

Deep Sea 2003: Conference on the Governance and Management of Deep-sea Fisheries

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Modelling the distribution of two fish species on seamounts of the Azores

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1. INTRODUCTION

Seamounts are biologically distinctive habitats of the open ocean exhibiting a number of unique features (see Rogers 1994 for a review). They are characterized by the presence of substantial aggregations of deep-bodied fishes in the water column (Boehlert and Sasaki 1988, Koslow 1996, 1997, Koslow *et al.* 2000). These aggregations are supported in the otherwise food-poor deep sea by the enhanced flux of prey organisms past the seamounts and the interception and trapping of vertical migrators by the uplifted topography (Tseytlin 1985, Genin, Hauray and Greenblatt 1988, Koslow 1997). The discovery of these fish aggregations coincided with declines in shallow-water traditionally exploited stocks (Watson and Pauly 2001) and led to seamounts being increasingly targeted by trawlers throughout the world's oceans (e.g. the massive, but short-lived, fishery for pelagic armourhead (*Pseudopentaceros wheeleri*) in the North Pacific; the development of orange roughy and oreosomatid fisheries in the waters around New Zealand and southeastern Australia and subsequently in the North Atlantic (Rogers 1994, Clark 1999, Koslow *et al.* 2000) and elsewhere. Deep-sea seamount fish communities are highly susceptible to overfishing because they are long-lived, slow growing species with late maturity and low recruitment rates (Koslow 1997, Rico *et al.* 2001). Thus, when managing such fisheries, caution is required to reduce the risks of overexploitation (Clark 2001, Morato 2003).

2. THE AZOREAN FISHERY

The Azores (located in the region of 36–40 °N, 24–32 °W) are the most isolated Archipelago of the North Atlantic (Santos *et al.* 1995) with nine islands spread along a tectonic zone running WNW-ESE (Figure 1). Fishing activity started with the colonization of these islands during the 15th century and fish constituted one of the main human subsistence resources (Menezes 1996). In the last two decades the situation has changed with artisanal exploitation having been successively replaced with commercial fishing (Santos *et al.* 1995). As a consequence, the abundance of several species, and thus the catch rates of the commercial fleet, have started declining over the last few years, while fish stocks have already displayed sign of intensive exploitation (Menezes 2003).

Since no trawl fishery operates around seamounts in the Azores, bottom longlining that targets demersal and deepwater species comprises the most important fishery for the local economy. In fact, even though this fishery does not exceed 5 000 tonnes a year,

they still represent a considerable value (Silva and Krug 1994, Silva, Krug and Menezes 1994, Krug 1995, Menezes 1996). The blackspot seabream (*Pagellus bogaraveo*) has traditionally been the main target species of this fishery, but in recent years several other species, such as the alfonsino (*Beryx splendens*), have also become important.

Most of these species are

confined to seamounts, offshore banks and upper-slopes of the islands where bottom longlining occurs down to 1 000 m depth. Despite the large area (1 million km²) of the Azorean Exclusive Economic Zone (EEZ), the potential area for commercial bottom longlining occupies only approximately 3 percent of the zone.

Little is known about the number of seamounts, their characteristics or their associated fish populations despite the importance of seamounts for local fishing activities. The purpose of this paper is to (a) identify seamounts in the Azorean EEZ, (b) compile information about seamounts' characteristics, i.e. location, minimum and maximum depth, area of the summit and the seamount, elevation above the seafloor and distance to the nearest seamounts, etc. and (c), estimate some indices of relative abundance using the CPUE of two fish species (alfonsino and blackspot seabream) at several seamounts. Because the size, degree of isolation (Menezes 2003) and slope (Clark, Bull and Tracey 2001) of the seamounts are, among other physical features, important ecological determinants of the abundance of exploited seamount fish populations, this work will include (d), a preliminary attempt of modelling alfonsino and blackspot seabream abundances in seamounts using the above-mentioned physical characteristics as predictors variables. These models can be shown to be useful for predicting the abundance of seamount-inhabiting fish species, especially in data-deficient situations.

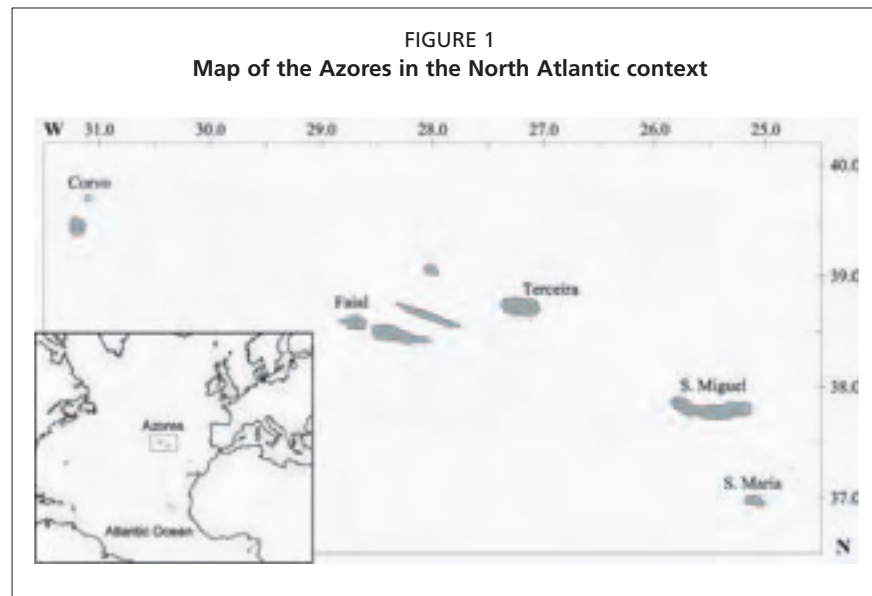
3. METHODS

3.1 Seamounts' physical characteristics

The seamounts around the Azores considered by this study were identified using bathymetric contour maps. Only those that satisfied the following criteria were considered:

- i. having the peak shallower than 1 200 m depth, the limit above which most commercially important fish communities inhabit (Menezes 2003)
- ii. having an elevation above the seafloor greater than 100 m (as described by Clark *et al.* 2001) and
- iii. having a distance from adjacent seamounts greater than 2 nautical miles (nm) and ability to determine that the catch is from single seamount (Clark *et al.* 2001).

