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Short communication

Biomass removal from shore-based whaling in the Azores

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ABSTRACT

Knowledge on historical fisheries removal is essential for adopting an ecosystem approach to the management of marine resources. Shore-based whaling was an important economic activity for the Azores archipelago with 23,557 sperm whales (*Physeter macrocephalus*) captured between 1896 and 1987. The corresponding biomass is unknown because local official fisheries statistics report this extractive component in number of sperm whales and total oil production. The objective of this study was to estimate total sperm whale biomass removed during shore-based whaling operations using two different methods: (1) a function of length of males and females and (2) a function of oil extraction efficiency. The estimated sperm whale biomass removed from Azorean waters by shore-based whalers between 1896 and 1987 was 361,039 tonnes (250,297–619,561 tonnes). For the period 1950–1987, sperm whale catches represented 29% of the total biomass removed by fisheries, including whaling. At the peak of whaling activity (1950–1957), sperm whale catches were about twice the amount reported by the fisheries sector. The results show that biomass removal by whaling was important in the scope of the regional fisheries. Consequently, including sperm whale biomass extractions into the total marine fisheries catch for the Azores is of high relevance for implementing an ecosystem approach to management.

1. Introduction

The recent Marine Strategy Framework Directive[1] intends to adopt an ecosystem approach to the management of marine resources, biodiversity and habitats. Therefore a strategy based upon innovative science addressing the complexity of marine ecosystems is needed (Browman et al., 2004). The ecosystem approach to management must be built on a scientific rationale that will link ecological processes to ecosystem-level patterns (Browman et al., 2004). In doing so, it will help managers to recognize ecological limits to avoid the loss of ecosystem integrity and to maintain marine resources and habitats in viable conditions (Mullon et al., 2004).

Incorporating ecosystem approaches into marine resources and habitats management involves accounting for a number of important interactions that are not routinely evaluated. For example, bycatch, discards or mortalities of non-target species, indirect effects of harvesting on ecosystems, interactions between biological and physical components of ecosystems, among many others (Sissenwine and Murawski, 2004) are some of the forgotten components of marine systems. Thus, knowing total biomass removals from marine environments is of paramount importance for implementing an ecosystem based approach to fulfil the requirements established by the Marine Strategy Framework Directive.

Located on the mid-Atlantic ridge, the Azores is a Portuguese archipelago composed of nine islands, with a maritime territory of about a million square kilometres. Although the time of their discovery remains controversial, they were first colonized by Portuguese navigators in the early 15th century. Due to their strategic geographic location, by the 16th century the Azores had become an important centre of trade between Europe, America, Africa and India. As one might expect, fishing including whaling has always been an essential activity for the local community (Teixeira, 1981).

Two types of whaling activities, essentially targeting sperm whales (*Physeter macrocephalus*), were developed in the Azores and co-occurred for a period of time. From 1765 to the 1920s offshore whaling (also known as "American Pelagic" *sec.* Reeves and Smith, 2006) was conducted in the waters around the Azores (Clarke, 1954) mostly by whaling vessels under British and American flags (Tønnessen and Johnsen, 1982). Catches made in the Azores waters by the offshore whaling fleets are unknown and difficult to trace back (Clarke, 1954), thus were not considered in this study. Shore-based whaling was conducted by the local population from 1850s to 1987, peaking in the 1950s and steadily decreasing thereon (Brito, 2008; Clarke, 1956). In this type of whaling, lookouts on shore were used to spot the whales. The hunt was undertaken from small

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[1] Directive 2008/56/EC of the European Parliament and of the Council of 17 June 2008 establishing a framework for community action in the field of marine environmental policy (Marine Strategy Framework Directive).

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open boats using hand-held harpoons and lances. Processing of the carcasses was done on land, first using large pots over direct fire (*tryouts*) that were slowly replaced by processing plants using autoclaves. Azorean shore-based whaling was in all similar to the "American-shore" (*sec*. Reeves and Smith, 2006) and held some resemblance to the shore-based whaling conducted by the Basques in the Bay of Biscay between the XI and XVI centuries (Reeves and Smith, 2006). Shore-based whaling was the first large-scale commercial fishery developed in the Azores, peaking in the 1940s and decreasing by the 1960s as it was being substituted by the more profitable fisheries such as the pole-and-line for tuna and the handline fisheries for demersal fish species (Martin and Melo, 1983).

