ICES Journal of Marine Science Advance Access published February 19, 2013

ICES Journal of Marine Science

ICES International Council for the Exploration of the Sea
CIEM Conseil International pour l'Exploration de la Mer

ICES Journal of Marine Science; doi:10.1093/icesjms/fst024

Total marine fishery catch for the Azores (1950–2010)

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Pham, C. K., Canha, A., Diogo, H., Pereira, J. G., Prieto, R., and Morato, T. Total marine fishery catch for the Azores (1950–2010). – ICES Journal of Marine Science, doi.10.1093/icesjms/fst024.

Received 18 September 2012; accepted 28 January 2013.

Official fishery statistics often fail to report what has been truly extracted from the marine environment. Therefore, in this study, we estimated illegal, unreported, and unregulated (IUU) catch in the context of a small-scale fishery (the Azores) and provide an improved compilation of official catches, including whaling. Reconstructed removals during 1950–2010 total 1.10 million t (95% CI, 1.06–1.16 million t), a factor of 1.17 higher than the amount reported in Azorean official statistics. Unreported catches were attributed to foreign fishing activities (27%), recreational fishing (25%), discards from the demersal fishing fleet (21%), baitfish for the pole-and-line tuna fishery (11%), discards from pelagic longlining (7%), local pelagic fleet landing outside the Azores (3%), coastal invertebrate harvesting (6%), and big-game fishing (0.1%). The overall low level of unreported catches compared to other locations might reflect the small-scale nature of the fisheries, the geographic isolation of the islands, and the small size of its community.

Keywords: Azores, baitfish, catch reconstruction, discards, IUU fishing, small-scale fisheries.

Introduction

Global failure in managing the world's fisheries can be partly attributed to incomplete knowledge of total fishery removals (Watson *et al.*, 2011). Fishery management measures based on official landing statistics, which only represent a portion of what is being extracted from the marine environment, are almost certain to fail (Zeller *et al.*, 2008; Pauly, 2009). The portion of the catch not accounted for in official statistics is generally referred to as "illegal, unreported, and unregulated" (IUU) catch, which, although challenging to estimate, has proven to be highly important (Ainsworth and Pitcher, 2005; Agnew *et al.*, 2009; Varkey *et al.*, 2010; Kleiven *et al.*, 2012). As an example, the unreported catch in developing countries can surpass official landing statistics by up to tenfold (Zeller and Pauly, 2007). Even in some of the most developed nations, IUU catch in particular fisheries can attain similar levels (Kleiven *et al.*, 2012). IUU catch not only includes illegal fishing, but also legal fishing practices (e.g. recreational fishing) that are not mandated to be reported and, therefore, do not enter official catch statistics (Bray, 2000). Such activities can have a severe impact on target fish populations, and in some cases can represent larger catches than from commercial activities (Coleman *et al.*, 2004; Kleiven *et al.*, 2012). Although management measures to control IUU catch have been implemented by regional fisheries management organizations (RFMOs), these have generally failed due to a lack of adequate governance (Agnew *et al.*, 2009).

General concerns also exist about the quality of the data reported in official landing statistics, especially for earlier data when catch amounts were misreported (Watson and Pauly, 2001), were not attributed to the correct species (Watson *et al.*, 2011), or when catch amounts were in number rather than weight (Lleonart *et al.*, 2006). Such discrepancies will further weaken stock assessments or ecosystem-based models used for resource management. The compilation of the best available official statistics, together with the estimation of IUU catch, to provide total catch time-series, is of great value for accurate management of natural resources, and there has been a large effort to reconstruct fishery catches around the globe (Zeller *et al.*, 2006a, 2006b, 2007; 2011a; 2011b; Wielgus *et al.*, 2010).

Contrary to large-scale fishing, many small-scale fisheries are good examples of long-term sustainable fishing (Pitcher *et al.*, 2010). These fisheries may have a number of attractive features including good management practices and compliance with management regulations. In the Azores, small-scale fishing operations, as defined by Carvalho *et al.* (2011a) (i.e. boats < 12 m in length), are responsible for the greater part of the total landed volume. Pitcher *et al.* (2010) have suggested the Azores to be one of

those places with a thriving local fresh-fish market and a local community where local fishers increased political pressure to legislate and implement local regulations, thus improving management practices and compliance. Whether these good management practices and compliance in small-scale fisheries may be reflected in the level of unreported catch is still unknown.

The Azores has an efficient and unique system for fishery data collection dating back to the 1970s. With the exception of part of the pelagic longline catch landed outside the Azores, and tuna going directly to processing factories, all catches by Azorean vessels must be landed at the auction houses distributed throughout the islands. These auction houses all belong to one company (Lotaçor SA) that is responsible for transferring all landings data to local authorities. Tuna-processing factories must also report all landings to Lotaçor SA. The unique commercial fishing activity not entering local statistics is the catch of pelagic longliners landed outside the Azores by regional vessels and other Portuguese and foreign fleets. Even though they may possibly be reported elsewhere, such removals are combined with catches from other areas and are difficult to trace.

The objectives of this study were twofold: (i) to provide a complete and accurate compilation of official catches from 1950 to 2010, including whaling, and (ii) to estimate IUU catches in Azorean waters and place them in a global context. Catch amounts arising from foreign fleets are also included. The overall goal of this study was to understand if small-scale fisheries such as those in the Azores are efficient in controlling the level of unreported catch.

Material and methods

The methodologies used for reconstruction of the Azores catch were adapted from Pitcher *et al.* (2002) and Zeller *et al.* (2006a, 2007), and consisted essentially of six general steps: (i) identification of existing locally reported catch time-series (National Institute of Statistics of Portugal; Regional Services of Statistics of the Azores); (ii) identification of fisheries sectors, time-periods, species, and gears not covered in Step (i); (iii) search for available alternative information sources containing additional data or qualitative information related to items identified in Step (ii); (iv) development of data anchor points in time for missing data items; (v) interpolation for time-periods between data anchor points for missing data items; and (vi) estimation of final total catch time-series. Additionally, 95% confidence intervals of the catch were estimated separately for each component.

Study area and fishing sector

The Azores is a Portuguese archipelago composed of nine islands, with a maritime territory encompassing nearly a million square kilometres and for which marine resources are central to the local economy (Figure 1). With the absence of a continental shelf and surrounding great depths, fishing occurs around the island slopes and the many seamounts present in the area (Silva and Pinho, 2007; Morato *et al.*, 2008). Commercial whaling was the first large-scale commercial fishery, peaking in the 1940s and decreasing by the 1960s, being substituted with the more profitable fisheries such as the pole-and-line tuna and demersal fisheries using handlines (Martin and Melo, 1983).

The Azorean fishing industry saw significant changes during the 1980s as bottom and surface longlines were introduced (Pereira, 1988a; Menezes, 1996). The 1980s were also crucial for the fishing industry, as the expansion in air transportation allowed exportation of fresh fish products abroad. In 1986, Portugal joined the European Economic Community (EEC), creating new trade opportunities for Azorean products. Furthermore, as an outermost region of the European Union (EU), the Azores benefited from large public subsidies (Carvalho *et al.*, 2011b). Subsidies for fleet renovation resulted in the introduction of modernized and larger boats built from materials other than wood and equipped with highly technological equipment such as radar and sonar, with increased storage capacity and autonomy which allowed an expansion of fishing activities farther offshore and into deeper waters (e.g. Pinho *et al.*, 2001; Machete *et al.*, 2011). In parallel, a series of ports and landing sites with cold-storage facilities were constructed (Silva *et al.*, 1994; Menezes, 1996).

Today, the Azorean fishing industry is composed of four main components: a small-net fishery for small pelagic species (blue jack mackerel, *Trachurus picturatus*, and chub mackerel, *Scomber colias*) with total catch of 1500 t in 2010 (data obtained from Lotaçor, 2011), a pole-and-line tuna fishery (14 000 t in 2010), bottom longline and handline targeting demersal fishes (3000 t in 2010) and pelagic longline targeting swordfish (*Xiphias gladius*) (150 t in 2010). There were no reports of cetacean bycatch in these fisheries (Silva *et al.*, 2011).

The current fishery resource management strategy of the Azores is based on the EU Common Fishery Policy, implemented primarily through total allowable catches (TACs) for various species including blackspot seabream (*Pagellus bogaraveo*), alfonsinos (*Beryx splendens* and *B. decadactylus*), and deepwater sharks such as *Deania* spp., *Centrophorus* spp., *Etmopterus* spp., *Centroscymnus* spp., and kitefin shark (*Dalatias licha*) (EC Reg. 2340/2002; EC Reg. 2270/2004). Apart from fish quotas, the regional government of the Azores has implemented technical measures over the years, such as minimum landing sizes or weights, minimum mesh sizes, limitation of licences for some specific gears (e.g. trammel nets), area and temporal closures, and bans on the use of specific gear. An example is the Azores regulation that prohibited deep-sea trawling, which recently became an EC regulation (EC 1568/2005).