Bathymetric data used to estimate depth contour maps were taken from the "Global seafloor topography from satellite altimetry and ship depth soundings" database (Smith and Sandwell 1997, <<http://topex.ucsd.edu/sandwell/sandwell.html>>).



A Kriging method was used to interpolate data and build bathymetric contour maps using Surfer 7.05 (Surface Mapping System Golden Software Inc.). Areas and distances were estimated using MapViewer 4.00 (Thematic Mapping System, Golden Software Inc.).

The characteristics chosen to describe seamounts were: (a) latitude and longitude of the centroid of the seamount, (b) minimum depth, (c) elevation (i.e. depth range between the peak and base of the seamount), (d) base area, ($Area_{base}$; for seamounts with a base deeper than 2000 m, the area of base was taken as the area of the 2000 m contour), (e) a slope index (see below) that represents the average steepness of the flanks of the seamount, and (f), distance to nearest seamount (nm).

3.2 Relative abundance indices

Relative abundance indices (using catch per unit effort) were estimated for alfonsino and blackspot seabream from data collected in 2002 by observers on board two 27 m commercial bottom longline vessels, the **Cidade Celestial** and **Íris do Mar**, from 34 fishing events on eight seamounts in the Azorean EEZ. CPUEs were estimated as the number of fish ($CPUE_n$) and catch weight (in kg; $CPUE_w$) of fish per 1 000 hooks.

3.3 Multiple regression models

Multiple linear-regression models were used to estimate abundance indices for alfonsino and blackspot seabream based on the following assumptions: (a) exploration rates are similar on all seamounts, (b) all longline fishing sets target both species on all seamounts sampled and (c), longline catch rates (CPUE) are an indication of relative abundance of each species on each seamount.

Multiple regression models were computed having the indices of fish abundance ($CPUE_n$ and $CPUE_w$) as dependent variables and the physical seamounts characteristics as independent variables. The resulting equations that had better fits were used to predict the index of abundance for the two fish species on the seamounts for which there were no data.

At this stage, only three physical characteristics of seamounts (predictors) were taken into account for multiple regression models:

i. Area of the seamount shallower than 850m ($Area_{<850}$)

The area of the seamounts is known to limit the abundance of alfonsino (Vinnichenko 1997). Since blackspot seabream is highly dependent on benthic habitats (Morato *et al.* 2001), seamount area might also affect their abundance. Thus, it is expected that the larger the area of the seamount, the higher the values that the abundance index might display. Since these two fish species are known to occur within the top 850 m of the water column (Menezes 2003), for the purpose of this study the area of the seamount shallower than 850 m was considered.

ii. The slope of the seamount (Slope)

Slopes of seamounts are positively correlated with the biomass of some seamount aggregating fish (Clark *et al.* 2001). Thus, the abundance index of alfonsino is expected to increase with a corresponding increase in slope of the seamount. In the case of seabream, such relationship may not hold true. The average slope of the flanks of the seamounts were estimated as $\text{Arctangent}[\text{elevation}/\sqrt{(\text{Area}_{base}/\pi)}]$ expressed in degrees.

iii. Distance to the nearest seamount (Dist.)

The degree of isolation of a seamount may affect fish abundance (Menezes 2003) and thus, the distance (nm) to the nearest seamount was estimated from bathymetric contour maps. The majority of seamount fishes form local populations (Vinnichenko 1998), that, in general, remain throughout their life cycle in the vicinity of the seamount (Clark *et al.* 2001, Vinnichenko 1998). Exchange of genetic material among populations probably occurs only during the

early life-history stages through passive dispersion of eggs and larvae by currents. However, blackspot seabream display ontogenetic changes in habitat preference with juveniles inhabiting the waters of island shelf, whereas adults move to deeper waters and to offshore seamounts (Menezes 2003, Morato *et al.* 2001). In general, the abundance index is expected to increase with a corresponding decrease in distance from neighbouring seamounts.

4. RESULTS

4.1 Seamounts physical characteristics

Overall, 136 seamounts were identified from the bathymetric contour maps. The depths of their peaks ranged from close to the surface to approximately 1 200 m, while their base depths ranged from 550 to 2 000 m (Figure 2). Seamount mapping revealed a mean elevation of 460 m (SD = 351m), with mean peak of 813 m (SD = 298m) and mean depth at base of 1 273 m (SD = 309 m). Most of the mapped seamounts had an elevation between 100 and 300 m (Figure 3). Thus, our study included 17 underwater mountains with heights above 1 000 m referred to as seamounts, 37 between 500 – 1 000 m referred to as knolls and 85 with elevations lower than 500 m referred to as hills. This classification is based on the US Board of Geographic Names (1981) in Rogers (1994).

The base area of Azorean seamounts ranged from 1.39 to 6 000 km² (mean = 337 m², SD = 720 km²). However, seamounts with a base area smaller than 200 km² were more numerous (Figure 4). The slope index of the seamounts ranged from 0.85 ° to 9.82 ° (mean = 3.68 °, SD = 1.94 °). Slopes ranging from 2 ° to 5 ° were more common (Figure 5).