Catch statistics in numbers of sperm whales taken by shore-based whaling in the Azores have been reviewed by Brito (2008). Although the number of animals harvested is useful for some type of population dynamic models, biomass estimates are necessary when constructing ecosystem-based models (Pauly et al., 2000). For example, ecosystem models incorporating whale biomass have been used to evaluate the potential competition for marine resources between marine mammals and fisheries (Morissette et al., 2012), especially when commercial fisheries are thought to be negatively impacted by whale predation (Gerber et al., 2009). There is good evidence that sperm whales strongly depress and partially regulate populations of their prey and may be important players in the exchange of nutrients in the ocean (Whitehead, 2006). Additionally, whale biomass estimates are essential for understanding the role great whales have in the movement and storage of carbon in marine ecosystems and how human activities such as whaling may have impacted the oceans' carbon cycle (Pershing et al., 2010). Developing reliable and repeatable methodologies to estimate whale biomass removal by whaling is therefore essential.

Up to now, no attempts have been made to estimate sperm whale biomass removals from whaling activities in this region of the Atlantic Ocean, hampering its inclusion in ecosystem model approaches. Here we apply two approaches to estimate biomass removals from shore-based whaling in the Azores. We then proceed to compare the results obtained from each approach and discuss the dimension of the whale fishery in relation to the total biomass removed by fishing activities in the region.

2. Methods

2.1. Data sources

Historical data on the shore-based captures of sperm whales and sperm whale oil production in the Azores archipelago were compiled for the period 1896–1987 from different sources: Statistics of the maritime fisheries of the continent and adjacent islands (Anonymous, 1897–1942), Industrial statistics (Anonymous, 1943–1964), International whaling statistics (Anonymous, 1954–1984), Agriculture and feeding statistics (Anonymous, 1965–1968), Fishing statistics (Anonymous, 1969–1985), Azores statistical yearbook (Anonymous, 1983–1988), and Clarke (1954, 1956). Additionally, data on sperm whales sex and size for particular years were obtained from GAPB (Grémio dos Armadores da Pesca da Baleia), a Portuguese whalers association (unpublished data). When discrepancies were found in catch statistics from different sources, the higher values were kept. These databases refer only to shore-based whaling and do not account for whales captured by pelagic whaling fleets.

2.2. Biomass calculation

Two methods to estimate total sperm whale biomass were used: as (1) a function of mean body weights of males and females estimated from length and (2) a function of oil extraction efficiency from world catches between 1948 and 1973 (Holt, 1981).

2.2.1. Biomass from sperm whale length

Sperm whales show a pronounced sexual dimorphism, with adult males attaining much larger body weights than females (Whitehead, 2009). To account for those differences, we attempted to characterize the sex composition of the catch using data presented for the whole archipelago for different periods (1948–1954, 1968, 1969 and 1972). From 1948 to 1954 ($n = 4137$), we assumed a mean male proportion of 68.4% (range: 64.5–72.6%; Clarke, 1956). This mean male proportion was used for the subsequent calculations for the period between 1896 and 1960. From 1961 onwards ($n = 540$), we assumed a mean value of 79.6% (range: 70.0–87.7%) obtained from data for 1968, 1969 and 1972 (GAPB bulletins).

Using the GAPB bulletins length at sex data, we estimated a mean body length of 12.3 m (range: 6.0–19.0 m) for males and of 10.2 m (range: 7.0–13.0 m) for females. Mean body weights of 19.1 tonnes (range: 12.2–30.0 tonnes) for males and of 11.2 tonnes (range: 7.4–17.1 tonnes) for females were estimated using the weight–length relationship calculated by Lockyer (1976).