Reported landings in the Azores

Reported in local statistics

Official catch statistics for the Azores were obtained from various landings databases. For the period 1950–1980, data from the Fisheries Statistics of Mainland and Adjacent Islands (Anon., 1950–1971, 1971–1983) was used. For 1981–1992, official statistics were obtained from Lotaçor SA, while for 1993–2010, they were obtained from the database maintained by the Department of Oceanography and Fisheries, University of the Azores (DOP/UAç) in conjunction with Lotaçor SA. Grouped catch data (e.g. miscellaneous fish and crustaceans) were disaggregated to the species level according to the species reported in subsequent years, their relative proportions, and expert knowledge (see Supplementary material for details). When available, various reports and grey literature were used to complement the official statistics compilation, especially since taxonomic resolution of early statistics was not accurate. Official catch statistics for tunas for the period 1950–1992 were obtained from Pereira (1995). For the period 1987–1992, official swordfish catches were obtained from Simões (1995), who distinguished between catches originating from the Azorean fleet and those from other Portuguese fleets. Official catch data for small pelagic species

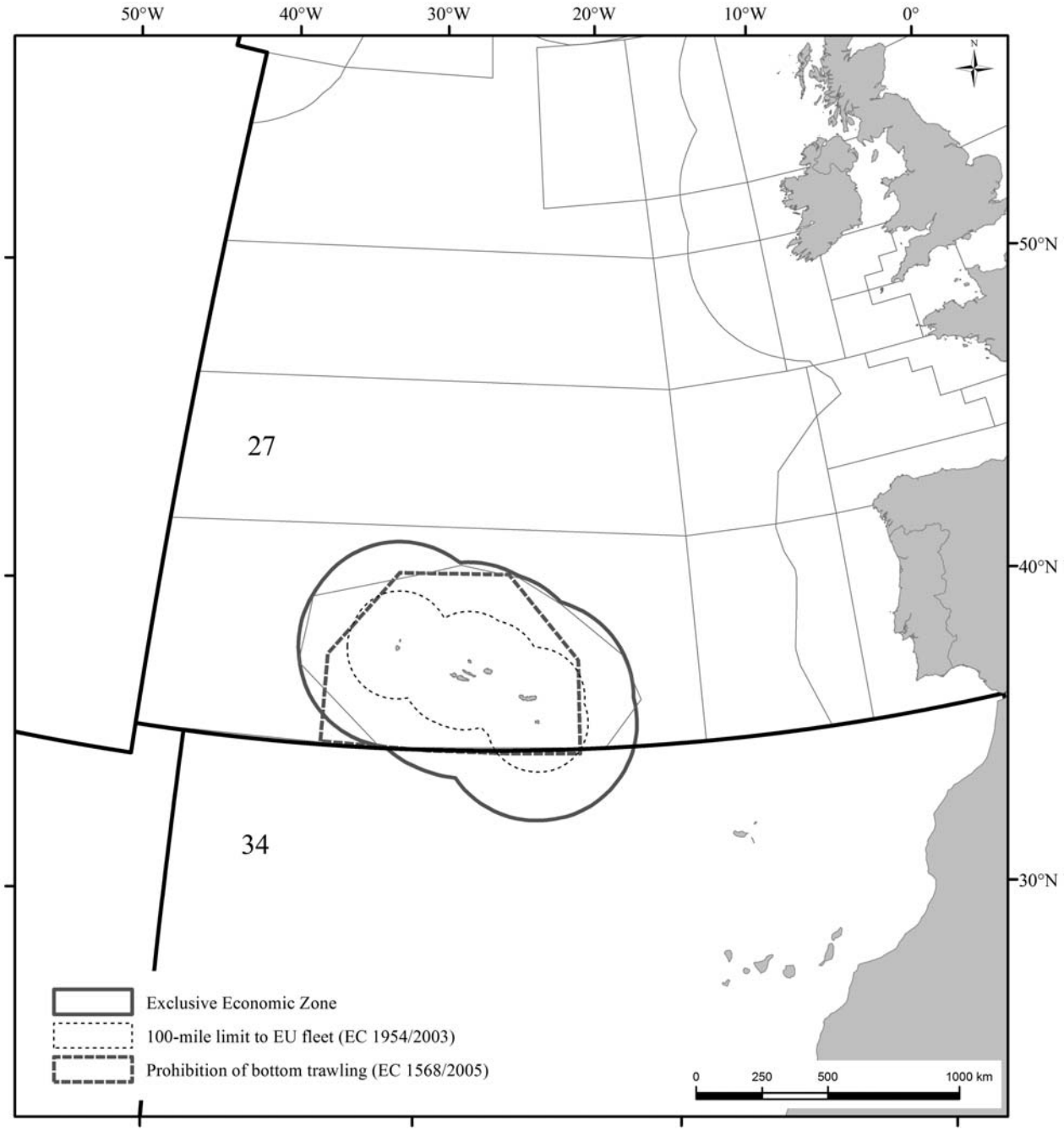

Figure 1. The Azores archipelago, its exclusive economic zone, 100-mile limit to EU vessels, area prohibited to bottom trawling, FAO statistical area, and ICES rectangles.

(blue jack mackerel; chub mackerel; European pilchard, *Sardina pilchardus*; and bogue, *Boops boops*) were obtained from Isidro (1996). The kitefin shark catch statistics presented by Silva (1987b) were used for the period 1971–1986.

Reported by FAO

Most of the Azorean maritime territory is located within FAO Statistical Area 27 with the exception of the southernmost part, which lies within Area 34 (Figure 1). However, the Azorean fleet operates almost exclusively within Area 27. Being a Portuguese archipelago, catches from the Azorean fleet are not distinguished from those of mainland Portugal and Madeira in the statistics reported by FAO. The catch amount reported to FAO by the Azorean fleet was estimated by matching the species present in local official statistics with the ones reported by FAO. When a particular taxon was not reported by the FAO, the catch was attributed to the next taxonomic level. When no match was possible, the remaining catch amount was considered to be unreported.

Shore-based whaling

Historical data on the shore-based captures of sperm whales (*Physeter macrocephalus*) and sperm whale oil production in the Azores archipelago were compiled from different sources,

including the Fisheries Statistics from the Mainland and Adjacent Islands (Anon., 1950–1971, 1971–1983), International Whaling Statistics (Anon., 1954–1984), the Azores Statistical Yearbook (Anon., 1983–1988), published reports (Clarke, 1954, 1956), and unpublished data (Silva, 1987a). Official statistics are only available as total number of sperm whales captured and total amount of oil production. Biomass of sperm whale catch for the period 1950–1987 was calculated using the mean oil extraction efficiency for world catches between 1948 and 1973 calculated by Holt (1981). The details of the methodology were reported by Prieto *et al.* (2013). Mean oil extraction efficiency was considered the most appropriate method, considering almost all Azorean processing factories after 1950 were equipped with autoclaves (Prieto *et al.*, 2013).

Illegal, unreported, and unregulated (IUU) catch

Bottom longline and handline – fleets landing in the Azores

Total unreported catch from the bottom longline fishery, such as discarded, consumed by the crew, offered, or used as bait, was estimated based on data collected by fishery observers from 2004 to 2010 (Observer Programme for the Discards in Azorean fisheries; PORPESCA). For the purpose of this study, we assumed 100% mortality for all species throughout the study period since observers reported 100% mortality for discarded fish. Observer data were used to estimate discarded proportions based either on landings of individual species (Table 1) or total landings for all demersal fish (see Supplementary material). From 1950 to the mid-1980s, the inshore handline was the main bottom fishing gear in use until the bottom longline was introduced in 1984 (Menezes, 1996). Therefore, discard rates from 1950–1983 were calculated using discard proportions from observers, but applied only to inshore species. For 1984–2010, total discards were estimated using the discard rates for all species reported by observers. For years when the TAC for alfonsinos was exceeded (2007–2010), discard rates were adjusted according to the number of months the fishery was closed (see Supplementary material).

Table 1. Target species of the Azorean bottom longline fishery and associated discard rate (% of landings) based on observer data between 2004 and 2010.