With the exception of four isolated seamounts (Dist. = 35, 43, 58 and 61 nm) all 132 other seamounts have at least one seamount within 15 nm. The distance between seamounts ranged from 2 nm (predefined) to 61 nm (mean = 5.75 nm, SD = 7.33 nm), with most values occurring within 2 and 5 nm (Figure 6).

CPUE_n and CPUE_w for alfonsino ranged from 0.08 to 11.19 fish per 1 000 hooks and from 0.23 to 9.65 kg per 1 000 hooks respectively (Table 1). For blackspot seabream, CPUE ranged from 0.0 to 20.14 fish per 1 000 hooks and from 0.0 to 16.18 kg per 1 000 hooks respectively (Table 1). Seamounts with higher CPUEs were Cruiser and A3 for alfonsino, and Cavala and A3 for blackspot seabream.

4.2 Multiple regression models

The preliminary multiple regression models developed using the variables of slope, Area_{<850} and Dist. are summarized in Table 2. The large standard errors associated with the estimated parameters denote weak relationships with the abundance indices; thus caution should be applied when interpreting the results:

- i. $\text{Ln}(\text{CPUE}_n)_{\text{alfonsino}} = -5.947 + 0.00019 \cdot \text{Area}_{<850} + 1.106 \cdot \text{Slope} + 0.490 \cdot \text{Dist}$
- ii. $\text{Ln}(\text{CPUE}_w)_{\text{alfonsino}} = -4.909 + 0.00027 \cdot \text{Area}_{<850} + 0.966 \cdot \text{Slope} + 0.404 \cdot \text{Dist}$
- iii. $\text{Ln}(\text{CPUE}_n)_{\text{seabream}} = -1.827 + 0.00018 \cdot \text{Area}_{<850} + 1.207 \cdot \text{Slope} - 0.142 \cdot \text{Dist}$
- iv. $\text{Ln}(\text{CPUE}_w)_{\text{seabream}} = -2.620 + 0.00047 \cdot \text{Area}_{<850} + 1.134 \cdot \text{Slope} + 0.076 \cdot \text{Dist}$

The regression analyses explained a high degree of the variability in the data ($R^2 > 0.75$) with the exception of the $\text{Ln}(\text{CPUE}_w)$ for seabream ($R^2 = 0.46$) (Figure 7). The equations with better fits were for alfonsino [$\text{Ln}(\text{CPUE}_w)$] and for blackspot seabream [$\text{Ln}(\text{CPUE}_n)$]. These were used to predict the indices of abundance on the seamounts (Figures 8 and 9) for which we had no data.

5. DISCUSSION

This work was the first attempt to identify the seamounts in the Azorean EEZ and thus confidence in the results is still weak owing to the data deficient situations. The

