Experimental fisheries for black scabbardfish (*Aphanopus carbo*) in the Azores, Northeast Atlantic

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In this study, we used fisheries observers’ data to analyse and describe the experimental fishing of black scabbardfish in the Azores in terms of type of gear, fishing operation, catch per unit effort (cpue), and fish size compositions. Standardized catch in numbers per 1000 hooks varied from 103 to 210 fish with an overall average of 132 fish per 1000 hooks. Recorded cpue values were similar to those recorded for Madeira and mainland Portugal in early 2000 but were higher than those observed in mainland Portugal for recent years. Bycatch was similar to that observed for other longline fisheries but much lower than in the North Atlantic deep-water trawl fishery. Fish size composition showed differences between locations in the Azores. Fish in Pico and São Jorge/Graciosa were consistently smaller than in other areas sampled and this may reflect the occurrence of an additional species, *Aphanopus intermedius*, in this area as proposed by gene analyses. Black scabbardfish (of possibly two species) may be considered an alternative resource for Azorean fisheries. Based on experience from other scabbardfish fisheries, however, it is suggested that fishing mortality should be maintained at a low level, traditional fishing methods should be encouraged, and bycatch should be closely monitored. Future studies of biology and distribution, stock assessments, and fisheries management advice should take into account the probable occurrence of two very similar species in the area. This study also highlights the importance of maintaining the fishery monitoring programme for the black scabbardfish fisheries in the Azores.

Keywords: Azores, black scabbardfish, deep sea, deep-water fisheries, longline, observer programmes.

Introduction

In the past few decades, fishing fleets around the world have increased the exploitation of deep-sea resources (Morato et al., 2006a). Because of the lack of basic data on the ecology and biology of target species and limited attention placed on deep-water stocks, stock assessments and scientific management advice have lagged behind the development and exploitation of many fisheries (Pankhurst, 1999; Haedrick et al., 2001; Gordon, 2003; Bailey et al., 2009). It was appreciated too late that deep-water fisheries usually target highly vulnerable species (Morato et al., 2006b), which may explain the observations of rapid stock declines (Koslow et al., 1995; Clark, 2001; ICES, 2003; Devine et al., 2006; Bailey et al., 2009) and slow recovery after stock collapses (Baker et al., 2009). There are, however, some examples around the world where deep-water fish species have been targeted for more than a century, mainly around oceanic islands with steep slopes (Moore, 1999; Menezes et al., 2006). These fisheries are typically labour-intensive and use handlines or longlines from small boats. The Madeira traditional black scabbardfish deep-water fishery is one long-standing example. This probably started in the early 1800s when local fishers, targeting deep-water squalid sharks at 600–800 m, accidentally caught a few black scabbardfish (*Aphanopus carbo*; Noronha, 1925; Leite, 1989).

Currently, black scabbardfish have been increasingly targeted by the Portuguese, French, and Irish fishing fleets (Gordon et al., 2003; Large et al., 2003; ICES, 2006; Bordalo-Machado and Figueiredo, 2009). This species may show relatively fast growth for a deep-water fish, with maturation at an age of 3–4 years (100 cm total length) and longevity ranging from 12 to 24 years (Morales-Nin and Sêna-Carvalho, 1996; Morales-Nin et al., 2002). Despite the insufficient and inconclusive information about the biology and life history of this species, some indicators suggest that abundances are declining in some areas of the Northeast Atlantic (Lorance and Dupouy, 2001; ICES, 2008); this motivated the implementation of a TAC system in 2003 (ICES, 2006).

Black scabbardfish occurs in the Azores between 800 m and 1500 m (Menezes et al., 2009) but were not targeted by local fishers. The low market price in the Azores probably limited the development of the fishery there. Occasional, experimental fishing targeting black scabbardfish started in 1998 with a single fishing vessel, and the fishery was closely monitored by on-board observers. This experiment created a unique opportunity to gather life-history data, which are often missing for deep-sea species, and at the same time allowed monitoring of fisheries activity from its inception. In this study, we used observer data to analyse and describe the start of the black scabbardfish
fisheries in the Azores in terms of type of gear, catch per unit effort (cpue), and size composition.

**Material and methods**

**Study area**
The oceanic archipelago of the Azores, located in the Northeast Atlantic, consists of nine islands, several islets and many seamounts and banks of volcanic origin. The scattered location of the islands defines an immense exclusive economic zone (EEZ) of \( \approx 1 \) million km\(^2\). Recent estimates showed that seamounts are common topographic features of the Azores EEZ, with an average density of 3.3 peaks of all sizes per 1000 km\(^2\), and \( \approx 63 \) large and 398 small seamount-like features (Morato et al., 2008). Seabed shallower than 700 m covers \( <1\% \) of the EEZ, reflecting the narrowness of the island and seamount slopes. This study covered mainly the central and eastern Azores fishing grounds, with the western group of the EEZ, around Corvo and Flores islands, not investigated (Figure 1).