		Discard rate (%)		
Taxon name	**Common name**	**min**	**average**	**max**
Beryx decadactylus	Alfonsino	1.7	6.2[a]	10.7
Beryx splendens	Splendid alfonsino	13.0	18.2[a]	23.3
Conger conger	European conger	12.7	17.5	22.4
Epigonus telescopus	Bulls-eye	3.2	13.1	23.0
Galeorhinus galeus	Tope shark	0.0	11.4	22.9
Helicolenus dactylopterus dactylopterus	Black belly rosefish	8.4	13.9	19.3
Lepidopus caudatus	Silver scabbardfish	37.7	135.7	233.7
Molva macrophthalma	Lings	1.7	17.8	34.0
Mora moro	Common mora	1.2	5.7	10.1
Muraena helena	Mediterranean moray	6.5	19.1	31.6
Pagellus bogaraveo	Blackspot seabream	2.0	3.0	4.1
Pagrus pagrus	Common seabream	0.8	1.4	1.9
Phycis blennoides	Greater forkbeard	1.3	3.5	5.7
Phycis phycis	Forkbeard	4.3	7.8	11.2
Polyprion americanus	Wreckfish	0.1	0.4	0.8
Pontinus kuhlii	Offshore rockfish	2.6	5.0	7.4
Raja clavata	Thornback ray	9.1	30.6	52.0
Scorpaena scrofa	Largescaled scorpionfish	0.0	0.9	2.0

[a]Discard rate value when the fishery is opened. For years when the TAC has been exceeded, discard rates were adjusted according to the month when the fishery was closed.

Bottom longline and handline – fleets landing outside the Azores

Between 1991 and 1998, eight boats from mainland Portugal obtained licences to catch silver scabbardfish (*Lepidopus caudatus*) within Azorean waters. The catch was landed in mainland Portugal and not included in the Azores official catch statistics. Catch data for these boats were obtained from logbooks and landing data in mainland Portugal (Gui Menezes, unpublished data).

Pelagic longline – fleets landing in the Azores

Pelagic longlines targeting swordfish were first introduced in the Azores in 1987 (Pereira, 1988a), for which blue sharks (*Prionace glauca*), short-fin mako sharks (*Isurus oxyrinchus*), and loggerhead sea turtles (*Caretta caretta*) are the principal discarded species (Simões, 1998). Other pelagic organisms are occasionally caught by this gear but the sum of their catch never exceeds 1% of the total catch. Therefore, other pelagic organisms were not considered in the reconstruction. Estimation of shark discards was based on logbooks available between 1992 and 2010 (João Gil Pereira, unpublished data). Analysis of the data suggests that a typical longline set (~1000 hooks) catches an average of 0.44 t of swordfish, 1.18 t of blue shark, and 0.04 t of short-fin mako shark. Bycatch of loggerhead turtles was estimated assuming a mean number of turtles per fishing set of 1.4 (Marco Santos, unpublished data) and an individual weight of 19.8 kg (Bjorndal, Bolten, and Martins, unpublished data). These estimates are slightly higher than those reported by Ferreira *et al.* (2001), but were obtained from a longer period, covered more longliners, and thus were considered more realistic. Not all sea turtles caught by the pelagic longline fleet die, but no estimates of hooked loggerhead mortality after gear removal are available for the Azores. For the purpose of this study, we adopted a mortality rate of 30% (Lewison *et al.*, 2004), which was considered the most appropriate for the local fishery (M. Santos, pers. comm.). Assuming such proportions to be constant back in time, and considering swordfish is rarely discarded (Simões, 1998), total shark and turtle bycatches were extrapolated from official swordfish catches. For shark species, the amount discarded was obtained by subtracting catches reported in official statistics from the total estimated catch. From 1993 onwards, blue shark meat gained commercial value (Simões, 1995), and discards decreased as Azorean boats began to land a portion of their catch outside the Azores (see section below).

Pelagic longline – fleets landing outside the Azores

Since 1993, Azorean boats with large storage capacities targeting swordfish in Azorean waters have travelled to Spain or mainland Portugal to land part of their catch (Simões, 1995). These catch data are not transferred to official Azorean statistics and are very difficult to trace as they enter general Portuguese statistics without being attributed to Azorean waters. Data from logbooks (available for 1992–2010) were used to estimate the catch amount captured in Azorean waters, but landed elsewhere

(João Gil Pereira, unpublished data). Analysis of logbook data suggests that an average of 30% of the swordfish captured in Azorean waters are landed outside Azorean auction houses. With this figure, landing statistics of Azorean auction houses were used to estimate the remaining fraction landed outside the Azores. After having estimated total swordfish catches, the bycatch of blue shark and short-fin mako shark were also estimated using catch proportions from logbook data (see above).

Boats from mainland Portugal began pelagic longline fishing for swordfish within the Azorean exclusive economic zone (EEZ) in 1987. The amount landed outside the Azores was estimated using logbook data for the period 1987–2005 (João Gil Pereira, unpublished data) and vessel monitoring system (VMS) data for the period 2006–2010 (Morato *et al.*, unpublished data). Analysis of logbooks suggested that 21% of the swordfish caught in Azorean waters were landed in the Azores, while the rest were landed in Spain or mainland Portugal. This is also supported by Simões (1995), who reported that only 4 out of the 20 boats (20%) from the mainland operating in the Azores in 1993 landed their catch there. From 2006–2010, total swordfish catches were estimated by combining the number of fishing sets estimated by VMS data and a mean catch per set estimated from logbook data. The amount of swordfish landed outside the Azores was then calculated by subtracting the catch landed in the Azores for boats from mainland Portugal obtained from Simões (1995) and the DOP/UAç database from the estimated total swordfish catch. Blue shark, short-fin mako shark, and sea turtle bycatch was estimated as above.

Spanish pelagic longliners have been fishing in the Azores since 1968, but stopped in 1980 following the establishment of the 200-nautical mile EEZ in 1977 (Rey, 1987). The Spanish fleet returned to Azores waters in 2004 when European vessels were allowed to fish to within 100 miles of the Azores, as a result of the Western Waters Regulation under the Common Fisheries Policy (EC 1954/2003). Landings by Spanish vessels in Azorean harbours are extremely rare as most boats land their catch in Spain. Apart from three occasional landings that never exceeded 1 t, there are no official landing records for Spanish fishing activities in Azorean waters. Catch estimates (for the period 2006–2009) based on VMS (Morato *et al.*, unpublished data) and observer data for Spanish vessels (Vandeperre *et al.*, unpublished data) suggested that an average of 16% of the Spanish catch in the Northeast Atlantic declared by the International Commission for the Conservation of Atlantic Tunas (ICCAT) lies within the Azores 200-mile limit. Assuming this proportion is similar for past years, the catch for 1968–1980 was calculated using ICCAT catch data for the Northeast Atlantic. Rey (1987) reported that, during this period, swordfish represented 40% of the total catch from pelagic longline, and the remaining 60% was composed primarily of blue shark and short-fin mako. With this proportion, total shark catches were estimated. For recent years, observer data reported that swordfish catches by Spanish pelagic longliners represent ~20% of the total catch (F. Vandeperre, pers. comm.). In order to distinguish between the two shark species, the proportion recorded by observers in more recent years was applied to the total catch (94% blue shark, 6% short-fin mako). The same methodology was used to estimate catches for 2004–2005, when the Spanish fleet was allowed to fish to within 100 miles of the Azores, but no VMS data were available. In a similar approach to that used for the Portuguese fleet, VMS data for the period 2006–2010 permitted the identification of the number of vessels operating in Azorean waters (from 37–46 annually) along with the total number of longline sets executed. Using onboard observer data on the average weight of swordfish, blue shark, and short-fin mako shark caught per set, the total weight of each species could be estimated for 2006–2010. Turtle catches were estimated as above.

Pole-and-line

IUU catches for tuna species (skipjack tuna, *Katsuwonus pelamis*; yellowfin tuna, *Thunnus albacares*; bigeye tuna, *Thunnus obesus*; albacore, *Thunnus alalunga*; Atlantic bluefin tuna, *Thunnus thynnus*) are almost non-existent; tuna go directly to processing factories or the fish auction system, and there were no reports of bycatch of any sort, including cetaceans (Silva *et al.*, 2011). On the contrary, the amount of baitfish used by the pole-and-line fishery is not reported to local authorities, remaining largely unknown and unmanaged. For the purpose of this study, the estimation of total baitfish catches was based on data collected by observers onboard tuna fishing boats from 1998–2010 (POPA – Programa de Observação para as Pescas dos Açores; Machete and Santos, 2007). Since the fishery observer programme covers only a portion of the tuna fishing activity every year (usually around 50% of the total tuna catch per year), the first step was to estimate baitfish catches for that portion of the fleet not covered by the observer programme. This was done by extrapolating the baitfish catch amounts covered by the observers to the missing fraction. For years not covered by the observer programme, the estimation of baitfish catch was based on linear and non-linear relationships between tuna catch and baitfish catch obtained for the period 1998–2010 using the observer data (see Supplementary material). The baitfish catch was attributed to particular species based on yearly proportions reported by observers for each tuna species.