FIGURE 2
Base and peak depths of mapped Azorean seamount

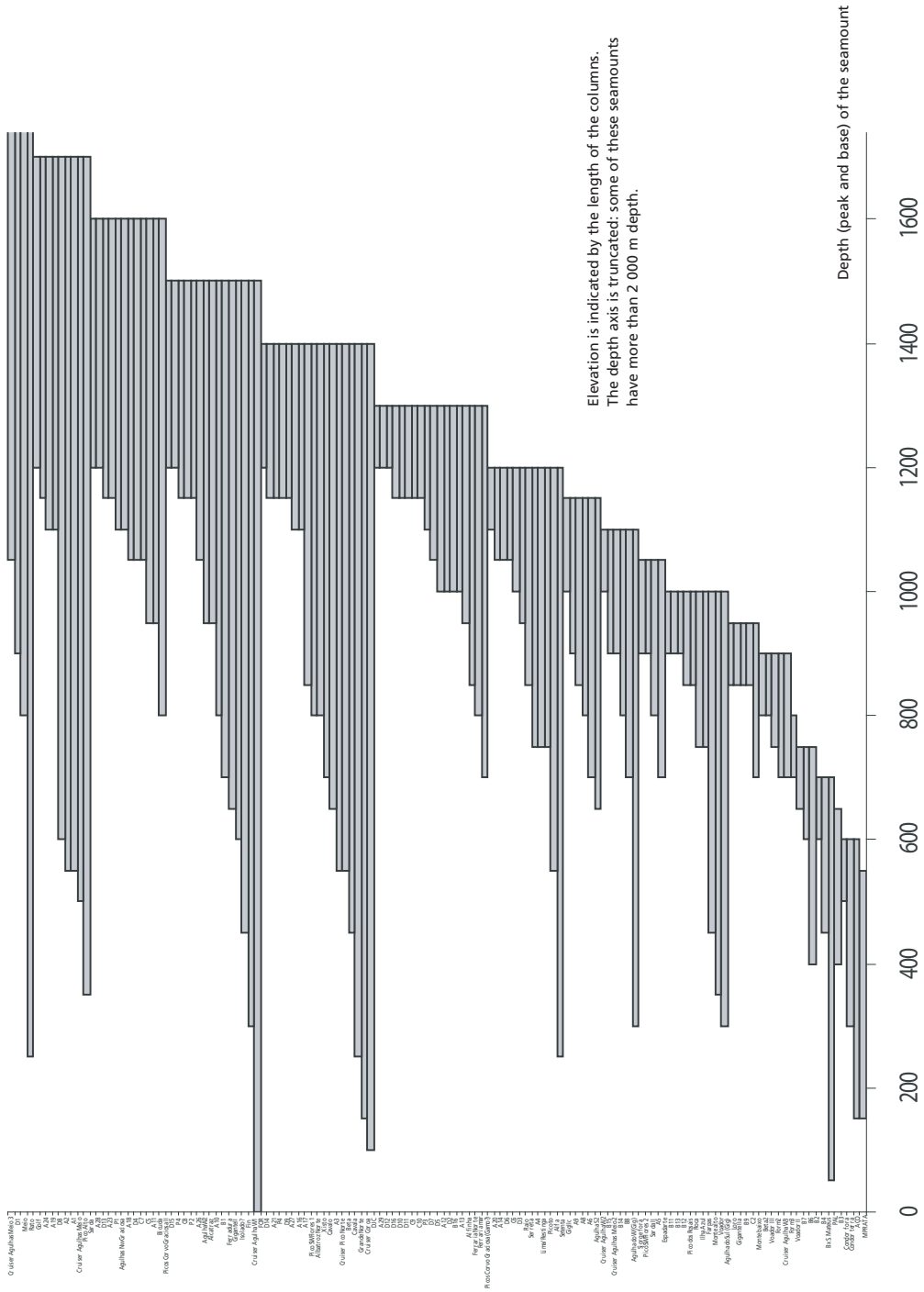


FIGURE 3
Frequency of seamounts elevations

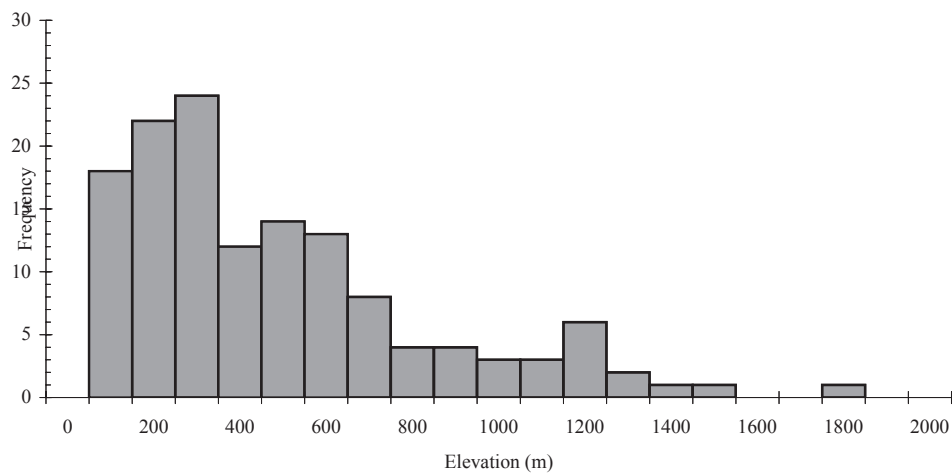


FIGURE 4
Frequency of area of the seamounts' base

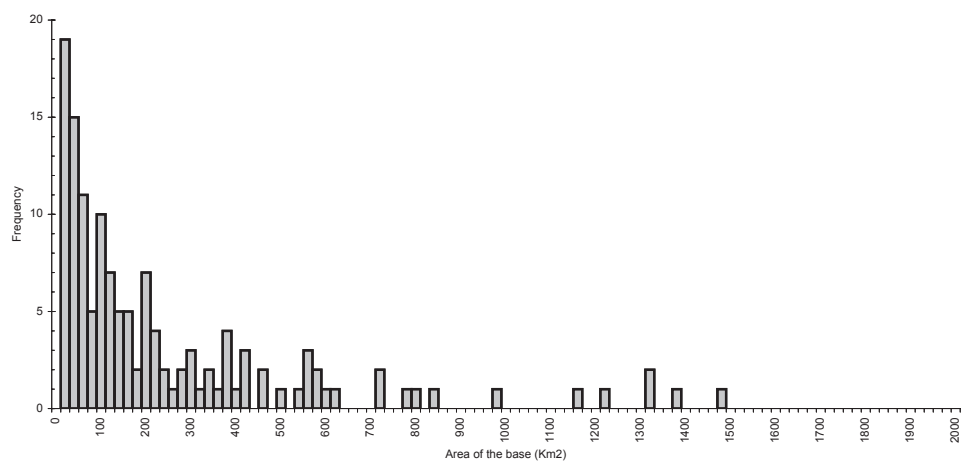
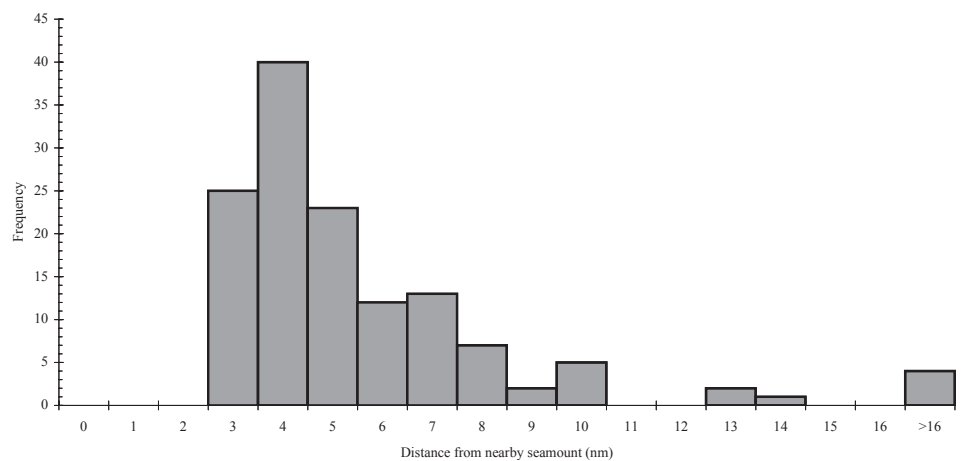