**Gear and fishing operation**
A drifting bottom longline, consisting of a main line connected to several perpendicular vertical lines (free lines), generally 900 (\( \pm 100 \)) m long with a buoy attached to the upper end (Figure 2), was the gear used in this exploratory fishery. The main line drifts above the bottom, fishing at different distances from the seabed, which ranges from 1000 to 1900 m deep (average 1400 m). Mustad hooks number 5 were used in all sets. The total number of hooks used by the fishing gear ranged from 840 to 7644 (average 3625 hooks; Table 1), and they were connected to the main line through 3.5-m-long leaders (or gangions). Soak time averaged 10 h.

**Data collection**
The Azores Fisheries Observer Programme (POPA) was launched in 1998 to certify the pole-and-line tuna fishery as dolphin-safe, but was later extended to monitoring other fisheries (Machete and Santos, 2007). The programme deploys trained observers on board fishing vessels to record data on fishing activities and other scientifically relevant information. Georeferenced data collected on board included time, depth of fishing, type of gear, soak time, and catch of black scabbardfish and other species per fishing set. Fork length (FL) and weight of black scabbardfish were recorded. In this study, we used data from 240 sets collected by observers on board different fishing vessels during 1999 (\( n = 13 \)), 2000 (\( n = 47 \)), 2003 (\( n = 45 \)), 2004 (\( n = 10 \)), and 2005 (\( n = 125 \)). In addition, fish size (FL) was measured for 596 black scabbardfish in 1999, 2023 in 2000, 2667 in 2003, 866 in 2004, and 4712 in 2005.

**Data analyses**
Fish catches are usually influenced by many factors in addition to fish abundance, including fishing fleet, fishing location, year, season, and many environmental conditions. Consequently, catch data are usually standardized to remove the impact of such factors. Generalized linear models (GLMs) are the most common method for standardizing catch and effort data (Maunder and Punt, 2004) and assume that the expected value of a response variable is related to a linear combination of
explanatory variables (Guisan et al., 2002). Here, we used GLM techniques to standardize black scabbardfish catch data reported from drift bottom longline sets. The initial set of explanatory variables used included year, month, geographic areas, and vessel as categorical variables and depth of fishing and number of hooks as continuous variables. A Poisson error distribution with loglink function was used. The backward stepwise regression method was used to select the best set of explanatory variables. Alternative model structures were compared using the Akaike Information Criterion (AIC), but explanatory variables were included in the final model only if the deviance was reduced (or pseudo-coefficient of determination pseudo-$r^2$ was increased) by 2% (Horn, 2003). The general expression of the initial GLM is:

$$\text{Catch}_n \sim \text{year} + \text{month} + \text{fishing area} + \text{vessel} + \ln(\text{number of hooks}) + \text{poly(depth, 2)}.$$  

Years included in the standardization were 1990, 2000, and 2003–2005. Five geographic areas were used: Mar da Prata, the channel between São Jorge and Graciosa, the channel between Sao Jorge and Pico islands, Santa Maria, and south of Pico. All boats involved in the experimental fishery were included and the depth ranged from 650 to 1900 m. The size of hooks or soak time may influence the cpue of longline gear (Løkkeborg, 1994). These factors were accounted for in the model, however, by using the fishing boat as an explanatory variable. Standard graphical diagnostic statistics were performed to evaluate the quality of the final model adjustment and to attempt to identify model misspecification and heteroscedasticity.

**Results**

The total number of black scabbardfish caught during the fishing experiments was 110 244 fish with a total estimated weight of 222 t. Most of the longline sets were on the island slopes of Santa Maria (36% of all sets) and south of Pico (31%) on the island slopes. In 2005, some new areas were investigated between Pico and São Jorge islands (12%) and São Jorge and Graciosa islands (7%). Fishing areas changed between years; only the Santa Maria fishing grounds were sampled every year (Figure 1).

Bycatch species accounted for 4.0–7.5% of the total number of fish caught and 32 species of teleost fish, 10 elasmobranch species, and 1 cephalopod. The most common bycatch species was the leafscale gulper shark (*Centrophorus squamosus*) with 4013 fish (Supplementary Table S1) and an estimated landing of 12.3 t. Other sharks totalled 5.6 t, whereas teleost species weighed 0.8 t. In terms of cpue, the highest value recorded was 11.1 fish per 1000 hooks for leafscale gulper shark in 1999.

