value sharply contrasts with 45 g/hook found in the former study by Bordalo-Machado and Figueiredo (2009). Uncertainty associated with these numbers in both studies, due to the lack of this information in logbooks, is high; as such, these figures rely on information provided by the skippers during interviews in ports. Bordalo-Machado and Figueiredo (2009) considered that CPUE calculated as the ratio of landings per

number of trips is the best option to consider for effort standardization applied to abundance studies, not only due to the lack of data precision but also to their better availability.

Despite increase in the spatial extent of the fishery during the last decades, a smaller number of vessels was found to operate in the northern region, where the steeper bathymetry contributes to reduce the fishing area for this species, concentrating the fishing activity within a narrow fringe area at depths from 1 000 to 1 500 m.

Concerns have been recently expressed by the EU (DG MARE) on VMEs protection in deep-sea areas of the Northeast Atlantic where they are known or are likely to occur (Regulation (EU) 2022/1614), comprising EU waters of the Iberian Coast ecoregion, including one area in which fishing activity was identified in this study. ICES was requested to carry out an annual assessment of these Northeast Atlantic areas (ICES, 2023) and present spatial management scenarios for VMEs protection, based on updated information on mobile bottom-contacting gear (MBCG) fishing activity. Static gears are characterized by having a lesser impact on seafloor integrity when compared to bottom trawls; however, in its advice, ICES (2023) points out to the need of further investigations to understand the risk of significant adverse impacts from static gear fishing on VMEs. In this study information is provided, at a fine-scale resolution, on the distribution and intensity of fishing pressure in these areas using the black scabbard fish bottom longline, contributing with base-level information to be used in support of management plans for these areas.

This type of longline is a stone-buoy system, partially set off the bottom and thus, reduced physical impact is expected in the seabed and benthic communities. Nonetheless, threats can arise from the removal of deep-sea by-catch species that are particularly vulnerable, mainly composed of deep-sea sharks included in the list of species regulated by Reg (EU) 2016/2336. In fact, in previous studies (Bordalo-Machado & Figueiredo, 2009; Gordon, 2003), the existence of non-negligible by-catch fraction was reported, composed of deep-sea sharks including the Portuguese dogfish *Centroscymnus coelolepis* and the leaf-scale gulper shark *Centrophorus squamosus*. Shark by-catch in Portuguese deep-water longlines was specifically addressed by Figueiredo, Machado, & Gordo, 2005, where total annual landings of these two species in Sesimbra altogether varied between 780 and 1300 tons between 1991 and 2000, representing around 10% of all landings in this port. A comparable by-catch would be expected here; however, the black scabbardfish is virtually the only species reported in the e-logbooks, with extremely low reported by-catch percentage varying from less than 5.0% in 2014 to 0.2% in 2016. Possibly, e-logbook catch records such as the ones analysed here do not mirror species composition due to under-reporting or discarding practices for these by-catch species. On the other hand, the small amount of by-catch reported in the e-logbooks analysed in this study, with lowfin gulper shark, *Centrophorus lusitanicus* (CPL) and tope shark, *Galeorhinus galeus* (GAG) as the two main species, has a distinct composition from that of the previous studies. Misreporting issues, observed by in 2009 and 2010 (Lagarto et al., 2012), and persisting until 2016 (Lagarto et al., 2017, p. 16), explain these differences, suggesting that specimens landed as *Galeorhinus galeus* correspond in fact to leaf-scale gulper shark *Centrophorus squamosus* and Portuguese dogfish *Centroscymnus coelolepis*. Misreporting is likely to have increased as a reaction to the restrictions imposed by the European Union (EU) for deep-water sharks, including these last two species, whose landings have been prohibited since 2010 (Council Regulation (EC) No 1359/2008 for the list of species included in Annex I of Regulation (EC) No. 2347/2002).