FIGURE 5
Frequency of the seamounts' slopes



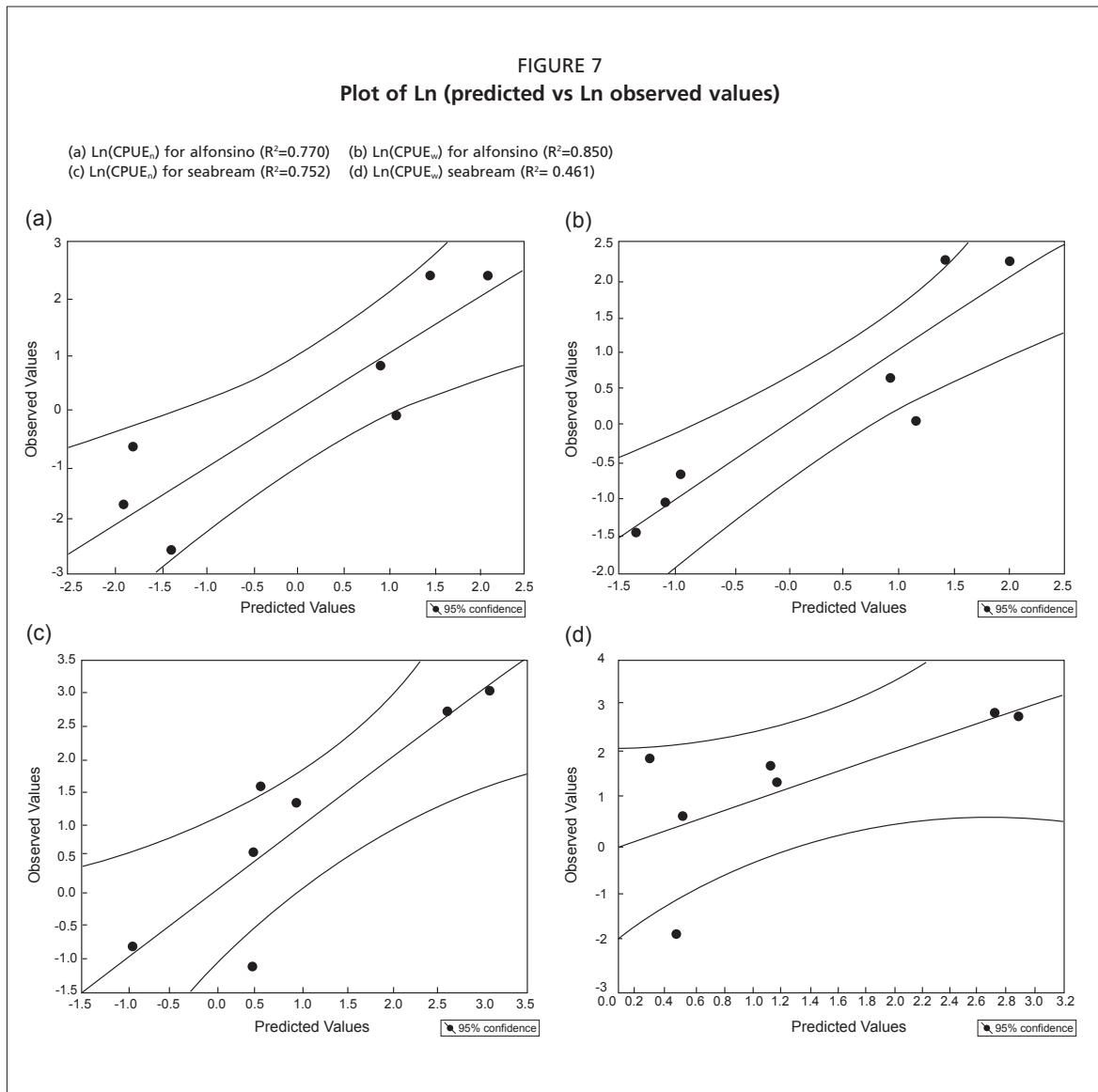
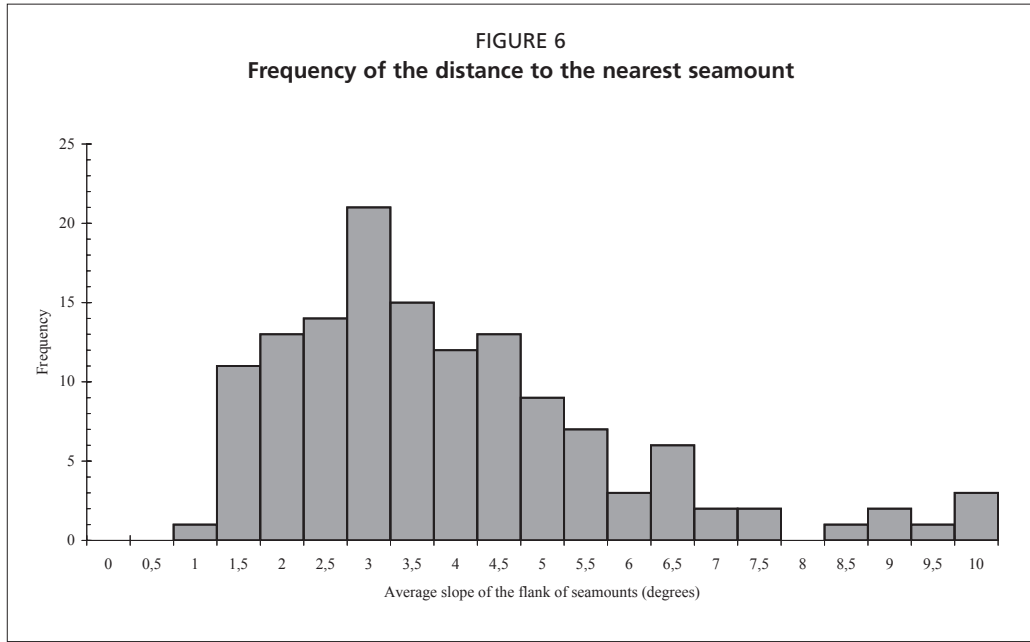