2.2.2. Biomass from oil extraction efficiency

The most reliable conversion ratio from oil production to biomass of sperm whale is presented in oil barrels per tonne of sperm whale (Holt, 1981). This is an indirect method that relies on the assumption that the ratio presented by Holt (1981) is representative of the oil extraction efficiency from land stations in the Azores. To account for uncertainty associated with the conversion, we used the minimum, mean and maximum values in Holt (1981) to estimate a range of whale biomass catch. Data on oil production were firstly converted to oil barrels and then to biomass of sperm whale. Data for oil production was declared in litres up to 1937 and in tonnes thereon. Data prior to 1937 was converted to weight by calculating the oil density from data for the period between 1933 and 1937, declared in both units. Values of oil density obtained for those years varied between 0.873 and 0.877. The mean value 0.876, well within the published values for sperm whale oil (Brocklesby, 1941), was used to convert volume to weight. After oil yield values were all in tonnes, they were converted to number of barrels using the standard value of 170 kg/barrel (Anonymous, 1954). Biomass of sperm whale catch was then calculated as a function of the three oil extraction efficiencies, i.e. number of oil barrels per tonne of sperm whale (Holt, 1981).

3. Results and discussion

A total catch of 23,557 whales from shore-whaling in the Azores was recorded for the period between 1896 and 1987. The slight difference from the value reported by Brito (2008; 23,525 individuals) resulted from discrepancies found in different sources. In this study, we opted to keep the higher figures found. Total estimated sperm whale biomass removals for the whole period varied between 250,297 and 619,561 tonnes depending on the estimation method (Table 1 and Fig. 1).

For great part of its shore-based whaling history, whale processing in the Azores was undertaken using very inefficient pre-industrial technology (Clarke, 1954; Figueiredo, 1996). Processing plants using autoclaves for the oil extraction were progressively introduced from 1937 to 1956 (São Miguel island factory: 1937; Faial island factory: 1942; Flores island factory: 1944; Pico island, São Roque factory: 1946; Pico island, Lajes factory: 1955; Santa Maria island factory: 1956). From 1946 onwards, more than 70% of the captures were processed in islands with factories equipped with autoclaves and it is safe to assume that the overall oil extraction efficiency increased. Therefore, the biomass estimate based on

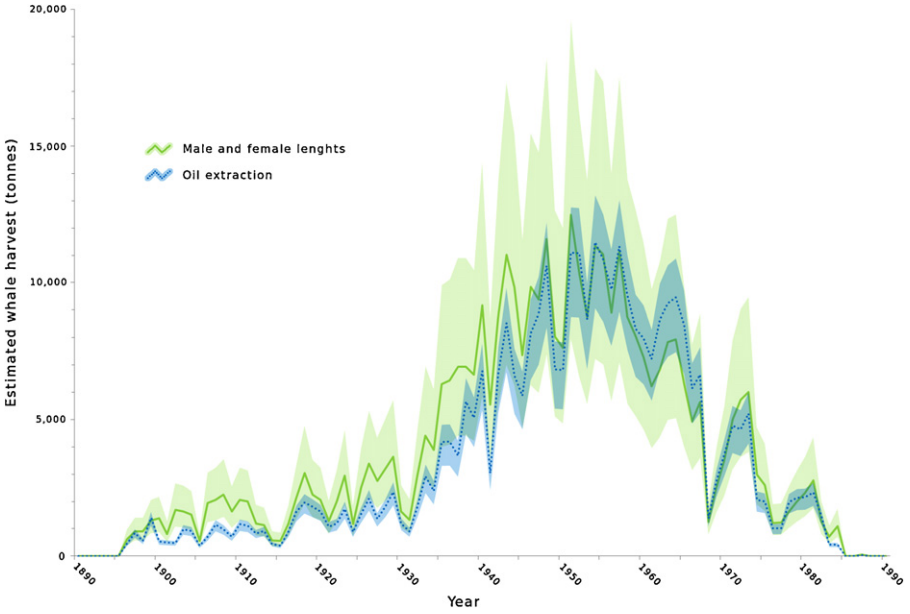

Fig. 1. Estimates of sperm whale biomass removal by shore-based whaling in the Azores from 1896 to 1987 using different methods. Shaded areas correspond to upper and lower limits of each estimation method.

the lower oil extraction efficiency is probably more appropriate for 1896–1946. For the second period (1947–1987), when the efficiency increased, biomass estimates should probably follow a value closer to the mean oil extraction efficiency. The figures calculated based on the maximum oil extraction efficiency are probably an underestimation of sperm whale biomass and are presented here as a low a limit for the uncertainty of the method.