Trawling

In 2001, one large bottom trawler from the company S. Macário Indústria de Pescas Lda was allowed to undertake an experimental fishery for orange roughy (*Hoplostethus atlanticus*) within the Azores EEZ (Melo and Menezes, 2002). All catches were recorded by observers and included in this study.

Between 1973 and 1977, the Soviet Union undertook some fishery expeditions at various seamounts in the Northeast Atlantic using bottom trawls. Catch data from these vessels were reported by Vinnichenko (2002), but there is no information on the location of the trawls, namely those inside the Azorean EEZ. However, since a map of the fishing areas was presented, we have estimated that 25% of the total fished area was within the 200-mile EEZ of the Azores. Thus, 25% of the reported catch was assumed to have originated in the Azores.

Commercial harvesting of coastal invertebrates

A wide variety of small invertebrates are consumed by the local community, constituting an important resource for all the islands (Santos *et al.*, 1995). The main invertebrate species include patellid limpet (*Patella candei* and *Patella aspera*), common octopus (*Octopus vulgaris*), spiny lobster (*Palinurus elephas*), giant barnacle (*Megabalanus azoricus*), slipper lobster (*Scyllarides latus*), and some crabs (e.g. *Maja squinado*, *Grapsus grapsus*). With the exception of limpet in the 1980s, these species are not exported and are traditionally sold to local restaurants and households without entering the official statistics

(Ferraz *et al.*, 2000). Limpet and octopus are by far the most commonly captured invertebrates and were the only species included in this study. Giant barnacle, slipper lobster, spiny lobster, and other crabs are collected to some extent, but estimation of their catch is extremely challenging and hard to verify.

Limpet harvesting in the Azores was divided into two components: those collected by hand in the intertidal zone during low tide, and those harvested by snorkel-divers (Martins *et al.*, 1987). Since snorkelling began in the Azores in 1970 (Martins *et al.*, 1987), limpets were assumed to be harvested strictly by hand from 1950–1969 and harvested using both techniques from 1970–2010. Estimates of limpet harvest were complex due to the sparse availability of data and diverse types of protocols used to estimate abundance. A detailed description of the methods used to estimate limpet harvest is available in the Supplementary material. In general, we have used (i) catch-per-unit-effort for hand collecting (Diogo, 2007) and snorkelling (Santos and Santos, 2005), (ii) harvest levels for different islands based on their population size and recreational index (see Supplementary material), and (iii) interannual variability in abundance measured by *in situ* sampling (Ferraz and Menezes, 1998, 1999; Ferraz and Santos, 2000; Santos and Santos, 2005; Delgado *et al.*, 2006) or mean weight-per-landing event from official landings data. We have also considered sporadic events reported in the literature, such as a limpet stock collapse on São Miguel Island in 1988 and 1989 (Ferraz *et al.*, 2001), and a strong decrease in limpet abundance in the central group of the archipelago in 1982–1987 that was partly attributed to a disease (Ferraz *et al.*, 2001).

Common octopus harvest was reconstructed based on inquiry data by Gonçalves (1993) adjusted on a yearly basis for the number of octopus fishers (according to the total Azorean population registered each year) and an abundance index derived from official catch statistics (see Supplementary material).

Recreational fishing

The main recreational fishing activities in the Azores are spear fishing, boat fishing, coastal rod fishing from shore, and hand collecting (Diogo, 2007). The anchor point using 2004 as the reference year of *per capita* recreational catch and species composition was obtained from Diogo (2007). The estimated spear fishing and boat fishing catch for Faial and Pico was extrapolated for other islands using the number of licences for both activities. For line fishing from shore and hand harvesting activities (for which licences are not mandatory), we used an indirect method based on a recreational index calculated for each island (see Supplementary material). Total estimated catch for these activities in 2004 was 471 t. Using this anchor point, catches from the recreational sector were estimated for other years by modifying two factors from the estimation of Diogo (2007): (i) natural abundance of target species, and (ii) number of fishing events, i.e. fishing effort. Species abundance was adjusted yearly according to the official commercial landings reported from the artisanal sector for the species that are targeted by recreational activities. The number of operations was adjusted according to the total Azorean population for each year. We also considered time of appearance and relative importance of the three activities to adjust species catch estimates. For example, spear fishing began in the 1970s in the Azores (H. Diogo, pers. comm.), coastal rod fishing was extremely important in the past, whilst boat fishing only appeared after engines were introduced. Therefore, catch by spear fishing was estimated from 1970, whilst the importance of boat fishing was adjusted using the number of commercial boats with engines as a proxy for the importance of recreational boat fishing.

Big-game fishing

Game fishing for large pelagic fish began in the mid-1980s (Pereira, 1988b), peaked in the 1990s, with up to eight boats registered on the island of Faial, and is still active today (L. Gallagher, pers. comm.). With the exception of one report briefly describing the activity from 1984–1987 (Pereira, 1988b), there is little data on total fish removal. In the early days, most of the blue marlin (*Makaira nigricans*) caught were landed, but by 1989, big-game fishing became essentially a catch-and-release activity. For recent years, total blue marlin mortality rarely exceeded two individuals per boat per year. Estimation of total removals by this activity was based on (i) data available from Pereira (1988b) for the period 1984–1986; (ii) landings reported by ICCAT for 1987–1988 and 1993–1996; and (iii) information exchanged from Captain Les Gallagher who, since his arrival in the Azores, registered the number of boats conducting this activity on Faial (the main harbour for this activity). For the periods 1989–1992 and 1997–2010, total catch of blue marlin per year was calculated using the number of boats registered by Captain Gallagher and assuming (i) an annual catch of two blue marlin per boat, and (ii) a mean weight of 210 kg (Pereira, 1988b). White marlin (*Kajikia albida*) biomass was estimated assuming a catch rate of this species to be 20% that of blue marlin (as reported by Pereira, 1988b) and a mean individual weight of 30 kg (Amorim and Arfelli, 2001).

Results

Reported landings

Reported by local statistics

Official statistics for the period 1950–1981 included catches for only 21 species and contained large amounts of unidentified fish, molluscs, or crustaceans (34 500 t). This amount was successfully allocated to 34 new species believed to have been landed during that period (Figure 2). From 1981 to 2001, catch data reported as aggregated groups were attributed to 7 new species.

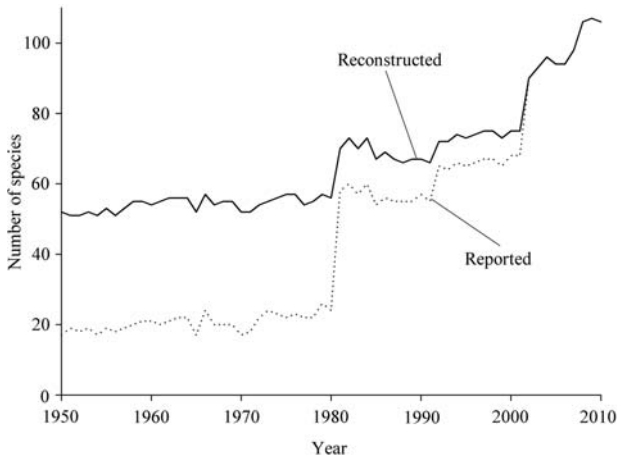

Figure 2. Reported and reconstructed number of species for official fishery statistics of the Azores between 1950 and 2010.

After allocating catch to the species level, the total amount of unidentified catch for the period 1950–2010 was reduced from 34 500 t to 1862 t (1950–2010). Overall, the number of species landed in the Azores increased from about 55 in 1950–1980, to 71 in 1981–2001, and to about 106 in 2010. The overall increase in the number of species reflects the introduction of new fishing gear (e.g. bottom and pelagic longline in the 1980s), the exploitation of new fishing grounds, and the increased value of some species around the year 2000. A list of all reconstructed species and their corresponding annual catch is available in the Supplementary material.

A total catch of 11 621 sperm whales from shore whaling in the Azores was recorded for the period 1950–1987. Using the mean oil extraction efficiency, the equivalent estimated sperm whale biomass removal since 1950 was 202 377 t, varying between 11 480 t in 1954 and 65 t in 1987, when the last sperm whales were captured.