**Black scabbardfish catch and cpue**

The GLM selected for the standardization of the catch had month, area, boat, and number of hooks as significant explanatory variables (Table 2). The variables year and depth of fishing were removed from the initial model because the residuals’ deviance was not reduced by at least 2% (Table 2). Leaving year and depth out of the analyses led to only minor reductions in explained deviance and AIC. These two variables were considered unnecessary given their low explanatory power. The GLM used to standardize black scabbardfish catch in the drift longline sets explained

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**Table 1. Number of hooks per drift longline set used during the black scabbardfish experimental fisheries in the Azores.**

<table>
<thead>
<tr>
<th>Year</th>
<th>Mean</th>
<th>s.d.</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>1999</td>
<td>3 705</td>
<td>357</td>
<td>3 335–4 560</td>
</tr>
<tr>
<td>2000</td>
<td>4 026</td>
<td>1 448</td>
<td>840–7 680</td>
</tr>
<tr>
<td>2003</td>
<td>3 245</td>
<td>915</td>
<td>180–5 040</td>
</tr>
<tr>
<td>2004</td>
<td>2 498</td>
<td>221</td>
<td>2 168–2 668</td>
</tr>
<tr>
<td>2005</td>
<td>3 635</td>
<td>815</td>
<td>2 430–7 644</td>
</tr>
<tr>
<td>Overall</td>
<td>3 625</td>
<td>1 056</td>
<td>840–7 680</td>
</tr>
</tbody>
</table>

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**Figure 2.** Sketch of the longline fishing gear used in the black scabbardfish experimental fisheries in the Azores.
42% of the catch variability (Table 2). The observed vs. predicted values plots and the several residual plots show no violation of model assumptions (Figure 3).

The effects of some significant variables on the black scabbard-fish catch, as detected by GLM, are presented in Figure 4. Each variable is considered by fixing the other variables at the most frequent level (month = 7, area = Santa Maria, boat = “Cidade Celestial”). Standardized catch in numbers per 1000 hooks varied from 103 to 210 with an overall average of 132. The standardized catch per 1000 hooks varied seasonally (Figure 4a), but the patterns were not very clear. In terms of area, the standardized catch was higher in the area south of Pico and in the channel between Sao Jorge and Graciosa Islands (Figure 4b), but that area had very few records. Standardized catch showed a positive logarithmic relationship with the number of hooks (Figure 4c), which also varied between boats (Figure 4d).

**Black scabbardfish size composition**

Fish size ranged from 56 cm to 147 cm FL, with a mean size of 108 cm. It is worth noting that the size frequency distribution of fish caught south of Pico was skewed towards smaller sizes than other areas (e.g. Santa Maria; Figure 5).

![Figure 3](https://example.com/image3.png)

**Table 2.** Analysis of deviance table for the GLM exploratory models.

<table>
<thead>
<tr>
<th>Explanatory variables</th>
<th>Δdev</th>
<th>AIC</th>
<th>Pseudo-$r^2$</th>
<th>p-value (Chi-squared analysis)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Exploratory model 1</td>
<td>26 778</td>
<td>28 266</td>
<td>0.44</td>
<td>0.44</td>
</tr>
<tr>
<td>Exploratory model 2</td>
<td>26 861</td>
<td>28 347</td>
<td>0.44</td>
<td>0.44</td>
</tr>
<tr>
<td>Final model</td>
<td>27 485</td>
<td>28 966</td>
<td>0.42</td>
<td>0.42</td>
</tr>
</tbody>
</table>

The impact on the explained deviation and AIC of dropping each main effects factor from the GLM are also shown. Null deviance 47 784.

![Figure 4](https://example.com/image4.png)
Discussion

The black scabbardfish fishery in the Azores has received sporadic experimental activity despite previous indications that a potential for a fishery exists (Vinnichenko, 1998; Hareide and Garnes, 2001). The resource may still be regarded as a nearly virgin stock in the region. 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. The commercial value of the species is, however, well-established in other regions (Gordon et al., 2003; Large et al., 2003; ICES, 2006; Bordalo-Machado and Figueiredo, 2009).

In general, the fishing gear used experimentally in the Azores was similar to the gears described for other regions (Martins and Ferreira, 1995; Bordalo-Machado and Figueiredo, 2009). The average number of hooks per set applied in the Azores (~3625) was similar to that used in Madeira or the mainland Portugal fisheries in the early 1990s, but lower than used in recent years; 7000–8000 were reported recently in Madeira and 4000–10 000 in the mainland (Reis et al., 2001; Bordalo-Machado and Figueiredo, 2009; Bordalo-Machado et al., 2009).