TABLE 1
Data used for deriving multiple regression models to predict abundance indices of two fish species for seamounts lacking CPUE data

Seamount names are: (a) Princess Alice, (b) Sarda, (c) Cavala, (d) Cruiser Coroa, (e) A3, (f) Monte alto, (g) Monte baixo and (h). Voador. The CPUE_n is in number of fish per 1 000 hooks and CPUE_w in kg of fish per 1 000 hooks. **Depth_h** and **depth_b** are depths of the peak and the base respectively. **Elev.** is the elevation of the seamount from the base to the peak. **Slope** is the average slope of the flanks of the seamounts. **Dist.** is the distance to nearby seamount.

Name	Lat.	Long.	Depth _h (m)	Depth _b (m)	Elev. (m)	Base area (m ²)	Area _{-850 m} (km ²)	Slope (°)	Dist. (nm)	Alfonsino		Blackspot seabream	
										CPUE _n	CPUE _w	CPUE _n	CPUE _w
a	37.89	29.28	50	700	650	1471.0	3461.0	1.72	3.03	0.17	0.35	1.80	3.93
b	37.44	33.23	350	1 700	1350	5999.7	838.0	1.77	9.68	2.18	1.95	0.42	1.84
c	38.35	30.7	450	1 400	950	447.9	110.3	4.55	4.07	0.90	1.11	20.14	15.68
d	34.16	30.29	150	1 400	1 250	765.1	433.6	4.58	5.87	11.17	9.60	0.00	0.00
e	37.4	32.11	650	1 400	750	306.8	18.7	4.34	5.32	11.19	9.52	14.66	16.18
f	37.25	31.48	450	1 000	550	590.7	392.7	2.30	4	0.08	0.53	0.32	0.16
g	37.45	31.19	700	950	250	119.4	60.2	2.32	3.2	0.50	0.23	4.83	6.33
h	37.56	30.75	350	1 000	650	521.3	148.0	2.89	5.5			3.86	5.32

TABLE 2
Statistics of the preliminary multiple linear regression

	Alfonsino		Blackspot seabream	
	$CPUE_n$	$CPUE_w$	$CPUE_n$	$CPUE_w$
Intercept	- 5.947 (2.394)	- 4.909 (1.510)	- 1.827 (2.300)	- 2.620 (3.341)
Slope				
Area₈₅₀	0.19E ⁻³ (0.54E ⁻³)	0.27E ⁻³ (0.34E ⁻³)	0.18E ⁻³ (0.47E ⁻³)	0.47E ⁻³ (0.69E ⁻³)
Slope	1.106 (0.484)	0.966 (0.305)	1.207 (0.501)	1.134 (0.728)
Index Dist.	0.490 (0.241)	0.404 (0.152)	- 0.142 (0.217)	0.076 (0.315)

S.E. in parenthesis.

method used to identify seamounts, seafloor topography from satellite altimetry and ship depth soundings, lacked resolution and thus, prevented the identification of some seamount peaks or even the whole seamount. A better, but costly, solution would be to perform extensive *in situ* depth soundings that would provide good bathymetric data for the estimation of seamounts depths (peak and base), areas and slopes. In addition, because the estimates of catch-per-unit effort were based on data for only 34 fishing events and eight seamounts and were gathered by commercial fishing boats, they lack robustness and encompass a high degree of uncertainty. To surpass these limitations, it would be desirable to expand the ongoing research fishing cruises to a larger number of seamounts in the Azores. Another weakness of this work is that some assumptions may not hold true. This is mainly the assumption that the exploration rates are similar for all seamounts. Thus, it would be desirable to include an extra parameter in the multiple regression models (e.g. a dummy variable) to express the degree of exploitation of the seamount. Moreover, the variability in fish abundances could be attributed to more physical parameters, apart from those included in this study. When taking these concerns into account, the multiple regression models presented here should be treated with caution.

The sea-bottom topography of the Azores region is complex mainly because of them increased tectonic and volcanic activities. This study showed that the Azores region is apparently dominated by ‘hills’. However, it is necessary to point out that our study did not consider all underwater features (e.g. base depths < 2 000 m, peaks < 1 200 m) and that some of the criteria used to identify seamounts established *a priori* may have biased the analysis.

Since the main topographic feature of the Azores are ‘hills’, and not ‘seamounts’ or ‘knolls’, it is likely that the study area may support a less conspicuous population of seamount aggregating fishes compared to that known for areas with similar topography in the world’s oceans (Vinnichenko 1999). Moreover, the mean peak depth (estimated at 813 m) was deeper than the maximum depth where the greatest abundance of the fish species studied is known to occur. This implies limited habitat availability for the two fish species in the region and, as a result, limitations in the area where the traditional bottom longline fleet could operate, as has been advocated by several authors, e.g. Menezes (2003). This is particularly the case for the Azorean fishing fleet, which, with the exception of few developing deepwater fisheries for *Aphonopus carbo* and *Chaceon affinis*, fishes to a maximum depth of 600 m. These fishing grounds represent less than one percent of the entire Azorean EEZ (Menezes 2003).