Biomass estimates based on the sperm whales' size showed higher uncertainties when compared with the oil extraction efficiency method. The biomass from sperm whale length method was influenced by the sex-ratio adopted, the mean size by sex and by the uncertainty around the weight–length relationship. The overall prevalence of males in the estimated sex ratio may be explained by the whalers' active selection for larger animals, whenever that was possible (Clarke, 1954). Using two sex ratios for different periods (before and after 1960) is more realistic than using a static proportion: developments in hunting methods (including larger and more potent towing boats) and the decrease of the effort meant that whalers could focus on the larger animals, increasing the relative frequency of males in the catch. Although the estimated mean size of males and females may had slightly improved if more data were available, these would not have a major effect in the estimates. But, in contrast, accounting for the uncertainty around the weight at length estimation produced a large variation around the catch estimates.

Total official statistics compiled for the Azores for the period 1950–1987 suggest that commercial fishery extractions, including whaling, summed 695,458 tonnes, with annual extractions varying between 10,445 tonnes in 1968 and 24,973 tonnes in 1965 (Pham et al., 2013). Overall, sperm whale catches represented 29% of the total marine extractions for the Azores, with a maximum contribution of 65% in 1952. During this period, fisheries for small-pelagic species (*Trachurus picturatus* and *Sardina pilchardus*) and tuna were the two other principal fishing activities for the Azoreans. By the mid-1970s, sperm whale catches had decreased substantially, representing between 2% and 16% of annual marine fisheries catch including whaling. Sperm whale harvest lost its importance to the tuna and demersal fishing sectors whilst fishery for small pelagic maintained its fair contribution. The fishery for demersal resources expanded when bottom longline was introduced in the islands in the mid-1980s. In 1987, whilst commercial whaling ceased, pelagic longline targeting swordfish was initiated (Pereira, 1988).

Table 1
Total estimated sperm whale biomass removal from the Azores for the period 1896–1987 based on two different methodologies: (1) biomass from sperm whale length and (2) biomass from oil extraction efficiency (Holt, 1981).

	Biomass estimate (tonnes)		
Estimation method	Lower limit	Central value	Upper limit
Biomass from sperm whale length	250,297	393,542	619,561
Biomass from oil extraction efficiency	271,336	343,816	395,253

4. Conclusions

With this work we have successfully obtained sperm whale biomass removal by applying complementary methodologies, despite incomplete datasets. To the best of our knowledge, this was the first time that oil production was used to estimate biomass removal by whaling. We have shown that as long as the basic operational details of the activity are understood, this methodology is reliable and repeatable producing extremely useful results. Given that this method is independent of the number of animals harvested, it can be useful in situations where catch statistics are absent or incomplete. Moreover, it is applicable to any other species as long as a conversion factor from oil yield to gross animal weight is available.

The estimates from the two methods are of the same order of magnitude, although biomass estimates from sperm whale length have a much higher variation. Nevertheless, the central values estimated by the two methods are in agreement and probably represent good approximations to the biomass extracted by shore-based whaling. From the present analyses, we suggest that using a combination of minimum (for 1896–1946) and mean (for 1947–1987) oil extraction efficiencies for estimation of total sperm-whale biomass is the most valid (361,039 tonnes).

The results obtained showed that biomass removal by whaling was important in the scope of the regional fisheries in the past. As

highly movable organisms and important predators, whales likely play diverse and important ecological roles in the ecosystems they integrate. We argue that including sperm whale biomass extractions into the total marine fisheries catch for the Azores is of high relevance for implementing an ecosystem approach to management. Namely, ecosystem models of the past fitted to real data will help understanding the impact of whaling cessation on the prey species, fisheries and other components of the local marine biodiversity.

The data analysed here refers only to the shore-based whaling component and no inferences were attempted to estimate the catches by "pelagic" whaling fleets. The present assessment is thus a conservative estimate and the total biomass of sperm whales taken in the Azores is bound to be higher than that presented here. In the future, efforts should be made to integrate that fraction of the catch to have a more comprehensive idea of the real impact of whaling into the marine ecosystems in the region.

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