Standardized cpue in the Azores was similar to that recorded in Madeira (Reis et al., 2001) and the Portuguese mainland in the past (ICES, 2006), but higher than that observed in mainland Portugal in recent years (Bordalo-Machado and Figueiredo, 2009). These comparisons suggest that the Azores has relatively lightly exploited resources of this species with a likely potential for commercial exploitation. However, cpue monitoring should be maintained in future to allow abundance-trend analysis. If the fishery becomes commercial, such information is essential to ensure optimal management of the resource.

The black scabbardfish fishery in Madeira has been considered a rare example of a deep-water fishery that, because it has
traditionally used hook-and-line gear, has proved sustainable over a period of \( \sim 150 \) years (Shotton, 2005). Currently, the black scabbardfish fisheries are much more industrialized in other regions, such as the French deep-water freezer trawlers that operate in northern European waters (Bordalo-Machado and Figueiredo, 2009), where cpue data show a constant decline in populations (ICES, 2008). In the southern European waters, between the Azores, mainland Portugal, Madeira, and the Canary Islands, where catches are made by artisanal deep-sea longline fisheries, catches and biomass appear to have remained stable, but it has been recommended that effort should not be increased (ICES, 2008).

Bycatch associated with longline fishing gears is usually regarded as being of conservation concern (Yokota et al., 2006). In this study, however, we found low bycatch values similar to those observed for other longline fisheries, such as in Madeira or mainland Portugal (Martins and Ferreira, 1995; Bordalo-Machado and Figueiredo, 2009), varying between 3 and 5% of the high black scabbardfish catch. In contrast, bycatch has been reported to be high in North Atlantic deep-water trawl fisheries targeting black scabbardfish (Anon, 2002). In the Azores, as in other regions, deep-sea sharks (mainly leafscale gulper shark, *C. squamosus*) were the main bycatch (Martins and Ferreira, 1995; Moura et al., 1998; Gordon, 2001; Gordon et al., 2003; Large et al., 2003). There is growing concern generally about the bycatch, but despite the low catches they do need to be monitored closely in future if the fishery is to be expanded in the Azores. In particular, effort should be made to minimize or reduce the bycatch of deep-water sharks through technical improvements in the longline used. It is technically impossible to have a zero bycatch of deep-water sharks, but it is necessary to avoid discards and misreporting of deep-water sharks if the fishery develops. One option would be to limit the fishery of black scabbardfish to a quota set according to a sustainable level of shark bycatch.

Fish size composition observed in the Azores was similar to that observed just outside its EEZ (Vinnichenko, 1998) and in other southern areas of the North Atlantic (ICES, 2006). The observed differences between locations in the Azores may reflect the presence of a second species of black scabbardfish. Fish in Pico were consistently smaller than in other areas sampled. Stefanni and Knutsen (2007) used genetic analysis to establish that two species of Trichiuridae occurred in the Azores—*A. carbo* and *Aphanopus intermedius*—and that in Pico *A. intermedius* dominated, characterized by smaller fish.

This study suggests that the black scabbardfish in the Azores is an almost unexploited resource. Provided appropriate caution is taken to prevent exploitation developing beyond sustainable levels, there is a potential for a new longline fishery. This would allow diversification of local fisheries and a reduction in fishing effort applied to the traditional demersal species. Based on experience from other black scabbardfish fisheries, however, it is suggested that fishing mortality should be maintained at a low level, traditional fishing methods should be encouraged, and close monitoring of bycatch species should be implemented. It would seem to be a matter of some urgency to clarify distribution patterns and differences in life-history strategies of the two species of black scabbardfish that appear within the fishing area. It is envisaged that multispecific regulation would have to be implemented because the species are difficult to distinguish morphologically. Studies of the biology of both species should be carried out and relevant biological differences with implications on the management of both species evaluated. This study has also highlighted the importance of maintaining the fishery monitoring programme for the black scabbardfish fisheries in the Azores.

**Acknowledgements**

We thank Simon Hoyle (Oceanic Fisheries Program, Secretariat of the Pacific Community) and two anonymous reviewers for their comments, which greatly improved the manuscript. We wish to acknowledge POPA for the collection and provision of observer data and Emmanuel Arand for the fishing gear diagram.

**Supplementary material**

Supplementary material is available at ICESJMS online.

**References**