In the study area, most seamounts displayed gentle slopes ranging from 2° to 5°, which implies the existence of habitat favourable to benthic-dwelling fish species. Indeed, the blackspot seabream tends to inhabit gentler sloping areas and exhibits

FIGURE 8
Plot of the estimated index of abundance (kilos of fish per 1 000 hooks) for Alfonsino in the seamounts in the Azores.
Area of the circles proportional to the natural logarithm of the $CPUE_w$

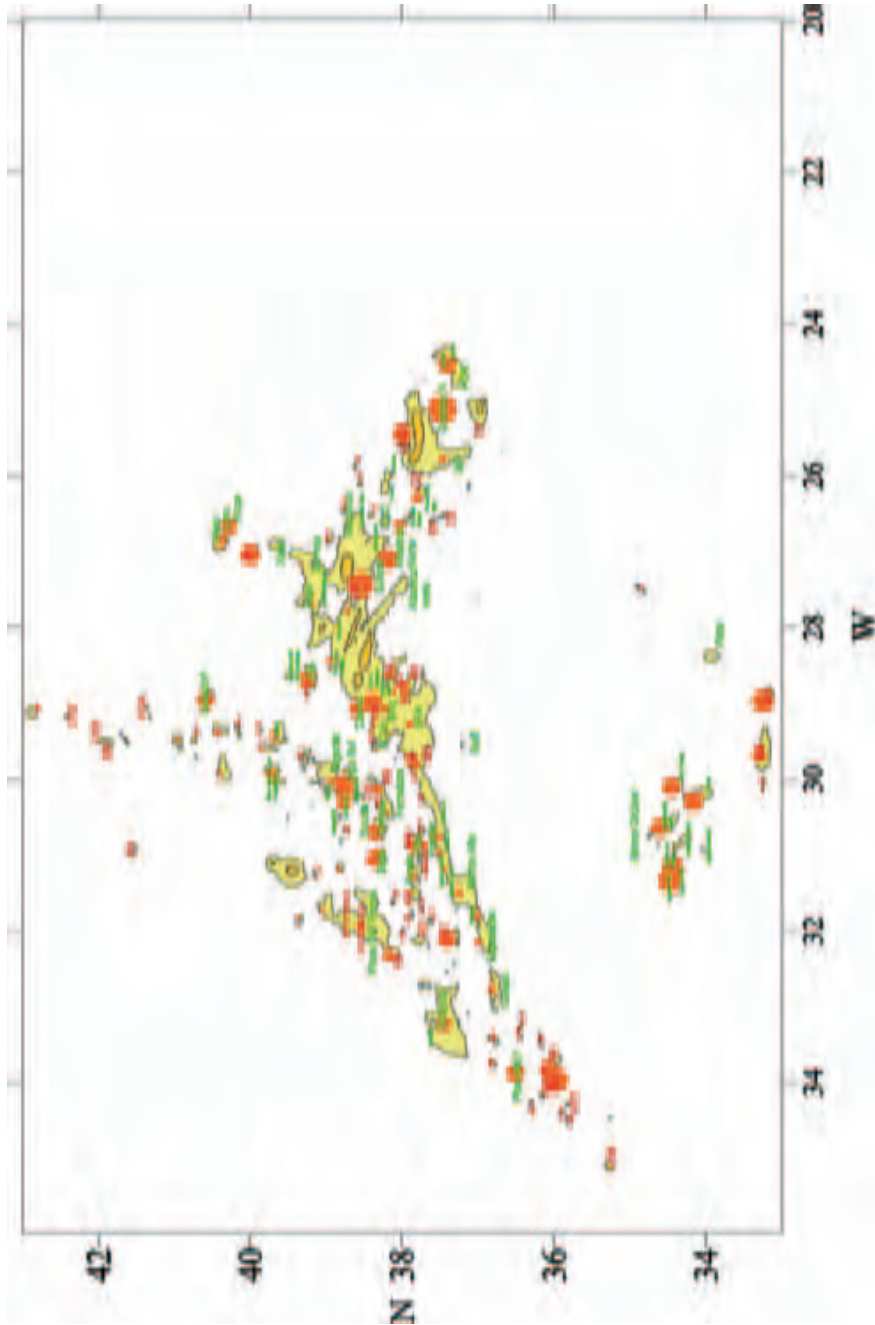
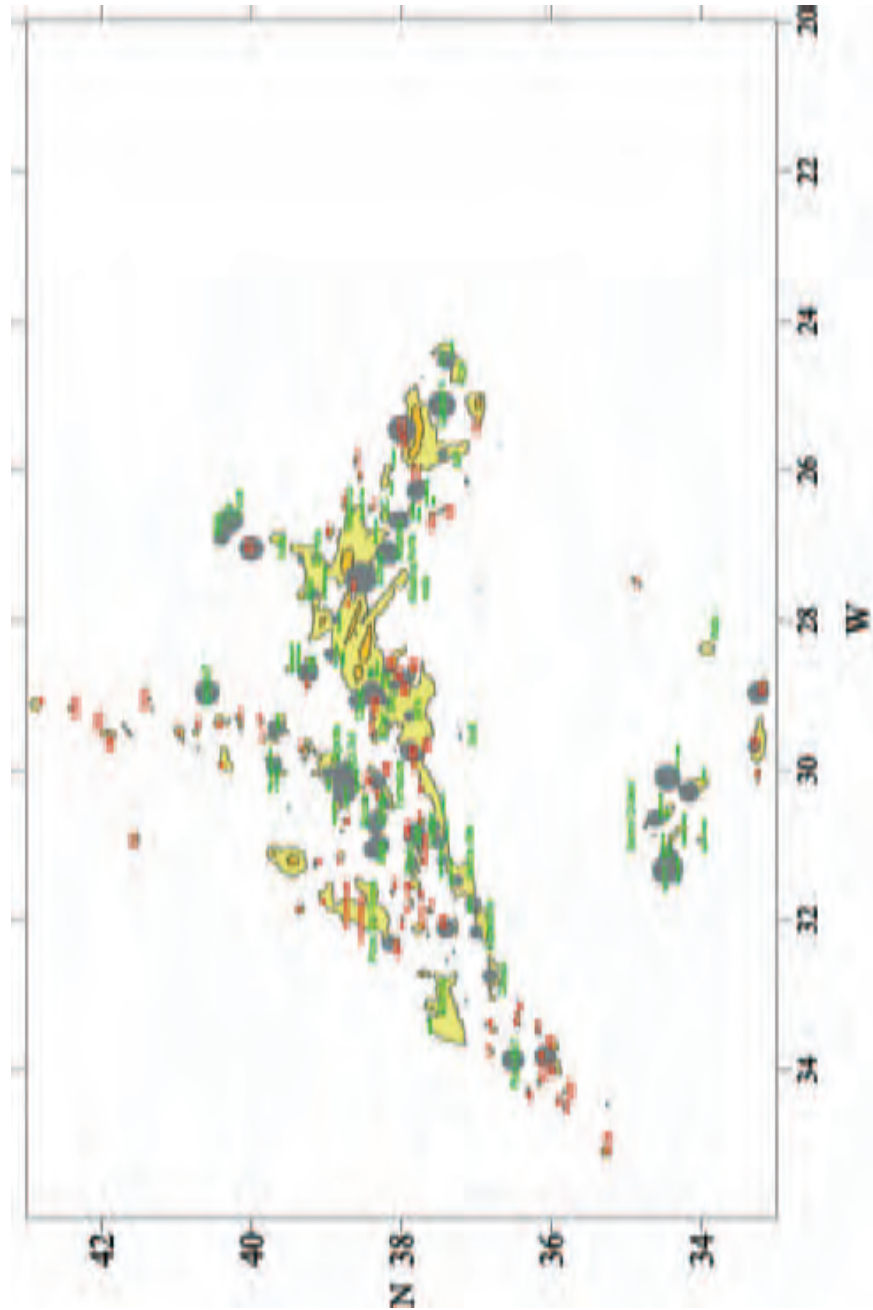