Official statistics compiled for the period 1950–2010 suggest a total extraction of 945 000 t, ranging from 7141 t in 2001 to 24 973 t in 1965. From 1950 to 1987, sperm whale catches represented 29% of the total reported marine extractions, with a maximum of 65% (11 095 t) in 1952 (Figure 3). During this period, fisheries for small pelagic species (blue jack mackerel and European pilchard) and tuna were the two other main fishing activities for the Azoreans. The official catch of small pelagic fish fluctuated between 1865 t in 1952 and 5276 t in 1965. Catches of tuna increased from 825 t in 1950 to 7400 t in 1984, when subsidies for fleet renovation allowed the introduction of larger fibreglass boats (Pereira, 1995). By the end of the 1970s, sperm whale catches had decreased substantially, being replaced by the more profitable tuna and demersal fishing sectors, whilst the fishery for small pelagics maintained its fair share. The fishery for demersal resources expanded when the bottom longline was introduced in the islands in the mid-1980s, with total catches varying between 3345 t in 1984 and 5711 t in 1995. In 1987, whilst commercial whaling had been phased out, pelagic longlining targeting swordfish was initiated (Pereira, 1988a). Despite its high market value, the contribution of swordfish to the total catch is small (<5%), varying between 60 and 632 t per year.

Reported by FAO

From 1950–2010, the total catch reported by the FAO for the Azores was 710 906 t. This amount is 234 271 t less than what was obtained from local Azorean official statistics, the difference being largely due to the absence of sperm whales and algae in the FAO statistics. Excluding these two components, only 7091 t were missing from the catch reported by FAO. Deep-water sharks (nine species) and demersal fishes (four species) were the principal groups missing from the FAO reports. A total of 95% of the missing fraction was identified between 1950 and 1985.

Illegal, unreported, and unregulated (IUU) catch

Bottom longline and handline – landed inside the Azores

Total discards from the demersal fishery were estimated to be 35 000 t (95% CI, 20 000–60 000 t) for the period 1950–2010, representing 32% of the landings reported by the fishery. The level of discards varied considerably during the study period (Figure 4). The estimated discards from 1950–1983 corresponded to an average of 13% of the reported catches for demersal species per year, ranging from 134–350 t per year (Figure 4). The major discarded species during this period were European conger (*Conger conger*) (average of 65 t per year), silver scabbardfish (average of 25 t per year), forkbeard (*Phycis phycis*) (18 t per year), and black belly rosefish (*Helicolenus dactylopterus dactylopterus*) (13 t per year). For the period when bottom longlines and handlines were both in operation (1984–2010), yearly discards ranged from 16% of the reported landings in 2005 to 49% in 1997. During this period, total unreported catches from the bottom

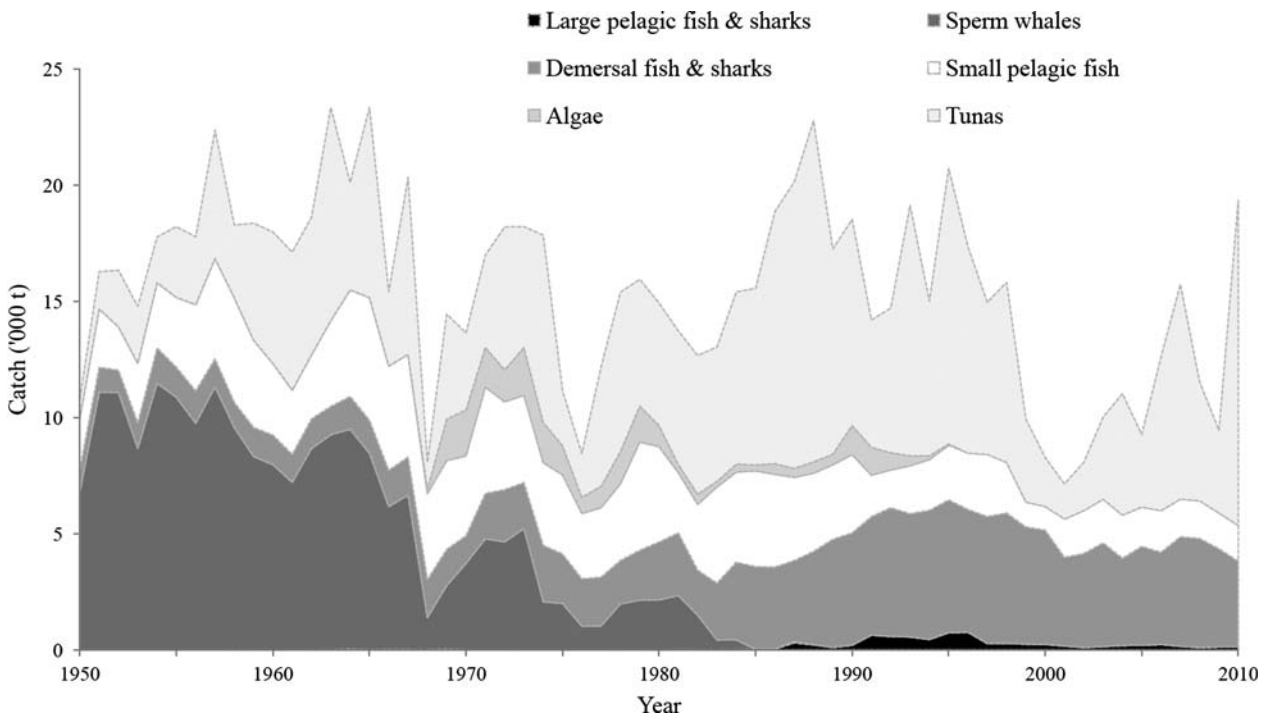

Figure 3. Total official catches in Azorean waters for the major groups for the period 1950–2010.

longline fishery averaged 1009 t per year (95% CI, 385–2506 t). Deep-water sharks were represented by at least ten species and accounted for 16% of the discards. These species were never landed and accounted for an average of 135 t of discards per year. Highest discard rates occurred between 1994 and 1998, when a considerable amount of silver scabbardfish were caught, but not reported. Other species with high discard amounts included black belly rosefish and alfonsinos, especially in years when the TAC was exceeded and discards reached more than 40% of the reported catch.

Bottom longline and handline – landed outside the Azores

Total catch from mainland Portugal boats fishing for silver scabbardfish between 1991 and 1998 was 2881 t. Of this amount, 2088 t was silver scabbardfish and 390 t was bycatch of 21 different species, such as European conger, blackspot seabream, and blackbelly rosefish.

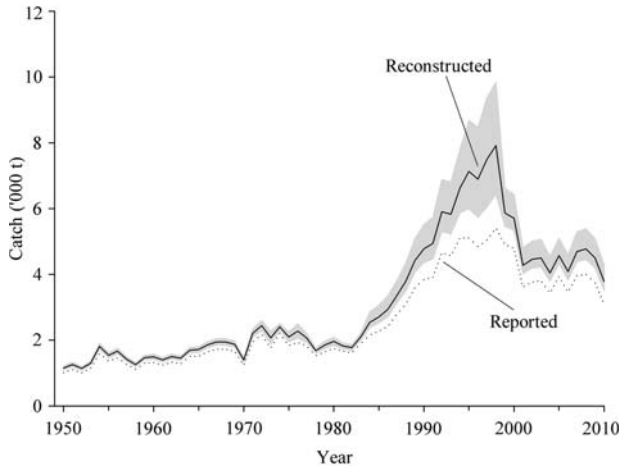

Figure 4. Official and reconstructed catch amount of bottom longline and handline activities in the Azores for the period 1950–2010 (excluding catches landed outside of the Azores). Shaded area represents the 95% confidence intervals.

Pelagic longline – catch landed inside the Azores

Since the time of its introduction, the Azorean pelagic longline fleet was estimated to discard a total of 11 000 t (95% CI, 10 000–12 000 t) of blue shark and short-fin mako shark. Discards varied between 75 t in 2008 to a maximum of 1365 t in 1991 (Figure 5a), corresponding to IUU levels of up to 278% of the amount reported in official statistics. Prior to the mid-1990s, blue shark and short-fin mako shark had little economic value and were mainly discarded at sea, resulting in high IUU proportions. During that period, an average of 608 t of blue shark and 21 t of short-fin mako shark were estimated to be discarded each year. Between 1992 and 1994, pelagic sharks began to appear in Azorean auction houses (although in small numbers) and discards thereafter decreased as shark meat gained higher commercial value and was landed outside the Azores, entering other statistics (see section below). The average IUU catch of sharks by the Azorean fleet during this later period (1995–2010) was estimated to be 418 t per year (408 t of blue shark, 10 t of short-fin mako shark), whilst mean official shark catches were 73 t per year. The total biomass of marine turtles killed as a result of bycatch was estimated to vary between 1.0 and 12.7 t per year, with a total of 107 t (95% CI, 91–134 t).

Pelagic longline – catch landed outside the Azores

Between 1993 and 2010, the Azorean fleet was estimated to catch an additional 4382 t (95% CI, 1300–9800 t) of swordfish, blue shark, and short-fin mako shark that were landed outside the Azores (Figure 5b). Mean swordfish catch was estimated to be 70 t per year, with a total of 1261 t (95% CI, 400–2700 t). Mean shark catch landed outside the Azores was 173 t per year, with a total catch estimated to be 3100 t (95% CI, 1000–7000 t).