5. Conclusions and recommendations

The results complete and update information on the black scabbard fishery; the fleet's spatial dynamics is specifically addressed, representing the first attempt to estimate quantitative and spatially explicit information on the variations in fishing effort and fishery-based

abundance index (CPUE) at a fine-scale resolution, for this fishery, along the entire Portuguese continental slope. These variations should be updated through time, based on the analysis of fisheries-dependent monitoring data as proposed in this study; to this purpose, georeferenced data from the fishing activity should be made available on a regular basis. Likewise, it would be important to improve the information in e-logbooks concerning finer measures of effort, based either on more precise registers of set-up and haul-back operations or gear characteristics, such as the number of hooks used in each deployment; the lack of this information prevented us from attaining most accurate estimates of CPUE. In addition, it would be extremely important to regularly analyse catch samples obtained across the entire geographical area where the fishery takes place, at the different depths, either during the commercial activity and independent surveys. This would allow to clarify the relationship between commercially based and independent CPUE series, not only for the black scabbard but also for by-catch species in this fishery. Finally, it would be of interest to investigate the existence of informal property rights; from an economic perspective, the existence of such agreements may be a strategy adopted by fishers in order to ensure security about future catch possibilities.

CRedit authorship contribution statement

Aida Campos: Writing – original draft, Supervision, Methodology, Funding acquisition, Conceptualization. **Pedro Leitão:** Writing – review & editing, Formal analysis. **Luís Sousa:** Writing – review & editing, Software. **Victor Henriques:** Writing – review & editing, Methodology, Formal analysis.

Ethic statement

The authors confirm that the ethical policies of the journal, as noted in the author guidelines page for Aquaculture and Fisheries, have been adhered to. No ethical approval was required for this study as the dataset used for this article consisted of field samples that were collected following a commercial fishing practice in accordance with the local legislation and institutional requirements. No other authorization or ethics board approval was required to conduct this study. The captured animals were not exposed to any additional stress other than that involved in commercial fishing practices, and no further direct or indirect manipulation with the fish or other animals were conducted during the trials. Therefore, no information on animal welfare or on steps taken to mitigate fish suffering and methods of sacrifice is provided. This study did not involve endangered or protected species.

Declaration of generative AI and AI-assisted technologies in the Writing process

The authors declared they did not use service AI, and took full responsibility for the content of the published article.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix 1. – Total activity for the black scabbard fleet as given by the numbers of landings corresponding to fishing trips, with indication of the ports of departure and arrival

	Port of departure	Port of arrival							
		Matosinhos	Aveiro	F. Foz	Nazaré	Peniche	C. Caparica	Cascais	Sesimbra
North	P. Varzim	1							
	Matosinhos	286							1
Centre	Aveiro		461	11	1	1			4
	F. Foz		9	192	2	4			3
	Nazaré		1	1	2	1			
	Peniche			5		1351	1		11
Lisbon area	C. Caparica								1
	Cascais							1	12
	Sesimbra			1		5	3	6	3285
	Total	287	471	210	5	1362	3	7	3317

Appendix 2. – Different combinations of fishing licenses for the black scabbard fleet along with the combinations actually used. FPO: pots and traps; GNS: gillnets; GTR: trammel nets; LHP: pole and line fishery; LLS: bottom longline; LLD – drifting longline; LX: other gears

Year	License combinations	Number of licensed vessels	Number of vessels using
2014	FPO + GNS + GTR + LHP + LLS	2	
	FPO + LHP + LLS	2	
	FPO + LLS	1	1
	GNS + GTR + LHP + LLS	2	
	GNS + LHP + LLS	1	
	LHP + LLD + LLS	1	
	LHP + LLS	5	
	LLS	1	14
Total		15	15
2015	FPO + GNS + GTR + LHP + LLS	2	
	FPO + GNS + LHP + LLS	1	
	FPO + GNS + LLS	1	1
	FPO + LHP + LLS	2	
	FPO + LLS	1	1
	GNS + GTR + LHP + LLS	2	
	GNS + LHP + LLS	1	
	LHP + LLD + LLS	1	
	LHP + LLS	7	
	LLS	1	16
LLS + LX		1	
Total		19	19
2016	FPO + GNS + GTR + LHP + LLS	2	
	FPO + GNS + LLS	1	
	FPO + LHP + LLS	2	
	FPO + LLS	1	1
	GNS + GTR + LHP + LLS	2	
	GNS + LHP + LLS	1	
	LHP + LLS	7	
	LLS	1	16
Total		17	17

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