FIGURE 9
Plot of the estimated index of abundance (number of fish per 1 000 hooks) for Blackspot seabream in the seamounts in the Azores. Area of the circles proportional to the natural logarithm of the CPUE_t.



a higher association with the benthic habitat, where it feeds on fish and benthic invertebrate such as ophiurids (Morato *et al.* 2001). In contrast, gentle slopes may not provide favourable conditions for alfonsino, since it tends to aggregate along intermediate slopes of seamounts and feeds in the water column on the flux of prey organisms that pass the seamounts (Morato-Gomes *et al.* 1998) in a similar way to orange roughy (Clark *et al.* 2001).

Most of the mapped seamounts in the Azores can hardly be considered isolated since the distance among them ranged from 3 to 5 nm. For those fish populations that tend to migrate among seamounts, it is probable that the study area may provide favourable conditions for their dispersal. This may be particularly true for some demersal fish species, such as the blackspot seabream, which migrate from coastal waters surrounding islands to offshore seamounts during different stages of their life cycle (Menezes 2003, Morato *et al.* 2001). On the other hand, the lack of isolated seamounts may not provide favourable conditions for alfonsinos. This may be particularly true because isolated seamounts are likely to have a greater enhancement of primary production caused by the particular local hydrographic conditions (Genin and Boehlert 1985, Dower, Freeland and Juniper 1992, Odate and Furuya 1998, Mouriño *et al.* 2001), which results in increased prey densities (Boehlert and Genin 1987). Such food resources attract fishes, such as the alfonsino (Morato-Gomes *et al.* 1998), that prey on macroplankton and nekton. Therefore, the degree of isolation should play an important role in the formation of different habitat types, which attract fish species possessing different attributes and life strategies. For instance, overexploitation of isolated fish communities that lack the ability to migrate among seamounts could result in local extirpation of fish stocks (Menezes 2003). Thus, the degree of isolation should be seriously considered when developing management plans for seamount fisheries. The lack of isolated seamounts along with the gentle slopes of Azorean seamounts and other factors may explain the low abundance of fish aggregation species found by Vinnichenko (1999) on these seabed features.

6. CONCLUSIONS

Deepwater fisheries in general, and seamount fisheries in particular, are usually characterized by a boom and bust sequence (Koslow *et al.* 2000) with the targeted fish stocks showing signs of overexploitation within approximately ten years of the beginning of the fishery. This was the case for the orange roughy fishery off New Zealand, Australia, and the North Atlantic (Branch 2001), the pelagic armourhead fishery over seamounts in international waters off Hawaii (Sasaki 1986), and the blue ling (*Molva dipterygia*) fishery in the North Atlantic (Bergstad, Gordon and Large (s.d.)). Since fish stocks that aggregate around seamounts can be rapidly depleted, maintenance of seamount fisheries has depended on the discovery of unexploited seamounts.

There is a rising concern about threats to seamount ecosystems in the EEZ of coastal states and the high seas; and several countries, such as Canada, Australia and New Zealand, have begun to take action to protect such 'fragile' communities. In the Atlantic however, no action has been taken so far; yet, the 'Oslo and Paris' (OSPAR) Commission has listed seamounts as threatened habitats that require urgent conservation action. The developing 'OSPAR Marine Protected Areas' programme could provide some insight towards such an objective. In addition, seamounts dominated by hard substrata present in the EEZs of European Community country-members (e.g. Portugal) may also qualify as protection sites under the European Habitats Directive (1992, Natura 2000 code 1170 "reefs" in the Interpretation Manual of European Union Habitats EUR 15/2). Further action could include changes in fishing practices, such as switching from trawling (where this method of fishing is undertaken) to longlining, in order to minimize destruction of seabed habitats and associated fauna.

7. ACKNOWLEDGMENTS

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