In 1987, six pelagic longline boats from mainland Portugal were registered to operate in the Azores (Simões, 1995), whilst VMS data in 2010 suggest that 31 boats were fishing within Azorean waters. Since the beginning of their activity, the total catch of sharks and swordfish landed outside of the Azores was estimated to be 11 600 t (95% CI, 6 900–26 600 t) (Figure 5b). Swordfish catches totalled 2500 t (average of 104 t per year) whilst sharks (short-fin mako and blue shark), totalled 9100 t (average of

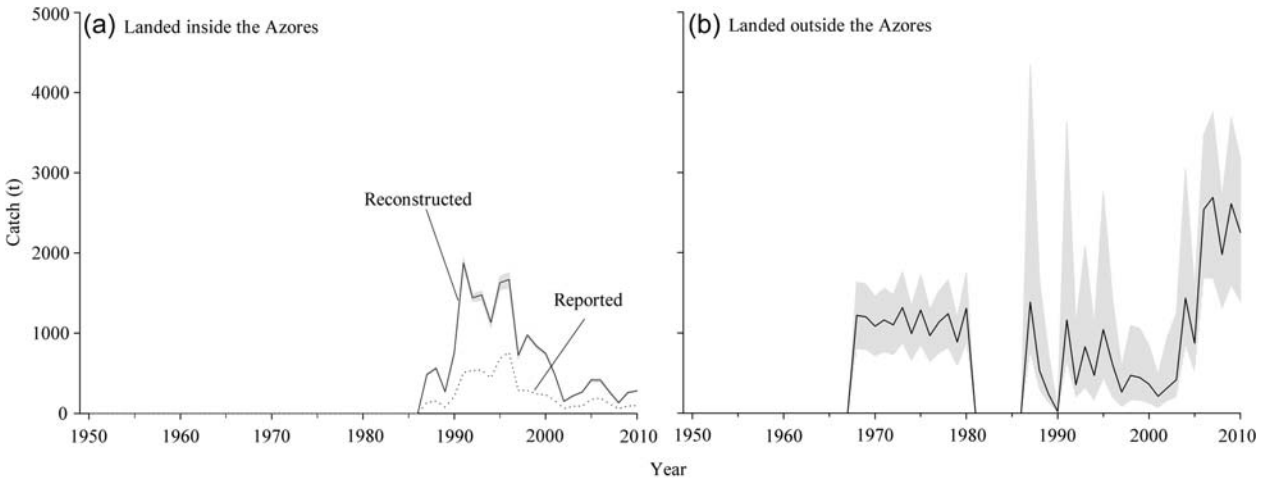

Figure 5. (a) Official and reconstructed catch amount for the pelagic longline activities in the Azores (excluding catches landed outside of the Azores), (b) reconstructed catch of pelagic longline activities landed outside of the Azores by the Azorean, mainland Portugal and Spanish fleets for the period 1950–2010. Shaded area represents the 95% confidence intervals.

380 t per year). In addition, the fleet was estimated to have discarded 64 t (95% CI, 40–137 t) of loggerhead sea turtles (mean, 2.6 t per year).

During their 20 years of fishing activity, the total catch by Spanish longliners in Azorean waters was estimated to be a factor of 1.5 higher than the catch made by the Azoreans over a 24-year period (1987–2010). For the first period of their activity (1968–1980), the total swordfish and pelagic shark catch was estimated to be 14 800 t (95% CI, 9700–19 800 t), with an average catch of 1140 t per year (Figure 5b). After resuming their fishing activity in 2004 and until 2010, the Spanish fleet was estimated to have caught a total of 7300 t of swordfish and sharks (95% CI, 4800–9800 t), with an average of 1050 t per year. Records of Spanish landings in Azorean harbours are almost non-existent, with only 1.8 t of swordfish reported since 1950. Discards of loggerhead sea turtles totalled 151 t (95% CI, 100–200 t) and averaged 8 t per year.

Pole-and-line

Estimates of catches of baitfish for tuna pole-and-line fishing, as derived from observer programme data, suggest that in order to catch the reported 350 000 t of tunas over the period 1950–2010, the amount of baitfish required was 16 800 t (95% CI, 11 900–22 000 t). Baitfish catch varied from 86 t in 1950 to 713 t in 1995, with an average of 276 t per year (Figure 6a) representing between 2.7 and 31.7% of the officially reported catch for small pelagic species (excluding blackspot seabream). On average, the two major species of baitfish (Figure 6b) were European pilchard (46%) and blue jack mackerel (45%). The remaining fraction (9%) included juvenile blackspot seabream, chub mackerel, bogue, boarfish (*Capros aper*), and longspine snipefish (*Macroramphosus scolopax*).

Trawling

The catch from the experimental fishery for orange roughy (2001–2002) totalled 403 t: 373 t of orange roughy and 30 t of other deep-water fish and shark species, such as black scabbardfish (*Aphanopus carbo*), Risso's smooth head (*Alepocephalus rostratus*), and sleeper sharks (*Somniosus microcephalus* and *Centroscymnus coelolepis*) (Melo and Menezes, 2002).

Fishing by the Soviet Union on seamounts south of the Azores occurred between 1973 and 1977, with a total estimated catch within the Azores of 6315 t. The main species were silver scabbardfish, blue jack mackerel, chub mackerel, and alfonsinos. This represents 32.5% of the reported catch of the same species for those years.

Commercial harvesting of coastal invertebrates

The total unreported catch of octopus and limpet was estimated to be 9700 t (95% CI, 9300–10 300 t), whilst the catch officially landed for the same period was 1850 t (Figure 7). Total catch of limpet in the Azores was estimated to range from 4 t in 1960 to 131 t in 1984. The unreported component of the limpet catch was estimated to be about 60-fold the amount reported in official statistics each year. The unreported catch of octopus varied between 54 t in 1988 and 285 t in 1970, 10–30-fold higher than the official statistics. These values are probably still underestimates since we were very conservative in all the assumptions. Furthermore, other invertebrate species such as giant barnacle, slipper lobster, spiny lobster, and other crabs were not included.

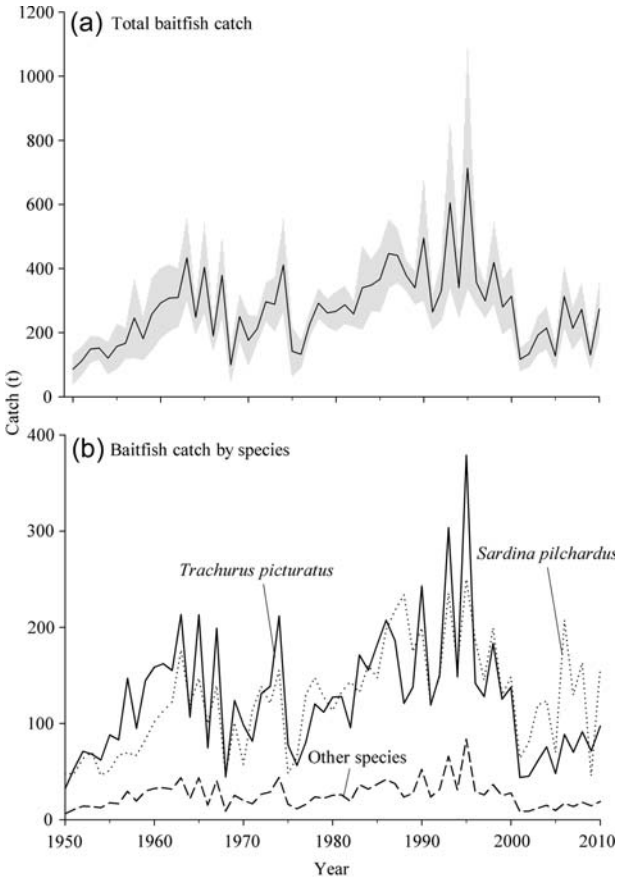

Figure 6. (a) Total baitfish catch and (b) baitfish catch by species for the pole-and-line tuna fishing fleet in the Azores for the period 1950–2010. Other species include blackspot seabream, chub mackerel, bogue, boarfish, and longspine snipe fish. Shaded area represents the 95% confidence intervals.

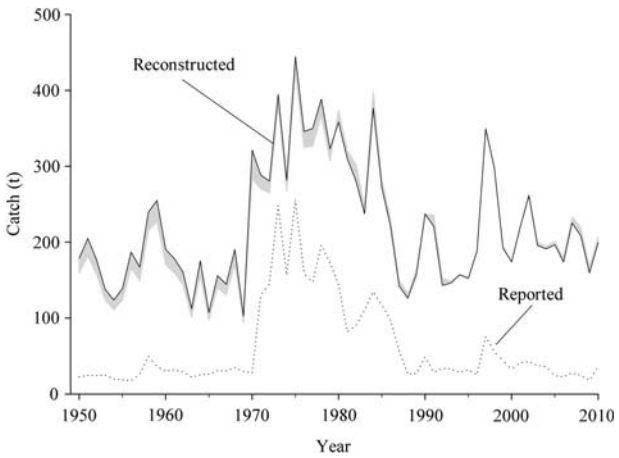

Figure 7. Official and reconstructed catch amount of coastal invertebrates in the Azores for the period 1950–2010. Shaded area represents the 95% confidence intervals.

Recreational fishing

Total catch by the recreational sector for the entire period was estimated to be 38 900 t (95% CI, 37 900–40 400 t), 6% of the official

landing statistics reported by the commercial sector. Catch from the recreational sector was estimated to vary between 300 and 950 t per year. The contribution of each recreational activity towards the total catch varied substantially during the study period (Figure 8). Overall, boat fishing and coastal rod fishing were the most important recreational activities in terms of catch volume, contributing 96% of the total estimated catch. Total catch arising from spear fishing was estimated to fluctuate between 4 and 48 t per year, whilst hand collecting of intertidal invertebrates is the smallest activity (5 t per year average).

The most important species in terms of volume are the white seabream (*Diplodus sargus*), with a total catch of 6500 t (220% of official statistics), blacktail comber (*Serranus atricauda*), with a total catch of 4700 t (85% of official statistics), chub mackerel, with a total catch of 3000 t (15% of official statistics), and parrotfish (*Sparisoma cretense*), with a total catch of 2970 t (60% of official statistics).

Big-game fishing

Total removal of blue and white marlin by the sportfishing sector from 1984–2010 was estimated to be 91 t (95% CI, 71–110 t). ICCAT reported a maximum removal of 10 t of blue marlin by the sportfishing sector in 1993, a value not present in local fishery statistics. Our estimates suggest that, for the past ten years, the average blue marlin mortality has been 1.5 t per year. Prior to 1990, many blue marlin caught by sportfishers were landed; during that period, the average blue marlin catch was estimated to be 6 t per year.

Overall

The reconstructed fishery catch (including sperm whales) in Azorean waters totalled 1.10 million t (95% CI, 1.06–1.16 million t) for the period 1950–2010, 17% higher than the amount reported in official statistics (Figure 9). For comparison with other studies, whaling catches were not included in further estimates. Therefore, the total reconstructed fishery catch, excluding sperm whales, was 900 000 t for the period 1950–2010. From that amount, 160 000 t (95% CI, 120 000–220 000 t) were not included in official statistics (22% of official statistics) and ranged between 720 and 6600 t per year, with foreign fishing activity being the largest contributor (27%), followed by catches from the recreational sector (25%), discards from the demersal fishing fleet (21%), baitfish for the pole-and-line tuna fishery (11%), discards from pelagic longlining (7%), harvesting of coastal invertebrates (6%), Azorean boats landing outside the Azores (3%), and big-game fishing (0.1%).

Between 1950 and 1967, average unreported catches represented 13% of the total official landings (average, 1150 t per year). This figure increased to an average of 27% between 1968 and 1980 (3000 t per year) when Spanish and Soviet fishing fleets began operating within Azorean waters. Between 1981 and 1986, it dropped to an average of 11%, when the EEZ was established, but increased thereafter to 27% (1987–2010), reflecting the introduction of bottom longline and pelagic longline operations that generated high amount of discards.

Catches by foreign and local fleets landing outside the Azores cannot be considered to be truly unreported because they enter fishery statistics elsewhere. Omitting this amount from our reconstruction suggests that the true IUU for the study period was 111 000 t (95% CI, 87 000–143 000 t), 15% of official statistics, with a corresponding total reconstructed catch of 828 000 t.

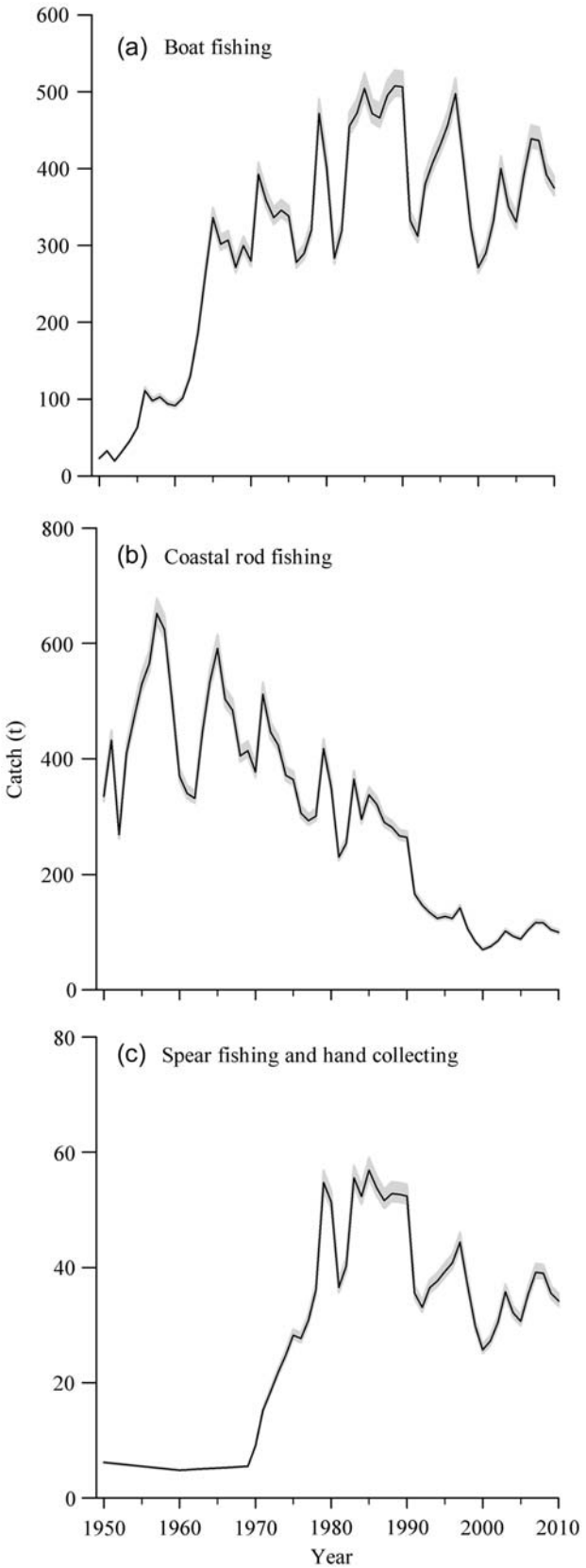

Figure 8. Catch by the recreational sector in the Azores for the period 1950–2010 for (a) recreational boats, (b) coastal rod fishing, and (c) spear fishing and hand collecting. Shaded area represents the 95% confidence intervals.

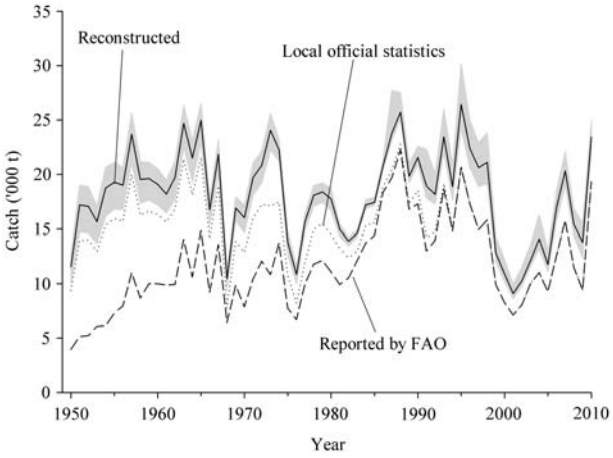

Figure 9. Total reconstructed, reported catches in local official statistics (including sperm whales) and by the FAO for Azorean waters for the period 1950–2010. Shaded area represents the 95% confidence intervals.

A detailed table compiling the reported catch, estimated IUU catch, and total reconstructed catch for all species is presented in the Supplementary material. Species with the highest level of unreported catches included blue shark, for which the total catch in Azorean waters was estimated to be a factor of 18–40 higher than the amount reported in local statistics. Being landed outside the Azores, shortfin-mako and swordfish also had a high level of unreported catch (factors of 6–13 and 1.2–4 higher than official catch amounts, respectively). Other species with high, unreported amounts included discards from bottom longlines, such as silver scabbardfish (factors of 1.1–3.1 higher than official catches), but also deep-water shark species of little commercial interest, such as velvet belly lantern shark (*Etmopterus spinax*) and gulper shark (*Centrophorus granulosus*). In addition, species of recreational interest, such as white seabream, parrot fish, or blacktail comber, had unreported catches up to twofold higher than official amounts. On the other hand, species of high commercial interest, such as blackspot seabream, tunas, European conger, and wreckfish (*Polyprion americanus*), all had unreported catches $<$20% of official statistics.

Discussion

Total fishery extraction of marine organisms within the Azorean EEZ for the period 1950–2010 was 1.10 million t, 160 000 t higher than the amount reported in official Azorean statistics (17%). Even though cetaceans are important components of marine ecosystems, they are generally not incorporated in fishery reconstruction. Excluding sperm whales, the total reconstructed catch was 900 000 t, 22% greater than official statistics.

When comparing our reconstruction of official catch data to the catch reported by FAO for the Azores, we estimated that 234 271 t of marine organisms failed to be included in FAO statistics. This is largely due to sperm whales and algae, which, although included in local statistics, are never included in FAO reports. Ignoring sperm whales and algae, the overall discrepancy in catch amount between local official statistics and FAO statistics was estimated to be low (7091 t) and more prominent before 1985.

Catch from foreign and Azorean fleets landing outside the Azores represented the largest fraction of catch unreported in local official statistics, and was estimated to be 47 000 t during the study period. Even though foreign catch should be landed elsewhere, it is not attributed to the Azores when reported to management bodies, such as the International Council for the Exploration of the Sea (ICES) or ICCAT. For example, according to ICES and ICCAT, Spanish vessels do not fish in Azorean waters even since EU fleets have been allowed to fish within 100 miles of the Azores in 2004 (EC Reg. 1954/2003). However, our results suggest that between 2004 and 2010, Spanish pelagic longliners caught 4800–9800 t of swordfish and sharks within the Azorean EEZ. It is likely that the Spanish catch originating from Azorean waters is attributed to other areas of the North Atlantic, thus impeding efficient management measures.

Catch landed outside the Azores cannot be considered to be true IUU fishing as it is actually landed and entered into fishery statistics elsewhere. Omitting this component, the total IUU catch in the Azores decreased from 160 000 to 111 000 t, 15% of the amount reported in local statistics. This figure is low compared to IUU levels found in most parts of the world, especially in developing nations, where small-scale artisanal fisheries are normally missing from official statistics (e.g. Tanzania, Jacquet *et al.*, 2010), but also in some European countries, such as Denmark, where catches have been estimated to be a factor of 1.4 higher than the amount reported by ICES (Zeller *et al.*, 2011b). Likewise, small-scale fishery catches by the United States, Canada, and Russia in the Amerasian Arctic were estimated to be 75-fold higher than the catch reported to FAO (Zeller *et al.*, 2011a). In contrast, the present study shows that in the Azores, all commercial fisheries are included in official statistics. Catches arising from the commercial sector, with the exception of baitfish for the pole-and-line fishery, are reported as part of a very efficient data-collection system. Furthermore, illegal trade of fishery products by local fishers is insignificant because of the small size of the local communities and the geographic isolation of the islands, making exports through official systems more profitable to fishers.

Excluding catch amounts landed outside the Azores by foreign and local fleets, recreational fishing was the principal contributor to total IUU catch. Recreational catches were also a key component in the catch reconstruction of other island states, such as Corsica (Le Manach *et al.*, 2011) or the Cayman Islands (Harper *et al.*, 2009). Even though it represents a small component of total fishery removals (about 4%), recreational catch was considerable for some species (e.g. parrotfish, white seabream, blacktail comber). Recreational fishing can severely impact target populations (Coleman *et al.*, 2004); therefore, estimates of total removals from this sector are critical for the sustainable management of fishery resources (Cooke and Cowx, 2004). The ICES Working Group on Recreational Fisheries Surveys has called for monitoring of these activities in Europe and for the inclusion of recreational catches in stock assessment models (ICES, 2012). Having a licensing system was very useful in our effort to estimate recreational catch. Although licences are mandatory for some recreational activities, it would be important to expand the licensing system to other recreational activities (i.e. coastal rod fishing and hand-collecting activities). In addition, regular surveys of recreational activities should be undertaken regularly to obtain information on catch composition and illegal activities in the Azores (ICES, 2012). This would permit a better assessment of the impact of recreational fishing on the Azorean coastal marine resources and improve management. If data on total catch removal by

recreational fishing are unknown, managing the resource solely by controlling the number of licences would be meaningless.

Discards from the demersal fishery were the second largest contributor. Species such as silver scabbardfish had catches greatly surpassing official catch statistics. Other emblematic discarded species included deep-water sharks present in the IUCN red list of endangered species, such as the "critically endangered" blue skate (*Dipturus batis*) or the "vulnerable" deep-water spiny dogfish (*Centrophorus squamosus*), which are never landed. Although it is beyond the scope of this paper to discuss the issue of discards in detail, it is worth mentioning that our results suggest that the establishment of a TAC system for the multispecific bottom fishery greatly increased discard rates without decreasing catch levels. For example, years when the TAC for alfonsinos was reached, landings stopped, whilst discards increased. Although data on post-release mortality are not available for alfonsinos, survival is highly unlikely considering the depth from which they were retrieved. Such unreported mortality undermines the effectiveness of the TAC system to manage those species, as was previously suggested for other European fisheries (Daan, 1997; Khalilian *et al.*, 2010).

Unreported catch by the pelagic longline fishery represented 7% of the total IUU and was dominated by blue sharks. Estimates of blue shark catch between 1987 and 2010 were considerable, exceeding the amounts reported in official statistics by a factor of eight. IUU catch of blue shark by pelagic longline is a major threat to North Atlantic populations, and improved estimation of total removal by other fleets will be fundamental to tackling the problem (Campana *et al.*, 2006; ICCAT, 2009).

Baitfish requirement for the pole-and-line tuna fishery was a small component of the total unreported catch, with an overall tuna:baitfish ratio (21:1) well within the ratio reported for other pole-and-line fishing operations (Gillett, 2011).

Although insignificant relative to the overall removal amount, the level of unreported catch of coastal invertebrates was high compared to official statistics and is likely to be much higher than estimated here since our estimation was based on a limited amount of data, coupled with the fact that other species, such as giant barnacles, spiny lobster, and slipper lobster, were not included. Improved estimation of illegal catches of limpet is essential since there is growing evidence that these stocks are overexploited (Martins *et al.*, 2008, 2011; Santos *et al.*, 2010).

Despite our generally conservative approach, we feel that our estimates are trustworthy, and we are confident that the total catch estimates are in the correct order of magnitude, especially compared to other localities where little data are available, making such reconstruction less accurate (see examples in Zeller and Pauly, 2007). The large amount of literature available on Azorean fisheries and the various monitoring programmes permitted a catch reconstruction based on reliable anchor points for each fishery component, and currently provides the best estimate available on total fishery removals from the Azores region. The level of IUU revealed to be lower than for many locations around the globe. Yet, our study points out the need to implement new monitoring programmes for some fishery components that would help improve the management of IUU fishing in the Azores.

Supplementary material

The following supplementary material is available at the *ICES Journal of Marine Science* online: (i) in-depth description of the exact methods used for estimating catches, and (ii) final reconstructed and official catch amounts for each individual species.

Funding

We acknowledge funds provided by FCT to the LARSyS Associated Laboratory and IMAR-University of the Azores/the Thematic Area E of the Strategic Project (OE and Compete), and by the DRCTC – Government of the Azores multiannual funding. TM was supported by POPH, the QREN European Social Fund and the Portuguese Ministry for Science and Education. CKP was supported by a doctoral grant from the Portuguese Science Foundation SFRH/BD/66404/2009. This work is part of the research project "2020: towards ecosystem-based management of the Azores marine resources, biodiversity and habitats M2.1.2/I/026/2011".

Acknowledgements

A number of people contributed to this work through numerous discussions and data sharing. These include Pedro Afonso, Alan Bolten, Gilberto Carreira, Rogério Ferraz, Les Gallagher, João Gonçalves, Eduardo Isidro, Miguel Machete, Gustavo Martins, Helen Martins, Gui Menezes, Mário Rui Pinho, Filipe Porteiro, Dália Reis, João Santos, Marco Santos, Ricardo Santos, Hélder Silva, and Frederic Vandeperre. We would also like to thank all the fishery observers who have been collecting data and the anonymous referees whose comments and suggestions greatly improved the manuscript. Finally, we would like to thank Dirk Zeller and Sarah Harper for their guidance during the entire reconstruction process.

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Handling editor: Emory Anderson